THE STATE OF NATURAL AND CULTURAL RESOURCES IN THE COLORADO RIVER ECOSYSTEM

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ABSTRACT

The status of physical, natural and cultural resources of the Colorado River affected by Glen Canyon Dam are summarized to provide relevant information to stakeholders and the newly formed Adaptive Management Work Group. In addition, this 1997 (Fiscal Year 1998) State of the River Ecosystem Report derives most of its understanding of riverine resource status from analyses of data collected prior to, during and after the 1996 Bureau of Reclamation Beach/Habitat-Building Flow experiment, hereafter referred to as the "1996 Test Flow."

Physical resources and processes are related to mainstream and tributary flow and sediment interactions from the 1996 Test Flow mobilized sediments, rejuvenated numerous sand bars, including 50% to 84% of river camping beaches, and deposited protective sediments in arroyos having cultural sites. However, bar-building did not exceed that observed from the 1983-1984 high flows.

Substantial erosion occurred during the high sustained flows of late 1996 and 1997, after the 1996 Test Flow. During the 1996 Test Flow, bar building was rapid in eddies downstream of the Little Colorado River, and secondary recirculation was identified as an important sediment redistribution process. The 1996 Test Flow reworked new debris flows at tributary mouths, reshaping some Grand Canyon rapids. Sediment storage on the bed of the Colorado River was reduced until mid-summer 1997, when monsoon flooding in the Paria River contributed substantial new fine sediments. One hypothesis from this above information is that more frequent, short-duration high flows may help conserve sediment in this system.

Changes in water flows affect aquatic biological resources including the aquatic foodbase and fisheries. High flows in 1996-1997 resulted in extensive colonization of the 8,000 cfs to 20,000 cfs zone by benthic macrophytes and invertebrates, which comprise the aquatic foodbase. The 1996 Test Flow reduced this foodbase briefly, but it recovered quickly and minimal impact was reported on the fisheries. The 8,000 cfs constant flow of August 30 through September 1, 1997 desiccated exposed macrophyte beds, but also created minimal impact on the fisheries.

Endangered humpback chub have a restricted breeding range in the Little Colorado River (LCR), and the population may be declining. Native suckers breed in tributaries, including the LCR, and like humpback chub, their young are probably susceptible to thermal shock as they drift into the mainstream. Neither native fish nor rainbow trout were detectably affected by the 1996 Test Flow and their populations appear to be similar to the pre-1996 Test Flow condition. The

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[1]For the purpose of this document, the Colorado River ecosystem is defined as the Colorado River mainstem corridor and associated riparian and terrace zones primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, a distance of approximately 293 river miles.

Glen Canyon reach supports a blue-ribbon rainbow trout fishery, of which as much as 70% may be naturally produced.

Water flows and sediment affect terrestrial biological resources, such as wetland and riparian soils, vegetation and fauna, including several species of concern. The Test Flood in 1996 buried pre-existing sandbar vegetation, homogenized riparian soil texture, and increased groundwater and soil nutrient concentrations in 1996-1997. Slight gradients established under constant flows may direct groundwater flow patterns. Wetland and riparian vegetation has become established since 1963, and some was scoured by high flows. Sandbar ground cover vegetation buried by the 1996 Test Flow has recovered little and the seed bank was reduced, but previously established woody vegetation did not suffer dramatic mortality. The timing of the 1996 Test Flow limited saltcedar seedling establishment, but constant high flows in latter 1996 through 1997 allowed more establishment in 1997. These impacts were observed throughout National Park Service lands and on the Hualapai Reservation below Mile 250.

Terrestrial species of concern are being monitored to determine long-term population trends and responses to adaptive management floods. The Kanab ambersnail exists at Vaseys Paradise in native and non-native herbaceous vegetation. The 1996 Test Flow reduced its habitat and population size and recovery in the flood zone has been limited by slow reestablishment of host plant vegetation. Endangered southwestern willow flycatcher wetland feeding habitat was reduced by the 1996 Test Flow, but no direct impacts on nesting trees or on the birds themselves were detected. The -9 Mile Spring populations of northern leopard frog and Niobrara ambersnail survived the 1996 Test Flow and exist in good abundance in 1997. No 1996 Test Flow impacts on endangered peregrine falcons or threatened bald eagle were discernable, and 1997 populations appear reasonably robust.

The short-term and long-term impacts of the currently implemented Preferred Alternative, coupled with planned floods, may include short and long-term changes in populations of some species of concern and in some habitat types, as well as tradeoffs between aquatic and terrestrial resource components. As such, future planned high flows in this ecosystem are likely to continue to require consultation with the U.S. Fish and Wildlife Service.

Monitoring and mitigation was conducted at cultural resource locations, including archaeological and ethnobotanical sites, that had the potential to be affected by the 1996 experimental flow. Monitoring occurred at 36 archaeological sites and mitigation activities at eight locations along the river corridor. Ethnobotanical resources were monitored at five locations and at the Goodding willow at Granite Park. The overall findings of the cultural resources studies done in conjunction with the 1996 Test Flow strongly suggest that it either had no adverse effect, or had a beneficial effect, on cultural resources. Sediments were redeposited along terrace margins providing a stabilizing buffer to deposits containing cultural materials. Ethnobotanical resources experienced areas of scouring that promoted a later renewal of vegetation. Preventative stabilization was conducted at the Goodding willow and it appeared healthy during the 1996 growing season.

Monitoring that has been conducted subsequent to the 1996 Test Flow indicates that physical impacts continue at some of the monitored resource locations. Surface erosion appears to be the most frequent physical impact. Bank slumpage, gullying and arroyo cutting is present at resource locations where drainage systems are actively changing to achieve the dam-induced, lowered river baselevel. These impacts were identified at approximately 34% of the monitored sites. Ethnobotanical resources appear to be recovering and monitoring continues. The Goodding willow at Granite Park has continued to be monitored as continuous high flows in 1997 may have removed stabilized sediments in the root area.

The economic implications of conducting 1996 Test Flows, or future, as-yet-undefined "Adaptive Management Flows," primarily relate to changes in power generation. However, changing flow regimes can affect other resources, including recreational whitewater boating and sport fishing which will be evaluated in future flows. Assessment of resource reports of adaptive management flows to date have largely focused on evaluation of impacts on power revenues. The 1996 Test Flow Flow resulted in a loss of generation, which had to be replaced by purchases to meet Western's contractual commitments to deliver power, and thus repay dam operation and maintenance costs. This resulting additional cost was approximately $3,900,000.

INTRODUCTION

Many of the physical, biological and cultural resources and processes of the Colorado River ecosystem affected by Glen Canyon Dam are dynamic, and although most changes do not normally occur abruptly, resources may change considerably through time. Some resources do change in a punctuated fashion, rapidly responding to changes in flow regimes. For example, sand bars rejuvenated by the 1996 Beach/Habitat-building Flow began to erode immediately after the event. Other resources shift more gradually; for example, the aquatic foodbase in the Glen Canyon reach changed more gradually during Interim Flows (1991 to 1995).

Assessment, use, management and effective protection of ecosystem products and services requires a clear definition of the desired future condition of resources and processes, and must be based on knowledge of antecedent conditions and trends through time.

Monitoring and science programs are critical in providing appropriate knowledge of resource change resulting from differing dam operations. Effectively managed flow regimes can enhance many resources in this ecosystem, and a science-based adaptive management process is the best approach to assure effective management that optimizes stakeholder concerns while affording appropriate protection, management and use of the river ecosystem.

Colorado River ecosystem stakeholders have requested from the GCMRC an annual evaluation of state of the river ecosystem resources. This report also fulfills part of the requirements of Section 1804, subsections (c) and (d) of the 1992 Grand Canyon Protection Act, as well as some requirements of the 1995 Glen Canyon Dam Environmental Impact Statement (GCD-EIS) and 1996 Record of Decision (ROD). This evaluation, combined with information on predictions of future reservoir storage and weather, can be used as resources to discuss potential flow regimes to protect and/or enhance the Colorado River ecosystem. This report presents the 1997 state of the Colorado River ecosystem in relation to the March/April 1996 Experimental Flow (45,000 cfs for 7 days, hereafter referred to as the 1996 Test Flow), and subsequent high sustained flows (20,000-27,000 cfs) in 1996 and 1997.

FLOW HISTORY

Discharge from Glen Canyon Dam in 1996 and 1997 reflected the transition from Interim Flows to ROD management strategies, and a transition from a relatively normal year to a high inflow year (Figure 1). Dam releases in 1996 generally varied between 8,000 cfs and 19,000 cfs, with high end fluctuating flows predominating prior to, and after the Beach Habitat Building Flow. During the late March/early April 1996 Test Flow, discharge was maintained at 45,000 cfs for 7 days. Lower fluctuations in flows occurred in the autumn of 1996.

High snowpack accumulation in the Rocky Mountains in the winter of 1996-97 increased the likelihood of high flows into Lake Powell, and discharge levels from Glen Canyon Dam were increased to a constant 27,000 cfs in late February and March 1997. High constant flows of 24,000 predominated in March and April, and was maintained at nearly constant flows of 20,000 to 21,000 cfs from May through August. A 3-day constant 8,000 cfs flow experiment was conducted from August 30 through 1 September (Labor Day) to compare sandbar size and distribution with that of previous years.

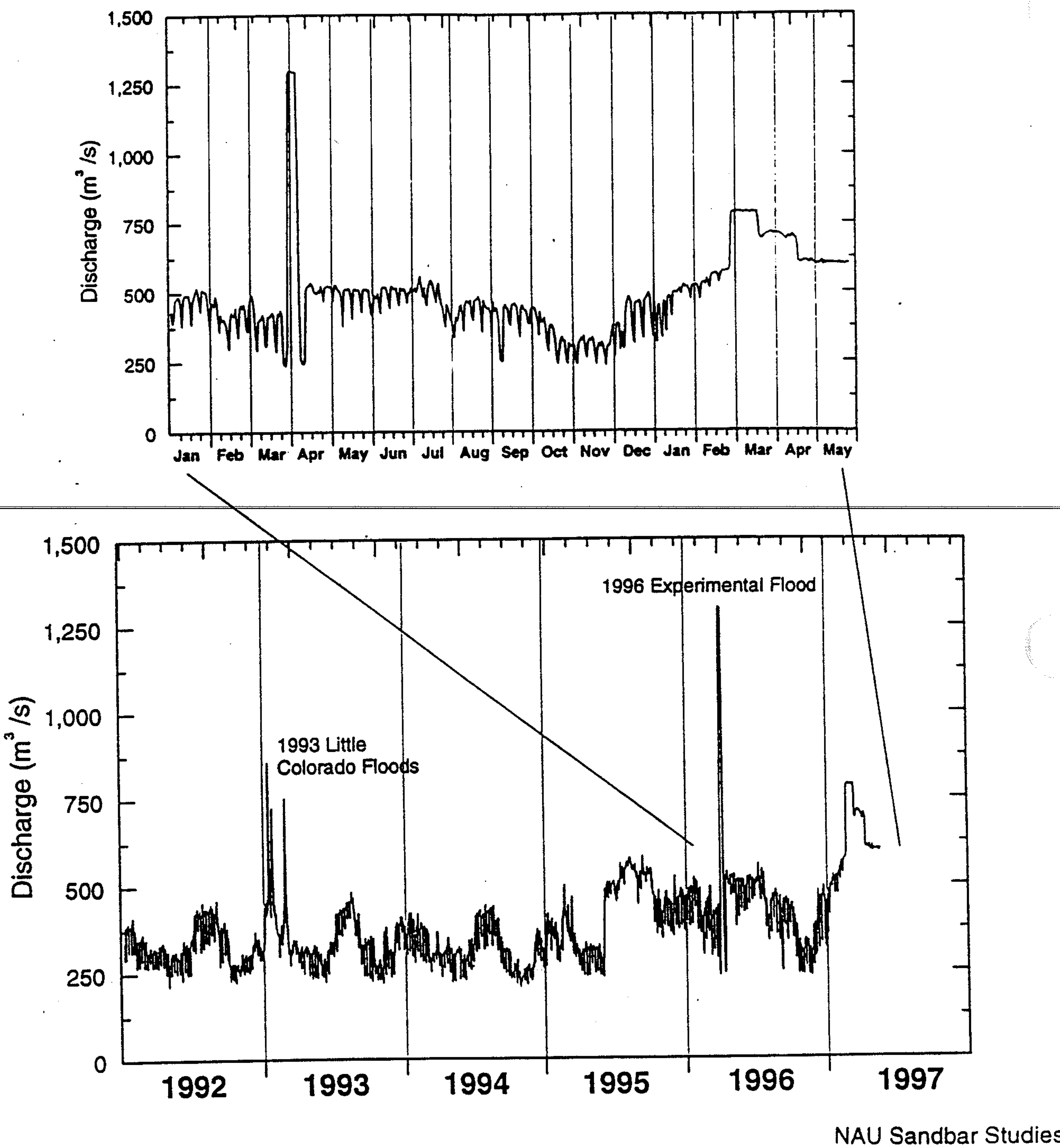


Figure 1: The Colorado River hydrograph at the U.S. Geological Survey stream-gaging station at Grand Canyon (near Phantom Ranch), 1992 to 1997.

PHYSICAL RESOURCES

The March/April 1996 Test Flow was a scientific and sediment management success: however, it created nearly as many new questions and concerns as it did new sand bars. Many of the new beaches have been partially or substantially eroded by 1996 and 1997 high steady flows.

Flow and Sediment Relationships: The 1996 Test Flow provided an opportunity to collect important data on streamflow, water chemistry, and sediment transport at discharges well above powerplant capacity. The U.S. Geological Survey collected data at five streamflow gaging stations on the mainstream and in four tributaries (Konieczki et al. 1997). Reach-averaged flow rates were measured by tracking the movement of a tracer dye, and sediment movement was measured by measuring bed elevation at a network of 120 monumented cross-sections before and after the 1996 Test Flow.

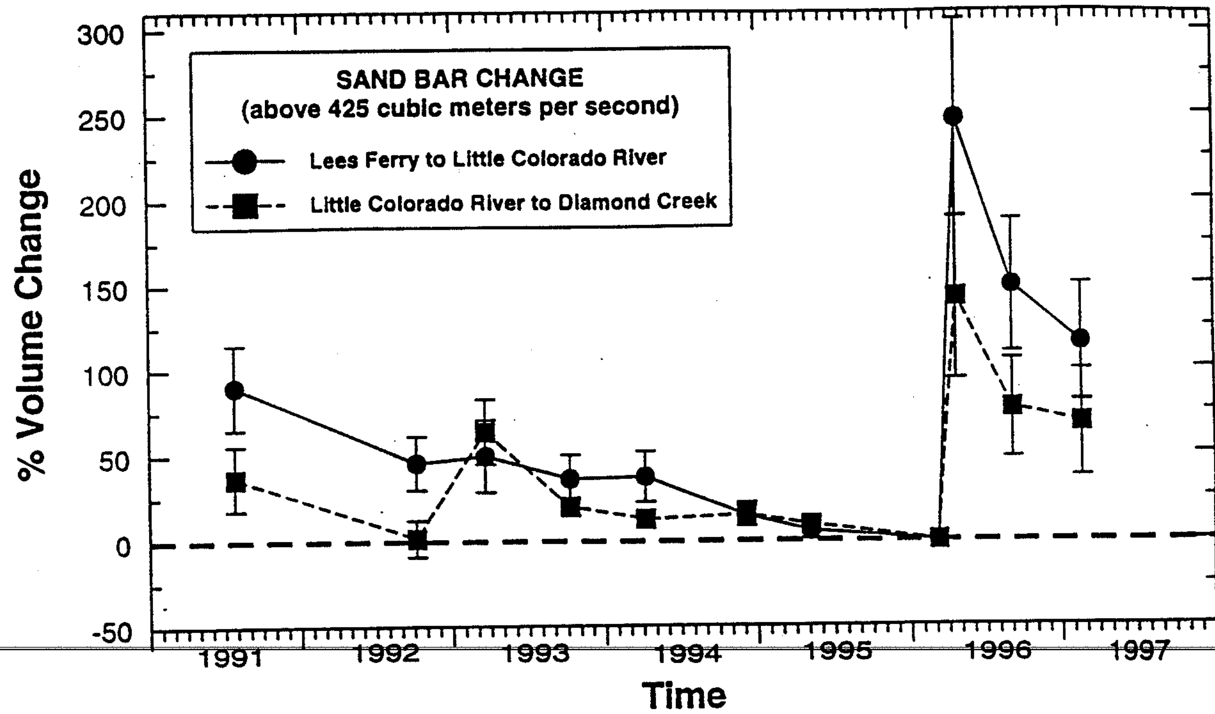
Sand stored in the mainstream below Glen Canyon Dam was mobilized at discharges between 20,000 and 45,000 cfs, and was deposited as separation, reattachment and channel margin bars throughout the river corridor (Figure 2). However, deposition varied by geomorphic reach, and with respect to sediment availability (upstream versus downstream of the LCR). Beach-building in many reaches did not meet or exceed that observed following the high-flow period that occurred between June, 1983 and October, 1984, largely because the 1983 peak flow (97,000 cfs) was twice the magnitude of the 1996 Test Flow.

The primary hypothesis tested during the 1996 Test Flow was whether artificial flooding could be used for sediment management. Sand was entrained quickly and efficiently by the flood, and aggradation occurred rapidly at most depositional sites throughout the Colorado River ecosystem. In some cases, subaqueous bar surfaces accumulated up to five meters of new sand, far in excess of researcher predictions. Deposition of sand in fan-eddy complexes occurred so quickly that some research instrumentation was buried. Overall, the 1996 high release was effective in restoring some of the sediment transport processes.

Suspended sediment concentrations within mainstem flow and within eddies fell off rapidly during the first 48 hours after stage reached 45,000 cfs, and continued to decline at a slower rate throughout the seven-day long peak flow. The particle-size distribution of suspended sediment simultaneously coarsened in the main stem and in eddies as the sediment concentrations declined.

Sediment Transport Process: During the flood, rapid deposition was attributed to "secondary recirculation" within eddies and along shorelines in pools and runs. This process had not been previously recognized by USGS researchers in Grand Canyon, and reduced sand export to Lake Mead. Secondary recirculation was especially effective in system-wide deposition of channel-margin bars; an important point with respect to sediment conservation.

Hysteresis, a change in sediment transport/deposition with respect to discharge over time, was documented by USGS in association with sediment coarsening and reduced sediment concentrations during the 1996 flood. A similar phenomenon was previously documented in



NAU Sandbar Studies

Figure 2: Percent sand bar volume change upstream and downstream from the Little Colorado River confluence, 1991-1997. Zero on the Y-axis represents the February 1996 condition, immediately prior to the March/April 1996 Test Flow. Error bars are ±1 sd. Data courtesy of Parnell et al. 1997, Northern Arizona University.

the 1950s on the Colorado River, but has never before been documented below Glen Canyon Dam under controlled flood conditions. The shifting particle-size response over a relatively short time period (48 hours) during the flood, suggests that the system may be perpetually sediment limited; especially upstream of the Little Colorado River confluence. Finer sand inputs from the Paria and Little Colorado Rivers may not remain in storage for more than a few days to weeks under high-constant ROD dam operations.

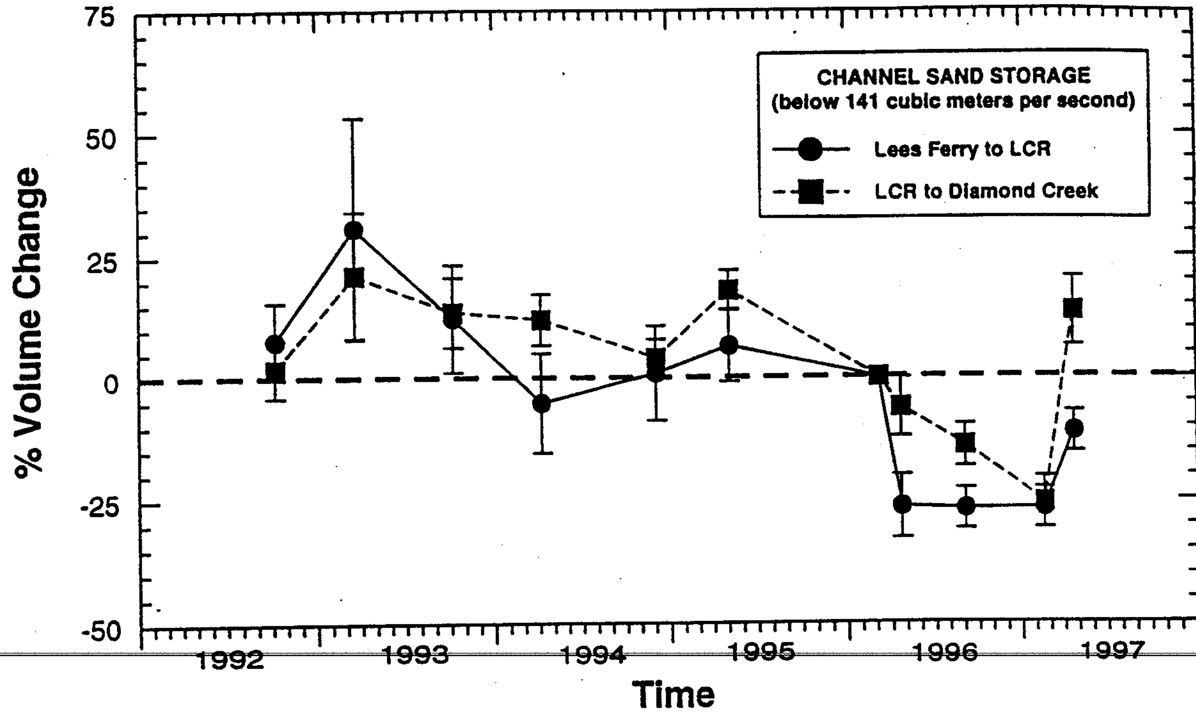
Sand Bar Rejuvenation: The 1996 Test Flow caused a net increase in the area and volume of high-elevation sand deposits throughout Grand Canyon, regardless of location or geomorphic setting of the deposits (Figure 2). The volume of sand deposits at elevations greater than the 15,000 cfs stage increased by more than 90 percent among 34 survey sites (Parnell et al. 1996). These sites were 197 percent larger than they had been immediately prior to the flood. Abundant new high-elevation sandbars were mapped along 16 miles of river in the Point Hansbrough—Saddle Canyon and Little Colorado River—Unkar Rapids study reaches (Schmidt 1997).

There was a consistent form of bar response throughout Grand Canyon. Low elevation parts of reattachment bars in the centers of eddies, as well as the adjacent mainstream channel, were scoured, while the reattachment zones were filled (Schmidt 1997; Figure 3).

The 1996 Test Flow impacts also varied by reach (Figure 2). The flood caused a net increase in the area and volume of sand at sites upstream from the Little Colorado River. Sites upstream from the LCR measured by Northern Arizona University proportionally increased more than sites located elsewhere (Parnell et al. 1996). Although there was a reach-average response for bars, there was also substantial variability in net aggradation from site-to-site. Specific sites eroded more or deposited more than the average condition. The distribution of responses seems to be normally distributed (Parnell et al. 1996, Schmidt 1997).

Sandbars were 97% larger after the Test Flow than immediately prior to the Test Flow. High rates of erosion occurred at all sites during the 6 months immediately following the flood (Figure 2). Nevertheless, sandbars were 97 percent larger than they had been immediately prior the flood. Typically, high elevation sand deposits have eroded, low elevation parts of eddy bars have increased in area, and channel pools remain in a scoured condition (Parnell et al. 1996; Kaplinski et al. 1997).

Until the summer monsoons in August 1997, the bed of the Colorado River below Glen Canyon Dam existed in a coarsened state. Because of below average inputs from the Paria and Little Colorado rivers, and because of the constant 18,000 cfs of 1995, the 1996 Test Flow of 45,000 cfs, and the long-term sustained 20,000 to 27,000 cfs high releases, the sand stored in the channel appeared to be as coarsened as it had been following the 1983-1986 high flow period. Under such conditions, a flood identical to the one that occurred in 1996 would likely have a much lesser depositional impact on sandbars, as well as downstream sediment transport.



NAU Sandbar Studies

Figure 3: Percent channel sand volume change upstream and downstream from the Little Colorado River confluence, 1991-1997. Zero on the Y-axis represents the February 1996 condition, immediately prior to the March/April 1996 Test Flow. Error bars are ±1 sd. Data courtesy of Parnell et al. 1997, Northern Arizona University.

Sedimentary structures studied in flood deposits revealed that bed forms evolved during the flood from climbing ripples to cross-stratified dunes. This shift correlated closely with coarsened sediment textures seen in beach trenches. Usually, this bed-form evolution would be associated with increased flood power associated with, but in this case the phenomenon could only indicate sediment limitation, since flood magnitude was constant.

Debris Fans and Rapids: Twenty-five new debris flows occurred in Grand Canyon between 1987 and 1995, and these flows created 2 new rapids and narrowed 9 other rapids. Recently aggraded debris fans and rapids were reworked by the 45,000 cfs flood to varying degrees, depending on local site conditions and on the length of time since debris flows occurred. The 1996 Test Flow rearranged many of these fans and increased the width of many rapids. Most of the reworking of the fans occurred during the rising limb of the 1996 Test Flow (Webb et al. 1997). Older deposits generally showed less response to flood reworking than did the most recent sites, such as Badger and Lava Falls Rapids.

Fan and rapid reworking was more dependent on peak flood magnitude than on flood duration. A flood with a higher peak flow for a single day would likely have had a more significant reworking impact than the 1996 Test Flow. If aggraded fans and rapids are a management concern in the future, then larger flood peaks of shorter duration following debris flows may be most effective in reversing aggradation of fan-eddy complexes; however, such flows are presently outside the flow criteria specified in the ROD.

None of the debris fans aggraded by debris flows since 1986 were completely restored to pre-debris flow conditions. Increased fan elevations resulting from recent debris flows have had an enhancing effect on low-velocity pools that form upstream of these natural check dams. Enhancement of upper pools has been associated with increases in bed-storage capacity for sand locally. Hence, long-term increases in channel-stored sand above aggraded fans will likely occur through time as future debris flows occur; especially if such sites remain only partially reworked by floods similar to the 1996 Test Flow.

Campsite Rejuvenation: The 1996 Test Flow greatly increased campsite availability, and campsites remained enlarged for at least 6 months following the event. Fifty percent of all campsites in all reaches increased in usable area (Kearsley and Quartaroli 1997). Eighty-four percent of all beaches monitored by the Colorado River guides and located in critical reaches increased in usable area (Thompson et al. 1997). However, the 1996 Test Flow did not restore sandbars to their pre-dam condition, nor were they restored to their condition of the mid-1980s (Kearsley and Quartaroli 1997, Schmidt 1996). Prolonged high flows in 1996 and 1997 subsequently eroded many of those campsite beaches.

Sediment and Cultural Sites: It has been hypothesized that dam-related erosion of channel margin sand deposits and reduced high flows, has resulted in headward erosion of arroyos and the archeological sites they protect. Interuption of the process of spring-flood sediment deposition by Glen Canyon Dam may have exacerbated erosion of these culturally significant sites.

The 1996 Test Flow deposited new sand in these arroyo mouths, deposits which remained in place through 1996, temporarily protecting these sites. In combination with site stabilization/mitigation efforts implemented by the NPS, the 1996 Test Flow appears to have provided temporary protection against ongoing terrace drainage erosion at these archeological sites.

Sediment Management: Both Glen and Marble Canyons may be in a persistent, long-term state of sediment deficit, since former estimates of sand inputs from the Paria and outflow from Marble Canyon did not take hysteresis into account. Based on existing model results, sand outputs from Marble Canyon exceed sediment inputs from the Paria when hysteresis is included in the model. This condition suggests that a "scour wave" may have slowly migrated downstream from Glen Canyon Dam since 1963. The scour wave may have slowed temporarily after reaching the geomorphic boundary in Marble Canyon where the river widens significantly (about river mile 38-40).

Future management flows may require consideration of sediment storage, in concert with other resource needs in the various reaches, and also the particle-size distribution of those sediments. Hence, future efforts should focus on monitoring sediment availability and grain-size distribution. More frequent, higher magnitude (35,000 to 90,000 cfs) but shorter duration flows may be recommended in the future to test the hypothesis of rapid deposition of sand through secondary circulation along the Colorado River. In combination with coarsened particle-sizes, such flows may allow for maximum sediment conservation under high flow periods. Such floods used as sediment management tools would quickly deposit finer sand in the channel at high elevations along the river's shorelines while coarsening sand stored on the mainstem bed. Coarsened sand on the bed may act to reduce downstream transport to Lake Mead under ROD operations by shifting the suspended sediment transport curve.

New science noted above suggests that short duration floods of greater magnitude than the 1996 Test Flow may conserve sand by storing it at higher stage elevations. These high flows might be used when stored sediments are in a coarsened condition and may not be effective at all sites. At other times, such as following a period of high flood frequency from the Paria and LC Rivers occurring in dry years, smaller magnitude floods of somewhat longer duration might be the proper prescription. Adaptive management releases would be designed for the antecedent conditions and objectives preceding such a high flow. During surplus years, one scenario might be to use annual or more frequent high flows to store sediment. Once deposited at higher stages, even high sustained releases would have a limited capacity to export sand out of the system because bed materials would be coarsened. Smaller floods (perhaps in conjunction with tributary inflows) might be sufficient for sediment management objectives during dry years. However, the ROD states that high flows are only to be conducted in high inflow years, and use of the spillways for flows >45,000 cfs remains controversial.

BIOLOGICAL RESOURCES

The Glen Canyon Dam Environmental Impact Statement (GCD-EIS) recommended that high flows be utilized as a means of restoring the Colorado River ecosystem and its associate resources. This recommendation was tested during the 45,000 cfs 1996 Test Flow. This report documents the state of the aquatic food base, fisheries, and wetland and riparian habitats and assemblages in Glen and Grand canyons. The information presented here is derived from the research and monitoring activities conducted in relation to the BHBF, and presented at the April 1997 Flood Symposium held in Flagstaff, Arizona. At this time, limited monitoring data are available from the river corridor for the first part of 1997.

Aquatic Food Base

Flow rate, turbidity, substratum distribution, solar insolation, and water temperature are the primary factors influencing the development of the aquatic food base in the Colorado River ecosystem. The structure of the aquatic food base in the Colorado River ecosystem was altered by the closure of Glen Canyon Dam in 1963, and the corresponding changes in river discharge (i.e., virtual elimination of extreme seasonal fluctuations), organic budget (i.e., greatly diminished allochthonous inputs), suspended sediments (i.e., virtual elimination from the Glen Canyon reach), water temperature (i.e., cold and constant vs. warm and fluctuating) and reduced nutrient concentrations. In response to these changes, an aquatic foodbase developed in the tailwaters of Glen Canyon Dam that is based on the filamentous green alga, *Cladophora glomerata* and associated epiphytic diatoms, as well as chironomid midges and the freshwater amphipod, *Gammarus lacustris*. These biotic communities, while present, are greatly modified and reduced in the variably turbid and turbid waters below the confluences of the Paria and Little Colorado Rivers.

The 1996 Test Flow strongly scoured the benthic foodbase in the mainstream; however, recovery was extremely rapid (one month at some sites; Shannon et al. unpublished). Displacement of *Cladophora glomerata* by other aquatic macrophytes was dramatic in 1995 and early 1996, possibly as a result of low nutrient concentrations from Lake Powell.

The 1997 discharge regime of high steady flows has resulted in the colonization of the varial zone and enhanced aquatic foodbase biomass (Figure 4). In addition, the typical reduction in benthic biomass with distance from Glen Canyon Dam that normally results from increasing turbidity over distance downstream, did not develop. Rather, biomass estimates of the phytobentos are highly variable between sites and seasonally within sites.

High steady flows enhanced benthic growth by reducing light and hydraulic variability in 1996-1997 (Shannon et al. 1997, unpublished). The aquatic foodbase biomass reached its highest level since monitoring began in 1990. Higher, steady mainstream flows dilute tributary-derived suspended sediment loads, and apparently provide a more consistent habitat and light regime (i.e., continuous low light) that enhances benthic productivity. Thus, high steady releases have improved the aquatic habitat conditions as compared to those under fluctuating flows.

Fisheries

The Colorado River and its tributaries in Grand Canyon currently support four of eight historic species of native fishes, including humpback chub (*Gila cypha*), flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), and speckled dace (*Rhinichthys osculus*). Fewer than 10 confirmed razorback sucker (*Xyrauchen texanus*) have been captured in the last 10 years. Colorado squawfish (*Ptychocheilus lucius*), bonytail chub (*G. elegans*), and roundtail chub (*G. robusta*) were extirpated soon after Glen Canyon Dam was completed in 1963.

Since 1958, a total of 24 non-native fish species have been reported to exist in the Colorado River of the Grand Canyon (Valdez and Ryel 1995). The most abundant species today include rainbow trout (*Oncorhynchus mykiss*), carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), and channel catfish (*Ictalurus punctatus*).

The role of backwaters as nursery habitats for young native and for non-native fish has been studied by the Arizona Game and Fish Department and by Northern Arizona University researchers in 1996 and 1997. Stevens et al. (1997, unpublished) reported that a large return current channel backwater near mile 55.5R was not scoured by the 1996 Test Flow, and was reduced in size by 50% to 80% across the range of ROD flows. The backwater received nitrogen-enriched groundwater and it warmed dramatically during the summer months. The benthic flora and fauna recovered over the 1996 growing season, but plankton density remained extremely low. This backwater supported larval and young native flannelmouth suckers and speckled dace during the spring and early summer. Non-native carp spawned twice (in mid-summer 1996 and early spring 1997) during the study period.

TOTAL MACROINVERTEBRATES

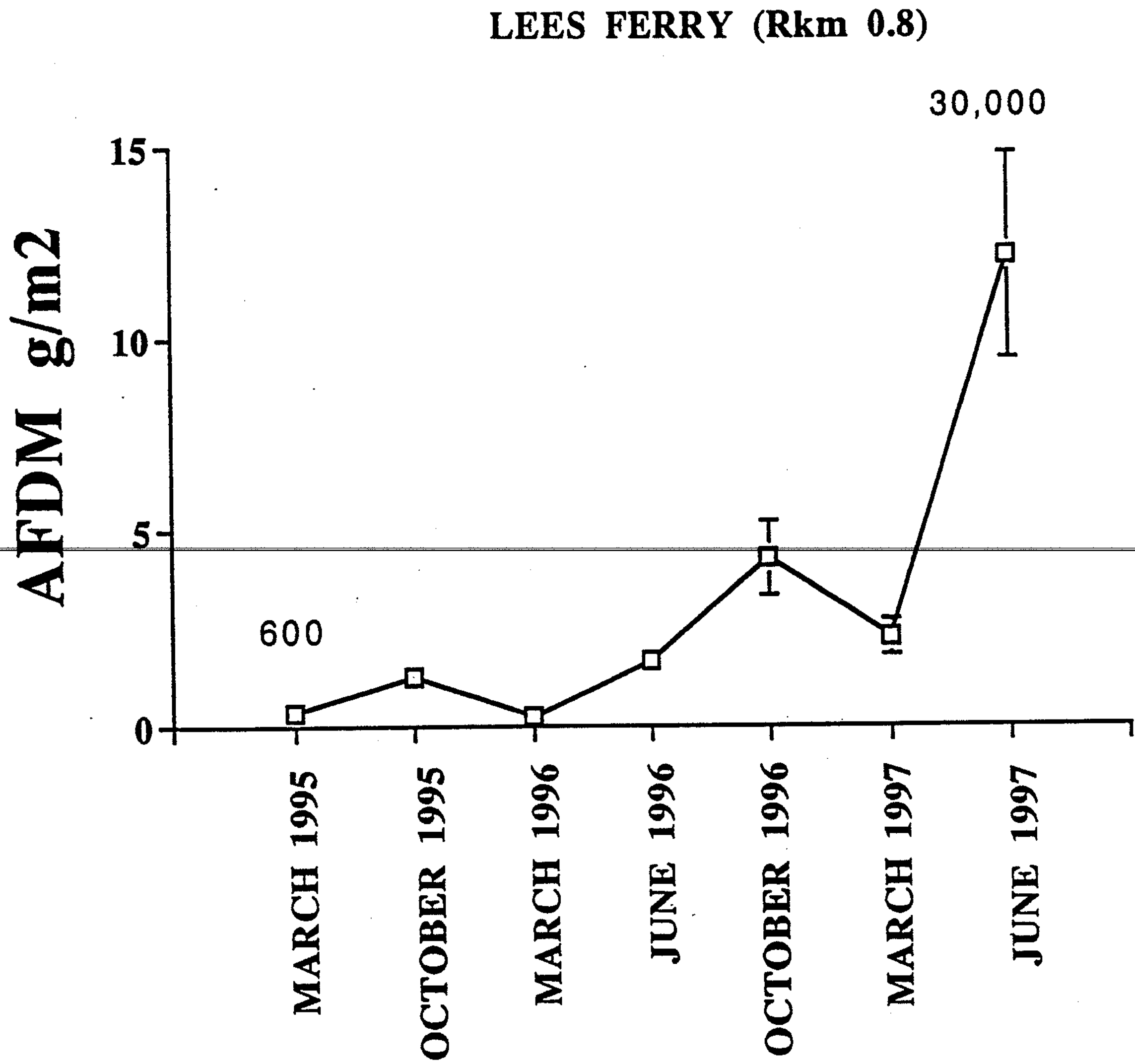


Figure 4. Macroinvertebrate biomass at Lees Ferry Cobble Bar, in the Colorado River, over the past three years. An overall increase in macroinvertebrate biomass is seen during this period of generally high steady flows. Numbers for 3/95 and 6/97 indicate densities/m2. (± 1 SE)

Figure 4: benthic macroinvertebrate ash-free dry standing biomass at Lees Ferry, March 1995 - June 1997. Error bars are ± 1 se. Numbers represent invertebrate density/m^2. Data courtesy of Shannon et al. (1997), Northern Arizona University.

Non-native Fish:

The number and diversity of common non-native fishes in Grand Canyon remains relatively low. Although potentially reduced from pre-dam levels, Carp remain a relatively abundant non-native species in Grand Canyon, with large numbers seen year-around in the lower LCR, and commonly throughout the mainstem. Carp have been present in the river since the late 1880's, but no pre-dam population data are avaiilable for Grand Canyon, and the effects of carp on native species remain undocumented. Channel catfish aggregate annually in spring and early summer in the LCR for presumed spawning. This species is a documented predator of humpback chub, and may be the subject of a control program in 1998. Fathead minnows are abundant in mainstem backwaters, and population increases may be attributable to more stable mainstem flows. Although densities may be temporarily decreased by high flows, many tributaries in Grand Canyon harbor populations for reinvasion into the mainstem. Red shiners are becoming more common in the LCR, in the mainstem downstream, and are very abundant in the lowermost Grand Canyon. Other non-native species such as black bullhead (*Ameiurus melas*), green sunfish (*Lepomis cyanellus*), largemouth bass (*Micropterus salmoides*), and plains killifish (*Fundulus zebrimus*) continue to be uncommon in the mainstem, although their numbers can be expected to increase with stabilized flows and more permanent backwaters.

Trout: The blue-ribbon rainbow trout fishery from the dam to Lees Ferry is currently partially sustained by natural reproduction: 70 percent of the rainbow trout in the tailwater are naturally produced, while 10 years ago, most fish were of hatchery origin. Although large trout in excess of 5 pounds were numerous before 1983, these large fish are now rare (Figure 5). Nevertheless, a large population of trout is currently being sustained by the high biomass of amphipods (*Gammarus lacustris*), midges (Chironomidae) and blackflies (Simuliidae) in the Glen Canyon reach. The condition of trout in this population has improved since the implementation of Interim Flows in 1991 (Figure 6). Further downstream, resident populations of rainbow trout persist throughout Marble and Grand Canyon, and spawn in and around seasonally warm tributaries, such as Nankoweap Creek, Shinumo Creek, Deer Creek, and Tapeats Creek. The trout population in and around Bright Angel Creek has become increasingly dominated by brown trout (*Salmo trutta*) in the last 15 years (Valdez and Ryel 1995).

Native Fish:

Remaining native fish populations are variously dispersed through Grand Canyon, but all four species seem to be experiencing difficulties with reproductive success and recruitment. Mainstem water temperatures of 8°C to16°C continue to be below optimum ranges (16-22°C) for reproduction and survival of eggs and larvae of these warm water species.

Lee's Ferry Electrofishing - Catch/Minute by Size Category by Year

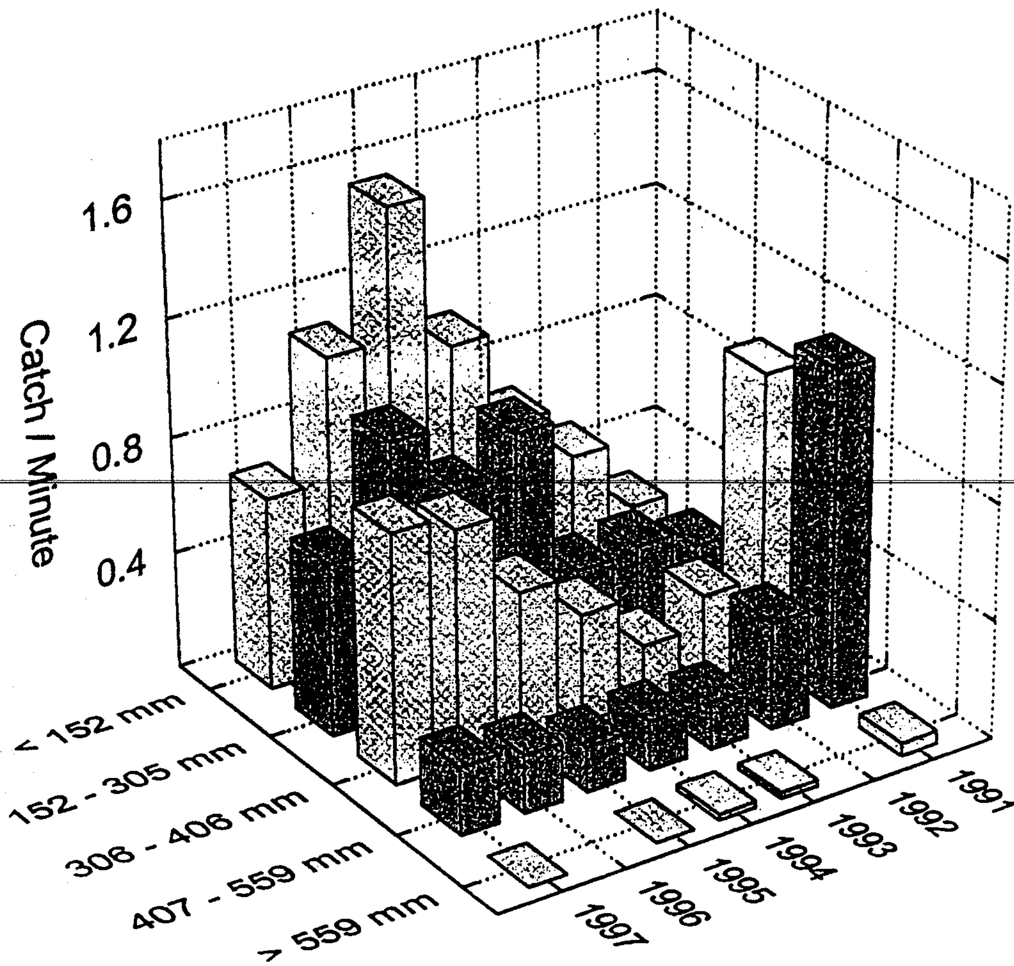


Figure 5: Arizona game and Fish Department trout electroshocking catch/min by size category, 1991 - 1997 in lower Glen Canyon. Data courtesy of A. Ayers, Arizona Game and Fish Department, Flagstaff.

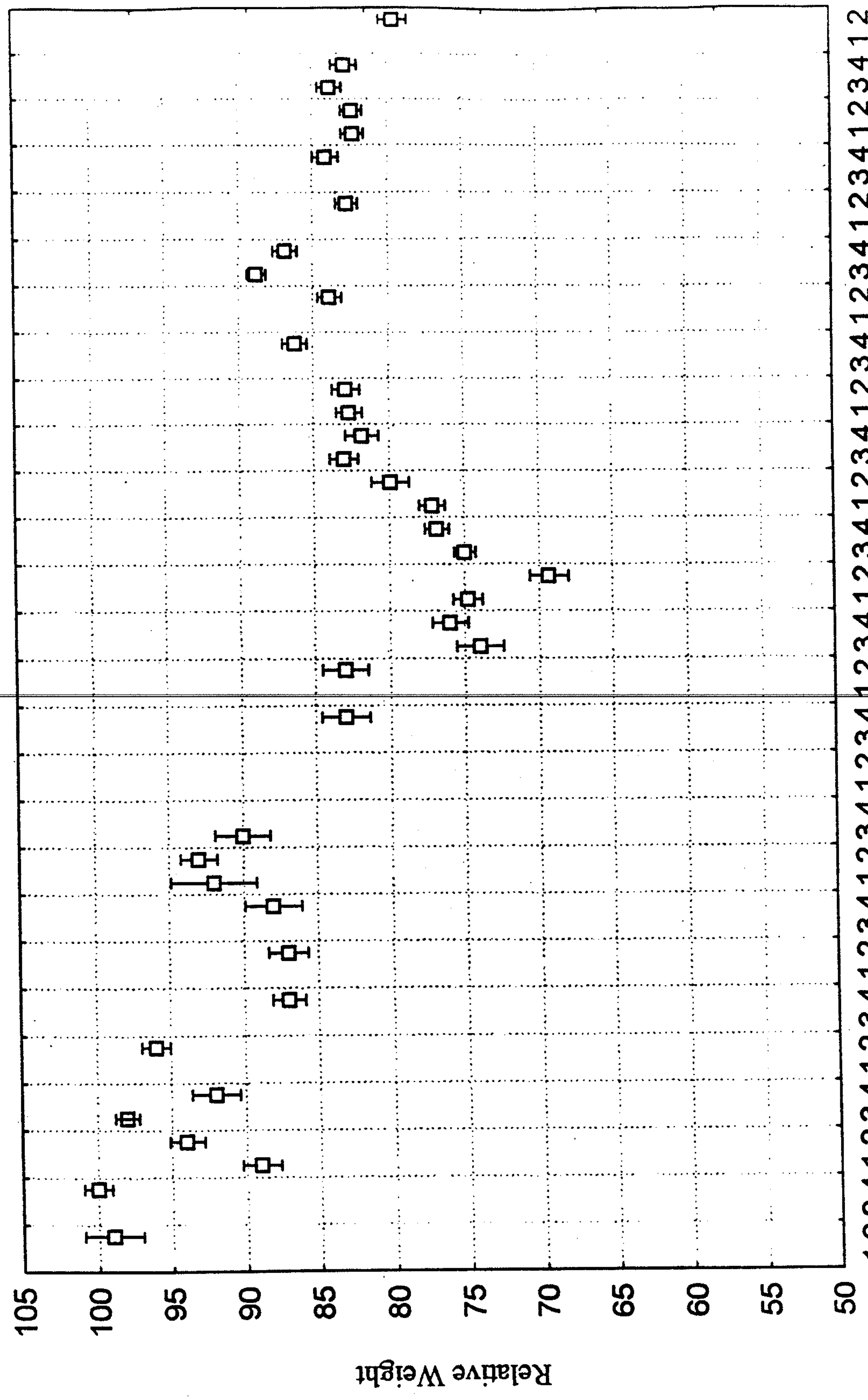


Figure 6: Arizona game and Fish Department trout condition, 1984 - 1996 in lower Glen Canyon. Data courtesy of A. Ayers, Arizona Game and Fish Department, Flagstaff.

Humpback Chub: The endangered humpback chub persists as eight mainstem aggregations totaling currently about 3,700 adults (Valdez and Ryel 1995). The aggregation in the Little Colorado River (LCR) contains about 4,600 adults. These spawn primarily from March through May, with adults from the proximate mainstem aggregation (Miles 56 to 76) ascending simultaneously. Adults in other mainstem aggregations peak in reproductive condition in May-June, but mainstem spawning remains undocumented, although about 100 post-larval chub were observed and captured in a warm spring in 1993 at RM 30, where an aggregation of about 50 adults reside (Valdez 1997).

Multiple census estimates of the LCR aggregation indicate a decline in numbers of adults from 1983 to 1992 and 1991 to 1995 (Douglas and Marsh 1996). Causes for this decline are unknown. Recent dam operations, under interim flows and the modified seasonally-adjusted steady flows, have reduced stage fluctuations, somewhat stabilized shoreline habitats and backwaters, and increased macroinvertebrate food production for fish. Impacts on humpback chub have not been fully understood and regular monitoring of adults and juveniles is required to determine long-term trends in this species.

The Asian tapeworm (*Bothriocephalus acheilognathi*) has been reported in humpback chub from Grand Canyon since 1990 (Clarkson et al. 1997). The effect on the species remains unknown.

Flannelmouth Sucker and Bluehead Sucker: The native suckers normally spawn in late winter and early spring at temperatures of <16°C. Their eggs do develop at these low temperatures, but survival beyond hatching is dependent on warmer temperatures. Flannelmouth sucker and bluehead sucker are widely dispersed throughout Grand Canyon, with highest numbers reported during spring at tributary mouths, including Bright Angel Creek, Kanab Creek, Shinumo Creek, the Little Colorado River, and Havasu Creek. Although reproductive success is reported from most of these tributaries, juvenile suckers in the mainstem are uncommon, and length-frequency distribution for both species indicate low recruitment to adult-sized fish (Valdez and Ryel 1995). It is hypothesized that larval suckers suffer from thermal shock as they drift from warm tributaries to the colder mainstem (C. McIvor, personal communication). Recently, about 500 adult flannelmouth suckers have been observed annually at RM 4 (above Lees Ferry) in spawning aggregations (T. McKinney, personal communication). Despite cold water temperatures of about 10°C, these fish are producing viable eggs, but the fate of the larvae is unknown.

Speckled Dace: Little synthesis of previously collected data on speckled dace in Grand Canyon has been performed. This is the most common native fish species in the mainstem and in most tributaries. Little is known about population size, distribution, reproductive success, movement, or survival for this species in Grand Canyon. Because of their widespread distribution and abundance, they may serve as a regional indicator species; however, this would require a synthesis of existing information on this species.

Status and Management Implications:

The 1996 Test Flow had little effect on native fishes. Shifts in habitat use were noted for speckled dace, but no changes in density by any of the four native species were noted (Valdez and Cowdell 1996). Short-term decreases in fathead minnows were observed, but densities exceeded pre-flood levels by late summer in 1996, indicating reinvasion from tributaries. Downstream displacement of juvenile rainbow trout was also seen during this high flow, but no significant decreases were seen in the tailwater fishery.

Low flows of 8,000 cfs, such as that which occurred during the Memorial Day weekend, for aerial photography, may have resulted in the loss of some of the aquatic foodbase, but no documentation exists regarding the impacts of low flows on the fish populations in Glen or Grand canyons, provided low down-ramping rates ($\leq$1500 cfs/hr) occur. The absence of high mainstem flows that impound tributary mouths may be detrimental to descending larval native fish from about mid-May to early July, but those larval fish still face cold mainstem temperatures. Low flows in early May is thought to have the least effect on humpback chub because most mainstem adults are in the LCR spawning and no young are present in the mainstem. Low flows (8,000 cfs) in the fall are expected to have limited impact on native or non-native fish. The protocol of using low flows to provide photograph documentation of changing sediment deposits will be extensively reviewed in FY1998.

Terrestrial Processes and Biota

Sand Bar Nutrient Dynamics: Research by Parnell et al. (1997) revealed that the 1996 Test Flow buried large quantities of sand bar vegetation, and decomposition of that material substantially increased soil and bank-stored groundwater nitrogen and carbon, but not ortho-phosphate concentrations.

Their analyses of carbon and nitrogen dynamics indicate that bank storage may strongly influence mainstream nutrient concentrations. Springer, working with Parnell et al. (1997), demonstrated that slight gradients of directional groundwater movement are established under prolonged constant flows. Constant flows of around 20,000 to 27,000 cfs have dominated the 1996 and 1997 hydrographs.

Wetland and Riparian Vegetation: The management objectives expressed in the GCD-EIS emphasize management for open sand bars, as well as maintaining emergent wetland and woody sandbar/channel margin vegetation. As the primary objective of the 1996 Test Flow was the building of sand bars, riparian vegetation was expected to sustain some reduction in cover.

Research by Ayers and Kearsley (1997) suggests that established return current channel marshes were not greatly altered by the 1996 Test Flow, but grassland and herbaceous cover was substantially reduced. Stevens et al. (1995) predicted that the Preferred Alternative would "train" wetland and sandbar vegetation to lower stage elevations, making it more susceptible to scour by high flows. The "training" prediction was demonstrated during Interim Flows (1991 through 1995), and post-1996 Test Flow observations indicate that those new low-stage wetlands were extensively scoured by the flood (Stevens, personal communication).

Constant high flows in 1996 and 1997 precluded germinationin in shallow channel margin habitats. In contrast to wetlands, established woody vegetation on sand bars and along channel margins largely survived the 1996 Test Flow, growing up through newly deposited sand and becoming reestablished (Ayers and Kearsley 1997).

The newly deposited sediments were well sorted fine sand, with a reduced seed bank. Bar surfaces are higher, and therefore drier, than those prior to the 1996 Test Flow. This reduces the potential for germination of many riparian species. Therefore, the newly formed sand bars are less likely to be overgrown by germinating tamarisk or seep willow, and more likely to become colonized by clonal or rhizomatous species (e.g., coyote willow, arrowweed and camelthorn).

An additional concern was that non-native plant species would become more widely distributed by hydrochory (dispersal by water). The 1996 Test Flow was scheduled to allow sufficient time after the flood to dry out the sand bars and limit tamarisk germination. In this respect, the 1996 Test Flow was quite successful. While not wholly preventing tamarisk germination, relatively little establishment was observed at -6.5R, 43L, 44L, 55.5R, 65L and 194L by Stevens (personal observation). However, constant high flows through 1996 and 1997 have allowed the tamarisk seedlings that became established to grow rapidly. Among the other non-native species: camelthorn vigorously resprouted and recolonized many sand bars; tumbleweed and lovegrass appear to have become more widely distributed; and Ravenna grass distribution also increased to the river corridor downstream from Diamond Creek for the first time (Stevens, personal observation).

Ethnobotanical resources along lower Colorado River appear to have been affected in a fashion similar to that which occurred in the upstream reaches (Christensen 1997, Jackson et al. 1997). High flow effects extended below Mile 250, indicating that potential impacts of planned flooding may occur onto the upper reservoir reach.

Kanab Ambersnail: The Kanab Ambersnail (KAS) at Vaseys Paradise were studied prior to, during and for a full year following the 1996 Test Flow to determine the impacts and consequences of high flows on this population (Figure 7). During the 1995 growing season Stevens et al. (1997) reported that: 1) the KAS occurs preferentially on native cardinal monkeyflower and non-native watercress; 2) the population has an approximately annual life cycle; and 3) the population increased by nearly an order of magnitude during the mid-summer reproduction period to an estimated 100,000 individuals.

In response to the U.S. Fish and Wildlife Biological Opinion on the 1996 Test Flow, 1,242 KAS were marked and moved above the 45,000 cfs stage by an interagency team (Stevens and Meretsky 1997). Monitoring of marked individuals and the population occurring below the ca. 100,000 cfs stage was conducted in 1996. Those studies indicated that the 1996 Test Flow scoured 68.5% of the primary KAS habitat lying downslope from the 45,000 cfs stage, and all KAS below the 45,000 cfs stage were lost to the flood waters (Figure 7). KAS habitat is recovering rather slowly, and several years may be required for full recovery of the KAS habitat and population. The habitat and snail population is being monitored.

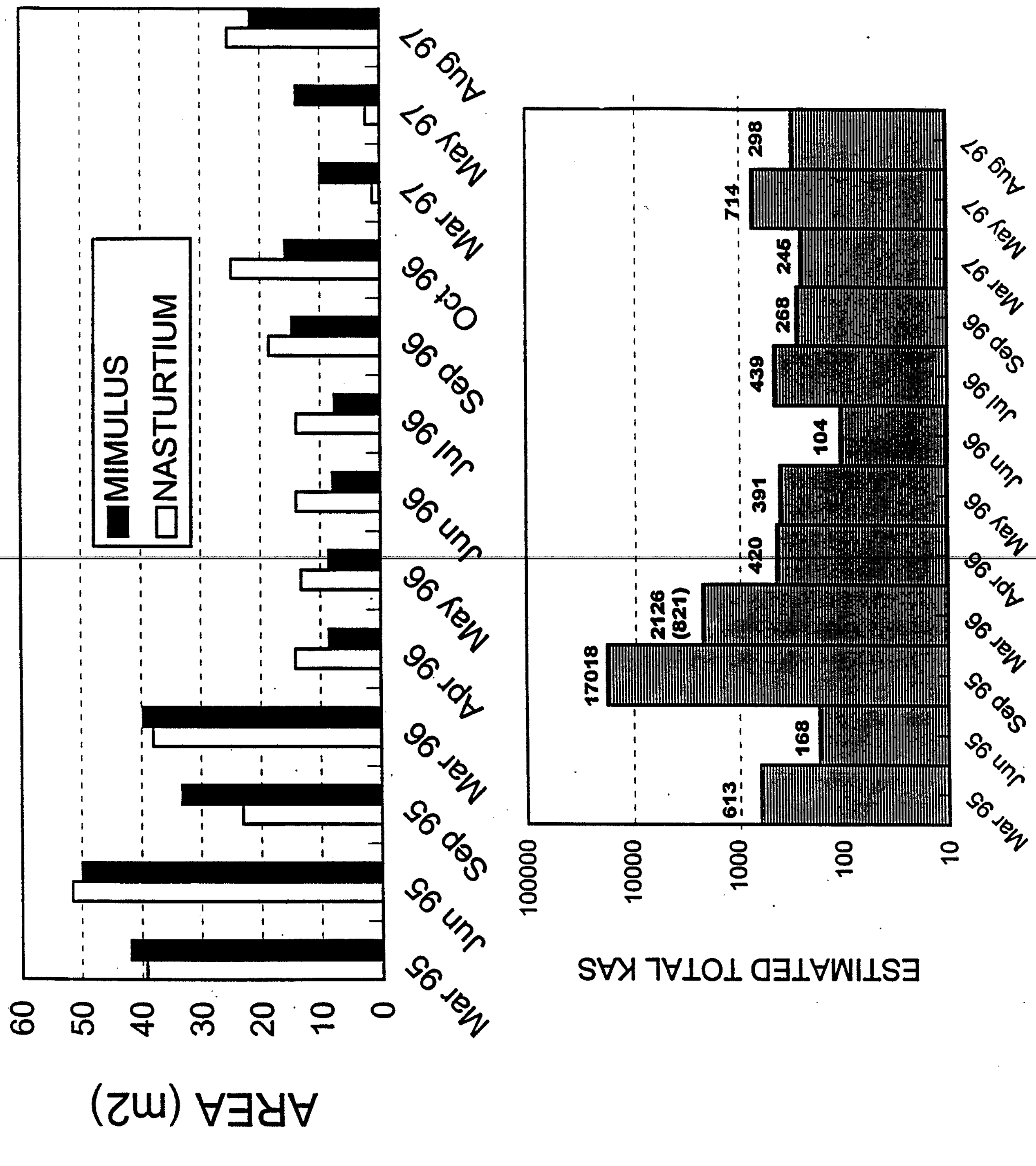


Figure 7: Upper graph - Kanab ambersnail habitat area (m2) for monkeyflower and watercress downslope from the 45,000 cfs stage at Vaseys Paradise, 1995 - 1997.
Lower graph - Kanab ambersnail estimated population size downslope from the 45,000 cfs stage at Vaseys Paradise, 1995 - 1997.

Northern Leopard Frog and Niobara ambersnail (Oxvloma h. haydeni): The leopard frog population at -9L were monitored before and after the 1996 Test Flow, and the population was little affected and recovered quickly (Spence 1997). The ambersnail population at that riverside spring is unique and persisted through the Test Flow as well. Pending completion of genetic analyses by the Arizona Game and Fish Department, monitoring of that snail population may be warranted in the future.

Southwestern Willow Flycatcher: The four historic southwestern willow flycatcher (SWWF) nest sites in Grand Canyon occur in dense stands of tamarisk beside fluvial marshes from Mile 50.5 to Mile 71 (Stevens et al. 1997b). SWWF nest in tamarisk and forage in channel margins and marshes. As a result of the FWS Biological Opinion on the 1996 Test Flow, an interagency task force surveyed vegetation cover and marsh area at the four sites prior to, and after, the 1996 Test Flow. Analysis of these data demonstrated that 1996 Test Flow impacts on nest stands were minor, and no nest sites or nest trees were affected. In contrast, marshes associated with nest site stands were reduced in area by 1% to 70%, and little recovery was observed during the 1996 growing season. Marshes at SWWF sites appear to have increased slightly by May 1997, but no mapping is planned for 1997 (Stevens personal observations).

A single pair of SWWF reproduced in Grand Canyon in 1996, possibly fledging two young. The 50.5L territory was used as an attempted nest site in 1997, but the SWWF nest was parasitized by brown-headed cowbirds, and failed. This is the first year since 1983 where no known SWWF nesting success occurred in upper Grand Canyon. A SWWF pair on the Hualapai Indian Reservation successfully fledged 2 young.

Other Avifauna: Wintering passerine birds in Glen Canyon apparently left their wintering grounds along the river as the 1996 Test Flow was initiated (Spence 1997); however, the timing of migration is poorly understood and these results should not necessarily be interpreted as 1996 Test Flow impacts. The 1996 Test Flow was planned to avoid significant impacts to wintering bald eagle, and no evidence of impact was found. Stevens (personal observation) reported no more than three bald eagles concentrated at Nankoweap Creek at one time in late March 1997. The lack of a substantial winter bald eagle concentration is attributed to a poor trout spawn and cold tributary water temperatures in March. The spring 1997 migratory belted kingfisher population along the river appeared to be within normal population levels (Stevens, personal observation).

Conclusions and Management Implications for Biotic Resources

Wetland and riparian vegetation, and other terrestrial biological resources, along the Colorado River are undergoing gradual recovery from the 1996 Test Flow, while other resources have largely recovered (e.g., Kanab ambersnail but not its habitat, and the northern leopard frog; Table 1). The relatively constant high mainstream flows largely prevent marsh recolonization at the pre-1996 Test Flow low stage elevations, but high flows have inundated the established return current channel marshes, improving plant vigor in those settings. Slow recovery of low elevation KAS habitat at Vaseys Paradise may limit recolonization of habitat patches. Also, slow recovery of SWWF marshes may exert a slight negative impact on foraging ecology, but SWWF are too few for such an impact to be statistically demonstrated. The KAS and SWWF in Grand Canyon are being monitored. While management of the Lake Mead ecosystem is not directly coordinated with Glen Canyon Dam management, such regional habitat impacts may play a role in avian population dynamics within Grand Canyon.

The short-term and long-term impacts of the Preferred Alternative coupled with planned flooding may include long-term changes in some populations of species of concern and of some habitat types (Tables 1 and 2). Impacts to terrestrial biological resources are traded off against potential benefits to aquatic resources, and some of the consequences of this management strategy will take a decade or more to detect, particularly with low level monitoring intensity. Therefore, continued monitoring of species and habitats of concern is recommended, and should be coupled with synthesis of existing information. Additional monitoring effort at the -9 Mile Spring may be warranted to evaluate the condition of the ambersnail population there. Observation of Ravenna grass downstream from Diamond Creek indicates that the NPS and Hualapai Tribe may wish to engage in a control program there, and continue their control programs in Glen and Grand canyons, before this invasive non-native grass and other non-native plant species become widespread in the lower Grand Canyon.

Table 1. Impacts on terrestrial biological resources in three management divisions of the Colorado River corridor downstream from Glen Canyon Dam resulting from the 1996 Test Flow.

Resources	Glen Canyon	Management Divisions	
		Grand Canyon	Hualapai Reservation
Vegetation	0	- to slight +	0 to slight -
Kanab Ambersnail	NA	-	NA
Leopard Frogs	0	NA	NA
Avifauna			
--Waterfowl	0	NE[1/]	NE
--Bald eagle	0?	NE	NE
--Peregrine falcon	0?	NE	NE
--SWWF	NA	0 to slight -	NA
--Winter passerines	0?	NE	NE

[1/]These resources were either <u>N</u>ot <u>E</u>valuated, or insufficient evaluation occurred to assess change.

Table 2. Long-term implications of the preferred alternative, including planned floods, on terrestrial biological resources.

Resource. Assemblage or Process	Site	Comments
Fluvial Marshes	Throughout	Forcing wetland vegetation to lower stage elevations in normal years, but increasing susceptibility to scour at low stages.
Sand Bar Vegetation	Throughout	Forcing riparian vegetation to lower stage elevation, and scour of low stage marshes.
Kanab Ambersnail	31.5R	Reduction in primary habitat and population; No anticipated threat to population
Northern Leopard Frog	-9.0L	No anticipated threat to habitat for population
Peregrine Falcon	Throughout	The role of changing vegetation should be assessed. No probable population impacts.
Bald Eagle	Upstream of LCR	Manage through appropriate timing of high flows and limit human interference during spring concentration periods.
Belted Kingfisher	Throughout	No anticipated threat to this migratory population. Indirect impacts may accrue from the increased peregrine falcon population.
Southwestern Willow Flycatcher	50.5-71	No impact on nest stands, but significance of reduced marsh area is unclear. Probably no direct threat to the population.

CULTURAL RESOURCES

Cultural resources along the Colorado River corridor include archaeological sites, water sources, sediment and mineral deposits, plants and animals, and locations identified as traditional cultural properties. All of these resources have the potential to be affected by the operations of Glen Canyon Dam. The ultimate goal of the cultural resource efforts related to Glen Canyon Dam operations is *in-situ* preservation, with minimal impact to the integrity of the resources (Balsom 1997).

Many of the cultural resources of the river corridor are dependent upon the sediment deposits which form the alluvial terraces. Since the completion of Glen Canyon Dam, the sediment resource has declined, and alluvial terraces have eroded. A system-wide method for regenerating the river terraces and redistributing sediment is an essential component to maintaining integrity for cultural resources.

The 1996 Test Flow presented an opportunity to study the effects of high flow discharge from Glen Canyon Dam on alluvial terraces and margin deposits along the river corridor. The effects of these flows on the margin deposits and terraces is an especially important area of study since many of the terraces are of relatively recent origin and contain buried cultural remains.

The overall findings of the cultural resources studies performed in conjunction with the 1996 Test Flow strongly suggest that the flow had either no adverse effect, or had a beneficial effect, on cultural resources. These findings validate the presumption that habitat building flows can offer a system-wide mitigation for cultural resources which are threatened by the lack of sediment in the Colorado River. However, some locations, especially in the Glen Canyon Reach, did experience loss of sediments or redeposition of sediments in a way that could be detrimental to cultural resources. Native vegetation appears to have responded well to the 1996 Test Flow, suggesting that periodic flooding is beneficial to the native plant species.

Continued monitoring will be necessary to determine the duration of the beneficial effects of sediment deposition on beaches, which protect cultural resources by slowing the erosion of the terraces on which they are located. The relatively high steady flows which have been released from Glen Canyon Dam since the spring 1996 Test Flow have caused significant erosion to the newly built alluvial terraces. Although most cultural resources appear more stable than prior to the 1996 Test Flow, the need for additional sediment deposition is apparent.

1996 Test Flow Impacts on Cultural Resources

The Bureau of Reclamation's 1996 Test Flow was expected to provide system-wide mitigation to most cultural sites in the Colorado River corridor through the accumulation of additional sediment. A positive effect was presumed but not guaranteed. As a result, mitigation was conducted at these sites. Monitoring of archaeological sites and other kinds of cultural resources, ethnobotanical resources, beaches, and sediment accumulation at the mouths of arroyos was undertaken to assess the results of the 1996 Test Flow. Terraces were studied in the Glen Canyon reach to determine whether terrace erosion occurred in this area as the loss of terrace deposits would impact the archaeological materials contained in the sediments.

The overall findings of the cultural resources studies done in conjunction with the 1996 Test Flow strongly suggest that the 45,000 cfs flow had either no effect, no adverse effect, or a beneficial effect on cultural resources. These findings support the original contention that habitat building flows can offer a system-wide mitigation for cultural resources. Some locations, especially in the Glen Canyon Reach, did experience loss of sediments or redeposition of sediments in a way that, in the long run, could be detrimental to cultural resources.

Specific results include:

1) At four of the five sites mapped, the flow had a beneficial effect upon the river terraces as evidenced by the increase in the amount of sediment at the base of the terraces;

2) The inundation model was very accurate at three of the six terraces under study, however at three sites the model predicted greater inundation than what actually occurred;

3) The flow had an immediate overall positive effect on the cultural resources proximal to the river, however this gain may be of short duration without additional maintenance flows of equal or greater volume;

4) At three of four study locations, sediments were elevated into the mouths of ephemeral arroyos which may slow erosion of sediments containing archaeological materials;

5) The Hualapai Tribe monitored ethnobotanical resources at five sites in conjunction with the 1996 Test Flow in 1996. Some ethnobotanical resources were initially scoured by the 1996 Test Flow; however, after a recovery period of several months the vegetation resources were neutrally or positively affected.

6) The Goodding willow at Granite Park underwent preflow stabilization efforts to slow erosion. The tree was not adversely affected by the 1996 Test Flow.

One caution that should be heeded in the planning of future 1996 Test Flows flows is that flows higher than 45,000 cfs will impact other cultural resources than those monitored and mitigated in this study. Additional monitoring will be necessary to determine the duration of the beneficial effects of sediment deposition on beaches, which protect cultural resources by slowing the erosion of the terraces on which they are located. However, if the newly deposited sediments are shown to slow erosion significantly, the system-wide benefits from the 1996 Test Flow will be well worth repeating, from the perspective of the cultural resources protection.

The National Park Service conducted a study of river running risks and injuries during the 1996 Test Flow (Jalbert 1996). This study reported that 45,000 cfs flows constitute no greater risk of boating accidents than other flow levels, and the flow enhanced visitor experience.

Cultural Resources In 1996 and 1997

Several monitoring and mitigation efforts were conducted by the National Park Service (NPS) and Native American tribes following the 1996 Test Flow in 1996 and during 1997.

Archaeological Sites

Archaeological site monitoring and management was conducted along the river corridor by the NPS (Leap et al. 1997). Monitoring was conducted at 97 sites along the corridor and remedial activities were undertaken at 57 sites. The sites were selected based on protocols established under the Programmatic Agreement (PA) and the Historic Preservation Plan (HPP). A total of 104 monitoring episodes were conducted at these sites in 1997. Ninety-two percent of these episodes revealed the presence of physical and/or visitor impacts.

Physical impacts are divided into eight categories that include surface erosion, gullying, arroyo cutting, bank slumpage, eolian/alluvial erosion or deposition, side canyon erosion, animal-caused erosion, and others. Impacts directly related to dam operations include bank slumpage, gullying and arroyo cutting in locations where drainage systems are actively changing to achieve the dam-induced, lowered river baselevel. Eighty-nine percent of the sites (N=86) monitored in FY 97 had some form of physical impact. This percentage is consistent with physical impact data recorded in the prior year. Surface erosion is the most commonly observed impact to archaeological sites, occurring at 62% of the sites (N=60). Surface erosion may or may not be related to dam operations. Of the impacts directly related to dam operations, bank slumpage occurs at 24% of the sites (N=23) and gullying and arroyo cutting is identified at 34% of the sites (N=35) that have river-based drainage systems that are believed to promote erosion at the adjacent cultural resources. The highest frequency of impacts appears to occur at sites with structures/storage features, artifact scatters, and roasters/hearths, the most common archaeological sites encountered in the river corridor. The majority of the impacts appear to occur within the geomorphic river reaches 5 (Mile 61 to 76) and 10 (Mile 160 to 214).

Visitor impacts are separated into five categories that include trails, collection piles, on-site camping, criminal vandalism and other, undefined impacts. Trails are the most frequent impact (42% of the sites, N=44), followed by collection piles (14%, N=15), and on-site camping (4%, N=4). Visitor impacts tend to occur at the same frequent site types listed above for physical impacts. The majority of impacts appear to occur within River Reaches 4 (Mile 35 to 61), 5 and 10 that have high site densities and popular river camps, where layovers with time for exploration above the beaches is possible.

Mitigative measures were conducted at five sites under the direction of an Hopi Tribe archaeologist. The efforts included data recovery of specific features at sites. The results of the excavation will be disseminated in the near future.

Ethnobotanical Resources

The Hualapai Tribe cultural resources personnel monitored ethnobotanical resources at five sites following the 1996 Test Flow of 1996 and then six months later to assess the effects of the high water on riparian plants and their rate of recovery (Phillips: 1997). The study sites were visited in October and November, 1996, and the longer term effects of the flood and the pattern of recovery began to become apparent. The general trend was for stabilization of the habitat and recovery of vegetation. Several trends were noted:

1) Unstable sediment deposits near the shore were re-worked during the summer with much of the shoreline sediment deposited by the flood. Upper beach deposits remained somewhat unstable. In the October and November monitoring trips, it appeared that there was some habitat stabilization.

2) Many species and individual plants affected by the flood recovered during the summer. This recovery approached but usually did not equal pre-flood levels after six months. Arrowweed and scouring rush buried in sediment by the flood grew through more and 1 meter of sand to become re-established on the newly deposited sediment.

3) Two exotic species, Bermuda grass (*Cynadon dactylon*) and camel thorn *(Alhagi camelorum)*, consistently increased in first six months following the 1996 Test Flow. Increases in these two non-native species may be considered a negative effect of the 1996 Test Flow.

4) The Goodding willow at Granite park appeared healthier than it had for several years during the 1996 growing season following the 1996 Test Flow. Possible loss of stabilization materials and erosion of the underwater bank at the shoreline during high releases in the summer of 1996 and since February, 1997 are potential cause for concern.

Economic Impacts

The economic implications of conducting 1996 Test Flows or, in the future, "Adaptive Management Flows," primarily relate to changes in power generation due to changes in flows through the dam's turbines. However, changing flow regimes can affect other resources, including recreation such as whitewater boating and sport fishing. Assessment of resource reports of adaptive management flows to date have largely focused on evaluation of impacts on power revenues. The 1996 Test Flow resulted in a loss of generation which had to be replaced by purchases to meet Western's contractual commitments to deliver power. The resulting additional cost was approximately $3,900,000.

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