Colorado River Native Riparian Vegetation in Grand Canyon: How Has Glen Canyon Dam Impacted These Communities?

by Susan B. Infalt

ABSTRACT

Native riparian vegetation has changed considerably along the mainstem of the Colorado River between Glen Canyon Dam and Lake Mead since the closure of the dam. Old high water line (OHWL) plant species are in decline despite the shift some species have made into new, lower zones of the riparian area. Plants and sediment substrates directly adjacent to the river have been subjected to much less scour and desiccation with the post-dam hydrograph, and many woody species have been able to colonize much larger areas relative to pre-dam conditions. Novel communities such as return current channel marshes have developed in the canyon due to the lack of scour in backwater habitats. Overall, there has been a significant increase in the areal extent of riparian vegetation along this section of the Colorado River.

The 1996 test flood was expected to scour existing riparian and marsh vegetation. Monitoring conducted after the flood revealed that vegetation was buried rather than scoured, and was able to recover to pre-flood levels within six months. Flows the size of the test flood, 45,000 cfs (1,274 m^3/s), are inadequate to achieve current vegetation management goals, and will thus need to be modified if vegetation management goals are to be met.

INTRODUCTION

This paper will discuss the characteristics that make riparian zones in general extremely important ecosystems, and more specifically the riparian areas along the Colorado River from Glen Canyon Dam to Lake Mead. I will describe the processes that affect the structure and function of riparian areas, as well as the effects riparian vegetation has on other biotic and abiotic components of the system. I will also describe the historical composition of native riparian vegetation communities in the Grand Canyon, and examine how they have changed since the construction of Glen Canyon Dam, and how past, present, and future management regimes have and may alter the dynamics and persistence of different vegetation types.

Riparian areas are the ecotones between aquatic and terrestrial systems which encompass sharp gradients of environmental factors, ecological processes, and plant communities (Gregory et al. 1991). This interface results in an area that has higher species diversity and population densities than adjacent habitats (Johnson 1991). Vegetation serves as a substratum and food for animal life, and is thus a good indicator of the overall health of the riparian ecosystem (Johnson 1991).

The processes of erosion and deposition of sediments create new surfaces and scour riparian habitats, resulting in a highly dynamic zone with ever-changing patterns and stages of vegetation succession. During periods of low discharge, exposed channel areas are colonized by herbaceous plants and seedlings of trees and shrubs. The frequency of flooding of the lower zone discourages the establishment of large perennial species both by surface erosion and the physiological stress imposed by periodic inundation. Floodplains, terraces or hill slopes adjacent to active channels may be occupied by herbs, shrubs, and trees often with a gradient of age classes reflecting the history of flooding. The frequency and magnitude of flooding events diminish laterally away from the channel and will determine the relative elevation of different vegetation classes (Gregory et al. 1991).

Riparian vegetation is especially sensitive to changes in minimum and maximum flows (Auble et al. 1994). Auble et al. (1994) defined and analyzed cover types of riparian vegetation on the Gunnison River on the western slope of the Rocky Mountains in Colorado (longitude 107˚45' west, latitude 38˚34'30" north). Dam operations have reduced peak flows in this system, allowing development of vegetation on the canyon bottom, and cover types differed significantly according to position on the inundation-duration gradient, along with corresponding differences in soil particle size (Auble et al. 1994).

Riparian plant communities are greatly influenced by channel dynamics, and they in turn influence the evolution of geomorphic surfaces, as well as many other biotic and abiotic factors of the riparian system (Figure 1). Roots of riparian species increase resistance to erosion of the substrate, and aboveground stems increase channel roughness during overbank flows, thereby deceasing the erosive forces of floodwaters and retaining material in transport (Gregory et al. 1991). Riparian plants contribute large woody debris and other organic matter to stream channels, modify microclimatic factors (temperature, light, humidity), intercept nutrients in groundwater before they enter the stream channel, and provide food and habitat cover for both aquatic and terrestrial species. In turn, some riparian plant species depend on animals (Clover and Jotter 1944) and hydrologic processes for seed and propagule dispersal.

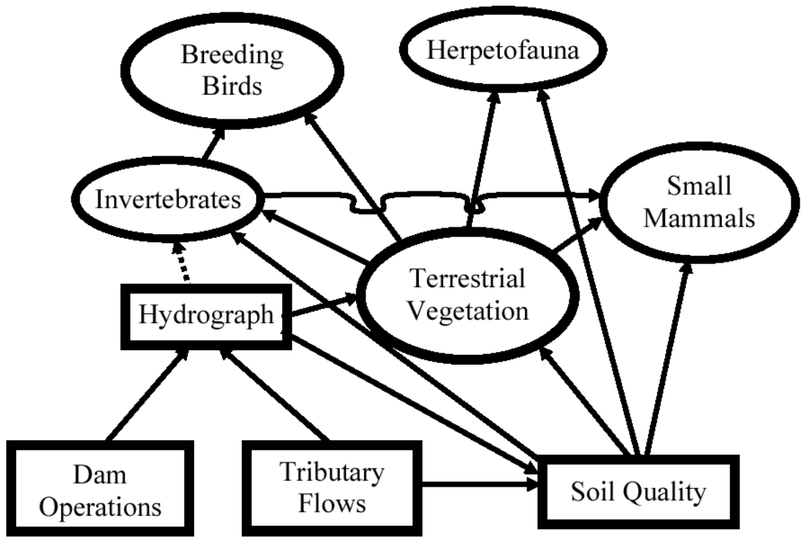

Figure 1: Relationships between biotic and abiotic components of the riparian system (Kearsley et al. 2003)

The quality, type, and seasonal patterns of litter inputs are determined by vegetation composition. Organic materials are decomposed by heterotrophic microorganisms, aquatic macroinvertebrates, and physically abraded into smaller particles, or leached and released as dissolved organic matter. Abundance and composition of detritivore assemblages are determined in large part by the plant composition of riparian zones (Gregory et al. 1991).

The Colorado River in Grand Canyon supports 275 miles (443 km) of riparian habitat, the longest contiguous riparian corridor in the United States (Anderson and Ruffner 1987). Riparian areas are extremely valuable in arid regions and contribute to the biotic diversity of the region disproportionately to their area, supporting animals that are rare or absent in surrounding habitats. Surveys in the 1970s listed 807 species of vascular plants along the Colorado River in Grand Canyon (Johnson 1991).

Water diversions and dams have caused dramatic changes in riparian plant communities by altering the flood regime. Most southwestern riparian communities rely on periodic flooding to remove non-native and non-riparian species and to establish conditions conducive to community regeneration (Kearsley and Ayers 1999). Since the closure of Glen Canyon Dam (GCD), riparian zones of the Colorado River basin have been in a state of transition.

Unfortunately, the only botanical surveys existing for the canyon were from two trips in the 1940s until later intensive surveys initiated in the 1970s, post dam closure (Johnson 1991).

HISTORICAL COLORADO RIVER RIPARIAN COMMUNITIES

Before the closure of GCD, the riparian vegetation along the Colorado River in the Grand Canyon was characterized by three vegetation belts running parallel to the river. The zone closest to the river was subject to annual scouring floods, and supported only ephemeral herbaceous species and seedlings of woody species that would invade between floods (zone 3 in Figure 2). The zone farthest from the river was not influenced by river flows and was composed of desert vegetation (zone 1 in Figure 2). Between those two zones was a vegetation community whose lower boundary was delineated by the high water line of major floods, and the upper boundary defined by the level of soil saturation by annual floods which provided moisture for sufficient duration to allow for germination and establishment of seedlings and the availability of suitable soil (zone 2 in Figure 2). This area was termed the old high water line (OHWL) riparian zone (Anderson and Ruffner 1987), (Figure 2).

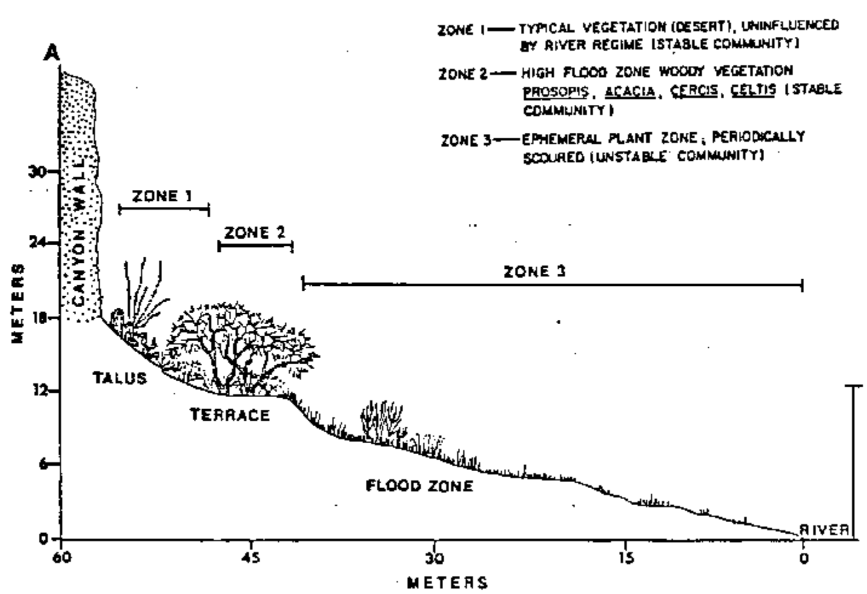

Figure 2: Pre-dam riparian vegetation zones (Anderson and Ruffner 1987).

Characteristic species of the OHWL zone (zone 2 in Figure 2) included Apache plume (*Fallugia paradoxa*), redbud (*Cercis occidentalis*), netleaf hackberry (*Celtis reticulate*), western honey mesquite (*Prosopis glandulosa*), and catclaw acacia (*Acacia greggii*). Western honey mesquite and catclaw acacia are the dominant species from river mile (RM) 40 to Lake Mead (Anderson and Ruffner 1987). The OHWL is an extremely important habitat in the Grand Canyon. It provides nesting sites for birds, cover for reptiles and amphibians, breeding sites for insects, and mesquite and acacia pods provide an abundant carbohydrate rich diet for many insects, mammals, and birds (Anderson and Ruffner 1987).

Mesquite is an obligate riparian species in the Grand Canyon, found mainly on alluvial terraces and talus slopes (Figure 3). It is a long-lived phreatophyte (deep-rooted plant that obtains water from some permanent water source) with large belowground biomass and a taproot capable of reaching great distances to the water table. Its lifespan is often greater than 100 years, which means that many of the mature plants within the Grand Canyon were there before GCD was closed. Fruits mature in July/August, and the seeds generally germinate in August/September after the summer rains, though some may overwinter and germinate in April as moist soils warm (Anderson and Ruffner 1987).

Catclaw acacia is also a long-lived phreatophyte (some individuals spanning pre- and post-dam periods), but is more drought tolerant than mesquite and is not restricted to riparian zones in the Grand Canyon (Anderson and Ruffner 1987), (Figure 3). Acacia is found on most substrates in the canyon, including crevices in steep bedrock outcrops, and is distributed continuously from RM 40 to Lake Mead (whereas mesquite is rare between RM 77 and RM 165 due to a lack of alluvial terraces), but often occurs in lower densities than mesquite (Anderson and Ruffner 1987).

Figure 3: Western honey mesquite (far left (www.livingdesert.org) and center left (www.tarleton.edu)) and catclaw acacia (far right (www.peds.arizona.edu) and center right (www.nps.org)).

Above the OHWL community in the talus or desert uplands is a community that is largely independent of the influence of the river. Characteristic species include creosote (*Larrea* *tridentata*), ocotillo (*Fouquieria splendens*), barrel cactus (*Ferocactus cylindraceus*), and numerous other cacti (*Opuntia* spp. and others) and desert scrub species (Johnson 1991; taxonomy from Baldwin et al. 2002).

The lowest riparian zone is continually subjected to scouring events. This zone is comprised mainly of herbaceous ephemerals, annuals, and perennials (Johnson 1991).

Overall, large-statured riparian vegetation was rare in the pre-GCD Grand Canyon as was noted in the journals of pre-dam river runners who recorded specific locations of good shade trees along the river (Webb et al. 2002). Where it was found, it occurred generally as specimen individuals of cottonwood (*Populus fremontii*) and willows (*Salix* spp.), (Table 1), which have now been displaced or joined by many exotic species.

Year	Notes
1869	Few native trees are noted. The canyon is described as barren.
1872	Few native trees are noted.
1890	Several trees are noted and photographed. No tamarisk is visible (Webb, 1996).
1923	USGS expedition photographs show no tamarisk, nor do the diaries mention it. They photographed the Goodding willow at Granite Park and large cottonwoods at mile 196 and 222.
1937	Sharp notes large increase in native willow trees downstream from Lava Falls Rapid.
1938	Clover observed "some tamarisk coming in now on sandbars" in the vicinity of Saddle Canyon (mile 47). Otherwise, she specifically noted few tamarisk trees between Lees Ferry and Lake Mead. She notes "weedy baccharis" but no tamarisk at Spring Canyon (mile 204).
1938	Huge cottonwood trees were reported at President Harding Rapid (Cook, 1987) and the expedition slept under a "huge willow" at mile 194. Nevills observed the deltaic deposits at the head of Lake Mead were covered with tamarisk.
1940	Goldwater notes a large cottonwood tree was present at mile 220.
1942-47	Nevills observed invasion of tamarisk at the mouth of Spring Canyon.
1947	Nevills expedition finds shade under tamarisk trees at Kanab Creek in 1947.
1948	Nevills expedition finds shade under tamarisk trees at Whitmore Wash (mile 185); Doerr notes that willow trees were also present. Marston notes that "willows decorate wide sandy beaches" near mile 190. Doerr and Nevills report that a large willow across from Pumpkin Spring (mile 213) was being gnawed by beavers. Masland rested under a large willow tree at Diamond Creek. Doerr reports canyon mouths on Lake Mead supported dense stands of young tamarisks and willows.
1951	S. Reilly noted "beautiful green tamarisks" at Badger Rapid. The camp at Salt Water Wash had "many tamarisks" as well as the debris fan at President Harding Rapid. Reilly especially noted "the smell of tamarisks" in the vicinity of Tanner Rapid.
1950s	P.T. Reilly notes tamarisk at Bridge (mile 237) and Spring Canyons. Tamarisk was noted at Beamer's Cabin up the Little Colorado. He does not note cottonwood or other native trees.
1955	P.T. Reilly notes the willows and tamarisk at Spring Canyon were damaged by a flash flood. Beer photographs in 1955 show widespread tamarisk.
Early 1960s	Litton observed that tamarisk on the Lake Mead delta was periodically destroyed by rises in the elevation of the lake; he photographed the barren delta.
Early 1960s	Frost remembers a cottonwood tree at the mouth of Kanab Creek.
1970	Martin (1971) notes huge increase in tamarisk.
1977	J.N. Staveley remembers seeing the cottonwood tree at mile 220.

Table 1: Historical accounts of native and non-native vegetation in Grand Canyon (Webb et al. 2002).

IMPACTS OF DAM CLOSURE

The riparian ecosystem of the Grand Canyon is considered to be a naturalized ecosystem (Johnson 1991). This is because though it has been modified by alteration of the disturbance regime and introduction of exotic species, there has been no appreciable loss of native riparian plant species. Prior to the construction of the dam, the riparian community was shaped by three pulse-related river features: seasonal flow patterns and maximum and minimum flows, nutrient and sediment transport and turbidity, and fluctuations in water temperature (Johnson 1991). The riparian environment in the Grand Canyon has become much more mesic, due largely to cessation of souring from silt-laden spring floods, and a relatively constant year-round water supply to riparian plants (Johnson 1991).

New Vegetation Communities

The closure of GCD has drastically decreased the variability of flow levels and frequency of scouring floods (Figure 4), allowing the development of more permanent vegetation communities in the old ephemeral zone and in beach and cobble areas (Walters et al. 2004), (Figure 5).

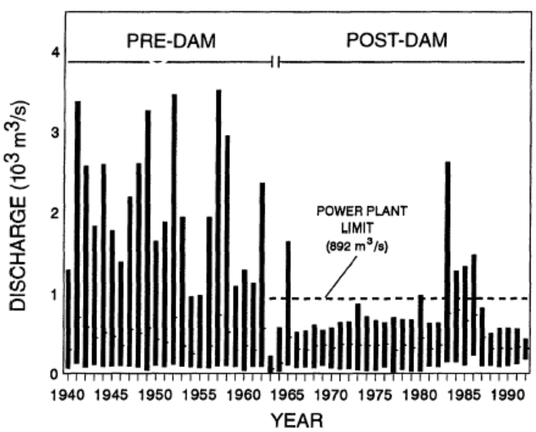

Figure 4: Annual maximum and minimum daily mean flows of the Colorado River at Lees Ferry (Stevens et al. 1995).

Figure 5: Vegetation encroachment at Deer Creek Falls, (RM 136.1-R) from 1923 (left) to 1972 (right), (Webb et al. 2002).

The New High Water Line Community

One new post-dam community has been termed the new high water line (NHWL), and consists of fast growing trees and shrubs (Anderson and Ruffner 1987), (zone 4 in Figure 6). The NHWL community is distinguished by a mix of sandbar willow (*Salix exigua*), arrowweed (*Pluchea sericea*), seepwillow (*Baccharis salicifolia* and *B. emoryii*), desert broom (*Baccharis sarothoides*), and tamarisk (*Tamarix ramosissima*), (Johnson 1991). Vegetation cover in the NHWL showed a significant increase from 1965 to 1980 (Johnson 1991). Much of this may be exotic species, such as tamarisk (King 2005, this volume), but some native species of the OHWL community have colonized the NWHL. Since many other riparian communities of the Southwest are experiencing the effects of desertification due to water management, the increasing riparian vegetation of the Grand Canyon is becoming of great habitat value for obligate and facultative riparian animal and plant species on a regional scale.

Subadults of woody OHWL species are rare in the OHWL, and most establishment of these species occurs in the NHWL, indicating that ambient precipitation is not enough to support these species in habitats that are now outside the zone of the rivers influence (Anderson and Ruffner 1987). In many modified rivers of the Southwest, tamarisk has out-competed and displaced native riparian species. However, tamarisk has not been known to cause a loss of plant species in the Grand Canyon (Johnson 1991), and in fact no known riparian plant species have been extirpated from the canyon.

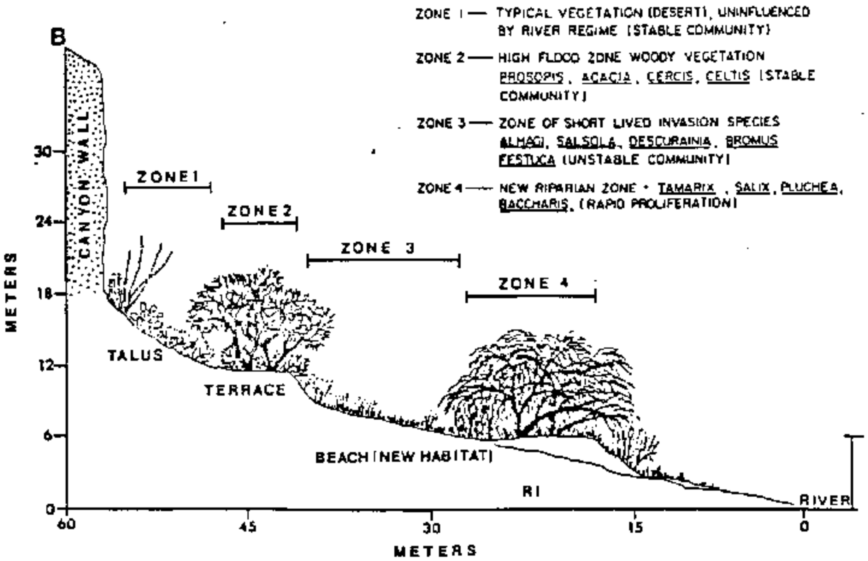

Figure 6: Post-dam riparian vegetation zones (Anderson and Ruffner 1987).

Marsh Development

No marshes were found along the Colorado River through the Grand Canyon before GCD that were not fed by perennial tributaries or springs (Webb et al. 2002). Completion of GCD has resulted in the development of many new marshes along the mainstem of the Colorado River (Stevens et al. 1995). Many reattachment bar platforms and return current channels (RCC) of fan-eddy complexes have been invaded by riparian and wetland vegetation. Under historical flows, suspended fine sand and silt aggraded in RCCs and were deposited as veneers over coarser sediments. These finer sediments contain higher concentrations of nitrate and soluble phosphate, and exhibit greater water holding capacities (Stevens et al. 1995). Historical flooding would scour these areas, keeping them as open backwater habitats. In the absence of scouring floods, marsh vegetation has been able to successfully colonize these sites (Figure 7). In October of 1991, Stevens et al. (1995) identified 730 marshes between Lees Ferry and Diamond Creek, excluding very small marshes. Marshes are now found between stages associated with discharges of 15,000-31,500 cfs (425-892 m^3/s), (Stevens et al. 1995). Large daily flow fluctuations increase the wetted area of the banks, therefore increasing the area of the bar available for colonization. Four marsh associations were identified by Stevens et al. (1995)

which were associated with differing conditions of daily inundation frequency and soil texture (King 2005, this volume). For example, conditions that promoted development of cattail/reed associations contrast those that promote development of tamarisk/arrowweed stands.

Figure 7: Invasion of marsh vegetation at Cardenas Creek (RM 70.9-L). 1890 (left) and 1993 (right), (Webb at al. 2002).

Decline of the Old High Water Line Community

Plants of the OHWL have been in decline due to a lack of flooding (Kearsley and Ayers 1999). High late spring snowmelt floods historically provided moisture to the plants of the OHWL during the flowering and fruiting season, and prior to seed germination in the midsummer (Anderson and Ruffner 1987). Summer floods carried high sediment loads which may have been important to replenishing nutrient levels in shoreline soils. The absence of such historical flows and the current post-dam flows may reduce vigor of adults and seedlings through nutrient deficits, and cause erosion in the new high water line removing seedlings and reducing areas available for colonization (Anderson and Ruffner 1987). The OHWL is becoming more xeric, which may result in acacia becoming the new dominant, as it is more drought tolerant than mesquite. Younger age classes of acacia occurred in significantly higher densities than younger age classes of mesquite throughout the river corridor in Anderson and Ruffner's 1987 study. They also determined that most adults of the two species were found in the OHWL community while most of the younger age classes were found in the NHWL or tributaries. Over time, this will lead to a great reduction in the populations of these species in the OHWL communities as the adults that became established before the dam senesce, and are not replaced by individuals of younger age classes. Tree ring analysis of acacia indicates that the post-dam hydrograph has reduced annual growth in adults of the OHWL zone, and aerial photo analysis shows a reduction in the extent of mesquite and acacia from reduced growth rates and/or increased mortality

(Anderson and Ruffner 1987). The 2-3 year old saplings had a higher survivorship than the 3-5 year old saplings, which would not be expected. The 3-5 year old age class at the time of this study became established during the high flows of 1983, and is now located higher on the shore than the zone of influence of the normal high regulated flow and may be in decline due to a lack of soil moisture (Anderson and Ruffner 1987). The high 1983 flows provided conditions suitable to establishment by these species, but the low flows in the years that followed have left these plants stranded, possibly before they were able to establish taproots to a permanent water supply. Lowest mortality overall for mesquite and acacia was found in the NHWL (Anderson and Ruffner 1987). This indicates a spatial shift of this community type downward into a zone more proximal to the active channel due to new managed flow regimes.

IMPACTS OF THE 1996 TEST FLOOD

Management Goals

The overall management goal of the 1996 test flood was to return flooding as a community organizing force in the river corridor of Grand Canyon. The flood was roughly half the magnitude of the pre-dam mean annual spring runoff floods, and a third of the 10 year event, but was expected to be adequate to restore some of the natural dynamic forces which shaped the pre-dam physical and biotic systems (Kearsley and Ayers 1999). The primary vegetation management goals were to set back riparian succession by removing large amounts of high water zone plants that had colonized camping beaches, to rejuvenate return-current habitats by scouring existing vegetation, and to provide water to the old high water line vegetation (Kearsley and Ayers 1999).

Results

Two riparian habitat types, return-current channel marshes and riparian woodland/scrubland, were expected to be affected by the flood both by direct scouring of vegetation and by depletion or burial of seed banks (Figure 9). Kearsley and Ayers (1999) studied riparian patches dominated by obligate wetland species and riparian woodland/shrubland species to analyze the results of the test flood. They found that some plants were removed or buried (mostly the lowest-growing species, grasses and small herbs), but the extensive habitat rejuvenation expected by planners failed to occur. Though study sites did show a significant loss of vegetation (approximately 20% of total vegetative cover), no sites showed an overall significant change in area covered by wetland vegetation. Burial by the floodwaters led to an almost indetectable change in wetland vegetation, as some species thrived after burial (*Typha* spp., *Phragmites* spp., and *Salix* spp.), (Figure 8). Seed banks were found to have lost an average of 45% of their individuals as compared to pre-flood conditions. Some species showed considerable loss (more than 80% for two native species) while others showed almost no effect from the flood (Kearsley and Ayers 1999). Therefore, the proportion of species such as cattail (*Typha domingensis*) and dropseed grasses (*Sporobolus* spp.), (Figure 8) increased significantly relative to other species (Kearsley and Ayers 1999).

Figure 8: *Typha domingensis* (far left (members.iinet.net)), *Phragmites australis* (center left (www.funet.fi)), *Salix exigua* (center right (www.biosurvey.ou.edu)), and *Sporobolus airoides* (far right (www.plantdelights.com)).

Study sites experienced very little scouring, and were instead buried under about 1.5 to 5 ft (0.5 to 1.5 m) of sediment. Seeds may not have actually been removed from the study sites, but are still not expected to contribute to future populations, as the seeds of many species will lose viability rapidly, and those that may be capable of persisting will remain buried until flows exceed power plant capacity or aeolian processes bring them to the surface (Kearsley and Ayers 1999).

Common Name	Scientific Name	Habitat Zone	Effect of Dam	Effect of 1996 Flood
Barrel cactus	*Ferocactus cylindraceus*	Desert	None/Positive[1]	None
Creosote	*Larrea tridentata*	Desert	None/Positive[1]	None
Ocotillo	*Fouquieria splendens*	Desert	None/Positive[1]	None
Prickly pear	*Opuntia* spp.	Desert	None/Positive[1]	None
Apache plume	*Fallugia paradoxa*	OHWL	Negative	None/Negative[3]
Catclaw acacia	*Acacia gregii*	OHWL	Negative	Negative[3]
Netleaf hackberry	*Celtis reticulata*	OHWL	Negative/Unknown[2]	Unknown
Redbud	*Cercis occidentalis*	OHWL	Unknown[2]	Unknown
Western honey mesquite	*Prosopis glandulosa*	OHWL	Negative	Negative[3]
Baccharis	*Baccharis* spp.	NHWL/Ephemeral	Positive	None/Positive
Boxelder	*Acer negundo*	NHWL/Ephemeral	Positive	None/Unknown
Cottonwood	*Populus fremontii*	NHWL/Ephemeral	Positive	None/Unknown
Willow	*Salix* spp.	NHWL/Ephemeral	Positive	None/Positive
Cattail	*Typha* spp.	Ephemeral	Positive	Positive
Dropseed grass	*Sporobolus* spp.	Ephemeral	Positive	Positive
Horsetail	*Equisetum* spp.	Ephemeral	Positive	None/Unknown
Reed	*Phragmites* spp.	Ephemeral	Positive	Positive
Rush	*Juncus* spp.	Ephemeral	Positive	None/Unknown
Sedge	*Carex* spp.	Ephemeral	Positive	None/Unknown
Spike rush	*Eleocharis* spp.	Ephemeral	Positive	None/Unknown

NOTES:

1. Though the desert zone is thought to be independent of the influence of the river, it is possible that the low post-dam flows and shift in the high water line has provided an opportunity for desert species to increase their range by colonizing increasingly xeric areas in the OHWL community.

2. Based on the life history characteristics of these species, it may be possible that they have been able to shift to lower zones in the riparian area without any detriment from the dam, or even possibly increase in abundance.

3. These species have been able to colonize the NHWL, but are not flood tolerant. About half the populations of these species were drowned during the high flows of 1983, and it is possible that some were lost in the 1996 test flood.

Figure 9: Summary of effects on individual plant species.

DISCUSSION

The model produced by Auble et al. (1994) demonstrates that inundation duration can be successfully utilized as a predictor of vegetation distribution because it is correlated with flow-related variation in many environmental variables including shear stress, sediment deposition and erosion, soil moisture, depth to groundwater, and soil oxygen concentration. Sites with high inundation durations are likely to be closer to groundwater when not flooded, are likely to be inundated to greater depths when flooded, and are likely to be subject to greater and more frequent shear stress than sites with low inundation durations (Auble et al. 1994). Effective management of fluvial wetlands and riparian woodlands requires an understanding of existing and potential species distributions and responses to flow patterns within the context of clearly defined management goals and objectives (Stevens et al. 1995).

The effects of flooding have their greatest influence on seedlings. Seedlings are limited in where they can establish by moisture conditions, and are at greater risk of drowning, scour, and desiccation than older age classes (Anderson and Ruffner 1987). The effects of sediment particle size and the factors influenced by size (nutrient and moisture holding capacity) on seed germination have implications for future flood designs (Kearsley and Ayers 1999). Riparian species have higher germination success in fine, moist, nutrient laden soils.

Management Considerations

To determine the success that current flow regimes (pulse flows) and proposed flows will have on management of riparian vegetation, specific goals must be defined. Riparian vegetation provides valuable habitat to some special status species and increases productivity and diversity of the river corridor, but was not historically as spatially extensive as it is now, and has come into direct conflict with goals regarding management of backwater habitat for the endangered humpback chub (*Gila cypha*), (Campos 2005, this volume) and beach campsites.

If managers want to encourage wetlands and the persistence of vegetation in the lower riparian zones to maintain or increase habitat for terrestrial species (Dettman 2005, this volume, and Schell 2005, this volume), floods should be carried out for short periods (3 days or fewer) to minimize the loss of organic matter (which would speed recovery of wetlands) and scour. If unvegetated areas are desired, floods should last for longer periods of time (Kearsley and Ayers 1999). Based on pre-dam conditions and the 1983-1984 high flows, Kearsley and Ayers (1999) suggest discharges of 77,700 to 88,300 cfs (2,200 to 2,500 m^3/s) to accomplish goals of vegetation removal from return-current channel marshes.

The fact that the 1996 controlled flood failed to produce the desired management goals of scouring riparian vegetation and providing water to OHWL communities is likely the result of the small size of the flood relative to historical flood events. If these remain the major goals of river managers, flows will need to have much greater magnitude and duration. It is impossible to provide moisture to the OHWL when flows only reached 45,000 cfs (1,274 m^3/s), (Patten et al. 2001), and the OHWL plant community begins at about the 90,000 cfs (2,550 m^3/s) flow line (Kearsley et al. 2003). Flows of the 1996 test flood were also not sufficient enough to scour marshes. Only herbaceous vegetation was removed by the test flood. Woody species were buried, but many were able to resprout and take advantage of the nutrient rich deposits and the nutrients released through decomposition of plants that were buried and unable to recover.

Management Recommendations

I recommend that future flows be much of greater magnitude and duration to achieve goals of scouring low riparian zones and water recharge for OHWL communities. However, it should be noted that longer floods may conflict with sediment storage goals (Booth 2005, this volume). I believe that some scouring and renewal of marsh habitat is possible, and that increasing the level of the high water line may boost growth and survival of the species inhabiting those areas, but that scouring of established woody vegetation in the lower riparian zones may be more difficult to achieve. Woody plants like tamarisk and willows have been able to establish and grow in the old ephemeral zone. These plants are successful sprouters, and can have very deep or dense rhizomatous root system, which will make them difficult to remove completely and difficult to subdue resprouts. If dam operations cannot feasibly release flows of historical magnitudes, it may be necessary to use mechanical removal of well established adults followed by larger, more frequent floods to reinstate the desired erosion/deposition cycle and herbaceous community structure to these areas.

Riparian vegetation in the Grand Canyon has incurred vast changes since the construction of GCD, and will not be modified in a way consistent with management goals if flow regimes remain as they are.

REFERENCES

Anderson, L.S. and G.A. Ruffner. 1987. Effects of Post-Glen Canyon Dam Flow Regime on the Old High Water Line Plant Community along the Colorado River in Grand Canyon (Report number GCES/22/87). National Park Service, Grand Canyon National Park. Grand Canyon, Arizona.

Auble, G.T., J.M. Friedman, and M.L. Scott. 1994. Relating riparian vegetation to present and future streamflows. *Ecological Applications*, **4**(3): 544-554.

Baldwin, B.G., S. Boyd, B.J. Ertter, R.W. Patterson, T.J. Rosatti, and D.H. Wilken, eds. 2002. The Jepson Desert Manual. University of California Press, Berkeley, California.

Clover, E.U., and L. Jotter. 1944. Floristic studies in the canyon of the Colorado and tributaries. *American Midland Naturalist* **32:** 591-642.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience*, **41**(8): 540-552.

Johnson, R.R. 1991. Historic Changes in Vegetation along the Colorado River in the Grand Canyon. Colorado River Ecology and Dam Management, Proceedings of a Symposium, May 24-25, 1990, Santa Fe, New Mexico. National Academy Press, Washington D.C.

Kearsley, M.J.C. and T.J. Ayers. 1999. *Riparian Vegetation Responses: Snatching Defeat From The Jaws Of Victory And Vice Versa*. The Controlled Flood in Grand Canyon. Eds. R.H. Webb, J.C. Schmidt, G.R. Marzolf, and R.A. Valdez. Washington D.C., American Geophysical Union.

Kearsley, M.J.C., N. Cobb, H. Yard, D. Lightfoot, S. Brantley, G. Carpenter, and J. Frey. 2003. Inventory and Monitoring of Terrestrial Riparian Resources in the Colorado River Corridor of Grand Canyon: An Integrative Approach. 2003 Annual Report. Submitted to Grand Canyon Monitoring and Research Center. U.S. Geological Survey, Flagstaff, Arizona.

Patten, D.T., D.A. Harpman, M.I. Voita, and T.J. Randle. 2001. A Managed Flood on the Colorado River: Background, Objectives, Design, and Implementation. *Ecological Applications*, **11**(3): 635-643.

Stevens, L.E., J.C. Schmidt, T.J. Ayers, and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. *Ecological Applications*, **5**(4): 1025-1039.

Walters, C., T. Melis, D. Topping, L. Coggins, B. Ralston, C. Burbridge, C. Palmer. 2004. Evidence for the Failure of the Modified Low Fluctuating Flow Alternative (MLFFA) to Benefit Most Ecological Resources in Grand Canyon. Glen Canyon Dam Adaptive Management Program, Technical Work Group Report. http://137.77.133.1/uc/envprog/amp/twg/mtgs/04jun30/JK-MLFFA.pdf

Webb, R.H., T.S. Melis, and R.A. Valdez. 2002. Observations of Environmental Change in Grand Canyon, Arizona. (Water-Resources Investigations Report 02-4080). U.S. Geological Survey. Tucson, Arizona.