ASSESSMENT OF HUMAN INFLUENCE ON RIPARIAN CHANGE IN THE VERDE VALLEY, ARIZONA

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"When I first saw the Verde Valley it was a hunter's and stockman's paradise. Wild game was everywhere and the grass was knee high and plentiful. The land was like a sponge and when it rained the water was absorbed into the ground immediately, so very little rain ran into the river channel. And the small amount that did run into the riverbed stood in pools which became stagnant and polluted with malaria germs, consequently many people were stricken with malaria."

Charles Willard, regarding his arrival in the Verde Valley in 1879[1]

"[My] chief lament is change of seasons from an abundance of rain in the Verde Valley and the heavy snows in the mountains all around to unprecedented drought that has made a trickle of the Verde in what it used to be. … The havoc wrought by erosion and stripping of the region in general of its wooded growth and absence of grass adds to unhappy disappointment."

Charles Stemmer, valley resident since 1898, reflections in the early 1950s[1]

INTRODUCTION

Riparian vegetation in the Verde Valley, Arizona is constantly changing. Some changes are due to natural causes while others are due to human activity in the watershed. Prior to this study, no one had quantified increases or decreases in the extent and distribution of riparian vegetation. To investigate and quantify riparian change in the northwest half of the Verde Valley, Northern Arizona University initiated this study. Cottonwood-willow and mesquite stands were evaluated and mapped by interpreting historic aerial photographs. Then changes in the distribution of vegetation were analyzed. Land use and river channel area were also mapped and changes analyzed. This report relates the results of these analyses and assesses to what extent changes are due to natural causes or due to human activity.

In assessing the causes of vegetation change, eight criteria were evaluated qualitatively and, where possible, quantitatively. These criteria include the natural factors of climate, flooding, and channel morphology changes as well as the human influenced variables of land use, water table decline, introduction of non-native plant species, grazing, and sand & gravel extraction. Each of these criteria will be addressed in this report to give a picture of how the Verde Valley riparian area has changed over the last 60 years and what has influenced those changes.

Because this project produced over twenty large maps, we have chosen to provide those maps in digital format, instead of paper format. Attached to the inside back cover of this report is a CD ROM containing ArcView (ESRI 1998) shapefiles, which display all the riparian vegetation, land use, and channel morphology covers for 1940, 1954, 1968, 1977, 1989, and 1995 on a base of USGS 7.5-minute topographic maps. Attribute tables are attached to each theme. A "readme" file on the CD explains how to install and view the files. ArcView 3.1 software is a minimum requirement to view the shapefiles. Imagery on which this analysis was based is composed of very large files that occupy multiple CDs, so the imagery was not included here. If you have a need for this imagery, contact the Arizona Water Protection Fund.

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[1] Verde Valley Pioneers Association. 1954. Pioneer stories of the Verde Valley of Arizona. As told by themselves and compiled by the Book Committee, Camp Verde?, AZ. 1933: pp. 1-106, 1954: pp. 107-213.

DESCRIPTION OF THE ENVIRONMENT

The research area extends along the Verde River from two miles below the Oak Creek confluence upstream to 7 miles above Clarkdale and includes the mouth of Oak Creek (Figure 1). It can be accessed from the towns of Clarkdale and Cottonwood using city streets; Arizona Highways 260 and Alt 89A; County Road 139, U.S. Forest Service Roads 147, 147A, and 131, and other public and private roads. The study area is divided into a core area and two smaller areas (Figure 1). Explanation of the divisions is in the methods section.

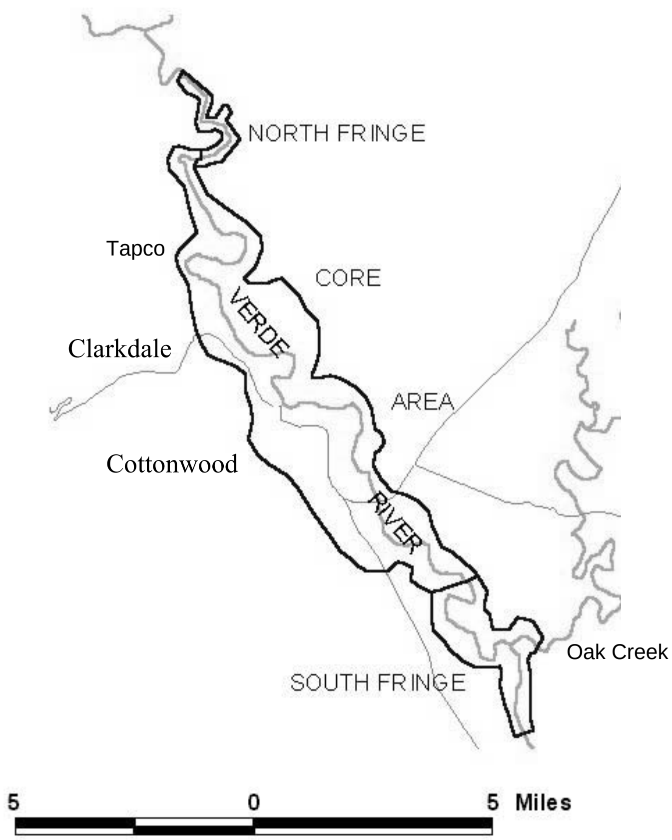

Figure 1. Upper Verde Valley Riparian Area Historical Analysis Study Area Map showing North Fringe, Core Area, and South Fringe.

Geology

Philip A. Pearthree described the geology of the Verde Valley in a report titled "Historical Geomorphology of the Verde River" (Pearthree 1996). The following narrative is a synopsis of his work.

The Verde Basin is a structural feature formed by uplift on each side of the valley. The Black Hills are uplifted southwest of the Verde Fault and the Mogollon Rim is uplifted northeast of faults in the Sedona area. During the Tertiary period, 8 to 2 million years ago, sediments were deposited in a large freshwater lake while the Verde Basin was naturally dammed at the southern end, before the Verde River formed. These lake sediments make up the Verde Formation, which underlies the entire study area. The Verde Formation is characterized by limestone and fine-grained silt- and clay-rich deposits. The limestone beds are resistant to erosion and form cliffs throughout the study area, but particularly at the northern fringe (upstream of Tapco) and southern fringe (downstream of Verde Village). The Verde Valley started developing in its modern form about 2.5 million years ago when the natural dam at the southern end of the valley breached. Downcutting has continued to the present. During the downcutting of the valley, various Quaternary alluvia have been deposited on top the Verde Formation. Table 1 summarizes the location and age of the alluvia found in the study area (Table 1).

Table 1. Quaternary Alluvium in the Upper Verde Valley Riparian Area Historical Analysis study area (Pearthree 1993).

Unit	Location	Period	Age
Qc	Active channels	Modern	
Qty	Lower terraces	Holocene	< 10,000 years
Qfy	Channels and low terraces of tributaries streams	Holocene	< 10,000 years
Qtmo	Older mid-level terraces	late to middle Pleistocene	10,000 to 500,000 years
Qfmo	Older mid-level terraces and alluvial fans associated with tributaries	late to middle Pleistocene	10,000 to 500,000 years
Qto	Very high terraces	early Pleistocene	1 to 2 million years
Qfo	Very high alluvial fans of tributaries	early Pleistocene	1 to 2 million years

Riparian environments in the Verde Valley exist almost entirely on young alluvial deposits or at the interfaces between young deposits and various older units (Pearthree 1993). This is because the younger alluvium has a high capacity for storing and conducting water. The phreatophytes, cottonwood, willow, and mesquite, require that their roots reach groundwater to survive and flourish. Cottonwood-willow stands generally occur in the alluvium of active channel areas (Qc), while mesquite stands are usually found in the other types of alluvium.

Climate

The high elevation areas surrounding and within the Verde watershed influence the climate of the area, because moisture-laden airmasses, on encountering these topographic features, rise, cool, and precipitate moisture. Annual precipitation normally ranges from 18 to 26 inches, in the portions of the watershed which contribute streamflow to the study area, with greater precipitation occurring near the Mogollon Rim. In the valley itself, precipitation normally ranges from 12 to 17 inches per year (Owen-Joyce 1983).

Precipitation is seasonal with two wet periods, one during the winter and another during the summer monsoon. Frontal systems bring winter storms that usually produce snow at higher elevations and rain in the valley. Winter storms can cause widespread flooding, especially when rain falls on melting snow at higher elevations. Summer storms are often short-lived but intense, causing local flash flooding (Owen-Joyce 1983).

Hydrology

> *"**Artesian Flow Strong At Cottonwood** - For almost two weeks the artesian well in the Willard addition at Cottonwood has been flowing steadily and as yet there is not the slightest diminution of the flow. The water comes out at a rate of 100 gallons a minute. Previous experience with artesian wells in the Verde valley has been that after a few days they have ceased to flow."*
>
> The Jerome Sun, Tuesday, May 8, 1917

Sandra Owen-Joyce and C.K. Bell described the hydrology of the Verde Valley in a report titled "Appraisal of Water Resources in the Upper Verde River Area, Yavapai and Coconino Counties, Arizona" (Owen-Joyce 1983). The following narrative is a synopsis of their work.

The water-bearing rock units of the upper Verde River area are grouped into a large regional aquifer. In the Verde Valley, the regional aquifer includes alluvium along the Verde River, the Verde Formation, and underlying basalt flows, Supai Formation, and Redwall Limestone. On the east side of the valley, the Verde Formation is underlain by and hydraulically connected to the Supai Formation. West of Cottonwood, wells obtain water from the Redwall Limestone beneath the Verde Formation. No known borehole has completely penetrated the Verde Formation in the central part of the valley. Generally, the regional aquifer is unconfined, but in some places water in the Verde Formation, Supai Formation and Redwall Limestone is confined and has artesian conditions. The Verde Formation is the principle unit of the regional aquifer in the Verde Valley. In most places the alluvium along the Verde River in the study area is hydraulically connected to the Verde Formation and is part of the regional aquifer. The alluvium is generally less than 50 feet thick.

The Verde River is a perennial stream supplied by groundwater discharge, ephemeral tributaries, and perennial tributaries such as Sycamore Canyon and Oak Creek. The recharge area for the regional aquifer that discharges to the river is a large area, mostly distant from the Verde River. Base flow of the streams that drain the regional aquifer therefore varies little with precipitation or from year to year. Base flow does vary seasonally, however, in relation to the amount of water used by plants, with a maximum base flow in January/February and a minimum base flow in July/August. Irrigation diversion can temporarily reduce low flow conditions, but long term changes in base flow may indicate changes in the amount of water stored in the aquifer.

There are no major surface water impoundments within the study area, but there are small diversion dams, which supply water to O.K. Ditch, Cottonwood Ditch, Hickey Ditch, Pecks Lake, and Jordan Ditch. Some small diversions have come and gone during the past several decades. Some farmland has also been directly watered from the river by using pumps.

Pecks Lake and Tavasci Marsh lie in an old meander of the Verde River that was cut off about 10,000 years ago. Pecks Lake was created around the turn of the century as part of a golf course for executives of the United Verde Extension. It is fed by a manmade diversion from the Verde River. Tavasci Marsh receives some tailwater from Peck's Lake, but the marsh existed prior to the lake. It is fed by Shea Spring, which emerges from limestone beds of the Verde Formation along the north wall of the meander bend.

HISTORY OF HUMAN INHABITATION

Presettlement

Prior to settlement by Europeans, the Verde Valley was occupied by a series of native peoples. Prehistoric people lived along the river since 5,000 or 6,000 years ago (Byrkit 1978). By 700 AD, Hohokam and Southern Sinagua influences were established and agriculture advanced rapidly (Beard 1987). The population expanded and around 1100 AD the first rooms of the Tuzigoot pueblos were built. The Tuzigoot Phase peaked between 1300 and 1400 AD, but the pueblos were abandoned by 1425, about the time Yavapais and the Tonto Apaches came to occupy the valley. Theories regarding the cause of the abandonment include invasion by foreign cultures, depleted soil conditions, disease, and breakdown of trade relations. The Yavapai-Apache have lived in the Verde Valley since the Sinagua left, but when the Spanish arrived they were living in thatch-roofed huts, not pueblos.

In 1583 the Spanish explorer Antonio de Espejo visited the Verde Valley searching for copper mines in the Black Hills. He determined that the mines were not worth developing at that time. In 1598, Marco Farfan de los Godos also journeyed to the future site of Jerome, but again the Spanish chose not to exploit the ore deposits. In the earliest written account of what Espejo named El Rio de los Reyes (the River of the Kings), he described the Verde River valley:

> *"This place is surrounded by an abundance of grapevines and by many walnut and other trees."*

Anglo Settlement

Furtrappers entered the valley in the early 1800s and the Verde's beaver population was depleted. By the 1830s beaver pelts were no longer marketable and trapping ceased (Beard 1987). Gold was discovered at Lynx Creek in 1863 and Prescott became the territorial capital in 1864. Finally in 1865, a small group of Anglos began farming at the confluence of Clear Creek and the Verde River. Conflicts with local Indians led to the establishment of Camp Lincoln that same year. (Camp Lincoln was renamed Camp Verde then moved in 1871 to the present location of Fort Verde State Park.) By 1875, the Yavapai were removed to the San Carlos Reservation.

Mary Boyer who arrived in 1874 described the river…

> *"the Verde River at that time was just about the size of Woods ditch today. Wild mustard and grass grew profusely everywhere and large cottonwood trees could be seen in the distance."*[1]

Charles Stemmer, born in Prescott in 1883, remembers traveling through the Verde Valley as a child…

> *"There were stacks of wild hay on the bench land of the valley. The erosion on the Verde and its tributaries was hardly noticeable and I heard folks say many were sick with malaria. Many small lagoons all along the Verde furnished breeding places for mosquitoes and sometimes clouded parts of the valley."*[1]

Cattle by the thousands were introduced to the region in 1875. By the 1880s overstocking occurred. There were an estimated 40,000 cattle in the Verde Valley in the 1880s (Munson 1999). During the drought of 1894 and 1895, close to one hundred thousand cattle in Yavapai County died of starvation and another 40,000 were shipped out on rail (Culley 1966). Overgrazing caused increased runoff and erosion during the 1890s and contributed to what is known as "The Incisional Event", a time when many streams throughout the region downcut dramatically. As wet years followed dry, the denuded landscape gave rise to dramatic flooding.

Charles Stemmer speaking of the period from 1898 to 1908…

> *"[They moved from the ranch north of the river at Cottonwood] owing to the fact that there were no bridges then across the Verde or its tributaries and much of the time the Verde was a raging torrent and we kids couldn't get to school..."*[1]

Arriving in 1878, the four Willard brothers were among the first Verde Valley settlers, driving cattle down to Arizona from northern Nevada. They helped develop irrigation and found the town of Cottonwood. In the 1880s, the cattle boom ended and Willards turned to farming. They helped organize construction of Cottonwood Ditch. Today, Willard family descendants own the Cottonwood Waterworks utility that supplies drinking water to the town (Byrkit 1978).

The town of Cottonwood started out as a meeting place in the 1870s for cattlemen who camped under the big cottonwood trees which stood in a wash that ran into the Verde River. The place was known as 'The Cottonwoods". When a post office was finally established in 1885, the town's name "Cottonwood" became official, although the town was not actually incorporated until 1960. The first settlers marketed hay and grain at Camp Verde and later Jerome, but they also ran cattle. Cottonwood has grown to town of about 8,300 people (U.S. Census Bureau 2001).

The neighboring town of Clarkdale was founded in 1912 as a residential and business facility to serve the employees of the United Verde Copper Company and was wholly owned by the company. In 1935, Phelps-Dodge Corporation purchased United Verde's holdings including Clarkdale. The town properties were sold in 1954 after mining operations ceased. Clarkdale incorporated in 1957. The population today is about 3,200 people (U.S. Census Bureau 2001).

Mining

Christine D. Beard described mining history of the Verde Valley area in a master's thesis titled "Smoke Men on the Hill: The Environmental Effects of Smelter Pollution in the Verde Valley, Arizona, 1919-1935" (Beard 1990). The following narrative is a synopsis of her work.

In 1873, the first mining claims were staked on Mingus Mountain and Cleopatra Hill. In 1882, the United Verde Copper Company bought the existing claims, built a reduction plant and began refining the ore at Jerome. After struggling financially much of the mine was bought by William Clark in 1888 who successfully expanded it. This expansion greatly increased the population of the Jerome and Verde Valley. By 1915, there were about 15,000 people living in Jerome alone.

Mining had environmental consequences. The Black Hills around Jerome were virtually denuded of timber to heat the homes of the town's residents and to run the furnaces of the copper companies. Deforestation exacerbated the erosion caused by overgrazing. In 1915, the Jerome smelter was shut down to make way for an open pit mine, and a new smelter was built at Clarkdale. By 1920, the plant had a capacity of 6.3 million tons of ore per month. A second smelter was built by another copper company, United Verde Extension, at Clemenceau in 1918. The smelters resulted in a smoke-filled valley. Sulfur dioxide in the smoke mixed with dew that settled on plants, formed sulfuric acid, and damaged plants. Fields and orchards nearest the smelters were impacted the greatest (Figures 2 and 3). In 1918, the first of many lawsuits were filed as valley farmers charged that smelter smoke had damaged their crops and orchards. The mining company claimed farmers were suffering from poor farming practices, diseases and insects. The lawsuits continued into the 1930s, but farmers won only a few cases.

In 1938, The United Verde Extension depleted its orebody and closed all operations. The United Verde Copper Company (owned by Phelps Dodge since 1935) closed its smelter in 1950 and ceased mining in 1953. Remnants of the mining era include a large black slag heap next the Verde River at Clarkdale and a large unremediated tailings pile near Tuzigoot National Monument.

Figure 2. Smelter site and Verde River at Clarkdale, prior to smelter, c. 1910. Looking northwest upstream from the road on the east side of the river across from the present-day black slag heap. (Allen 1937)

Figure 3. Aerial view of site in Figure 2, 1940. Looking north upstream. Edge of the black slag heap is in lower right-hand corner. "X" marks approximate location where photo in Figure 2 was taken. Note bare sediment where trees and pasture existed in c. 1910.

METHODS

Aerial Photo Acquisition

Stereo aerial photographs were purchased for the study area, depicting each of the past 6 decades (Table 2). Some years required a combination of flights to create complete coverage. The 1989 photos were mostly shot during summer 1989, but a few small gaps were filled with 1990 photos. Neither the 1995 Rupp photos nor the 1997 USDA photos gave complete coverage of the study area, so we used a combination of the two years. The 1995 photos covered populated areas from the southern study area boundary up to Tapco (Figure 1). The 1997 photos covered national forest land from Tapco up to the northern study area boundary (Figure 1).

Table 2. Specifications of aerial photography used in the Upper Verde Valley Riparian Area Historical Analysis.

YEAR	DATE FLOWN	AGENCY	PROJECT	SYMBOL	SCALE	COLOR	SOURCE
1940	9/23/40	SCS	USDA 8920	COU	1:31,680	B/W	National Archives
1954	12/19/54	SCS	SCS-16-54	DXI	1:20,000	B/W	National Archives
1968	5/25/68	Forest Service		ETB	1:15,840	B/W	USDA
1977	10/15/77	Forest Service	613090		1:24,000	color	USDA
1989	5/20/89	Forest Service	613090		1:12,000	color	USDA
	6/6/89	Forest Service	613090		1:12,000	color	USDA
	6/2/90	Forest Service	613040		1:40,000	color infrared	USDA
	8/2/90	Forest Service	623040		1:15,840	color	USDA
1995	6/20/95	Yavapai County	GIS		1:15,840	color	Rupp
	6/1/97	Forest Service	613090		1:15,840	color	USDA

It was not possible to obtain identical photography for every decade (Table 2). Differences in timing of photography, scale, and color were inevitable. As much as possible, we tried to purchase photography covering the entire study area. We accomplished this for every year except 1940. Because the southern end of the study area was missing in the 1940 coverage and because the northern end had too much shadow effect in places, only the central portion (from Verde Village to Tapco) was used for comparison to the other years. The northern end of the 1954 coverage also had shadows from cliffs that obscured vegetation, so only the southern and central portions were used (from the southern study area boundary to Tapco). Because only the area from Verde Village up to Tapco had complete and useful coverage for all years, the study area was divided into 3 sub-parts. We made the Verde-Village-to-Tapco stretch the "Core Area" (Figure 1). The small stretches on either side of the Core Area we called the "South Fringe" and "North Fringe" (Figure 1).

Creation of Digital Imagery

Aerial photographs were scanned and georeferenced to create digital images for use in ArcView mapping software (Environmental Systems Research Institute. 1998). Geographer Kyle Bohnenstiehl scanned the aerial photos at 600 d.p.i, then georeferenced the resultant images using Imagine software by identifying UTM coordinates and registering the images (ERDAS 1999). UTM coordinates were identified either by comparison to USGS 7.5 minute topographic maps or by comparison to digital orthophotos produced by the USGS using 1997 photography. A minimum of 12 ground control points was used per image, generally with several points visible on adjacent images. A non-linear rubber sheeting algorithm was used in ERDAS Imagine 8.3 to georeference the scanned photos to a UTM12N/NAD 27 projection (ERDAS 1999). Minimum pixel sizes (m^2) for each photo set were as follows: 1940 - 4.0 or 1.0; 1954 - 4.0; 1968 - 0.5; 1977 - 4.0; 1989 - 1.0; 1995 - 4.0 or 1.0.

Because the non-linear rubber sheeting algorithm used to georeference imagery did not output RMS error, an alternative method was used to evaluate how accurately the digital imagery was georeferenced. Images were compared with USGS digital ortho-photo quarter quads (DOQQs). Six points were selected at road intersections throughout the study area. UTM coordinates for each intersection were found for each year of imagery. The coordinates were compared to the DOQQ coordinates and root mean square (RMS) errors were calculated. Average RMS errors (in meters) for each year are as follows: 1940 - 15.05; 1954 - 20.79; 1968 - 5.81; 1977 - 11.22; 1989 - 9.67; 1995 - 6.70; 1997 - 26.41. RMS errors were generally lowest at the center of the study area and highest at the north end.

Some of the imagery was photomosaiced to create one smooth image out of several photos. An automated mosaic process was used in Imagine 8.3, using digital cutlines and automatic tone balancing (ERDAS 1999). Mosaiced imagery was created for the years 1995, 1989, 1977, and 1968 from the southern study area boundary up river to the Hwy. 89 bridge. Also, 1989 photos north of the Hwy 89 bridge were photomosaiced in strips.

Photo Interpretation and Mapping

Aerial photos were interpreted representing the years 1940, 1954, 1968, 1977, 1989, and 1995. Photos were viewed in stereo using a stereoscope so that they looked three-dimensional. Simultaneously, georeferenced digital images of the same photos were viewed on a computer screen and the mouse was used to digitize around features using ArcView software to create polygons (Environmental Systems Research Institute 1998). Polygons were assigned attributes by adding information to data tables that were attached to feature themes in ArcView. Most digitizing was completed while viewing the imagery at scales ranging from 1:1,000 to 1:3,500.

Sharon Masek Lopez completed the riparian vegetation interpretation by mapping mesquite and cottonwood-willow stands as individual ArcView themes with density attributes. Tree density within an individual stand was classified as high, medium, or low density (100%, 70% and 30% crown coverage respectively) by visual comparison to a crown density scale (Paine 1981). In some places, other tree species were mixed in with our target species. Based on field reconnaissance, these other species tended to account for about 20% or less of the total area and were included in the riparian tree stands, as there was no practical way to omit them. The interspersed species included hackberry, tamarisk, tree of heaven, and other domestic trees.

Geographer Loretta Morgan interpreted land use in four distinct categories - agriculture, commercial/industrial, high density residential (< 2 acres per parcel) and low density residential (≥2 acres per parcel). The agriculture cover type included cultivated fields and irrigated pastures. The commercial/industrial cover type included businesses, industries, schools, motels, parking lots, golf courses, and mining-industry-related waste. Each of the four land uses was digitized (in the manner described in paragraph 1 of this section) as an individual theme in ArcView, so that assigning attributes was not necessary. Geographer Angela Marino and geologist Jeff Kennedy assisted with the land use interpretation and mapping.

Geographer Paul Lauck interpreted river morphology in the active channel area by mapping river channel and adjacent bare sediment together as one ArcView theme. He assigned attributes to designate polygons as channel or sediment. For some areas, Paul digitized (in the manner described above) bare sediment without any vegetation included. For other areas, he digitized whole bars and the overlap area of riparian vegetation was subtracted to give the estimated area of bare sediment.

The designation "Open Space" was given to any land that did not have a designated land use and was not covered by riparian trees, river channel or bare sediment. Open space included range land, undeveloped land, and some roadways.

Quality Assurance

To assure high quality interpretation, the 1995 riparian interpretation was groundtruthed. Sharon Masek Lopez conducted field reconnaissance on six different dates to assure accuracy in her interpretations. Prior to the beginning of the study, Ms. Lopez inspected the study area at public access points on September 26, 1998 and took notes and photographs to familiarize herself with the riparian vegetation. After completing portions of the 1995 photo interpretation she conducted groundtruthing as shown in Table 3.

Table 3. Groundtruthing dates and locations for UVVRAHA study.

Date	Areas checked
July 16-17, 1999	South boundary of study area up to Hwy 89A bridge; Dead Horse Ranch State Park; Burnett property at Cottonwood
July 22, 2000	Hwy 89A bridge up to and including Clarkdale
August 13, 2000	North side of river 1-2 miles upstream of Oak Creek confluence; Bridgeport; Clarkdale; Pecks Lake; Tapco
December 19, 2000	Oak Creek confluence; Verde Village; Bridgeport; Clarkdale; Pecks Lake; Tapco (Accompanied by Abe Springer)

Initially, groundtruthing was conducted by drawing tree stands on mylar overlays over the 1995 aerial photos, then making enlarged photocopies of the mylars, taking the photocopies into the field and writing notes on the photo copies. On subsequent outings Ms. Masek Lopez simply wrote notes on mylar overlays over the 1995 aerial photos. Photographs were taken in the field. Important outcomes of the groundtruthing included:

- Creosote bush patches and tree of heaven stands had been confused for mesquite so corrections were made.
- Separation of cottonwood and willow was found not practical.
- Other tree species comprised up to 20% of the cottonwood-willow stands and there was no practical way of separating them out.
- In 1999, some young growth in the strand was not large enough on the 1995 photos to map, yet these young stands are an important consideration for conservation.
- Many dead and dying cottonwood and willow trees were discovered in 1999 that had been alive in 1995. This discovery led to a related study on tree mortality by the Cottonwood Nature Club. The club found that trees were affected by a variety of pathogens including septoria fungus, pleurotus fungus, wet wood bacteria, and mistletoe. (See Appendix E.)

After the 1995 photography was interpreted and the trees mapped, then preceding years were mapped with continuous comparison between years to insure consistent coverage.

There were three levels of quality assurance in the interpretation and mapping of the land use, river morphology and riparian vegetation. First, while mapping, each cartographer compared between years by simultaneously displaying polygons from other years to insure consistency of coverage and interpretation. Second, Sharon Masek Lopez checked the covers after conducting field reconnaissance. Minor corrections were made to the covers before they went to the GIS analyst for tabulation of acreage totals. Third, after the raw data was returned by the GIS analysis and was graphed over time to evaluate trends, some inconsistencies were discovered and corrected by Sharon Masek Lopez. This was accomplished by creating separate ArcView themes to map additions and/or subtractions to specific covers as necessary. Acreages were calculated using the "X-tools" extension of ArcView. The covers that were corrected by this method were 1954 and 1968 commercial-industrial, 1968 mesquite, and all decades of river morphology. Extensive correction of bare sediment acreages was necessary because the subtraction of cottonwood-willow coverage did not account for other types of vegetation covering sediment bars.

Analysis of Cover Type Area and Distribution

Kyle Bohnenstiehl of North American Geographical Information Systems performed the analysis of cover type area and distribution. Using the ArcView attribute tables, he calculated the number of acres of each land cover and vegetation class for the three sub-parts of the study area (Environmental Systems Research Institute 1998). Raw vector files were updated with an item in the table called "ACRES" which was calculated from the auto-generated item "AREA" which was in square meters because of the UTM projection utilized. See the "Results" section and Appendix A for land-cover acreage results.

It is important to note that results were not modeled using grid cells. Instead, total acres were compared from one cover to the next. Therefore, for the purposes of this study, it was not critical that the registration of the layers be exactly the same. The study area was large and the sample sizes were very large (there were over 20,000 vegetation polygons alone). Therefore, any significant trends that we saw should be valid. If, however, the ArcView shapefiles are used in the future for modeling efforts, great care should be taken in selection of grid size to minimize error due to minor differences in registration.

Statistical Analysis

Results were statistically analyzed using SAS JMP software (SAS Institute Inc. 1997). First, all coverage data (for land use, river morphology, and riparian vegetation) were entered as acres into a spreadsheet, along with the years, and a correlation matrix was generated to look for possible relationships. Any two columns generating Pearson's correlation coefficients of ± 0.8000 to 0.9999 were then plotted and lines were fitted using regression analysis to find significant relationships. In other SAS JMP spreadsheets, historic precipitation and flood flows were evaluated and models were generated to look for significant relationships between these factors and riparian vegetation distribution.

RESULTS

The study area was divided into three parts - a North Fringe, a Core Area, and a South Fringe. This was necessary because we were unable to obtain 1940s photo coverage of the South Fringe, and because shadows on the 1954 and 1940 photos obscured vegetation in the North Fringe. Only in the Core Area were we able to make comparisons between photos for all six decades. The body of this report displays results for the Core Area only. South Fringe and North Fringe results can be found in tabular form in Appendix A.

Land-use changes

Land-use patterns in the study area have changed from largely agricultural in the early years, to increasingly urbanized in the later years. The most noticeable shift occurred between 1968 and 1977 when the combined land use area of low density residential, high density residential, and commercial/industrial increased 71% (Table 4, Figures 4 and 5). These three combined land use areas increased from 1081 acres to 1851 acres while agricultural area decreased from 1223 acres to 1028 acres. In other words, non-agricultural land uses overtook agricultural land use between 1968 and 1977. After 1977, agriculture continued to decline. Meanwhile, low density residential, high density residential, and commercial/industrial continued to increase.

Table 4. Historic land use and open space in the Core Area of the Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

	LAND USE									**OPEN SPACE**
	Low Density Residential		**High Density Residential**		**Commercial /Industrial**		**Agriculture**		**Total**	
	acres	*% of total*	acres	*% of total*	acres	*% of total*	acres	*% of total*	acres	acres
1940	163	*8*	117	*6*	511	*25*	1270	*62*	2061	6731
1954	268	*10*	84	*3*	597	*23*	1620	*63*	2569	6353
1968	279	*13*	180	*8*	622	*27*	1223	*53*	2305	6568
1977	684	*24*	423	*15*	744	*26*	1028	*36*	2881	6075
1989	851	*25*	787	*23*	843	*25*	956	*28*	3437	5491
1995	1125	*28*	1067	*27*	1116	*28*	656	*17*	3965	4927

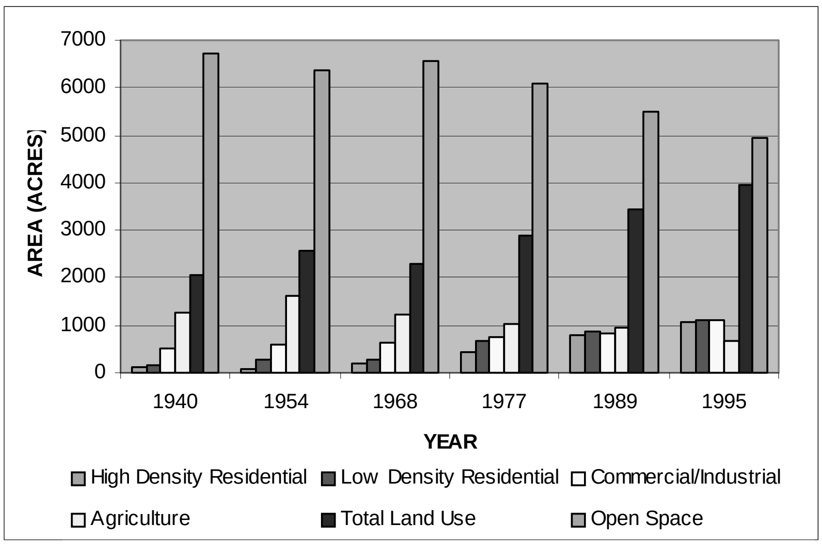

Figure 4. Historic land-use and open space coverage in the Core Area, Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

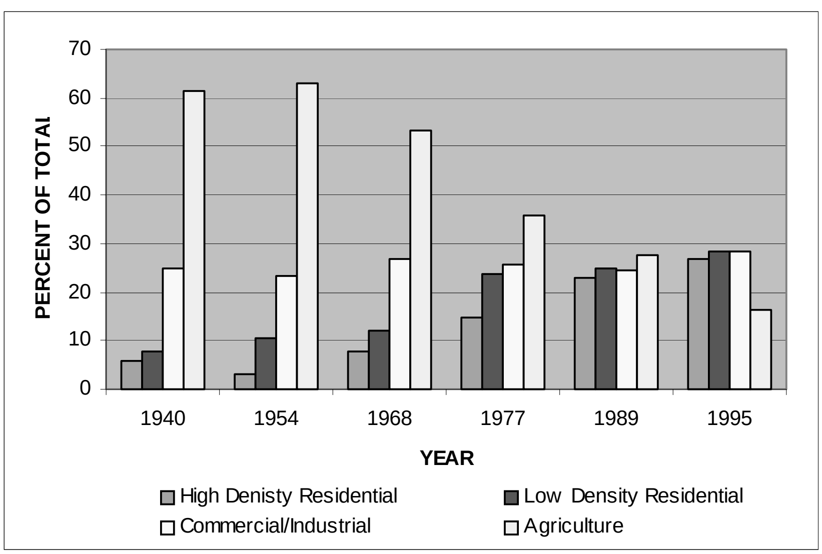

Figure 5. Historic land-use coverage by percent of total in the Core Area, Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

River Morphology

Baseflow of the Verde River measured by the gauge near Clarkdale is 70 to 80 cfs (USGS 1999). However, baseflows between Clarkdale and Camp Verde cannot easily be calculated due to the large number of irrigation diversions and the lack of gauging sites (Verde NRCD 2000). Based on gauging station data, the river was apparently at or near baseflow for each of the aerial photo dates that have gauging data (Table 5). No gauging data is available for the Verde River near Clarkdale for 1940 and 1954. However, gauging data from "Oak Creek near Cornville" on 9-23-40 and 12-19-54 showed discharges of 35 cfs and 33 cfs respectively (USGS 1999), indicating baseflow condition at Oak Creek and implying baseflow condition for the Verde River near Clarkdale on those dates. Because the river was presumably at or near baseflow for all photo dates, comparison of channel area and adjacent bare sediment among the six decades is valid.

Table. 5. Discharge at "Verde River near Clarkdale" gauging station on aerial photo dates (USGS 1999).

Aerial Photography Date	Discharge (cfs)
05-25-68	71
10-25-77	76
10-15-77	76
05-20-89	76
06-06-89	77
08-02-90	93
06-20-95	82
06-01-97	73

The Verde River's channel and adjacent bare sediment area changed continually from 1940 to 1995 (Table 6, Figures 6 and 7). The area occupied by river channel decreased from 1940 to 1968 then increased from 1968 to 1995. Meanwhile the adjacent bare sediment area decreased from 1940 to 1977 then increased from 1977 to 1995

Table 6. Channel & bare sediment acreage and percent of total in the Core Area, Upper Verde Valley Riparian Area Historical Analysis, 1940-1995

	RIVER MORPHOLOGY				
	Channel		**Bare Sediment**		**Total**
	acres	*% of total*	acres	*% of total*	acres
1940	202	*29*	502.87	*71*	705
1954	139	*28*	363.00	*72*	502
1968	126	*29*	308.24	*71*	434
1977	129	*37*	221.25	*63*	350
1989	149	*37*	249.88	*63*	399
1995	217	*38*	349.26	*62*	566

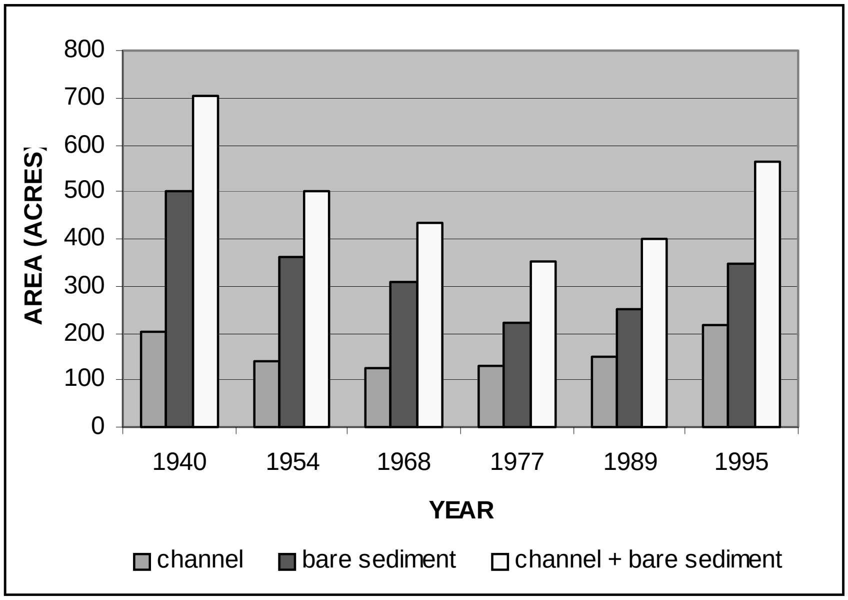

Figure 6. Channel and bare sediment area in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

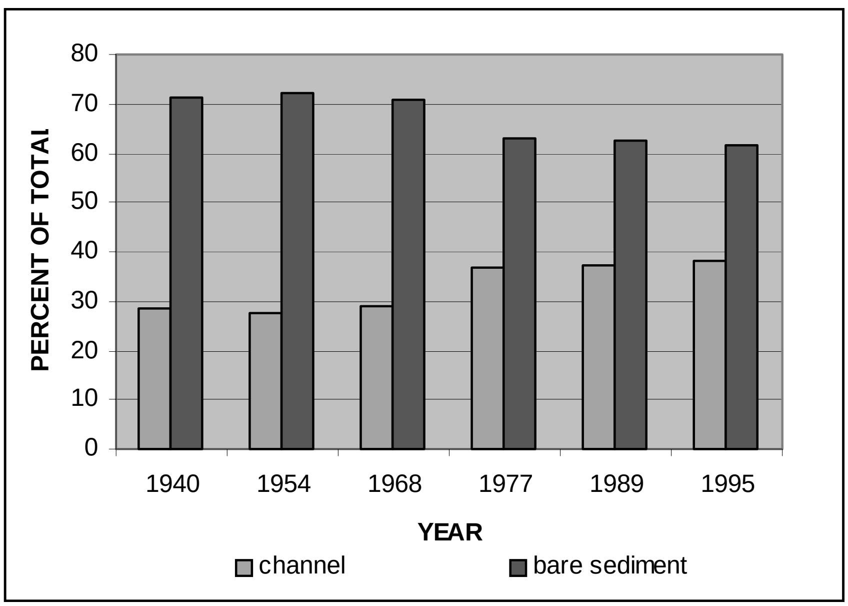

Figure 7. Channel & bare sediment as percent of total in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

Woody Riparian Vegetation Distribution and Changes

Woody riparian vegetation was either classified as mesquite or cottonwood-willow and each class was differentiated as high, medium, or low density (100%, 70%, or 30% canopy closure respectively). In general, mesquite comprised approximately ¾ of all woody riparian vegetation in the UVVRAHA Core Area and cottonwood-willow comprised the remaining ¼ (Table 7). Overall, riparian coverage has remained surprisingly stable in the core area over the last 60 years. Total riparian coverage has varied ±4% from an average of 1415 acres. There was a low of 1356 acres in 1940 and a high of 1475 acres in 1995 (Table 7 and Figure 8).

Table 7. Total riparian tree coverage in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

	Mesquite		**Cottonwood-willow**		**Total**
	acres	*% of total*	acres	*% of total*	acres
1940	1086	*80*	270	*20*	1356
1954	1012	*75*	346	*25*	1358
1968	1110	*70*	442	*30*	1452
1977	864	*61*	550	*39*	1414
1989	998	*70*	436	*30*	1434
1995	1063	*72*	412	*28*	1475

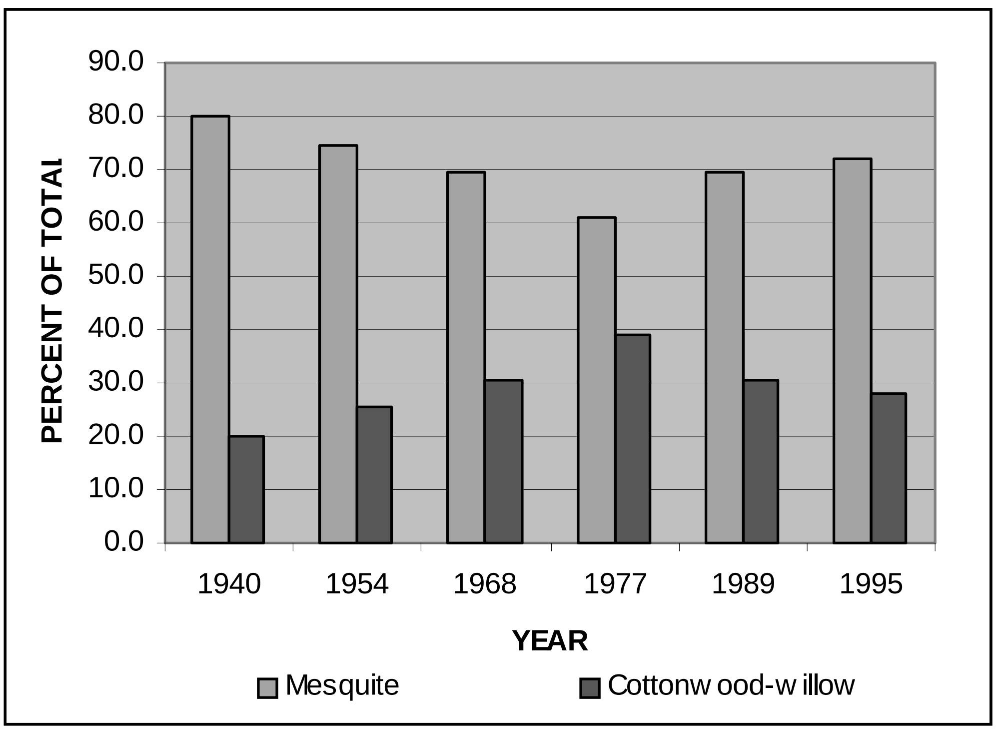

Figure 8. Composition of riparian coverage by percent of total in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

Total mesquite coverage varied from -15% to +9% from an average value of 1022 acres (Table 8 and Figure 9). Low density mesquite increased from 340 acres in 1940 to a high of 423 acres in 1968, then generally decreased (Table 8). [The 1977 value for low density mesquite is erroneously low, because lower quality base-imagery made it difficult to differentiate low density mesquite from the background colors; by interpolation, the 1977 low-density mesquite value is probably closer to 350 acres, rather than 265 acres.] Medium density mesquite decreased from a high of 564 acres in 1940 to a low of 378 acres in 1968 and remained at slightly less than 400 acres from 1977 through 1995 (Table 8). High density mesquite decreased from 1940 to 1954 but continually increased after 1954, from a low of 164 acres in 1954 to a high of 391 acres in 1995. In short, mesquite stands have generally approached a more even distribution of densities as low and medium density stands decreased and high density stands increased (Figure 9).

Table 8. Mesquite coverage in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

	MESQUITE						
	Low Density		**Medium Density**		**High Density**		**Total**
	acres	*% of total*	acres	*% of total*	acres	*% of total*	acres
1940	340	*31*	564	*52*	182	*17*	1086
1954	361	*36*	487	*48*	164	*16*	1012
1968	423	*42*	378	*38*	209	*21*	1110
1977	265	*31*	390	*45*	209	*24*	864
1989	318	*32*	391	*39*	289	*29*	998
1995	274	*26*	398	*37*	391	*37*	1063

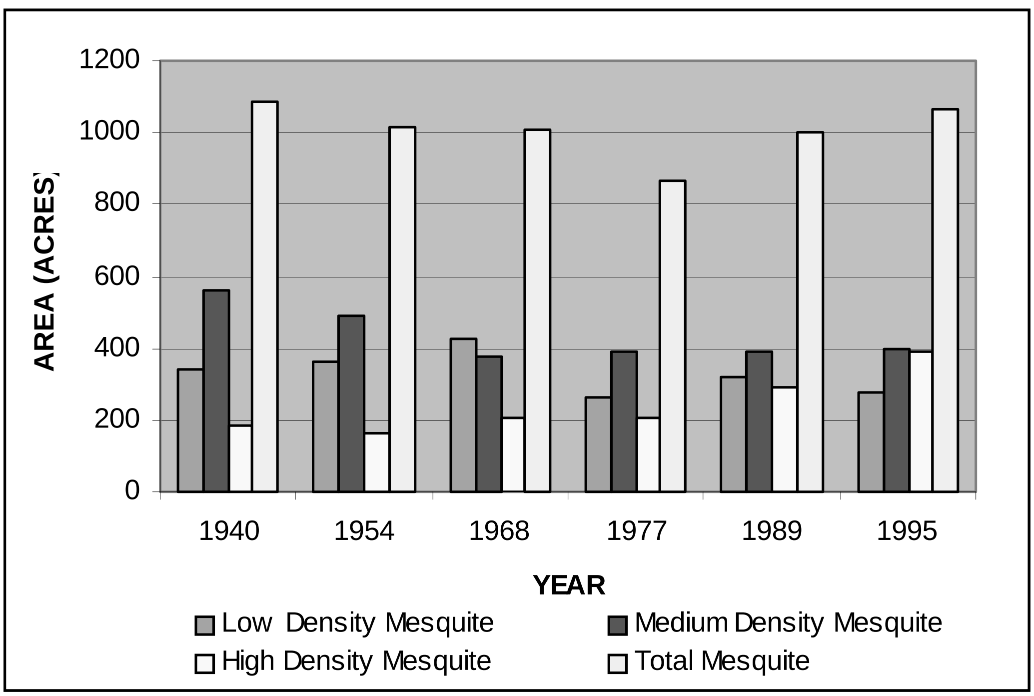

Figure 9. Mesquite coverage by density in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

Cottonwood-willow coverage showed more variability than mesquite coverage. Total cottonwood-willow coverage varied ±34% from an average value of 410 acres (Table 9 and Figure 10). Of the cottonwood-willow stands, high-density stands showed the greatest variation. These stands are composed primarily of mature trees and make up the gallery forest that most people picture when thinking of riparian vegetation. High-density cottonwood-willow increased from 128 acres in 1940 to a peak of 388 acres in 1977, a 203% gain. After 1977, high-density cottonwood-willow decreased continually to 239 acres in 1995, a 38% loss (Figure 10). Based on field reconnaissance, high density cottonwood-willow continued to lose area into year 2000.

Medium-density cottonwood-willow stands increased from 1940 to 1968, from a low of 84 acres to 131 acres (Table 9 and Figure 10). From 1968 through 1989, medium density cottonwood-willow remained level at about 130 acres, followed by a gain of 13 acres between 1989 and 1995 to the high of 145 acres. Low-density cottonwood-willow accounted for the smallest area of riparian coverage. Low-density cottonwood-willow decreased from a high of 58 acres in 1940 to a low of 22 acres in 1954, then increased to 34 acres in 1989 and decreased to 28 acres in 1995 (Table 9 and Figure 10).

Table 9. Cottonwood-willow coverage in the Core Area,
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

	COTTONWOOD-WILLOW						
	Low Density		**Medium Density**		**High Density**		**Total**
	acres	% of total	acres	% of total	acres	% of total	acres
1940	58	*21*	84	*31*	128	*47*	270
1954	22	*7*	111	*32*	212	*61*	345
1968	25	*6*	131	*29*	286	*65*	442
1977	33	*6*	130	*24*	388	*70*	551
1989	34	*8*	132	*30*	271	*62*	437
1995	28	*7*	145	*35*	239	*58*	412

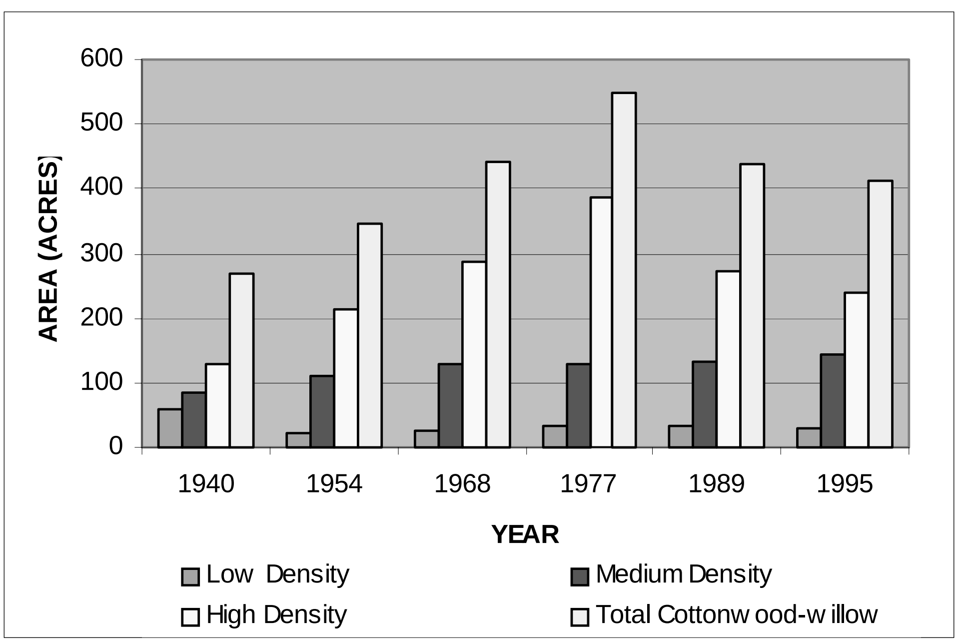

Figure 10. Cottonwood-willow coverage by density in the Core Area
Upper Verde Valley Riparian Area Historical Analysis, 1940-1995.

Statistical Analysis

Appendix B gives the results of regression analysis for all cover types using various alpha levels. Here we will discuss just a few statistically significant relationships.

Three trends over time were significant at alpha-level 0.01. Both low-density residential land use and medium-density cottonwood-willow increased linearly over time, at $\alpha=0.01$. Medium-density mesquite decreased and then increased over time according to a quadratic regression, at $\alpha=0.01$

Seven trends over time were significant at alpha-level 0.05. Both high-density residential land use and high-density mesquite increased linearly at $\alpha=0.05$. Both agricultural land use and medium-density mesquite decreased linearly at $\alpha=0.05$. Channel area, adjacent bare sediment, and combined channel and sediment all decreased and then increased over time according to a quadratic regression, at $\alpha=0.05$.

Five regression analyses revealed relationships *between* various cover types. Four of these relationships were significant at alpha-level 0.01. One relationship was significant at alpha-level 0.02. There was a positive linear relationship between high-density mesquite and nonagricultural land uses. There was a negative linear relationship between medium-density cottonwood-willow and medium-density mesquite. There were negative linear relationships between bare sediment and both high-density cottonwood-willow and total cottonwood-willow. At alpha-level 0.02, there was a negative linear relationship between high-density mesquite and agricultural land use.

DISCUSSION

Results of this study showed that, generally speaking, mesquite stands were strongly influenced by changes in land use, whereas cottonwood-willow stands were not. Cottonwood-willow stands were strongly influenced by river morphology changes. Cottonwood-willow stands appear to have been largely influenced by the varying frequency and magnitude of flooding, which created both beneficial and deleterious circumstances. The following discussion will address the ways in which natural causes and human activities in the watershed may have influenced riparian vegetation in Verde Valley.

Influences prior to 1940

The historic period addressed in this study began in 1940, but many changes in riparian vegetation happened prior to 1940. By the time Anglos settled the Verde Valley, aboriginal peoples had impacted the riparian area for thousands of years, cutting wood for fires and in more recent centuries farming the low terraces along the river. Earliest accounts of the river speak more of the lush grass on the river terraces and less of the trees. At the time of settlement, large cottonwood trees were uncommon enough to serve as landmarks. From 1865 to 1880, settlers cleared terraces, dug irrigation ditches, and raised crops where riparian vegetation probably had been. They also used trees to build, furnish, and heat their homes. After overgrazing in the 1880s caused increased runoff in the watershed, the river corridor shifted from having many cienagas and a slow-flowing narrow river, to a profile more similar to today with a wider, swifter-flowing channel and few adjacent wetlands. Acid precipitation caused by smelter smoke from 1917 to the late 1930s undoubtedly damaged many riparian trees, considering that some neighboring orchards lost as much as 30% of their fruit trees (Brisley 1920). Hence, the riparian community of 1940 was one that had been greatly altered by European Americans for over 70 years already. The 1940s through the 1970s could rightly be considered a recovery period, a time when the riparian corridor recovered from numerous human impacts.

Natural Causes of Riparian Change

Climate

From 1940 to 1995, climate showed an apparent trend of moving from drier to wetter in the study area and in places that contributed to Verde River streamflow through the study area. The following graphs demonstrate this (Figures 11, 12, and 13). It is important to note that a polynomial trendline is less accurate at the extreme ends of the data. Because apparently more moisture was available to riparian trees for the years 1968, 1977, 1989, and 1995, we would expect increased riparian coverage during those years compared to 1940 and 1954. In fact, average riparian cover for the period 1968-1995 was 8.3% higher than average cover for 1940-1954. In particular, there was an increase in high-density vegetation in the later years. Average high-density mesquite coverage for 1968-1995 was 59% higher than for 1940-1954. Average high-density cottonwood-willow coverage for 1968-1995 was 74% higher than for 1940-1954. These results suggest that climate may have a strong influence on riparian change in the study area.

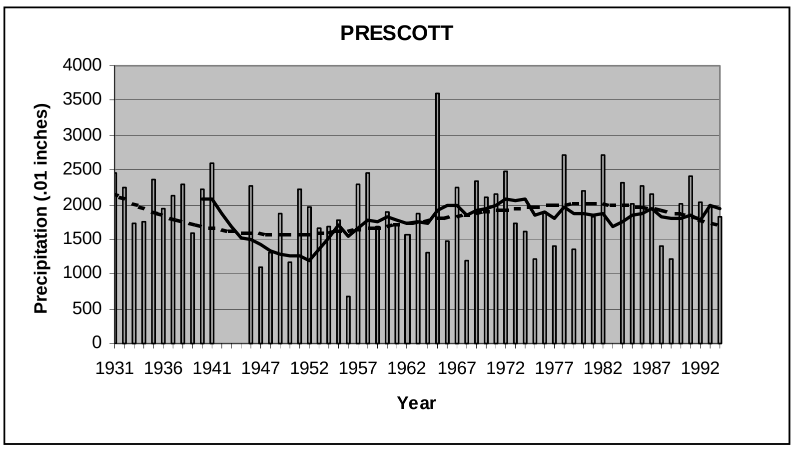

Figure 11. Annual precipitation (1931-1994) in headwaters contributing to streamflow in the Upper Verde Valley Riparian Area Historical Analysis study area (VWA 2001). The solid line is a 10-year-moving-average trendline. The dashed line is a 3rd-order-polynomial trendline.

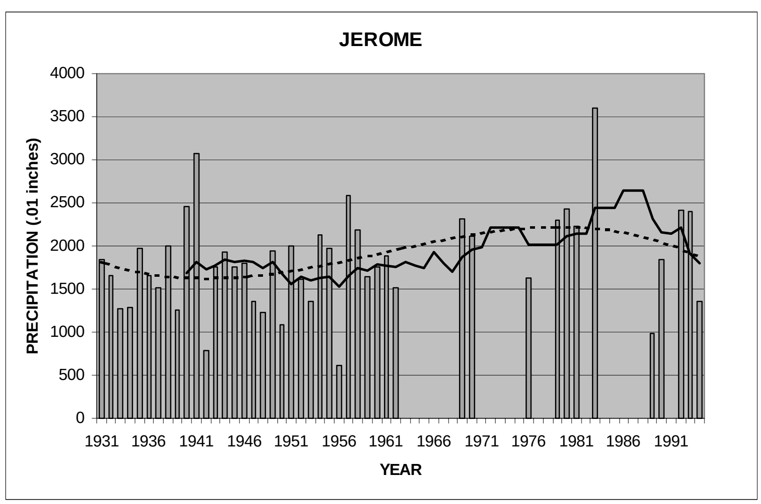

Figure 12. Annual precipitation (1931-1994) in nearby uplands contributing to streamflow in the Upper Verde Valley Riparian Area Historical Analysis study area (UCC 2000). The solid line is a 10-year-moving-average trendline. The dashed line is a 3rd-order-polynomial trendline.

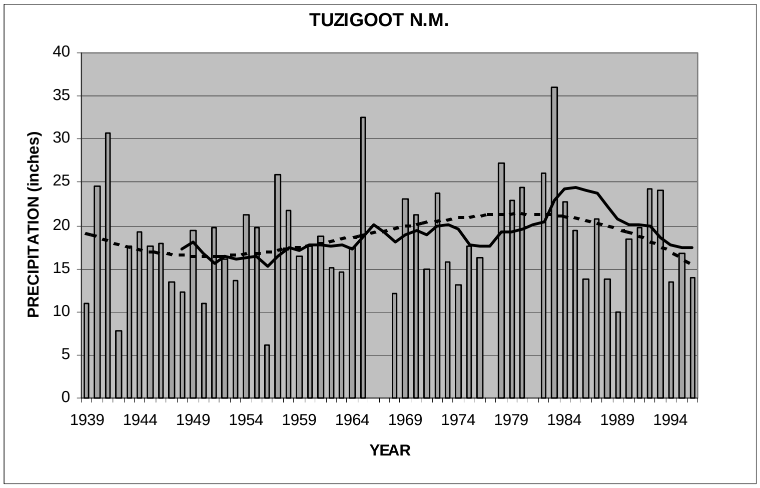

Figure 13. Annual precipitation (1939-1996) within the Upper Verde Valley Riparian Area Historical Analysis study area (UCC 2000). The solid line is a 10-year-moving-average trendline. The dashed line is a 3rd-order-polynomial trendline.

Flooding

No streamflow data exists within the study area between 1930 and 1964, but the nearest gauge on Oak Creek gives some indication of the likely incidence of floods from 1948 to 1964. The graph of Oak Creek peak streamflow (1948-1998) implies that there was probably a lower frequency and magnitude of flooding in the Verde Valley prior to 1965 (Figure 14). Whereas there was little flooding during the dry years prior to the mid-1960s, series of large floods occurred on the Verde River during the 1970s through the 1990s (Figure 15). Regression analysis reveals that the magnitude of floods increased significantly (p=0.0652) from 1965 to 1995 (Figure 16). Although the increased magnitude of flooding appears largely related to natural causes, research into this phenomenon was beyond the scope of this study. More research is needed to determine whether watershed alteration has contributed to increased magnitude of flooding.

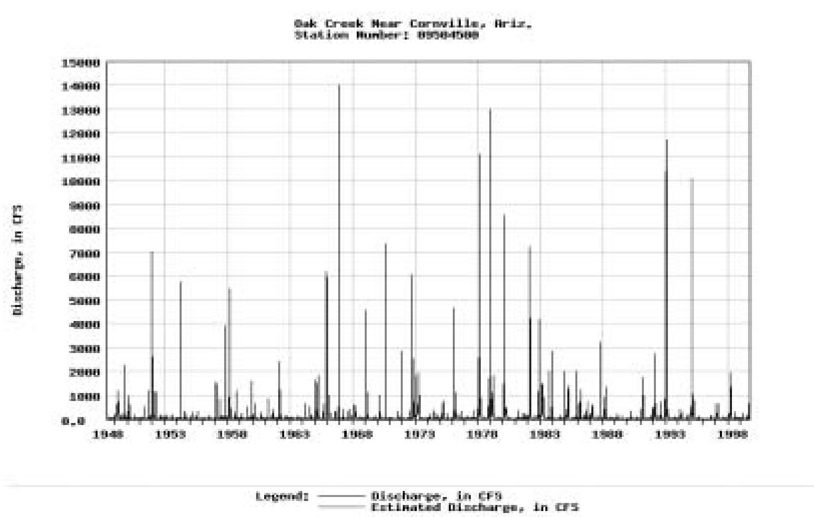

Figure 14. Daily mean streamflow at Oak Creek gauge near Cornville, 1948-1998 (USGS 1999). Notice the lower peaks prior to 1965. Lower peak stream-flows on the Verde River are inferred for the same period from this data.

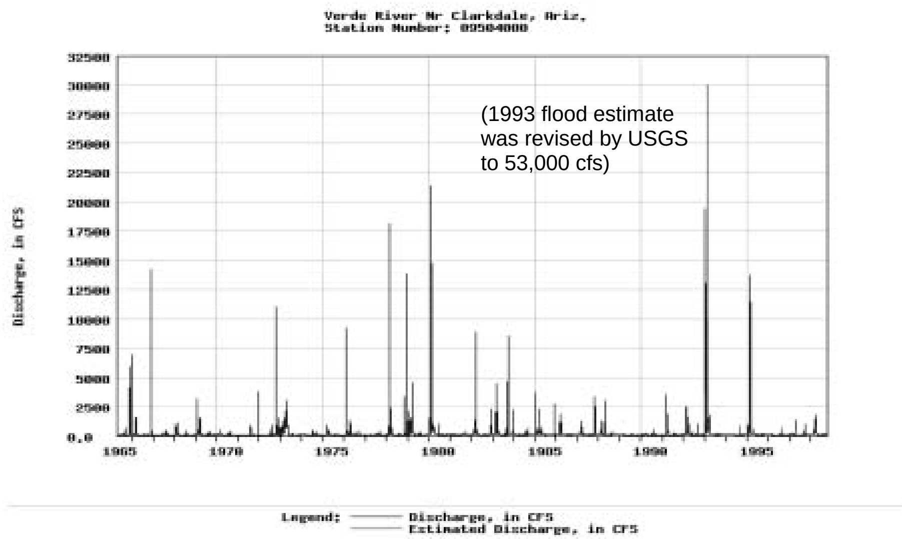

Figure 15. Daily mean streamflow at the Verde River near Clarkdale, 1965-1999 (USGS 1999).

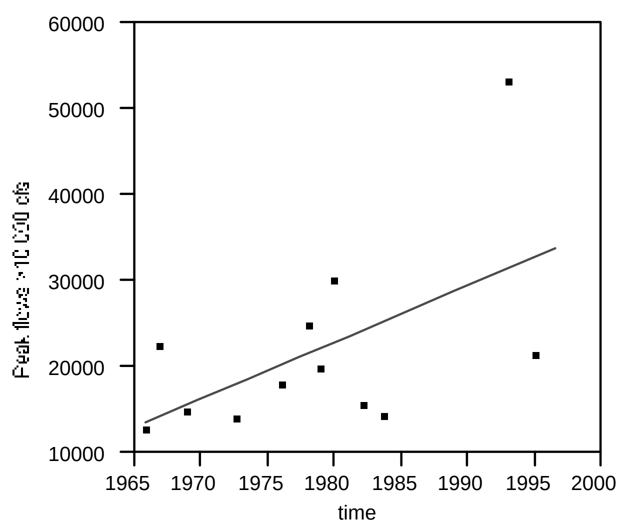

Figure 16. Peak flows greater than 10,000 cfs at the "Verde River near Clarkdale" gauge 1965 to 1995. Regression shows increasing magnitude of floods.
Regression formula: -1.27e6 + 655.34 time,
with p=0.0652.

Floods can have both beneficial and deleterious effects on riparian vegetation. Some flooding is necessary to help regenerate cottonwoods and willows, because near-channel silt deposition creates the appropriate soil and moisture conditions for germination and growth of these species (Stromberg et al. 1991). Moderate floods of the early 1970s were followed by increases in cottonwood-willow stands as observed on the 1977 aerial photography. Higher magnitude floods can cause damage though.

In February 1993 an estimated 53,000 cfs flood passed through the Verde Valley at Clarkdale. This large flood removed a substantial amount of vegetation, shifted sediment, and caused the river channel to change shape and location. Figure 17 shows cottonwood-willow stands at Deadhorse Ranch State Park during 1977, 1989, and 1995. The 1993 floods removed a wide swath of trees, which is clearly visible on the figure. Because high-density cottonwood-willow decreased during the same time frame that flood magnitudes increased, the natural occurrence of flooding appears to have had a large influence on riparian change in the study area.

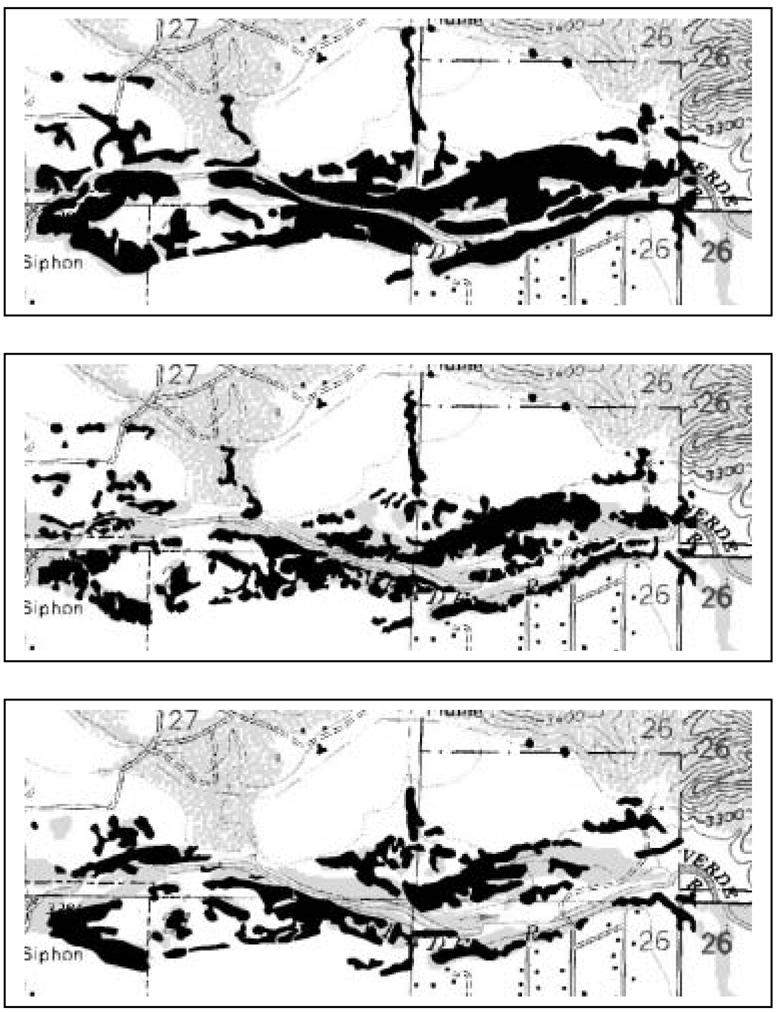

Figure 17. Cottonwood-willow stands at Deadhorse Ranch State Park in 1977, 1989, and 1995. Notice the widening swath of trees removed from next to the channel by floods.

River Morphology Changes

Rivers are dynamic systems and changes of morphology and vegetation within and around the channel are inevitable. The river channel's surface area and the area of adjacent bare sediment both decreased and then increased again (Table 4, Figures 5 and 6). The year 1968 was the turning point in these morphological changes. We have already inferred that the climate trend was from dry to wet with greater precipitation after the mid-1960s. It seems plausible, therefore, that there is a trend in the river's fluvial geomorphology that parallels the trend in climate.

There are other plausible explanations for the changes in river channel morphology, such as changes in runoff due to alteration of the watershed. The observed trends in channel area could imply some kind of landscape-scale geomorphological shift causing increased sediment discharge. However, a previous study determined that, in fact, sediment input from the watershed has *not* increased (Beyer 1997). Instead, sediment already in the system has been re-activated by flooding to create the bare sediment areas (Beyer 1997). This assertion is supported by Parker 3-Step assessments of range condition on portions of Kaibab National Forest that contribute to discharge at the "Verde River near Clarkdale" gauge (Brewer 2000). The Parker 3-Step test includes ground cover and soil stability ratings. These ratings indicate sediment discharge from Kaibab N.F. lands has actually decreased in the past 30-40 years (Brewer 2000). Regardless of the cause of river channel morphology changes, these changes have undoubtedly caused loss of some cottonwood-willow gallery forest. Hence, the natural occurrence of river morphology change is considered a large influence on change in area of woody riparian vegetation in the study area.

Effects of Human Activity

If this study only compared change in land use to change in riparian area, we might suspect that urbanization caused a decline in the cottonwood-willow gallery forests. However, we also looked at the natural influences of climate, flooding, and changing river morphology and gained some insight into their effects. Also, statistical analysis revealed no significant relationships between land use coverage and cottonwood-willow coverage. Therefore, the trends in land use and cottonwood-willow appear simply coincidental. On the other hand, mesquite coverage was directly influenced by land use changes, according to statistical analysis, which showed that high-density mesquite increased as nonagricultural land uses increased. While high-density mesquite increased, low- and medium-density mesquite decreased, either due to conversion to high-density mesquite or by conversion to residential land use, so that that total area of mesquite remained relatively stable. Given this information, it seems likely that total mesquite coverage might have increased if it had not been for increased land use. The following paragraphs describe other possible effects of increasing urbanization.

Stormwater runoff

Urbanization leads to creation of impervious surfaces such as streets, parking lots, and roof tops, which allow water to runoff rapidly. During a flood produced by the larger watershed, if it is raining in Clarkdale and Cottonwood during the flood, the localized runoff could add to an instantaneous peak flow. In fact, there was significant precipitation at Tuzigoot weather station each flood day in January and February 1993 (Jan. 8 - 0.47", Jan. 17 - .82", Feb. 9 - 0.42", Feb. 20 - 0.39") (House 1995; UCC 2000). Because we have already established that flooding has a large impact on the riparian corridor, it is reasonable to suspect that urbanization has locally exacerbated the impact of floods to some extent. Further research is necessary to determine the extent of that impact.

Decreasing Agriculture

Because cottonwood-willow area decreased during the same time that agricultural area decreased, there may be a correlation between the two. Declining cottonwoods and willows might be linked to decreasing irrigation, although we did not rigorously analyze this. Further research is needed to determine whether agriculture in the Verde Valley is a net benefit to riparian vegetation.

Groundwater level changes

As groundwater has been utilized to provide drinking water for the growing population of Cottonwood and the surrounding area, the depth to groundwater has increased in places. Near the river, water levels have remained relatively constant. Farther from the river, water levels have varied with time, especially at distances greater than ½ mile from the river.

Index wells demonstrated declining groundwater levels along profiles at Bridgeport, Cottonwood, and Centerville (Figure 18). These index wells were identified by inspection of the Wells 55 and GWSI databases (Mason 1999). The criteria for index wells were that they include water level data from more than one decade and those water levels represent an unconfined condition (as indicated by the well's perforated interval where possible, otherwise inferred by relationship to neighboring water levels). Index well data were used to generate three cross-sections of the water table from west to east across the river. (See Appendix C. to view water level data and water table profiles.)

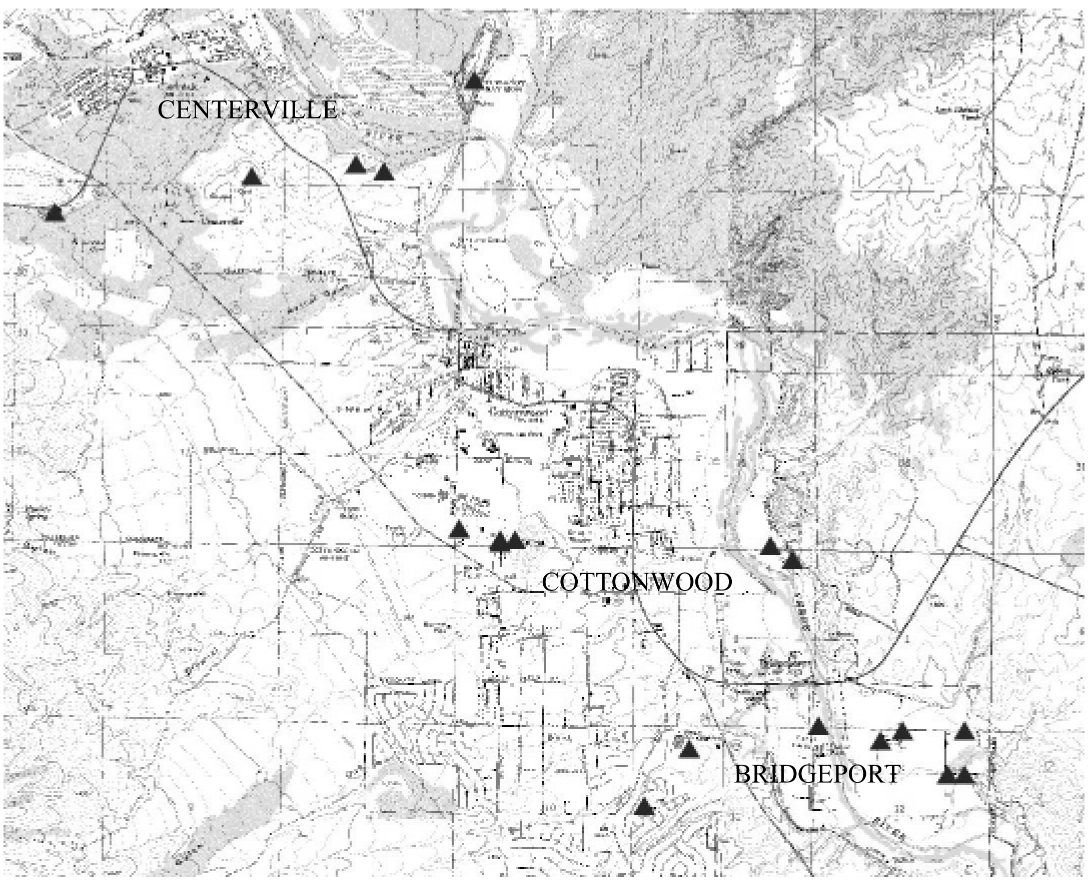

Figure 18. Map of index wells used for water table profiles, Upper Verde Valley Riparian Area Historical Analysis.

At Centerville, there has been very little land-use development along the transect and water levels have remained relatively constant. At 0.4 miles west of the river water levels declined 15 feet from 1978 to 1999, an average rate of 0.7 feet per year. Elsewhere along the profile changes in water level were negligible. (See Appendix C, Figure 1.)

At Cottonwood, water levels varied little on the east side of the river and within 0.3 miles west of the river (based on index wells north of the cross-section). However, on the west side, depth to groundwater increased. In 1959, the water level in well A-16-03 34CCD1, 1.3 miles west of the river, was 36 feet above the elevation of the river. Then the depth to the water table increased 8 feet to 1964. The record on well A-16-03 34CCD1 stops after 1967, but well A-16-03 34CCD2 lying 31 meters due south begins its record in 1972. In 1977, the water level in this second well was down 27 feet from the 1964 level and was the same elevation as the adjacent river. Sometime between 1977 and 1999 the water table 1.3 miles west of the river dropped 66 feet below the elevation of the river. (See Appendix C, Figure 2.)

Overall, the water table 1.3 miles west of the Verde River at Cottonwood dropped 101 feet in forty years, from 1959 to 1999. The rate of decline accelerated from an average 1.6 ft/yr (1959-1977) to 3.0 ft/yr (1977-1999). A well 1.5 miles west of the river had an average water level drop of 3.8 feet per year from 1994 to 1999.

The water table profile at Bridgeport has similar characteristics to the profile at Cottonwood. There was only a slight decline in the water table on the east side of the river. Water levels in well A-15-03 12ADB1 (0.7 miles east of the river) dropped 22 feet between 1964 and 1994 from 16 feet below the surface to 38 feet below the surface. Although this still leaves water in the root zone of mesquite, the greater depth to groundwater probably caused stress to mesquite trees. In fact, of the mesquite trees that remained after development began, some did experience declining density. Water levels dropped more noticeably on the more populated west side of the river. In well A-15-03 11BCC lying 1.1 miles west of the river, water levels dropped 39 feet between 1977 and 1999. Although the water table at that well had always been too deep to directly provide water to the roots of phreatophytes, the depression caused by the declining water table is of concern, especially with the river now 93 feet higher in elevation. (See Appendix C, Figure 3.)

Invasive tree species

Although invasive tree species were not mapped as part of the methods of this study, invasive trees were observed during ground-truthing. Also, residents of the study area gave accounts of non-native trees (Burnett 1999b). Two species in particular appear to successfully compete with native riparian vegetation. In the past decade, tamarisk and tree-of-heaven have increased noticeably.

Tree-of-heaven (genus *Ailanthus*) was widely planted in Clarkdale and Cottonwood in the 1930s (?) after acid precipitation from the copper smelters damaged many existing trees. The trees grew and spread rapidly. *Ailanthus* prefer moist sites and compete vigorously for water and nutrients with native riparian trees. Some residents have observed a marked increase of *Ailanthus* in the riparian area over the past 30 years.

Tamarisk or "salt cedar" (genus *Tamarix*) has been in the active channel area of this study area at least since 1940. There is a large decadent stand of tamarisk at the base of the large slag heap in Clarkdale and some other old stands in the mile upstream of the slag heap. Tamarisk in the study area seems to prefer areas that are frequently disturbed, such as at the mouths of tributaries or at river bends. Residents have noticed an increase in young tamarisk since the 1993 flood. Some young tamarisk appears to outcompete young cottonwood and willow, as observed at Dead Horse Ranch State Park by the Cottonwood Nature Club (Burnett 1999b).

Grazing

Although we did not collect any specific data on grazing, some effects of past grazing can be inferred from land use and riparian tree coverage. Medium density cottonwood-willow generally increased throughout the historic period at the same time that open space and agriculture decreased and residential land use increased. Probably, there was more grazing in the riparian area in the 1940s and 1950s, but grazing declined as more people moved in and cattle were excluded. Without the grazing pressure, young cottonwood-willow would have had a higher rate of survival and would have grown into the medium-density stands of trees. Therefore, it is plausible that increasing absence of grazing has benefited the riparian area over time. Cows were observed grazing in the active channel area during groundtruthing at Tapco. This particular reach has supported more young cottonwood-willow in the past than it does now and may benefit from exclusion of grazing in the active channel area.

Sand & gravel

There have been two notable sand & gravel mining sites within the study area. During the 1980s, Valley Concrete operated a large mining site in the active channel area just north of old downtown Cottonwood and upstream of the bridge to Dead Horse Ranch State Park. Another smaller operation (owner unknown) was located adjacent to Verde Village and operated mainly during the 1970s while the streets and foundations of Verde Village were being constructed. Both operations appeared to impact the riparian area during and after material extraction. However, the smaller operation at Verde Village appeared to have had less of an impact and by 1995 the riparian area seemed to have largely recovered.

Whereas the Valley Concrete site and the 1.5 miles of river downstream from it represent only 17% of the length of river in the Core Area, this reach accounts for 34% of the loss of high-density cottonwood-willow in the Core Area between 1977 and 1995. Figure 17 shows how the river channel area widened over time downstream of the mining site. Increasing flood magnitudes can account for much of this effect, but proximity of the sand and gravel mining site may have been an influence also. Because the 1993 flood passed through the broad mining site and then into a section where the river channel was closely bounded by trees, flood waters may have been subject to a Bernoulli Effect, as they funneled into the reach at Deadhorse Ranch State Park. A Bernoulli Effect could have increased the velocity and force of floodwaters, leading to the removal of additional trees. Although this is one suggestion of how sand and gravel mining might have exacerbated the effects of flooding, quantification of these possible effects was outside the scope of this study.

Summary of Influences on Change in Area of Riparian Vegetation

In general for the Cottonwood-Clarkdale area from 1940-1995, natural causes appear to have influenced changes in cottonwood-willow area more than human activity; and human activity appears to have influenced changes in mesquite area more than natural causes. Table 10 summarizes the level of influence of four natural and five human-activity-related agents of riparian change, as perceived by the author.

Table 10. Qualitative evaluation of influences on change in area of woody riparian vegetation in the Upper Verde Valley Riparian Area Historical Analysis study area.

AGENT OF RIPARIAN CHANGE	LEVEL OF INFLUENCE: Cottonwood-willow			Mesquite		
	High density	Medium density	Low density	High density	Medium density	Low density
NATURAL CAUSES						
Climate	H	M	M	H	M	M
Flooding	H	M	M	L	L	L
River Morphology changes	H	M	M	n/a	n/a	n/a
Tree Pathogens	H	M	L	unknown	unknown	unknown
HUMAN INFLUENCE						
Land-use change	M?	M?	M?	H	H	H
Increasing depth to water table	L	L	L	M	M	M
Invasive non-native tree species	L	M	H	L	L	L
Grazing	M	M	M	M	M	M
Sand & gravel mining	M	M	M	L	L	L

Conclusion

This study attempted to evaluate changes in woody riparian vegetation in a portion of the Verde Valley and assess to what degree changes were due to natural causes or human influence. Basic information about the surface area of riparian vegetation, land uses, and river morphology gave insight into the processes that influenced riparian change. Linear regression analysis of results showed that the most significant influence of human activity was on the density and distribution of mesquite. Cottonwood-willow was mostly influenced by natural occurrences of flooding and subsequent river morphology changes. Further research is needed to address questions that arose during the course of this study, such as the impact of increased urban stormwater runoff on instantaneous peak flows in the Verde River or the complex relationship between agricultural irrigation and water availability to riparian plants. It is our hope that the ArcView covers we generated will be helpful to others as they pursue greater understanding of the interaction among water, people, and nature in the Verde Valley.

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