PLANNED FLOODING AND RIPARIAN TRADE-OFFS:

THE 1996 COLORADO RIVER PLANNED FLOOD

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Original research submitted for publication in Ecological Applications to:

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Ithaca, NY 14850-5616

15 December 1997

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ABSTRACT

Regulated Colorado River ecosystem restoration through planned flooding involves tradeoffs between relictual pre-dam and novel post-dam resources and processes, between aquatic and terrestrial components, and between management of individual resources versus ecosystem characteristics. We review the terrestrial (wetland and riparian) impacts of a 1,275 m3/s test flood conducted by the Bureau of Reclamation in March/April 1996, which was designed to improve sediment management downstream from Glen Canyon Dam in the Colorado River ecosystem. Although the test flood successfully restored sand bars throughout the river corridor, it scoured channel margin wetlands, including endangered Kanab ambersnail (KAS) and southwestern willow flycatcher (SWWF) foraging habitat. It buried ground-covering riparian vegetation under >1 m of fine sand, but only slightly altered previously established return current channel marshes and perennial sandbar vegetation. Pre-flood control efforts and appropriate timing of the test flood prevented germination and range expansion of non-native Ravenna grass and tamarisk. The flood also was timed to prevent direct population impacts to endangered avian species. A total of 1275 KAS were translocated above the flood zone, and an estimated 840 endangered snails were lost to the flood. Slight impacts on ethnobotanical resources were detected more than 430 km downstream on upper Lake Mead, and those plant assemblages recovered rapidly. Careful design of flood hydrograph shape and seasonal timing is required to mitigate terrestrial impacts during efforts to restore essential geomorphic and aquatic habitats and processes in this regulated river ecosystem.

KEYWORDS: Colorado River, endangered species, Glen Canyon Dam, management tradeoffs, planned flooding, restoration, riparian ecology.

INTRODUCTION

Flooding is an important natural phenomenon on most rivers, reorganizing and resetting the physical and ecological development of aquatic and riparian habitats (Junk et al. 1989, Gregory et al. 1991). Flow regulation that reduces flood frequency may increase the stability of downstream aquatic and riparian ecosystem domains (Risser and Harris 1989, Sedell et al. 1989, Johnson et al. 1995). Reduction in disturbance intensity in naturally highly disturbed ecosystems has been predicted to increase biodiversity (Connell 1978, Huston 1979), and this prediction is supported in some large, regulated river ecosystems, which developed substantial new riparian vegetation and larger, more stable faunal populations following impoundment (e.g. Rickard et al. 1982, Anderson and Ohmart 1988, Johnson 1991). As human-dominated ecosystems, most if not all large regulated rivers support both relictual (pre-dam) and novel (post-dam) aquatic and terrestrial resources and processes. Relictual and novel components, as well as the economic benefits associated with flow regulation, are variously valued by society, intensifying the debate on management priorities (Stevens and Wegner 1995). Management actions that restore natural dynamics on regulated rivers, such as planned floods, may differentially affect relictual versus novel components, aquatic versus terrestrial components, and the management of individual components versus ecosystem characteristics. Careful consideration of the shape and seasonal timing of restoration hydrographs is essential for optimizing planned flood effects on the wide array of resources and processes of concern in regulated river ecosystems.

Recently proposed river ecosystem management strategies have focused on simulation of natural hydrographs, particularly restoration of flooding (Naiman et al. 1995, Sparks 1995, Stanford et al. 1996); however, significant conceptual and practical issues limit potential restoration of large regulated rivers (Ward and Stanford 1983, Gore and Shields 1995, Johnson et al. 1995). Reduced flood frequency is only one facet of environmental change downstream from large dams: changes in sediment transport, thermal and nutrient dynamics, and the introduction of non-native species (including parasites and diseases) may exert larger impacts than does flood supression (e.g., Miller et al. 1983, Minckley 1991, Brouder and Hoffnagle 1997). Therefore, flood restoration cannot be expected to solve all ecological problems in regulated rivers, and may negatively affect valued novel and economic components.

Prediction of flow regime impacts on aquatic and floodplain recently has been advanced through the development of hydrologically-based models (e.g., Auble et al. 1994, Blinn et al. 1995, Power et al. 1995). For example, post-dam lower riparian zone vegetation develops in response to comparatively subtle gradients of inundation frequency, scour disturbance, soil texture and channel geomorphology (Hupp 1988, Day et al. 1988, Stevens et al. 1995), but few experiments on river ecosystem restoration using planned flooding have been conducted (Molles et al. 1995 is an exception). In part, this is because flood frequency and magnitude can only be substantially manipulated where human population density is low (e.g., Izenberg et al. 1996). Regulated river floodplains are typically subject to a wide array of land management strategies, including intensive agricultural and industrial development; however, the regulated river floodplains or reservoir shorelines of >30 large national parks in the United States are managed for preservation (Jackson et al. 1992). The National Park Service (NPS) management strategy revolves around preservation of natural and cultural resources for the enjoyment of future generations, although the highly altered condition of many of those regulated river ecosystems makes restoration a challenging goal.

The Colorado River is one of the most thoroughly regulated rivers in the United States (Hirsch et al. 1990, and e.g., Ohmart et al. 1988). Glen Canyon Dam is one of its two largest dams, and is managed by the Bureau of Reclamation under the federally designated Adaptive Management Work Group, a committee of diverse stakeholder representatives which makes recommendations to the Secretary of

Interior regarding dam management. The Secretary bases dam management decisions on the Colorado River Storage Project Act of 1956, the Grand Canyon Protection Act of 1992, the 1995 Glen Canyon Dam Environmental Impact Statement (GCDEIS, Bureau of Reclamation 1995) and the 1996 Record of Decision (ROD) in an effort to balance hydropower production with downstream environmental concerns. The GCDEIS and ROD emphasize a management strategy involving limited daily flow fluctuations to enhance in-channel storage of tributary-derived sediments, coupled with occasional planned floods to rejuvenate sand bars and aquatic habitats through lower Glen and Grand canyons (Bureau of Reclamation 1995). Low fluctuating flows were implemented in 1991 to increase in-channel sediment storage.

To test the effectiveness of this flow management strategy, the Bureau of Reclamation conducted a 7 day-long, constant 1275 m^3/s experimental flood from 26 March through 2 April 1996 from Glen Canyon Dam to upper Lake Mead, including all of Grand Canyon. This test flood successfully restored sandbars throughout the Colorado River corridor (Hazel et al. in press). In addition to sediment management, cooperating federal, state and tribal agencies and environmental representatives identified the following objectives for this flood for terrestrial (wetland and riparian) biological resources: 1) maintain open sandbars for camping, 2) provide water to pre-dam upper riparian zone vegetation, and 3) meet these objectives without significant adverse impacts to endangered species. These objectives differ from those described in the GCDEIS (pages 51-57) and the ROD, which emphasize maintenance of a variety of wetland and perennial riparian vegetation assemblages as wildlife habitat, particularly for endangered species and ethnobotanical concerns.

In this study we summarize the impacts of the test flood on terrestrial biological components and processes in the Colorado River ecosystem in Glen and Grand canyons. Specifically, we address planned flood impacts on riparian soils, wetland and sandbar vegetation, ethnobotanical resources, and terrestrial species of concern. We discuss resource management trade-offs in relation to aquatic versus terrestrial, relict versus novel, and single species versus ecosystem-scale values in this large, aridlands, regulated river ecosystem.

STUDY AREA

Glen Canyon Dam was completed in 1963, and lies 26 km upstream from Lees Ferry (km 0), from which distances along the river are measured. It impounds 33 km^3 Lake Powell reservoir, and controls most of the flow through the study area and into Lake Mead. The river flows 472 km between the dam and Lake Mead, including the remaining 26 km of lower Glen Canyon and all of Grand Canyon. This portion of the river flows from 975 m to 370 m elevation. It is constrained by bedrock and talus slopes, and is surrounded by the 2100 m to 2800 m-high Colorado Plateau. The river flows through 13 bedrock-controlled reaches that vary in characteristic width and depth (Schmidt and Graf 1990, Stevens et al. 1997c). The climate is continental and arid, with a mean total annual precipitation of 213 mm/yr at Phantom Ranch (km 142; Sellers et al. 1985). Vegetation in these reaches includes xeric Mohave desertscrub in upland settings, and desert riparian and strandline assemblages along the river (Warren et al. 1992). Other aspects of the geomorphology and ecology of this large desert river ecosystem are described by Howard and Dolan (1981), O'Conner et al. (1994), Johnson (1991), Stevens et al. (1995, 1997a), and Bowers et al. (1997).

Impoundment reduced sediment transport, the mean and variability of temperature in the river, and flood frequency (Howard and Dolan 1980, Stevens et al. 1997c). Virtually no suspended inorganic sediments pass through the dam, but the suspended load increases over distance downstream as the Paria River (km 1) and Little Colorado River (LCR, km 98) and other tributaries contribute sediment. Erosion of sandbars has occurred during post-dam time (Howard and Dolan 1981, Schmidt and Graf 1990, Hazel et al. in press). Cold hypolimnetic releases and introduction of 20 non-native fish has led to the virtual or complete extirpation of 4 of the 8 native fish species in this portion of the river (Minckley 1991, Valdez and Ryel 1997).

Flood control allowed profuse stands of riparian vegetation to colonize river shorelines, especially in the wider reaches of the river (Turner and Karpiscak 1980; Johnson 1991). Local vegetation zonation, and system-wide, reach-based and local/microsite spatial scale differences influence vegetation cover and composition (Johnson 1991; Stevens et al. 1995). This novel post-dam vegetation directly or indirectly supports expanding terrestrial animal populations, including: endangered Kanab ambersnail (*Oxyloma haydeni kanabensis*, Stevens et al. 1997b), threatened wintering bald eagle (*Haliaeetus leucocephalus*; Brown et al. 1989), endangered peregrine falcon (*Falco peregrinus anatum*; Brown et al. 1992), summer breeding and winter waterfowl (Stevens et al. 1997a), and abundant Neotropical migrant songbirds, including endangered southwestern willow flycatcher (*Empidonax trailii extimus*; Brown 1988, Brown and Trossett 1989, Petterson and Sogge 1996, Stevens et al. 1996a). In addition, several Native American cultures and the NPS value the numerous archeological, historic and other culturally significant sites along the river, and the river corridor is intensively used by recreational river runners (Myers et al. in press).

SYNOPSIS OF TERRESTRIAL BIOLOICAL IMPACTS

In the following sections we describe and discuss the methods and results of individual terrestrial studies that were conducted before, during, and $\geq$2 growing seasons after the test flood (Table 1).

Riparian Soils

Soil texture (sediment grain size distribution) is an important determinant of potential vegetation development along the Colorado River (Stevens 1989, Stevens et al. 1995). Kearsley and Ayers (1996) evaluated surficial soil texture in each of numerous vegetation polygons mapped at 9 large recirculation zones through the river corridor. Grainsize was assessed using a subjective scale from 1 (clay) to 3 (coarse sand), and the subjective scale was refined by conducting sieving analyses. Their data suggested that the test flood homogenized (reduced variability) of soils on sand bars, which aggraded with well-sorted fine sand. At km 89R, a large reattachment bar, Stevens et al. (1996b) reported that the grain size of surficially deposited sediments was strongly negatively correlated with current velocity measured during the flood. Fine sand deposition was restricted to sites that sustained velocities >0.2 m/s, while silt was deposited where velocity was <0.2 m/s. Stevens et al. (1996b) also reported that return current channels (RCCs, *sensu* Schmidt and Graf 1990) with high pre-flood concentrations of silt and clay, were not scoured by the test flood, despite velocities of up to 0.9 m/s.

Recirculation zones are a characteristic geomorphic unit of this canyon-bound river (Schmidt and Graf 1990) and may influence local and reach-based nutrient dynamics in this eddy-dominated river ecosystem through ground water flow patterns in sand bars. The transport rate of water and associated nutrients through the km 89R reattachment bar was examined through measurement of hydraulic conductivity of the aquifer materials (Springer et al. in press). The sediments deposited on the bar by the test flood caused the existing sediments to be compressed under the additional mass, greatly reducing the hydraulic conductivity, and therefore the velocity of ground water and nutrient transport through the bar.

Parnell et al. (in Stevens et al. 1996b) demonstrated that the test flood buried large quantities of wetland, grass and herbaceous vegetation under 1-2 m of fine sand. They sited 44 wells (1.5, 3 and 6 m deep) in large reattachment bars at the km -10.5L, 89R and 312L. Field nutrient analyses included nitrate, nitrite, ammonium, and dissolve oxygen (DO), and laboratory analyses included non-purgeable organic carbon (NPOC) and orthophosphate. Ground-water NPOC and ammonium increased by 85-278% and 79-

617%, respectively after the flood, and remained elevated for more than one year afterwards, decreasing in mid-1997. Ground-water DO concentrations decreased at 2 of the sites, reflecting increased microbial decomposition of buried vegetation. These data suggest a linkage between ground-water and surface-water nitrogen concentrations. In contrast, ground- water and surface-water orthophosphate concentrations appeared to be little affected by the test flood, but may be affected by large, rapid changes in discharge.

Wetland and Riparian Vegetation

Fluvial marshes along the post-dam Colorado River exist on silt/clay sediments in low-lying, low velocity settings (Stevens et al. 1995). Pre- and post-flood mapping analyses of wetland vegetation by Kearsley and Ayers (1996) indicate little overall impact of the test flood on large, well-established marshes in RCCs. At their km 89R study site Stevens et al. (1996b) reported that current velocities of 0.9 m/s were not sufficient to scour the RCC floor. At the km 312L site, high densities of cattail (*Typha* spp.) and common reed (*Phragmites australis*) stems may have further reduced current velocity and limited scour. Large RCC marshes are relatively rare, and Stevens (unpublished data) found that the numerous, small patches of channel margin marsh vegetation that had developed during interim flows (low fluctuating flows from 1991 to 1996) were scoured on a system-wide basis. Density of these small marsh patches decreased by 20% to 40%, with more scour observed in narrower, downstream reaches.

Sandbar and channel margin riparian provides novel habitat for high biodiversity and abundance of invertebrates and terrestrial vertebrates (Johnson 1991). Sandbar vegetation was altered by the test flood, but impacts varied between ground-cover and perennial species. Aggradation of 1-2 m of fine sand on sandbar surfaces buried highly productive, ground-covering grass and herbaceous assemblages (Kearsley and Ayers 1996, Stevens et al. 1996a,b). In contrast, pre-established woody perennial species, such as tamarisk (*Tamarix ramosissima*), coyote willow (*Salix exigua*), seep willow (*Baccharis* spp.) and other species, grew up through the new sand deposits and experienced little mortality. Profuse regrowth and rapid recovery of overall perennial cover may have been influenced by increased soil nutrient availability documented by Parnell et al. (in Stevens et al. 1996b).

Kearsley and Ayers (1996) documented a reduction in the sandbar seed bank by germinating seeds from 3 surficial soil samples/vegetation polygon. Soil samples from below the flood stage showed an 80% reduction in seedling density and species richness following the flood, while samples from above the flood stage revealed little overall pre- versus post-flood difference.

The test flood was specifically scheduled to avoid dispersal and germination of non-native plant species, including tamarisk and Ravenna grass (*Saccharum ravennae*). Tamarisk is well known as a flood-dispersed invading species; however, its seeds are short-lived and do not persist over winter (Stevens 1987). The test flood was timed to allow at least several weeks for the reworked sand bar surfaces to desiccate, and thereby prevent germination of tamarisk. Although this scheduling strategy was highly successful, the subsequent high/steady flow regime in 1996 and 1997 allowed some successful tamarisk establishment (Stevens, personal observation).

Ravenna grass is a tall, European bunchgrass that was introduced by the NPS as an ornamental at Wahweap Marina on Lake Powell. The invasion of this species, as well as giant-reed (*Arundo donax*) and Russian olive (*Eleagnus angustifolia*) into the river ecosystem was recognized in 1991 by Stevens and Ayers (1995). In 1992, as discussions of planned flooding began, a non-native plant control program was initiated using volunteer labor. This program mechanically removed approximately 10^4 Ravenna grass plants, and numerous individuals of Russian olive and giant-reed. As a result of this effort, those species have not proliferated (Kearsley and Ayers 1996), and the on-going NPS monitoring and control program has been highly effective in preventing further invasion (K. Crumbo, Grand Canyon NPS Wilderness Coordinator, personal communication). Similarly, non-native *Lepidium latifolium* (Brassicaceae) and *Eragrostis curvula* (Poaceae) distributions were not obviously affected by the test flood (Kearsley and Ayers 1996), but non-native camelthorn (Fabaceae: *Alhagi camelorum*) may have increased through hydrochory or in response to the nutrient pulse as a result of the test flood (Stevens, personal observation).

Pre-dam, upper riparian zone (URZ) vegetation was identified by stakeholders as a resource that could benefit from the test flood. This vegetation zone characterized the pre-dam river ecosystem, and may be in a state of long-term decline because of failing recruitment (Stevens and Ayers 1995). However, exhaustive stem growth and dendrochronological studies by Anderson and Ruffner (1988) failed to document increased growth under flows of >2700 m^3/s in 1983 and flows >1275 m^3/s in 1984-1986. This stakeholder objective was not pursued during the test flood because: (1) existing literature demonstrated that no relationship exists between high flows and URZ vegetation growth, and (2) the 1996 test flood stage and duration were much shorter than those of the 1983-1986 floods in which the original research had been conducted.

Ethnobotanical studies by the Hualapai Tribe also indicated that although the flood-related increases in grain size were detectable for >430 km downstream from the dam, and >20 km onto upper Lake Mead, overall flood impacts on riparian vegetation were nominal (K. Christensen and A.M. Phillips, III, Hualapai Tribe, personal communication). They documented reduced plant species richness at 2 of 4 large study sites, but equivalent cover prior to and after the flood, and rapid recovery of that vegetation during 1996.

Species of Special Concern

Kanab Ambersnail: Known populations of endangered Kanab ambersnail (KAS, Succineidae: *Oxyloma haydeni kanabensis*) occur only at 2 springs in the Southwest, one of which is Vaseys Paradise (VP) at Colorado River km 51R (Stevens et al. 1997b). The VP KAS population occurs primarily on 2 host plant species: native crimson monkey flower (*Mimulus cardinalis*) and non-native watercress (*Nasturtium officinale*), and the cover of the host plant species increased downslope from the 1275 m^3/s stage at VP following dam construction. The Kanab Ambersnail Interagency Monitoring Group (KAIMG, 1997; Meretsky et al. in press) documented the test flood impacts on this snail population. Topographic surveys at VP before the flood revealed that 157.2 m^2 of KAS habitat existed downslope of the 1275 m3/s stage, including 51.3 m^2 of monkeyflower and 39.2 m^2 of watercress. The flood scoured 67.4% of the flood zone vegetation, leaving only 14.3 m^2 of monkeyflower and 14.1 m^2 of watercress; however, virtually none of the remaining habitat was suitable for KAS occupation. Habitat recovery was monitored through 1997, and requires >2 full growing seasons to return to pre-flood levels, with slow recolonization of scoured, high angle bedrock surfaces.

The KAIMG (1997) sampled a total of 180 20-cm-diameter plots before the flood and estimated that 2115 KAS existed below the 1275 m3/s stage. A total of 1275 KAS were marked and moved above the 1275 m^3/s +0.5 m stage prior to the flood. Based on 96 20-cm-diameter plots or full patch counts from the mid-April 1996 post-flood population survey, an estimated 400 KAS existed downslope from the peak flood stage. They observed that several KAS had recolonized a watercress patch just below the 1275 m^3/s stage by mid-April, 1996. Monthly KAS population surveys in these same habitat patches revealed that the KAS population in the lower VP study area remained lower than 1995 population levels well into 1997.

Southwestern Willow Flycatcher: Endangered southwestern willow flycatchers (SWWF) nest in the wide reaches of the Colorado River in Grand Canyon (Brown 1988). Over the past 2 decades of study, SWWF have built nests in dense groves of non-native tamarisk, occasionally with a scattered overstory of taller trees, near fluvial marshes. A 1996 U.S. Fish and Wildlife Service Biological Opinion on the test flood defined several measures to mitigate impacts on the SWWF in Grand Canyon. Stevens et al. (1996a) studied habitat changes at 4 historic nest sites in Grand Canyon. Fluvial marshes associated with these sites were dominated by common reed, horsetail (*Equisetum* spp.) and cattail. SWWF research activities included verifying stage-to-discharge relations, quantifying flow depth and velocity at nest sites; nest site and foraging habitat structure, and litter/understory characteristics; and nesting success.

Stage-to-discharge relationships at nest sites were within 0.4 m of predicted elevations (Stevens et al. 1996a). Nest stand vegetation impacts were nominal: 2 stands were slightly scoured, and 3 sites sustained a slight reduction in groundcover and/or branch abundance at <0.6 m above the ground; however, no reduction in branch abundance or alteration of stand composition occurred, and high flows did not reach any historic nest trees. Impacts on marsh foraging habitats were more severe, with decreases in area of 1% to >72%. Two of 4 SWWF sites regained vegetated area during the summer of 1996, while 2 other marshes sustained slight additional losses in cover through the 1996 growing season.

Petterson and Sogge (1996) reported 3 singing SWWF, but only one successfully breeding pair along the Colorado River in upper Grand Canyon in 1996. The single pair apparently fledged 2 young. SWWF nesting success in this system is limited by brown-headed cowbird (*Molothrus ater*) brood parasitism (Brown 1994). In 1997 SWWF failed to nest successfully in upper Grand Canyon for the first time since monitoring began in 1983, because of cowbird brood parasitism (M. Sogge, U.S. Geological Survey Biological Resources Division, unpublished data).

Other Species of Concern: Several other rare populations were monitored during the test flood. A single population of northern leopard frog (*Rana pipiens*) exists at -9 Mile Spring, a riverside spring at km -15L (Drost and Sogge 1995). Although most of its habitat was inundated by the test flood, the frog population persisted apparently without major impact (Spence, personal communication). The exceptionally warm winter of 1995-96 allowed the frog population to be active prior to the event. Also, one of 2 known populations of Niobara ambersnail (*Oxyloma h. haydeni*) in Arizona occurs at that spring, and likewise survived the test flood.

The seasonal timing of the test flood was designed to prevent major impacts to other avian species. Threatened bald eagle concentrate in upper Grand Canyon during February and early March, to feed on non-native spawning rainbow trout (*Oncorhynchus mykiss*; Brown et al. 1989). By staging the test flood one month after the height of eagle concentration, no impacts were anticipated or observed on this threatened species, save those induced by human disturbance (Brown and Stevens 1997). Neotropical migrant passerine birds and endangered peregrine falcon typically do not commence nesting until early to mid-April (Brown et al. 1992), and belted kingfisher (an Arizona state species of concern) is most abundant during April (Stevens et al. 1997a) . As with non-native plant issues, appropriate hydrograph scheduling can be used to avoid undesirable impacts on biological resources.

DISCUSSION AND MANAGEMENT IMPLICATIONS

The 1996 test flood was successful as a sediment management exercise; however, terrestrial biological management activities largely focused on mitigation of negative impacts. This ecosystem restoration effort presents one practical and two valuation and trade-off dilemmas. First, and from a practical standpoint, management for aquatic and sediment-related resources and processes may directly conflict with management for some riparian resources and processes (Table 1). The planned flood restored sand bars and, while well-intended, it created only 0.6 ha of new fish nursery habitat and largely failed to rejuvenate those backwater habitats (B.Ralston, Applied Technology Associates, Inc., personal communication). However, it reduced shoreline vegetation that supports endangered wetland and riparian snail and avifauna species. Management for both aquatic and terrestrial endangered species requires detailed knowledge of life histories and population, as well as administrative flexibility in year-to-year management strategies.

Second, societal valuation of pre-dam versus post-dam resources and processes is complicated by the developing refugial condition of the post-dam river ecosystem (Stevens and Wegner 1995). In contrast to widespread loss of wetland and riparian habitat throughout the Southwest (Dahl 1990), diverse and biologically productive habitats developed as an unanticipated consequence of flow regulation downstream from Glen Canyon Dam. Native riparian fauna has extensively colonized this increasingly rare and fragmented habitat type, and the high levels of biodiversity confer considerable regional conservation value to this altered river ecosystem. Present management strategies emphasize resource protection when legally mandated (e.g., endangered species and archeological sites); however, management of ecologically important components (e.g., wetlands, sandbars, and rare but legally unprotected populations, such as the Niobara ambersnail and the northern leopard frog) and processes (e.g., riparian plant succession) has been nebulous and may change through time. Adaptive ecosystem management by the Adaptive Management Work Group involves discussion, learning and cooperation between stakeholders who have conflicting management missions, and will have a lasting impact on ecosystem development (Table 2). The loss or precipitous decline of at least 9 vertebrate species in the post-dam river corridor in Grand Canyon National Park is one indication of the need for improved management in this system. However, the lack of information on the pre-dam benthos and fishery in Grand Canyon, as well as the poor condition of native fish populations in the largely unregulated Cataract Canyon reach upstream from Lake Powell, complicates the on-going debate over the desired future condition of the regulated river ecosystem.

The third dilemma facing adaptive management is resolution of conflicts between managing individual species versus the overall Colorado River as a human-dominated ecosystem, including the socio-economic values associated with hydroelectric power generation and recreation. The 1996 planned flood had a range of impacts on the ecosystem, and adoption of the GCDEIS flow plan will have long-term consequences. This was likely the first of numerous such events that may be conducted, and decisions regarding future flood frequency and hydrograph shape are the subject of on-going debate. Analysis of sediment storage and export from 34 recirculation zones throughout the river corridor indicates that no more than 10% of the sediment moved in eddies during the test flood contributed to bar building in those eddies (Hazel et al., in press). By itself, those results suggest that high flows should occur only on a 10-yr basis, depending on tributary delivery rates. However, shorter duration, more frequent floods may be useful to store tributary-derived sediment in channel margins, thereby prolonging residence time. The test flood only increased sand bar volume and area for 1 - 2 yr, but impacts on endangered KAS, its habitat, and riverine marshes last $\geq$2 yr. These and other biological impacts may be considered as permanent if planned flood frequency continues at a two-yr frequency in this system. Again, flexibility in year-to-year management may provide options for managing this diverse suite of ecological and socio-economic resources and processes.

ACKNOWLEDGMENTS

We thank the Bureau of Reclamation Glen Canyon Environmental Studies Program staff, Applied Technology Associates, Inc., the Arizona Game and Fish Department (especially D. Kubly and J.

Sorensen), the U.S. Fish and Wildlife Service (especially D. Bills and R. Marshall), the Grand Canyon Monitoring and Research Center, the Hualapai Tribe, the National Park Service (especially J.R. Petterson), Northern Arizona University, and O.A.R.S., Inc. for administrative and logistical support. Volunteers too numerous to name individually contributed many hours to data collection and are thanked for their dedication and enthusiasm. Anonymous reviewers provided valuable comments on earlier versions of the manuscript.

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Table 1: Impacts of the 1996 test flow on terrestrial biota in 3 land management divisions of the Colorado River corridor downstream from Glen Canyon Dam, Arizona.

Resource	Management Division: Glen Canyon	Grand Canyon	Hualapai Indian Reservation
Vegetation			
Wetland	0 to -	0 to -	0 to -
Perennial bar/channel margin	0	0	0 to -
Upper Riparian Zone	0	0	0
Non-native species colonization	0	0 to slight +	0 to slight +
Kanab ambersnail	NA	-	NA
Niobara ambersnail	0	NA	NA
Northern Leopard Frog	0	NA	NA
Avifauna			
Waterfowl	0	0	0
Bald eagle	0	0	0
Peregrine falcon	0	0	0
Belted Kingfisher	0	0	0
Southwestern willow flycatcher	NA	0 to slight -	NA?

Table 2: Long-term implications of the GCDEIS flow regime, including planned floods, on wetland and riparian biota, assemblages, and processes in the Colorado River ecosystem downstream from Glen Canyon Dam.

Species or Assemblage	Site (km)	Comments
Fluvial marshes	Throughout	Some reduction in cover and productivity
Sand bar vegetation	Throughout	Some reduction in cover and productivity
Pre-dam upper riparian zone vegetation	Throughout	No benefit of short-duration flow; possible long-term decline because of failing recruitment and lack of flows > 3540 m^3/s (pre-dam annual floods)
Kanab Ambersnail	51R	Reduction in primary habitat, population from 1995 conditions; no anticipated threat to population.
Niobara ambersnail	-15L	Slight negative threat to habitat and population.
Northern Leopard Frog	-15L	Slight anticipated threat to habitat and population.
Peregrine Falcon	Throughout	No measurable population impacts.
Bald Eagle	Upstream of km98	Manage through appropriate timing of high flows and human disturbance
Belted Kingfisher	Throughout	No anticipated threat to population.
Southwestern Willow Flycatcher	81-472	No impact on nest stands; reduction of foraging habitat in marshes; significance unclear, but minor threat to population.