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Technical Report

LOWER VERDE RIVER RIPARIAN VEGETATION

June 2004

Prepared for

Salt River Project
P.O. Box 52025
Phoenix, Arizona 85072-2025

Prepared by

ERO Resources Corporation
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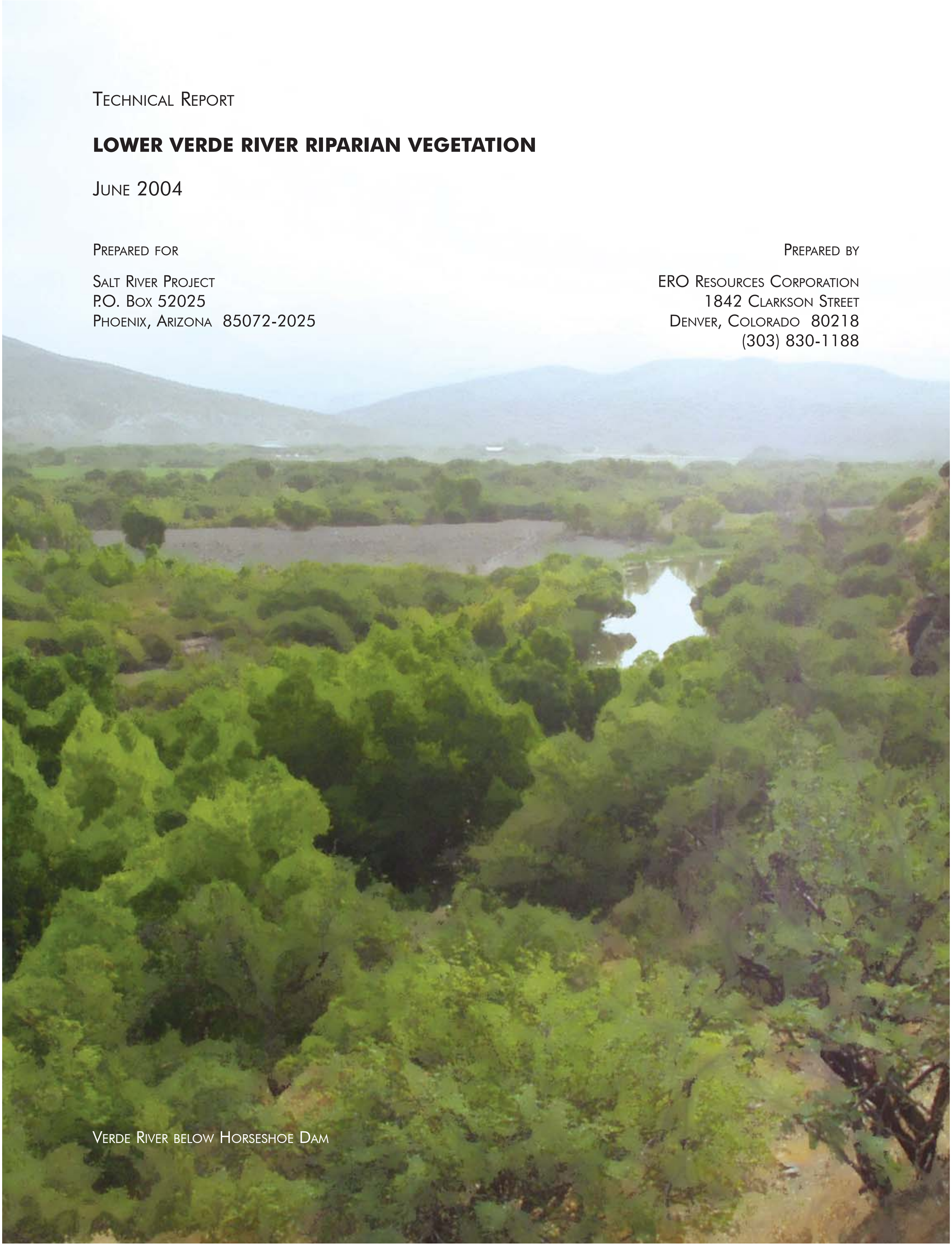

Verde River below Horseshoe Dam

TECHNICAL REPORT

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RIPARIAN VEGETATION

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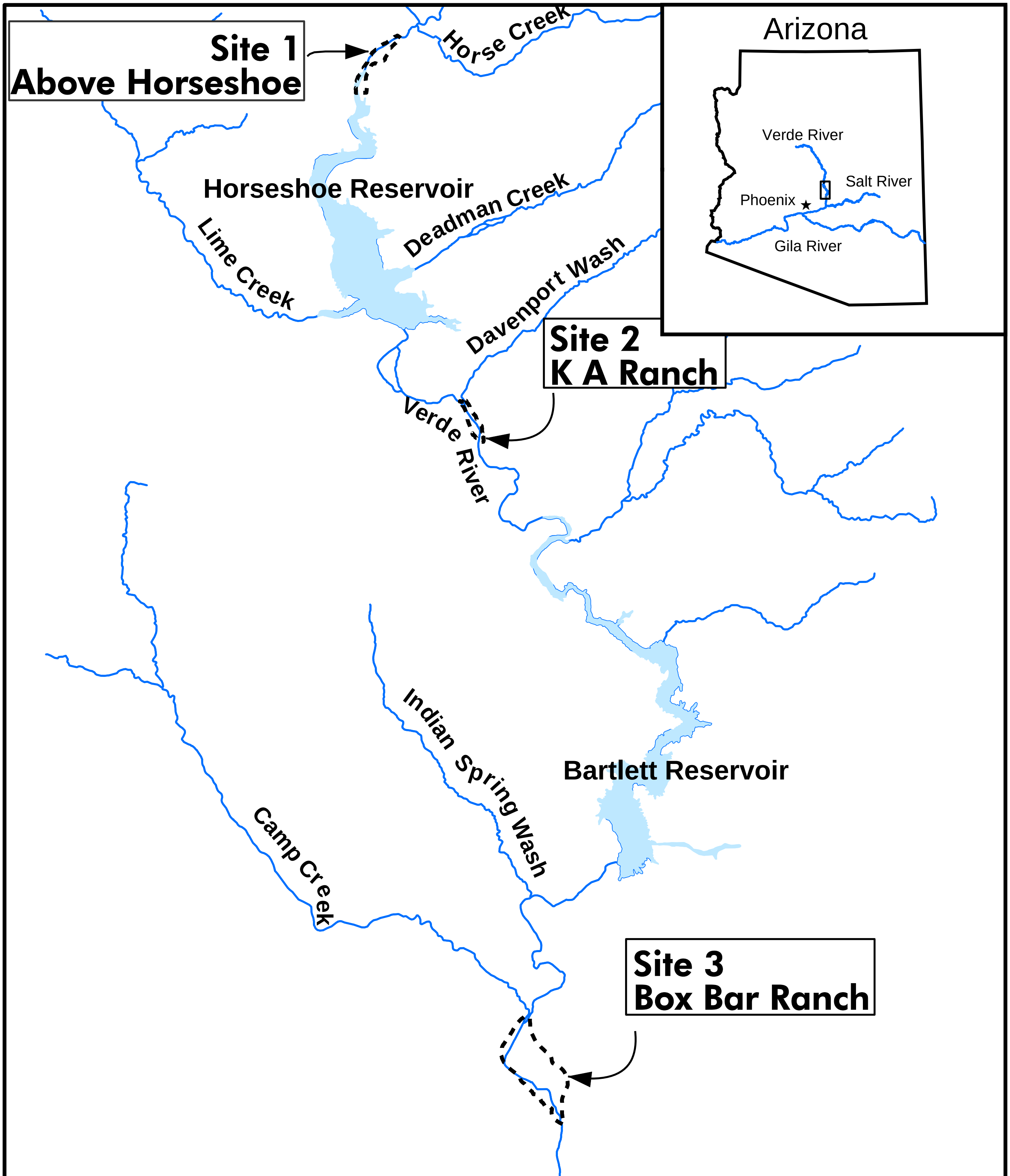
JUNE 2004

Introduction

As part of the Salt River Project's evaluation of the effect of Horseshoe and Bartlett reservoirs on tall woody riparian vegetation along the lower Verde River, ERO Resources investigated the current (2002) and historical (1934 to 1997) riparian plant communities along the lower Verde River. This study of tall woody vegetation focuses on cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*) because these trees are nesting habitat for various species of birds, including the threatened bald eagle, endangered southwestern willow flycatcher, and candidate yellow-billed cuckoo. The purpose of the study was to examine habitat trends for these three species of birds, not to examine the rate of woody vegetation establishment, or changes in amounts of individual species.

Vegetation was investigated at three sites along the lower Verde River. Site 1 (Above Horseshoe) is located directly upstream of the Horseshoe high water mark. Site 2 (KA Ranch) is located about 2.5 miles downstream of Horseshoe. Site 3 (Box Bar Ranch) is located about 4 miles south of Bartlett (see Figure 1). The investigation was designed to evaluate historical vegetation trends relative to dam construction and operations, and as a baseline study to monitor future changes in vegetation communities. Historical photography was analyzed to identify trends in tall, woody vegetation stands. The earliest available aerial photographs (1934) predate the construction of Bartlett Dam, which was completed in 1939, and Horseshoe Dam, which was completed in 1946 with additional storage added in 1951.



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Legend

- Rivers
- Project Area Boundaries
- Reservoirs

1 Inch = 2,000 Feet

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Figure 1
Location Map

Prepared for: Salt River Project
File: w:/workspace/2346verde/locator.mxd
September 2003

Mussetter Engineering, Inc. (MEI) conducted a companion study of fluvial geomorphology at the three study sites in support of this vegetation analysis (MEI 2004). The MEI analysis focused on inundation and substrate stability at each of the three study sites. A summary of the conclusions of the MEI study are provided at the end of the Literature Review section below.

This study did not collect depth to ground water in relationship to tall woody vegetation cover. No data currently exists for ground water depths along the lower Verde River. However, field observations and substrate sampling by MEI revealed that the soils in the study areas are composed of coarse material with relatively little clay and silt content (MEI 2004). In this coarse alluvium, ground water should flow freely. It is a reasonable assumption that the ground water table is closely tied to the surface water level in the lower Verde River. Thus, depths to ground water can be estimated using the cross sections in Appendix A of the MEI (2004) report.

History of Land Use and Flooding on the Lower Verde River

Prior to settlement by Anglos, Native Americans lived along the lower Verde River and used the lower Verde watershed for hunting and gathering. Increasing numbers of Anglos came to the area in the mid to late 1800s. Fort McDowell was established in 1865 allowing homesteads and settlements to be located along the lower Verde River in the late 1800s and early 1900s. Land uses along the lower Verde River in that period consisted primarily of grazing, ranching, and farming. Riparian areas and stream terraces along the lower Verde have been used for livestock grazing for over 100 years. More recently, recreation has become a major land use in this area. Land use, particularly grazing, along the lower Verde River was probably slightly more intense prior to 1934 than it has been in the years since construction of Bartlett and Horseshoe Dams. Grazing has decreased in some areas, which is partially offset by increased recreational use.

Floods along the Verde River since 1891 are presented in MEI's geomorphic study report (MEI 2004) and are summarized below. The two largest flood events, in 1891 and 1993, are comparable in volume. The 1934 photos are believed to be representative of conditions on the Verde River prior to construction of Bartlett and Horseshoe Dams because no unusually large flood events were documented in the years prior to 1934.

Large Floods on the Verde River Pre-and Post Dam Construction.

Year	Volume (cfs)
1891	150,000
1906	96,000
1920	95,000
1927	70,000
1938[1]	100,000
1952[2]	81,600
1978	91,400
1979	94,000
1980	94,800
1993	145,000
1995	108,000

[1]Bartlett Dam was constructed in 1934.
[2]Horseshoe Dam was constructed in 1946 and expanded in 1951.

Literature Review

Some scientists have expressed concern that operation of Horseshoe and Bartlett is precluding downstream recruitment of cottonwood and willow trees (AGFD in prep.; McNatt et al. 1980; FWS 2002, Appendix J; FWS 2003). Dams may have either a positive or negative effect on downstream tall woody vegetation depending on the timing and extent of alteration to fluvial processes (Williams and Wolman 1984; FWS 2002; Braatne et al. 1996; Everitt 1995; Fenner et al. 1985; Poff et al. 1997; Rood and Mahoney 1990; Shafroth et al. 2002).

Cottonwood and willow are pioneer riparian species that depend on episodic floods and shallow water tables to provide conditions conducive for establishment of new stands of trees (FWS 2002, Appendix I; Scott et al. 1993; Shafroth et al. 1998; Stromberg 2001). Areas of scoured alluvium or fresh sediment deposits favorable for seedling recruitment. Establishment of new stands require relatively large flood events where the flow recedes slowly following the flood. Typically, these flood events have a return interval of about 1 in 7 to 1 in 50 years or more, depending on the river (Braatne et al. 1996; Mahoney and Rood 1998; Rood et al. 1998; Scott et al. 1996, 1997; Stromberg et al. 1991, 1993; Stromberg 2001). These larger flood events simultaneously destroy mature trees in some locations, starting the cycle of succession over again (FWS 2002, Appendix I; Stevens and Waring 1986).

The timing and duration of the flood flows are critical for seedling establishment and survival. In Arizona, cottonwood and Goodding willow disperse seeds from March through May, and the seeds are only viable for a few days or weeks (Brown et al. 1977; Braatne et al. 1996; Fenner et al. 1984; Reed 1993; Shafroth et al. 1998; Stromberg 1997). Seedling roots grow fast (up to ½ inch per day) but a rapid decline in the water table or very hot weather will stress and kill the seedlings (Fenner et al. 1984; Braatne et al. 1996; Mahoney and Rood 1992, 1998). Conversely, scouring or inundation for a few weeks by a flood subsequent to seedling establishment also may kill the seedlings (Stromberg 1993; Shafroth et al. 2002; Gladwin and Roelle 1998). Thus, young cottonwood trees are most likely to become established on low terraces or in inactive side channels where young roots can readily reach the water table but frequent scouring or inundation does not occur (Brady et al. 1985; Irvine and West 1979; Scott et al. 1997; Stromberg et al. 1993).

Seedlings and young trees are also eaten or trampled by cattle and horses, a major cause of mortality in many areas (Braatne et al. 1996; Fenner et al. 1985; Rood and Mahoney 1990; Scott and Auble 2002; Scott et al. 2003; Stromberg and Chew 1999). Recreation trampling, scouring by floods, water diversions, exotic plants, beavers, and other factors are causes of mortality of seedlings and young trees (Braatne et al. 1996; Scott and Auble 2002; ERO 1986).

For the first several years, cottonwood saplings grow relatively slowly while energy is directed to root growth (Braatne et al. 1996). Along the Hassayampa River near Phoenix, average heights of cottonwood are generally less than 3 feet after 2 years of growth, and average heights of willow are less than 1.5 feet (Stromberg 1997). However, once the roots are established near the water table, which is typically 2 to 5 feet from the surface for saplings, the trees grow rapidly to heights of 20 to 40 feet or more (Braatne et al. 1996; Stromberg et al. 1996; Reed 1993). Reproductive maturity in cottonwood is reached in 5 to 10 years and slightly earlier in Goodding willow (Braatne et al. 1996; Reed 1993).

Once established, cottonwood and willow trees may die from a variety of causes—drought, scouring floods, channel incision, fire, ground water pumping, channelization, agricultural clearing, and beaver (Scott et al. 1999, 2000; Braatne et al. 1996; Stromberg 1993; McNatt et al. 1980). Cottonwood trees may live for 130 years or more in areas where the ground water table is within 15 feet of the surface (Braatne et al. 1996; Rood and Mahoney 1990; Stromberg et al. 1996).

Appendix 1 contains relevant excerpts from many of the references used in this study and additional articles of interest. Caution should be used in extrapolating data and opinions derived from studies in one river basin to other areas because each river system is unique with respect to its physical and hydrological characteristics, the relative size and operation of the reservoirs, and vegetation communities (Everitt 1995). For example, studies along the lower Bill Williams River in western Arizona reflect the presence of Alamo Dam, a flood control facility that is designed to capture virtually all high flows (Shafroth et al. 1998, 2000, 2002). This is substantially different than storage on the Verde, where the capacity of Horseshoe and Bartlett is only about two-thirds of the average annual flow and large floods continue to occur below the dams (SRP 2002b).

Past Studies on the Lower Verde River below Horseshoe and Bartlett Reservoirs

Several studies and publications pertaining to tall woody vegetation along the lower Verde River are available. The Department of Zoology at Arizona State University (Ohmart 1979) evaluated the historical changes in riparian vegetation and wildlife along the Verde River as part of a study to assist planning for future river development. The report identified a number of factors influencing riparian vegetation along the Verde River since the mid-1800s such as inundation by Bartlett and Horseshoe, phreatophyte eradication, irrigation development, changes in river flow, grazing, land development, and invasion of tamarisk.

McNatt et al. (1980) studied riparian habitat and instream flows on the Fort McDowell Reservation near the mouth of the Verde River. The report found high cottonwood mortality in the late 1970s, possibly from the combined effect of severe drought and ground water pumping. Large releases of water from Bartlett Dam every 8 to 10 years or planting of cottonwoods was recommended to maintain a productive cottonwood community. The report also concluded that a minimum flow of 200 cfs would maintain and enhance fish and wildlife resources and riparian habitat.

In 1986, as a part of water right negotiations among SRP, the United States, the Fort McDowell Indian Community, and other parties, ERO evaluated the riparian vegetation communities on the Fort McDowell Reservation using ground and aerial vegetation surveys, analysis of historical aerial photos dating from 1934, coring of cottonwoods to determine age, soil studies, and analysis of surface and ground water hydrology (SRP 2002a). In 2001, SRP did extensive hydrological analysis on the effect of Horseshoe and Bartlett on river flow (Id.). Findings from the 1986 and 2001 studies are summarized below:

- The status of cottonwood and willow along the lower Verde River results from a combination of natural fluctuations and man-induced changes, including such factors as channel migration, land use, pumping, drought, and dam operations.
- Broad, extensive areas of riparian woodland were not present prior to dam construction.
- River morphology has not changed significantly since the construction of Bartlett Dam.
- Given the small size of the SRP reservoirs on the Verde in relation to annual runoff, the natural hydrograph is not substantially modified by reservoir operations.
- Vegetation density on the active floodplain of the lower Verde River has increased since the late 1930s when river flows became regulated as the result of the construction of Bartlett Reservoir.
- Some cottonwood regeneration continues to occur on the Reservation; for example, a number of saplings near the Highway 87 bridge resulted from high flow events in 1978 and 1980.
- Recreational use of riparian areas and grazing by cattle and horses are major impacts on establishing cottonwood/willow communities along the lower Verde. As a result, recruitment of new trees and shrubs from high flow events has been limited.
- Upstream from the Fort McDowell Reservation, above Needle Rock, a relatively high-gradient channel and riparian land uses (e.g., grazing) appear to be the biggest factors limiting riparian vegetation.
- Management of recreation and livestock impacts or re-establishing by direct plantings have the greatest potential to promote perpetuation of cottonwood and willow on the Reservation.

- High bank cottonwood trees that are overly mature have been a focus of concern due to bald eagle nests. These cottonwood trees appear to be decadent primarily as a result of age and disease and a declining water table due to the natural migration of the channel to the other side of the floodplain.
- A minimum stream flow of 100 cfs would have a beneficial effect on sustaining cottonwood and other riparian vegetation by helping to maintain stable ground water levels.

A minimum flow of 100 cfs released from Bartlett Dam was incorporated into the Fort McDowell Indian Community water rights settlement and has been in effect since 1994 (SRP 2002b).

In 1999, Dr. William Graf prepared a paper on the fluvial hydrology of regulated rivers for incorporation into the Southwestern Willow Flycatcher Recovery Plan (FWS 2002, Appendix J). Dr. Graf used 1945-1991 gage data above and below the dams and 1904-1944 gage data at the lower gage location to evaluate the effects of storage and releases of water on Verde River flows. Major findings in the paper are:

- The dams created conditions of numerous periods of very low flow and no flow, which result in a loss of the surface water stream and less recharge to the alluvial aquifer.
- Larger "ordinary low flows" for most of the year provide ecological benefits by increasing ground water recharge and a larger surface water stream.
- Reduced mean annual peak flow and increased variability of annual peak flows have resulted in a smaller active channel.
- Fine sediment is stored behind the dams and is not deposited along the channel downstream resulting in poor substrate for cottonwood, willow and tamarisk.

SRP had concerns with the hydrological analyses of the Verde River and discussed these concerns with Dr. Graf, which changed some of his opinions (SRP 2002a). For example, Dr. Graf was not aware that a minimum flow had been established, which alleviates one of the major concerns expressed in his paper (Id.).

In a study of vegetation and hydrologic conditions above and below Horseshoe and Bartlett, Beauchamp and Stromberg found that Fremont cottonwood and Goodding willow have similar cover above and below the dams, and that tamarisk cover has increased below the dam since 1995 (Beauchamp and Stromberg 2004). Beauchamp and

Stromberg believe that extended late spring/early summer releases from the dams in 1995 may have provided increased opportunity for tamarisk recruitment (Beauchamp and Stromberg 2004).

Fluvial Geomorphology study of the Verde River

As noted in the introduction, a companion study of fluvial geomorphology was conducted in association with this vegetation analysis (MEI 2004). In summary, the MEI report concludes:

- Bartlett and Horseshoe have caused little, if any, morphological or sedimentological adjustment of the Verde River.
- The changes in hydrology caused by the dams reduce the frequency of inundation and mobilization of sediments. The effect downstream of Horseshoe is less than the effect downstream of Bartlett because of the smaller capacity of Horseshoe.
- The reduction in frequency of flood events below Bartlett enables vegetation to become better established and withstand higher magnitude floods.
- Alternative reservoir operations, ranging up to the full release of flood flows, would have an insignificant effect on the duration of inundation and sediment mobilization on geomorphic surfaces.
- Changing reservoir operations would have little effect on the disturbance regime important for establishing and maintaining the health of riparian vegetation.
- Increased summer flows of 200 to 1,400 cfs below Bartlett may be responsible for supporting additional vegetation along the Verde River channel.

Methods

ERO and MEI selected the three study locations during an aerial reconnaissance of the lower Verde River on November 4, 2002. The sites were chosen because they are located in relatively wide floodplains that would allow recruitment of tall woody vegetation and are suitable for hydraulic modeling. For purposes of this Vegetation Technical Report, the floodplain is defined as the valley bottom area that is affected by flooding. The three sites chosen are the primary sites on the lower Verde River in the vicinity of Horseshoe and Bartlett Reservoirs suitable for hydraulic modeling in which the floodplain is wide enough to potentially support the large stands of tall woody vegetation that are habitat for the southwestern willow flycatcher. One additional site, immediately downstream of the outlet of Bartlett Reservoir potentially could support large stands of woody vegetation, but this site is so close to the outlet of Bartlett Reservoir that it was determined not to be appropriate for hydraulic modeling. Beauchamp and Stromberg (2004) also used the site below Bartlett Reservoir (the Box Bar Ranch site) and six other sites above and below the reservoirs for their vegetation studies. The Box Bar Ranch site also was used as a study area for a study conducted by Marler et al. (2004). In the Marler et al. study, the Box Bar Ranch site and four other sites along the lower Verde and Salt rivers were used as reference areas for native vegetation in a relatively natural state. Marler et al. compared vegetation at the Box Bar Ranch site and other sites with vegetation along the Salt River in Phoenix that receives wastewater effluent.

Transects at each site used for this study were documented by global positioning system coordinates and staked with rebar to serve as control points for future surveys.

On November 5 through 7, 2002, ERO Resources examined the vegetation stands at the three sites. The boundaries of these vegetation stands were hand sketched in the field on 2002 aerial photographs at a scale of 1 inch = 500 feet. Stand types were classified according to canopy height and dominant species.

Historical aerial photography was gathered for each of the three study sites. Although efforts were made to find pre-1934 oblique photos to provide additional historical perspective, no photos were found that depicted good overviews of riparian areas along the lower Verde. Photo dates for aerial coverage varied by site, as shown in Table 1. Aerial photographs were scanned at high resolution (400 dpi) and plotted at a consistent scale (approximately 1 inch = 200 feet) for delineation of vegetation. The minimum mapping unit was approximately 100 feet by 100 feet, or ¼ acre.

Table 1. Aerial Photograph Availability.

Date of Photography	Type of Photography	Above Horseshoe (Study Site 1)	KA Ranch (Study Site 2)	Box Bar Ranch (Study Site 3)
1934	B&W	X	X	X
1953	B&W	X		X
1967	B&W		X	X
1968	B&W	X		
1976	Color		X	X
1980	B&W and Color	X	X	X
1988	Color	X		X
1992	B&W	X		X
1997	B&W	X	X	X
2002	Color	X	X	X

Aerial photography used for vegetation mapping was not rectified. Each photograph was registered using a digitizing table by locating four or more reference points. The 1953, 1992 and 1997 aerial photos were black and white and had relatively poor resolution. The accuracy of the delineated boundaries and vegetation types is compromised by poor photo quality. Identifying features, such as canopy size and texture, are less obvious in photos with poor resolution. All other sets of aerial photography were either color or had high resolution; therefore, the accuracy for delineations using these photos is relatively high.

2002 Vegetation Types

Several types of vegetation stands were identified on the study sites during 2002 field investigations (Table 2). Several of the vegetation stand types were further divided into subcategories based on height characteristics and density to better identify potential flycatcher habitat areas. Historical vegetation was delineated for the three study sites, referencing the 2002 delineation and field review to identify vegetative stand characteristics that could be readily observed on historical aerial photography. These stand types were used to delineate both current (2002) and historical (pre-2002) vegetation stands.

Table 2. Description of Riparian Vegetation Stand Types.

Type	Definition
Tall Woody Vegetation	
Cottonwood	More than 80%* cottonwood in either dense or sparse stands
Mixed riparian > 15 feet	No single species (cottonwood/willow/tamarisk) comprises more than 80%*, trees generally more than 15 feet in height
Mixed riparian > 15 feet, low density	No single species (cottonwood/willow/tamarisk) comprises more than 80%*, trees generally more than 15 feet in height, but noticeably more open with more spacing between trees
Mixed riparian < 15 feet	No single species (cottonwood/willow/tamarisk) comprises more than 80%*, trees generally less than 15 feet in height
Mixed riparian < 15 feet, low density	No single species (cottonwood/willow/tamarisk) comprises more than 80%*, trees generally less than 15 feet in height, but noticeably more open with more spacing between trees
Other Vegetation	
Mesquite	More than 80%* mesquite
Strand	Areas with dense or sparse vegetation including woody and non-woody plants directly adjacent to stream channels and in gravel bars
Shrub	Densely vegetated but few woody plants; mostly burro brush less than about 10 feet in height
Sparsely vegetated	Areas with less than 30%* vegetative cover, including bare sandbars
Tamarisk < 15 feet	More than 80%* tamarisk, trees generally less than 15 feet in height

* Cover relative to other woody species.

Species and characteristics of each stand type are described below.

Cottonwood

In dense stands, there is more than 80 percent relative cover of Fremont cottonwood. Because overstory and mid-canopy cover is quite dense (canopy cover ranges up to 100 percent), vegetation in the understory often is sparse. In sparse cottonwood stands, canopy cover ranges from 40 to 50 percent. Vegetation in the understory includes Goodding willow, tamarisk (*Tamarix ramosissima*), and mesquite (*Prosopis velutina*).

Mixed Riparian Stands Greater Than 15 Feet Tall

Mixed riparian stands greater than 15 feet in height generally have a dense overstory composed of Fremont cottonwood, Goodding willow, tamarisk, and mesquite. Because overstory and mid-canopy cover is quite dense (canopy cover ranges from 70 percent to 100 percent), vegetation in the understory often is sparse. The same species common in the understory of mixed riparian stands greater than 15 feet in height are also common in mixed riparian stands less than 15 feet in height, but the cover of understory species is more sparse in mixed riparian stands with tree height greater than 15 feet (see species listed below) than mixed riparian stands less than 15 feet in height. Canopy cover is generally high, ranging from 80 percent to 100 percent, and structural diversity is high. Shrubs are common in the middle layer of the canopy (between 5 and 10 feet), and deadfall, standing dead, and snags are common.

Mixed Riparian Stands Less Than 15 Feet Tall

Mixed riparian stands with canopies less than 15 feet in height include young riparian stands along the Verde River streambank and in abandoned backwater channels.

Along the Verde River and in abandoned side channels where the water table is near the soil surface, mixed riparian stands contain many hydrophytic species. Dominant species include Fremont cottonwood, Goodding willow, seep willow (*Baccharis salicifolia*), giant reed (*Arundo donax*), narrow and broad-leaved cattail (*Typha latifolia* and *T. angustifolia),* tamarisk, arrowweed (*Pluchea purpurascens*), spikerush (*Eleocharis* spp.), barnyard grass (*Echinochloa crus-galli*), cocklebur (*Xanthium strumarium*), Bermuda grass (C*ynodon dactylon*), wood sorrel (O*xalis corniculata*), and beggarsticks (*Bidens cernua*). Canopy cover ranges from about 30 percent to 70 percent. These stands are characterized by openings between tree crowns in areas that are frequently inundated, and high structural diversity, with species in the understory (less than 3 feet tall), middle layers (3 to 8 feet tall), and the overstory (8 to 15 feet in height).

Some mixed riparian stands occur in areas where soils are drier, and infrequently saturated. Common species in drier mixed riparian areas are Fremont cottonwood, Goodding willow, tamarisk, some mesquite, Bermuda grass, lovegrass (*Eragrostis* spp.), sand dropseed (*Sporobolus cryptandrus*), Jimson weed (*Datura meteloides*), blue grama (*Bouteloua gracilis*), and desert broom. Canopy cover ranges from 20 percent to 70 percent, and structural diversity is moderate.

Mesquite

Stands with more than 80 percent relative cover of mesquite are common on higher terraces. Mesquite stands along the Verde River tend to be relatively static; these areas are generally too high above the river and water table to be flooded frequently and to establish other vegetation types.

Strand

Strands are located directly along the edge of the river, and are often composed of the same species as the mixed riparian stand type, including Fremont cottonwood, Goodding willow, tamarisk, and mesquite, as well as herbaceous species. However, strand vegetation is dynamic and is frequently scoured by flooding. Strand vegetation may contain individual Fremont cottonwood and Goodding willow trees over 15 feet in height, but overall this vegetation type is generally shorter and dense.

Shrub

Shrub vegetation generally includes upland burro brush (*Hymenoclea salsola*) shrublands and may also be composed of a mix of species from the Mixed Riparian and Sparsely Vegetated stand types. Shrub stands often are located on terraces above the river, and do not receive adequate moisture to maintain riparian communities or develop the structural height of the mixed riparian type. If a flood scours upland shrub gravel bars or rechannelizes the river to supply adequate hydrology, shrub areas may develop into mixed riparian stands.

Sparsely Vegetated

The sparsely vegetated stand type includes gravel bars and coarse sediment deposits in the lower Verde River floodplain. Some areas of gravel bars are devoid of vegetation (less than 10 percent canopy cover), some are dominated by forbs such as buckwheat (*Eriogonum inflatum*), rattlesnake weed (*Euphorbia albomarginata*), desert marigold (*Baileya multiradiata*), groundsel (*Senecio* spp.), Parry's dalea (*Dalea parryi*), skeleton weed (*Lygodesmia* spp.), ground cherry (*Chamaesaracha coronopus*), wild cucumber (*Marah gilensis*), desert straw (*Stephanomeria pauciflora*), desert milkweed (*Asclepias subulata*), and canyon ragweed (*Ambrosia ambrosendes*).

Gravel bars that are flooded less frequently are dominated by desert brome (*Baccharis sarothroides*), burro brush, and scattered mesquite. Other species include sand sage (*Artemisia filifolia*) and many of the same forbs as mentioned above. Canopy cover ranges from 10 percent to 20 percent, and there is little structural diversity because most shrubs are between 2 and 4 feet in height.

Tamarisk Stands

Tamarisk stands occur in areas that are periodically flooded or seasonally subirrigated. In general, tamarisk stands are monospecific, with little or no vegetation in the understory. Canopy cover is high in tamarisk stands, ranging from 80 percent to 100 percent, and structural diversity is low. Tamarisk stands are generally less than 15 feet in height.

2002 Site Characteristics

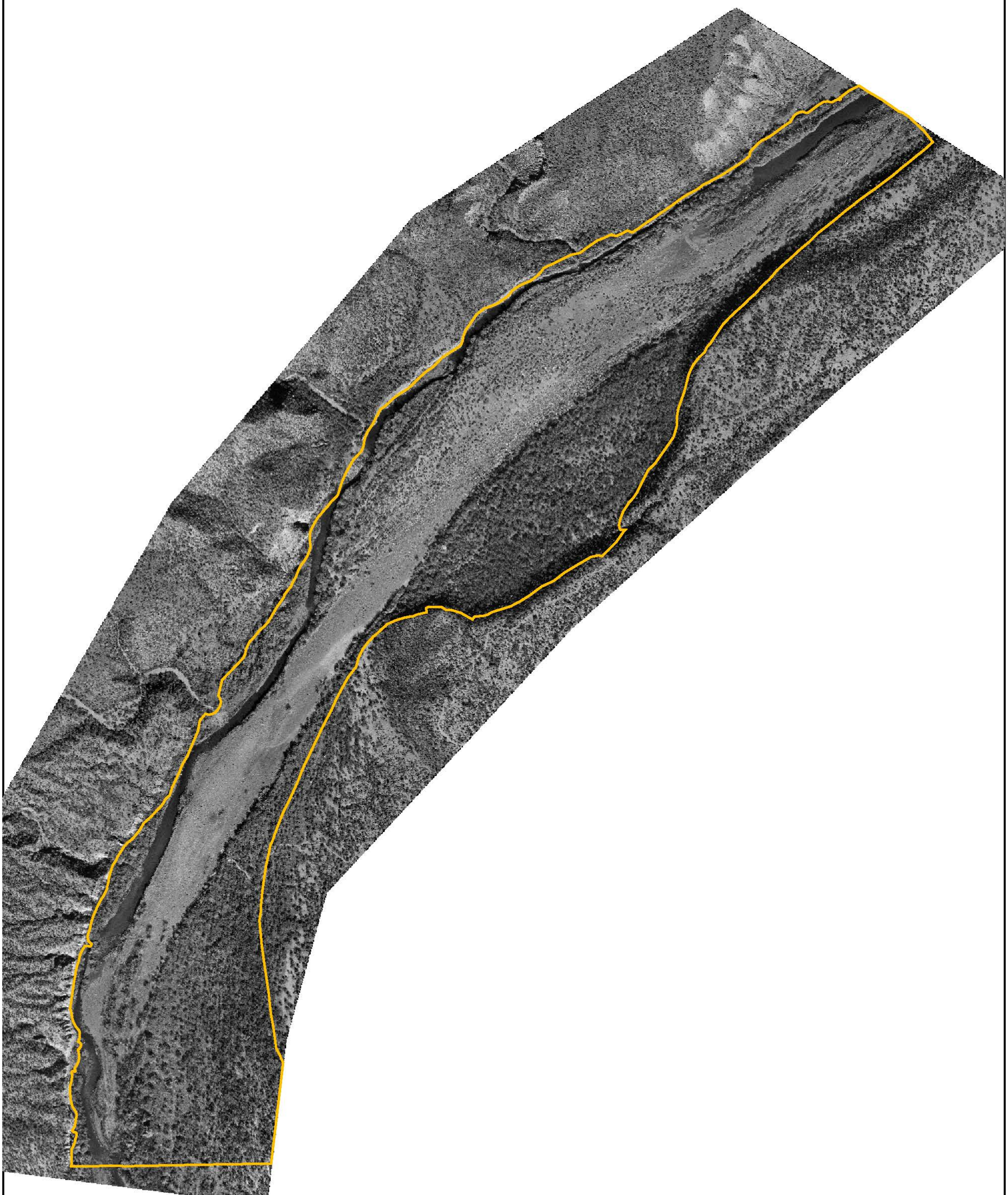
Above Horseshoe

This study site along the Verde River upstream of Horseshoe begins just above the high water mark and is approximately 1.5 miles long (Figure 2). The channel is relatively restricted compared to the other sites and the valley floor along the river varies from 700 to 1,300 feet wide. The west edge of the floodplain is more stable, although narrow, and dominated by cottonwoods. The east side of the floodplain is wider and the vegetation has historically been less stable, as discussed below under Results. Most of the dominant vegetation types are transient, including strand, sparsely vegetated, and shrub areas. Some stands of tall woody vegetation exist, mostly on the north and south ends of the study area. Minor tributaries join the Verde River along this river reach.

Human use at this study site is low. Access and recreation use are limited but the area has been grazed historically. The size of this site is approximately 156 acres.

KA Ranch

The KA Ranch study site is approximately 2.5 miles downstream of Horseshoe dam, and is approximately 1 mile long (Figure 3). The river takes a sharp bend in the study site at the Davenport Wash confluence. At the north end of the study site above the confluence with Davenport Wash, a farm/ranch operation exists on the north side of the Verde River. Average width of the riparian corridor at the KA Ranch study site is about ¼ mile. The eastern side of the floodplain is steep, with little permanent vegetation. Two small, mature cottonwood stands occur along the east edge of the site. The western side of the floodplain is flatter than the eastern side, with lower terraces dominated by frequently scoured vegetation types, including strand, shrub, and sparsely vegetated classes. The upper terrace is dominated by mesquite. Other than Davenport Wash, no other major tributaries enter the Verde River in this river reach.



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Above Horseshoe Vegetation Study Area

0 300 600 Feet

1 inch = 600 feet

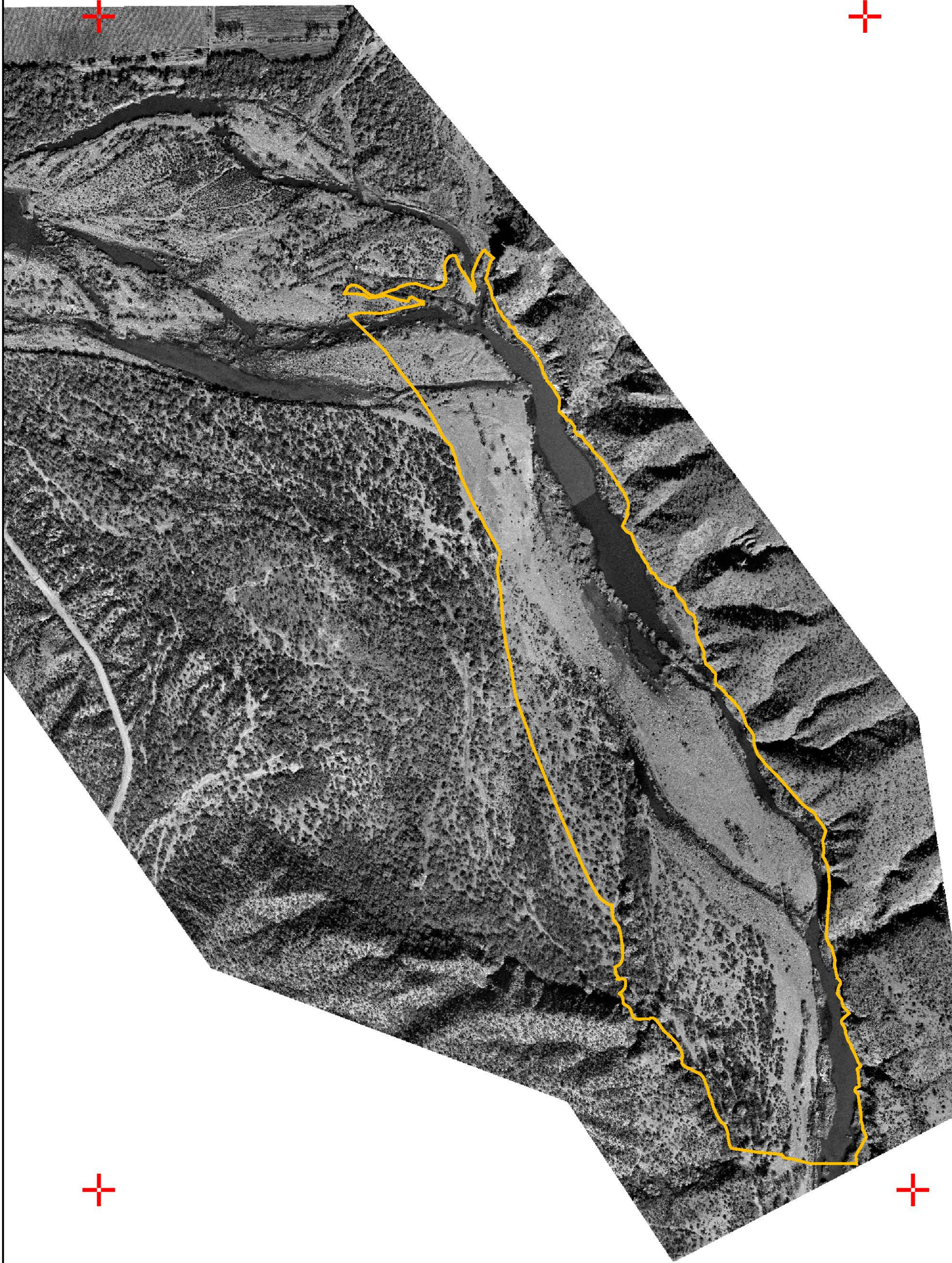
N

Figure 2

Site 1 Above Horseshoe

2002 Photo

File: w:/2346verde/ka_ranch_veg (MS)
November 2003



KA Ranch Vegetation Study Area

0 250 500 Feet

1 inch = 500 feet

N

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Figure 3
Site 2 KA Ranch
2002 Photo

File: w:/2346verde/ka_ranch_veg (MS)
November 2003

Human use at this site is high. The KA Ranch operation is located on the north side of the Verde River at the northern edge of the site. The KA Ranch has a lease from the USFS that permits cattle grazing in this study site when range conditions allow. A paved road provides access to Horseshoe Reservoir and a recreation area below the dam, and parallels a portion of the KA Ranch study area. In addition, a network of informal roads, jeep trails, and livestock trails provides access to the riparian area and riverbank throughout the study site. The size of this site is approximately 80 acres.

Box Bar Ranch

The Box Bar Ranch study site is approximately 6 miles downstream of Bartlett dam, and approximately 2.5 miles long (Figure 4). The riparian zone is much wider at this site than at the other two study sites—an average of about ¾ mile. The riparian zone narrows at both the north and south ends to ¼ to ½ mile. Several ephemeral unnamed tributaries converge with the Verde River in this reach. Camp Creek, an ephemeral sandy wash, is the largest tributary and drains into the river at the northern end of the Box Bar Ranch study area. The western side of the floodplain throughout the study site at this location is slightly steeper and narrower than the eastern side. Stands of dense woody vegetation are present along the western edge of the site along an abandoned main channel, and tend to be 5 to 10 acres in size. Although the eastern side is wider, it is elevationally higher than the western side, and stands of dense woody riparian vegetation are less common. The eastern side is dominated by mesquite. Historically, the Box Bar Ranch site has less woody vegetation than the other two sites. The lower percent of tall woody vegetation is evident in the 1934 photos and in all subsequent photos. The lower percentage of tall, woody vegetation at this site does not appear to be related to reservoir operations and is more likely related to the width of the floodplain in this relatively large study site.

Recreation use at this site is high. The Box Bar Ranch operation is located southwest of the site. Prior to 1986, the USFS permitted grazing in the area. Now, only occasional trespass cattle are found along this reach of the Verde. A network of paved and informal roads and jeep trails provides access to the riparian area and riverbank throughout the study site. The size of this site is approximately 880 acres.

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Box Bar Vegetation Boundary

0 450 900 Feet

1 inch = 900 feet

N

Figure 4
Site 3 Box Bar Ranch
2002 Photo

File: w:/2346verde/box_bar_ranch (MS)
November 2003

Results

Vegetation Trends in General

As shown in Figure 5, overall vegetation composition has remained fairly constant over the past 70 years for the three sites, with a slight increase in the percentage of tall woody vegetation. In 1934, the percentage of tall woody vegetation comprised 2 percent of the total area of all three study sites, while other vegetation types comprised the remaining 98 percent. In 2002, the overall percentage of woody vegetation was 8 percent and other types comprised the remaining 92 percent.

Vegetation Trends Above Horseshoe

At the Above Horseshoe study site, the channel has remained in the same general position within the floodplain during the past 70 years. It appears that many sparsely vegetated bars and banks present in 1934 and 1953 photos have gradually converted to taller and denser vegetation types. Large canopies consistent with cottonwood and mixed riparian stands are apparent in 1988 photography. In addition, some areas along the banks of the river in the southeastern part of the study area that appear in 1953 photos to be dominated by mesquite became tall dense mixed riparian stands in 2002 photos. Vegetation acreages are presented in Table 3 and the percentage trend is shown in Figure 6.

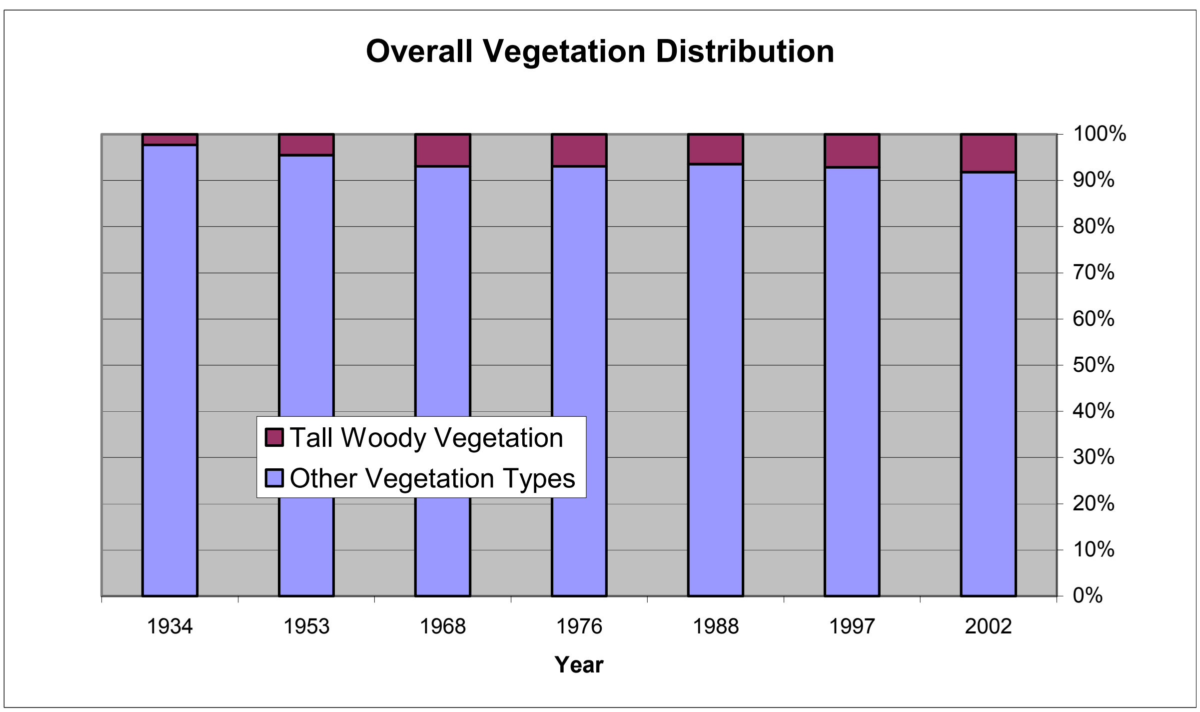


Figure 5. Overall Vegetation Distribution at the Three Study Sites.

Table 3. Summary of Vegetation Acreage for Above Horseshoe (Site 1).

Vegetation	Year						
	2002	1997	1992	1988	1968	1953	1934
Tall Woody Vegetation							
Cottonwood > 15', dense	8.0	10.3	7.2	7.9	0.3	0.0	0.0
Cottonwood > 15', sparse	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mixed riparian < 15', dense	4.5	0.0	0.0	0.0	0.0	0.0	3.5
Mixed riparian < 15', sparse	3.2	0.6	1.7	0.0	4.2	7.1	0.0
Mixed riparian > 15', dense	12.1	4.8	3.0	7.1	2.8	0.0	2.2
Mixed riparian > 15', sparse	2.9	3.1	2.9	0.8	4.7	2.3	3.8
Subtotal	30.7	18.8	14.7	15.8	12.0	9.4	9.5
Other Vegetation Types							
Mesquite	66.5	60.8	65.6	69.2	70.6	77.5	78.9
Strand	1.9	5.9	8.8	6.2	4.2	2.2	8.5
Shrub	20.7	32.1	14.4	48.1	37.1	43.6	51.6
Sparsely vegetated	38.5	40.7	55.6	19.4	14.0	27.7	12.8
Tamarisk < 15'	5.4	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	133.1	139.6	144.4	142.9	125.9	151.1	151.7
TOTAL	163.8	158.3	159.1	158.7	137.9	160.5	161.2
% Tall Woody	19%	12%	9%	10%	9%	6%	6%

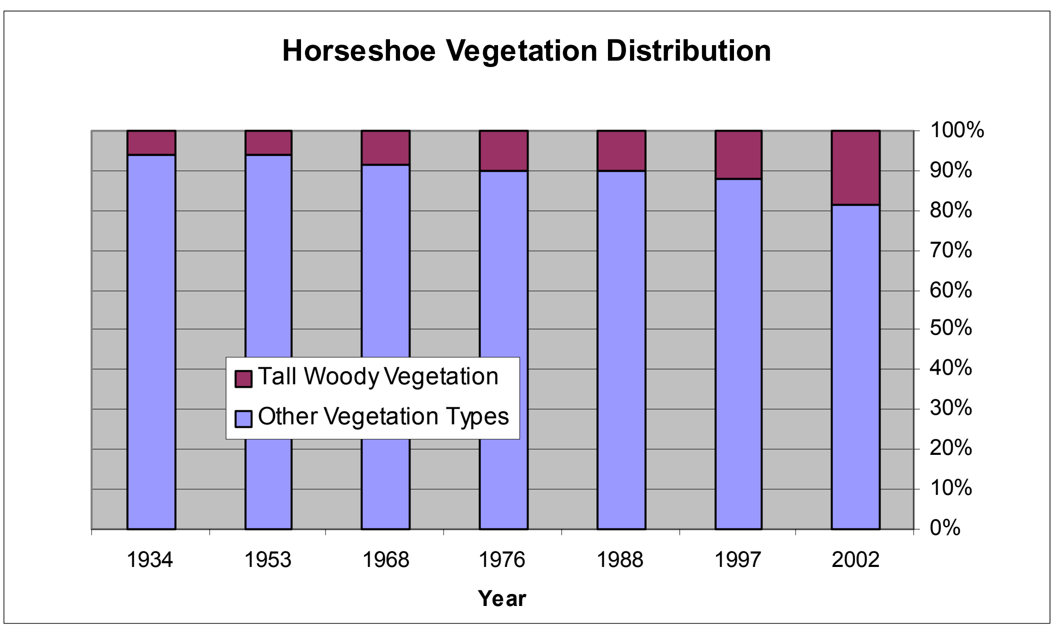


Figure 6. Vegetation Distribution Above Horseshoe.

Vegetation Trends at KA Ranch

The KA Ranch study site appears to be strongly influenced by sediment contributions from Davenport Wash, which enters the Verde at the north end of the site. The sediment contributed by this relatively large wash and the delta formed at its mouth regularly cause the river to shift course in this area during major floods. As a result, the vegetation is more variable at this site than at the other two study sites.

The eastern edge of the floodplain at the KA Ranch site in most places is the toe of a steep slope. Small pockets (about 1 acre in size) of tall, dense woody vegetation have persisted in protected areas along the east bank. Along the western side of the floodplain, the riparian zone is wider and shows evidence of periodic changes of channel location, and inundation and scouring of secondary channels. As on the east side, there is an abrupt slope change on the west bank of the floodplain. At the toe of the steep slope, cottonwood and mixed riparian stands of tall woody vegetation have established and matured over the past 70 years. The 1934 and 1953 photos show evidence of scouring and a shift in the river channel. In the photos spanning to 2002, the abandoned river channel has filled with mesquite in areas that are slightly higher in elevation and drier, with mixed riparian and cottonwood forests in areas that are lower and wetter. In the northern portion of the study site, the 1953 photography shows areas approximately 2 to 5 acres in size of developing tall woody vegetation; these areas persist through 1976, but are no longer evident in 1980 photography. High flows in 1978 and early 1980 realigned the river and scoured the bars and banks in this area.

Tall woody vegetation cover increased from 4 percent in 1934 to 18 percent in 1953 at the KA Ranch site. In 1980, tall woody vegetation cover decreased from 21 percent to 13 percent, and then increased to 19 percent in 1997, following the 1993 flood. Vegetation acreages are presented in Table 4 and the trend is shown in Figure 7.

Table 4. Summary of Vegetation Acreage for KA Ranch (Site 2).

Vegetation	Year						
	2002	1997	1980	1976	1967	1953	1934
Tall Woody Vegetation							
Cottonwood > 15', dense	2.4	3.0	0.6	2.7	5.1	0.0	0.0
Cottonwood > 15', sparse	2.8	2.3	0.0	3.6	3.2	2.0	0.0
Mixed riparian < 15', dense	1.9	2.2	0.0	0.0	0.0	0.0	0.8
Mixed riparian < 15', sparse	0.9	0.8	4.9	7.2	9.5	7.4	0.0
Mixed riparian > 15', dense	2.7	2.9	0.0	0.0	2.4	3.5	2.5
Mixed riparian > 15', sparse	7.3	4.7	2.7	4.1	0.8	1.4	0.0
Subtotal	18.0	15.9	8.2	17.7	21.0	14.3	3.4
Other Vegetation Types							
Mesquite	26.5	26.3	36.4	37.8	31.8	1.5	0.0
Strand	8.1	7.0	0.7	6.4	9.5	3.5	10.7
Shrub	12.7	9.1	2.3	16.3	18.4	53.5	63.7
Sparsely vegetated	20.5	25.1	16.5	4.8	4.6	8.7	8.3
Subtotal	67.8	67.4	55.9	65.3	64.2	67.2	82.6
TOTAL	85.8	83.3	64.1	82.9	85.2	81.6	86.0
% Tall Woody	21%	19%	13%	21%	25%	18%	4%

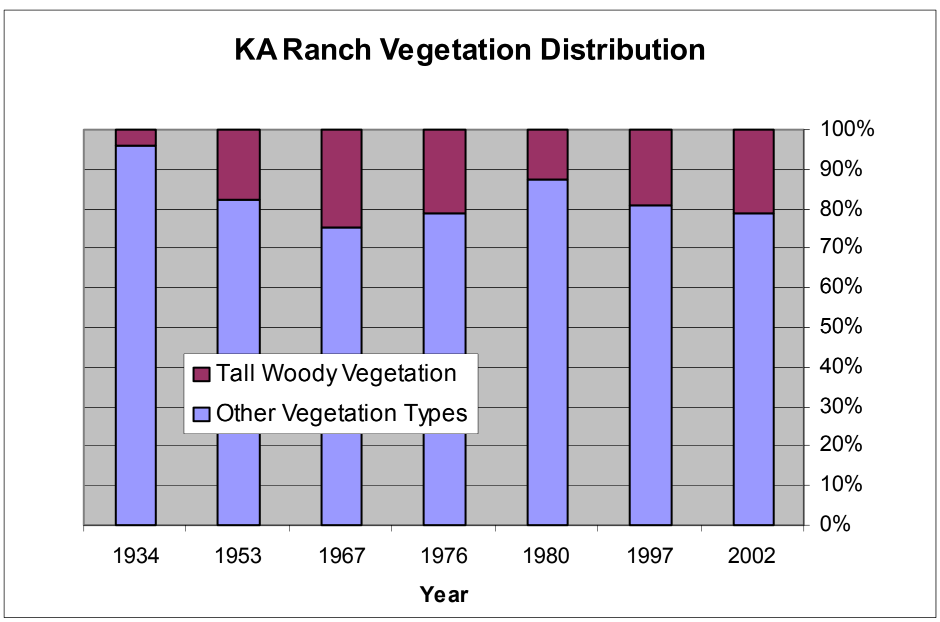


Figure 7. Vegetation distribution at KA Ranch.

Vegetation Trends at Box Bar Ranch

At the Box Bar Ranch site, shrub, strand, and sparsely vegetated classes are common along lower terraces immediately adjacent to the river channel in all years of photography. Tall, dense woody vegetation has established primarily at the mouth of intermittent drainages and in abandoned river channels. Between 1976 and the present, the river has shifted to the east, and tall woody vegetation has established in an old river channel along the west bank. Many mixed riparian stands less than 15 feet in height and with low density are present throughout the reach. If the channel continues to migrate east and no large floods scour this area within the next 10 to 20 years, these stands will likely mature into tall woody stands with a cottonwood overstory. Vegetation acreages are presented in Table 5 and trends are shown in Figure 8. In addition, Figure 9, Figure 10, Figure 11, and Figure 12 show the vegetation delineations for comparison of 1934, 1953, 1988, and 2002 vegetation conditions. Historically, the Box Bar Ranch site has less woody vegetation than the other two sites. The lower percent of tall woody vegetation is evident in the 1934 photos and in all subsequent photos.

Table 5. Summary of Vegetation Acreage for Box Bar Ranch (Site 3).

Vegetation	Year								
	2002	1997	1992	1988	1980	1976	1967	1953	1934
Tall Woody Vegetation									
Cottonwood > 15', dense	5.2	4.0	4.8	5.3	0.5	0.0	2.7	0.0	1.7
Cottonwood > 15', sparse	8.2	12.4	17.3	11.5	18.9	29.1	27.0	19.4	6.3
Mixed riparian < 15', dense	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.6
Mixed riparian < 15', sparse	17.6	16.4	12.6	20.1	6.1	0.0	2.1	8.7	3.3
Mixed riparian > 15', dense	10.7	11.3	8.5	0.0	3.2	0.0	4.0	0.0	0.0
Mixed riparian > 15', sparse	2.8	2.7	4.3	9.7	0.0	15.9	8.8	0.0	0.0
Subtotal	44.5	46.7	47.4	46.6	30.0	44.9	44.5	27.0	12.8
Other Vegetation Types									
Mesquite	633.4	622.3	628.6	568.6	533.1	519.9	451.7	367.4	438.1
Strand	46.4	48.5	43.4	20.0	8.0	47.6	30.0	21.7	34.8
Shrub	112.2	118.3	136.4	183.9	250.8	262.3	347.6	451.9	345.8
Sparsely vegetated	50.3	59.4	44.4	36.8	40.2	15.9	17.8	21.4	47.9
Subtotal	842.4	848.5	852.8	809.2	832.0	845.6	847.1	862.4	866.6
TOTAL	886.8	895.2	900.2	855.8	862.0	890.5	890.5	889.4	879.4
% Tall Woody	5%	5%	5%	5%	3%	5%	5%	3%	1%

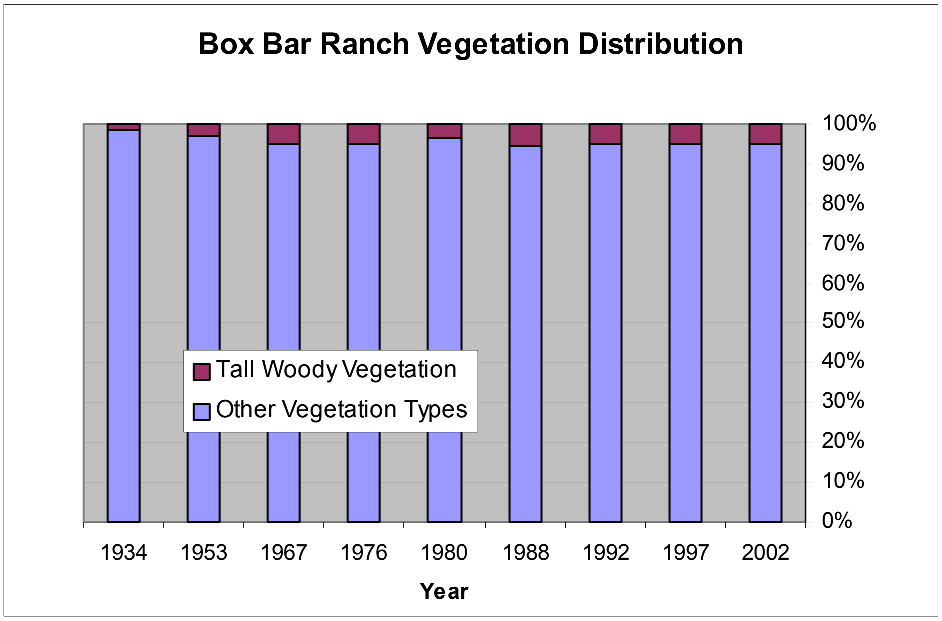
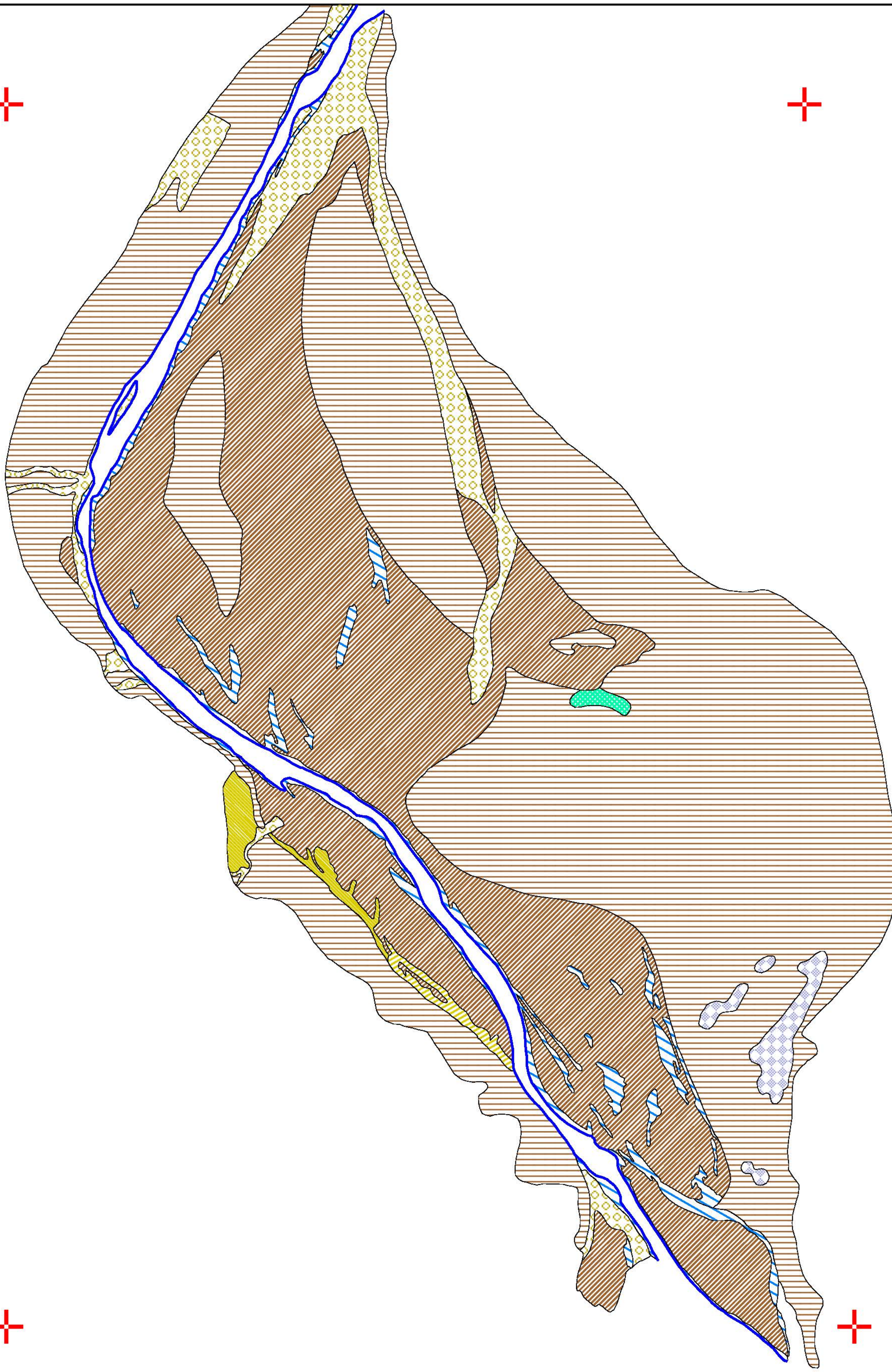


Figure 8. Vegetation Distribution at Box Bar Ranch.



Box Bar Ranch - 1934 Vegetation

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Vegetation Types

- Cottonwood > 15' HD
- Cottonwood > 15' LD
- Mesquite
- Mixed Riparian < 15' HD
- Mixed Riparian < 15' LD
- Mixed Riparian > 15' HD
- Mixed Riparian > 15' LD
- Strand
- Shrub
- Sparsely Vegetated
- Tamarisk < 15'
- River

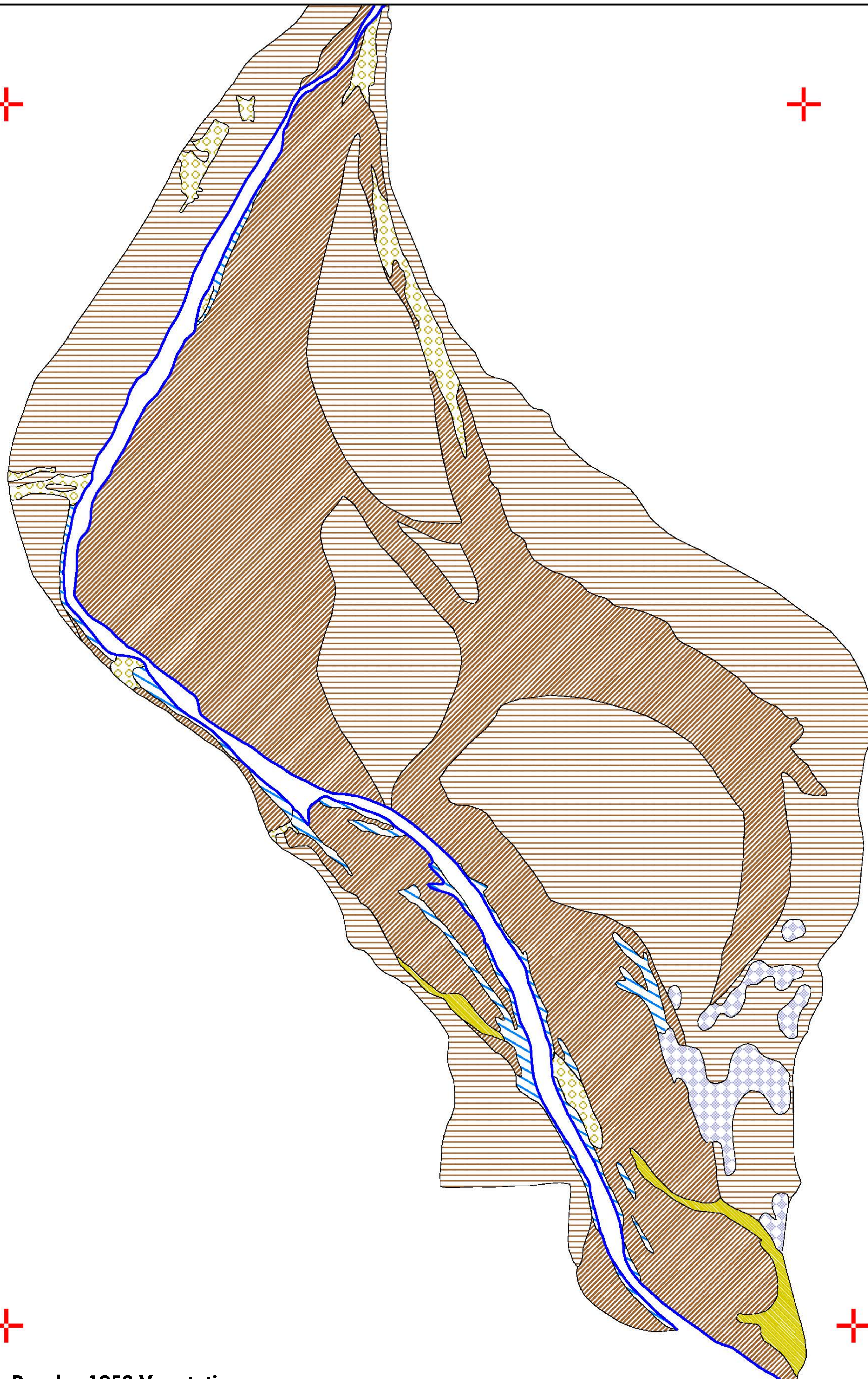
0 450 900 Feet

1 inch = 900 feet

N

Figure 9
Site 3 Box Bar Ranch

File: w:/2346verde/box_bar_ranch (MS)
November 2003



Box Bar Ranch - 1953 Vegetation

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Denver, CO 80218
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Fax: 830-1199

Vegetation Types

- Cottonwood > 15' HD
- Cottonwood > 15' LD
- Mesquite
- Mixed Riparian < 15' HD
- Mixed Riparian < 15' LD
- Mixed Riparian > 15' HD
- Mixed Riparian > 15' LD
- Strand
- Shrub
- Sparsely Vegetated
- Tamarisk < 15'
- River

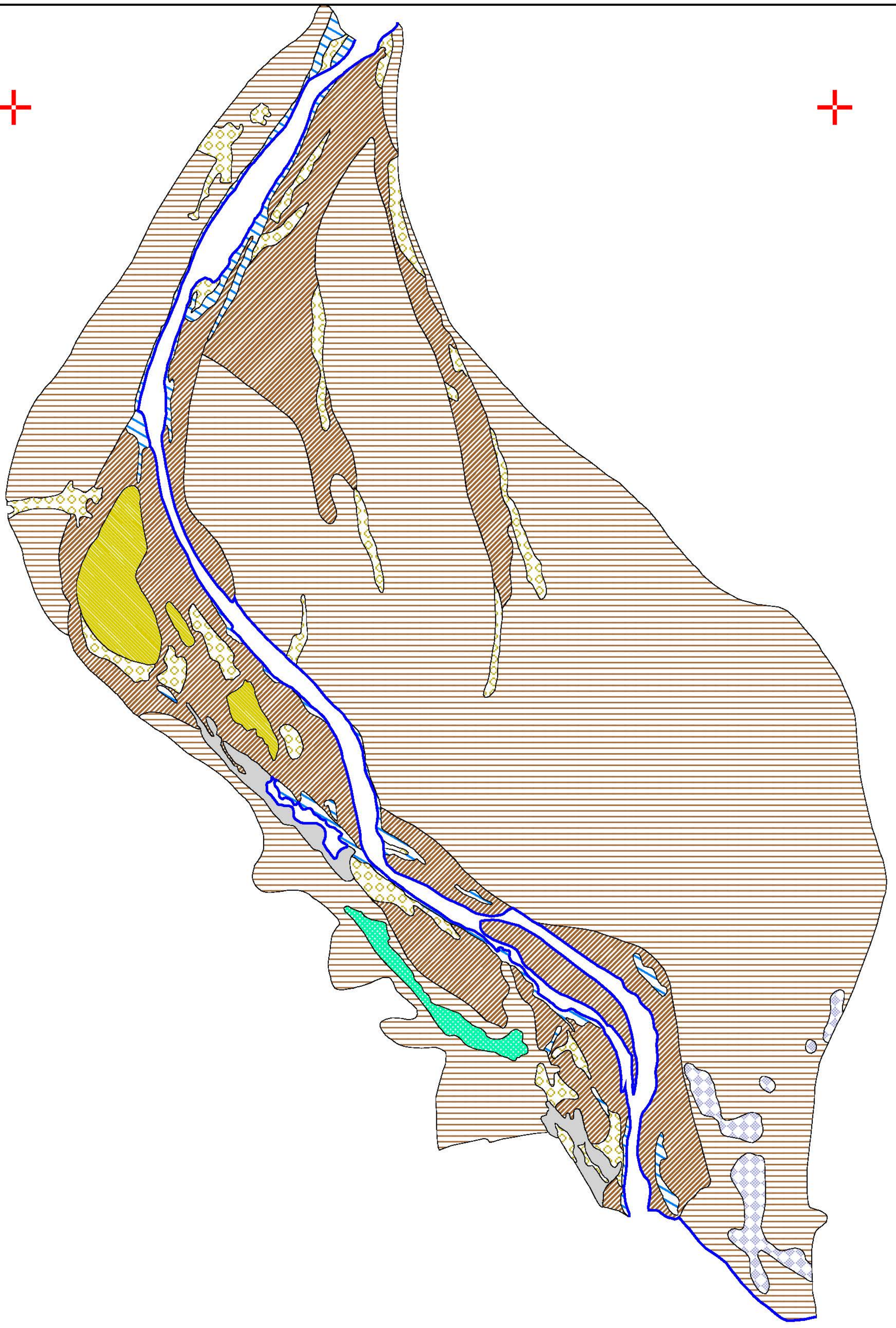
0 450 900 Feet

1 inch = 900 feet

N

Figure 10
Site 3 Box Bar Ranch

File: w:/2346verde/box_bar_ranch (MS)
November 2003



Box Bar Ranch - 1988 Vegetation

Vegetation Types

- Cottonwood > 15' HD
- Cottonwood > 15' LD
- Mesquite
- Mixed Riparian < 15' HD
- Mixed Riparian < 15' LD
- Mixed Riparian > 15' HD
- Mixed Riparian > 15' LD
- Strand
- Shrub
- Sparsely Vegetated
- Tamarisk < 15'
- River

0 450 900 Feet

1 inch = 900 feet

N

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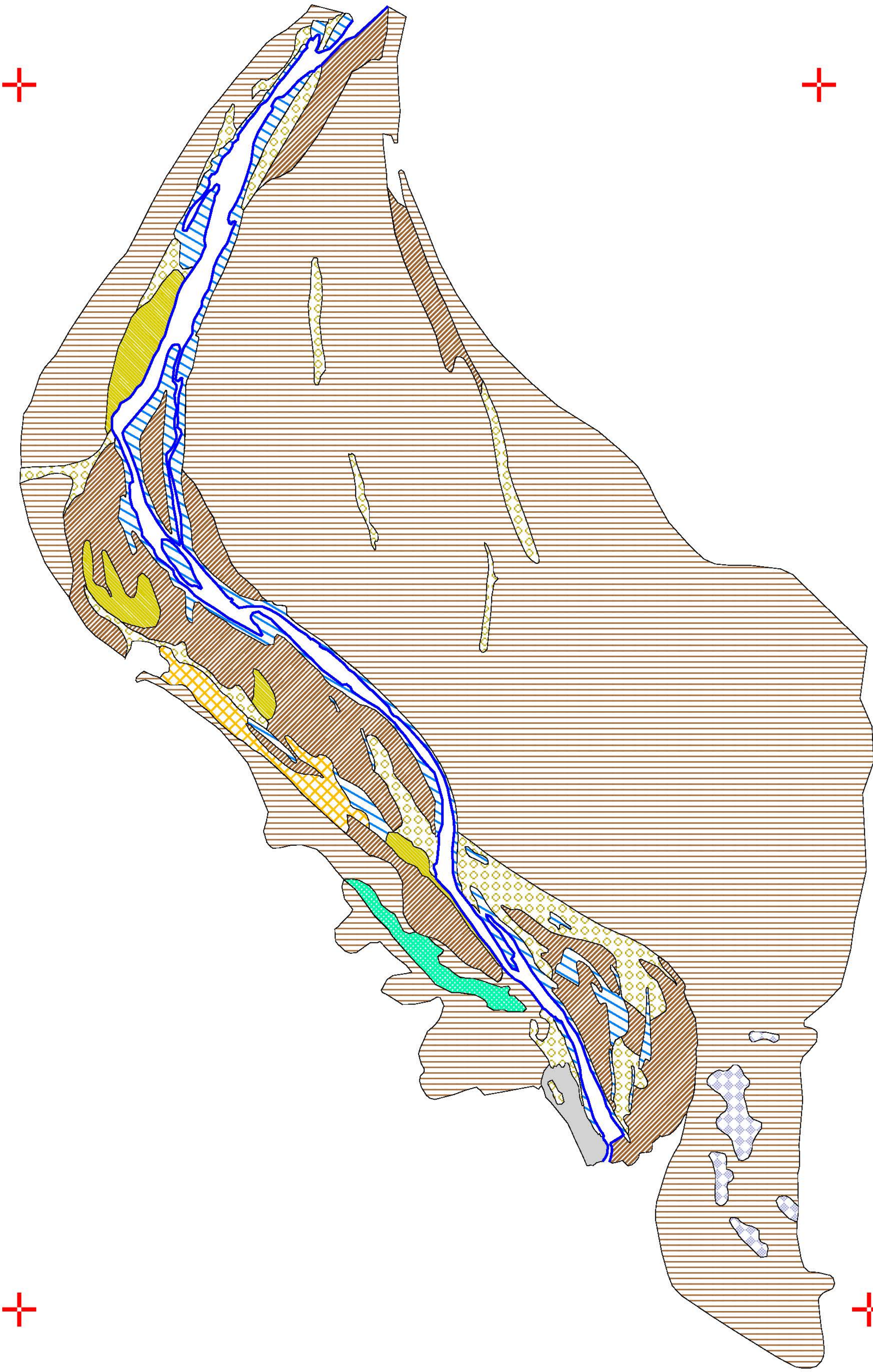
Figure 11
Site 3 Box Bar Ranch

File: w:/2346verde/box_bar_ranch (MS)
November 2003



Box Bar Ranch - 2002 Vegetation

Vegetation Types

- Cottonwood > 15' HD
- Cottonwood > 15' LD
- Mesquite
- Mixed Riparian < 15' HD
- Mixed Riparian < 15' LD
- Mixed Riparian > 15' HD
- Mixed Riparian > 15' LD
- Strand
- Shrub
- Sparsely Vegetated
- Tamarisk < 15'
- River

0 450 900 Feet

1 inch = 900 feet

N

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Figure 12
Site 3 Box Bar Ranch

File: w:/2346verde/box_bar_ranch (MS)
November 2003

Discussion

Riparian vegetation trends were compared for each study site relative to regulation of water flows by the operation of Horseshoe and Bartlett. The study site above Horseshoe is the only non-regulated site. The other two sites—KA Ranch and Box Bar Ranch—have flows regulated by Horseshoe and Bartlett, respectively.

This study of riparian vegetation describes general trends and changes in vegetation in regulated and unregulated reaches of the lower Verde River. The study was not designed to address individual recruitment events above and below the dams in response to floods because individual recruitment events are also influenced by site topography, geomorphology, land use, and other variables. However, this study provides useful information on long-term historical recruitment trends along the lower Verde relative to flow regulation by Horsehoe and Bartlett.

Vegetation Trends in General

The general trend in tall woody vegetation cover ranged from about 2 percent in 1934 to about 8 percent in 2002. Tall woody vegetation cover did not change appreciably between 1988 (94 percent) and 1997 (93 percent) although a 145,000 cfs flood occurred in 1993 between the time the 1988 and 1997 photos were taken. The 1993 flood was similar in volume to the 1891 flood (150,000 cfs). In addition, relatively large flood events occurred in 1956, 1971, 1978, 1979, 1980, and 1995, which were similar in volume to floods that occurred prior to the 1934 photo (1906, 1920, and 1927). The lack of change in vegetation cover following the 1993 flood, and during a time period when floods of similar volume occurred as the volume of the floods preceding the 1934 photo indicates that the lower vegetation cover in 1934 versus 2002 probably was a result of a more frequent flood events. Both the KA Ranch and Box Bar Ranch sites exhibit an overall pattern of increasing tall woody vegetation except for 1980 when acreages decreased for a period of time before increasing again.

Above Horseshoe

At the site with no flow regulation—Above Horseshoe—the percentage of tall, woody vegetation has increased about 3-fold over the past 70 years (Table 3 and Figure 6). In 1934, tall woody vegetation accounted for approximately 6 percent of the total vegetated cover. In 2002, tall woody vegetation increased to about 19 percent of the total. Stands of cottonwood and mixed riparian woody vegetation have established in areas that appear to be scoured on the 1934 and 1953 photography. At the Above Horseshoe site, tall woody vegetation decreased slightly between 1988 and 1992. The reason for this decline is not known because there were no large floods in these years.

KA Ranch

At the site with flow regulated by Horseshoe—KA Ranch— there has been a 4- to 6-fold increase in tall woody vegetation since the earliest aerial photographs in 1934, although the percentage of tall woody vegetation does not exhibit a steady trend of increase. Beginning at 4 percent in 1934, tall woody vegetation increased to 25 percent in the 1967 photo, declined to a low of 13 percent in 1980, then increased to 21 percent in 2002.

Box Bar Ranch

At the site with the flow regulated by both Horseshoe and Bartlett—Box Bar Ranch—the percentage of tall woody vegetation increased about 5-fold over the past 70 years from 1 percent to 5 percent (Figure 8), a slightly greater increase than the unregulated site above Horseshoe (Figure 6). Beginning at 1 percent in 1934, tall woody vegetation increased to 5 percent in the 1976 photo, declined to 3 percent in 1980, then increased to 5 percent in 2002. Historically, the Box Bar Ranch site has less woody vegetation than the other two sites. The lower percent of tall woody vegetation is evident in the 1934 photos and in all subsequent photos.

Conclusion

Along the lower Verde River, the area covered by tall woody riparian vegetation is dynamic in both the regulated and unregulated reaches. In general, the acreage of tall woody vegetation has increased at all study sites since aerial photos first became available in 1934, prior to the construction of Bartlett and Horseshoe dams in the late 1930s and early 1940s. Some of this increase in tall woody vegetation may be due to invasion of tamarisk. Although the study was not designed to determine whether the reservoir or reservoir operations have a specific effect on cover of specific species such as tamarisk, long-term trends for native vegetation types for the study sites indicate that flow regulation has not had a significant adverse effect overall on establishment and maintenance of native tall woody vegetation stands. The slight increase in tall woody vegetation at the two regulated sites over the past 60 years suggests that the dams may have provided a slight long-term benefit to persistence of woody stands by reducing the frequency and magnitude of scouring. More recently, the minimum flow of 100 cfs below Bartlett since 1994 has likely benefitted tall woody vegetation downstream of the dam, including the Box Bar Ranch study site. Prior to 1994, the lower Verde would occasionally have no flow, which could cause phreatophytes to become stressed or die, depending on the duration that the stream did not run.

The findings of the vegetation study are consistent with the findings of the fluvial morphology study conducted by MEI (2004). The fluvial geomorphology study concluded that alternate reservoir operations ranging up to the full release of flood flows would have an insignificant effect on the duration of inundation and sediment mobilization on geomorphic surfaces, that Bartlett and Horseshoe operations have caused little, if any, morphological or sedimentological adjustment of the Verde River, and that the reduction in frequency of flood events below Bartlett Reservoir enables vegetation to become better established and withstand higher magnitude floods (MEI 2004).

References

AGFD (Arizona Game and Fish Department). In prep. Conservation assessment and strategy for the bald eagle in Arizona. Nongame and Endangered Wildlife Program Tech. Rep., Arizona Game and Fish Department, Phoenix, AZ.

Beauchamp, V. and J.C. Stromberg. 2004. Cottonwood-Willow Stand Structure on Regulated and Unregulated Reaches of the Verde River, Arizona. Presentation at Arizona Riparian Council March 2004 meeting. Phoenix, Arizona.

Braatne, J.H., S.B. Rood, and P.E Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. In Stettler, R.F., H.D. Bradshaw, Jr., P.E. Heilman, and T.M. Hinckley, eds. Biology of *Populus* and its implications for management and conservation. NRC Research Press. Ottawa, Ontario, Canada.

Brady, W., D.R. Patton, and J. Paxson. 1985. The development of southwestern riparian gallery forests. Paper presented at the Riparian Ecosystems and Their Management: Reconciling Conflicting Uses Conference. Tucson, AZ, April 16-18.

Brown, D.E., C.H. Lowe, J.F. Hausler. 1977. Southwestern riparian communities: Their biotic importance and management in Arizona. Pages 201-211 *In* R.R. Johnson and

D.A. Jones (eds.), Importance, Preservation and Management of Riparian Habitat: A symposium. Rocky Mountain Forest and Range Experimental Station, Fort Collins, CO.

ERO Resources Corporation (ERO). 1986. Draft: Fort McDowell Indian Reservation Riparian Study. Prepared for Salt River Project.

Everitt, B.L. 1995. Hydrologic factors in regeneration of Fremont cottonwood along the Fremont River, Utah. *In* Natural and anthropogenic influences in fluvial geomorphology. J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock (eds.). Geophysical Monographs, 89:197-208.

Fenner, P., W.W. Brady and D.R. Patton. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management, 38:135-138.

Fenner, P., W.W. Brady, and D.R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. Desert Plants, 6(1):55-58.

FWS (U.S. Fish and Wildlife Service). 2002. Southwestern willow flycatcher recovery plan. Albuquerque, NM.

FWS (U.S. Fish and Wildlife Service). 2003. Intra-Service Biological and Conference Opinion. Issuance of a Section 10(a)(1)(B) permit to Salt River Project for operation of Roosevelt Lake. February 21.

Gladwin, D.N. and J.E. Roelle. 1998. Survival of plains cottonwood (*Populus deltoides* subsp. *Monilifera*) and tamarisk (*Tamarix ramosissima*) seedlings in response to flooding. Wetlands 18:669-674.

Irvine, J.R. and N.E. West. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. 1979. The Southwestern Naturalist, 24(2):331-346.

Mahoney, J.M. and S.B. Rood. 1992. Response of a hybrid poplar to water table decline in different substrates. Forest Ecology and Management, 54:141-156.

Mahoney, J.M. and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. Wetlands, 18(4):634-645.

Marler, R.J., D.T. Patten, and J.C. Stromberg. 2004. Riparian Vegetation Community Development along the Effluent-Receiving Salt River near Phoenix, Arizona. Presentation at Arizona Riparian Council March 2004 meeting. Phoenix, Arizona.

McNatt, R.M., R.J. Hallock, and A.W. Anderson. 1980. Riparian habitat and instream flow studies, lower Verde River: Fort McDowell Reservation, Arizona. Riparian Habitat Analysis Group, U.S. Fish and Wildlife Service, Region 2. Albuquerque, New Mexico. June.

Mussetter Engineering Inc. (MEI). 2004. Inundation and substrate stability study to support Verde River vegetation analysis, November 2003 Draft. Prepared for Salt River Project, Phoenix, Arizona. May 20, 2004.

Ohmart, R.D. 1979. Past and present biotic communities of the lower Colorado River mainstem and selected tributaries, Vol. IV *in* Past and present biotic communities of the lower Colorado River mainstem and selected tributaries, Volume IV: The Salt

River, Verde River, Agua Fria River, Bill Williams River. Bureau of Reclamation Department of the Interior, Boulder City NV, November 1982.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47(11):769-781.

Reed, W.R. 1993. Salix gooddingii. In: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2003, October). Fire Effects Information System, Available: http://www.fs.fed.us/database/feis/ [ERO Resources, 10/25/03].

Rood, S.B. and J.M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. Environmental Management, 14:451-464.

Rood, S.B., A.R. Kalischuk, and J.M. Mahoney. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands, 18:557-570.

Scott, M.L. and G.T. Auble. 2002. Conservation and restoration of semiarid riparian forest: A case study from the Upper Missouri River, Montana. *In* Flood Pulsing in Wetlands: restoring the Natural Hydrological Balance, pp. 145-190. B.A. Middleton (ed.). John Wiley and Sons, Inc.

Scott, M.L., G.C. Lines, and G.T. Auble. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments, 44:399-414.

Scott, M.L., G.T. Auble, and J.M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7:677-690.

Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14:327-339.

Scott, M.L., M.A. Wondzell, and G.T. Auble. 1993. Hydrograph characteristics relevant to the establishment and growth of western riparian vegetation. *In* H.J. Morel-Seytoux (ed.), Proceedings of the Thirteenth Annual American Geophysical Union Hydrology Days, pp. 237-246. Hydrology Days Publications, Atherton, CA.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management, 23(3):347-358.

Scott, M.L., S.K. Skagen, and M.F. Merigliano. 2003. Relating Geomorphic Change and Grazing to Avian Communities in Riparian Forests. Conservation Biology 17(1):284-296.

Shafroth, P.B., G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams Reservoir, Arizona. Wetlands, 18(4):577-590.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist, 60:66-67.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications, 12(1): 107-123.

SRP (Salt River Project). 2002a. Appendix 1: SRP Perspectives, Verde River hydrology and other factors in relation to potential flycatcher habitat below Horseshoe Reservoir. *In* comments of designation of critical habitat for *Empidonax traillii extimus* submitted to FWS Arizona Ecological Services Office. June 13.

SRP (Salt River Project). 2002b. Roosevelt habitat conservation plan, Gila and Maricopa counties, Arizona. December.

Stevens, L.E., and G.L. Waring. 1986. Effects of post-dam flooding on riparian substrates, vegetation, and invertebrate populations in the Colorado River corridor in Grand Canyon, Arizona. Terrestrial Biology of the Glen Canyon Environmental Studies.

Stromberg, J.C. 1993. Fremont cottonwood-Goodding willow riparian forests: A review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science, 26(3):97-110.

Stromberg, J.C. 1997. Growth and survivorship of Freemont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist, 57(3):198-208.

Stromberg, J.C. 2001. Restoration of riparian vegetation in the south-western United States: Importance of flow regimes and fluvial dynamism. Journal of Arid Environments, 49:17-34.

Stromberg, J.C. and M. Chew. 1999. Restoration of riparian ecosystems in the arid Southwest: challenges and opportunities. *In* Shafroth, P.B., B. Tellman, and M.K. Briggs (technical coordinators). 1999. Riparian ecosystem restoration on the Gila River basin: opportunities and constraints. Issue Paper No. 21. Water Resources Research Center, The University of Arizona, Tucson.

Stromberg, J.C., B.D. Richter, D.T. Patten, and L.G. Wolden. 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53(2):118-130.

Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers, 2(3):221-235.

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of ground water decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. Ecological Applications, 00(0).

Williams, G.P. and M.G. Wolman. 1984. Downstream Effects of Dams on Alluvial Rivers. USGS Professional Paper 1286. U.S. Government Printing Office, Washington, DC.

APPENDIX 1
EXCERPTS AND NOTES FROM VEGETATION REFERENCES

Amlin, N.A. and S.B. Rood. 2001. Inundation tolerances of riparian willows and cottonwoods. Journal of the American Water Resources Association, 37(6):1709-1720.

- "The greater inundation tolerance of willows versus cottonwoods is consistent with observations along Midvale Creek, Montana, where beaver dams created a pond in which *P. trichocarpa* died while willows thrived after five years."

Auble, G.T. 1999. Riparian restoration using physical manipulation and natural seedfall. *In* Shafroth, P.B., B. Tellman, and M.K. Briggs (technical coordinators). 1999. Riparian ecosystem restoration on the Gila River basin: opportunities and constraints. Issue Paper No. 21. Water Resources Research Center, The University of Arizona, Tucson.

- Riparian restoration strategies that simulate the physical processes by which rivers create fluvial disturbance patches have potential advantages of cost and use of local genetic material.
- Manipulation of the physical conditions is most practical on sites that are most similar to natural disturbance patches; excavated depressions or relict disturbance features such as abandoned side channels.

Baker, W.L. 1990. Climatic and hydrologic effects on the regeneration of *Populus angustifolia* James along the Animas River, Colorado. Journal of Biogeography, 17:59-73.

- "Seedlings were most abundant in years with cool winters, wet springs, and cool, wet falls."
- "Model results suggest good seedling years occurred more frequently (about every 3.4 years) than stand-origin years (about every 10-15 years)."

Beauchamp, V. and J.C. Stromberg. 2004. Cottonwood-Willow Stand Structure on Regulated and Unregulated Reaches of the Verde River, Arizona. Presentation at Arizona Riparian Council March 2004 meeting. Phoenix, Arizona.

- Evaluated woody vegetation stands at three study sites above Horseshoe Dam and four study sites below Horseshoe and/or Bartlett dams to determine how Bartlett Dam operations have altered the flow regime of the lower Verde River, and how the structure of cottonwood-willow stands differs between above and below dam reaches.
- Cottonwood and willow recruitment has not been affected by the dams because periodic large floods occur.
- Higher tamarisk density below the dams may have been caused by late spring/early summer dam releases in 1995.
- Management recommendations: 1) Allow winter/spring floods whenever possible; 2) avoid late spring/early summer flow recession; and 3) establish a vegetation monitoring program.

Boucher, P.F., S.H. Stoleson, R.S. Shook, R.D. Pope, and J. Monzingo. Undated. Multi-purpose riparian restoration on the Gila River: bank stabilization creates willow flycatcher habitat.

- "In 1995, faced with a legal obligation to reduce erosion of riverbanks in the Gila River Bird Area, the Silver City Ranger District initiated a riparian restoration project intended to stabilize banks while creating habitat for the flycatcher."
- "The project was undertaken in three phases…The first step was to retire the entire riparian corridor from grazing…Second, the vertical eroded banks were sloped. Heavy equipment was used to excavate the cobble bed to expose the water table. Exposed banks and weedy fields adjacent to the project were planted with a mix of native grass seed (*Bouteloua gracilis, Buchloe dactyloides, Elymus smithii,* and *Sporobolus cryptandrus* at approx. 15.6 kg/ha) to reduce erosion. Both sides of the excavated channel were planted with poles and cuttings of native woody species: *Populus fremontii, Salix gooddingii, Salix exigua, Platanus wrightii,* and *Alnus oblongifolia*…The first set of poles planted in 1995 had reached average heights in excess of 6 m by August of 2000."

Braatne, J.H., S.B. Rood, and P.E Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. *In* Stettler, R.F., H.D. Bradshaw, Jr., P.E. Heilman, and T.M. Hinckley, eds. Biology of *Populus* and its implications for management and conservation. NRC Research Press. Ottawa, Ontario, Canada.

- “The river systems and alluvial floodplains inhabited by riparian cottonwoods are the product of a complex array of interrelated fluvial geomorphic processes (Leopold 1995; Leopold et al. 1964).”
- “The environmental features of riverine systems provide a variable water supply and periodic, yet repeated, disturbances to which riparian cottonwoods have adapted. But there is variability in fluvial processes from year to year, and it has significant effects on the long-term health and vigor of riparian cottonwood forests.”

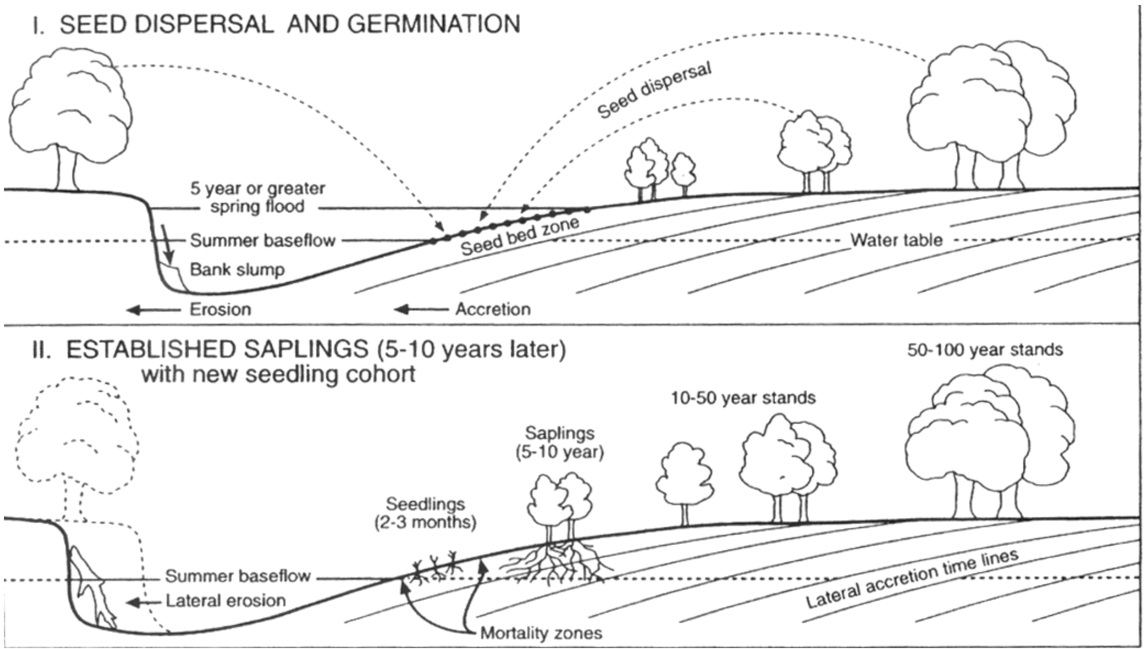
Table 2. Life history traits and ecological properties of *Populus fremontii*.

Life History Trails/Ecological Properties	Species Characteristics
Reproduction	
Flowering time	February – March (*P. fremontii)*
Seed dispersal time	March – April (*P. fremontii)*
Seeds/tree/yr	25+ million (*P. deltoides)*
Dispersal agents/distance	Air and water/several km (all spp.)
Asexual traits	Limited to crown breakage and flood-related disturbance
Germination/Establishment	
Seed variability (natural conditions)	1 – 3 wk (*P. fremontii)*
Seed germination	24 h/bare
Seedling root growth rates	4 – 12 mm/d (*P. fremontii)*
Soil salinity	0 – 1500 mg/L (*P. fremontii)*
Growth/Maturation	
Age at reproductive maturity	5 – 10 yr (*P. fremontii)*
Lifespan	130+ yr (*P. fremontii)*
Mature stand density (trees/ha)	50 – 400+/ha (*P. fremontii)*
Rooting depths of mature stands	3 – 5+ m (all spp.)

- “In the arid Southwest, flowering by *P. fremontii* is over by late February to early March.”
- “Given the lack of endosperm, full sunlight is critical as seedlings are highly dependent upon photosynthate derived from cotyledons and juvenile leaves for sustained growth and development.”
- “Conditions essential for seedling recruitment are not met on an annual basis. In fact, suitable conditions occur irregularly, on intervals of 5 to 10 yr or longer.”
- “On less sinuous arid-region rivers, such as the Hassayampa River, cottonwoods establish in large numbers at infrequent intervals, after large, erosional floods that scour sediment from terraces (Stromberg et al. 1993). This pattern has been referred to as a general-replenishment model, characterized by infrequent (ca. 30-50 yr recurrence intervals), large floods that set up recruitment conditions over large areas of the floodplain (Stromberg et al. 1993; Hughes 1994).”

- "Early stages of sapling growth and stand development are influenced by seasonal flooding, drought, grazing, fire, and other site-specific conditions. Vulnerability to drought persists until sapling roots reach the moist soil associated with late-season alluvial water tables at depths of two meters or more. Major flooding events (10- to 50-yr floods) eliminate young saplings as well as mature trees, though losses associated with these floods are often compensated by additional seedling recruitment on newly, exposed microsites."
- "Height growth during the early stages of sapling development may be limited, as energy is preferentially allocated to rapidly growing roots. Two- to three-year-old cohorts of *P. fremontii* ranged from 5 to 50 cm tall (Stromberg et al. 1991, 1996a)."
- "Negative impacts on riparian cottonwood forests across western North America (listed in likely descending order of importance; the ranking would vary across river systems (revised from Rood and Mahoney 1990) include: livestock grazing; water diversion; domestic settlement; exotic plants; onstream reservoirs; channelization; agricultural clearing; gravel mining; direct harvesting; and beavers."
- "In many areas in western North America the heaviest pressure on riparian cottonwoods is related to livestock grazing (Table 3). Cattle browse and trample seedlings and saplings, thereby preventing replenishment of the forest. Management efforts to control livestock grazing include rotational grazing and exclusion fencing. This limits cattle use of riparian areas for short periods of time (ca. 5 yr) to allow younger trees to outgrow their most vulnerable stage."
- "Another major cause of the decline of riparian cottonwoods is river damming and water diversion (Tables 3, 4, and 5). Declines of cottonwoods downstream from dams in semi-arid regions of North America are well documented. Fortunately, these impacts are site specific since it is largely the pattern of downstream flow regulation, rather than simply the presence or absence of dams, that determines the effect on riparian ecosystems. Although cottonwood decline has been common, occasional increases of cottonwoods have occurred following damming and stream flow modification, thus confirming that river type and flow patterns are critical factors in influencing riparian cottonwood forests."
- "Although root suckering of the *P. deltoides* and *P. fremontii* (Sect. *Aigeiros*) is uncommon, even these species appear to respond to some mechanical disturbance."

Figure 6. Patterns of seed dispersal, germination, and establishment in relation to microtopographic position and river stage of a meandering river (Modified from Bradley and Smith 1986).



Brady, W., D.R. Patton, and J. Paxson. 1985. The development of southwestern riparian gallery forests. Paper presented at the Riparian Ecosystems and Their Management: Reconciling Conflicting Uses Conference. Tucson, AZ, April 16-18.

- "Habitats suitable for tree reproduction are recognizable by their position relative to the active water course. These sites are typically located in overflow channels and receive flow only during floods."
- "Two study areas were selected which were felt to be representative of well-developed riparian gallery forests in the Southwest. The Gila River Bird Habitat Area (hereinafter termed Gila BHA) was 16 km southwest of Cliff, New Mexico. The Winkelman study area was 7 km southeast of Winkelman, Arizona, and was on the San Pedro River. Both sites exhibited a development continuum from seedling through mature stands."
- "Nursery-bars were located in overflow channels on both study areas."
- "Major flooding events are potentially destructive because overflow channels provide a natural pathway for water flow."

- "Observations at both study areas suggested that mature to sub-mature stands of cottonwood-willow may result from the coalescing of smaller nursery-bars into a larger stand (Figure 1)."
- "Age distributions inferred from DBH measurements (Table 3) indicated that as stands mature, the habitat became progressively less suitable for regeneration. Little or no regeneration of mesic riparian species takes place in stands which have developed beyond the nursery-bar stage. Shading, aggradation within the stand due to sediment deposition, shifting river patterns, and possibly other factors combine to provide adverse conditions for seedling establishment."
- "Establishment and development of southwestern riparian gallery forests appears to follow an orderly, well-defined sequence. Starting with the creation of favorable seedbed, stands progress from nursery-bars to senescent individuals as habitat is continually modified. The riverine system plays an important role in the survival and development of these stands. Flooding, when light or moderate, favors establishment and development through deposition of nutrient-rich sediments and increased soil moisture. Successful regeneration cannot be expected on an annual basis, since it depends greatly on a "proper sequence of flooding," i.e., no flood large enough to be catastrophic until any given stand is sufficiently well developed to provide its own protection. Major flooding is catastrophic, regardless of the developmental stage."

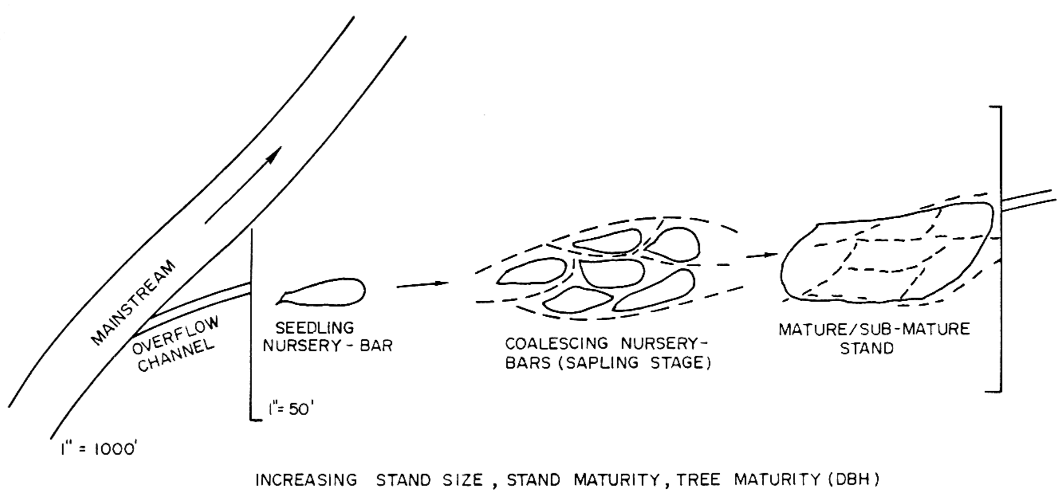


Figure 1.--Riparian development sequence showing coalescing of seedling nursery-bars in an overflow channel into a mature stand.

Briggs, M. 1999. Benefiting from past experiences: Lessons gained from the experiences of past riparian recovery efforts. *In* Shafroth, P.B., B. Tellman, and M.K. Briggs (technical coordinators). 1999. Riparian ecosystem restoration on the Gila River basin: opportunities and constraints. Issue Paper No. 21. Water Resources Research Center, The University of Arizona, Tucson.

- *"Restoration* is an attempt to create an ecosystem exactly like the one that was present prior to disturbance (often referred to as "pre-development conditions")."
- "*Rehabilitation* creates an ecosystem that is similar (but not identical) to the ecosystem that was present prior to the disturbance."
- "Replacement or *reallocation* strategies generally do not attempt to restore an ecosystem to its pre-disturbance condition. Instead, the original ecosystem is replaced by a different one."
- "Lesson 1: Develop Project Objectives that are clear and specific."
- "Lesson 2: Understand the current ecological condition of the site."
- "Lesson 3: Identify and address causes of ecologic decline."
- "Lesson 4: Fostering processes of natural regeneration can produce significant results."
- "Lesson 5: Develop the recovery effort from a watershed perspective."
- "Lesson 6: Post-project considerations are critical to the effectiveness of the restoration effort."
- "Lesson 7: Prioritizing projects/sites is essential for effectively allocating restoration resources."
- "Lesson 8: Involving communities can be critical to success."

Brown, D.E., C.H. Lowe, J.F. Hausler. 1977. Southwestern riparian communities: Their biotic importance and management in Arizona. Pages 201-211 *In* R.R. Johnson and D.A. Jones (eds.), Importance, Preservation and Management of Riparian Habitat: A symposium. Rocky Mountain Forest and Range Experimental Station, Fort Collins, CO.

- "Forests and woodlands in Arizona dominated by cottonwood and willow (*Populus fremontii, Salix gooddingii, S. bonplandiana* and others) are confined primarily to riparian environments below 3,500 feet on clay or other fine soil and rock deposits."
- "Interrupted examples of cottonwood-willow forests are still found along the Verde, Hassayampa, San Pedro, Bill Williams, Colorado and other rivers. Indications are that these communities are maintained through periodic winter-spring flooding. Stabilized water flows result in decadent stands, in which the dominant species are lacking in reproduction. Cottonwood

regenerates itself principally from seed, unlike sycamore and other broadleaf riparian species that reproduce by sprouting, forming clones (Horton et al. 1960). Further indications of the subclimax nature of this community are the "new" stands adjacent to portions of the Verde River and Santa Cruz rivers, which were generated after heavy winter-spring runoffs on these drainages in 1965 and 1967 respectively."

Busch, D.E., N.L. Ingraham, and S.D. Smith. 1992. Water uptake in woody riparian phreatophytes of the Southwestern United States — a stable isotope study. Ecological Applications, 2:450-459.

- "At floodplain study sites along the Bill Williams and lower Colorado Rivers (Arizona, USA), naturally occurring D and ^{18}O were used to distinguish among potential water sources. Isotopic ratios from potential uptake locations were compared to water extracted from the dominant woody taxa of the study area (*Populus fremontii, Salix gooddingii,* and *Tamarix ramosissima*) to elucidate patterns of water absorption."
- "With the possible exception of *Tamarix*, it appears that the dominant woody taxa of the study area are obligate phreatophytes."

Carothers, S.W., G.S. Mills, and R.R. Johnson. 1989. The creation and restoration of riparian habitat in southwestern arid and semi-arid regions. *In* Kusler, J.A. and M.E. Kentula (eds.) Wetland creation and restoration: The status of the science. Volume I: Regional reviews. EPA/600/3-89/038:359-376.

- "Many planted riparian forests do not reproduce and their longevity is therefore determined by the lifespan of the individual trees. Mitigation provided by such forests is temporary."
- "Important considerations for riparian creation or restoration projects in the Southwest include:
  - Depth to water table
  - Soil salinity and texture
  - Amount and frequency of irrigation
  - Effects of rising and dropping water tables on planted trees
  - Protection from rodent and rabbit predation
  - Elimination of competing herbaceous weeds
  - Protection from vandalism, off-road vehicles, and livestock
  - Monitoring of growth rates as well as survival
  - Project design flexible enough to allow for major modifications"
- "In one current project (Mills and Tress 1988) where the water table is between 25 and 30 feet, watering has been done for nearly two growing

seasons and most trees do not appear to have made it to the water table though most are large and healthy."

- "A neutron probe, which measures soil water content, used in PVC vertical access tubes buried to the water table is a useful device for determining how deep irrigation water and tree roots have gone (see Mills and Tress 1988)."
- "One unresolved issue involving irrigation is its timing and amount. One school of thought, which appears to use the most reasonable, is to give the trees an overabundance of water so that the soil is saturated to the water table nearly constantly. Another school of thought is that trees should be watered less frequently and stressed to some degree to encourage deeper root growth."

Collier, M., R.H. Webb, and J.C. Schmidt. 2000. Dams and rivers: A primer on the downstream effects of dams. USGS Circular 1126. Denver, CO.

- "The challenge for today's manager is that yet other factors now exist in the dam-management equation — those centered on management of the downstream river corridor and its ecology. Scientifically based management of regulated rivers adds a new layer of objectives to the already complex task of the water-resource engineer who designs the strategies of multipurpose reservoir management."
- "The upper Salt River has all the characteristics of a healthy unregulated river. Typical of rivers in the Southwest, it displays a wide range of flow and sediment transport — it is capable of quickly changing from minimal flow to awesome flood. This river is always in the process of adjusting its channel to the equilibrium that exists between erosion and deposition. The Salt offers a standard against which to compare regulated rivers."
- "All other things being equal, dams of different design and operation will produce dissimilar effects downstream. The hydrograph created by a dam that produces load-following power will look totally different than one from a dam whose reservoir provides base-load power. Flood-control operations have different impacts than run-of-the-river releases. Dams operated for water-supply or irrigation purposes have different effects than hydropower dams."
- "Floods are a key element in the future management of dams. Without period high flows, some channels downstream from dams will aggrade with sediment or narrow with overgrown vegetation."

Cooper, D.J., D.R. D'Amico, and M.L. Scott. 2003. Physiological and morphological response patterns of *Populus deltoides* to alluvial groundwater pumping. Environmental Management 31(2): 215-226.

- "Between 3 and 27 July 1996, four large pumps were used to withdraw alluvial groundwater from a cottonwood forest along the South Platte River, near Denver, Colorado, USA."
- "Our results suggest that *Populus deltoides* ssp. *monilifera* is extremely sensitive to even short term (1-3 weeks) groundwater pumping that lowers the water table below the deepest annual water table depth."
- "Our results are likely valid for many sand- and cobble-bedded river systems that have coarse-textured sediments at the lowest rooting depths."

Devitt, D.A., J.M. Piorkowski, S.D. Smith, J.R. Cleverly, and A. Sala. 1997. Plant water relations of *Tamarix ramosissima* in response to the imposition and alleviation of soil moisture stress. Journal of Arid Environments, 36:527-540.

- "*Tamarix* can be subjected to significant soil water deficits and still respond rapidly to the presence of water."

Everitt, B.L. 1968. Use of the cottonwood in an investigation of the recent history of a flood plain. American Journal of Science, 266:417-439.

- "The age distribution of cottonwoods, observations on the ecology of the floodplain vegetation, and in particular the sandbar colonizing habits of the cottonwood indicate that the germination and growth of the cottonwood is intricately related to the discharge of the river, movement of the channel, and development of the flood plain."

Everitt, B.L. 1995. Hydrologic factors in regeneration of Fremont cottonwood along the Fremont River, Utah. *In* Natural and anthropogenic influences in fluvial geomorphology. J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock (eds.). Geophysical Monographs, 89:197-208.

- "A regeneration of thickets of Fremont cottonwood along the middle portion of the Fremont River, Utah, followed the spring snowmelt flood of 1973. The 1973 spring flood was the largest May discharge in 25 years of record at Caineville Gage. Although smaller than late seasonal floods, the 1973 spring flood was sufficiently large to cause channel scour and overbank deposition, and occurred during the floodplain construction phase of the geomorphic cycle on the Fremont River. The flood was followed by a season of high base flow, and several hydrographically quiet years. Cottonwood has not regenerated downstream from the confluence of Muddy Creek at Hanksville, where the spring flood becomes insignificant compared to late season floods. The ten storage reservoirs in the Fremont basin are high in the watershed, and are operated for irrigation storage only. Their passive regulation of the flow of the lower river most likely aided the 1973 cottonwood regeneration."

- "Reservoir storage on the upper Fremont River undoubtedly affects spring runoff on the lower river, but the long-term effect of reservoir operation on cottonwood regeneration is not immediately obvious. Because the reservoirs are at high elevation, they partially regulate the flow from the last melting snow which provides the tail end of the spring runoff. During normal years, reservoir operation causes the spring flood on the lower river to peak lower and earlier, precluding cottonwood regeneration. However, in extraordinary years such as 1973, the reservoirs probably delayed the flood peak rather than advanced it, and most certainly contributed to the long tail of moderate summer flow which aided seedling survival. Lastly, a century of reservoir construction on the Fremont River has probably contributed to the channel shrinking and floodplain construction which was a necessary precondition of the 1973 cottonwood regeneration."
- "On the Fremont River, cottonwood regeneration has been sustained by one single event during the last century. This regeneration was spawned by the coincidence of a rare hydrologic event with the floodplain construction phase of the geomorphic cycle on the central Fremont River. Great care is needed in predicting vegetation response from a few cases. Reduction in the spring snowmelt flood by reservoir operation has been credited with both reducing cottonwood forests along the Gila River in Arizona (Fenner and others, 1985), and expanding cottonwood woodland along the Platte River in Nebraska (Johnson, 1994). It may be, to paraphrase Ian Malcolm (Crichton, 1990), that each case rolls off the knuckles of nature in a different direction. A comprehensive model can only be developed as more case histories are added to the data set."

Fenner, P., W.W. Brady, and D.R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. Desert Plants, 6(1):55-58.

- "The seeds of Freemont cottonwood (*Populus fremontii*) lose viability within 1 to 5 weeks after dispersal."
- "Three study sites were chosen. The first was a cottonwood gallery forest in an overflow channel of the Salt River, near Phoenix, Arizona, approximately 3 km upstream from Granite Reef Dam. The age class distribution of cottonwoods at this location was bimodal. When the study was started, large decadent trees dominated the population. But during the 2 years of the study, numerous seedlings became established. Associated species included willow (*Salix gooddingii* Ball), mesquite (*Prosopis juliflora* Swartz DC), and a thick carpet of annual grasses in the spring."
- "Roots were observed to grow at an approximate average rate of 6 mm per day; therefore, theoretically, water table levels may recede at this rate through the spring and summer. The declining water table tends to promote root

growth to greater depth, as opposed to the situation with a perched water table, which would cause a shallow root system to develop. At the previously mentioned root growth rates, following a receding water table, most establishing seedlings could tap ground water at depths of 72 cm by the end of the summer, and could potentially reach 162 cm."

Fenner, P., W.W. Brady and D.R. Patton. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management, 38:135-138.

- "The effect of dams on downstream river flow and the consequent modification of the riparian habitat was studied along the lower Salt River in central Arizona. Dams were found to change the magnitude of river flows and change the seasonal timing of flows in such a way that the habitat appeared less adapted for regeneration of *Populus fremontii*. Modification of river flow patterns, therefore, appears likely to have been a significant factor causing change in vegetation along the Salt River."
- "The area selected for this study was the Blue Point Cottonwoods, a proposed Forest Service Scientific/Education Natural Area located between Stewart Mountain Dam and Granite Reef Dam."
- "Changes in the Salt River system have been attributed primarily to these three activities: grazing…ground water pumping…and dam and reservoir systems."

Friedman, J.M., M.L. Scott, and W.M. Lewis. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19:547-557.

- "We tested the hypothesis that establishment is now prevented by absence of the bare, moist substrate formerly provided by floods and channel movement. Along Boulder Creek, a dammed stream in the Colorado plains, we tested the effects of disturbance (sod removal), irrigation, and addition of seed on the establishment of seedlings of plains cottonwood (*Populus deltoides* subsp. *monilifera*) and peachleaf willow (*Salix amygdaloides*). In unirrigated, undisturbed plots, mean cottonwood density was 0.03 seedlings/m^2. Irrigation or disturbance alone produced mean cottonwood densities of 0.39 and 0.75 seedlings/m^2. Plots that were both irrigated and disturbed produced a mean cottonwood density of 10.3 seedlings/m^2. The effects of irrigation and disturbance on cottonwood establishment were significant ($P < 0.005$); added seed had no significant effect ($P = 0.78$)."
- "We conclude that cottonwood establishment along Boulder Creek is limited by the scarcity of bare, moist sites safe from future scour. Establishment of peachleaf willow was significantly affected only by disturbance; daily sprinkler irrigation did not provide sufficient moisture to increase survival of this species. Our results demonstrate the feasibility of restoring plains

cottonwood forests using natural seedfall, even where only widely scattered adult trees are present. Because use of natural seedfall conserves the genetic makeup of the local population, this method may be preferable to the use of imported cuttings."

FWS (U.S. Fish and Wildlife Service). 2002. Appendix J: fluvial hydrology of regulated rivers in the range of the southwestern willow flycatcher; in Southwestern willow flycatcher recovery plan. Albuquerque, NM.

Dr. William Graf prepared a paper on the fluvial hydrology of regulated rivers for incorporation into the Southwestern Willow Flycatcher Recovery Plan (FWS 2002, Appendix J). Dr. Graf used 1945-1991 gage data above and below the dams and 1904-1944 gage data at the lower gage location to evaluate the effects of storage and releases of water on Verde River flows. Major findings in the paper are:

- Historically, the dams created conditions of numerous periods of very low flow and no flow, which result in a loss of the surface water stream and less recharge to the alluvial aquifer.
- Larger "ordinary low flows" for most of the year provide ecological benefits by increasing ground water recharge and a larger surface water stream.
- Reduced mean annual peak flow and increased variability of annual peak flows have resulted in a smaller active channel.
- Fine sediment is stored behind the dams and is not deposited along the channel downstream resulting in poor substrate for cottonwood, willow and tamarisk.

FWS (U.S. Fish and Wildlife Service). 2003. Intra-Service Biological and Conference Opinion. Issuance of a Section 10(a)(1)(B) permit to Salt River Project for operation of Roosevelt Lake. February 21.

- "Operation of lower Verde River dams has altered the hydrologic regime of the lower Verde River by reducing the magnitude, frequency, timing, and duration of high flow events."
- "Grazing, recreation, and other land uses have combined with the effects of dam operations to impede natural regeneration of riparian communities" [citations omitted].
- "These effects are expected to continue into the foreseeable future."
- "Recent changes in the reach below Bartlett Dam are likely to reduce, to some degree, effects of dam operations and recreation. In 1993, a minimum flow of 100 cfs flow was implemented below Bartlett Dam."
- "Also, the Fort McDowell Yavapai Nation closed the Verde River area through their lands to non-tribal members and hired their own Police

Department in 1997. This helped reduce recreational activities that have contributed to poor regeneration of riparian trees."

Gladwin, D.N. and J.E. Roelle. 1998. Survival of plains cottonwood (*Populus deltoides* subsp. *monilifera*) and saltcedar (*Tamarix ramosissima*) seedlings in response to flooding. Wetlands, 18(4):669-674.

- Survival rates following inundation were much higher for both salt cedar and plains cottonwood after over-wintering; cottonwoods seedlings survived better both in the initial year and subsequent year.
- Plains cottonwoods do not bear seed until after about 10 years.

Graf, W.L. 2001. Damage control: Restoring the physical integrity of America's rivers. Annals of the Association of American Geographers, 91(1):1-27.

- "Reduce *fragmentation* of rivers by changing operating rules for some dams to include the maintenance of downstream environmental quality, re-engineering some dams for downstream objectives, and removing antiquated or unsafe dams."
- "Improve the *physical integrity* of rivers under provisions of the Clean Water Act by including in policy the concept of physical integrity as an equal partner with biological and chemical integrity."
- "Include *functional physical systems* as parts of a conceptual framework for research and policy efforts."
- "Use the *indicator parameters* of channel width, water discharge, channel patterns, and channel sinuosity in measurement and monitoring programs for adaptive management of rivers."
- "In basic research, emphasize explanations of why rivers *change* rather than their tendency toward hypothetical equilibrium states. In decision making, create policies to emphasize human accommodation to change rather than trying to exert complete control of rivers."
- "Preserve as much as possible of the tiny amount of remaining rivers that is in a pretechnological condition. In restoration efforts, address *naturalness* by specifying goals that are scientifically reasonable and socially acceptable."
- "In research and policy predictions, forecast the locational characteristics of rivers using *probabilistic* methods rather than relying on absolute certainties."
- "Organize policy making for rivers according to regions that are *watersheds*."
- "In funding research and building policies for river preservation and restoration, insure *geographic representativeness* by including all regions of the nation."

Horton, J.S., F.C. Mounts, and J.M. Kraft. 1960. Seed germination and seedling establishment of phreatophyte species. Colorado State University, Rocky Mountain Forest and Range Experiment Station in cooperation with the University of Arizona at Tucson and Arizona State University at Tempe.

- "In June 1958, seeds of tamarisk and seepwillow were sown in pots for a second study, with submergence varying from 1 to 6 weeks…Four to 6 weeks will kill a majority of tamarisk seedlings…The 12-week old tamarisk appeared to survive submergence better than younger plants."
- "Tamarisk produces seed abundantly over a long period (April to October)."
- "Tamarisk spread along streams and rivers can be controlled by management of water flow. Along the Salt River, tamarisk seedlings become established on river banks during slowly receding flows that coincide with periods of high seed production. Rapidly receding flows are less favorable for seedling establishment, especially during hot weather when the banks dry out quickly."

Howe, W.H. and F.L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. The Southwestern Naturalist, 36(2):218-224.

- "Many western species of riparian trees and shrubs, such as willows (*Salix* sp.) and cottonwoods (*Populus* sp.) are adapted to predictable spring flooding caused by snowmelt (White 1979). These species exhibit such characteristics as large seed crops, seed dispersal by light wind or water, fast growth rates, low shade tolerance, high flood tolerance, short seed viability (1 to 6 weeks) and early summer seed dispersal timed to coincide with late spring and early summer floods (White 1979, and references therein). Decreased flood frequency, reduced peak flows of those floods, and shifts in the timing and duration of high water levels, potentially disrupt population requirement of native riparian plant species."
- "The riparian habitats at Bernalillo have been heavily impacted by human activity, and it is probable that parts of it have been cleared by fire, off-road vehicles, tree cutting, and other human use. These cleared areas may become suitable germination sites for cottonwoods. Today, artificial clearing may be replacing river meandering as the primary mode of vegetation succession for cottonwood and other riparian species on the Rio Grande."

Hunter, W.C., B.W. Anderson, and R.D. Ohmart. 1987. Avian community structure changes in a mature floodplain forest after extensive flooding. Journal of Wildlife Management, 51(2):495-502.

- "High water flows in 1978 through 1980 caused the death of 99% of all Fremont cottonwoods (*Populus fremontii*) and 64% of all Goodding willows (*Salix gooddingii*) on a 120-ha area near the confluence [of the Bill Williams River] with the Colorado River."

Irvine, J.R. and N.E. West. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. 1979. The Southwestern Naturalist, 24(2):331-346.

- "*Populus fremontii* was found only on broad flood terraces in wide sections of the upper part of the study area. The oldest, largest trees of this species were located beyond the zone of usual flooding, probably rooting to the shallow water table in these sections of the river canyon."

Knighton, M.D. 1981. Growth response of speckled alder and willow to depth of flooding. USDA Forest Service, Research Paper NC-198. North Central Forest Experiment Station, St. Paul, MN.

- "Net growth of all shrubs was severely reduced when the water level was at or above the root crown. These differences were not visible during the first growing season but became readily apparent as the second season progressed."

Mahoney, J.M. and S.B. Rood. 1992. Response of a hybrid poplar to water table decline in different substrates. Forest Ecology and Management, 54:141-156.

- "Water drained fastest from the gravel-filled tubes, intermediate in the mixture and slowest from the sand-filled tubes. The effects of rapid water table decline were most severe on plants grown in the gravel and least severe on those grown in sand. Transpiration, height, leaf number, leaf area, and plant health decreased with increasing rates of water table decline and increasing gravel content in the substrate. The reduction in transpiration and plant growth indicates that rapid water table decline caused drought stress of the poplars. Root elongation was promoted in all substrates by water table decline. The results indicate that alterations to river flow that cause abrupt drops in riparian water table will retard the transpiration and growth of riparian poplars. These effects will be more severe along floodplains with coarse substrates."

Mahoney, J.M. and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. Wetlands, 18(4):634-645.

- "This paper describes the "recruitment box," an integrative model that defines the stream stage patterns that enable successful establishment of riparian cottonwood seedlings."
- "Cottonwood roots grow about 0.5 to 1 cm per day or 60 to 100 cm in the first year."

- "A capillary fringe exists above the water table and is often 30 to 40 cm in elevation, but can range from about 5 to 130 cm depending on substrate texture."
- "The rate of stream stage decline is also critical for seedling survival and should not exceed 2.5 cm per day."
- "Flood events with recurrences of about 1 in 5 to 1 in 10 years often satisfy the model and provide stream stage patterns with a gradual decline through the recruitment box."
- "Cottonwood seedling recruitment is episodic and relatively rare even along free-flowing streams. It has been repeatedly concluded that flood events enable cottonwood seedling recruitment both through geomorphic impacts and direct hydrologic patterns (Johnson et al. 1976; Rood and Mahoney 1990; Scott et al. 1996; and citations in Table 1 [these citations are: Bradley and Smith 1986; Baker 1990; Cordes 1991; Howe and Knopf 1991; Reid 1991; Stromberg et al. 1991; Marken 1994; Rood et al. 1997; Scott et al. 1997; Cordes et al. 1997; Rood et al. 1998a])."
- "The recruitment box model also contributes to the understanding of cottonwood reproductive ecology. The hydrologically-based model partially explains why moderate and large flood events directly enable cottonwood recruitment, whereas smaller flood events are often insufficient for cottonwood replenishment. Although smaller peaks moisten the suitable recruitment zone, the falling limb of the hydrograph is very rapid after the peak flow, and thus, the rate of stage decline is too abrupt for seedlings to retain root contact with the descending moist zone. In contrast, with moderate flood events, the peak is well above the recruitment box, and the rapidly falling portion of the falling limb of the hydrograph occurs while the hydrograph stage is above the recruitment zone. As the hydrograph descends into the recruitment box, the rate of stage decline will have slowed to a rate that is gradual enough that the seedlings can maintain root contact."

Marler, R.J., D.T. Patten, and J.C. Stromberg. 2004. Riparian Vegetation Community Development along the Effluent-Receiving Salt River near Phoenix, Arizona. Presentation at Arizona Riparian Council March 2004 meeting. Phoenix, Arizona.

- Evaluated five transects along the Salt River below Stewart Mountain Dam and along lower Verde River below Bartlett Dam and compared the vegetation with five transects along the Salt and Gila rivers near their confluence, which receive effluent.
- Found similar woody and herbaceous vegetation on both reaches.

McNatt, R.M., R.J. Hallock, and A.W. Anderson. 1980. Riparian habitat and instream flow studies, lower Verde River: Fort McDowell Reservation, Arizona. Riparian Habitat Analysis Group, U.S. Fish and Wildlife Service, Region 2. Albuquerque, New Mexico. June.

- McNatt et al. (1980) studied riparian habitat and instream flows on the Fort McDowell Reservation near the mouth of the Verde River.
- The report found high cottonwood mortality in the late 1970s, possibly from the combined effect of severe drought and ground water pumping.
- Large releases of water from Bartlett Dam every 8 to 10 years or planting of cottonwoods was recommended to maintain a productive cottonwood community.
- The report also concluded that a minimum flow of 200 cfs would maintain and enhance fish and wildlife resources and riparian habitat.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47(11):769-781.

- "Riparian plant species are also strongly affected by altered flow timing (Table 2). A shift in timing of peak flows from spring to summer, as often occurs when reservoirs are managed to supply irrigation water, has prevented reestablishment of the Fremont cottonwood (*Populus fremontii*), the dominant plant species in Arizona, because flow peaks now occur after, rather than before, its germination period (Fenner et al. 1985)."
- "A large body of evidence has shown that the natural flow regime of virtually all rivers is inherently variable, and that this variability is critical to ecosystem function and native biodiversity. As we have already discussed, rivers with highly altered and regulated flows lose their ability to support natural processes and native species. Thus, to protect pristine or nearly pristine systems, it is necessary to preserve the natural hydrologic cycle by safeguarding against upstream river development and damaging land uses that modify runoff and sediment supply in the watershed."
- "Most rivers are highly modified, of course, and so the greatest challenges lie in managing and restoring rivers that are also used to satisfy human needs. Can reestablishing the natural flow regime serve as a useful management and restoration goal? We believe that it can, although to varying degrees, depending on the present extent of human intervention and flow alteration affecting a particular river. Recognizing the natural variability of river flow and explicitly incorporating the five components of the natural flow regime (i.e., magnitude, frequency, duration, timing, and rate of change) into a broader framework for ecosystem management would constitute a major advance over most present management, which focuses on minimum flow and on just a few species. Such recognition would also contribute to the

developing science of stream restoration in heavily altered watersheds, where, all too often, physical channel features (e.g., bars and woody debris) are recreated without regard to restoring the flow regimes that will help to maintain these recreated features."

Roelle, J.E., D.N. Gladwin, and B.S. Cade. 2001. Establishment, growth, and early survival of woody riparian species at a Colorado gravel pit. Western North American Naturalist, 61(2):182-194.

- "Several authors have reported that inundation by standing water can be a significant mortality factor for some riparian seedlings (Gladwin and Roelle 1998). *Populus* and *Tamarix* have been best studied in this regard, and, in general, results indicate that susceptibility to inundation decreases significantly after the 1st year."

Rood, S.B. and J.M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. Environmental Management, 14:451-464.

- "Recent reports have described substantial declines of riparian poplar forests downstream from dams in Alberta, Canada; Montana, North Dakota, Wyoming, Colorado, and Arizona, USA."
- "Dams were found to contribute of forest failure by (1) reducing downstream flows and/or (2) altering flow patterns to attenuate spring flooding and/or stabilize summer flows."
- "Potential methods for mitigating the impacts of dams on downstream forests include downstream flow schedules that (1) retain occasional spring flooding, (2) taper off rather than abruptly drop downstream flow, and (3) provide adequate flows throughout the summer. Poplar forest stabilization and recovery can be further promoted by fencing to protect trees from livestock grazing and trampling, or artificial site preparation such as cultivation or scarification to encourage poplar regeneration."
- "Brown and others (1977) studied riparian forest communities, including *P. fremontii* and *P. angustifolia*, along western Arizona rivers. They found that the present-day forest abundance was substantially less than that described in historical reports. The declines in forest densities and abundance were attributed to reduced stream flow following damming and grazing pressure from livestock. It also was proposed that channelization, increased water salinity, and groundwater pumping have contributed to the stress of Arizona's riparian poplars. In their analysis, Brown and others (1977) recognized the importance of spring flooding for seedling establishment. They noted that river reaches with stabilized river flows were characterized by decadent forest stands. Conversely, considerable seedling replenishment was observed along

the unregulated Verde and Santa Cruz rivers following the high spring runoff years of 1965 and 1967."

- "Large riparian poplars are commonly 100 to 150 years old…"
- "Cattle prefer the young poplar seedlings and saplings as a food source and trample others (Behan 1981). These losses decrease poplar replenishment in the grazing area. The significance of cattle grazing is illustrated by the recovery or survival of forests along river reaches that have been protected by fencing (Behan 1981; Crouch 1979b). In adjacent unfenced areas that cattle can access, poplar forests continue to decline. The negative impact in areas of intensive cattle production is potentially very severe."
- "Most riparian poplars can be asexually propagated without difficulty through shoot cuttings."
- "Augering holes for transplanting will also improve transplanting success by aiding root growth through a compacted substrate (Anderson and Ohmart 1979)."
- "Scarification is a standard silvicultural practice to promote suckering in broad-leafed woody plants, including poplars."

Rood, S.B., A.R. Kalischuk, and J.M. Mahoney. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands, 18:557-570.

- "Following heavy rain in early June 1995, flows of the Oldman River in Alberta, Canada were the highest on record (since 1911). This "flood of the century" preceded cottonwood seed release, and created suitable sites for seedling establishment. After the flood peak, the Oldman River Dam and tributary dams were operated to deliver a relatively natural and gradual river stage recession of about 2.5 to 5 cm per day."
- "Seedlings that survived through 1996 and 1997 occurred at elevations ranging from 1.7 to 3 m, but seedlings above 2.5 m grew slowly."
- "Thus, a major flood enabled a massive cottonwood seedling recruitment event that commenced in the flood year. The extensive recruitment occurred along a dammed river and was probably promoted deliberately by gradual stream stage decline after the flood peak."

Schaeffer, S.M., D.G. Williams, and D.C. Goodrich. 2000. Transpiration of cottonwood/willow forest estimated from sap flux. Agricultural and Forest Meteorology, 105:257-270.

- "We used the heat-pulse velocity technique in this study to estimate transpiration in 12 such forest patches along a perennially flowing reach of the San Pedro River in southeastern Arizona."

- "Sala et al. (1996) and Devitt et al. (1998) reported maximum evapotranspiration rates in stands of salt cedar of 10-12 mm per day. Even though these estimates include evaporation from the soil surface, and come from a different river system, these rates are more than twice the rate found in cottonwood/willow forest as reported here."

Schmidt, J.C., R.H. Webb, R.A. Valdez, G.R. Marzolf, and L.E. Stevens. 1998. Science and values in river restoration in the Grand Canyon. BioScience, 48:735-747.

- "If flooding is crucial to the recovery of flood-adapted species but the absence of floods is crucial to the conservation of terrestrial endangered species in new habitats, then managers face n intractable dilemma."
- "The National Research Council (NRC 1992) argued that ecological restoration means returning 'an ecosystem to a close approximation of its condition prior to disturbance' and that 'restoring altered, damaged, or destroyed lakes, rivers, and wetlands is a high-priority task.' "

Scott, M.L., M.A. Wondzell, and G.T. Auble. 1993. Hydrograph characteristics relevant to the establishment and growth of western riparian vegetation. *In* H.J. Morel-Seytoux (ed.), Proceedings of the Thirteenth Annual American Geophysical Union Hydrology Days, pp. 237-246. Hydrology Days Publications, Atherton, CA.

- "In arid and semi-arid regions of western North America, natural regeneration of woody riparian vegetation is dependent on adequate moisture. Because water is often limiting, the timing and pattern of water delivery are crucial to the long-term maintenance of riparian vegetation."
- "Riparian species such as cottonwood and willow disperse seeds over a two- to six-week time period. Seed dispersal for cottonwood and willow typically coincides with peak flows resulting from snowmelt runoff or spring thunderstorms. Dispersed seeds lose germinability rapidly; thus, seeds must encounter suitable germination sites soon after release. In addition to timing of peak flows, the magnitude of the peak flow is critical in preparing seed beds suitable for germination. Germination and establishment typically take place on freshly deposited alluvium in channel positions low enough to provide adequate moisture but high enough to escape scour from subsequent floods and ice. Characteristically, establishment occurs following medium to large floods. Once seedlings are established, root growth must keep pace with declining river stage and water table. If river stages decline too rapidly, drought stress produces substantial seedling mortality. However, manipulative experiments indicate that some cottonwood seedlings can keep pace with alluvial water table declines of 8 cm/day and by the end of the first growing season may send a tap root to depths approaching 1 m. Provided drawdown does not greatly exceed this rate and base flow conditions do not cause alluvial groundwater to retreat below 1 m, seedling recruitment is likely to be successful. Lower peak flows in years immediately following

establishment also contribute to long-term survival of cottonwood and willow. With increasing size, cottonwood and willow become more resistant to removal by scouring and burial by sediments."

- **"Hydroelectric Development.** A run-of-the-river hydroelectric facility has little impact on the downstream hydrograph. As storage capacity increases, however, hydropower operations tend to attenuate the peak (II) and augment lower flows IV and V), thus producing a "flatter" hydrograph. Because the timing of the snowmelt peak (II) is often unchanged, moist alluvial surfaces are still available during the receding limb (III) for germination. However, the "flatter" hydrograph may substantially reduce the potential area for establishment by (a) reducing the difference between the peak flow and the summer or low flow, (b) reducing the rate of channel meandering through attenuation of the more powerful peak flows, and (c) reducing year-to-year variability in the magnitude of both peak and low flows."

Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14:327-339.

- "Consideration of such effects in water management decisions has been hampered by the apparent variability of responses of bottomland tree communities to flow alteration. When the relation between streamflow and tree establishment is placed in a geomorphic context, however, much of that variability is explained, and prediction of changes in the tree community is improved."
- "Flood deposition can occur along most streams, but where a channel is constrained by a narrow valley, this process may be the only mechanism that can produce a bare, moist surface high enough to be safe from future disturbance. Because of differences in local bedrock, tributary influence, or geologic history, two nearby reaches of the same stream may be dominated by different fluvial processes and have different spatial and temporal patterns of trees."

Scott, M.L., G.T. Auble, and J.M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7:677-690.

- We determined date and elevation of tree establishment and related this information to historical peak stage and discharge over a 112-yr hydrologic record. Of the excavated trees, 72% were established in the year of a flow > 1400 m^3/s (recurrence interval of 9.3 yr) or in the following 2 yr.
- Almost all cottonwoods that have survived the most recent flood (1978) were established > 1.2 m above the lower limit of perennial vegetation (active channel shelf).

- Effective management of flows to promote or maintain cottonwood recruitment requires an understanding of locally dominant fluvial geomorphic processes.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management, 23(3):347-358.

- *"Populus* demonstrated a threshold response to water table declines in medium alluvial sands; sustained declines ≥ 1 m produced leaf desiccation and branch dieback within three weeks and significant declines in live crown volume, stem growth, and 88% mortality over a three-year period."
- "In contrast, more gradual water table declines of ~ 0.5 m had no measurable effect on mortality, stem growth, or live crown volume and produced significant declines only in annual branch growth increments."
- "Trees growing in association with a formerly stable water table may be more sensitive to declines than trees formerly associated with a more variable water table environment."

Scott, M.L., G.C. Lines, and G.T. Auble. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments, 44:399-414.

- "Ages of young cottonwood and willow stems adjacent to the present channel and radial stem growth of surviving cottonwoods were consistent with the inference that channel incision, associated with sustained flooding in January and February of 1993, lowered channel elevations throughout the affected reach. Well records and soil redoximorphic features indicate that channel incision caused net water-table declines ≥ 1.5 m on portions of the adjacent flood plain where cottonwood stand mortality ranged between 58 and 93%. In areas where water-table declines were estimated to be < 1.0 m, stand mortality was 7-13%."
- "The consequences of incision to riparian ecosystems is dependent on several factors including the magnitude and extent of channel incision and its effect on the water table in the adjacent flood-plain aquifer, the texture of alluvial sediments, the degree of hydraulic connection between the aquifer and stream, the site-specific water-table regime, and the climatic setting. Our results, along with those of others, suggest that riparian cottonwood forests along sand bed rivers in relatively arid regions of the U.S., are vulnerable to water-table declines associated with channel incision, and that declines of ≥ 1.5 m may be expected to produce mortality and loss of forest area in existing stands (Scott et al., 1999; Shafroth et al., 2000)."

Scott, M.L. and G.T. Auble. 2002. Conservation and restoration of semiarid riparian forests: A case study from the Upper Missouri River, Montana. *In* Flood Pulsing in Wetlands: restoring the Natural Hydrological Balance, pp. 145-190. B.A. Middleton (ed.). John Wiley and Sons, Inc.

- "For large flow-controlled rivers, full restoration of natural, regionally specific stream flow patterns is not likely. In these situations, scientific understanding of the physical and biotic processes responsible for creating and sustaining riverine and riparian ecosystem values is critical to making wise decisions about partial restoration efforts in the context of competing social and economic values."
- "Of particular concern is how flow management and livestock grazing are influencing the distribution and abundance of riparian cottonwoods and associated wildlife species."
- "Historical accounts are consistent with contemporary observations that cottonwood forests are sparse, and dendrogeomorphic analyses indicate that a majority of existing trees were established following infrequent, large flood pulses."
- "Livestock grazing greatly reduces seedling densities."
- "Reconstruction of unregulated peak flows indicates that although the frequency of large flood pulses has not been influenced by upstream dams, the magnitude of these events has been reduced from 40 to 50 percent."
- "Riparian bird surveys demonstrate that avian diversity along the upper Missouri is significantly related to the flow-related geomorphic processes responsible for the establishment and survival of new cottonwood and willow patches, combined with a reduction in or elimination of grazing, following establishment of these patches."
- "However, although flood pulses are necessary, they are not sufficient. In addition to grazing, future human development on the floodplain of the upper Missouri and its tributaries could increasingly limit the potential to produce flood pulses. Thus, riparian forest restoration on the upper Missouri River will require integrated land and water management activities throughout the entire basin."

Scott, M.L., G.C. Lines, and G.T. Auble. 2002. Channel incision and riparian cottonwoods: Mojave River, CA. USGS, Fort Collins, CO. Available: http://www.mesc.usgs.gov/products/presentations/mojave/mojave.asp. Downloaded July 11, 2002.

- Water table declines $\geq$ 1.4 m
- Tree mortality 60 to 95%
- Water table declines < 1.4 m
- Tree mortality 1 to 13 %

Scott, M.L., S.K. Skagen, and M.F. Merigliano. 2003. Relating Geomorphic Change and Grazing to Avian Communities in Riparian Forests. Conservation Biology 17(1):284-296.

- "Avian conservation in riparian or bottomland forests requires an understanding of the physical and biotic factors that sustain the structural complexity of riparian vegetation. Riparian forests of western North America are dependent upon flow-related geomorphic processes necessary for establishment of new cottonwood and willow patches."
- "We suggest that structural differences between cottonwood-shrub, cottonwood, and shrub-steppe patch types reflect local geological controls on the frequency and extent of cottonwood and willow establishment, subsequent riparian vegetation succession, and grazing pressure."
- "Cottonwood-shrub patches develop in less constrained, geomorphically active channel reaches, where cottonwood and willows establish and grow adjacent to existing stands on newly created alluvial surfaces formed by lateral and vertical accretion. Vegetation succession and additional vertical sediment accretion in the absence of grazing results in a structurally diverse habitat with a relatively diverse assemblage of birds. Cottonwood patches develop on elevated alluvial deposits in constrained channel reaches following infrequent large floods. A lack of subsequent geomorphic change, in combination with vegetation succession and chronic livestock grazing, results in a structurally simplified habitat patch and reduced bird diversity."
- "Preserving the breeding bird abundance and diversity characteristic of riparian forests of this arid region will require the maintenance of flows and associated geomorphic processes responsible for the establishment and survival of woody vegetation (Scott et al. 1997; Bovee and Scott 2002) in combination with management of livestock grazing."

Scott, R.L., W.J. Shuttleworth, D.C. Goodrich, and T. Maddock. 2000. The water use of two dominant vegetation communities in a semiarid riparian ecosystem. Agricultural and Forest Meteorology, 105:241-256.

- "The results indicate that the grassland relied primarily on recent precipitation, while the mesquite obtained water from deeper in the soil profile. Neither appears to be strongly phreatophytic, which suggests that the dominant, natural groundwater withdrawals in the Upper San Pedro Basin are mainly confined to the narrow cottonwood/willow gallery that lines the river."

Shafroth, P.B., J.M. Friedman, and L.S. Ischinger. 1995. Effects of salinity on establishment of *Populus fremontii* (cottonwood) and *Tamarix ramosissima* (saltcedar) in southwestern United States. Great Basin Naturalist 55(1):58-65.

- "We grew both species from seed in planters of sand subjected to a declining water table and solutions containing 0, 1, 3, and 5 times the concentrations of major ions in the Rio Grande at San Marcial, NM. Germination of *P. fremontii* declined by 35% with increasing salinity. Germination of *T. ramosissima* was not affected."

Shafroth, P.B., G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams Reservoir, Arizona. Wetlands, 18(4):577-590.

- "The four species examined were the native *Populus fremontii, Salix gooddingii,* and *Baccharis salicifolia* and the exotic *tamarix ramosissima*. We modeled locations suitable for germination of each species along eight study transects by combining historic discharge data, calculated stage-discharge relationships, and seed-dispersal timing observations. This germination model was a highly significant predictor of seedling establishment."
- "The basal area of mature woody vegetation, the maximum annual depth to ground water, and the maximum rate of water-table decline were the variables that best discriminated between quadrats with and without seedlings."
- "In the Recruitment Box model, Mahoney and Rood (1998) estimate 2.5 cm d^{-1} as a generalized maximum rate of water-table decline, which is similar to our observed maximum rates of decline where seedlings survived for both the 1993 (average 1.2-4.4 cm d^{-1} and 1995 cohorts (average 2.8-4.2 cm d^{-1}."
- "For the 1995 cohort, the maximum depth to water table effectively separated plots with seedlings from those without seedlings for three of four species. In previous studies, *Populus* spp. have been observed to become established anywhere from 20 to 260 cm above the annual low water level; however, seedlings at lower elevations may be vulnerable to removal by future high flows. At the end of the first growing season, most of the woody seedlings in our study became established within this range."
- "High stand basal area can inhibit seedling establishment through various integrated mechanisms, including poor germination on accumulated leaf litter, reduced soil moisture, and low light."
- "Our phenology observations suggest that, on the Bill Williams River, a flow recession beginning in early March could result in seedling zones with only *Populus*. As flows continue to decline through the spring and summer, however, more bare sediment would be exposed, which can be colonized by later dispersing species such as *Salix, Tamarix*, and *Baccharis.*"
- "Along a regulated river, even carefully managed flows are unlikely to supply the full degree of natural functions provided by unregulated flows (Ellis et al. 1996; Schmidt et al. 1998). These limitations may simply need to be recognized and accepted, or there may be other actions that can be taken to

mimic the missing function. For example, in densely vegetated reaches, even the maximum possible, post-dam discharge of the Bill Williams River is not large enough to result in geomorphologic change that would produce extensive new bare areas ideal for seedling establishment. Removal of overstory vegetation from densely vegetated areas, in conjunction with prescribed flows to provide favorable hydrologic conditions, could be used to enhance seedling establishment."

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist, 60:66-67.

- "We observed groundwater dynamics and the response of *Populus fremontii, Salix gooddingii*, and *Tamarix ramosissima* saplings at 3 sites between 1995 and 1997 along the Bill Williams River, Arizona. At a site where the lowest observed groundwater level in 1996 (-1.97 m) was 1.11 m lower than that in 1995 (-0.86 m), 92-100% of *Populus* and *Salix* saplings died, whereas 0-13% of *Tamarix* stems died. A site with greater absolute water table depths in 1996 (-2.55 m), but less change from the 1995 condition (0.55 m), showed less *Populus* and *Salix* mortality and increased basal area. Excavations of sapling roots suggest that root distribution is related to groundwater history."
- "For example, on the Bill Williams River, flows from Alamo Dam upstream of our sites could be managed to promote survival of desirable species. This could be accomplished by intentionally varying flows in early years following an establishment event to promote deeper root growth and hence less vulnerability to lower water tables during inevitable dry periods. Another stream flow management option would be to release a mid- to late-summer pulse to resaturate the soil column and raise water tables. Such summer pulses commonly occurred prior to the construction of Alamo Dam in association with monsoonal precipitation, but they have been virtually eliminated since completion of the dam."

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications, 12(1):107-123.

- "We studied the Bill Williams River in western Arizona, USA, to understand dam-induced changes in channel width and in the areal extent, structure, species composition, and dynamics of woody riparian vegetation. We conducted parallel studies along a reference system, the Santa Maria River, an unregulated major tributary of the Bill Williams River. Flood magnitude on the Bill Williams River has been dramatically reduced since the closure of Alamo Dam in 1968: the 10-yr recurrence interval flood in the pre-dam era was 1397 m^3/s vs. 148 m^3/s post dam."

- "An analysis of a time series of aerial photographs showed that channels along the Bill Williams River narrowed an average of 111 m (71%) between 1953 and 1987, with most narrowing occurring after dam closure."
- "Woody vegetation along the Bill Williams River was denser than that along the Santa Maria River."
- "Patches dominated by the exotic *Tamarix ramosissima* were marginally more abundant along the Bill Williams River than along the Santa Maria River, whereas the abundance of patches dominated by the native *Populus fremontii* or *Salix gooddingii* was similar across rivers. Relative to *Populus* and *Salix*, *Tamarix* dominates floodplain vegetation along the Bill Williams River."
- "Recent seedling establishment occurred in wider bands along the Santa Maria River, likely due to larger floods and associated seedbed formation along the Santa Maria River. Seedling survival rates were generally higher along the Bill Williams River, perhaps due to higher summer flows."
- "The dense riparian vegetation along the Bill Williams River is of regional importance because it is considered the best remaining example of this type of habitat in the highly degraded lower Colorado River system. Thus, despite evidence that its abundance is largely attributable to regulated streamflow conditions, maintaining this regionally unique habitat is a priority."
- "If a management goal were to expand regeneration of pioneer trees, mechanical clearing of selected stands of woody vegetation prior to a managed flow release could be effective. If increasing the proportion of *Populus* and *Salix* were a management goal, then releases may be timed and controlled in a manner to favor the establishment of these species over *Tamarix*. Augmenting the supply of *Populus* seed may provide it a competitive edge in mixed, *Tamarix/Populus* seedling patches."
- "Higher summer flow releases should ensure maintenance of existing vegetation while promoting relatively vigorous growth and perhaps slightly expanded vegetated areas within intermittent reaches. Higher summer flows may maintain existing ratios of *Populus/Salix* to *Tamarix*, whereas lower summer flows could increase the proportion of *Tamarix* and to a lesser extent *Salix*."

Sher, A.A., D.L. Marshall, and S.A. Gilbert. 2000. Competition between native *Populus deltoides* and invasive *Tamarix ramosissima* and the implications for reestablishing flooding disturbance. Conservation Biology, 14(6):1744-1754.

- "Our results suggest that even in the presence of an invader that positively responds to disturbance, reestablishment of historical flooding regimes and post-flood hydrology can restore this ecosystem by promoting its dominant plant species."

- "Our study provides strong evidence that *Populus* seedlings are more effective competitors than *Tamarix* seedlings under conditions intended to simulate the floodplain environment."

Smith, S.D., D.A. Devitt, A. Sala, J.R. Cleverly, and D.E. Busch. 1998. Water relations of riparian plants from warm desert regions. Wetlands, 18:687-695.

- "Analysis of water-loss rates indicate that *Tamarix*-dominated stands can have extremely high evapotranspiration rates when water tables are high but not necessarily when water tables are lower."
- "If we continue to manage arid riparian ecosystems as we have done in the past, by extensive impoundment, channelization, and diversion practices that effectively eliminate floods and lower water tables, then the situation is unlikely to change."
- "Nevertheless, recent efforts that have attempted to reintroduce historical flow regimes into regulated rivers, such as the flood releases into the Grand Canyon, are an encouraging new direction."

Springer, A.E., J.M. Wright, P.B. Shafroth, J.C. Stromberg, and D.T. Patten. 1999. Coupling groundwater and riparian vegetation models to assess effects of reservoir releases. Water Resources Research, 35(12):3621-3630.

- "Streamflows were designed to enhance cottonwood/willow recruitment from March to May to favor site occupation by cottonwood (March-April) and by willow (April-May) before tamarisk seed is dispersed."

Table 3. Depth to Water Ranges Observed for Willow and Cottonwood on the San Pedro River, Arizona and Used in the Geographic Information System.

Species	Age	Min DTW,* m	Max DTW,† m
Salix gooddingii	juvenile	0.091	2.0
(Goodding willow)	mature	0.091	3.2
Populus fremontii	juvenile	0.21	2.0
(Fremont cottonwood)	mature	0.091	5.1

Depth to water ranges are taken from Stromberg et al. (1996).

*Min DTW is the minimum depth to water observed for the species.

†Max DTW is the maximum depth to water observed for species.

Stevens, L.E. Riparian plant succession along the dam-regulated Colorado River, Grand Canyon, AZ. National Park Service, Grand Canyon, AZ.

- "Construction of Glen Canyon Dam upstream from the Grand Canyon permitted a profuse stand of riparian vegetation to colonize the formerly flood-scoured river corridor."

- "Erratic dam operations favored a plant community dominated by *Tamarix*, while a more stable discharge regime favored dominance by native species. Dam-influenced coarsening and nutrient-depletion of riparian soils reduced the availability of safe germination sites and favored the expansion of native clonal species, such as *Salix exigua* and *Tessaria sericea*, over species that only colonize by seed (e.g., *Tamarix, Baccharis*, and *Celtis*)."

Stevens, L.E., and G.L. Waring. 1986. Effects of post-dam flooding on riparian substrates, vegetation, and invertebrate populations in the Colorado River corridor in Grand Canyon, Arizona. Terrestrial Biology of the Glen Canyon Environmental Studies.

- "Flood-induced plant mortality was significant in this system, and reduced riparian plant abundance by more than 50% below the 1,700 m^3/sec stage. Sources of mortality included: 1) removal, which was dependent on plant architecture; 2) drowning/thrashing; and 3) burial beneath newly deposited fluvial sediments. Mortality was strongly differential, with relatively high survivorship of *Tamarix chinesis, Salix exigua,* and *S. gooddingii*."
- "Tree-forming species with deep tap roots (e.g., *Salix gooddingii, Prosopis, Acacia,* and *Tamarix*) were more resistant to removal by scouring, as compared to clonal species (e.g., *Salix exigua*)."
- "Plant mortality was strongly correlated with proximity to the river (stage), with more than 49% mortality in Zone A, 26% mortality in Zone B, and nearly 18% mortality in Zone C."
- "Plant mortality varied according to substrate type. Mortality was highest on cobble substrates, moderate on sand and mixed sand-cobble substrates, and lowest on bedrock. Mortality was also positively correlated with current velocity."
- "Both *Salix* and *Tamarix* were capable of rapid regrowth, but *Salix* grew faster than *Tamarix* in some settings."

Stromberg, J.C. 1993. Fremont cottonwood-Goodding willow riparian forests: A review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science, 26(3):97-110.

- "The reproductive biology of Fremont cottonwood and Goodding willow is strongly tied to fluvial processes, with seedling recruitment of both species dependent upon periodic flood flows to deposit and moisten alluvial sediment bars. Mature plants often become isolated on high floodplains some distance from the active channel, but continue to remain hydrologically dependent on a shallow riparian water table. Restoration and preservation of these species-rich forests depends upon removal of activities that interfere with natural ecosystem processes (e.g., livestock which destabilize and erode recruitment bars; dams and diversions that lower water tables and prevent channel meandering and sedimentation)."

- "Fremont cottonwood-Goodding willow forests occur along floodplains of large, low gradient ($L < 0.005 \pm 0.002$ m/m; Szaro 1989, 1990), perennial streams in wide, unconstrained valleys, such as Rosgen's (1985) type C or type D streams…Optimal conditions for forest development are along depositional environments, where fine-grained alluvial substrates are present in the floodplain. Such streams often have multiple historical and/or active channels that undergo continual lateral adjustment as they meander and form new alignments."
- "Tree-ring studies within the Hassayampa River system indicate that Fremont cottonwood and Goodding willow also establish on a large scale about once a decade, during or after years with flood flows greater than or equal to the 7-year return event (> 250 cms)."
- "Main causes of mortality for cottonwood and willow seedlings are drought and summer or fall floods."
- "Fremont cottonwood seedlings are somewhat more tolerant of drought than are Goodding willow, but moist soils throughout the growing season are a necessity for establishment of both species; a soil moisture content of about 10% is believed to be a minimum for survivorship of seedlings."
- "Mature cottonwood and willow trees survive these dynamic changes by possessing lateral surface roots as well as moderately deep roots (about 3 m; Zimmerman 1969) that extend into the water table."
- "Hydrologic Threats. Manipulation of water resources and fluvial processes pose some of the greatest threats to Sonoran cottonwood-willow systems, and may interfere with essential hydrological process (e.g., flooding); reduce availability of basic abiotic needs (e.g., water or nutrients); or cause direct mortality."
- "For example, 46% to 84% of the Fremont cottonwoods at a site along the Verde River died during a dry period in the 1970s due to a combination of low flow release from Bartlett Dam and ground water pumping from the Verde River Infiltration Gallery and Well Facility (McNatt et al. 1980)."
- "Land Use and Other Threats. Livestock grazing — within southwestern cottonwood-willow ecosystems, unregulated livestock grazing has been implicated as a primary cause of decadent age structures, wherein many stands have large, old trees but few saplings or small trees (Brotherson et al. 1983; Fenner et al. 1984; Rucks 1984; Shanfield 1984)."
- "Additional threats include: Land Clearing; Watershed Degradation; Mining; Road Development; Recreation; Fire; Elimination of Beavers; and Exotic Species."

Stromberg, J.C. 1997. Growth and survivorship of Freemont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist, 57(3):198-208.

- "During winter 1993, Arizona experienced regional river flooding. Floodwaters at the Hassayampa River eroded floodplains and created a 50-m-wide scour zone available for colonization by pioneer plant species. The slow rate and long duration of the floodwater recession allowed establishment of spring-germinating native trees (mainly Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*))."
- "As the Hassayampa River floodwaters receded in 1993, woody plants germinated in exposed moist soils in the following sequence: Fremont cottonwood (March-April), Goodding willow (April-May), salt cedar (May-September)."
- "Souring flows should be released during early spring in potential recruitment years for cottonwoods and willows. The flood flows need to be of sufficiently high magnitude and duration to rework sediments and create bare surfaces lying within about 1 m of the "base-flow" alluvial groundwater table."
- "At Date Creek, which is grazed/browsed by cattle from November to March, selective browsing on Fremont cottonwood seedlings caused them to lose their height advantage over salt cedar."

Stromberg, J.C. 1998. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments, 40:133-155.

- "In the middle basin of the San Pedro River, saltcedar dominates only at the drier sites where the surface and ground-water conditions no longer support cottonwood-willow forests. At sites with perennial (or near-perennial) stream flow, saltcedar is co-dominant with Fremont cottonwood. However, saltcedar has been declining in importance at these sites, perhaps due to recent occurrence of conditions that favor cottonwood establishment (frequent winter flooding, high rates of stream flow during spring, exclusion of livestock)."
- "…Saltcedar has increased in relative abundance at sites that show evidence of ground-water decline."
- "Various studies suggest that Fremont cottonwood-Goodding willow forests are best developed where ground-water is about 1 to 3 m below the flood plain surface (McQueen and Miller 1972; Stromberg et al. 1991, 1996; Busch and Smith 1995) whereas saltcedar stands retain high density and biomass at ground-water depths up to about 7 to 10 cm."

Stromberg, J.C. 1998. Functional equivalency of saltcedar (*Tamarix chinensis*) and Fremont cottonwood (*Populus fremontii*) along a free-flowing river. Wetlands, 18(4):675-686.

- "Saltcedar was functionally equivalent to Fremont cottonwood for about half of the traits construed as indicators of riparian ecosystem functions."
- "Also in contrast to the working paradigm, saltcedar appeared to enhance the maintenance of floristic biodiversity. Understory herbaceous cover and species richness were significantly greater than in cottonwood stands, perhaps due to soil differences that developed between the two stand types (e.g., higher clay content in saltcedar soils)."

Stromberg, J.C. 2001. Restoration of riparian vegetation in the south-western United States: Importance of flow regimes and fluvial dynamism. Journal of Arid Environments, 49:17-34.

- "Along some reaches in which floods have been suppressed but stream flows not diverted, riparian biomass has increased. For example, riparian vegetation has increased significantly along the Bill Williams River, a small tributary to the Colorado, since closure of Alamo Dam in 1968. Most of the new vegetation, however, is composed of the exotic woody plant *Tamarix ramosissima* and the dense riparian forests have become fire-prone."
- "Primary root causes of riparian loss and degradation are alteration of herbivory regimes, disruption of hydrologic regimes, and direct conversion to irrigated cropland and urban areas."
- "As a broad restoration guide, restoration of natural stream flow regimes is fundamental…[but] may not be the preferred option in all circumstances."
- "On many streams in western United States and Canada, recruitment rates of *Populus* and *Salix* species have declined because floods have been suppressed or altered in ways that do not meet their regeneration requirements."
- "Sediment and nutrients can be restored to some below-dam reaches by adding sediment bypass structures (Schmidt et al. 1998)."
- "Primary root causes of riparian loss and degradation are alteration of herbivory regimes, disruption of hydrologic regimes, and direct conversion to irrigated cropland and urban areas."
- "The Rio Salado project is a joint effort by the City of Phoenix, U.S. Army Corps of Engineers, and other groups, and is funded largely by Federal monies. Goals include creation of wildlife habitat and passive recreational opportunities; indirect benefits including economic revitalization of neighborhoods along the river corridor also are anticipated. While the outcome of this effort remains to be seen, the project is conceptually flawed as a true ecosystem restoration effort because it involves artificial approaches that do not address the root causes of ecosystem degradation. There are no

plans to release water or sediment from upstream dams or to recharge the alluvial aquifer. Rather, the plan calls for releasing pumped ground water into excavated surface channels and planting 75,000 contract-grown trees. The rehabilitation efforts probably will result in creation of an urban park with some wildlife habitat value. It remains to be seen how biodiversity, bioproductivity, and ecosystem resilience will compare to that of free-flowing streams, in the absence of a restored flood regime and ground water source, and without connectivity to high-quality riparian ecosystems."

- "What are the consequences of restoring flood waters but not associated sediments? Such questions demand research. In restoration contexts, these questions could be tested using an adaptive management approach until uncertainty levels decline."
- "One branch includes transpiration studies, which seek to determine how much water a plant population or assemblage needs by asking how much it uses. Techniques ranging from canopy-scale micrometeorological measurements of heat flux to plant-scale measurements of sap flow and heat-pulse velocity have revealed a wide range of responses to the question of "how much water does a patch of riparian vegetation require?" Transpiration rates vary with stand composition, biomass structure, and plant age. Along Arizona's San Pedro River, transpiration rates among *Populus fremontii* patches ranged from 3 to 6 mm per day (Schaeffer et al. 2000). Young, densely foliated stands transpired more water than did older stands, although individually, old *P. fremontii* trees transpired more water than young ones. Transpiration rates also vary with water availability (Devitt et al. 1997). *Populus* trees along the San Pedro River transpired twice as much water when growing at sites with shallow vs. deep ground water (Goodrich et al. 2000). Flood-inundated *Tamarix ramosissima* along New Mexico's Rio Grande transpired twice as much water as did those that were not flooded (Cleverly et al. 2000). Bioproductivity and transpiration rates of other riparian plant species, including *Prosopis velutina* and *Sporobolus wrightii*, vary depending on the quantity of summer rains (Scott et al. 2000a). With sufficient data on transpiration rates by plant assemblage and with vegetation maps, one can estimate total water use rates for long river reaches (O'Keefe and Davies 1991; Goodrich et al. 2000). With a knowledge of the water requirements for high-quality states of each assemblage, one can estimate the amount of water necessary to restore or maintain ecosystem integrity."
- "Continued establishment of *Populus fremontii* and *Salix gooddingii* depends on periodic occurrence of years with appropriately timed flood flows, high growing-season stream flows, and very shallow water tables (Everitt 1995). Along free-flowing streams in the Sonoran Desert, regeneration floods occur about once every 5-10 years."
- "There are several sustainable solutions for restoring stream flows and raising water tables to levels that allow for recovery of hydrophytic and mesophytic vegetation types such as *Populus-Salix* forests or riverine marshlands, while also allowing for water extraction for human consumption. Water can be

stored in aquifers rather than reservoirs, municipal water can be recycled and released into stream channels, stream channels rather than canals can be used for water delivery, efficiency of municipal, agricultural, and industrial water-use can be increased, and extraction demands can be reduced. Ultimately, integrated, watershed-based approaches to water management are needed to reverse adverse effects of ground water mining and surface water diversions. All water users, municipal agricultural, or industrial, need to work together and address water overdraft problems."

- "**Loss of sediment.** Dams and reservoirs impede downstream flows of sediment. Reduced transport of silt and clay may reduce biodiversity below dams, given that abundance of herbaceous riparian species tends to increase on fine soil textures (Stromberg 1998a; Jansson et al. 2000a). Biodiversity also declines as dynamic fluvial processes, such as channel migration, erosion, and sedimentation, become static (Shields et al. 2000) and spatial and temporal heterogeneity decline (Pollock et al. 1998). Orthophosphates typically adheres to clays and silts and thus decline in below-dam systems as fine sediments are deposited in reservoirs, contributing to downstream productivity declines. Sediment and nutrients can be restored to some below-dam reaches by adding sediment bypass structures (Schmidt et al. 1998). Other barriers imposed by dams, such as restricted dispersal of plant propagules (Jansson et al. 2000b), are more difficult to remedy, short of de-commissioning dams. Given such limitations, there is a need to assess economic and environmental costs and benefits of all dams in the south-western United States, as a basis for deciding which warrant removal or breaching (Shuman 1995; Born et al. 1998). At some sites, dam removal provides substantial ecological benefit, while minimal reducing the production of "goods" (Wunderlich et al. 1994)."

Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers, 2(3):221-235.

- "Analysis of present-day and historical data indicates that floods play a primary role in the recruitment of Sonoran riparian trees in the Hassayampa River system. Recruitment of Fremont cottonwood (*Populus fremontii*) and Goodding willow (*Salix gooddingii*) depends on: 1) large floods prior to the spring germinate period to remove herbaceous cover; 2) high spring flows or rains to stimulate germination on floodplains above the zone of frequent flood inundation; and 3) reduced post-germination flooding to reduce seedling mortality."
- "Recruitment has occurred at an average interval of 12 years, indicating that conditions are frequently suitable for establishment of the two species."
- "The trees, as least, have moderately deep roots (generally up to 8 m for cottonwood and willow…)."

Stromberg, J.C., J.A. Tress, S.D. Wilkins, and S.D. Clark. 1992. Response of velvet mesquite to groundwater decline. Journal of Arid Environments 23:45-58.

- "The bosque had high water potentials, large leaflets (> 7 cm^2), tall stature (> 12 m), and large vegetation volume (> 2 m^3/m^2) only where the water table was < 5 m below the surface. Trees became increasingly stressed as groundwater declined to 15-18 m."

Stromberg, J.C., S.D. Wilkins, and J.A. Tress. 1993. Vegetation-hydrology models: Implications for management of *Prosopis velutina* (velvet mesquite) riparian ecosystems. Ecological Applications 3(2):307-314.

- "Stand structure was strongly related to water availability. Management applications of the models include the ability (1) to identify minimum water-table depths for riparian stand maintenance and (2) to detect stressful hydrological conditions, via water potential measurements, before the onset of structural degradation."

Stromberg, J.C., B.D. Richter, D.T. Patten, and L.G. Wolden. 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53(2):118-130.

- "Depth to the floodwater ranged from 2.64 ± 0.20 m (mean ± SD) near the stream to 0.47 ± 0.31 m in the highest floodplain zone (*Prosopis* forest). An average of 8 cm of sediment was deposited on the floodplain, with maximum deposition (to 0.5 m) on densely vegetated surface 1-2 m above the water table."
- "*P. fremontii* pole trees on 1-2-m-high floodplains averaged 6% mortality, compared to 40% for those on low floodplains (< 1 m above the water table) where standing water was > 2 m."
- "The 1991 flood had peak discharge of 368 m^3s^{-1} on 1 March (Figure 2), a value about 3000 times greater than the base flow rate (0.1 m^3s^{-1})."
- "Discharge remained above base flow values through mid-April."
- "Peak water depth was 2.6 ± 0.2m and 0.5 ± 0.3 m (Table 1)."
- "Pole trees of *S. gooddingii, P. fremontii,* and *T. pentandra* grew on mid-height floodplains 1-2 m above the water table and had respective survivorship of 93%, 73%, and 38%. *Tamarix pentandra* was the only one of these three species that had much lower survivorship of pole trees in 1991 than in prior years. Saplings of these three species grew on floodplains ??? above the water table , and each had about 35% survivorship if the 1991 flood."
- "*Populus fremontii* poles on floodplains 1-2 m above the water table had 94% = 10 survival compared to 60% = 40 for those on floodplains < 1 m high

values for saplings were 54% = 46 for the higher floodplains and 30% = 38 for the lower. *P. fremontii and S. gooddingii* poles and saplings showed a threshold-type response in which survivorship declined sharply where water was > 1.5 m deep."

- "Stem survivorship average 50% for *B. salicifolia*, the most abundant shrub in the floodplain."

Table 1. Water depth and flow velocity on the Hassayampa River floodplain during floods of varying recurrence intervals, by riparian vegetation type. Values are means = standard deviation.

Vegetation Type	Water Depth (m)		
	2-year flood	5-year flood	10-year flood
Populus-Salix saplings	1.1 = 0.3	1.9 = 0.3	2.1 = 0.3
Baccharis salicifolia	0.8 = 0.4	1.5 = 0.5	1.7 = 0.5
Populus-Salix pole trees	0.8 = 0.4	1.6 = 0.5	1.8 = 0.6
Populus-Salix forest	0.4 = 0.4	0.8 = 0.5	0.9 = 0.6

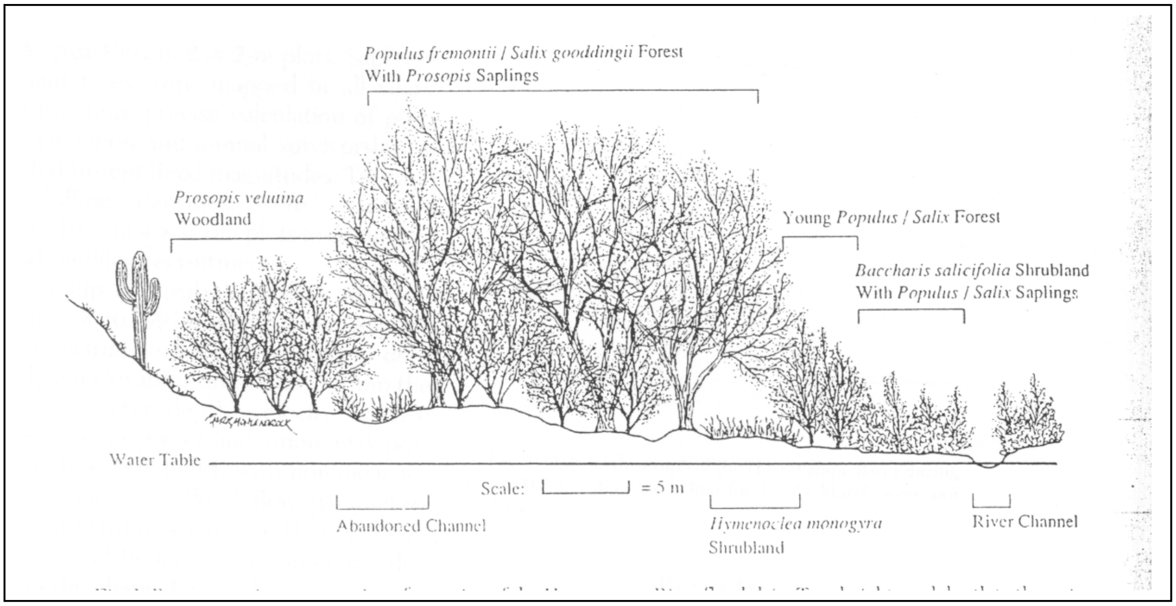
Table 3. Annual survivorship of dominant riparian trees and shrubs in the Hassayampa River floodplain. Data are for years with a 5-year return flood (1988-89), < 1-year flood (1989-90), and 10-year return flood (1990-91).

Species	Size Class or Growth Form	Survivorship (%)		
		1988-89	1989-90	1990-911
Prosopis velutina	mature tree[a]	NS[b]	NS	100
Salix gooddingii	mature tree	NS	NS	100
Populus fremontii	mature tree	NS	NS	100
Prosopis velutina	pole tree	100	91	100
Salix gooddingii	pole tree	87	80	93
Populus fremontii	pole tree	86	89	73
Tamarix pentandra	pole tree	95	87	38
Prosopis velutina	sapling	76	87	82
Salix gooddingii	sapling	64	78	36
Populus fremontii	sapling	43	58	30
Tamarix pentandra	sapling	84	75	37
Zyzyphus obtusifolia	shrub	100	100	100
Hymenoclea monogyra	shrub	96	100	83
Baccharis salicifolia	shrub	100	100	51
Tessaria sericea	shrub	100	100	17

[a]Mature trees have stems > 10 cm diameter; pole trees have stems 1-10 cm diameter; saplings have stems < 1 cm diameter and are greater than 1 year in age.

[b]NS = not sampled.

Figure 1. Representative cross section of a portion of the Hassayampa River floodplain. Tree heights and depths to the water table are to scale.



Stromberg, J.C. and D.T. Patten. 1995. Instream flow and cottonwood growth in the eastern Sierra Nevada of California USA. Regulated Rivers, 12:1-12.

- "Dendro-ecological studies indicated that radial growth of Populus trichocarpa was significantly related to annual streamflow at 20 riparian sites in the eastern Sierra Nevada of California."
- "At nearly all sites, the trees attained maximum growth at streamflow values higher than the long-term average annual flows and in most instances had maximum growth in years with annual flows equal to the maximum recorded flow."
- "Presently there are few streams flowing through wide valleys in the eastern Sierra Nevada that have not been diverted. Where flows have been restored, vegetation has recovered rapidly (Stromberg and Patten 1989). The need to restore flows to such streams is highlighted by the results of this study, showing that the maximum growth rates for trees in wide alluvial valleys occurred at flow volumes well in excess of average diversion period flows."

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: The San Pedro, Arizona. Ecological Applications, 00(0).

Table 6. Mean depth to groundwater, soil texture, and wetland indicator score for vegetation-landform patch types within the San Pedro River floodplain. Values shown are means ± 1 SD.

Vegetation-Landform Type	Mean Depth to Groundwater (m)	Combined Silt + Clay (%)
Sand bar/streambank	0.1 ± 0.3	22 ± 14
P. fremontii/S. gooddingii sapling	0.7 ± 0.6	31 ± 05
P. fremontii/S. gooddingii young forest	1.0 ± 0.6	36 ± 10
P. fremontii/S. gooddingii forest	1.9 ± 0.7	45 ± 14
P. fremontii old-growth forest	3.5 ± 1.8	50 ± 08

Stromberg, J.C. and M. Chew. 1999. Restoration of riparian ecosystems in the arid Southwest: challenges and opportunities. *In* Shafroth, P.B., B. Tellman, and M.K. Briggs (technical coordinators). 1999. Riparian ecosystem restoration on the Gila River basin: opportunities and constraints. Issue Paper No. 21. Water Resources Research Center, The University of Arizona, Tucson.

- "**How do we restore degraded ecosystems? *Restoration of Physical elements and Processes***. Hydrologic regimes and fluvial geomorphic processes are prime determinants of riparian community structure."
- "***Flood Flows and River Dynamism.*** The ultimate strategy for restoring natural processes is to remove all impediments to the natural flow regime, which in many cases means removing dams…We also can make compromises with respect to river management…For example, we know that the timing, magnitude, frequency and duration of flows are all important influences on riparian vegetation. We can rehabilitate riparian ecosystems by naturalizing flows so as to mimic the natural hydrograph, or flow pattern, of the river…Various flow release strategies that can be used to manage for cottonwoods and willows, and against tamarisk, on our regulated rivers are:
    - When releasing winter/spring regeneration floods, limit the summer duration of the flood flows (Stromberg 1997).
    - Release post-germination summer floods to increase the relative mortality of tamarisk seedlings (Gladwin and Roelle 1998).
    - Maintain high summer base flows and water tables to give a competitive edge to the native species.

- Additional measures such as clearing of vegetation with bulldozers may be necessary to mimic the functions that have been lost by truncating the flow peaks. These "active" restoration approaches, wherein one intervenes with some type of engineering approach or physical action, can serve to mimic natural processes and conditions at sites where natural processes cannot be fully restored (Friedman et al. 1995)."
- "***Ungulate Grazing.*** Will livestock exclusion restore riparian health? Sometimes, eliminating a stressor is all that is needed to enable natural recovery. Livestock removal (or reductions of higher-than-typical populations of elk and deer) can result in dramatic and rapid recovery of some elements of the riparian ecosystem, particularly where the ecosystem has not been degraded by other factors. Along the free-flowing upper San Pedro River, Arizona, cattle exclusion was followed by rapid channel narrowing and vegetative regrowth. New stands of cottonwood and willows and herbaceous plants developed in the wide, open stream banks, and song-bird populations increased (Krueper 1992)."
- "We also sorely need to increase our knowledge base in this area. There are few solid studies that demonstrate the consequences of grazing management schemes on *arid*-region riparian vegetation."

Tallent-Halsell, N.G., and L.R. Walker. 2002. Responses of *Salix gooddingii* and *Tamarix ramosissima* to flooding. Wetlands, 22(4):776-785.

- "Efforts to replant natives within the drawdown zone surrounding Lake Mohave, a lower Colorado River impoundment bordering Nevada and Arizona, have not been successful."
- "Even though adult Salix that are well-established are known to be flood-tolerant, transplants are not."
- "Our greenhouse experiment was conducted to evaluate problems encountered in the Lake Mead Recreation Area when efforts were made to restore native *Salix gooddingii* Ball. (Goodding willow) and *Populus fremontii* Wats. (Fremont cottonwood) poles (J. Haley, pers. comm.) to the drawdown zone of Lake Mohave."
- "Pinkney (1992) noted that southwestern riparian revegetation sites that are coarse are difficult to revegetate; the most desirable soil textures are sandy loams."
- "Native stands have been relegated to the often flooded strata of the riparian ecosystem."

Taylor, J.L. 2002. *Populus fremontii*. *In* U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (2003, April). Fire Effects Information System. Available: http://www.fs.fed.us/database/feis. Downloaded July 9, 2002.

- "The palatability of Fremont cottonwood to domestic livestock and wildlife has been rated as follows:

	CA	**UT**
Cattle	Poor	Fair
Domestic Sheep	Poor to Fair	Fair
Horses	Useless	Poor

- "Cattle grazing prevents successful regeneration of Fremont cottonwood seedlings and exclusion of grazing in Fremont cottonwood riparian zones has been recommended. However, Asplund and Gooch maintain that the impacts of grazing are unclear and that recruitment is affected more by flooding and the creation of suitable habitat than by grazing pressure."
- "Regulating stream flows to mimic the natural flood regime (duration, peak flow, and timing) could be used to establish Fremont cottonwood and decrease saltcedar. Decreased flooding, stabilized flows, introduction of exotics (saltcedar, Russian-olive, and leafy spurge (*Euphorbia esula*)), water diversion due to damming and agricultural use, and stream channelization have led to drought stress and the subsequent decrease in Fremont cottonwood and associated riparian species."
- "Fremont cottonwood is a fast-growing, obligate seeder, and reproduction primarily comes from establishment of wind-borne seeds…Regeneration is tied to the annual runoff regime of the area."
- "Fremont cottonwood reaches reproductive maturity between 5 and 10 years of age."
- "Suitable recruitment sites are created by the floodwaters of spring run-off. Seeds germinate almost exclusively on the freshly deposited, exposed alluvium left by receding floodwaters."
- "Soil types and structures include well-drained, alluvial, sandy to sandy clay loams with varying degrees of organic matter, clay or other fine soil and rock deposits, coarse, rocky and sterile soils, and fine-grained alluvial substrates. It has also bee described as fairly salt tolerant (< 1,500 mg/L)."

Taylor, J.P. and K.C. McDaniel. 1997. Restoration of saltcedar infested flood plains on the Bosque del Apache National Wildlife Refuge. Available: http://bhg.fws.gov/Literature/newpage12.htm. Downloaded February 14, 2001.

- "Saltcedar clearing is accomplished using a combination of herbicide, burning, and mechanical control techniques costing from $750 to $1300/ha.

Soil salinity and depth to water are the principle physical features limiting revegetation efforts. Cottonwood and black willow plantings and natural regeneration after timed irrigations have produced diverse habitats that support a wide array of faunal species in areas previously occupied by homogeneous saltcedar."

- "Water table fluctuations of < 0.6 m, which is ideal for pole planting survival (Swenson and Mullins 1985)."
- "Costs for planting 32 ha in unit 28 with 5,500 cottonwood and willow poles and 1,500 shrub seedlings averaged $7.75 per planting. In unit 29, 4,200 cottonwood and willow poles and 2,500 shrub seedlings planted over 28 ha and cost $7.30 per planting. Costs in unit 30 were lower than other units because poles were obtained on the refuge and no shrub seedlings were planted. Crew efficiency also increased, allowing 5,500 cottonwood and black willow poles to be planted on 23 ha for about $3.75 per plant."

Teskey, R.O. and T.M. Hinckley. 1978. Impact of water level changes on woody riparian and wetland communities. Vol. VI: Plains Grassland Region. Performed for Eastern Energy and Land Use Team, Water Resources Analysis (Formerly National Stream Alteration Team) Office of Biological Services, USDI Fish and Wildlife Service. FWS/OBS-78/89.

- "The series *Impact of Water Level Changes on Woody Riparian and Wetland Communities* provides a current summary of available information concerning the effect of water level imposed stress on a wide range of woody plants."

Excerpt from Table 1

Species	Size	Survival Under Constant Inundation
Platanus occidentalis (sycamore)	mature tree	B.1. 94% after 73 days (8).
Populus deltoides (eastern cottonwood)	mature tree	B.1. 100% after 73 days (8) B.3. Died after 2 years (6)
Salix nigra (black willow)	mature tree	B.1. 100% after 73 days (8) B.3. All died after 3 years (6)
	Seedling	A.1. 100% after 30 days (11, 15) C.1. 100% after 60 days (13)

A = Total submersion, B = Partial submersion, C = Soil saturation.
1 = during growing season, 3 = year-round

Williams, G.P. and M.G. Wolman. 1984. Downstream Effects of Dams on Alluvial Rivers. USGS Professional Paper 1286. U.S. Government Printing Office, Washington, DC.

- "Vegetation cover in and along channels downstream from the dams of this study either remained about the same or (most commonly) increased, following dam closure."
- "If one deals only with the flood plain as opposed to the channel and banks, the effect of floods is less clear. Some trees, for example, may grow better under periodic flooding, especially where vigorous scouring is less active or less effective than gentler inundation."
- "Regulation of high flows (magnitude, frequency, and duration) seems to be the only dam-related factor that is reasonably certain to encourage an increase in vegetation."
- "Channel vegetation blocks part of the channel, resulting in reduced channel conveyance, faster flow velocities in the channel thalweg, or both. Conveyance is decreased both by physical reduction of flow area by the vegetation and by impeding the sediment transport process and inducing bed "aggradation."
- "On the Republican River in Nebraska, vegetation decreased the channel capacity by 50 to 60 percent in some reaches (Northrop 1965). Such reduced conveyance leads to more frequent and longer-lasting overbank flooding."
- "Vegetation also enhances greater bed stability."
- "On most of the alluvial rivers surveyed, the channel bed degraded in the reach immediately downstream from the dam. Channel width is some cases showed no appreciable change, but in others, increases of as much as 100 percent or decreases of as much as 90 percent were observed."