WETLANDS, Vol. 17, No. 2, June 1997, pp. 292–300

MARSH DEVELOPMENT AFTER LARGE FLOODS IN AN ALLUVIAL, ARID-LAND RIVER

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Abstract: Large expanses of riverine marsh are rare in the desert Southwest, given the dry surface of many floodplain soils. Along the Hassayampa River, riverine marsh underwent a 5-fold increase (from 2% to 9% of the floodplain-channel area) after a large winter flood in 1993. Flood waters eroded terraces that had aggraded during frequent, smaller floods, widened the channel from about 3 to 50 m, and recharged the floodplain aquifer. The net effect of these changes was a lowering of the floodplain surface relative to the water table, a variable of critical importance to riparian plant composition in arid-land rivers. Olney's bulrush (*Scirpus americanus* Pers.), southern cattail (*Typha domingensis* Pers.), jointed rush (*Juncus articulatus* L.), and other obligate wetland species were abundant in 1993 and 1994 on areas with saturated surface soils or shallow water tables and often were intermixed with seedlings of early-seral tree species, including Fremont cottonwood (*Populus fremontii* S. Watson), Goodding willow (*Salix gooddingii* Ball), and salt cedar (*Tamarix chinensis* Loureiro and related species). The gain in riverine marsh and young cottonwood-willow stands occurred at the expense of mature cottonwood-willow forests and deep-rooted, velvet mesquite (*Prosopis velutina* Woot.) woodlands. Another large flood in 1995 scoured the channel of most existing vegetation and aggraded the 1993 flood channel. Early-seral tree species again established in moist soils exposed by the slowly receding flood waters. However, redevelopment of extensive marsh habitat was precluded by sediment deposition that increased the elevation of the floodplain surface relative to the water table. These changes highlight the transitory nature of riverine marsh and other vegetation patch types in the dynamic floodplains of alluvial, arid-land rivers and underscore the importance of maintaining flood flows of varying magnitude to maintain patch type diversity.

Key Words: arid-land river, flood disturbance, *Populus fremontii,* riparian vegetation, riverine marsh, vegetation change, wetlands

INTRODUCTION

Riverine marshes ("cienegas") were historically abundant in the southwestern U.S. but have become rare as a result of various water and land uses. Surface-water diversion and ground-water pumping have dewatered many riverine habitats, and others have been ditched and drained (Bryan 1928, Hendrickson and Minckley 1984). Dewatering, in concert with floods, drought, floodplain overgrazing, wood harvest, and road development, contributed to channel incision and conversion of marshes to riparian forest along some southwestern rivers during the late 19th century (Cooke and Reeves 1976). Overgrazing and timbering of watersheds may have further contributed to habitat conversions by decreasing infiltration rates and increasing peak flow rates and stream sediment loads.

Floods in arid-land rivers have great potential for altering channel geomorphology and vegetation cover and composition, partly because they have a large magnitude relative to base flow levels (e.g., Osterkamp and Costa 1987). In recent decades, El Niño weather patterns have resulted in frequent regional river flooding in the southwestern U. S. In 1993, Arizona experienced one of the most severe winter flooding episodes in state history in terms of magnitude, duration, and volume. This event was probably surpassed only by a similar episode in February, 1891 (House 1995). Vegetational response to the 1993 event and other recent large floods has not been quantified, however.

This study was conducted to determine the effects of large winter floods on patch dynamics of vegetation associated with a free-flowing, alluvial river. The Hassayampa River Preserve is managed by the Nature Conservancy for its natural values, allowing for study of flood-related patch dynamics without the added complexity of human-related impacts (Richter 1992). Information on effects of floods of varying magnitude, duration, and timing on Preserve vegetation dynamics (Stromberg et al. 1991, 1993) can serve as a reference data set (Brinson and Rheinhardt 1996) against which other rivers in the region can be compared.

STUDY AREA

The Hassayampa is an alluvial river that has perennial, intermittent, and ephemeral reaches as it flows from mountainous headwaters to its confluence with the Gila River in the Sonoran Desert of central Arizona. In the 8-km reach of the Hassayampa River Preserve (northwest Maricopa County, elevation ca. 600 m), shallow bedrock forces water to the surface and maintains perennial surface flows. Stream flow typically is less than 0.11 m^3s^{-1} during non-flood periods (Jenkins 1989). Surface-water has electrical conductivity of about 600–700 uS/cm (Jenkins 1989). Surface sediments are predominantly sand.

Mean annual rainfall at the Wickenburg station is 29 cm. The 1800 km^2 watershed above the Preserve is vegetated by Sonoran desertscrub, interior chaparral, semidesert grassland, and montane conifer forest (Brown 1982). River floodplains are vegetated mainly by Fremont cottonwood (*Populus fremontii* S. Watson) and Goodding willow (*Salix gooddingii* Ball) forests; velvet mesquite (*Prosopis velutina* Woot.) woodlands; burro brush (*Hymenoclea monogyra* Torr. & A. Gray) shrublands; and seep willow (*Baccharis salicifolia* [R. & P.] Pers.) shrublands. Prior to purchase by the Arizona Nature Conservancy in 1986, the Preserve floodplain was used for cattle grazing, recreation, and agriculture.

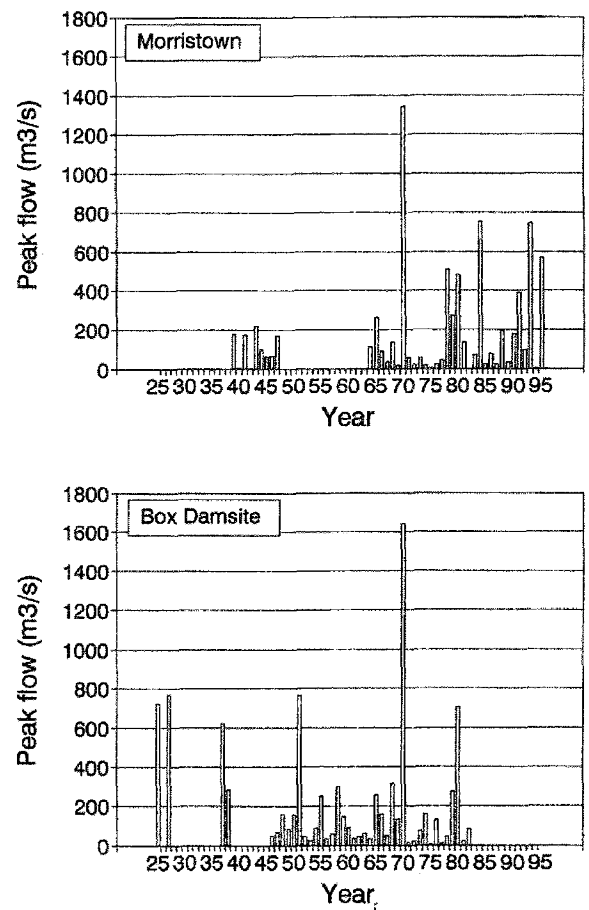

Figure 1. Instantaneous peak annual flows at two Hassayampa River gaging stations. Flow data were not collected at the Morristown gage in 1925–1938 and 1948–1963 nor at the Box Damsite gage in 1926, 1928–1936, 1939–1945, and after 1982.

METHODS

Flow data for the Hassayampa River were obtained from two USGS stream gages located in ephemeral reaches upstream and downstream of the Preserve (Figure 1). Data from these gages were used by Jenkins (1989) to calculate flood recurrence intervals. Flow velocity and water depth during the 1993 flood were calculated for two floodplain transects using the XSPRO channel cross-section analyzer program (Grant et al. 1992). Ground-water depth data were collected at Preserve monitoring wells perforated in the floodplain alluvium.

Field data were collected at eight transects established in the Preserve in 1987. A subset of the transects were surveyed in 1989, 1991, 1994, and 1996 for floodplain topography and surface elevation using an autolevel transit. Photographs were taken annually at two photo-points per transect. Permanent plots (n = 100) were located in 1987 at known distances along the transect lines, allowing for re-establishment of plot markers (rebar) that were removed or buried during floods. Density and diameter of woody plant stems, by species, were measured once per year from 1992–1995 in 2 × 2 m quadrats centered at each of the 100 plot markers. Smaller quadrats (1 × 1 m, n = 100) were sampled for woody seedling density and height, three to five times per year in 1993–1996. Plants were assumed dead if absent from quadrats. Herbaceous cover was sampled in the growing seasons of 1990–1996 in 100 1 × 1 m quadrats. The dominant species in each plot (species with greatest ground cover) was identified and classified according to its probability of occurrence in wetlands (Reed 1988). Riverine marsh species are considered synonymous with obligate wetland species.

Black and white aerial photographs were enlarged to approximate scales of 1:4,200 (1988 = pre-flood) and 1:7,100 (May, 1993 = post flood peak). Floodplain and patch type boundaries in a 1-km study reach were digitized from the photographs onto an ARCINFO Geographic Information System (GIS). Specific points on buildings, highways and other structures on both sides of the river were used for GIS registration points. Registration points were within the standard range (0.003 rms). Patch types included channel, riv-

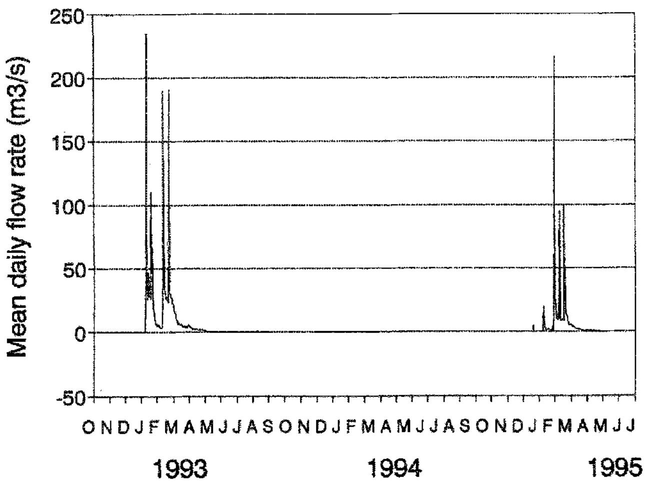

Figure. 2. Mean daily flows in the Hassayampa River at the Morristown gage in water years 1993, 1994, and 1995.

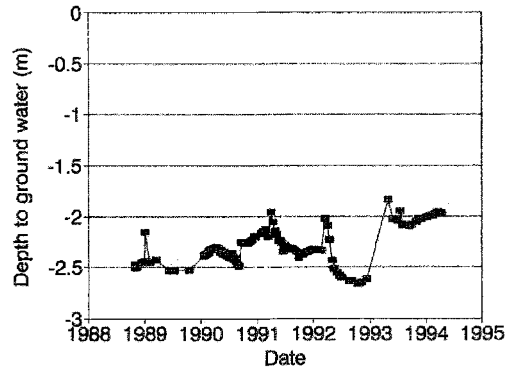

Figure 3. Depth to ground water in a monitoring well perforated in the floodplain alluvium at the Hassayampa River Preserve.

erine marsh, burro brush shrublands, four age classes of cottonwood-willow forest, and mesquite woodland. Seep willow shrublands were combined with the juvenile age class of cottonwood-willow because of difficulties in discriminating seep willow from tree saplings on aerial photographs. Patch types were verified using data collected from quadrats along four transects in the GIS study reach. Cottonwood age class was determined by using increment cores to age trees located in or near quadrats. The GIS database was queried for area per patch type, and for percentage conversion of each patch type to other patch types from 1988 to 1993. Patch type conversion from 1993 to 1996 was determined from quadrat data.

RESULTS AND DISCUSSION

Surface and Ground Water

On 8 January 1993, instantaneous flow rates in the Hassayampa River peaked at 745 m^3s^{-1}, a value with an approximate 25-year recurrence interval. Flood waters had an estimated maximum depth of 3.0 m on low floodplain terraces and a velocity of 2.1 ms^{-1}. Floods with larger instantaneous flow rates have occurred in the Hassayampa, but the 1993 event had an unusually long duration. The main peak was followed by a series of smaller flood peaks in January and February. Surface flow was above average in spring and summer of 1993 and was present through August at the Morristown gage, normally a dry reach (Figure 2). Groundwater levels in the floodplain alluvium increased by about 0.5 m after the flood pulse (Figure 3). Throughout 1994, instantaneous flow rates never exceeded 2 m^3s^{-1}. In 1995, instantaneous flow rates peaked at 566 m^3s^{-1} (15–20 yr recurrence interval) in February. Flows remained high in spring and summer of 1995 but diminished more rapidly than in 1993. Surface flow was present at the Morristown gage through June.

Geomorphic Change

The Hassayampa River typically has one active channel. Prior to the 1993 flood, the active channel was from

Table 1. Area of riparian patch types over time in a 1 km reach of the Hassayampa River and percent change in patch type area from 1988 to 1993.

	Patch Area in ha				1988–93 Change (%)
	1988	1993	1994	1995	
Unvegetated channel	0.6 (3%)	5.0 (23%)	1.2 (5%)	5.2 (24%)	+733%
Riverine marsh	0.4 (2%)	0.0 (0%)	2.0 (9%)	0.0 (0%)	−100%
Hymenoclea shrubland	2.4 (11%)	4.5 (21%)	4.5 (21%)	5.0 (23%)	+84%
Populus–Salix forest	6.7 (31%)	4.6 (22%)	6.4 (30%)	4.1 (19%)	−31%
Saplings + *Baccharis*	0.9	0.2	2.0	0.1	−90%
1980s cohort	0.2	0.1	0.1	0.1	−37%
1950s cohorts	5.2	3.9	3.9	3.5	−32%
1930s cohort	0.4	0.4	0.4	0.4	−10%
Prosopis velutina woodland	11.1 (52%)	7.2 (34%)	7.2 (34%)	7.0 (33%)	−35%

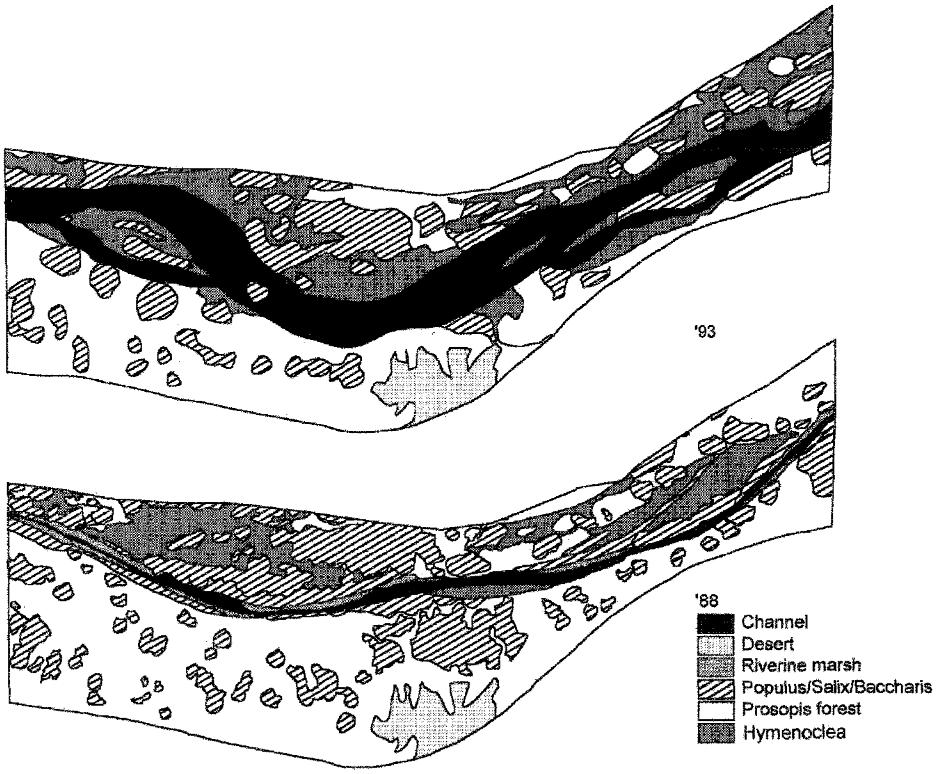

Figure 4. Vegetation map of a 1-km stretch of the Hassayampa River floodplain, indicating channel location and vegetation patch types in 1988 and 1993.

2 to 5 m wide and covered an area of 0.6 ha/km (Table 1). As of May, 1993, the channel was 40 to 50 m wide and covered an area of 5 ha/km. The channel changed course in many areas (Figures 4 and 5), and in some cases, the abandoned channel was filled with sediment (Figure 6) to depths greater than one meter. Overall, however, the flood was degradational. Mass wasting of

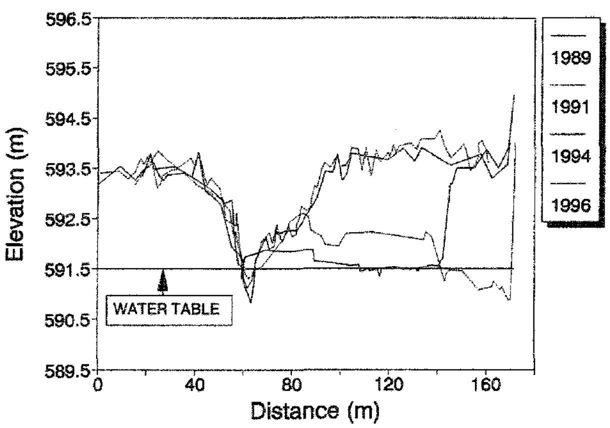

Figure 5. Cross-sectional profile of a Hassayampa River floodplain transect, showing surface topography during a non-flood year (1989) and after floods of varying magnitude (a 10-yr recurrence interval flood in 1991, a 25-yr flood in 1993, and a 15–20 yr flood in 1995).

floodplain terraces in concert with raised water tables resulted in substantial changes in elevation of the floodplain surfaces relative to the water table. Prior to the 1993 flood, less than 20% of the floodplain-channel surfaces were within one meter of the water table, and over 80% were elevated one or more meters above the water table (Table 2). Post-flood (1994), respective values were approximately 45% and 55%.

The 1995 flood waters were mostly contained within the pathway of the 1993 channel but did erode terraces and widen the channel in areas (Figure 5). An average of 10 cm of sediment was deposited throughout the floodplain in 1995 (as determined through comparisons of transect elevations), most of which was coarse sediment (sand and gravel) deposited in the 1993 flood channel (Figure 5). Smaller floods in the Hassayampa River (recurrence intervals ranging from 2 to 10 years) also have been depositional and have contributed to incremental building of channel banks and terraces with fine sediments (silts) at rates ranging from <1 to >8 cm per year (Stromberg et al. 1991, 1993).

These patterns of flood-related geomorphic change in the Hassayampa River are similar to those for other alluvial, arid-land rivers. Ish-Shalom-Gordon and Gutterman (1991) reported net surface lowering in a desert wash after a 100-year recurrence interval flood that caused erosion in the high energy phase followed by deposition in

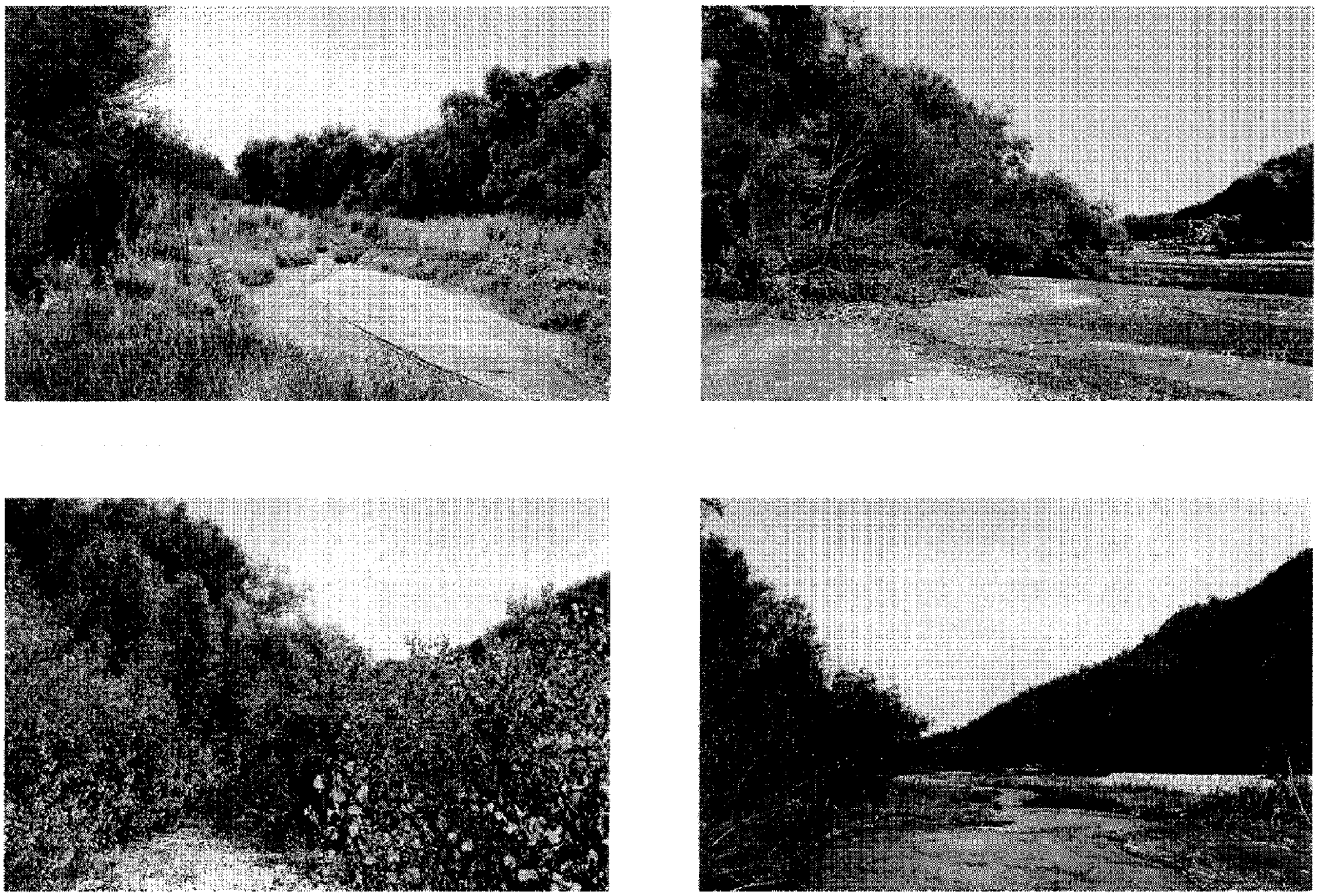

Figure 6. Repeat photos showing vegetation and channel condition in the Hassayampa River in 1989, 1993, 1994, and 1995 (left to right, from upper left). Note the presence of sediment and vegetation in the abandoned channel bed in 1994.

a low energy phase. Along the Paria River (Utah), Hereford (1986) reported that high flood discharges were associated with erosion and low flood discharges with aggradation. Burkham (1972) and Huckleberry (1994) observed that the channel of the Gila River (Arizona) was widened by major floods, while smaller floods carrying greater sediment loads were associated with channel narrowing and floodplain reconstruction. Riparian revegetation is integral to these processes of channel narrowing and consolidation of depositional bars into floodplains (Hupp and Osterkamp 1996, Scott et al. 1996).

Vegetation Change

Riverine Marshes. In 1988, the riverine marsh patch type occurred in the narrow band of saturated soils that lined the edge the active Hassayampa River channel. It covered 2% of the floodplain-channel area (Table 1). In 1990 and 1991, as well, riverine marsh species (primarily knot grass, *Paspalum distichum* L. and Olney's bulrush, *Scirpus americanus* Pers.) dominated only 2% of quadrats (Figure 7). Herbaceous cover was sparse immediately after the 1993 flood, but extensive patches of riverine marsh developed in areas of the flood channel with saturated surface soils or shallow water. By late summer of 1993 (data not shown), and continuing through 1994 (Figure 7), from 15 to 20% of quadrats were dominated by obligate wetland, riverine marsh species. Seedlings of early-seral tree and shrub species grew in about half of these quadrats. Marsh species composition shifted from dominance by shorter plants (e.g., jointed rush, *Juncus articulatus* L.; water speedwell, *Veronica anagallis-aquatica* L.) towards dominance by tall, emergent graminoids (e.g., southern cattail, *Typha domingensis;* Olney's bulrush) from 1993 to 1994. Source of propagules for the riverine marsh species (Skoglund 1990, Schwabe 1991) was not determined.

The 1995 flood scoured much of the existing marsh vegetation and precluded extensive marsh redevelopment. Riverine marsh species dominated only 2% of quadrats in summer 1995 (Figure 7) and 3% in fall of 1995. We attribute the reduced abundance of marshes in 1995 to lower stream flow rates in 1995 vs. 1993

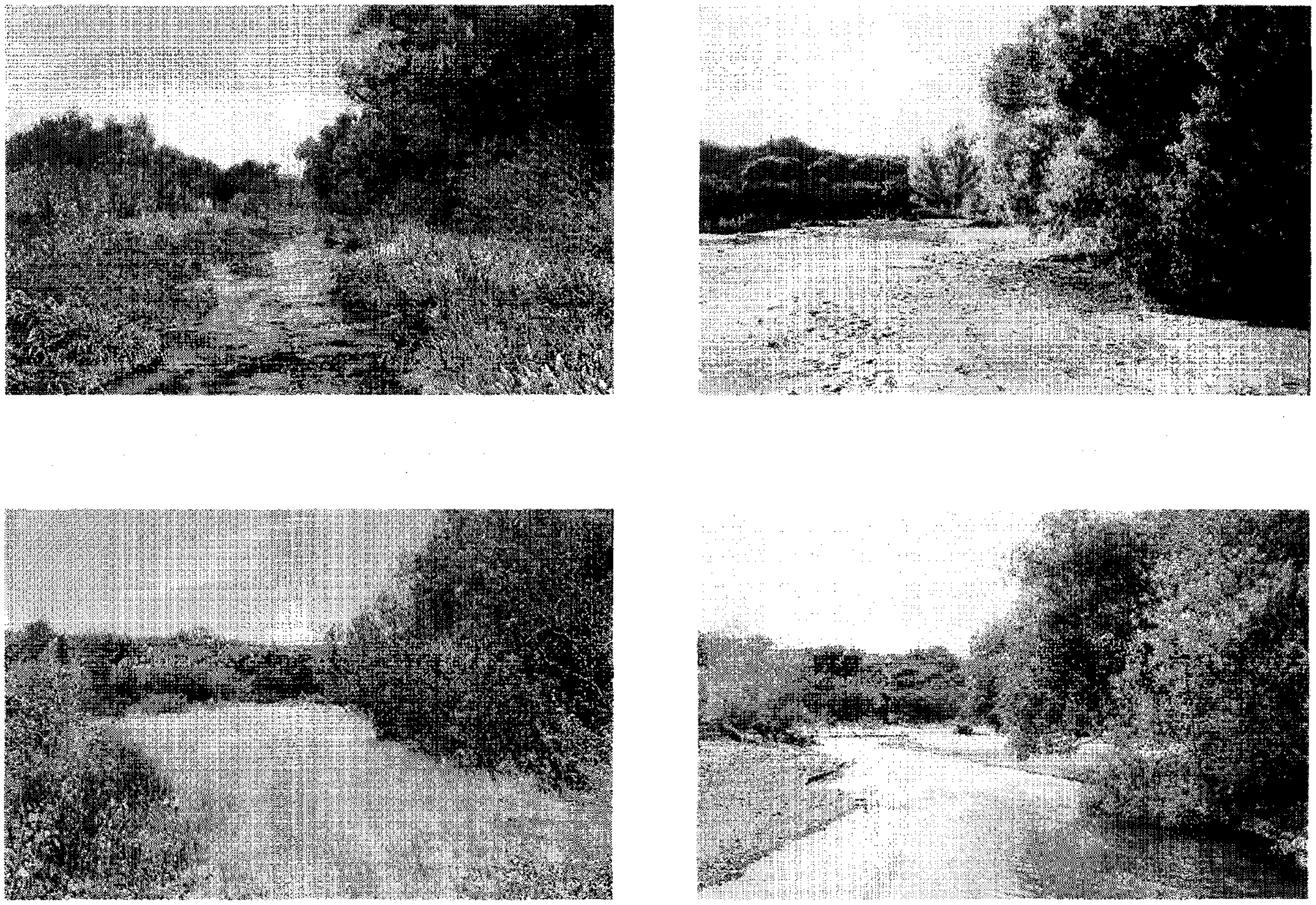

Figure 6. Continued

and greater expanse of aggraded floodplain surfaces. As floodplain terraces continue to aggrade during small floods, obligate wetland herbs are expected to become increasingly restricted to linear bands along the active channel, as occurred in the years prior to the 1993 flood. Most riverine marsh plants require standing water or very shallow water tables and will not survive on aggraded terraces where depth to ground-water may be several meters (Stromberg et al. 1996).

Table 2. Percentage of the Hassayampa floodplain-channel area in three elevation classes relative to the ground-water table. Values are means (plus or minus one standard deviation) of four cross-floodplain transects.

	Elevation Relative to Ground Water		
	<1 m	1–2 m	2–3 m
1989	17 ± 5	36 ± 6	47 ± 5
1991 (post 10-yr flood)	18 ± 6	37 ± 5	45 ± 7
1994 (post 25-yr flood)	46 ± 10	31 ± 7	23 ± 11

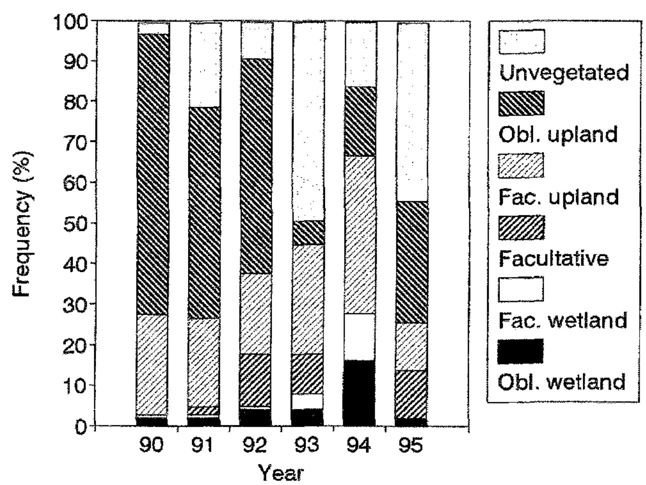

Figure 7. Relative frequency of plots dominated by herbaceous plants in five wetland indicator categories (obligate wetland, facultative wetland, facultative, facultative upland, obligate upland) over time at the Hassyampa River Preserve. Data were collected in May.

Expansion of marshes on the Hassayampa River after the 1993 flood contrasts with historical reports of flood-related destruction of marshes in the late 1800s and early 1900s on many Southwest US rivers. For reasons that are still being debated, large floods during that period resulted in both channel widening and downcutting (Cooke and Reeves 1976). Floodplain marshes could not survive the increase in substrate elevation relative to the water table, and marsh development was prevented in the incised channel by increased erosive forces resulting from steepening of channel gradient and stage-discharge relations. Floods in the Hassayampa River in 1993 caused channel widening but not channel incision, allowing for temporary expansion of marshes and perhaps replenishment of a marsh seed bank.

Seep Willow Shrublands and Cottonwood-Willow Forests. Seep willow is an evergreen shrub species that grows on channel edges and low floodplain terraces of the Hassayampa River, where ground-water is about 0.5 to 1.5 m below the floodplain surface. It forms narrow, linear strands along active and abandoned channels and often is intermixed with young Fremont cottonwood and Goodding willow. Fremont cottonwood and Goodding willow seedlings also occur on sites with shallow ground-water (ca. 0.5 to 1 m) although trees persist on aggrading terraces where depth to ground-water ranges to about 3 m (Stromberg et al. 1991, 1993).

Because seep willows border the active channel, they are frequently inundated or scoured by flood waters. After a 10-year recurrence interval flood in 1991, for example, seep willow underwent a 50% loss in stem density but rapidly recovered to pre-flood stem densities via sprouting from flood-prostrated stems that remained *in situ* (Stromberg et al. 1993). During the 1993 flood, in contrast, seep willow (and intermixed cottonwood-willow juveniles) patches were extensively eroded (90% loss in patch area) (Table 1), leaving few surviving plants to serve as sources for asexual recolonization. In 1993 and 1995, seep willow established mainly from seed in moist soils exposed near the active channel as flood waters receded (Stromberg et al. 1997).

Fremont cottonwood establish along the Hassayampa River in what has been described as a 'general-replenishment' mode (Bradley et al. 1991, and see Hughes 1994). This is characterized by infrequent pulses following large floods that set up recruitment conditions over large areas of the floodplain. Fremont cottonwoods have recruited about once every 12 years along the Hassayampa River (Stromberg et al. 1991), but only a few of these cohorts dominate the population. Cohorts from the 1950s (Table 1) occupied most (76%) of the cottonwood area in 1988.

The 1993 flood resulted in erosional loss of about 30% of the cottonwood-willow patch type. The extent of patch loss varied inversely with cohort age (Table 1) because younger cohorts grew on sites closer to the channel and were more likely to be eroded by flood waters. For example, the oldest cohort in the GIS study reach (established in the 1930s) occurred along an aggraded abandoned channel at the floodplain perimeter and was mostly outside of the 1993 scour zone. It underwent 10% loss in area in 1993 (from 0.42 ha to 0.38 ha). A cohort from 1991, in contrast, underwent 90% loss in area in 1993.

In 1993, seedlings of Fremont cottonwood, Goodding willow, and the introduced salt cedar (*Tamarix chinensis* Loureiro and related species) were abundant on moist, bare substrates created by the multiple-peak, long-duration winter floods. About 40% of the 5.0 ha/km flood channel developed into a cottonwood-willow-salt cedar seedling patch type (Figure 8). The 1995 flood, however, caused mortality of more than 95% of the 1993 tree seedlings (Stromberg et al. 1997) and eroded additional trees on the aggraded terraces (Figure 8). Tree seedlings again established in 1995 in moist soils exposed by the receding flood waters.

Burro Brush Shrublands. Burro brush is a clonal shrub that typically grows at low densities on alluvial sand-gravel deposits that are elevated about 1 to 3 m above the water table of the Hassayampa River. Burro brush shrublands occupied 11% of the floodplain-channel area in 1988 (Table 1). As a result of mass wasting during the 1993 floods, about a third of the burro brush areas were converted to flood channel. Burro brush also had high mortality on less extensively eroded sites. Eighty-eight percent of burro brush stems were either scoured, buried, or otherwise lost from quadrats during the 1993 floods. Many new sand-gravel bars were deposited in areas that were formerly cottonwood-willow or mesquite woodland (Figure 8). Woody debris desposited in these areas served to entrap burro brush root or stem fragments, from which burro brush formed new clonal stands. As a result, burro brush shrublands had a large (84%) net increase in area from 1988 to 1993. The 1995 floods redistributed and increased the area of sand-gravel deposits (Figure 8), which were again colonized vegetatively by burro brush. Burro brush was not observed to establish from seed in any year.

Mesquite Woodlands. Mesquite woodlands are a successional patch type that occur on the highest floodplain terraces (>2 m elevation) of the Hassayampa River. Mesquite woodlands were the most abundant of all patch types in 1988 (Table 1). In 1993, flood waters

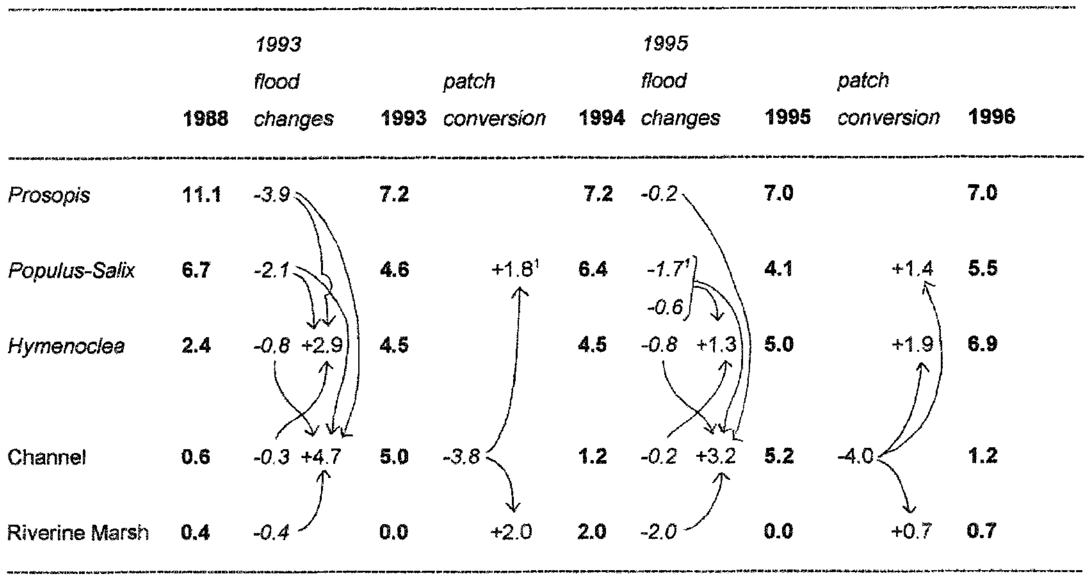

Figure 8. Diagram of patch area changes following large floods in 1993 and 1995 in a 1-km reach of the Hassayampa River. ([1] = seedlings).

eroded about a third of the mesquite woodlands. Most of the loss affected young, low-density woodlands nearest the active channel. High-density mesquite stands in non-eroded patches had low mortality. Thus, loss of mesquite patch area (35%; Table 1) was greater than stem mortality of mature mesquite (24%). Juvenile mesquite (those less than 1 m tall) grew mainly in the understory of mature cottonwood forests and on burro brush shrublands and had high (77%) flood-related mortality. The 1995 flood caused some additional stem mortality of mesquite (14% for juveniles and 3% for mature trees). Few mesquite seedlings were observed during the 1993/1995 periods of winter flooding, consistent with past studies at the Hassayampa River, indicating that mesquite establishment is enhanced by late summer floods and rains (Stromberg et al. 1991).

ACKNOWLEDGMENTS

Jennifer Read Allen, Mindy Coolidge, JoElle Don De Ville, Dave Gori, Leigh Hedrick, Kim Fox, Michael Mendelson, Carolyn Muemann, Leigh Rouse, and Bill Swenson variously assisted with floodplain surveys, vegetation sampling, plant identification, and hydrologic analyses. Thanks are due to Holly Richter, Jonathan Friedman, Clifford Hupp and anonymous individuals for providing helpful review comments and to The Arizona Nature Conservancy for allowing access to the Hassayampa River Preserve.

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Manuscript received 7 March 1996; revisions received 12 August 1996 and 1 March 1997; accepted 12 March 1997.