Glen Canyon Dam Beach/Habitat-Building Flow

Abstracts and Executive Summaries

April 1997

Table of Contents

(names in bold - presented paper at Symposium)

A.K.A.

Integrated research and the experimental flood: Background, objectives, design and implementation - **D. Patten** 1

PHYSICAL SYSTEM COMPONENT
Hydrology and Sediment

Effects of the 1996 experimental flood on water quality of Lake Powell and the Colorado River - **W. Vernieu,** and S. Hueftle 3

Reworking of aggraded debris fans by the 1996 Glen Canyon Dam beach/habitat-building flow on the Colorado River in Grand Canyon - R. Webb, **T. Melis**, P. Griffiths, J. Elliott, J. Pizzuto, T. Randle, and L. Hammack 4

Velocity and lonitudinal dispersion of the Colorado River in Grand Canyon during the controlled flood fo March 1996 - **J. Graf** 6

Modifications to a one-dimensional model of unsteady flow in the Colorado River through the Grand Canyon, Arizona - S. Wiele, and E. Griffin 7

Pre-vs. post-flood sandbar mapping and sedimentology - **J. Schmidt** 8

Sedimentologic and hydraulic observations of depositional processes during the 1996 experimental high flow - **D. Rubin**, R. A. Anima, and J. M. Nelson 9

Effects of the 1996 beach/habitat-building flow on Colorado River sand bars and sediment storage along the Colorado River corridor, Grand Canyon, Arizona - R. Parnell, **J. Hazel**, Jr., M. Kaplinski, M. Manone, A. Dale, L. Dexter, and J. Ellsworth 11

Modeling of sand deposition and erosion in a reach of the Colorado River below the Little Colorado River during the 1993 Little Colorado River flood and the 1996 beach/habitat-building flow - S. Wiele 19

Flow, sediment transport, and channel geomorphic adjustment in the Grand Canyon, Arizona gage reach of the colorado River during the 1996 Grand Canyon flood experiment - **D. Topping** 20

Topographic evolution of sand bars in lateral separation eddies in Grand Canyon during the 1996 experimental flood - **E. D. Andrews**, Chris Johnston, Jack Schmidt, and Mark Gonzales 23

Eddy bar responses to the sediment dynamics of pool-riffle environments - B. L. Cluer 24

Aquatic Biology

Flood effects on benthic metabolism of carbon and oxygen in the Glen Canyon Dam's tailwater: Results and long-term implications - **G. R. Marzolf**, C. J. Bowser, D. W. Stephens, R. J. Hart, and W. S. Vernieu 25

Carbon and oxygen dynamics in the Glen Canyon Dam's tailwater: Processes and observations during the 1996 experimental flood - **C. J. Bowser**, G. R. Marzolf, D. W. Stephens, R. J. Hart, and W. S. Vernieu 26

Effects of experimental flooding on periphyton and macroinvertebrates in Glen Canyon Dam tailwaters - **T. McKinney**, R. S. Rogers, and A. D. Ayers 27

Experimental flooding and rainbow trout in Glen Canyon Dam tailwaters - T. McKinney, **R. S. Rogers**, A. D. Ayers 28

Impacts of the Spring 1996 spike flow from Glen Canyon Dam on the aquatic food base in the Colorado River through Grand Canyon, Arizona - **J. P. Shannon**, D. W. Blinn, K. P. Wilson, P. L. Benenati, J. Hagan and C. O'Brien 29

Backwaters

Flood-inducted backwater rejuvenation along the Colorado River in Grand Canyon, Arizona - R. Parnell, A. Springer, **L. Stevens**, J. Bennett, T. Hoffnagle, T. Melis, and D. Stanitski-Martin 41

Effects of the 1996 Glen Canyon Dam controlled flood on nutrient spiraling along the Colorado River corridor, Grand Canyon, Arizona - R. Parnell, **A. Springer**, J. Bennett, and L. Stevens 52

The effects of the 1996 experimental beach/habitat-building flood in the Colorado River, Grand Canyon, on fishes, invertebrates, and their backwater habitats - **T. Hoffnagle**, W. Persons, M. Brouder, T. Dresser, Jr., and D. Speas 56

Fishes

The Great Flood of 1996: Response by native and non-native fishes in Western Grand Canyon - **W. Leibfried** 59

Effects of an experimental flood on fish and backwaters in the Colorado River, Grand Canyon, Arizona - **R. Valdez** 60

Response of flannelmouth sucker in the Paria River to an experimental spike flow in the Colorado River below Glen Canyon Dam - M. Thieme, and **C. McIvor** 63

TERRESTRIAL SYSTEM COMPONENT
Terrestrial Biology

Effects of the 1996 beach/habitat-building flow on vegetation, seed banks, organic debris, and germination sites - **M. Kearsley**, and T. Ayers 64

The river runs to mile 254 - **K. Christensen** 65

Partners in Slime - Assessment and mitigation of flood impacts on kanab ambersnail - L. Stevens, and **V. Meretsky** 66

Impacts of a beach/habitat-building flow from Glen Canyon Dam on the endangered Southwestern Willow Flycatcher in Grand Canyon, Arizona - L. E. Stevens, V. J. Meretsky, and J. R. Petterson 78

Glen Canyon National Recreation Area survey of terrestrial avifauna in Glen Canyon and potential effects of the 1996 controlled flood - J. Spence 91

CULTURAL, RECREATIONAL AND ECONOMICS COMPONENT
Cultural Issues

Mitigation and flood effects on cultural resources - **J. Balsom** 92

Channel margin deposit aggradation and archeological site stabilization - **M. Yeatts** 93

Effects of Coloraod River test flow experiment on Hualapai and Southern Paiute traditional ethnobotanical resources - **L. Jackson, C. Osife**, and A. Phillips, III 94

Recreational Issues

Campsite area changes - **L. Kearsley** 105

Grand Canyon River Guides' Adopt-a-Beach - **K. Thompson**, K. Burke, and **A. Potochnik** 106

The effects of the 1996 beach/habitat-building flows on observed and reported boating accidents on the Colorado River in Grand Canyon National Park - **L. Jalbert** 115

Economic Issues

Glen Canyon Dam beach/habitat-building test flow - An ex post analysis of hydropower cost (DRAFT PEER REVIEW NOT COMPLETED) - **D. Harpman** 123

Authors 126

Glen Canyon Dam beach/habitat-building flow

A.K.A.

Various names and abbreviations used by the authors for the 1996 Glen Canyon Dam beach/habitat building flow:

BHBF

Controlled flood

Controlled release

Controlled high discharge

Experimental beach/habitat-building flood or flow

Experimental flow or flood

Flood

Flood release

Grand Canyon flood

Great flood of 1996

High flows

Spike flow

Test flow

Test flow experiment

Integrated research and the experimental flood: Background, objectives, design and implementation

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ABSTRACT

The flood (a.k.a., controlled high discharge or beach/habitat building flow) from Glen Canyon Dam in spring 1996 was not an experiment done in isolation, but an experiment culminating years of research on the effects of operation of Glen Canyon Dam on the downstream riverine ecosystem. This research progressed in three phases: (1) Glen Canyon Environmental Studies (GCES) Phase I, a package of research projects designed to understand changes in several components of the riverine system below Glen Canyon Dam; (2) GCES Phase II, a more integrated program interrelating responses of ecosystem parameters to dam operations; and (3) the experimental flood, an integrated set of studies of ecosystem response to high discharge.

Development of GCES Phase II research was based on testing hypotheses of effects of varying discharges from Glen Canyon Dam on downstream ecosystem components and processes. These included responses of ecosystem components and processes that were related to the existence of the dam, and those that were independent of the dam's existence. Emphasis was placed on those physical factors that drove the system, primarily hydrological and sediment budget parameters. Importance of biological responses was determined through relationships to changes in physical parameters, or because of policy directives (e.g., Endangered Species Act). Understanding of how the total system responded to various dam operational scenarios was enhanced through use of a sequence of experimental controlled discharges from Glen Canyon Dam, each representing potential operations of the dam and therefore possible alternatives for dam operations under the Glen Canyon Dam EIS. Each scenario also increased the range of data points of system component response, a necessity for river modeling.

Information from GCES research programs followed by interim flow monitoring measurements indicated a slow but continuous degradation of the sediment sources used by biological components of the ecosystems as well as river recreational activities. Discussion of use of high discharges to mimic spring floods, replace elevated sediment deposits and scour shorelines began during NAS review of GCES Phase I (1986) and continued in earnest during GCES Phase II. Scientific recommendations for interim flow discharges (1991) emphasized the need of an accompanying high discharge. The first flood experiment plan was presented in 1993 and refined in 1994, anticipating a flood experiment in spring 1995. Because the Glen Canyon Dam EIS, which would include a "beach/habitat-building flow" recommendation, was not complete, and for various other "political" reasons, the flood experiment was delayed for a year to spring 1996.

This delay allowed development of a more integrated flood experimental design while permitting completion of NEPA processes associated with the Glen Canyon Dam EIS. The EIS objectives for conducting beach/habitat-building flows emphasized sediment deposition processes; for example, redeposition of high elevation sand, restore camping beaches, rejuvenate backwater

habitat, and maintain open sandbars for camping. Associated objectives emphasized the importance of protecting other riverine/canyon resources like cultural resources and endangered species. With these objectives as foundation and fourteen years of research data as background, scientists from federal and state agencies, and academia designed a research program that would study (1) water and sand movements, (2) sediment depositional dynamics, (3) aquatic ecological processes, (4) response of native and non-native fish populations, (5) terrestrial ecosystem responses, (6) cultural resource protection, (7) recreational use responses, and (8) economic variables. The research design encouraged interaction among these studies, in the field and in later interpretation.

Implementation of such a grandiose research program within a limited time frame for a short, controlled period required intensive logistical planning. This was accomplished through the Glen Canyon Environmental Studies and assistance of other scientific groups, especially the US Geological Survey. Final acceptance of the flood experiment by all interested parties was not complete until weeks before the event. The experiment demonstrated that to accomplish research of this magnitude, and to control resources that serve a wide population, cooperation must be achieved among all parties. This, along with the importance of information obtained from the study for future adaptive management decisions related to Glen Canyon Dam operations, are the "take-home" lessons of this experiment.

Effects of 1996 experimental flood on water quality of Lake Powell and the Colorado River

Bill Vernieu, and Susan Hueftle

ABSTRACT

In the spring of 1996, an experimental beach/habitat-building flow was released from Glen Canyon Dam for the primary purpose of redistributing sediment in the Grand Canyon. The 7-day 1,274 cms (45,000 cfs) release included 425 cms (15,000 cfs) from the Glen Canyon Dam river outlet works, withdrawing water from a depth 29 m below the penstock withdrawal zone. This represented the first operation of the river outlet works in almost ten years.

As part of the Bureau of Reclamation's long-term monitoring program on Lake Powell, conducted by the Glen Canyon Environmental Studies office, measurements of physical water quality parameters were taken before, during, and after the flood at several stations in Lake Powell.

Before the experimental flood, there existed a persistent chemical and thermal stratification slightly below the depth of the penstock withdrawal zone. Over the past several years, measurements have shown that the body of water below this zone has been relatively isolated from convective and advective mixing processes of the upper portions of the reservoir. This water is cooler, more saline, and has shown marked reduction of dissolved oxygen concentrations during this period.

The combined operation of powerplant and river outlet releases during the flood resulted in a weakening of this stratification, bringing water of reduced density and higher dissolved oxygen concentrations to the level of the river outlet works, and lowering the depth of chemical stratification in the reservoir. This effect persisted until February of 1997.

Releases to the Colorado River downstream showed a transient reduction in temperature and slight increase in salinity during the flood. Dissolved oxygen levels were brought to saturation by the turbulence of the river outlet works. During the year following the flood, salinity levels decreased and dissolved oxygen concentrations increased as a result of the fresh water that was routed through the reservoir by the high releases and operation of the river outlet works. The cold saline body of water below the zone of stratification remained isolated.

These effects may have significance in enhancing winter mixing processes and routing advective currents through Lake Powell. They show the value of varying the depth of powerplant withdrawal as a potential management tool for forestalling future water quality problems associated with a stagnant hypolimnion. Some insight into future selective withdrawal studies may also be gained from viewing water quality changes in Lake Powell and the Colorado River resulting from the operation of non-powerplant release structures.

Reworking of aggraded debris fans by the 1996 controlled flood on the Colorado River in Grand Canyon National Park, Arizona

Robert H. Webb, Theodore S. Melis, Peter G. Griffiths, and John G. Elliott

ABSTRACT

Debris flows from 600 tributaries in Grand Canyon periodically deposit poorly sorted sediment on debris fans along the Colorado River between Lakes Powell and Mead. Before regulation, stable fans and rapids along the river resulted from the interaction of tributary debris flows and large, mainstem floods. Floods in the Colorado River maintained fans and rapids as highly-reworked deposits of boulders and cobbles. After the closure of Glen Canyon Dam in 1963, decreases in stage and stream power associated with reduced annual peak flows drastically reduced the amount of debris-fan reworking. Previous research has shown that modest powerplant releases from Glen Canyon Dam, particularly in combination with tributary floods, can significantly rework aggraded debris fans. These limited flows have entrained boulders up to 1 m in diameter, although discharges greatly exceeding the maximum powerplant release (946 m^3/s) would be required to completely remove most aggraded fans.

From 1987 through 1995, debris flows constricted the Colorado River at the mouths of at least 25 tributary canyons in Grand Canyon National Park, Arizona, creating two new rapids and narrowing at least nine existing riffles or rapids. The highest peak discharge on the Colorado River in Grand Canyon between 1986 and 1996 was 960 m^3/s in January 1993. In March April 1996, we studied the effects of a 7-day flood release that peaked at 1,370 m^3/s on 18 recently aggraded debris fans downstream from Glen Canyon Dam.

The largest changes occurred at Badger and Lava Falls rapids, 38 and 312 km downstream from the dam, respectively; several other aggraded debris fans were only slightly changed. Areas of aggraded debris fans decreased by 2 to 42 percent; only the debris fan at Bedrock Rapid, which is controlled by a large bedrock outcrop, increased in area owing to deposition of reworked sediment on the downstream margin. Volumes decreased on seven of nine debris fans by 3 to 34 percent. The distal margins of most recently aggraded debris fans became armored with a lag of cobbles and boulders, and the width of the reworked zone on most debris fans increased by 4 to 30 m. Constriction of the river decreased at 11 of 18 debris fans, although some rapids, such as Tanner Rapid, became slightly more constricted at low discharges owing to changes in stage-discharge relations. Velocities on the left and right sides of Lava Falls Rapid decreased by about half, but velocities increased in three other rapids (e.g., Badger Creek Rapid). Stream power per unit width decreased in nine of ten rapids because of decreases in watersurface fall and widening of the rapids. Changes in the sizes of upper pool sand bars were inconsistent, although separation bars downstream from the reworked debris fan generally increased in size.

The amount of stream power generated by the controlled flood greatly affected the variability of reworking among the 18 debris fans. For a given discharge, mainstem reworking is expected to vary with channel and debris-fan geometry, the initial particle-size distribution of the deposit, and

distance from the dam. The elapsed time between debris flow and the controlled flood also was important because larger particles at older deposits became interlocked, imbricated, and (or) sutured together during smaller dam releases combined with tributary floods in January 1993 and August 1994. The effectiveness of future floods of similar magnitude in reworking debris fans will depend in part on the release history and extent of armoring in the period between the debris flow and the flood. If reworking of debris fans is a criterion for design of future controlled floods, our data support release of a higher peak discharge of shorter duration shortly after constricting debris flows occur.

Additional information on this study can be found in U. S. Geological Survey Open-File Report 97-16, by Webb, Melis, Griffiths and Elliott.

Velocity and longitudinal dispersion of the Colorado River in Grand Canyon during the controlled flood of March 1996

Julia B. Graf

ABSTRACT

Velocity and longitudinal dispersion of Colorado River streamflow were measured using a fluorescent dye tracer during planned releases of 1,275\x11m^3/s from Glen Canyon Dam in March 1996. The measurement was the third of four measurements planned to characterize streamflow and channel roughness over a wide range of releases, including those above powerplant capacity designed to maintain sandbars and other riparian resources. Channel roughness is known to vary with stage in this river to a much greater degree than is predicted by commonly used roughness equations, and accurate modeling of flow and sand transport requires that the relation of roughness to stage be well defined.

Dye was released 24.5 km downstream from the dam and sampled at eight locations in a 362 km reach starting about 13 km downstream from the injection. The channel geometry in the studied reach is controlled largely by bedrock type and is very irregular. Width-to-depth ratios in subreaches between sampling sites range from 6.7 to 23. Reach-averaged velocity determined from the travel time of the dye cloud was 1.8 m/s, and velocity in the subreaches between sampling sites ranged from 1.5 to 2.1 m/s. A previous measurement made in May 1991 at steady dam releases of 425 m3/s gave a reach-averaged velocity of about 1.0 m/s and a range of velocity from 0.75 to 1.1 m/s in subreaches between sampling sites. Although subreach velocity is not directly related to any of the quantitative measures of channel geometry currently available at either of the measured flows, both measurements showed a lower velocity in the 100 km upstream from the mouth of the Little Colorado River than downstream.

Time-concentration curves at all sampling sites are nearly symmetrical and closely approach a normal distribution. Curves lack the tails that are typical of measurements in most natural streams, suggesting that zones of stagnant water along the bed or banks that have been invoked to explain these tails in other rivers are not a significant factor in this river. The eddies that are characteristic of the Colorado River and are important areas of sand storage do not retain water for a long-enough period of time to affect the shape of the time-concentration curves.

Variance of the time-concentration curves is a measure of the longitudinal dispersion. Variance at sampling sites increased downstream throughout the reach for the 1991 measurement, whereas most of the increase in variance was measured in the upstream 100 km for the 1996 measurement.

Modifications to a one-dimensional model of unsteady flow in the Colorado River through the Grand Canyon, Arizona

Stephen M. Wiele, and Eleanor R. Griffin

ABSTRACT

Calculations of the downstream progression and evolution of discharge waves released from Glen Canyon Dam on the Colorado River through Grand Canyon have been based on hydraulic geometry derived from measurements made at a maximum discharge of 792 m^3/s (Wiele and Smith, 1996). Predictions of downstream hydrographs for larger discharges, such as for the March-April 1996 beach/habitat-building flow, which reached a maximum release of 1,270 m^3/s, have been based on extrapolations of that hydraulic geometry (Wiele, 1996). Data from the beach/habitat-building flow have been used to extend the model to higher discharges using a method that differs from that used to determine hydraulic geometry in the original model (Wiele and Smith, 1996). Scaling of the momentum equation shows that the wave is adequately represented by the kinematic wave equation on the receding limb of the beach/habitat-building flow hydrograph. The wave speed as a function of discharge can be determined from data obtained at streamflow-gaging stations. The wave speed, which is equal to dQk/dA, where Qk is the steady-flow discharge and A is the cross-sectional area, can then be integrated to determine the relation between discharge and cross-sectional area of the channel. A known value of the area corresponding to a given discharge provides the integration constant. This procedure has yielded an updated hydraulic geometry for the model of flow in the Colorado River between Glen Canyon Dam and Lake Mead that has been extended to 1,270 m^3/s. A numerical method modified for higher rates of change in discharge and the new hydraulic geometry have improved the accuracy of the model for discharges greater than about 800 m^3/s. A complete description of the model modifications can be found in Wiele and Griffin (1997).

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Wiele, S. M. 1996. Calculated hydrographs for the Colorado River downstream from Glen Canyon Dam during the experimental release, March 22-April 8, 1996: U. S. Geological Survey Fact Sheet FS-083-96.

Wiele, S. M. and Smith, J. D. 1996. A reach-averaged model of diurnal discharge wave propagation down the Colorado River through the Grand Canyon: Water Resources Research, v. 32, no. 5, p. 1375-1386.

Wiele, S. M. 1997. Modeling of sand deposition and erosion in a reach of the Colorado River below the Little Colorado River during the 1993 Little Colorado River flood and the 1996 beach/habitat-building flow: U. S. Geological Survey Water-Resources Investigations Report.

Pre- vs. post-flood sandbar mapping and sedimentology

John C. Schmidt

ABSTRACT

The location of high-elevation sand bars deposited by the 1996 flood was similar to that caused by earlier high discharges in Grand Canyon, but the area of exposed high-elevation sand was less. Maps of the distribution of newly-formed fine-grained deposits as they existed immediately after recession from the experimental flood were compared with similar maps showing the distribution of flood deposits in 1984 and 1993. These maps were made for 30 km of the river located in lower Marble Canyon and near the confluence with the Little Colorado River (LCR). Air photos taken in October, 1984 depict the river corridor following very high and long duration floods in 1983 and 1984, and air photos taken in May, 1993 depict sand bars four months after recession from a large natural flood in the LCR. GIS-analysis of these maps shows that flood sedimentation occurs within discrete eddy complexes or as linear channel-margin levees. There are approximately 150 of these eddy complexes in the study reaches. New deposits, often exceeding 1 m in thickness, were created in 1996 near the stagnation points of each complex, but low-elevation deposits in the center of complexes were typically eroded. Although the proportion of eddy complex area where deposition occurred typically exceeded the area of net erosion, a few sites in each study reach were extensively eroded and a few sites had very large areas of deposition. In the LCR reach, the average size of high-elevation eddy deposits was larger in 1993 than it was in other years. In this 20 km study reach, the total area of high-elevation sand was 271,000 m^2 in October, 1984, 282,000 m^2 in May, 1993, and was about 240,000 m^2 after recession from the 1996 flood.

Sedimentologic and hydraulic observations of depositional processes during the 1996 experimental high flow

D. M. Rubin, R. A. Anima, and J. M. Nelson

ABSTRACT

Sedimentologic and hydraulic observations during and after the 1996 high flow have yielded new information about the processes that transported and deposited sediment during that event. Suspended sediment sampling and optical backscattering measurements during the flow document a decrease in concentration and an increase in median grain size of suspended sediment. These observations suggest that the sediment source in the channel became somewhat depleted in fine-grained sediment during the seven days of high flow. This depletion was caused by preferential removal of fines from the channel (either by transport downstream or by deposition in eddies or along channel margins).

Evidence of coarsening of the mainstem sediment supply is also present in the high-flow eddy deposits; the mean grain size of these deposits systematically coarsens upward (Figure 1). At five sites where the high-flow eddy deposit was sampled vertically, mean grain size coarsens upward by roughly a factor of two, from 0.06 - 0.10 mm at the base to 0.10 - 0.19 mm at the top of the deposits. The increase in mean grain size occurs not merely by the removal of fines, but also by an increase in the modal size and an increase in size of the coarsest fraction. This upward coarsening was significant enough to cause a change in bed configuration from ripples to dunes on some bars.

Evidence of sediment liquefaction was observed both during and after the high flow. During the flow, a pressure transducer recorded the episodic slumping of an eddy-bar flank into the channel. After the flow, soft-sediment deformational structures were discovered in trenches that were dug through some eddy deposits.

Side-scan sonar and underwater video surveys were conducted prior to and after the high flow, to evaluate the effects of this event on the stream-bed distribution of sediment stored in six pools between the Little Colorado River and Tanner Rapid. Comparison of the two surveys indicates that pool-stored sediment was not significantly reduced in areal coverage by the high-flow event.

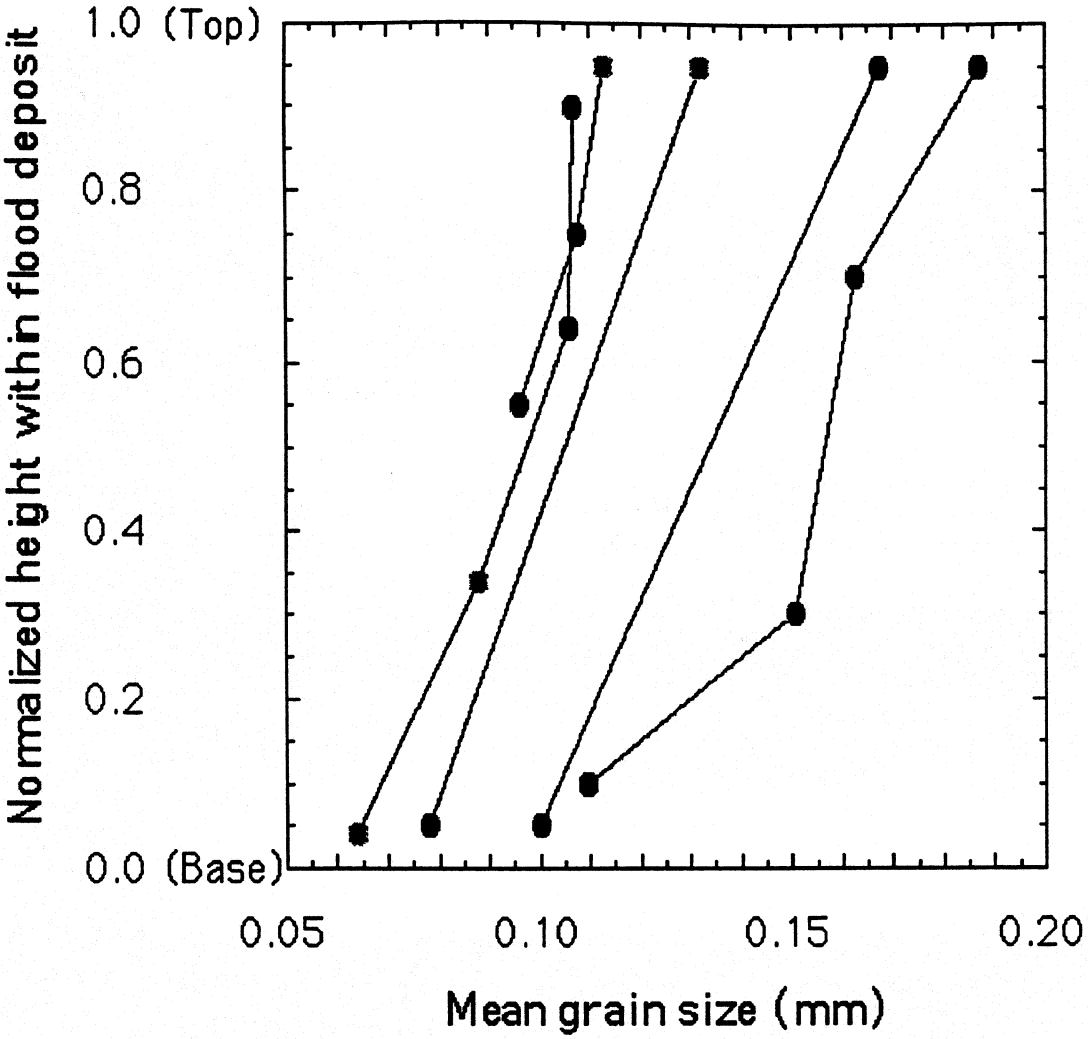

1.0 (Top)
0.8
0.6
0.4
0.2
0.0 (Base)
Normalized height within flood deposit
0.05
0.10
0.15
0.20
Mean grain size (mm)

Figure 1.

Effects of the 1996 beach/habitat-building flow on Colorado River sand bars and sediment storage along the Colorado River Corridor, Grand Canyon, Arizona

Roderic A. Parnell, Jr, Joseph E. Hazel, Jr, Matt Kaplinski, Mark F. Manone, Alan R. Dale, Leland Dexter, James Ellsworth,

EXECUTIVE SUMMARY

INTRODUCTION

Scientific research conducted during the U. S. Bureau of Reclamation's Glen Canyon Environmental Studies (GCES) program has led to a consensus that floods are necessary to maintain the Colorado River's geomorphic structure and related ecosystems downstream from Glen Canyon Dam (Bureau of Reclamation, 1995). Ecosystem diversity is intimately related to the natural disturbance of flooding and a beach/habitat-building flow was included in the Preferred Alternative recommended in the Glen Canyon Dam Environmental Impact Statement (GCDEIS) (Bureau of Reclamation, 1995). An experimental beach/habitat flow release with a high steady discharge of 1,274 m^3/s, hereafter referred to in this report as the "test flow," was released from GCD for seven days between March 26 and April 3, 1996 (Figure 1). As part of this experiment, we conducted sand bar survey river trips before, after, and six months following the test flow at thirty-four eddy complexes (EC) in Glen and Grand Canyons (Figure 2). The objective of this study is to compare topographic changes at the study sites before and after the test flow to quantify changes in sand bar morphology and eddy/channel sediment storage.

Methods

The sand bar surveys consists of separate topographic and bathymetric surveys at each site that are combined to form a Triangulated Irregular Network (TIN) surface model of channel, eddy, and sand bar topography. Plan area and volume were determined from each surface model within three distinct boundaries (bar, eddy, and channel) that enclose three distinct geomorphic regions within the complex. In order to compare sites of varying dimensions, volumes and areas were expressed as a percentage of the pre-flood surveys, conducted in February, 1996.

The sand-transport relations of Randle and Pemberton (1987) were used to construct a sand mass-balance model similar to that developed by Randle et al. (1993) for the GCDEIS. This budget was calculated by multiplying mean daily discharge data from selected USGS streamflow-gaging stations for each day between August 1, 1991-December 31, 1996, by the appropriate sediment rating relation.

Figure 1. Hydrograph of the test flow at USGS streamflow-gaging station, Colorado River at Lees Ferry (09380000). Note that this level of release is about 334 m^3/s (11,800 ft^3/s) greater than powerplant capacity and more than 566 m^3/s (20,000 ft^3/s) above the maximum discharge allowed under the Interim Operating Criteria.

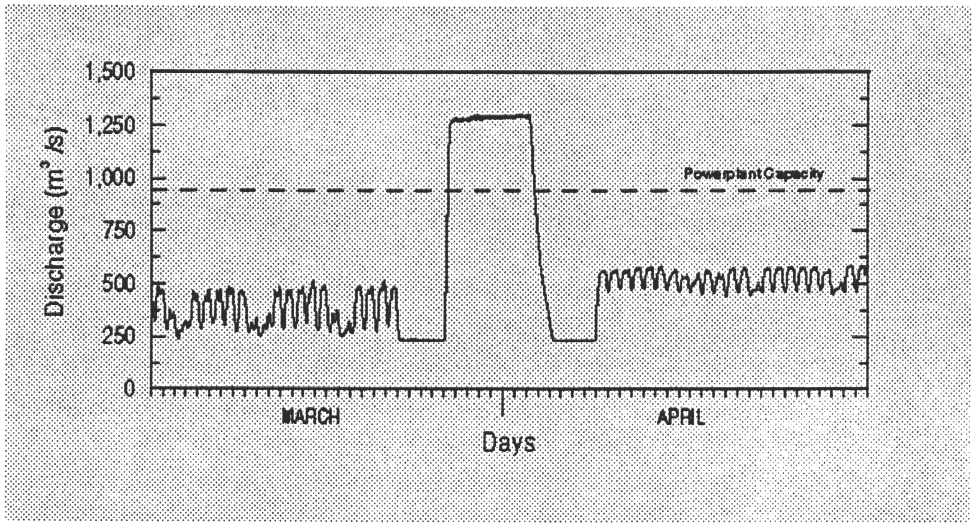
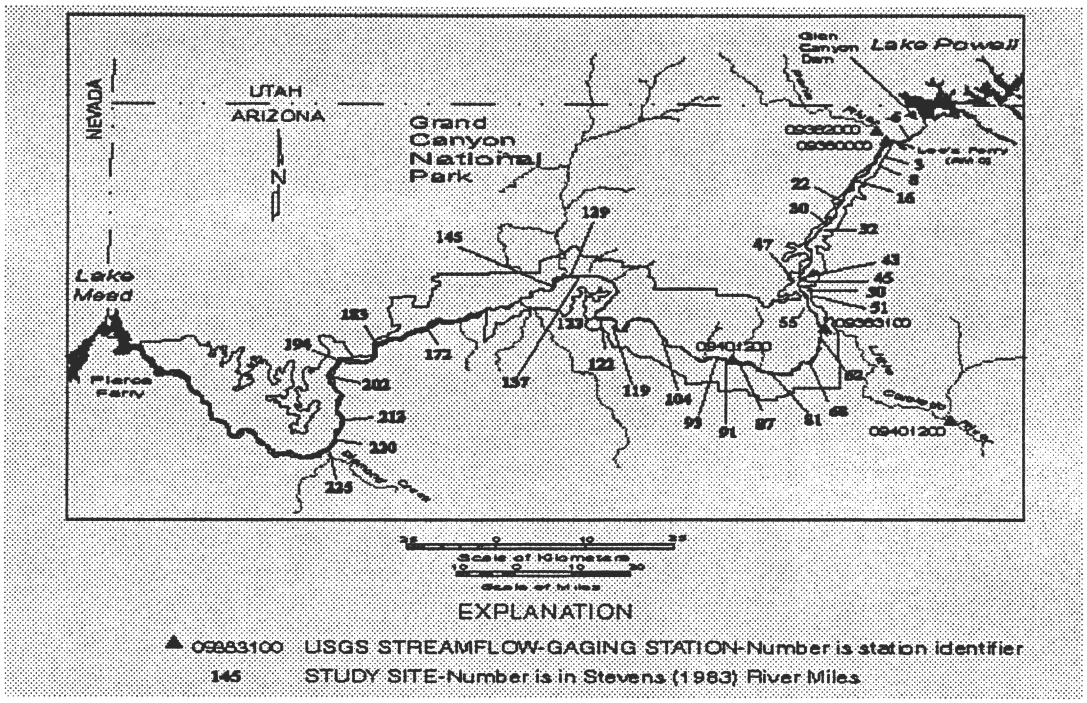


Figure 2. Location map showing Colorado River, major tributaries, Grand Canyon National Park, study locations, and USGS streamflow-gaging stations.



RESULTS

Effects of the Test Flow

The test flow resulted in a net increase in the volume of sand stored in channel-margin alluvial deposits, or sand bars. Sand bar volume measurements above 142 m^3/s (5,000 ft^3/s) increased an average of 48% (Table 1). The higher elevations of sand bars (> 426 m^3/s [15,000 ft^3/s]) gained an average of 176% (Figure 3). Deposition of sand to the upper boundary was critical because this section had the highest erosion rates during interim flows (5-7%/yr.; Parnell et al., 1996; Figure 3). Figure 4a shows the percent change of the study sand bars versus distance downstream and shows that the high flows resulted in a system-wide increase in sand bar volume, regardless of geomorphic reach or deposit type. In contrast to the large volumetric increase, the plan area of the bars increased only slightly by an average of 7% (Table 1). This marked difference between changes in sand bar volume and area indicates that, in general, the controlled high flow resulted in bars that were higher, but not necessarily wider.

Table 1. Average percent change of sand bar volume and area from 2/96 to 4/96

	ALL SITES		ABOVE LCR		BELOW LCR	
	Volume	Area	Volume	Area	Volume	Area
average	49	7	52	2	47	10
s.e.	10	5	13	7	13	6
# of sites	32	32	12	12	20	20

Figure 3. Upper bar volume, as a percentage of the 2/96 survey run, through the interim flow period.

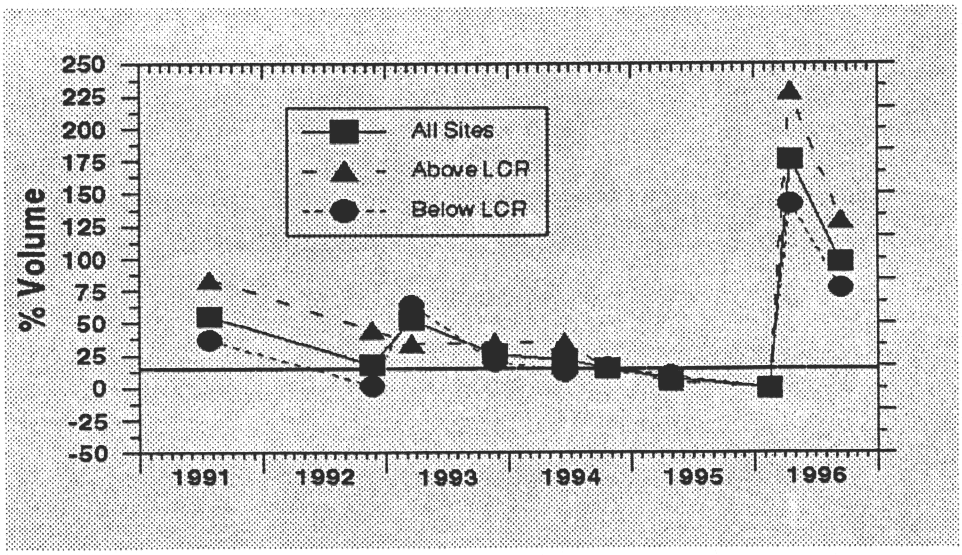
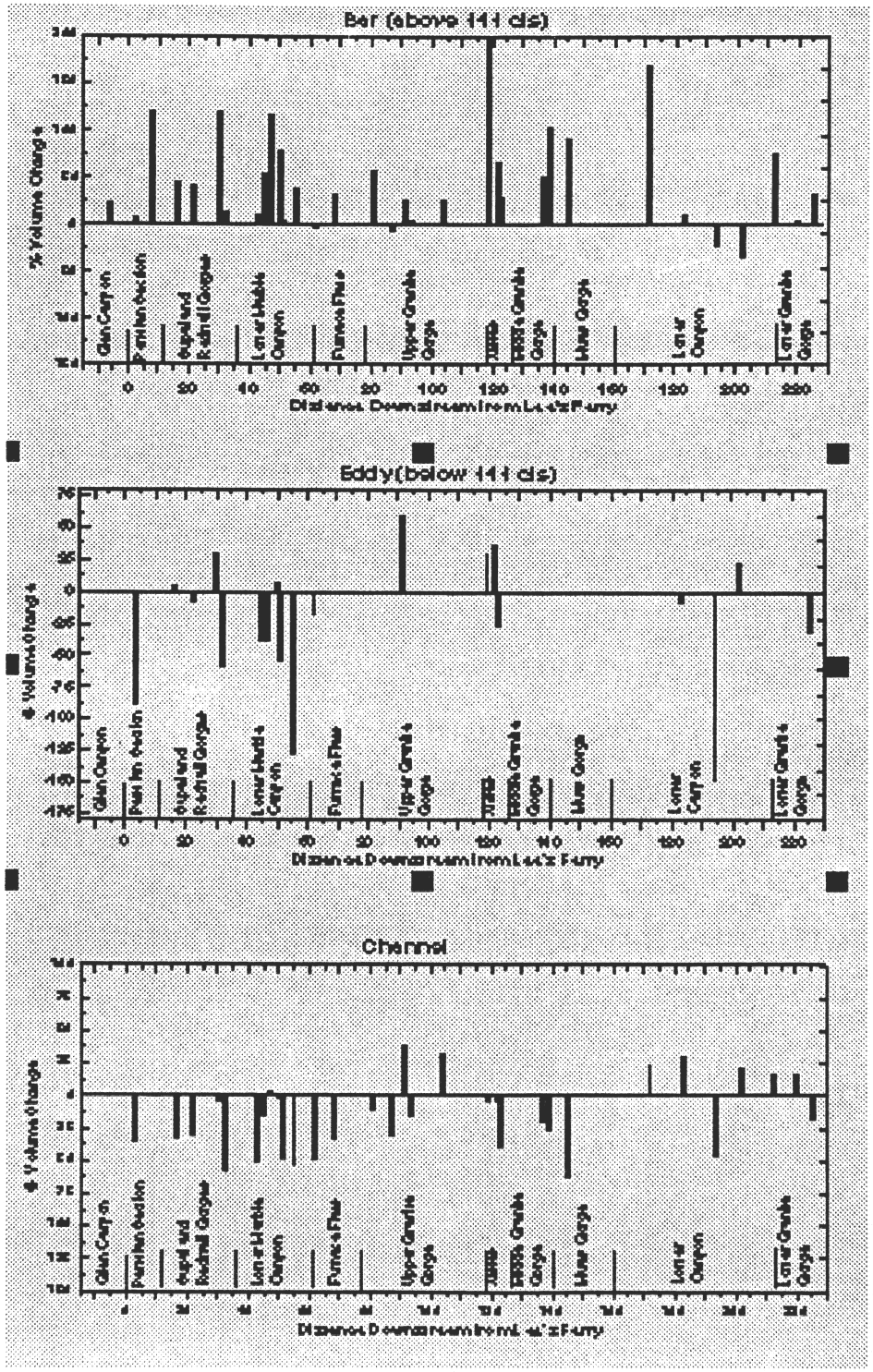
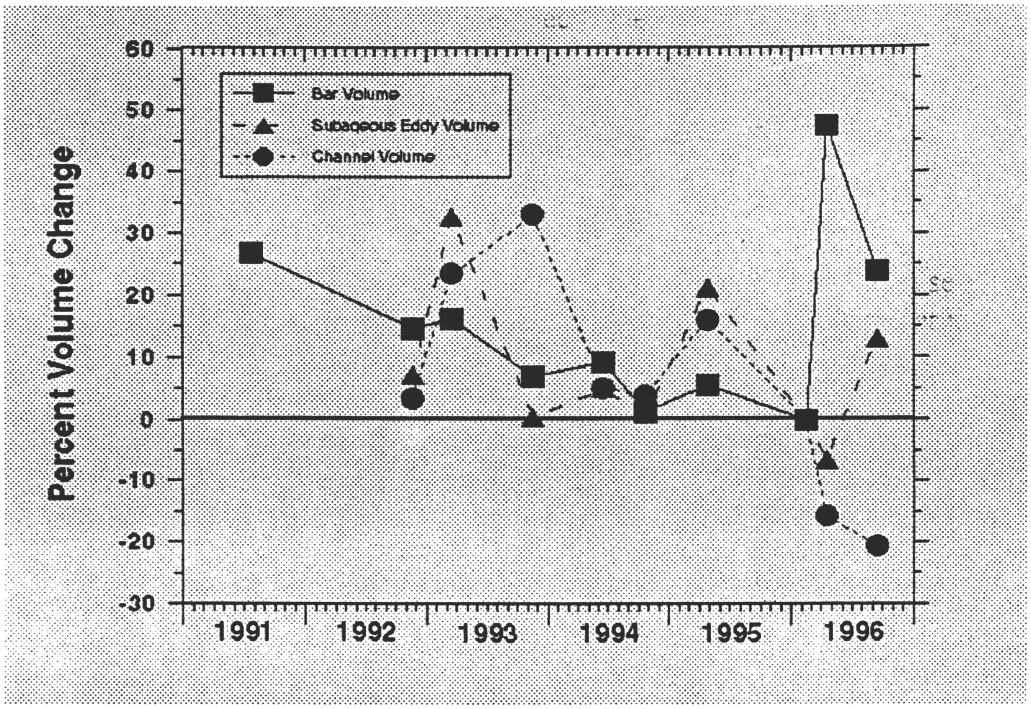


Figure 4. Percent change of volume relative to 2/96 surveys from the (A) sand bar; (B) eddy; and channel boundaries, versus distance downstream from Lees Ferry, AZ.



A consistent pattern of morphologic change was observed at the study sites. This pattern is characterized by 1 to 2 meters of deposition on the sand bars and scouring of the adjacent main channel and the upper areas of larger eddies (Figures 4 and 5). Reattachment bars in large recirculation zones were scoured in upstream areas of the eddy. Return-current channels that existed prior to the test flow were reshaped by aggradation rather than scour, or remained unchanged.

Figure 5. Bar, eddy, and channel volume as a percentage of the 2/96 survey through time.



Post-test flow effects of the GCDEIS Preferred Alternative

Sand bars eroded following the test flow as the system adjusted to "normal" dam operations. However, GCD flows following the test flows fluctuated from 16-20,000 ft^3/s, well above the 8-13,000 ft^3/s fluctuations typical for spring releases. Sand bar volumes decreased an average of 13% between April, 1996-September, 1996. Erosion of the upper sand bar boundary decreased the sand volume deposited during the flood from 176% to 97% greater than the pre-flood surveys (Figure 4). Eddies that were scoured during the test flow had recovered close to two-thirds of the volume lost during the test flow (Figure 5). The total volume of sand within the main channel boundary remained nearly the same or was less than that observed directly after the test flow (Figure 5). Because of the scoured condition of the main channel and the lack of significant tributary input following the test flow, aggradation during this time must have been from upstream eroding bars and channel margin deposits. Sediment that is eroding from beaches either is redistributed within the eddy or is in transport by the mainstem and is being trapped very efficiently by the eddies.

History of sediment storage changes from 1991 to 1996

Figures 6 and 7 shows that there was significant accumulation of tributary derived sand between 1992-1996 but little accumulation during the GCES Phase II experimental discharge test flow program conducted between June, 1990-July, 1991. Despite the reduced transport capacity of interim flows, cumulative storage did not substantially increase until large tributary inflows in 1993 (Figures 6 and 7). There was little accumulation between spring 1993-1995 (a period of low tributary inflow) because there was a balance between transport and supply. Tributary floods during the winter of 1995 increased sand storage by about 2 x 105 mg. However, a substantial decline in sand storage occurred between June-October, 1995 due to unusually high reservoir releases (nearly constant 20,000 ft^3/s), the 1996 beach/habitat-building flow, and because of high releases following the 1996 beach/habitat-building flow (average of 17,000 ft^3/s from April-July). This sequence of discharges removed two-thirds of the mass of sediment that had previously accumulated in Marble Canyon as a result of interim flow operating criteria.

Figure 6. Cumulative sediment storage in the Marble Canyon reach between 1990-1997. (A) sand mass-balance model using the sediment transport relations of Randle and Pemberton (1987), and measured sediment storage below the 5,000 ft^3/s stage elevation from the (B) main channel, and eddy systems at selected study sites.

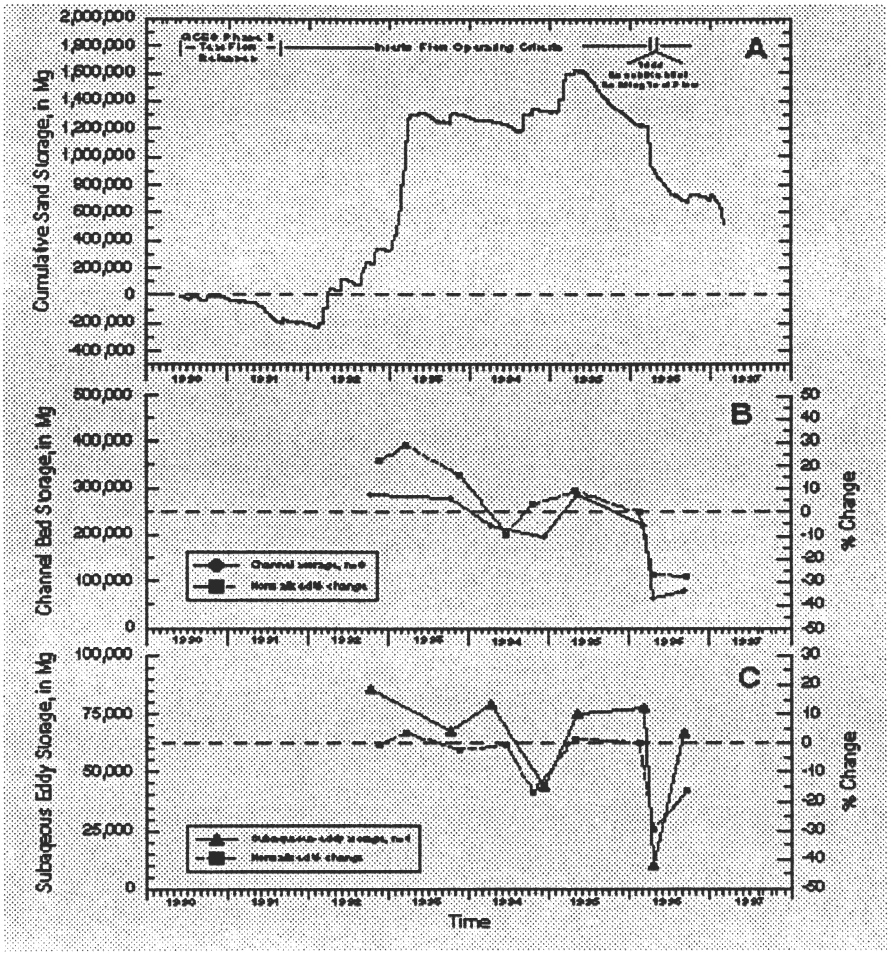
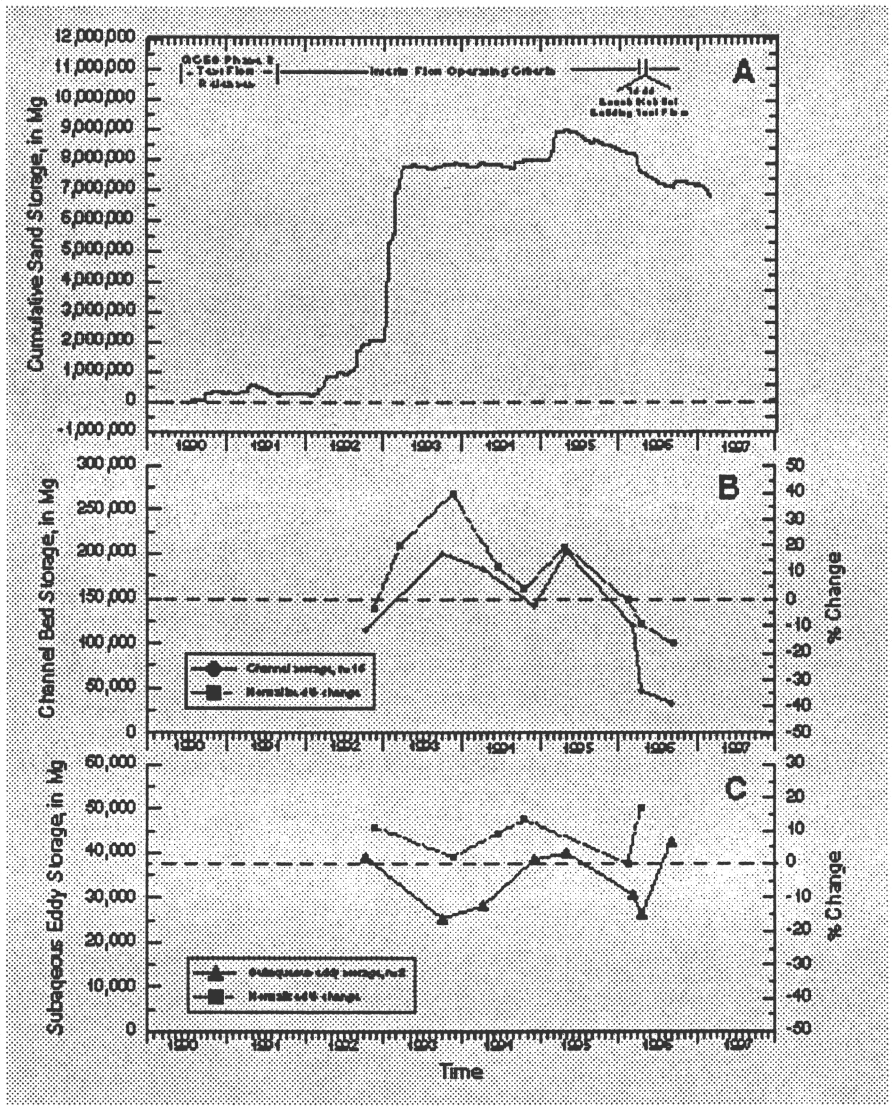


Figure 7. Cumulative sediment storage in the reach between the Little Colorado River and Diamond Creek 1990-1997. (A) sand mass-balance model using the sediment transport relations of Randle and Pemberton (1987), and measured sediment storage below the 5,000 ft³/s stage elevation from the (B) main channel, and eddy systems at selected study sites.



SUMMARY

The 1996 beach/habitat-building test flow significantly increased the volume of sand stored in channel-margin alluvial deposits, or sand bars by 48%. In contrast to large volumetric increase, sand bar plan area increased only slightly by 7% (Table 1). This difference between changes in sand bar volume and area indicates that, in general, the controlled high flow resulted in bars that were higher, but not necessarily wider.

The average response of eddy systems was to gain sediment. However, we measured a net deficit of sediment at large eddy systems in wide reaches of the river (e.g. lower Marble Canyon). This suggests that these eddies were a source of sediment that was mobilized during the test flow. The test flow also scoured the main channel adjacent to our study sites of sediment that had accumulated during the interim flow period.

Sediment mass-balance models highlight the importance of tributary inputs and "normal" dam operations to the long-term balance of sediment in the river corridor. For example, high dam releases before and after the test flow transported more sediment than the test flow itself. Increases in the sediment stored in a particular reach occur when tributary inputs exceed main channel transport capacities. During years of low tributary input, flows from GCD will most likely transport more sediment out of a given reach than will be supplied, resulting in a deficit of sediment stored along the channel. Flood flows should be used in such a scenario to remove the sediment from downstream transport by redistribution to the higher elevation channel-margin sand bars. Flow releases from GCD must be carefully managed in order to maintain a positive balance of sediment within the system.

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Modeling of sand deposition and erosion in a reach of the Colorado River below the Little Colorado River during the 1993 Little Colorado River flood and the 1996 beach/habitat-building flow

Stephen M. Wiele

ABSTRACT

A release from Glen Canyon Dam during March-April 1996, referred to as the beach/habitat-building flow (BHBF), was designed to test the effectiveness with which the riparian environment along the Colorado River could be renewed with discharges greatly in excess of the normal powerplant-restricted maximum. An important issue is the resemblance between deposition magnitude and location produced by the BHBF and deposition during pre-dam high flows. A flood on the Little Colorado River (LCR) in January 1993 contributed sand to the mainstem that elevated sand concentrations in the mainstem to levels comparable to pre-dam concentrations that occurred on the rising limb of seasonally high discharges (Topping, this volume). Sand concentrations during the BHBF were comparable to pre-dam concentrations during the falling limb of seasonally high discharges (Topping, this volume) which were about an order of magnitude lower than the concentrations during the LCR flood. The effect of sand concentration on deposition magnitude and location can be examined by comparing these two events.

Analysis of the depositional processes with a model of flow, sand transport, and bed evolution show that the high concentrations of sand during the LCR flood led to rapid deposition initially in the main channel, with a steady net accumulation of sand along the channel sides. The channel reached its maximum accumulation after about three days, after which all sand introduced at the upstream end was passed through to the reach below. During the BHBF, the lower sand concentrations led to scour of the main channel deposits that existed prior to the increase in discharge. Deposition was concentrated along the channel sides near the eddy reattachment point as sand carried in suspension settled out in this region of lower flow velocities.

In addition, sand concentrations declined during the BHBF raising the possibility that deposits formed early during the BHBF could be eroded later during the BHBF. Modeling results show that the sand deposits formed along the channel sides early during the high flow were only slightly affected by the decline in sand concentration over the course of the controlled flood. Details of the model and this application can be found in Wiele and others (1996) and Wiele (1997).

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Flow, sediment transport, and channel geomorphic adjustment in the Grand Canyon, Arizona gage reach of the Colorado River during the 1996 Grand Canyon flood experiment

David J. Topping

EXECUTIVE SUMMARY

The Colorado River in Grand Canyon is currently and historically (prior to the closure of Glen Canyon Dam) a supply-limited system with respect to both sand and finer sediment; supply-limited in this case means simply that the river would transport more material in a given size range if more material were available. In addition to the supply limitation, the system is characterized, both in the past and the present, by the non-coeval nature of the time of sediment supply and the time of high sediment transport capacity in the main channel.

In the pre-dam system, sand was seasonally supplied to and stored in the channel of the Glen and Grand Canyon reaches of the Colorado River by tributary floods during the monsoon season, which extends from mid July through early October. During the snow melt flood the following spring and early summer, the stored sand would be transported downstream with partial storage of the sand in high eddy deposits. Over the course of the annual snow melt flood, the supply of sand would be partially exhausted, causing concentrations of sand to decrease by about an order of magnitude. This effect is illustrated by the prominent hysteresis in the pre-dam suspended-sand rating curve. In the modern (post-dam) system, the supply of sand is only 10% of the pre-dam supply, and, as a result, the same magnitude of decrease in sand concentration during the course of a sustained high flow occurs over the time scale of days rather than weeks or months. This decrease in sand concentration is predicted to occur during the course of the current, i.e., spring 1997, high releases from the dam.

In the modern system, as in the historical one, significant sand-transporting flows do not occur simultaneously with sand supplying events. Sand is still supplied by tributaries (mostly the Paria and Little Colorado Rivers), but significant sand-transporting flows are produced somewhat arbitrarily with respect to the timing of sand-supplying events by dam operators who are required to meet power-generation needs and maintain reservoir levels. Because of this general mismatch in the timing of sand supply and transport, the grain-size distributions of the bed and suspended sand evolve during sustained high flows in both the pre-dam and modern systems, with both distributions coarsening as fines are winnowed out of the bed. Thus, the major decreases in sand concentration during sustained high flows in both the pre-dam and modern systems are produced by preferential depletion in the finer sands. This process is responsible for the inversely graded beach deposits described by Rubin and others (this volume).

This study was conducted in the reach at the Grand Canyon, AZ gage (station number 09402500) for two major reasons: (1) development of an understanding of sediment transport at this site, because of its historical sediment record beginning in 1925, allows the present state, with respect to the sand resource, of the Colorado River below the Little Colorado River to be placed in the context of the pre-dam "natural" system; (2) collection of a complete topographic,

velocity field, sediment-concentration field, and bed grain-size distribution data set during the 1996 flood experiment allows the development of a physically based flow and sediment-transport model coupled to the geomorphology and range of sediment supply at this site. This physically based approach provides for a more complete interpretation of the historical pre- and post-dam sediment data collected at this site.

During the 1996 flood experiment, the following data were collected in the Grand Canyon gage reach. Five cross-sections in the reach above the Kaibab suspension bridge were surveyed daily for the nine days bracketing the flood experiment. Daily suspended-sediment samples were collected from the USGS cableway using a Colorado River Sampler (the type of sampler used at this site prior to 1944), a P-61 sampler (used in both the point- and depth-integrating methodologies), and a D-77 bag sampler. Velocity profiles were measured with the P-61 sampler. Bed material samples were collected daily at five stations across the channel with a BM-54 sampler.

Scour and fill of the channel bed in the Grand Canyon gage reach is not directly related to the amount of sand in suspension. Indeed, only a few centimeters of net bed erosion are necessary to produce the measured volume of sand in the water column associated with the highest concentrations of suspended sand ever measured at this site. Rather, aggradation and degradation of the bed at the Grand Canyon cableway is driven by changes in the distribution of boundary shear stress in the reach, due to complicated local channel geometry, as a function of changing stage. Comparison of channel-bed topographic measurements made at the cableway during the 1996 flood experiment with earlier measured cross-sections from USGS discharge measurement field notes indicate that the bed elevation at the cableway during the 1996 flood experiment evolved in the same way as for similar rises in stage between 1923 and 1950. The bed at the cableway aggraded by about 2 m on the rising limb of the 1996 flood experiment, with sand supplied both from banks that were eroded in the reach upstream and from the upstream pool that was scoured. Within 20 days after the end of the flood, the bed at the cableway had degraded 2 m back to its pre-flood level with the deposition of new sediment on the margins of the channel upstream; again, in a manner similar to the pre-dam case, as indicated by the 1923-1950 measurements. Thus, the geomorphic response of the channel in the Grand Canyon gage reach during the 1996 flood experiment was similar to that during a pre-dam flood. Change in bed elevation at a cross-section is not necessarily sensitive to sand supply because bed elevation change can be driven primarily by reach-scale hydraulics.

The amount of sediment in suspension for any given discharge is highly sensitive to the grain-size distribution of the bed material and relatively insensitive to the thickness of sand on the bed (as long as the bed is completely covered by sand). Analysis of the pre-dam data and modeling using the data collected during the 1996 flood experiment indicate that a factor of 2 change in the median size of the bed material will result in a change in the suspended-sand concentration by more than an order of magnitude. This coupling of the evolution of the bed- and suspended-sediment grain-size distributions was evident during the flood. As the finest sizes were winnowed from the bed, the median size of the bed material changed from 0.3 mm to 0.4 mm and the concentrations of suspended sand decreased from a mean of 0.11% by volume on day 1 to a mean of 0.06% by volume from day 3 through day 7. Likewise, over the course of the flood, the concentration of

suspended silt and clay decreased from a mean of 0.035% by volume on day 1 to a mean of 0.008% by volume on days 3 through 7. As concentrations dropped off in response to the coarsening of the bed, the size distributions of the suspended sand evolved accordingly, with the median size of the suspended sand increasing from 0.12 mm to 0.2 mm. As is physically required, the evolution of the grain-size distribution of the suspended sand did not merely occur by a depletion in the fines, but by an increase in the concentration of coarser sand in suspension.

Point measurements of suspended-sand concentration and velocity made during the 1996 flood experiment have the same vertical structure as point measurements of suspended-sand concentration and velocity made during a similar pre-dam flow in May 1946 indicating that the hydraulics have not dramatically changed in this reach since at least 1946. The only difference between these data sets is that during the 1996 flood experiment sand finer than 0.25 mm was a factor of two lower in concentration than during the 1946 event. In other words, the supply of the finest sand sizes have been affected the most by the upstream presence of Glen Canyon Dam.

Comparison of suspended-sand measurements made during the 1996 flood experiment with all of the suspended-sand measurements made from 1944 to 1963, 1965 to 1971, and 1983 to 1986 indicates that no truly stable suspended-sand rating curve has ever existed at this site. Prior to closure of the dam, an apparently stable hysteresis loop existed only because the annual supply of sand averaged over all of the tributaries in Glen and Grand Canyons was stable over the period from 1944 to 1963 and the magnitude of the annual snow melt flood in the mainstem was also stable. After closure of the dam, the apparent stability of the rating disappeared and the variability in potential sand concentration increased by 1-2 orders of magnitude. From 1965 to 1971, and again during the 1996 flood experiment, sand concentrations were lower than pre-dam historical peak concentrations by about an order of magnitude, but were still comparable to the seasonally lower concentrations typical of the period from about May 21 to July 20 each year in the pre-dam system. During the high influx of fine sand during the January 1993 Little Colorado River flood, sand concentrations were probably as high as the highest measured pre-dam concentrations of 0.1-0.3% by volume, but only for a short period of time (see Wiele in this volume). From 1983 to 1986, in response to the large releases of 1983 to 1985, the system was severely depleted in the finer sands and the concentrations were an order of magnitude lower than they had ever been before. All of these changes in the "effective" sand rating curve for each period can be related to changes in the median size of the bed material with the median size: (1) seasonally ranging from 0.2 to 0.4 mm in the pre-dam era, (2) ranging from about 0.3 to 0.4 mm from 1965 to 1971 and during the 1996 flood experiment, (3) and being somewhat coarser than 0.5 mm during the 1983-1986 period. Because the current (1997 spring) high flows, about 24,000 to 27,000 cfs, in the Colorado River will transport an order of magnitude more sand out of the Grand Canyon than has come in during the last year from the Paria and Little Colorado Rivers, the river may quickly return to the more sand-depleted conditions typical of 1983-1986.

When completed, this methodology can potentially be used to evaluate sand resources in the Colorado River in a more powerful way than existing methods because it physically relates suspended sand concentrations to the grain-size distribution in the bed. More detailed sampling and modeling work is needed to fully realize this goal.

Topographic evolution of sand bars in lateral separation eddies in Grand Canyon during the 1996 experimental flood

E. D. Andrews, Chris Johnston, Jack Schmidt, Mark Gonzales

ABSTRACT

Sand bars deposited in lateral separation eddies are an essential biological and recreational resource of the Colorado River downstream from Glen Canyon Dam. Since 1986, sustained discharges substantially in excess of the powerplant capacity have not occurred, and approximately half of the sand bars which existed in 1986 have been degraded by erosion and encroachment of vegetation. A primary purpose of the experimental flood release from Glen Canyon Dam during the Spring of 1996 was to measure the rate of sand deposition and erosion as well as the adjustment of sand bar topography during a period of sustained high flow along the Colorado River through Grand Canyon National Park. The deposition rate of sand in an eddy is strongly influenced by the suspended sand concentration in the river channel along the outer boundary of the eddy. A second factor controlling the deposition and erosion of sand in an eddy is the morphology of the channel-debris fan-eddy complex. To consider the effects of suspended sand concentration and channel morphology, five eddies were selected and repeated, detailed bathymetric surveys of these eddies before, during, and after a flood of 45,000 ft^3/s for seven days were made to determine the topographic evolution of sand bars. Two of the eddies are located upstream of the Little Colorado River, which is the primary source of sand to the Colorado River through Grand Canyon, and three eddies are located downstream of the Little Colorado River. Evolution of sand bar topography was rapid, and large volumes of sand were redistributed quickly. Similarly, the rates of sand deposition and erosion were highly variable within and between eddies. Sand bars aggraded and degraded by as much as 4 meters within less than 24 hours. Subaqueous mass failures of oversteepened portions of the sand bar appeared to occur in all eddies. Comparisons of pre- and post flood sand bar topographies show that large quantities of material (as much as 1 X 105 m^3) were redistributed in an eddy during the flood. In most eddies, sand deposits at the eddy separation and reattachment points grew while sand was eroded from the channel and along the outer margin of the eddy.

Eddy bar responses to the sediment dynamics of pool-riffle environments

Brian L. Cluer

ABSTRACT

Rivers in bedrock channels often contain debris fans that create sand deposits in lateral flow separation zones. Debris fans are reworked by infrequent flood flows, which are more infrequent downstream from dams. Dams also reduce downstream sediment supply and the riparian environment suffers from a lack of rejuvenating floods and degradation of alluvial deposits.

During this investigation, one eddy bar in the dam-regulated Colorado River in Grand Canyon was stripped of 11,500m^3 of sand in a few hours. Monitoring programs have documented dozens of rapid erosion events throughout the Grand Canyon. This investigation was undertaken to determine (1) if the process occurs only in the regulated river environment, (2) the fate of sediment stripped from eddy deposits, and (3) what causes rapid erosion.

Investigation of similar deposits along the near-naturally flowing Colorado River near Moab, Utah, showed that eddy deposit stripping occurs annually during the rising limb of annual floods. Stripping was preceded by deformation of the pool adjacent to the eddy. Repeated channel mapping in the Grand Canyon showed the same pattern of pool deformation preceding scour of an eddy bar. The sediment stripped from eddies is transported downstream. Therefore, new eddy bars form from sand delivered from upstream.

Velocity field measurements, concurrent with repeated channel mapping, showed that high boundary shear stress exists along the toe of large bars. Large bars have slopes at or exceeding the angle of internal friction, so minor changes in the flow field can trigger slope failure. A calibrated two-dimensional flow model confirmed that minor deformation of the pool exit and entry slopes results in increasing shear stress beyond particle stability along the toe of the eddy bar.

Variation in sediment load between rising and falling limbs of flood flows causes temporary pool deformation. This process was documented in the natural river undergoing an annual flood flow and in the regulated river undergoing a daily hydropower flood flow. Slope failure, if sufficiently voluminous, may augment a rapid erosion event by increasing the sediment supply in the pool.

Flood effects on benthic metabolism of carbon and oxygen in Glen Canyon Dam's tailwater: Results and long-term implications

Marzolf, G. R., C. J. Bowser, D. W. Stephens, R. J. Hart, and W. S. Vernieu

ABSTRACT

Historic records and preliminary measurements of river chemistry were examined to determine whether diel changes might be caused by benthic photosynthesis in the reach and whether open stream methods could detect photosynthetically-driven chemical changes. Observations connected with this high flow experiment were designed, therefore, to test this basic idea and then, if the idea stood the test, to document flood effects on the photosynthetic community. Several measures of river chemistry (see Bowser et al.) were made at short-time and spatial intervals during the low-flow period before and after the flood. The diel amplitudes of change in oxygen concentration and pH were decreased by about 75% as a result of the flood that scoured substantial biomass from the reach. Parallel measurements on algae covered cobbles enclosed in metabolic chambers suggest that the efficiency of community metabolism of the remaining biomass increased as a result of the flood.

Carbon and oxygen dynamics in the Glen Canyon Dam's tailwater: Processes and observations during the 1996 experimental flood

Bowser, C. J., G. R. Marzolf, D. W. Stephens, R. J. Hart, and W. S. Vernieu

ABSTRACT

Carbon dynamics were examined during the low discharge periods (226 m^3/s) immediately prior to and following the high discharge period to assess the relative controls of atmospheric gas exchange and biologically mediated processes in this reach of the river. A 24-hour monitoring of tailwater sites was conducted at Lees Ferry (25 km from the dam) and at points 4.8, 9.7, and 14.5 km upstream. Dissolved oxygen concentration, pH, and temperature were measured at half hour intervals with less frequent measurements of alkalinity, DIC/DOC, and major ion chemistry.

The light-dependent variations in pH and dissolved oxygen indicated control by net primary production and respiration, especially at the more downstream sites (e.g., Lees Ferry). Differences in dissolved gas dynamics at stations were largely determined by the time of total daylight exposure for a given water mass, which in turn was determined by distance downstream of the dam, canyon wall shadow effects on local reaches of the river, orientation of the river stretch relative to transit of the sun, cloudiness, and depth/width variations of the local river channel. Evidence for the subsequent recovery of the algal community is available in the form of records from data loggers in place at Lees Ferry since mid-April when normal operation of Glen Canyon Dam was resumed.

Effects of experimental flooding on periphyton and macroinvertebrates in the Glen Canyon Dam tailwater

Ted McKinney, Roland S. Rogers, and Andrew D. Ayers

ABSTRACT

Periphyton and benthic macroinvertebrates were investigated in the tailwater of Glen Canyon Dam in the Colorado River, Arizona, prior to and following experimental flooding. The hypothesis tested was that flooding would have no negative effects on lotic periphyton or benthic macrofauna. Periphyton and benthic invertebrates provide important trophic linkages in the tailwater. Lotic biota differed in resistance to and resilience after the flood. Biomass (ash free dry weight - AFDW) of periphyton on cobbles was unaffected, but densities of chlorophyll *a* and diatom epiphytes were reduced within the week after the high discharge. Densities of periphyton and diatom epiphytes on cobbles reflected seasonal patterns of change following the flood, but epiphyte densities remained low in comparison to previous years. Differential loss of large/upright diatom taxa and lower total diatom densities following the flood potentially impacted the availability of food for macroinvertebrate grazers in the reach.

Submerged aquatic macrophytes were decimated by the flood, changing habitat for trout and the potential food base for benthic invertebrates. Composition of the macrophyte community recolonizing denuded depositional substrate was altered following recession of flood waters. *Potamogeton* sp. initially colonized substrate exposed by flooding, succeeding *Chara contraria*, which was the dominant pre-flood taxon in depositional habitat. *Chara* colonized extensively in the tailwater by about eight months post-flood.

Effects of flooding on benthic macroinvertebrates were site- and species-dependent. Densities of *Gammarus lacustris* declined 65%-70% in cobble bar and depositional habitats within the week after recession of flood waters, potentially impacting the food base for rainbow trout. Densities of chironomids and oligochaetes showed no decline during the week after flooding, but densities of snails and planarid flatworms declined about 70% at one cobble bar, and flatworm densities declined about 50% in depositional habitat. Densities of benthic macrofauna four to eight months following recession of flood waters reflected seasonal patterns of change and indicated recovery of taxa which were negatively impacted by the flood. Recovery of amphipod densities on cobble bars was apparent by about four months after the experimental discharge. However, recovery did not occur in depositional habitat until about four months later, coincident with colonization by *Chara*.

Experimental flooding and rainbow trout in the Glen Canyon Dam tailwater

Ted McKinney, R. Scott Rogers, and Andrew D. Ayers

ABSTRACT

Rainbow trout (*Oncorynchus mykiss*) were sampled by electro-fishing in the Glen Canyon Dam tailwater on the Colorado River, Arizona, prior to and following one week of experimental flooding. The hypothesis tested was that flooding would have no negative effects on the trout population in the tailwater. Rainbow trout provide an important recreational fishery and trophic link in the reach.

Relative abundance (catch-per-unit-effort - CPUE) of trout did not differ during the weeks just prior to and after the flood. Five to eight months following flood recession, abundance was comparable to that observed during previous years. Condition of trout was not affected by the experimental discharge. Mean length and weight of trout were greater and about 10% fewer fish <152 mm in length were caught within one week after than just prior to the flood, suggesting that some downstream displacement of smaller fish from the reach may have occurred due to the high flows. Strong recruitment of naturally-spawned trout into the population eight months later indicates that the spring flood did not prevent successful spawning.

Gammarus lacustris, chironomids and gastropods were predominant food groups in trout diets throughout the study. Frequency of occurrence of trout that had fed was similar during the week prior to and the week after the flood. Trout diets changed seasonally following the week after recession of flood waters, but no effects of flooding were apparent on selection or importance of major dietary components. No differential impacts of the flood were apparent on abundance, condition factor, lengths, weights or size-frequency distributions of trout collected from transects vegetated predominantly by filamentous algae or by submerged macrophytes. Results indicate that the spike discharge and loss of submerged macrophytes and lower amphipod benthic densities observed following the flood had no important negative impacts on the rainbow trout population.

Impacts of the Spring 1996 spike flow from Glen Canyon Dam on the aquatic food base in the Colorado River through Grand Canyon, Arizona

Joseph P. Shannon, Dean W. Blinn, Kevin P. Wilson, Peggy L. Benenati, Jessica Hagan, and Chris O'Brien

EXECUTIVE SUMMARY

INTRODUCTION

Discharge, suspended sediments, substrata, solar insolation and water temperature are the primary factors influencing benthic community structure in the Colorado River through Grand Canyon. Variability in river discharge can affect the structure and function of benthic communities by altering the stability and availability of substrata (Power et al. 1988, Cobb et al. 1992), water velocity (Peterson and Stevenson 1992), aerial exposure (Blinn et al. 1995), light quantity (Duncan and Blinn 1989) and water quality (Scullion & Sinton 1983). Regulated rivers eliminate seasonal hydrographic changes and remove important life history cues for some aquatic insects thereby reducing diversity (Power et al. 1988).

Statzner and Higler (1986) contend that changes in stream hydraulics are the major determinants in benthic invertebrate distribution, based on the intermediate disturbance hypothesis as outlined by Ward and Stanford (1983) and Reice and co-workers (1990). Under extreme discharge conditions (i.e., spring run-off) species numbers are relatively low, under less extreme but highly inconsistent conditions (i.e., zones of hydraulic transition) species richness is relatively high due to an overlap of species inhabiting the fringes of their niche requirements. These same criteria may operate in the Colorado River through Grand Canyon if flooding frequency is increased.

Studies in smaller lotic ecosystems in the Southwest have revealed the importance of floods in nutrient availability, particularly nitrogen (Grimm and Fisher 1986). Spates increase nutrient concentrations through hyporheic up-welling and run-off (Peterson and Grimm 1992). Particulate organic matter can also be released into the water column from the flood-plain, transported down stream, accumulated in depositional zones, and mineralized for assimilation following high flows (Elwood et al. 1983).

The structure of the benthic community in the Colorado River through Grand Canyon has been altered by the construction of Glen Canyon Dam through changes in river discharge, organic budget, suspended sediments and water temperature. Interim Flow (IF) criteria have increased the baseflow while reducing peak flow and hourly ramping rates from Glen Canyon Dam. A similar change in flow regime implemented on the Patuxent River, MD, caused a doubling in benthic macroinvertebrate density and improved community condition (Morgan et al. 1991).

Standing mass and habitat requirements of the benthos in the Colorado River through Glen and Grand Canyons were assessed seasonally from September, 1992 through June 1996.

Monitoring the lower aquatic trophic levels in this large river in an arid biome contributes to a better understanding of linkages between benthos and higher trophic levels, a prerequisite for resource management. Our seasonal sampling frequency was employed to compare high and low volume discharge months prior to collection trips. Sampling sites ($n = 12$) were the same as those established during GCES Phase II research flows and include low velocity pool/eddies and high velocity cobble bars in both wide ($n = 6$) and narrow ($n = 6$) reaches (Schmidt & Graf 1990, Blinn et al. 1992, 1994). We added a site at Gneiss Canyon (RKM 378), with Spencer Canyon (RKM 393) the tributary site, in cooperation with the Hualapai Division of Natural Resources.

Research Hypothesis: Spring 1996 Spike Flow discharge from Glen Canyon Dam will have an impact on the aquatic food base in the Colorado River through Grand Canyon.

RESULTS

Benthic Patterns: Monitoring

Interim Flows (IF) from June 1995 through the Spike Flow (SF) were at the upper limits of IF criteria. This coupled with a regional drought resulted in many changes in the structure of the benthic community in the Colorado River below Glen Canyon Dam. A comparison of the benthic community between March 1995 and March 1996 collections indicated an overall significant difference between these two periods for both riffle and pool habitats. Evaluating the differences between these two collecting trips is important for understanding the impacts of the SF as the March 1996 trip established our system-wide baseline. A similar comparison was made for June 1994 and June 1996 collection trips. We determined there was an overall significant difference between these collection trips and sites for riffle habitats, but pools only varied significantly between sites and not between trips.

Biomass in pools and riffles for collections during March 1995 and March 1996 revealed a system-wide impact of a wetter than normal winter of 1995. Detrital loads in pools decreased by ~90% from March 1995 to March 1996. We observed evidence of spates and debris flows from every perennial tributary from Nankoweap Creek to Diamond Creek during our March 1995 monitoring trip. An influx of woody debris from these events, coupled with high discharges the following year accounted for the removal of material by March 1996. In riffle habitats, *Oscillatoria* spp., miscellaneous algae/macrophytes/bryophytes (MAMB), and miscellaneous macroinvertebrate mass estimates were all significantly higher in 1996 than 1995 collections. However, simuliid larvae/pupae mass estimates were significantly lower by ~80% during March of 1996. This may have resulted from the higher IF discharges which lowered the amount of FPOM in the water column that is filtered as food by these animals. *Oscillatoria* spp. more than doubled in biomass in 1996 over 1995, probably because we were sampling higher in the channel due to high flows. It is in the lower varial zone that *Oscillatoria* thrives.

A comparison of benthic biomass estimates in pool and riffle habitats for June 1995 and June 1996 showed more significant categorical differences within riffles than pools, with an overall increase in biomass in 1996. Some fine sediment dwellers such as chironomids in pools and lumbriculids in riffles decreased in June 1996 collections, except for tubificids which increased by 80%. Turnover rates of tubificids in riffles may be faster than chironomids or lumbriculids, because tubificids took advantage of the ~90% increase in detrital material collected from riffles in June 1996 over 1995.

Biotic categories also differed significantly by site between March 1995 and 1996, with pools being more resistant to annual change than riffles. The shift in dominance from *C. glomerata* to the miscellaneous algae, macrophytes and bryophytes (MAMB) category at Lees Ferry is eventful when comparing sites between years, MAMB also increased below the Little Colorado River confluence. Chironomid mass increased at many lower Grand Canyon sites and was less variable in collections during March 1996 than in March 1995. *Gammarus lacustris* mass showed an overall decrease in 1996 compared to March 1995 AFDM estimates except at Two-Mile Wash (RKM 3.1) and Little Colorado River Island (LCR; RKM 98.6). This may have been in response to an increase in phytobenthos at these two sites. There was a system-wide increase in miscellaneous macroinvertebrate mass, composed primarily of tricopteran nymphs, between March 1995 and 1996.

Multivariate comparison between June 1994 and June 1996 benthic biomass estimates varied significantly by site, with riffles more susceptible to change than pools. June biomass estimates were higher overall at more sites in June 1996 than in June 1994 for *C. glomerata*, MAMB, chironomids, *G. lacustris*, tubificids and gastropods, however, lumbriculid mass was lower.

FPOM Drift Patterns: Monitoring

Fine particulate organic matter (FPOM) estimates were significantly different between October 1995 and March 1995 for total FPOM and zooplankton (MANOVA Wilks' Lambda; $f_{2,72} = 16$; $p < 0.001$). These seasonal patterns may be a result of dam operations resulting in variable discharge patterns. October collections were done with the flows ranging from 311 to 508 $m^3 \cdot s^{-1}$ with a standard deviation of 53 $m^3 \cdot s^{-1}$, while discharge during the March collections ranged from 227 to 508 $m^3 \cdot s^{-1}$ with a standard deviation of 94 $m^3 \cdot s^{-1}$. The higher and more consistent flows in October resulted in significantly more FPOM and zooplankton than the lower more variable flows in March.

Regression analysis for both October 1995 and March 1996 indicated that there is significant positive correlation between total FPOM and distance from GCD, while there was a significant negative correlation for zooplankton biomass estimates (AFDM) and distance from GCD. October total FPOM increased by 94% and 96% in March between the two most distant sites. The increase in total FPOM with distance down stream is similar to the CPOM pattern and is probably from the break-down of larger organic particles because of the hydraulic forces. The decrease in zooplankton AFDM estimates is most dramatic in Glen Canyon with a 50%

reduction between the Glen Canyon Gauge and Lees Ferry for both collections. This is the single largest reduction in 24 km through the study site. These results indicate a lack of recruitment from tributaries or back-water/return channels through the study site. The reduction in zooplankton biomass through the tailwaters may be from predation or the filtering action of primary producers. Miscellaneous zooplankton (planaria, first in-star diptera larvae, snail eggs, etc.) did not change significantly in biomass between sites ($p = 0.6$) for either collection. Lack of change in the biomass of miscellaneous zooplankton results from a continual reach-based source for these organisms, not just from Lake Powell as is the case for the zooplankton.

Composition of FPOM was dominated by detrital material with zooplankton representing <0.0001% the total FPOM estimate for both October 1995 and March 1996 collections. The zooplankton fraction was dominated Cyclopoidia copepods followed by Calaniod copepods, cladocerans and miscellaneous zooplankton for both October and March collections. Harpacticoids and ostracods were common but in low numbers, < 5 $m^3 \cdot s^{-1}$. Condition factors for zooplankton was consistently good with little or no degradation noted through the study site. Reproductive structures were rarely noted (<1 out of every 500 zooplankters), and were commonly egg sacs on female copepods. Copepod nauplii were also rarely encountered.

Benthic Patterns: Spike Flow

Multivariate analysis of benthic biomass from five cobble sites; Lees Ferry, Two-Mile Wash, LCR Island, Tanner Cobble and Lava Falls, with collection intervals designed to detect the impact and response of the benthos to the SF, indicated significant change for both collection interval and site. Univariate analysis indicated that only MAMB, lumbriculids and tubificids varied significantly for both collection interval and site. In order to assess the impact of the SF on the benthos we compared Hess collections taken during both the pre and post SF steady 227 $m^3 \cdot s^{-1}$ discharges and determined that the biotic categories responded differently at each site.

Cladophora glomerata did not change significantly at Lees Ferry or LCR Island after the SF, but did at all other sites. The relative lack of suspended sediment at Lees Ferry probably did not scour *Cladophora*, which was virtually eliminated at Two-Mile Wash located only 1 km down stream, but below the Paria River confluence. Recovery of *C. glomerata* equaled or surpassed that of the pre-SF estimates within one month at Lees Ferry and within two months at Two-Mile Wash and Tanner Cobble (Figure 1). A similar pattern of scour and recovery occurred for MAMB estimates.

There was little overall change in chironomid AFDM following the SF, but a steady increase in AFDM occurred over the two month period for *G. lacustris*. We noted that many *G. lacustris* were found stranded in pools as the water dropped during the SF, but egg masses and small size class amphipods (<2 mm) were noted during the one week and one month post collections. Whether this reproduction was a result of the SF or was normal for that time of year requires further investigation.

Organic Drift Patterns: Spike Flow

Multivariate analysis of CPOM organic drift estimates from five sites; Lees Ferry, Two-Mile Wash, LCR Island, Tanner Cobble and Lava Falls, with collection intervals designed to detect the impact and response of drift to the SF, indicated significant change for both collection interval and site. All biotic drift categories varied significantly by collection interval, while only *G. lacustris* and miscellaneous macroinvertebrates varied significantly by site. Comparisons of hydrostatic wave versus the actual water of the 1,274 $m^3 \cdot s^{-1}$ discharge revealed a significant difference (Kruskal-Wallis; $p < 0.01$) between the two with the hydrostatic wave carrying more organic material. These data revealed the greatest AFDM entrainment occurred during the up-ramp of the SF and that duration was not a factor for scour or entrainment.

Cladophora glomerata (Fig. 2), MAMB and detritus drift estimates all peaked during the wave 1,274 $m^3 \cdot s^{-1}$ and recovered or surpassed pre-SF drift following the benthic pattern for each site, except for detritus which was probably swept through the study site to Lake Mead. Aquatic diptera and miscellaneous macroinvertebrate drifting mass also peaked during the SF wave and recovered or surpassed that of pre-SF estimates by one month at Lees Ferry and Two-mile Wash. The miscellaneous macroinvertebrate category was composed primarily of tubificid worms during the SF which suggested disturbance and movement of the bedload as these organisms are sediment dwellers. Terrestrial insects represented 1.3% (36 out of 2,600) of the miscellaneous macroinvertebate category, which is low but is up by two orders of magnitude over values reported by Shannon et al. (1996).

Estimates for FPOM biomass varied significantly by collection date and site during the SF (Fig. 3). Zooplankton, miscellaneous zooplankton, detritus and total FPOM exhibited similar patterns as compared to CPOM, with the highest FPOM concentrations occurring within the hydrostatic wave and then tapering off through the steady 1,274 $m^3 \cdot s^{-1}$ discharge. Lees Ferry collections carried the highest total FPOM (1.7 ± 18 $g \cdot m^3 \cdot s^{-1}$ AFDM) as the hydrostatic wave passed Lees Ferry. This FPOM estimate at Lees Ferry increased by 92% while traveling the 24 km from the Glen Canyon collection, probably picking up riparian debris. However, there was a 70% decrease in FPOM as the hydrostatic wave reached Hells Hollow. This decrease corresponds with a three-fold increase in DOC between Lees Ferry and Hells Hollow, which may indicate hydraulic breakdown of the FPOM. At the post-227 $m^3 \cdot s^{-1}$ flow collections, FPOM estimates returned to pre-SF concentrations at Glen Canyon (0.004 ± 0.0006 $g \cdot m^3 \cdot s^{-1}$ AFDM) and Lees Ferry (0.02 ± 0.003 $g \cdot m^3 \cdot s^{-1}$ AFDM), however at Hells Hollow during this collection interval FPOM estimates were 2.5 times at the post collection than at the pre-SF collection. This may be a function of a higher discharge carrying more FPOM at Hells Hollow during this collection interval because river discharge never dropped below 340 $m^3 \cdot s^{-1}$, due to the draining of bank stored water.

Zooplankton biomass followed a similar pattern to that of FPOM biomass during the SF with the hydrostatic wave carrying the most zooplankton, with a decrease down stream and through the SF hydrograph. Zooplankton composition was dominated by Cyclopoida copepods at all sites and collection intervals except at Lees Ferry as the hydrostatic wave

passed transporting a high concentration of miscellaneous zooplankton. This concentration of miscellaneous zooplankters corresponds with the relatively high biomass of secondary producers in the tailwaters.

Examination of interval camera photographs during the SF showed an average of 1.4 large CPOM, easily visible bundles, passing by the cameras during the up-ramp, two bundles during the arrival of the water at 1,274 $m^3 \cdot s^{-1}$, 0.5 bundles during the steady 1,274 $m^3 \cdot s^{-1}$, and 1.2 bundles during the post steady flows. No large CPOM bundles were sighted during the pre-SF steady flows. These data indicate entrainment of large CPOM, primarily *Tamarisk* and some up-land vegetation that was stranded on beaches below the 1,274 $m^3 \cdot s^{-1}$ stage, which followed a pattern similar to that of CPOM with the peak concentration during the up ramp.

Large CPOM contributed a negligible mass to the transport of organic material during the SF in comparison to FPOM and CPOM estimates. Organic drift during the SF, including both pre and post steady flows averaged 0.24 $g \cdot m^3 \cdot s^{-1}$ of CPOM. This extrapolates to ~1.06 x 10^{-6} kg of CPOM after multiplying the mass of organic drift by the total estimate of water discharged during the SF. FPOM organic drift for the SF averages 0.22 $g \cdot m^3 \cdot s^{-1}$ or 0.97 x 10^{-6} kg for the entire SF period. For large CPOM using an average of ~22.2 bundles passing a given point every h, calculated from an average of 1.5 bundles per camera view of 250 m and a water velocity of 3.7 $km \cdot h^{-1}$, that each bundle weighed an estimated 4 kg AFDM (n = 10) then for the 11 days that bundles passed the cameras we estimate ~2.3 x 10^{-4} kg of large CPOM was transported by the SF. If we increase the mass of each bundle to 40 kg AFDM then we have ~2.3 x 10^{-5} or 400 kg AFDM for each bundle to reach the same order of magnitude that the CPOM and FPOM are in, ~2.3 x 10^{-6} kg.

Percent particle size of CPOM changed with site and collection interval with a decrease in the ≥10 mm size fraction during the steady 1,274 $m^3 \cdot s^{-1}$ flows, whereas both 1-9 mm and the <1 mm size fraction increased. This pattern held for all sites except for Hells Hollow which may have resulted from the break-up of large CPOM as it moves through the rapids of middle and lower Grand Canyon. Lees Ferry and Two-Mile Wash sites regained the ≥10 mm size fraction within one week after the end of the SF, which coincides the phytobenthic pattern for these two sites.
Particle size of CPOM drift in June 1996 was primarily ≥10 mm and is a reflection of the extensive primary producer growth that occurred following the SF. Late October 1996 CPOM collections were highly variable, probably as a result of spates from monsoon and late fall storms from July through the collection period. Both collection periods demonstrate the reach based pattern of organic matter, for example in October Nankoweap (RKM 84.8) collections had no ≥ 10 mm size fraction but at the gauge above the Little Colorado River, only 4 km down river, 50% of the CPOM was in the ≥ 10 mm fraction.

DOC-Spike Flow

Dissolved organic carbon (DOC) results were variable and changed according to collection site and collection interval during the SF. During the pre-SF 227 $m^3 \cdot s^{-1}$ collections of DOC

remained relatively constant through the study site. As the hydrostatic wave was sampled we found marked variability between sites and the highest concentration collected during the SF, 9.2 $mg \cdot L^{-1}$, at Hells Hollow (RKM 278.2). Concentrations were either higher or remained the same as the initial 1,274 $m^3 \cdot s^{-1}$ water passed the collection sites and decreased through the duration of the SF. Post-SF 227 $m^3 \cdot s^{-1}$ DOC concentrations were elevated over the 1,274 $m^3 \cdot s^{-1}$ collections. This elevation in DOC concentration and clear water resulted in the high primary producer estimates reported in our June 1996 monitoring collections. Rivers in the Mid-Atlantic region have annual mean DOC concentrations of between 3.4 and 5.8 $mg \cdot L^{-1}$ (Clair and Ehrman, 1996), while in the desert Jones et al. (1996) reported annual mean DOC concentrations of 3.4 to 7.4 $mg \cdot L^{-1}$, with a five year average of 4.8 $mg \cdot L^{-1}$ and a daily range of 0.9 to 10.5 $mg \cdot L^{-1}$ in Sycamore Creek, AZ. Flood water in Sycamore Creek carried average DOC concentrations of 6.6 $mg \cdot L^{-1}$ (Jones et al. 1996). System wide average in the Colorado River during the SF was 4.1 $mg \cdot L^{-1}$, ranging from 1.9 to 9.2 $mg \cdot L^{-1}$.

Dual Isotope Analysis: Spike Flow

Dual Isotope analysis of the SF revealed isotopic shifts through the hydrograph with riparian vegetation the major source of carbon and nitrogen. Dual isotopic plots of $\delta^{13}C$ and $\delta^{15}N$ when compared to data reported by Angradi (1994) gives an indication of the source of organic material. The isotopic composition of the river at Lees Ferry and Two-Mile Wash in the pre-SF 227 $m^3 \cdot s^{-1}$ discharge was primarily Lake Powell water, as the 1,274 $m^3 \cdot s^{-1}$ wave passed these sites the water had changed in isotopic composition to riparian vegetation, in <25 km below GCD. Lees Ferry and Two-Mile Wash isotopic signals remained primarily riparian through the steady 1,274 $m^3 \cdot s^{-1}$ flow, but instead of returning to the Lake Powell isotopic signal during the post-SF 227 $m^3 \cdot s^{-1}$, the signal matched that of fish. The source for this signal maybe from stranded trout during the down ramping. Down river sites at Carbon Creek (RKM 98.7) and Hells Hollow (RKM 278.2) showed a depletion of ^{13}C through the SF that was carried into the post-SF 227 $m^3 \cdot s^{-1}$ flow. ^{15}N did follow this pattern of depletion through the SF. Carbon Creek and Hells Hollow had more up-land vegetation than Lees Ferry and Two-Mile Wash, probably because of the accumulation of up- land vegetation within the above varial zone from tributary spates. Isotope samples taken from the gauge above the Little Colorado River (RKM 98.4) were omitted from analysis because they were identical to the Carbon Creek samples. Outliers maybe from marsh vegetation such as *Phragmites* spp. or maize from Havasupai Creek which were not included in Angardi's original study.

Light Intensity: Spike Flow

Light intensity, $Lumens \cdot m^{-2}$, measured 0.5 m below the surface at Lees Ferry and Carbon Creek revealed a similar pattern of diminishing light intensity as the SF hydrograph reached peak flow and then increased as the peak flow persisted. Light intensity values were jogged by one day because of the lag-time as the hydrostatic wave moved down river. The similarities in light intensities between sites almost 110 km apart is a reflection of how uniformly this restricted sediment and detritus laden river channel responded to the SF hydrograph. During the post-SF 227 $m^3 \cdot s^{-1}$ light intensity was increasing over time at both sites and is the primary

DISCUSSION

The beach/habitat building spike flow of March 1996 significantly altered the aquatic food base of the Colorado River through Grand Canyon. Scour and entrainment of both primary and secondary produces accrued at all sites, but varied among biotic categories. Recovery of the benthos to pre-SF conditions and that of other June 1994 was complete after one month for some sites. This recovery was much faster than our experimental results predicated. Although the phytobenthos did get scoured, cobbles were not completely barren. This coupled with virtually no tributary input of suspended sediment and the subsequent optimum light conditions allowed for a relatively quick recovery of the phytobenthic community. The SF flushed the system of fine particles, also contributing to the positive light conditions. The duration of the SF was longer than needed for benthic change as 90% of the change occurred with the arrival of the hydrostatic wave which occurred during the initial 24 h.

Macroinvertebrate biomass followed the same pattern as that of the phytobenthos and recovered quickly at all sites. The June 1996 trip had some of the highest biomass estimates and most taxa documented during this project. However, whether these patterns would have occurred without the SF because of the high steady IF discharges coupled with an extended period of clear water is not evident. Our data indicate that steady flows, high or low, contribute to aquatic food base biomass.

Drift estimates during June 1996, after two months of practically steady flows, reached that of fluctuating flows reported by Leibfried and Blinn (1988). These investigators stated that a positive side to fluctuating flows was entrainment of food for fish. This study indicates that during steady flows more "natural" conditions can create large amounts of drift after the benthos reaches a certain level of growth. We will not be able to follow this pattern this fall because of fluctuating and the steady low flows that occurred in August 1996. Angradi and Kubly (1994) reported on CPOM and FPOM concentrations in the Glen Canyon reach from September 1990 through December 1991, during GCES Phase II Research Flows. Both CPOM and FPOM values were an order of magnitude less than what we found during 1995 and 1996 collections. These differences may be attributed to the radically changing RF, which may have flushed the study site of POM during high flows, and produced results similar to post-SF results. Also Angradi and Kubly used an active collection system for collecting drift employing diaphragm pumps and Miller Tubes off a moving boat which may have under estimated the collections.

Haury (1988) reported during GCES Phase I studies that zooplankton densities in the Colorado River through Grand Canyon remained consistent, but showed a decrease in condition factors. Our present data set does not follow this pattern. We demonstrate a negative correlation between zooplankton density and biomass with distance from GCD and little change in condition. This may be because of the greater discharge range and more dramatic ramping rates that Haury collected under from 1980-1986, 84 to >1,275 $m^3 \cdot s^{-1}$ as compared to Interim Flows.

Copepods were the dominate crustacean in our October 1995 and March 1996 collections, which is similar to data reported by Haury (1988). Total zooplankton densities were an order of magnitude higher during Phase 1 collections than what we have collected in October and March. This change could be from limnological changes in Lake Powell over the past 15 years and the higher discharge pattern of Phase 1 studies. Densities in Glen Canyon, carried by the hydrostatic wave during the Spike Flow, were similar to those reported by Haury (1988).

Concentrations of DOC were positively correlated with discharge during the SF, and with concentrations decreasing towards the end of the 1,274 $m^3 \cdot s^{-1}$ flow and then increasing during the post-227 $m^3 \cdot s^{-1}$. These results are the opposite of the those reported by Jones et al. (1996) in the smaller Sycamore Creek, AZ, where concentrations were highest during low flow periods and little DOC residency was found. Glen Canyon Gauge samples were also elevated during the post-SF 227 $m^3 \cdot s^{-1}$, possibly from limnological changes within Lake Powell. Sand stored water draining from the beaches may also be releasing high DOC concentrations retained from the initial high flow period.

Dual isotope analysis of the SF using ^{13}C and ^{15}N showed that the water did change its isotopic composition through the hydrograph. Identifying the exact origin of these samples was not possible without using a third element such as sulfur. Also, composition of the benthic and riparian vegetation has changed since Angradi (1994) did his work in 1990 - 1991, therefore identifying the isotopic signal of these plants may yield more information on the change in organic material in the main stem during the SF.

Research hypothesis: Spring 1996 spike flow discharge from Glen Canyon Dam will have an impact on the aquatic foodbase in the Colorado River through Grand Canyon.

Fail to reject: Spring 1996 spike flow discharge had a significant positive impact on the aquatic foodbase in the Colorado River through Grand Canyon.

MANAGEMENT CONSIDERATIONS

This experiment needs to be run again as the clear water conditions from the drought in northern Arizona may have intensified the positive results of the SF. If the SF was conducted under a wet period with tributary input of suspended sediments the results may not have been positive for the aquatic foodbase. With the majority of changes occurring in the first 48 hour, the shape of the SF hydrograph could be steeper (80,000 cfs peak) and of only an hour or two duration with a slower down ramp (500 cfs/h), which would not use more water. A higher peak discharge may scour and suspend more of the nutrient laden fine sediments which were not altered by the 1996 SF.

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Flood-induced backwater rejuvenation along the Colorado River in Grand Canyon, Arizona

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EXECUTIVE SUMMARY

INTRODUCTION

Colorado River backwaters downstream from Glen Canyon Dam are biologically productive, low velocity, shoreline habitats that warm daily and seasonally, and may serve as important rearing environments for young fish (Holden 1978; Valdez and Clemmer 1982; Carter et al. 1985; Maddux et al. 1987; Arizona Game and Fish Department 1993, 1996; U. S. Bureau of Reclamation 1995, including the U. S. Fish and Wildlife Service Biological Opinion; Valdez and Ryel 1995). In Grand Canyon, backwaters form during high flows and evolve towards wetland or riparian (terrestrial) habitats after large flow events. Backwaters typically exist at low discharges when exposed eddy sand bars block recirculating flow. Backwater size and distribution depends on shoreline morphology. The largest and most common type of backwater in Grand Canyon is a return current channel (RCC; Schmidt and Graf 1990; the Type I backwater of McGuinn-Robbins). Recent studies demonstrate that backwater habitats decreased in area and number under Interim Flows (IF) from Glen Canyon Dam in Grand Canyon (McGuinn-Robbins 1995). Reduction in backwater size and number has coincided with a system-wide shift of sand bars from higher to lower elevations within most eddy depositional settings (Kaplinski et al. 1994, 1995). This shift in stored sediment reflects the reduced sediment supplies since 1963, and the reduced mean annual peak discharge associated with Glen Canyon Dam IF. The IF regime is similar to the Glen Canyon Dam Environmental Impact Statement (GCDEIS) Preferred Alternative, and the GCDEIS recommends coupling an IF-style operating regime with annual to decadal high flows. If native fish use backwaters as intensively in the lower Colorado River basin as in the upper basin, the long-term consequences of the GCDEIS Preferred Alternative may reduce backwater habitat availability, affecting native fish populations.

Resolution of GCDEIS and FWS Biological Opinion issues through adaptive management requires improved understanding of backwater dynamics, particularly by monitoring and analysis high flow impacts on individual backwaters. A seven-day 1,275 m^3/s release from Glen Canyon Dam was conducted in late March/early April 1996, to achieve sediment redistribution, backwater rejuvenation and reduction of non-native fish populations. This Test Flow is likely to be the only large flow event in the next few years, and therefore provided a unique opportunity to study the development of inter-related physical and biological processes that influence backwater habitat conditions in the post-dam Colorado River. On a system-wide basis, the Test Flow increased backwater area by 0.58 ha and 8 new backwaters were formed, a 2.1-fold areal increase and a 1.25-fold increase in backwater number, respectively (B. Ralston, ATA, Inc., personal communication). Despite the description of backwater distribution, few integrated analyses are available relating geomorphic, bank and surface water

chemistry, thermal stratification, and benthic and plankton standing mass to fish habitat development within individual backwaters.

In this summary, we present analyses of the extent of physical and biological rejuvenation of selected Colorado River backwaters resulting from the 1996 Bureau of Reclamation Test Flow from Glen Canyon Dam (Parnell et al. 1997). We emphasize a multidisciplinary approach to understanding fish nursery habitat processes during the 1996 growing season. Our specific objectives in 1996 were to collect, compile and inter-relate data on test flow related-changes in geomorphology, geochemistry, warming patterns, the fisheries food base, fish diet and fish distribution. Additional syntheses are underway.

METHODS, RESULTS AND DISCUSSION

Study Site Selection

Undisturbed backwater conditions are essential for accurate measurement and modeling purposes. The mile 55.5R study site was deemed one of the most appropriate sites at which to conduct these analyses because: (1) it contains a large RCC backwater which was likely to exist before and after the Test Flow; (2) it lies upstream from the Little Colorado River, and therefore responds primarily to dam operations, rather than the combination of mainstream and the Little Colorado River flows; (3) good historic photographs and bar evolution data are available (Rubin et al. 1990; Stevens et al. 1995); and (4) the site receives little recreational visitation, thereby reducing contamination of the backwater by waste water disposal. In addition to the mile 55.5R site, ancillary monitoring of RCC backwaters was conducted at miles -6.5R, 44R and 194L, which are important study sites for sand bar evolution and fisheries studies. The geomorphology and biological attributes of these large sand bars and their associated RCC backwaters have been extensively studied (Valdez et al. 1995), and all sites except 194L lie in Bureau of Reclamation GIS reaches.

Geomorphology

Return current channels which are connected to the mainstream form Type I backwater nursery habitats (McGuinn-Robbins 1995), and develop as a result of high flows reworking sediment deposits associated with tributary debris fans. Topographic and bathymetric survey data were collected at the 55.5 site in March (pre-flood), April (post-flood) and September (six months post-flood). These data demonstrate that the Test Flow scoured 54,829 m^3 of sediment from the mainstream channel (from the constriction to base of Mile 55.5R bar at stages <226 m^3/s); 13,962 m^3 were removed from the eddy (coupled with a 1,744 m^2 eddy area increase) below that same stage; and the bar aggraded 4,684 m^3 above that stage (with a concomitant decrease in area of 1,846 m^2). These data demonstrate that no more than 4,684 m^3 of sediment (6.8%) of the total 68,791 m^3 of sediment moved during the Test Flow contributed to bar building at this sediment conserving site. Much of the aggrading sediment may have been derived from upstream sources, not the local eddy complex, thus much less than 6.8% of the sediment locally stored may be used in eddy bar building.

We measured volumetric changes of the long-linear RCC at mile 55.5R. This is a typical Colorado River Type I backwater (McGuinn-Robbins 1995). Although surface flow velocities reached 0.9 m/s and were sufficient to deposit up to 1.8 m of new sand, these velocities were insufficient to scour the compacted silt floor of the RCC, preventing major restructuring of the RCC bed. Hypsometric analyses revealed that backwater volume decreased by at least 20% as a result of the Test Flow.

The topography of the mile 55.5R bar continued to change throughout the 1996 growing season. By mid-July the eddy had refilled with sand. The prominent reattachment ramp failed in late summer, probably because resumption of normal flows left the base of the newly formed ramp exposed to direct current and undercutting. A new, low-stage RCC developed in the refilled eddy. Infilling of our RCC study backwater was not appreciable in 1996, probably because of limited sediment input from the Paria River.

Hydrogeology

Drive-point wells were installed to quantify temporal variation in hydraulic conductivity in relation to nutrient storage and mobilization in the reattachment bar (Springer et al. 1996). We made one visit to the mile 55.5R backwater before, and three visits after, the Test Flow. Hydraulic conductivity measurements were conducted with a pneumatic-slug test on the wells. Water levels were measured in a network of 12 wells and river stages were measured at two gages in the mainstream and at two gages in the backwater during each visit. The $\leq$1.8 m of sediment deposited on the mile 55.5R reattachment bar during the Test Flow compressed the sediments, reducing the hydraulic conductivity.

Groundwater Geochemistry

Groundwater geochemistry may play a significant role in local nutrient dynamics, and therefore fisheries food base development, as well as affecting system-wide nutrient spiraling. We used the Test Flow to evaluate the hypothesis that flooding results in the biogeochemical rejuvenation of Colorado River backwaters through the burial and accelerated decomposition of organic material. We sited 44 wells (1.5, 3 and 6 m deep) in sand bars with active RCCs at miles -6.5R, 55.5R, and 194L. We sampled ground and surface waters immediately before, immediately after, and one month, two months, and six months after the Test Flow. Field analyses included pH, specific conductance , temperature, nitrate, nitrite, ammonium, and dissolved oxygen (DO). Laboratory analyses included measurement of non-purgeable organic carbon (NPOC) and orthophosphate.

The test flow buried living and detrital organic material under 0.1 to 1.8 m of well sorted fine sand at the study sites. Topographic surveys revealed little scour of RCCs at these sites and casual observation of many other RCCs immediately after the test flow further supported this observation. Established RCCs were reduced in depth, width and length. New RCCs that developed behind new reattachment bars were ephemeral and were already eroding one day after the end of the post-test flow 226 m^3/s constant flow. The amount of deposition varied over distance, with the least amount of deposition at mile -6.5R and the greatest deposition at mile 194L.

Groundwater in all beaches increased in concentrations of NPOC after the flood, ranging from 85-278% (mean concentrations from all beaches = 4.95+/-1.72 mg/L before; 22.5+/-21.4 mg/L after the event). NPOC concentrations at mile -6.5R increased from 3.95 (+/- 1.7) to 7.32 (+/-10.5) and had not recovered by 228 days after recession. NPOC concentrations at mile 55.5R increased gradually during recession and doubled (to 22.5 mg/L) by June of 1996. All groundwaters increased in ammonium, ranging from 79 to 617% (average from all beaches = 0.80+/-1.21 mg/L before; 5.82+/- 2.67 mg/L after the event). At mile -6.5R, ammonium concentrations continued to increase through the summer of 1996. Previous work at mile -6.5R documented slight decreases in ammonium between spring and summer (Parnell et al. 1996). Ammonium concentration increases at mile 55.5R began with the test flow recession and continued through the growing season. Ammonium levels are still elevated in the fall of 1996. The large spatial variability of ammonium concentrations resulted in high variance; however, increased levels in individual wells were significant.
Significant decreases in dissolved oxygen (DO) concentrations in bar-stored groundwater occurred at miles -6.5R and 55.5R. Increased ammonium and NPOC and decreased DO are consistent with increasing rates of microbial respiration in these sandbars. Average orthophosphate concentrations decreased at mile -6.5R after the flood, and then increased in the fall. This was attributable to increases at only a few wells. Orthophosphate concentrations decreased at mile 55.5R and remained low thereafter.

RCC surface waters displayed highly variable NPOC concentrations. Average NPOC at miles -6.5R and 55.5R increased through the autumn, 1996. Nitrate concentrations in the RCC increased through the summer and decreased through the fall. Increasing groundwater NPOC are reflected in increases in the RCC, which increased local mainstream concentrations.

Mainstream surface water orthophosphate concentrations did not appear to have been altered by the Test Flow. Changes in mainstream surface water NPOC concentrations can be attributed to seasonal conditions and conditions of flow from Glen Canyon Dam. In particular, NPOC increased in the mainstream significantly between the summer and fall at miles -6.5R and 55.5R. Because groundwater flow rates seldom exceed 0.5 m/d, low flows with duration of weeks are required to change groundwater flow patterns and increase groundwater flux into the mainstream. However, NPOC concentrations in the Glen Canyon reach were low and increased downstream. Therefore, our data suggest that NPOC is delivered to the mainstream by groundwater draining from alluvial deposits.

Because ammonium is converted to oxidized species in the presence of atmospheric oxygen, the large concentrations of ammonium in bar-stored groundwater are not reflected in surface waters. Dissolved inorganic nitrogen in surface waters is predominantly nitrate and nitrite. Nitrate increases in mainstream water are minimal and were not noticeably different than seasonal increases noted at the study sites in previous years (Parnell et al. 1996).

Orthophosphate concentrations in the Glen Canyon reach and at mile 55.5R did not vary as a function of the 1996 test flow.

Climate

Backwaters provide thermal refugia for young fish, and thermal development occurs on diel and seasonal time scales. Climate measurements were made at the mile 55.5R site during 2-4 d site visits in March, June, and September, including backwater and river water temperature, air temperature, wind speed, relative humidity, net radiation, soil heat flux, and cloud cover. Additional climate data were collected at critical points throughout the day in March, April, June, July, September, and October.

We studied three zones in and around the RCC backwater: the relatively isolated head, the mixing zone, and the river. The BB transect was selected as a relatively isolated cross-section in the head of the backwater. Water temperature there lagged behind air temperature and tracked it loosely. Backwater temperature exceeded 34° C on that transect on 23 July as air temperature exceeded 43° C. During July, midday temperatures between 10 and 40 cm depths varied by as much as 11° C. a decrease of 0.37° C/cm, on the BB transect thalweg. This transect was poorly stratified in April and September. Although BB temperatures were 15 to 24° C in June (well above the mainstream temperature of 9-11° C), high winds mixed the backwater and prevented stratification.

Farther riverward and well into the mixing zone, Transect CC 10 cm depth temperature lagged more slowly behind air temperature, and temperatures were less stratified during mid-summer. The maximum 21-23 July temperature range between 10 and 40 cm depths on the thalweg was less than 5° C; however, July backwater temperatures remained well above mainstream river temperatures throughout the day and night. Little thermal stratification was observed there from 17 to 20 September, although backwater temperatures ranged from 13 to 17° C, approximately 5° C warmer than the mainstream.

A preliminary model of backwater temperature at -10 and -40 cm depth on the CC transect revealed that 74% and 78%, respectively, of the variance in backwater temperature was explained by immediate and lagged air temperature and wind speed. The points sampled for this model were located approximately 50 m from the mouth of the backwater, and therefore indirectly affected by the river under the <600 m^3/s flows that occurred following the flood in 1996. Spot sample data revealed high levels of spatially discrete thermal stratification, with the head of the backwater responding more strongly to climate and the mouth area responding more strongly to river temperature and flow conditions. A more general model is under preparation to describe climate and discharge influences on backwater thermal stratification.

Aquatic Food Base

Water quality and food availability influence habitat suitability for fish using backwaters. We sampled water quality, as well as plankton and benthos distribution and standing mass before and the test flow, and through the 1996 growing season.

DO varied on a diel basis and in relation to temperature and mainstream flow. Substantial variation in DO concentration was observed in the mile 55.5R backwater from pre-dawn to mid-day in the mid-summer months, with values dropping substantially below that in the mainstream (ca. 10 mg/L) at night and rising to supersaturation (>13 mg/L) during the day. This reflects nocturnal respiration of the benthos and water column organisms, as well as the daytime production of oxygen by benthic macrophytes (e.g. Owens and Crumpton 1995).

Two L water samples were collected from discrete, georeferenced transects in the backwater using a hose and pump system, and we filtered 1 L of each 2L sample through pre-weighed Wattman No. 42 filters for plankton standing mass analyses. The remaining 1 L of sample were filtered through Wattman No. 42 filters, and preserved for plankton composition analyses. Comparable samples were collected in the mainstream. Plankton sampling revealed little AFDM of plankton in the RCC backwater or in the mainstream. June and July plankton AFDM values were <9 mg/L.

We used a petite Ponar dredge (0.023 m^2) to sample ooze and sand-dwelling benthos on numerous transects in the mile 55.5R backwater. Invertebrates were sorted and preserved in 70% EtOH for taxonomic analyses in the laboratory. Fine sediments were sieved through a 1.0 mm mesh filter to collect ooze invertebrates. Volume and area of sediment were measured, with a subsample saved for grain size analysis.

Macrophyte ash-free dry standing biomass (AFDM) at mile 55.5R was always considerably higher in the RCC mixing zone than in the adjacent sand-floored mainstream. Macrophyte AFDM in the RCC was lowest immediately following the Test Flow, and increased 5-fold to 34 g/m^2 in September, becoming senescent thereafter. Initially, several species colonized the post-flood RCC, including *Chara* sp., *Potomogeton pectinatus* and *Elodea canadensis*. By the end of the growing season, the floor of the RCC at a flow of 250 m^3/s was almost completely covered with a dense bed of *Elodea canadensis*, and the other macrophyte species had largely disappeared. Macrophyte cover returned to near 0 in February 1997 (Stevens, personal communication).

Benthic invertebrate composition and AFDM was strongly altered and reduced by the Test Flow. Benthic composition was strongly dominated by oligochaetes and *Chironomus* sp. midges prior to the Test Flow, with densities in excess of 30,000 organisms/m^2 in the mixing zone. Also, AFDM was substantially higher in the RCC backwater than in the adjacent sand-floored mainstream. Immediately following the test flow, benthic invertebrate AFDM in the head and mixing zones of the RCC had decreased by an order of magnitude and almost no invertebrates were collected in the mainstream. Benthic AFDM increased progressively over

the 1996 growing season, with September AFDM approximately 20% of the pre-flood levels. The summer composition included: oligochaetes > ostracods > *Chironomus* sp. midges > *Physella* sp. snails > *Fossaria obrusa* snails > *Pisidium* sp. clams > nematodes. Predatory aquatic invertebrate species increased in abundance in the water column through the 1996 growing season in the RCC backwater. October 1996 seining revealed hundreds of Corixidae, and numerous Notonectidae and Odonata (mostly Libellulidae). Thus, the potential for predation on small fish increased considerably through the growing season.

Fish Distribution

Fish distribution was monitored using an index of catch-per-unit-effort (CPUE), seasonal seining hauls by AGFD, and by direct observations. Minnow traps were used as a non-sacrificial, non-disruptive means of capturing small fish. Six minnow traps were set in each of the head, mixing zone and mainstream channel margin microhabitats. Traps were checked at least every 12 hour during each 48 hour sampling period. All fish captured were identified to species, and lengths were measured. We examined each individual for external parasites and injuries, but found none. CPUE was calculated as the number of fish captured/trap/hr set. CPUE provides a relative index of the number of fish in each microhabitat of the backwater between samples and will document fish distribution. CPUE of young fish was higher in the RCC backwater than in the mainstream throughout the growing season, except in April. After July, small fish were rare in the river, but remained abundant in the RCC.

The mile 55.5R backwater was extensively used as a rearing environment by native flannelmouth sucker and speckled dace, and by non-native carp (*Cyprinus carpio*). Young flannelmouth suckers were abundant in June, and decreased in abundance through September. High densities of extremely young (<22 mm) flannelmouth suckers were observed in the head of the backwater in June, nearly 100 m from the river. These flannelmouth suckers either spawned in the backwater, in the mainstream, in warm springs (e.g., near mile 30), or (improbably) in the Paria River at mile 1. Flannelmouth suckers >120 mm in total length were captured in minnow traps in July and September. Those fish probably belonged to the 1995 cohort, indicating that the prior year's age class re-occupy backwaters during the mid-summer months. Schools of >100 young dace and suckers concentrated in the shallow, clear head of the backwater in June and July. These data demonstrated that adult dace and all young native fish densities were higher in the backwater than in the adjacent river. The backwater was also used in late summer by adult carp, and nocturnally during the spring by adult rainbow trout.

Mature carp were observed moving into the macrophyte beds in the backwater during the nighttime hours in middle and late summer. Although we did not observe spawning behavior, carp spawning behavior is often associated with warm water and macrophyte beds (Lechleitner 1992). The abundant young carp observed in September and October indicated that carp spawned in, or adjacent to, the mile 55.5R backwater.

Rainbow trout (*Oncorhynchus mykiss*) were observed moving into the RCC at night from March through June. The trout moved into the backwater at night, and out as flows decreased

during the day. During the 226 m^3/s post-flood constant flow, the RCC backwater was perched and disconnected from the mainstream. Backwater dissolved oxygen levels decreased to <4 mg/L and maximum mid-day temperature exceeded 20° C. On the third day of these conditions, we observed mortality of rainbow trout. Therefore, poor water quality in perched RCCs can result in trout mortality even during the relatively cool spring months.

CONCLUSIONS

In summary, our 1996 data demonstrate that although substantial geomorphic rejuvenation of the mile 55.5R backwater did not occur, the test flow strongly affected backwater morphology and hydrogeochemistry, which in turn influenced subsequent biological development. Although surface flow velocities reached ca. 0.9 m/s and were sufficient to deposit up to 1.8 m of new sand, these velocities were insufficient to scour the compacted silt floor of the RCC, preventing major restructuring of the RCC bed. Deposition of new sand reduced maximum RCC volume by at least 20%, and produced a narrower but not deeper backwater. Low tributary inflows during 1996 limited aggradation of the RCC, therefore hypsometric relationships established during the Test Flow remained essentially unchanged.

Hydrogeochemical alteration of sandbars during flooding influences subsequent nutrient availability and spiraling. Hydraulic conductivity decreased by 20 to 40% under as much as 1.8 m of newly deposited sediment, affecting groundwater flow rates. Non-purgeable organic carbon (NPOC) concentrations in sandbar groundwater increased after the test flow from 85% to 278%. NPOC concentrations at mile -6.5R increased from 3.95 (+/- 1.7) to 7.32 (+/-10.5) mg/L, and had not recovered by 228 days after recession. NPOC concentrations at mile 55.5R increased gradually during recession and doubled by June of 1996. Ammonium concentration greatly increased in bar groundwater immediately after the test flow as buried vegetation began to decompose, and ammonium concentrations remained elevated through 1996.

The altered geomorphic condition of the bar, coupled with climate and mainstream flow patterns and temperature, produced thermal warming and stratification in the backwater. Thermally advantageous conditions existed for fish at least from June through September, as compared to the mainstream. Little plankton existed or developed in the backwater throughout the growing season. Benthic macrophytes were scoured from the RCC backwater by the test flow, but increased to levels approximately 5-fold greater than pre-test flow levels by September. Benthic invertebrate standing mass was reduced by approximately an order of magnitude by the test flow, but doubled over the 1996 growing season, reaching 20% of the pre-test flow standing mass levels by September. By the end of the growing season large populations of invertebrate predators (aquatic Heteroptera and immature Odonata) developed in the backwater.

Native and non-native fish occupation of the backwater varied on a daily and seasonal basis. Although native fish were numerically dominant in the backwater in the spring and summer, we observed trout moving into the backwater at night (during high flows) and out of the backwater during the morning as mainstream flows decreased. Speckled dace and flannelmouth sucker young-of-year (and previous year's cohort of flannelmouth sucker) were

more numerous in the backwater than in the river during all months except April. Young-of-year non-native carp dominated the backwater fish assemblage from July through October, and none were found in the mainstream. Therefore, this backwater appears to play a relatively important role as a rearing habitat for young fish as compared to the mainstream.

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Effects of the 1996 Glen Canyon Dam controlled flood on nutrient spiraling along the Colorado River Corridor, Grand Canyon, Arizona

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ABSTRACT

Biogeochemical cycling is the transportation and transformation of chemicals within ecosystems. Organic compounds with nitrogen and phosphorus make up major cellular components of organisms. Concentrations of these elements are highly dynamic and are transformed and stored rapidly by abiotic and biotic components of the aquatic ecosystem. Because the supply of these elements may be less than the biological demand, sources of nutrients like nitrogen and phosphorus may regulate the productivity of organisms.

Wetlands, like those developing associated with return current channel systems behind bars in the Grand Canyon, act as sinks for nitrogen and phosphorus. They can store nutrients by locking them up in chemical reactions with the sediment or as biomass. In addition, they can remove nutrients from the ecosystem, for example, through the microbial processes of converting nitrogen species to gases, which is called denitrification. However, there is growing consensus that not all wetlands are nutrient sinks. Wetlands are often chemically connected to adjacent ecosystems through inflow and outflow of surface and ground water, and the import and export of organic material via surface water. The unique hydrologic conditions brought about by fluctuating flows in the Grand Canyon markedly impact biogeochemical processes.We used the Glen Canyon Dam controlled release of 1996 to test the hypothesis that flooding results in the biogeochemical rejuvenation of Colorado River ecosystems through the burial and accelerated decomposition of organic material. We sited 44 wells (1.5, 3 and 6 meters depth) at beaches with return current channels (RCC) at miles -6R, 55.5R, and 194L downstream of Lees Ferry, Arizona. We sampled ground and surface waters immediately before, immediately after, one month after and two months after the event. Field analyses included pH, specific conductance, temperature, forms of soluble, available nitrogen (the most oxidized form, nitrate; intermediate nitrite; and the most reduced form, ammonium), and dissolved oxygen (DO). Laboratory analyses included orthophosphate (the predominant form of available phosphorus in water), dissolved inorganic carbon (DIC), and non-purgeable organic carbon (NPOC).

In addition to geochemical data, hydrogeological parameters of the beach aquifers were measured. Water levels and hydraulic conductivities were measured for each well and river stages were measured at temporary stage gages near the beaches. The velocity of ground-water in the beaches and the associated nutrient transport velocities are highly dependent on the hydraulic gradients formed between river stage and the water levels of the aquifer. Also, the velocity is dependent on the hydraulic conductivity and porosity of the sediments.

The deposition of up to 1.8 m of sediment on the mid-beach of 55.5R caused a 40% decrease in the hydraulic conductivity of wells in the midbeach. The extra sediment compressed the

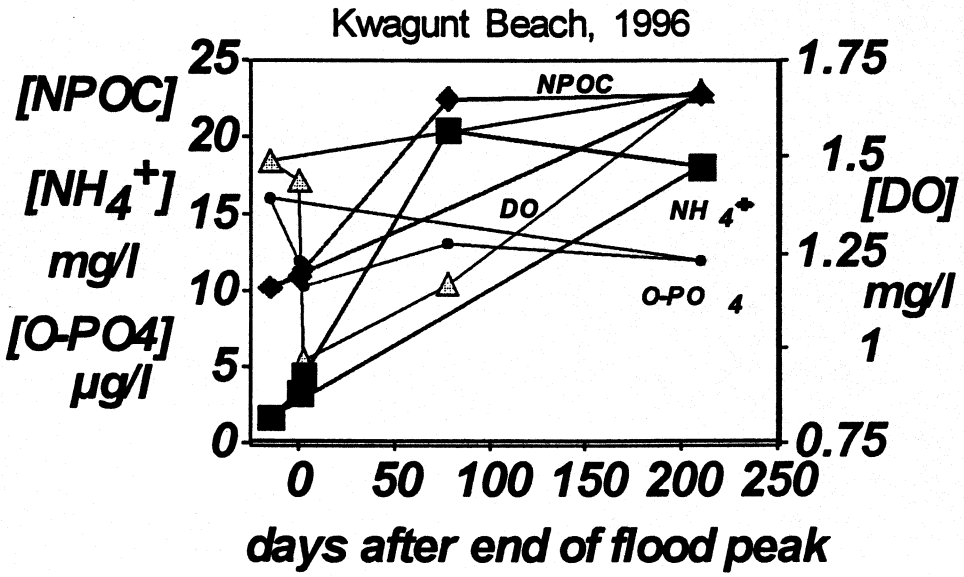
existing sediment decreasing the hydraulic conductivity and the storativity. Because there is a direct relationship between hydraulic conductivity and ground-water velocity, the flood caused ground-water and associated nutrients to be transported more slowly through the beaches. These velocities have increased after the flood as sediments have been removed from the sandbar by hydraulic and aeolian erosion.

We have used a preliminary, generic, numerical ground-water flow model, MODFLOW, (McDonald and Harbaugh, 1988) to simulate water levels and advective ground-water flow velocities in the beaches under steady and fluctuating river stages. Results of this preliminary model indicate that a very small area of the beach is influenced by river water during fluctuating flows. Ground-water velocities under fluctuating flow vary from zero to two feet per day. As the fluctuating cycle is repeated daily, river water can not travel more than two feet into the beach under one fluctuation. Under steady flow conditions, ground-water flowpaths form causing the entire beach to be influenced by water from the river. It takes as long as two months of steady flow for parts of the beach to be influenced by river water.

The model has indicated that nutrient transport under fluctuating flows will be limited to a very narrow zone near the interface of the beach sediments with the river. Only under steady flows is it possible for a ground-water flow scenario to develop to allow nutrient transport from portions of the beach outside of a narrow band near the river. Our future work includes investigating how the position of the eddy at the edge of a beach influences ground-water flow and associated nutrient transport and calibration of the model to steady flows of the winter/spring of 1997. These hydrologic processes not only create a flux of nutrients between the mainstem and groundwaters, but also create changes in the chemical forms and availability of the nutrients. Nitrogen occurs in many different forms (oxidation states), which depend upon the amount of oxygen or atmosphere in contact with the nitrogen compound. Thus, the relative abundance of oxygen in surface waters, backwaters, and shallow and deep groundwaters determines the form of nitrogen, its availability to plants, and its potential to leak from the ecosystem as a gas.

Because the test flow buried living and detrital organic material under 0.2-1.95 meters of sand at the study sites, abundant organic matter became available for microbial respiration. Groundwaters in all beaches had increases in NPOC ranging from 85-278% (average from all beaches: 5mg/l before to 23 mg/l after). All groundwaters show increases in ammonium ranging from 79-617% (average from all beaches: 1.0 mg/l before to 6 mg/l after. See Figure 1.

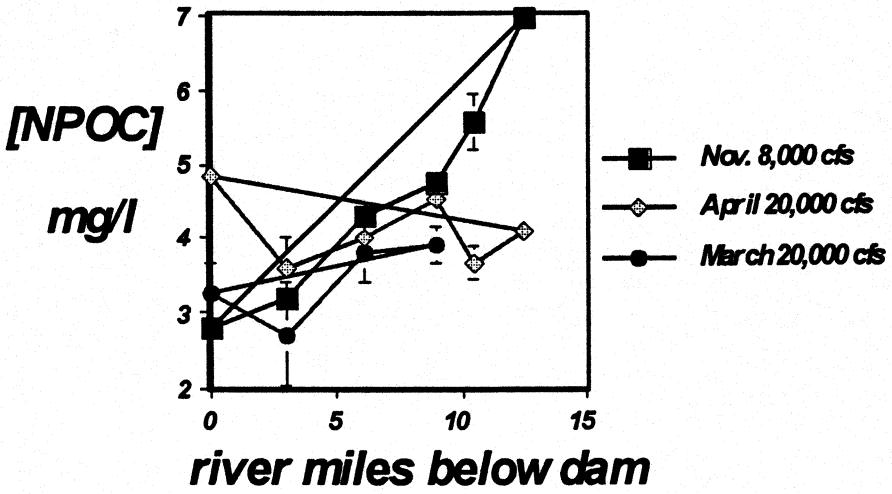
Figure 1. Increases in nutrients (NPOC, ammonium, and orthophosphate) and decrease in dissolved oxygen following flooding of Kwagunt beach during the 1996 controlled release.



Concentration increases for waters in individual wells are statistically significant. Dissolved orthophosphate in groundwaters increased from 11 µg/l before the flood to 12 µg/l after, an insignificant change. Significant decreases in DO concentrations in groundwaters occurred at two beaches.

The increases in ammonium and NPOC and decreases in DO we observe are consistent with the occurrence of increasing rates of microbial respiration within the beaches. These increases support the idea that flooding buries more organic material, making it available for microbial attack and breakdown. The microbial activity allows more nutrients to be released from standing biomass and be returned to the aquatic ecosystem where it can spur the growth of aquatic plants. The concentrations of NPOC in return current channel surface waters increased from 4 to 5 mg/l and in main stem water from 3 to 4 mg/l. These increases demonstrate a large release of dissolved carbon and nitrogen from the beaches to critical aquatic habitats, the return current channels, and to the main stem. See Figure 2.

Figure 2. Increasing concentrations of dissolved organic carbon occur moving downstream under low flow conditions flowing the 1996 controlled release, demonstrating the drainage of beach groundwaters into the mainstem. This drainage provides a large flux of carbon, nitrogen, and phosphorus into the mainstem.



The effects of the 1996 experimental beach/habitat-building flood in the Colorado River, Grand Canyon, on fishes, invertebrates, and their backwater habitats

Timothy L. Hoffnagle, William R. Persons, Mark J. Brouder, Thomas J. Dresser, Jr., and David W. Speas

EXECUTIVE SUMMARY

The 1996 experimental flood in the Colorado River, Grand Canyon was designed to improve conditions for native fishes by increasing backwater habitats and reducing the numbers of exotic competitory/predatory fishes. We examined the effects of the experimental flood on fishes, invertebrates, and their backwaters habitats. Three general objectives were addressed, each with specific hypotheses to be tested: (1) determine distribution, dispersal, and habitat use of native and exotic fishes before and after the controlled flood; (2) determine effects of the controlled flood on backwater habitats used by young-of-the-year and juvenile fishes; and (3) determine effects of the controlled flood experiment on lower trophic levels and food habits of humpback chub. Additionally, recovery of affected populations or habitats were monitored through the early fall following the flood. Data were collected on two time scales and river discharge conditions: (1) complete river trips (Lees Ferry to Diamond Creek) conducted before and after the flood and during the summer and early fall under fluctuating flows, and (2) sampling in the vicinity of the Little Colorado River (LCR) during the steady 8,000 cfs flows immediately before, during, and after the flood.

Native fishes were unaffected by the high flows while some exotic species were dispersed downstream. Plains killifish were removed from the mainstem Colorado River. Fathead minnow catch-per-unit-effort (CPUE) decreased in reaches immediately below the Little Colorado River. Rainbow trout were dispersed from the upper to lower reaches. However, these changes appear to have been short-lived. By September, plains killifish had reinvaded from tributary refugia and exceeded pre-flood numbers and fathead minnows had also increased to near pre-flood numbers.

Humpback chub, speckled dace, and fathead minnow catches were compared between low and high (flood) steady flows in talus, debris fan, and vegetated shorelines. Our data indicate segregation of habitat among these three species. Humpback chub appear to prefer talus shorelines and were caught more frequently there during the flood than at low flows. Speckled dace preferred debris fans at both high and low flows. Fathead minnows were most commonly captured in vegetation during low steady flows, but, during the high flows, they were rarely caught in any of the three shoreline types.

Under steady 8,000 cfs flows there were more backwaters present immediately after (39) than before (31) the flood. However, under operating flows, there were more backwaters prior to the flood (68) than afterwards (42). Backwater number further decreased in June (38) and there were 39 backwaters in September. Under steady 8,000 cfs flows, backwaters after the flood had a significantly greater mean surface area (285.1 m^2) than backwaters before the

flood (172.5 m^2). Twelve backwaters were surveyed during operating flows prior to the flood for intensive study, however the eddies of five of them were heavily scoured, leaving no backwater. Of the seven remaining backwaters present both before and after the flood, five increased in surface area. Maximum depth was measured in nine backwaters present both before and after the flood. Maximum depth increased in eight of the nine sites following the flood ($\bar{x}$=78 cm, n=9), a significant increase in mean maximum depth.

Sediment composition of backwaters also changed after the flood. Prior to the flood, sand and silt each comprised approximately 50% of the sediments with fine and coarse particle organic matter (FPOM and CPOM, respectively) comprising <2%, combined. After the flood, the percentage of sand (81.4%) increased significantly, becoming the dominant sediment type. Conversely, the flood significantly reduced the percentages of silt (17.7%), CPOM (0.2%), and FPOM (0.8%) in the backwaters by about 50% each.

Mean total invertebrate density was significantly lower after the experimental flood (3,581.8 individuals/m^2) than before (11,426.9 individuals/m^2). Mean density of individual invertebrate taxa was also significantly lower after the experimental flood, with the exception of oligochaetes. There was no difference in mean total invertebrate biomass after the flood. However, mean individual biomass of all taxa except oligochaetes significantly decreased after the experimental flood. Oligochaete density decreased during the summer and fall while densities of arthropods and chironomids increased. Mean individual biomass of all taxa was lowest during the summer, except chironomids and other dipterans. During the fall, mean individual biomass of all taxa increased with the exception of nematodes. Detrital biomass significantly increased following the flood (792.0 g/m^2) and was lowest during the summer (43.7 g/m^2). At four months following the experimental flood, benthic invertebrates had still not attained pre-flood levels.

Total zooplankton density was significantly greater after the flood (4,174/m^3) than before the flood (2,733/m^3). Zooplankton density significantly declined in river reaches below river kilometer (RK) 105.00 before the flood, but following the flood no significant decline was observed until below RK 265.49. Rotifers comprised 54.8% of the plankton before the flood and their percentage fell significantly to 37.4% despite no significant change in density. Copepods and copepod nauplii increased both in density and percentage of total zooplankton after the flood. Branchiopods were significantly reduced in number and percent of total zooplankton after the flood. Eleven zooplankton taxa (mostly littoral and/or phytophytic genera) were observed before but not after the flood, whereas only two limnetic taxa were unique to post flood samples. Total zooplankton density in June 1996 (5,239/m^3) did not differ significantly from post-flood density, but declined significantly to 1,300/m^3 in September. The flood may have caused the post-flood increase in zooplankton density (due to increases in nutrient availability) in the Colorado River, but this could also be due to normal, seasonal increases in water temperature and/or population dynamics of zooplankton (particularly winter forms such as copepods) in Lake Powell.

The stomach contents of 43 fish were used to evaluate the effects of the experimental flood on the feeding of adult humpback chub. The most common food items were simuliids, chironomids, *Gammarus lacustris*, coleopterans, and dipterans. Increases in the consumption of *Gammarus* and terrestrial invertebrates by humpback chub during the flood, while consumption of simuliids, chironomids, other aquatic invertebrates, and *Cladophora glomerata* decreases indicates that humpback chub are opportunistic feeders able to use food sources as they become available. No significant difference in mean total biomass of stomach contents among flood stages suggests, that although we observed shifts in diet, it appears that the effect of the experimental flood on the feeding behavior of adult humpback chub is minimal.

The experimental flood does not appear to have affected native fishes and only minimally affected exotic species. Backwater benthic invertebrates decreased while the effects on zooplankton were more complex. The beneficial increase in backwater numbers was only temporary. The affects of the Grand Canyon experimental flood on habitat for larval and juvenile stages of native species are more likely to be critical to fish populations.

The great flood of 1996:
Response by native and non-native fishes in Western Grand Canyon

William C. Leibfried

ABSTRACT

The controlled flood of 1996 at Glen Canyon Dam provided researchers with the opportunity to evaluate the response of physical and biological components of the Colorado River ecosystem to a 45,000 cfs flow. Due to limited funding and logistical support, studies were limited to only a few reaches of the river. The Hualapai Tribe and SWCA Inc. were responsible for monitoring the flood effects in Western Grand Canyon from RM 179 to 280. Electrofishing, netting, and minnow trapping were used to collect fishes before, during and after the flood. Stomach contents were sampled from fishes in this reach to determine the impacts of the flood on food habits. Ten species of fish were collected during our study. Native fishes appeared unaffected by the flood. Fathead minnows increased in abundance from 3.2% to 21.9% after the flood. Speckled dace increased from 13.8 to 21.2%. Rainbow trout electrofishing catch rates were significantly higher during the flood period. Below Diamond Creek, relative abundances of red shiner and fathead minnows were effected by the flood. Fathead minnows increased from 4.7 to 27.5% after the flood, while red shiner deceased from 51 to 30.4%. Overall, small non-native fishes (<200 mm TL) may have been negatively impacted by the flood flow. Observations made during electrofishing effort during the flood indicate the use of slack water shorelines over inundated riparian vegetation and flooded side canyons by both native and non-native fishes. Terrestrial invertebrates dominated the stomach contents of fishes between RM 179-188.

Effects of an experimental flood on fish and backwaters in the Colorado River, Grand Canyon, Arizona

Richard Valdez

EXECUTIVE SUMMARY

The Colorado River and its tributaries in Grand Canyon support 15 species of freshwater fish. Ten of these species are introduced and only five are native, including the federally endangered humpback chub and razorback sucker, as well as the flannelmouth sucker, bluehead sucker, and speckled dace. Three other native species are gone from Grand Canyon. There is a blue ribbon fishery for stocked rainbow trout for about 15 miles below Glen Canyon Dam in the cold clear tailwaters, and brown trout are locally common in tributaries further downstream. Carp and channel catfish are common downstream of the tailwater and fathead minnows are locally common in backwaters and tributaries.

A beach/habitat-building flow release was made from Glen Canyon Dam from March 22 through April 7, 1996, which consisted of four days of 8,000 cfs steady flows before and after a 7-day flood of 45,000 cfs. The flood was designed to build shoreline sand bars, increase backwater habitat for native fishes, and reduce the numbers of non-native fishes that are predators and competitors of native species.

The effects of this experimental flood on fishes and backwaters were evaluated by Arizona Game and Fish Department, BIO/WEST, Hualapai Department of Natural Resources, University of Arizona, U. S. Fish and Wildlife Service, Glen Canyon National Recreation Area, and Glen Canyon Environmental Studies. The following objectives were addressed:

Objective 1 Determine distribution, dispersal, and habitat use of native and non-native fishes in the Lees Ferry reach, near the mouth of the Little Colorado River, and below Lava Falls (RM 180-185) before and after the controlled flood.

Objective 2 Determine effects of the controlled flood on backwater habitats used by young-of-the-year and juvenile fishes.

Objective 3 Determine effects of the controlled flood experiment on lower trophic levels and food habits of humpback chub.

Distribution, Dispersal, Habitat Use

Few differences in fish distribution and abundance were seen before and after the flood. No significant decreases were seen in adult rainbow trout in the tailwater or in the endangered humpback chub further downstream. Differences in distribution and abundance were seen only for non-native species, including fathead minnows, plains killifish, and rainbow trout. Catch-per-unit effort (CPUE) of fathead minnows in minnow traps decreased significantly (0.8

fish/24 hr to 0.05 fish/24 hr, P=0.0001) along shorelines in the middle reaches of the canyon (75-90 miles below the dam, near Little Colorado River - LCR) following the flood, indicating a decrease in numbers of this non-native species. Similarly, mean CPUE of plains killifish seined in backwaters decreased significantly (1.1 fish/100 m^2 to 0 fish/100 m^2, P=0.0065), indicating nearly complete elimination of this species. Conversely, mean CPUE of juvenile rainbow trout seined in backwaters increased significantly (0.04 fish/100 m^2 to 0.3 fish/100 m^2, P=0.0146) following the flood, with a similar increase from shoreline electro-fishing. These results indicate that young rainbow trout were transported from upstream reaches, probably from local spawning aggregations like Nankoweap Creek. Shifts in habitat use were seen during the flood with aggregations of native and non-native fish in tributary inflows and large recirculating eddies.

Large numbers of adult native flannelmouth suckers, bluehead suckers, and humpback chub, as well as non-native carp, channel catfish, and rainbow trout were caught in trammel nets in tributary mouths and adult humpback chub, flannelmouth suckers, and rainbow trout were caught in low-velocity regions of large recirculating eddies. Radio tagged adult humpback chub also used these habitats.

During the flood, many adult fishes, such as native flannelmouth suckers, bluehead suckers, and humpback chub, as well as non-native carp, channel catfish, and rainbow trout, were caught with nets and electro-fishing at tributary mouths that became impounded by the higher mainstem flows. Radio tracking of 10 adult humpback chub revealed that many adult fish also used large recirculating eddies; i.e., areas in the mainstem with reverse current and small pockets of quiet water. The radio tagged fish and others, such as flannelmouth suckers, carp, and rainbow trout, seemed to be aggregated in a small triangular patch of calm water characteristic to the upstream end of large recirculating eddies.

Adult humpback chub were tracked with radiotelemetry before, during, and after the experimental flood. Net movement (resultant distance from first to last location) of nine fish during the flow (mean, 0.40 km; range, 0-1.24 km; 16 days) was not significantly different (t test, p=0.05) from net movement in the month preceding the flow (mean, 1.26 km; range, 0.1-2.95 km; 26-39 days), and comparable to movement of 69 radio tagged adults tracked in Grand Canyon during 1990-92 (mean, 1.49 km). Gross movement (sum of all movements) of the nine fish during the flow (mean, 0.90 km; range, 0-4.35 km, 16 days) was not significantly different from gross movement of the 69 fish monitored during 1990-92 (mean, 5.13 km; range, 0.32-16.93 km). Habitat used by the nine fish during the experimental flow (73% of contacts from eddies, 27% from runs) was similar to that used by 69 fish tracked during 1990-1992 (74% of contacts from eddies, 16% from runs, 7% from eddy return channels, 3% from pools, <1% from riffles).

Backwater Habitats

Based on aerial videography, the experimental flood resulted in a net increase of eight backwaters, when measured at the 8,000 cfs flow level. Based on ground census between the LCR and RM 105.4, at 8,000 cfs, five backwaters were found before the flood and seven were

found after. Backwaters after the flood had a significantly greater mean surface area than before the flood (172.5 m^2 to 285.1 m^2, P=0.0002). Many of the reattachment bars created by the flood were rapidly eroding under 8,000 cfs due to differences in flow patterns between 45,000 and 8,000 cfs. Hence, many of the newly created backwaters were likely to have been temporary.

Food Habits of Humpback Chub

A total of 45 adult humpback chub (25-450 mm TL) were treated with a non-lethal stomach pump to flush gut contents. Simuliids (blackflies) were the most common food item found, followed by chironomids (midges) and amphipods (*Gammarus lacustris*); these occurred in 97, 93, and 79 percent of all fish examined. The incidence of *Gammarus* in the diet increased substantially from before the flood (44%) to during (94%) and following (89%) the flood, apparently because of the large numbers of amphipods transported downstream. These results were similar to those reported for the species in Grand Canyon in previous studies, except for the increase in amphipods during and after the flood.

Response of flannelmouth sucker in the Paria River to an experimental spike flow in the Colorado River below Glen Canyon Dam

Michele Thieme, and Carole C. McIvor

ABSTRACT

Flannelmouth sucker (*Catostomus latipinnis*) spawn each spring in the Paria River, a tributary of the Colorado River 24 km downstream of Glen Canyon Dam. Adults stage in the Colorado River near the confluence in late February and early March and spawning takes place in the lower 12 km of the Paria River in March and April. However, few young-of-the-year (yoy) or subadult fish are captured in this region suggesting poor recruitment.

During the 45,000 cfs experimental spike flow of March 26 - April 4 1996, adults sought shelter from the flood in the inundated, much enlarged, Paria mouth. As the flood waters receded, these fish returned to the mainstem. Spawning in the Paria River proceeded as in non-flood years, and was apparently successful as evidenced by the capture of 576 yoy in late spring and summer.

Not only did the experimental spike flow not deter spawning of this native fish, but the permanent slack water pool in the Paria mouth formed by the relatively constant 20,000 cfs flow in the Colorado River following the flood, provided a rearing area for young fish. These young grew from a mean of 27.5 mm total length (TL) in mid-May to a mean of 88.3 mm TL by the end of September.

These data suggest the following: (1) a spring flood of the magnitude of the experimental spike flow has no detrimental effect of spawning movements of flannelmouth sucker, and (2) a seasonally adjusted steady flow of a minimum of 15,000 cfs forms a slack water pool in the Paria mouth that is used by yoy flannelmouth sucker as a rearing or nursery area.

Effects of the 1996 beach/habitat-building flow on vegetation, seed banks, organic debris, and germination sites

Michael J. C. Kearsley, and Tina J. Ayers

ABSTRACT

We measured the effects of the March and April 1996 experimental beach/habitat-building flow on riparian vegetation in the Colorado River corridor of Grand Canyon National Park. We used vegetation maps developed in 1995 as the basis of our assessments. These maps divided vegetation in each of nine sites into internally consistent vegetation patches, or vegetation polygons. We separated the effects of the flood on plants in the polygons into four categories: extant vegetation, weed species, surface organics, and substrate. First, we recorded the effects on extant vegetation in terms of the amount of damage to vegetation and the amount of change in the areal extent of vegetation patch types. Second, we compared the distribution of adults of three weed species before and after the flood to determine short-term effects on their populations. We determined the longer-term effects by comparing the seed banks of polygons before and after the flood. Third, we recorded the position of the high water mark "bathtub ring" of debris deposited by the flood, and any other significant deposits of debris from the flood. In addition, we assessed the effects of the flood on the depth of the surface organic material, or duff, in the polygons by comparing the 1996 and 1995 duff depth measurements taken during monitoring activities. Finally, we noted two significant effects of the flood on soils in the vegetation patches, particle size changes and deposition in return channel marshes.

The effects of the flood on extant vegetation were minor, and almost exclusively limited to patches adjacent to the river. Patches which were affected generally lost their complement of herbs and herbaceous perennials to deposition of up to 1.5 meters of sand. Many such patches had their perennial species return within six months. We did not detect a significant effect of the flood on adult weeds as measured by distribution within and among sites. However, the seed banks in all sites were severely affected. On average, seed banks lost roughly 80% of the individuals and 80% of their species richness as a result of the flood. Surface organics were redistributed during the flood, decreasing slightly in most vegetation patches and piling up significantly in areas where the "bathtub ring" was evident. Although there was no consistent effect of the flood on average particle sizes within sites, there was a significant loss in variability, due mostly to the burial of silt and clay sediments in return channel settings by fine sand. We also noted a change in the topography of return channel transects, especially in the narrowing of the channel due to deposition of sediments.

We believe that if the goals of the next high flows include the reduction of near-shore vegetation then releases will have to be higher. The minimal effects of the 1996 flows on shrubs and other woody plants showed that 45 kcfs produces insufficient forces for the removal of all but the smallest individuals. The loss of the seed banks should extend the effects of the flood on herbs and herbaceous species for several years, especially since the texture of the substrates in most patches has been changed.

The River runs to mile 245

Kerry Christensen

ABSTRACT

Many believe that the Colorado River in lower Grand Canyon, and therefore the operation of Glen Canyon Dam, have no influence on riparian vegetation or its substrates beyond Separation Canyon (river mile 239.5) because of the influence of Lake Mead. We created maps of habitat polygons and performed ground releve' sampling of each polygon at four sites below Separation Canyon pre- and post-flood to determine whether flows of 45,000 cfs had any effect on riparian resources on what most believe are the shores of Lake Mead.

At each site, we examined changes in habitat polygon areas and the effects of the flood on the number of plant species present per habitat polygon, percent cover and mean number of vertical canopy tallies at river miles 241.5L, 246.0L, 249.0L, and 254.0R. We found that of the habitat polygons affected by the flood, there were increases in polygon area at the two sites furthest upstream due to sand deposition while polygons declined in size downstream due to scouring.

At river miles 241.5L and 246.0L, there were significantly more plant species present per inundated polygon prior to the flood compared to afterwards. We feel that this loss in plant species was due to both burial and scouring. Present cover and canopy hits were not significantly affected at either site. At river miles 249.0L and 254.0R, neither mean number of plant species, percent cover or canopy hits were significantly affected by the flood. Although not significant, there were more plant species, greater percent cover and more canopy hits prior to the flood at river mile 249.0L compared to afterward.

With regard to substrate composition, there were significant changes in mean particle size of 18 of the 33 inundated polygons across the four sites. Generally, there were increases in particle size from clay soils to fine-grained sands while in some cases there were decreases in particle size as coarse-grained substrates were covered by fine-grained sands. The implications of these changes to vegetation community dynamics are unknown.

Although there were not drastic effects of the flood on riparian resources n lower Grand Canyon, that a significant reduction in mean number of plant species was seen at River Mile 241.5 and 246.0 show that the river does have influence below Separation Canyon. While there were not statistically significant effects on riparian vegetation at miles 249 and 254, there were declines in vegetation at some polygons and that they were substantially inundated suggests that the Colorado River has the potential to affect resources even to mile 254 and potentially beyond depending on the size of the flood.

Partners in slime: Assessment and mitigation of flood impacts on Kanab ambersnail

Lawrence E. Stevens, and Vicky J. Meretsky

EXECUTIVE SUMMARY

Abstract

The Kanab ambersnail (KAS; SUCCINEIDAE: *Oxyloma haydeni kanabensis* Pilsbry) is a small (<24 mm) endangered landsnail that occurs at two springs in the southwestern U. S.: Three Lakes (near Kanab, UT) and Vaseys Paradise (VP, Colorado River mile 31.5 in Grand Canyon, Arizona). We conducted a cooperative, interagency analysis on the impacts of the 1996 Beach/Habitat-Building Flow on the VP population of endangered KAS. The experimental flow was expected to inundate and potentially scour 11 to 16% of available KAS habitat, and to eliminate an equally high proportion of the KAS population there.

Survey of vegetation patches below the anticipated flood line immediately prior to the flood showed 66.23 m^2 in patches dominated by cardinal monkey flower (MICA: *Mimulus cardinalis*), and 38 m^2 in patches dominated by watercress (NAOF: *Nasturtium officinale*); these two species are the principal host plant species for KAS. Almost 52 m^2 of MICA-dominated patches (79%) and 24 m^2 of NAOF-dominated patches (63%) were eliminated outright during the flood, while the remaining patches, originally dense and robustly healthy, were sparsely vegetated and heavily damaged. The overall loss was in the neighborhood of 11% of primary habitat at VP. Vegetation has been slow to recolonize areas where it was eliminated outright; litter and soil are also absent from these areas, and plants must recolonize bare rock. Damaged areas retained some soil cover and are recovering more rapidly, although frequently in plant species other than the principal host plants.

Researchers marked 1,242 KAS from below the inundation level and moved them to habitat predicted to be uninundated during the flood. An early, mild spring permitted KAS to breed twice during the 1996 season, and estimated KAS populations in what remained of accessible portions of the site slightly exceeded estimations for the accessible portions (including habitat eliminated by the flood) in 1995. The VP KAS population is not considered to be at greater risk, numerically, than before the flood.

Forty-three marked snails were resighted after marking during the 1996 fields season. Of these, 11 had changed vegetation patches (25%), and four of these (9% of resightings) had changed vegetation type. Growth rates estimated from these snails averaged 2.1 mm/month.

Eighty-nine marked were found dead, as empty shells, most apparently preyed upon by *Peromyscus maniculatus* and *P. crinitus*. Mammal trapping was initiated beginning in April; trapping success was highest in April (18.8%), and decreased to 0% in July, then increased in September to 9.7%. This pattern generally followed seasonal density patterns of large KAS.

Assessment of KAS sampling techniques suggested that the current technique of searching 20-cm diameter circular plots balances habitat damage, areal accuracy and count accuracy as well as

any other plot size. Observation of the predicted and actual flood stage demonstrated that the stage model (STARS) was quite accurate at VP. Finally, greenhouse experiments have demonstrated that the two principal host plants can easily be propagated in captivity.

INTRODUCTION

KAS is a small (<24 mm), federally endangered landsnail that occurs at two springs in the southwestern U. S. (Pilsbry and Ferriss 1911, Pilsbry 1948, Spamer and Bogan 1993): Three Lakes (near Kanab, UT) and Vaseys Paradise (VP, Colorado River mile 31.5 in Grand Canyon, Arizona). KAS was proposed for emergency listing as an endangered species by the U. S. Fish and Wildlife Service in 1991 (England 1991a, 1991b), following their discovery at VP (Blinn et al. 1992, Spamer and Bogan 1993). The species was listed in 1992 (Anonymous 1992, England 1992). Two KAS populations formerly occurred in the Kanab area, but one population was extirpated by desiccation of its habitat. The remaining Utah population at Three Lakes occurs at several, small spring-fed ponds on cattail (*Typha* spp.; Clarke 1991). The Three Lakes site is privately-owned.

KAS were first collected at VP in 1991 (Blinn et al. 1992, Spamer and Bogan 1993), and an interagency team lead by the Bureau of Reclamation examined KAS ecology there in 1994 and 1995 (Stevens et al. 1995). KAS occurs primarily on two host plant species at VP: native cardinal monkey flower (MICA: *Mimulus cardinalis*) and non-native watercress (NAOF: *Nasturtium officinale*). VP is a popular water source and attraction site for Colorado River runners. Anthropogenic impacts are limited by the dense cover of poison ivy and the nearly vertical terrain: Grand Canyon National Park recommends that river runners remain at least 5 feet from vegetation. Within Grand Canyon, KAS apparently is restricted to VP in Grand Canyon: no KAS were observed at 81 other Grand Canyon springs surveyed from 1991 to 1995 by Stevens et al. (1995). Rematched historic photographs of VP (e.g., Turner and Karpiscak 1980:58-59) reveal that cover of the two host plant species has increased greatly at lower stage elevations since the completion of Glen Canyon Dam in 1963. The timing of KAS colonization of this post-dam vegetation is unknown, so we cannot determine the rate at which increased vegetation cover increased KAS habitat.

Topographic surveys in 1995 revealed rapid changes in vegetation cover over the growing season, with 5.9% to 9.3% of the primary habitat occurring below the 940 m^3/s (33,000 cfs) stage, and 11.1% to 16.1% occurring below the 45,000 cfs stage (Stevens et al. 1995). The total area of primary habitat was 0.09 ha, and the area of secondary habitat (patches of riparian vegetation that are not dominated by MICA or NAOF and are little used by KAS) was also 0.09 ha, for a total vegetated area of the spring of 0.18 ha in June 1995.

The total estimated KAS population at VP rose from 18,476 snails in March 1995 to as many as 104,000 snails in September 1995. Reproduction took place in mid-summer (Stevens et al. 1995). The estimated proportion of the KAS population occurring below the 33,000 cfs (940 m^3/s) stage rose from 1.0% in March to 7.3% in September; proportions occurring below the 45,000 cfs stage were 3.3% in March, 11.4% in June and 16.4% in September 1995.

Construction of Glen Canyon Dam increased the primary KAS habitat area by more than 40%, and probably resulted in an increase in the snail population (Stevens et al. 1995). The KAS population and habitat at VP apparently survived and recovered from innumerable flows much larger than the planned during the pre-dam era, and this species survived a total of six flows $\geq$ 1275 m^3/s (45,000 cfs) during the post-dam era (in 1965, 1980, 1983-1986). Short-term reduction in primary habitat area by scouring flows was not predicted to jeopardize the existence of KAS; however, the FWS Biological Opinion concerning the Beach/Habitat-Building Flow required analysis of direct and long-term flood impacts on this isolated population. The FWS Biological Opinion also required a full year of monitoring following the experimental flow. Data collected in March 1997 are not fully integrated in this summary, and will be presented in a report to the FWS later in 1997.

Study Area

VP is a cool-water, dilute dolomitic spring that issues from the Mooney Falls member of the Mississippian Redwall Limestone 0.9 km downriver from the mouth of South Canyon in Grand Canyon National Park, 51 km downstream from Lees Ferry, Arizona (Huntoon 1974). The spring issues at 925 m elevation from three primary mouths and divides into several large, and numerous, small rivulets as it flows ca. 90 m to the Colorado River. The climate is arid and continental, with a mean annual precipitation of 140 mm at Lees Ferry, the nearest weather station (Sellers and Hill 1974). Precipitation is bimodally distributed between summer and winter. Temperatures at Lees Ferry range from <0EF in winter to >110EF in summer. Although the east-facing aspect of the spring allows it to thaw relatively quickly after freezing winter nights, Stevens (personal observation) noted that the spring was nearly completely frozen and covered with ice during freezes in early January 1975 and December 1990. Aspect also protects the spring site from hot, direct mid-afternoon sunlight during summer.

KAS research is complicated by a number of physical and statistical constraints (Stevens et al. 1995). The cryptic morphology of KAS, steep topography of VP, dense cover of poison ivy (*Toxicodendron rydbergii*), fragile host plants, and the snail's behavioral ecology all influence sampling design, and the associated precision and accuracy of population estimation. VP is only accessible via a rugged trail from a remote North Rim location, or by a 1-2 day river trip from Lees Ferry, AZ. At VP, KAS avoid open areas, preferring decadent or dead MICA stems and any portion of living NAOF canopies. The stems of these primary host plant species are fragile and break easily during population surveys, making non-destructive sampling difficult. Many primary host plant patches lie on steep bedrock walls and are surrounded by dense stands of poison-ivy, thus access is limited and sampling is perilous. These issues make the study of KAS difficult, and require carefully trained field staff.

OBJECTIVES

The following flood impacts study components were designed through discussions with the Bureau of Reclamation (BOR), U. S. Fish and Wildlife Service (FWS), National Park Service (NPS), and Arizona Game and Fish Department (AGFD) to aid in risk and impact assessment, population monitoring and recovery: (1) sampling protocol assessment and validation; (2) obligatory short-term studies based on the Endangered Species Act and the FWS Biological

Opinion requirements; (3) studies to be used for longer-term (1 year) assessment of test flow impacts, and KAS management and recovery (also required by the Endangered Species Act); (4) ancillary studies that assist in (1) or (2); and (5) studies required by AGFD for the FWS Section 6 Cooperative Agreement and that help resolve issues in (1), (2) or (3). Studies in (5) conducted solely by AGFD are not reported here.

The study objectives were organized into the following outline.

1. High flow impacts on KAS habitat
   a. Determine potential primary habitat loss due to the high flow experiment
   b. Determine actual primary habitat loss due to the high flow experiment
   c. Determine mechanism(s) of habitat loss during the high flow experiment
   d. Determine mechanisms and recovery rate of primary KAS habitat after the test flow
   e. Determine historic development of KAS habitat, particularly watercress colonization

2. High flow impacts on the KAS population
   a. Determine proportion of KAS population at risk to loss during high flow experiment
   b. Determine proportion of KAS population actually lost during high flow experiment
   c. Determine mechanisms of KAS loss due to high flow experiment
   d. Determine KAS population recolonization for six months post-flood

3. Sampling and population surveying protocol assessment
   a. Refine stage-discharge relationship at VP
   b. Determine accuracy of KAS density measurements
   c. Determine effects of plot size on habitat impacts
   d. Determine species-area effects of plot size on KAS population estimation

4. Behavior studies
   a. Determine best marking technique for KAS survivorship/movement studies
   b. Develop a KAS ethogram
   c. Determine movement behavior in relation to the high flow
   d. Determine survivorship of marked and moved *versus* resident KAS
   e. Determine activity budgets and habitat use of resident and immigrant KAS throughout the growing season
   f. Determine KAS diet through the 1996 growing season
   g. Observe interactions between KAS, parasites, potential competitors and potential predators

5. Recovery and long-term studies
   a. Determine potential for growing KAS primary host plants in controlled environments
   b. Determine use of alternate host plant food sources
   c. Investigate comparable habitats in Grand Canyon for possible introduction sites

Measuring High Flow Impacts on KAS Habitat

Methods. We assessed potential KAS habitat loss using the methods of Stevens et al. (1995). The perimeters of all habitat patches lying downslope from the approximate 60,000 cfs (1,700 m^3/s) stage elevation (hereafter called the "low zone") were surveyed on 18-19 March 1996. Vegetation patches were resurveyed after the experimental flow in April 1996 and approximately bimonthly during the remainder of the 1996 growing season (through October).

March 1996 survey elevation data were related to the stage-to-discharge model developed for the mainstream at VP, which was based on the Bureau of Reclamation STARS hydraulic model (Randle and Pemberton, 1988). The STARS predicted stage elevation was used to predict the habitat area and KAS numbers to be affected by the flow, as well as to delineate the habitat from which snails were to be removed prior to the experimental flow (Meretsky et al. in prep).

Results. The March 1996 survey revealed that 163.7 m^2 of vegetation cover existed downslope from the estimated 45,000 cfs +1.5' stage (the worst-case inundation level), including 81.5 m^2 of patches dominated by MICA and 48.4 m^2 of patches dominated by NAOF. After the experimental flow, we determined that 157.2 m^2 of vegetation cover had existed downslope of the actual 45,000 cfs stage prior to the experimental flow, including 66.23 m^2 of MICA and 38 m^2 of NAOF.

Almost 52 m^2 of MICA-dominated patches (79%) and 24 m^2 of NAOF-dominated patches (63%) were eliminated outright during the flood, while the remaining patches, originally dense and robustly healthy, were sparsely vegetated and heavily damaged. The overall loss was in the neighborhood of 11% of primary habitat at VP. Vegetation has been slow to recolonize areas where it was eliminated outright; litter and soil are also absent from these areas, and plants must recolonize bare rock. Damaged areas retained some soil cover and are recovering more rapidly, although frequently in plant species other than the principal host plants.

Portions of two vegetation patches directly exposed to the flood water were left intact prior to the flood (no destructive sampling), and we observed that those patches were completely scoured by the high flow up to the 45,000 cfs stage elevation. Direct observation and measurement of scour (vegetation loss) were made during the rising hydrograph. We measured water velocity from a point between patches 4.5 and 5 during the upramp on 26 March. Velocities ranged from 0.5 m/sec to 1.5 m/sec at the surface, and from 0.6 m/sec to 1.5 m/sec at 0.5 m below the surface. The portion of VP above the debris fan lies at a steep angle to the current and immediately upstream of a riffle. The current near the shore was turbulent, and the water level surged. Consequently, water velocities varied considerably over short periods of time. Vegetation losses were attributed to high velocity, scouring flows and impacts by coarse debris.

We have acquired several historic photographs of VP from Dr. Robert Webb (U.S. Geological Survey, Tucson, AZ) since 1890, and other sources. We are using these photographs to determine the extent and composition of vegetation development at VP over time. We have surveyed vegetation scour lines and are relating them to elevations at our stage discharge model. This information will provide insight into interactions between non-native host plant introductions and dam operations, and will be presented in the final 1997 report.

Measuring High Flow Impacts on the VP KAS Population

Methods. We measured KAS density using the techniques of Stevens et al. (1995) and estimated KAS abundance above and below the predicted inundation level. We sampled a total of 180 20-cm-diameter plots in March 1996 and developed estimates for the population in the worst-case inundation zone and, after the flood, in the area actually inundated during the experimental flow. We observed KAS at the water's edge to determine the mechanism by which they were lost during the upramp, and we immersed samples of KAS for varying lengths of time to determine their resistance to immersion. Following the experimental flow, we resurveyed KAS population density on a monthly basis through the 1996 growing season.

Results. Field estimates suggested that 3,080-3,120 KAS existed below the 45,000 cfs + 1.5' stage, and were at risk to loss during the flood. We subsequently estimated that 2,154 KAS existed below the actual 45,000 cfs. The total estimated KAS population in the flood zone was 7.6-fold higher than that predicted on the basis of March, 1995 data. We attributed this difference to the warmer, drier 1995-96 winter (i.e., lack of prolonged freezing and local floods), and considerable expansion of primary host plant patches; more thorough searching in 1996 may have accounted for a small part of the difference.

On-site discussions with the FWS and NPS resulted in a modification of our marking and moving program (USFWS 1996, Meretsky et al. in prep). This revised FWS prescription for the site directed us to relocate and collect approximately 75% of the Kanab ambersnail individuals from 50% of the habitat expected to be inundated. The original prescription required that 90% of the snails be removed from the habitat to be inundated.

We marked and moved 1,242 KAS to other primary habitat at VP that lay above the estimated 45,000 cfs + 1.5' stage prior to the flood. This number was 72 more KAS than the 1,170 total recommended by the FWS memorandum. If we assume that all KAS not removed from the inundated area were lost, then at least 40.8% of snails in the inundated zone (16.7% of the snails below the 1,275 m^3 stage - the low-zone area surveyed prior to the flood) were lost. The uncertainty of the estimate is due to the fact that we removed snails from below the estimated 45,000 cfs + 1.5' stage, and we cannot be certain how many of the removed snails came from the area actually inundated.

We investigated snail movements near the rising water line by placing snails on vegetation above the water's edge and observing their actions. In all cases, snails were fully active when moved. The maximum time a snail remained on vegetation after the first contact of its stem or leaf with water was 4 minutes. Snails were removed by waves, or, in slack water, through flotsam impact. Survival through immersion is apparently less important than their inability to maintain their position in surging, debris-laden water.

During immersion experiments, snails were immersed for 12-65 hours. All snails removed from the water recovered to normal size and exhibited normal attachment to vegetation within 30 minutes of removal. Immersed snails became bloated with water and lost their attachment to vegetation after prolonged inundation; however, they were resistant to drowning by immersion in cold, well-oxygenated water.

We monitored the recovery of the population through the 1996 growing season. The low zone KAS population increased from: 441 in April, to 1,182 on 19 May, to 1,260 on 15 June, to 10,646 on 20 July during emergence of young from egg sacks, with an annual population decrease by 27 August following most reproduction, to 359 on 16 September. KAS were largely in dormant condition in October, and the population was not surveyed to prevent disturbance. Complete estimates are not available from August because *Toxicodendron* expansion precluded surveys in many patches.

The lower VP study area (below the approximate 1,700 m^3/s stage) exceeded the 1995 KAS population levels by 20 July 1996. This rapid recovery was attributable to an exceptionally warm, mild winter; whereas KAS had a single reproductive cycle centered in July in 1995, in 1996 there were two peaks of reproduction, one in June and a secondary peak in August. The warm winter and early spring apparently permitted snails to mature and reproduce twice within a single growing season. As a result, smaller size classes of snails overwintered in 1996-97, a phenomenon not previously observed for KAS. Despite the positive numerical result of the season, KAS habitat will require at least several years to recover from the effects of the experimental flow.

KAS Sampling and Protocol Assessment

Methods. We surveyed the water elevation during the upramp from 8,000 to 45,000 cfs to verify the STARS model (Randle and Pemberton 1988) predictions. We conducted surveys of 10-, 20-, 30-, and 50-cm-diameter plots in the flood zone, and then destructively sampled those plots to determine the accuracy of KAS sampling through follow-up sampling, as well as the effects of plot size on KAS density estimation.

Results. The STARS model prediction for the 45,000 cfs stage was within a few centimeters of the observed stage. Population sampling experiments revealed a complex relationship between plant species and plot size. The proportion of KAS found during destructive sampling after initial snail counts increased with plot diameter in MICA, but not in NAOF. In MICA, complete harvesting of 20-cm-diameter plots following the initial survey added, on average, 0.22 KAS/m^2, a 38.6% increase. In NAOF, follow-up harvesting added, on average, 0.35 KAS/m^2 (28.4%). Therefore, our existing plot-based analyses underestimate KAS abundance by as much as one third, but probably varies considerably between observers (a factor not tested in this analysis). Time expenditure and stem breakage during searches in 50-cm plots were prohibitive. The 10-cm plots were too small to allow for a well-defined perimeter. Stem breakage increased with plot diameter for both host plant species, and increased 2.1-fold on MICA and 4.0-fold in NAOF on 30-cm-diameter plots as compared to 20-cm-diameter plots. Consequently, we still favor the use of 20-cm-diameter study plots. Analyses of snail numbers presented in this document are consistent with those presented in earlier documents and do not incorporate the accuracy assessments described above.

Behavior and Movement Studies

Methods. Following a literature survey and consultation with members of the malacological community, we chose to mark KAS using fingernail polish (for snails <6 mm) and bee-dots (2-mm diameter, numbered, colored, plastic disks) secured with cyanoacrylate glue.

We attached bee dots to 10 *Catinella vermeta*, a common terrestrial snail at VP, and observed them for >2 weeks. The snails showed no ill effects from this experiment, and we concluded that this technique was appropriate for marking KAS.

We observed snails for approximately one hour and determined that the degree of emergence from shell, direction and distance of movement were the major observable behaviors. Behavior in response to other invertebrates was recorded when applicable. The approximate position of observed snails also was recorded on a site map.

We made focal observations on KAS before and after the high flow and through the 1996 growing season. Observations were made in four time categories: 0000-0559, 0600-1159, 1200-1759, 1800-2359. We attempted to observe each focal snail for 15 minutes, noting direction and distance moved, substrate, orientation to substrate and interactions with other invertebrates. We noted eyestalk damage for information on parasitism. At the end of each observation, we estimated total distance moved.

Fecal pellets were collected from KAS on both NAOF and MICA plants for diet analysis. Pellets were preserved in 70% EtOH. Results of diet analysis will be presented in the final report.

Results. We made focal observations on the behavior of 253 snails in 1996. Total distances moved per minute ranged from 0 to 2.48 cm/min, with values skewed toward slower movements. Differences between movements on major host plants were not consistent among months. Differences in distances moved during different times of day were not consistent on either host plant among months.

Researchers who observed snails at night noted that snails exposed to direct white light often moved into light-sheltered positions. As a result, we began using infrequent and/or strongly reduced light for observations. Additional analysis confirmed these informal observations of negative phototaxis during nighttime observations.

During the post-flood survey in April, we observed that several KAS in a low-lying NAOF patch (P7NU), probably carried there by a small rivulet that runs through the patch. All KAS found in the flood zone in April were located near the 45,000 stage elevation, and their presence below flood stage probably resulted from wash-down and other downslope movement, rather than persistence in inundated areas through the flood. We hypothesize that longer downslope movements, such as those into P7NU, were entirely due to wash-down as the newly occupied areas had sparse vegetation cover. Fewer than a dozen snails were observed below the 45,000 cfs stage during the remainder of the growing season.

Forty-three live marked snails were resighted after marking during the 1996 fields season. Of these, 11 had changed vegetation patches (25%), and four of these (9% of resightings) had changed vegetation type. Growth rates estimated from these snails averaged 2.1 mm/month. An additional nine snails were found dead at least one visit after they were marked; the shells suggested three inter-patch movements (the patches in which the shells were found were not below the original patches - gravity did not cause a "false" move). Three shells were found in the

patch in which the snail was originally marked, and three shells had insufficient data to determine movement. Relocations of marked snails were too few to permit mark-recapture estimates of survivorship.

Activity budgets and habitat use data of marked snails will be reported in the final 1997 report. Median KAS densities in 20-cm survey plots were statistically higher on MICA in March, whereas in all other months, densities were higher on NAOF, significantly so in April, July, August, and September. Calculations used raw medians from survey plots where the survey plot, not the patch, was the unit of measure. Higher densities on NAOF may be linked to the phenology of the species. This variety of NAOF is an annual and cycled twice during the 1996 growing season, maturing by June, and germinating in July-September, and the second population matured in late autumn. KAS densities were greatest on NAOF seedlings; densities were near 0 on senescent NAOF.

Eighty-nine marked, dead snails (mostly undamaged shells completely cleared of their occupants) were found during the 1996 field season. The first empty, marked shells were found the day after the first releases in March 1996. Caging experiments with other snail species at VP and potential invertebrate predators did not result in any predation. Finally, a deer mouse (*Peromyscus* sp.) was observed eating something in an area of recently released snails. Closer inspection revealed two newly-cleaned snail shells, and fresh mouse droppings.

We surmised that *Peromyscus* at VP forage on KAS, which explains, in part, the large number of intact shells of all sizes observed on the site. High *Peromyscus*-related mortality may be attributed to naturally high densities and possibly local enhancement of snail densities because we initially released marked snails in small groups around patch margins.

We obtained permission from NPS to trap and mark small mammals at VP, and we live-trapped small mammals in April, May, June, July and September. *Peromyscus crinitus* and *P. maniculatus* were the only rodents captured at VP during the 1996 growing season, although a ground squirrel (*Spermophilus spilosoma*) was repeatedly seen near the site during the day, but was not engaged in KAS predation. Mammal trapping success of the two mice in KAS habitat patches was highest in April (18.8%), and decreased to 0% by 20 July, then increased in September to 9.7%. This pattern generally follows the seasonal distribution of large KAS. During the March, we observed a *P. maniculatus* nest in P6MUS, and we trapped two immature *P. maniculatus* in April, additionally confirming that *Peromyscus* are successfully reproducing in the area inhabited by KAS.

In 1996 only a single KAS was found expressing sporocysts of *Leucochloridium cyanocittae*. This represents nearly an order of magnitude decrease in parasitism between 1995 and 1996.

Recovery and Long-term Studies

Methods. We removed six batches each of MICA and NAOF from VP, and propagated them in the Northern Arizona University greenhouse. Propagation of these species was also attempted using seed from the VP stock in mid-summer.

Results. Seed establishment of NAOF has been successful. All MICA seeds failed to germinate under standard greenhouse conditions; however, MICA root stock are readily transplanted and our experience with these samples indicates that this species can be used to establish additional habitat for KAS. Both plants can thus be propagated readily in captivity.

We are attempting to obtain NAOF stocks to evaluate its potential as an in-situ KAS food source. AGFD is investigating riparian sites on the Colorado Plateau, searching for other KAS populations, and assessing potential locations for establishing new populations of KAS.

Future Research Recommendations

These results demonstrate that KAS has an approximately annual life cycle, and the snail is influenced by host plant availability, interseasonal and interannual variation, and Colorado River flows. The extent of parasitism by *Leucochloridium cyanocittae* diminished in the 1996 growing season, as compared to the 1995 growing season, and the parasite's role in VP KAS population dynamics remains unclear. While underestimating KAS density to some extent, the approach used here is conservative and can be clearly and consistently applied to monitor population development of this species without undue damage to the host plants. Therefore we recommend continuing to employ the protocol used in this study to monitor this population. Additional marking of KAS may provide additional insight into movement and host plant patch fidelity. Additional small mammal trapping and marking will help determine mouse behavior and the extent of density dependent predation on KAS.

Because of the above uncertainties, we recommend continuing to monitor the VP KAS population, at least at bimonthly intervals in the future, and at least until laboratory experiments have been conducted to determine the potential for establishment of secondary populations in neutral habitats (e.g., in propagated habitat at Glen Canyon Dam), in natural sites, or until other wild populations have been located. Once such experiments are completed, secondary populations have been successfully established, or additional populations are discovered, it will be appropriate to revisit the monitoring schedule for this endangered species.

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Impacts of a beach/habitat-building flow from Glen Canyon Dam on the endangered Southwestern Willow Flycatcher in Grand Canyon, Arizona

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INTRODUCTION

The U. S. Fish and Wildlife Service (FWS) 1996 Biological Opinion on the Bureau of Reclamation Test Flow from Glen Canyon Dam identified several Reasonable and Prudent Measures (RPMs) to provide information on impacts to endangered species, including the endangered southwestern willow flycatcher (SWWF, *Empidonax traillii extimus*) along the Colorado River in Grand Canyon. The Bureau of Reclamation Glen Canyon Environmental Studies (GCES) Office undertook a series of monitoring activities to ensure that take of SWWF and its proposed critical habitat in Grand Canyon was minimized during the Test Flow (U.S. Bureau of Reclamation 1996a). These activities were conducted by an interagency team of biologists from Applied Technology Associates, Inc. (ATA), FWS, GCES and the National Park Service (NPS) at Grand Canyon National Park. Also, the NPS monitored the SWWF population in 1996. Here we report on the Test Flow Impacts to SWWF.

We incorporated the Biological Opinion RPMs in the following study objectives:

1. Conduct test flow to avoid adverse interactions with territorial SWWF by concluding the maximum flow portion (1275 cms) of the test flow no later than April 15, and preferably before April 1.
2. Verify the stage-discharge relationships and flow models used to predict elevation and flow at SWWF nest sites and monitor level of incidental take, quantify flow depth and velocity at each of the four historic territories.
3. Assess Test Flow impacts on understory structure at the four historic SWWF territories by measuring vertical structure, foliage height diversity, and habitat configuration. Evaluate changes in areal cover to determine if habitat changes can be measured by remote sensing.
4. Assist NPS SWWF population monitoring in 1996.

The FWS also suggested a schedule for initiation of formal consultation, continued monitoring, reporting schedules and limits on nest stand inundation during the Test Flow.

BACKGROUND

In Grand Canyon, SWWF population status, breeding season distribution, nesting habitat, and nest characteristics are documented in published papers (Brown 1987; Brown and Johnson 1987; Brown et al. 1987; Brown 1988a,b; Brown and Trossett 1989; Sogge et al. 1995), and monitoring reports from 1976 to 1995 (Carothers and Sharber 1976; Brown 1991; Sogge and Tibbitts 1992, 1994; Sogge et al. 1993, 1995; Tibbitts et al. 1994). SWWF distribution, habitat use and diet data were summarized in the Bureau of Reclamation Biological Assessment (1996b). Collectively, these data indicate that SWWF in Grand Canyon nest in relatively wide stands of

riparian vegetation along the wide reaches of the Colorado River in dense groves of tamarisk (*Tamarix ramosissima*), occasionally with a scattered overstory of taller trees (Brown and Trossett 1989, Tibbitts et al. 1994), and usually with nearby exposed sand bars or fluvial marshes. SWWF nests are typically 3.5 to 7 m above the ground and several m below the canopy and nest sites have a high percentage of canopy from 0 to 4 m above the ground (Brown 1988a; Tibbitts et al. 1994). SWWF usually nest over moist or wet soil, and Brown (Appendix A) reported that all SWWF nests recorded during the high flow years of 1984-1986 occurred over water and nest trees were at the water's edge or stood in shallow water. However, all nests detected in Grand Canyon during the past five years have been situated in tamarisk stands over dry ground on elevated terraces and at least several meters away from the river's edge.

Territories of willow flycatcher subspecies other than *E. t. extimus* occur in a wide variety of bottomland riparian, meadow and mesic upland habitats (e.g., *E.t. traillii* in eastern Massachusetts, Farley 1901; and southeastern Arkansas, Meanley 1952), *E.t. campestris* southern Michigan, Walkinshaw 1966, and in Wisconsin, McCabe 1991); and *E.t. adastus* in southeastern Washington, King 1955, and in north central Colorado, Sedgwick and Knopf 1992). SWWF breeding habitats appear to be more restricted to riparian settings. In the original description of this subspecies, Phillips (1948:513) described the SWWF as breeding "...in willows and other swamp bushes along the main rivers and streams."

Four areas have been consistently occupied by territorial SWWF in Grand Canyon: Miles 50.5L (1993 to 1995), 51.4L (1991 to 1995), 65.3L (1994 to 1995) and Cardenas Marsh at Mile 71.0L (1971 to 1994; U.S. Bureau of Reclamation 1996b). By convention, distance is measured from Lees Ferry, river miles of specific sites are regarded as names rather than as precise distances, and side of the river is designated as the viewer looks downstream. These four areas all lie in wide, low gradient reaches, with abundant lower riparian zone vegetation dominated by tamarisk and coyote willow (*Salix exigua*) on upper bar surfaces, and with associated fluvial marshes in reattachment bar settings. Fluvial marsh vegetation at those sites consisted of common reed (*Phragmites australis*), horsetail (*Equisetum* spp.) and other wetland species. We focused our analyses on these four sites and did not try to analyze habitat use of SWWF observed at other sites (e.g., above Lees Ferry or on upper Lake Mead).

METHODS

Objective 1: Complete the high flow no later than 15 April

The Test Flow was planned according to the Bureau of Reclamation schedule, with normal flows resuming prior to 15 April 1996.

Objective 2a: Verify Stage-to-Discharge Relationships at SWWF Nest Sites

We predicted the elevation and mid-channel water velocity of the 1,275 m^3/s stage using the STARS model (Randle and Pemberton 1987). During the high flow event we visited these sites and staked the high water stage (Table 1). We returned to the nest tree stands on 19-22 April

1996, two weeks after the high flows receded, and surveyed the high water stage elevation at each site except Cardenas Creek (Table 1). We compared these data against the model predictions to verify stage-to-discharge relationships from the STARS model.

Table 1: Schedule of 1996 SWWF habitat and stage surveys. Additional analyses of vegetation cover change were conducted at all sites using aerial photography for the pre-flow (24 March), immediately post-flow (4 April), and six months post-Test Flow periods (1, 2 September).

Site	Pre-Flow Habitat Survey Dates	During-Flow Stage and Velocity Measurement Dates	Immediately Post-Flow Habitat Survey Dates
50.5L	0229	0330	0419
51.5L	0301-02	0331	0420
Upper Palisades Cr.	0302	0331	0422
Cardenas Cr.	0325	0401	0423

Objective 2b: Monitor Incidental Take of Habitat

We visited each of the four historic nest sites prior to the high flow release (Table 1) and surveyed 10 transects (five at Cardenas Creek) from upslope of the nest trees to below the 566 m^3/s stage (Table 1). We used these transects for pre- and immediately post-Test Flow measurement of vegetation change. During the Test Flow from 30 March to 1 April 1996 we measured flow velocities in the mainstream and approximately 6 m from shore in the associated eddies, using a Marsh-McBirney velocity meter.

Objective 3: Measure Change and Recovery of Nest Site Stands

At each site, we collected data related to foliage height diversity, litter layer, and understory vegetation. We measured foliage height diversity using a woody foliage profile density technique modified from Dueser and Shugart (1978).

At the 50.5L, 51.5L and Upper Palisades Cr. sites, we surveyed 10 transects with 6 points/transect, attempting to place three points above the anticipated 1,275 m^3/s stage and three points below that stage. Because of time limitations we established only five transects at the Cardenas Cr. site, with 6 to 7 points/transect placed equally above and below the estimated 1,275 m^3/s stage. During the pre- and immediately post-Test Flow visits, points were surveyed using standard electronic total station equipment and protocol to determine elevation. Surveyed points at all sites were related to the GCES GIS control network.

We counted branch contacts above each surveyed point before and immediately after the Test Flow in the following layers: 0-0.5 m, 0.5-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m, 5-6 m, 6-7 m, and above 7 m. The lower one meter was split into two ½-m intervals to distinguish between impacts on ground litter versus those on attached low branches. Presence of litter and understory vegetation were noted at each point. Statistical analyses were based on presence or absence of litter and understory vegetation cover.

Branch height diversity was calculated at each survey point using a Shannon diversity index (Shannon 1948, Zar 1984) using the following intervals at each site: 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, and 7+ m. Because tamarisk is not in leaf in March, we could not identify which branches would bear foliage later in the season and we therefore elected to calculate branch height diversity rather than foliage height diversity. We also calculated a Shannon diversity branch contacts at each survey point. Maximum heights were recorded as 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, or 7.5 m. For branch height diversity analyses, any surveyed point that had no vegetation or which eroded away after the Test Flow was considered to have a diversity index value of 0.

We mapped vegetation polygons at marshes adjacent to the four nest sites using pre-flow, immediately post-flow, and 6 months post-Test Flow 1:4,800 Bureau of Reclamation black and white aerial photographs, using the techniques of Stevens and Ayers (1995). We attempted to quantify areal change of nest site stands using aerial photography, but were unable to obtain adequately accurate area estimates. Unlike the associated marshes, nest stands were not distinct from surrounding vegetation, so areas could not be consistently defined. Also, areal losses due to flood scour were so small in relation to the size of nest stands that, even if we could have defined the stands, the proportional loss would have been undetectable.

Several statistical analyses were judged against one-tailed probabilities. In all cases, one-tailed tests provided greater power to detect detrimental effects of inundation. Nonparametric statistical tests were used because tests for normality indicated severely nonnormal distributions of most data.

Objective 4: Coordinate/assist NPS SWWF Population Surveys

The Bureau of Reclamation coordinated and assisted the National Park Service in its planned monitoring of summer SWWF population size, distribution and nesting success in 1996 by providing funding and logistical support, and by assisting as needed in data collection. The NPS conducted monthly trips from March through July, and conducted a fledging success trip in July 1996.

RESULTS AND DISCUSSION

Test Flow Completion

The planned high release was conducted according to the Bureau of Reclamation schedule, with 1,275 m^3/s flows initiated on 26 March and terminated on 2 April 1996. Interim flows resumed on 8 April 1996.

Stage-to-Discharge Relationships

Predicted and measured peak stage elevations were remarkably close (Table 2). At the 50.5L and 51.5L sites, predicted peak stages were 9 and 14 cm lower than observed, respectively, and within 1 sd of the observed peak. These predictions were obtained by interpolating predictions between adjacent river cross-sections (50.62 and 50.01 cross-sections for the 50.5L site) or by using a

prediction for a nearby cross-section (51.57-mile cross-section for the 51.5L site). The predicted peak stage at the Upper Palisades Cr. site was 39 cm above the observed peak (i.e., conservative in its prediction). This prediction was obtained from interpolating values that the model provides which are themselves interpolated by the model from known cross-sections. The lower level of accuracy is thus associated with an area which is farther from known cross-sections. In this instance, at least, the less accurate prediction is also the most conservative, and still predicts peak flow stage to within 0.5 m of the observed elevation and within the error limits of the GCES GIS.

Table 2: Predicted and measured 1,275 m^3/s stage and surface velocity data for four historic SWWF nest sites. Velocity predictions were based on Randle and Pemberton (1987) STARS modeling results for the nearest cross-sections to the study site.

Site	Predicted Thalweg Velocity (m/s)	Measured Surface Thalweg Velocity (m/s)	Measured Surface Velocity In Eddy (m/s)	Predicted Elev (m)	Actual Elev (m) (1 sd)
50.5L	1.89	2.2	0.73	855.33	855.41 (0.093)
51.5L	1.30	2.1	0.01	855.06	855.20 (0.444)
Up. Palisades Cr.	2.59	2.1	0.81	821.51	821.12 (0.045)
Cardenas Cr.	1.68	1.8	0.08	801.62	— —

Incidental Habitat Take

Although predicted and measured flow depths were similar, predicted and measured peak flow velocities showed less agreement (Table 2). Predicted peak flow velocities differed by 0.31 to 0.8 m/s from measured velocities. Measured velocities were both faster and slower than predicted velocities, with no clear pattern of differences. We attribute the lack of pattern here to the high variability of surface velocity, which was subject to erratic turbulent flow at some sites during the peak release.

Velocities measured 6 m from shore in the eddies ranged from 0.01 to 0.81 m/s (Table 2), again reflecting different local flow patterns. The 51.5L eddy had very low velocity and may have been protected by dense vegetation. Velocities were not measured at nest trees because none were inundated by the high flow event.

Habitat Change and Recovery

Areal Changes in Nest Site Stands: At the 50.5L site, the river's edge in the inundated zone was scoured by less than 0.5 m on three transects, and a 1.0 m high ridge was scoured on one transect. All other low-lying points and transects at this site were essentially unaffected by the test flow, and all 30 surveyed points above the inundated zone were unaffected.

At the 51.5L site, the inundated river's edge portions of transects aggraded by 1.0 to 1.5 m on four transects. The low-lying portions of the upstream five transects were densely vegetated with coyote willow and tamarisk. Aeolian action may have been responsible for aggradation above the maximum Test Flow stage on two transects.

At the Upper Palisade Creek site (Mile 65.3L), aggradation occurred on the river's-edge points on six transects, while two transects were scoured, another was both scoured and aggraded, and the last was unchanged. The downstream transects changed more dramatically than did the upstream transects. The 30 surveyed points above the inundated zone were unchanged after the test flow.

The Cardenas Creek stand (Mile 71.0L) was little affected by the Test Flow, as demonstrated by aerial photograph analyses. Our estimation of the peak flow stage at this site was too high, and little of the area in the vicinity of the nest stand was inundated.

Following consultation with Mr. Robert Marshall (U.S. Fish and Wildlife Service, Ecological Services, Phoenix, AZ) in late summer 1996, it was decided that further disruption of nest site stands by remeasuring foliage height diversity was unnecessary.

Changes in Stand Characteristics: Branch density, as measured by branch contacts, was significantly lower in the inundated zone than in the non-inundated zone in the lower 0.5-m layer of the vegetation at the 50.5L and Upper Palisades Cr. sites (Table 3). Branch density in the inundated and non-inundated zones were not different in any other layers. Numbers of branch contacts decreased significantly after the Test Flow in the lower 0.5-m layer at the 50.5L, 51.5L and Upper Palisades Cr. sites; however, no other layers showed net decreases immediately post-flow (Table 3, asterisks). Although observers may have decreased branch-hit frequency in these dense tamarisk stands, that effect should have been equivalent above and below the 1,275 m^3/s stage, and therefore should not have influenced comparative results.

Table 3: Results of one-tailed Wilcoxon tests comparing change in number of branch contacts in eight vegetation layers before and immediately after the Test Flow at sample points above the 1,275 m^3/s stage and below that stage (one-tailed in the direction of greater decreases below the 1,275 m^3/s stage).

	P Values								
Site	0-0.5 m	0.5-1	1-2	2-3	3-4	4-5	5-6	6-7	7+
50.5L	0.001*	0.500	0.372	0.057	0.440	0.500	0.500	0.500	0.221
51.5L	0.288*	0.500	0.500	0.069	0.500	0.500	0.340	0.500	0.500
Upper Palisades Cr.	0.038*	0.265	0.474	0.500	0.161	0.500	0.500	0.170	0.500
Cardenas Cr.	0.500	0.412	0.500	0.500	0.500	0.500	0.417	0.500	0.500

* Significant decrease in number of contacts in inundated zone, from pre- to immediately post-Test Flow, (one-tailed signed-rank test).

Shannon branch height diversity index values did not decrease after the Test Flow, either within entire sites or within the inundated portions of sites (Table 4). Distribution of maximum vegetation height was equivalent before and after the Test Flow at all four sites, within in entire sites as well as in the inundated portions (Table 5). Because pre- and immediately post-Test Flow branch distributions were not significantly different, Shannon index values for diversity of maximum foliage height were calculated for the sum of both distributions at each site (Table 6).

Table 4: Median Shannon index values for branch height diversity (BHD) in whole sites and in inundated zones before and immediately after the Test Flow. P values represent results of one-tailed Wilcoxon tests to detect lower values following the high releases.

Site	Whole Site BHD			Inundation Zone BHD		
	Pre-flow	Post-flow	P	Pre-flow	Post-flow	P
50.5L	0.966	1.037	0.500	0.936	1.210	0.500
51.5L	1.021	0.992	0.500	1.008	0.993	0.500
Upper Palisades Cr.	1.058	1.268	0.500	1.041	1.119	0.500
Cardenas Cr.	0.693	1.050	0.500	0.599	0.780	0.500

Table 5: Results of Kolmogorov-Smirnov tests to determine equality of distribution of maximum foliage heights before and immediately after the Test Flow in whole sites and in the inundation zones.

Site	P values for H_o: pre-flow distribution of maximum foliage heights equal to post-flow distribution	
	Whole Site	Inundation Zone
50.5L	1.000	0.973
51.5L	0.993	0.699
Upper Palisades Cr.	0.375	0.782
Cardenas Cr.	0.830	0.627

Table 6: Shannon index for diversity of maximum foliage height in whole sites and in the inundation zones.

Site	Shannon diversity index	
	Whole Site	Inundation Zone
50.5L	1.9897	1.9940
51.5L	1.8465	1.8109
Upper Palisades Cr.	1.7442	1.8291
Cardenas Cr.	1.9671	1.5808

The diversity of maximum foliage height was greater than the median branch height diversity at all sites (Tables 4 and 6). Maximum foliage heights at all sites were quite diverse: the maximum possible value for eight layers is 2.079 and the minimum calculated value for a whole site was 1.744 (Table 6). Maximum foliage heights were diverse because the maximum canopy height at individual points varied considerably. Points with low canopy heights had few layers, and therefore had lower branch height diversity values. Thus, the structural pattern that contributed to high diversity in maximum canopy height also contributed to lower diversity in branch height (diversity among layers).

All sites lost litter in the inundation zone (Table 7). However, the proportion of bare ground increased significantly only at the 50.5L and 51.5L sites, as indicated by non-overlapping confidence intervals on the probability that a point in those sites lacked litter. Understory vegetation was altered by burial beneath newly-deposited sediment or by scouring high flows. Understory vegetation decreased after the Test Flow at the 50.5L, 51.5L and Cardenas Cr. sites (Table 8). Understory vegetation was absent from all points during both surveys at Upper Palisades Cr. Significant increases in the proportion of points without understory vegetation occurred only at the 50.5L site, as indicated by non-overlapping confidence intervals. The confidence intervals for the 51.5L site overlap only slightly. This is the only site for which a contingency test is nearly appropriate (expected values are too small at the other sites). The contingency table probability is 0.004, indicating that understory vegetation decreased at that site.

The pattern of decreasing branch contacts and understory vegetation, and increasing bare ground consistently reflects the scouring and deposition that occurred in the inundation zone. Small branches were broken off during inundation, and understory vegetation and ground cover were sometimes scoured or buried. Vegetation and ground cover are expected to recover. Most small branches in the 0-0.5m zone in the dense *Tamarix* nest site stands were dead prior to the Test Flow, and we do not expect regrowth. Changes to nest stands as a result of the Test Flow occurred only in the inundation zone, in the lowest layer. It is unlikely that such effects exert detectable negative impacts on SWWF.

Table 7: Change in the proportion of points without litter in the inundation zone before and immediately after the Test Flow. When all points surveyed in a site visit had litter, we computed a one-sided 97.5% confidence interval.

Site	Time	Mean	Lower 95% CL		Upper 95% CL	N of points
50.5L	Pre	0.0000	0.0000	-	0.1060	33
50.5L	Post	0.3030	0.1560	-	0.4871	33
51.5L	Pre	0.0278	0.0007	-	0.1455	36
51.5L	Post	0.4444	0.2795	-	0.6191	36
Upper Palisades Cr.	Pre	0.0690	0.0085	-	0.2276	29
Upper Palisades Cr.	Post	0.2069	0.0800	-	0.3974	29
Cardenas Cr.	Pre	0.0000	0.0000	-	0.4590	6
Cardenas Cr.	Post	0.1667	0.0042	-	0.6411	6

9-10 days old were still in the nest on 6 July, and on 21 July the adults were seen foraging busily in the vicinity of the nest in mid-morning, but no fledglings were actually detected. It is likely that at least one of the nestlings observed on 6 July successfully fledged.

CONCLUSIONS

The 1996 Test Flow had little, if any, biologically important impact on the Grand Canyon SWWF population or its nesting habitat. Marshes associated with the nest site stands were reduced in area by 1% to 75%; however, marshes are resilient and should recover relatively rapidly. We conclude that if there were any short-term impacts to the Grand Canyon SWWF, those impacts were not detectable. Similarly, no long-term impacts of the 1996 test flow on the Grand Canyon SWWF population are anticipated.

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All sites lost litter in the inundation zone (Table 7). However, the proportion of bare ground increased significantly only at the 50.5L and 51.5L sites, as indicated by non-overlapping confidence intervals on the probability that a point in those sites lacked litter. Understory vegetation was altered by burial beneath newly-deposited sediment or by scouring high flows. Understory vegetation decreased after the Test Flow at the 50.5L, 51.5L and Cardenas Cr. sites (Table 8). Understory vegetation was absent from all points during both surveys at Upper Palisades Cr. Significant increases in the proportion of points without understory vegetation occurred only at the 50.5L site, as indicated by non-overlapping confidence intervals. The confidence intervals for the 51.5L site overlap only slightly. This is the only site for which a contingency test is nearly appropriate (expected values are too small at the other sites). The contingency table probability is 0.004, indicating that understory vegetation decreased at that site.

The pattern of decreasing branch contacts and understory vegetation, and increasing bare ground consistently reflects the scouring and deposition that occurred in the inundation zone. Small branches were broken off during inundation, and understory vegetation and ground cover were sometimes scoured or buried. Vegetation and ground cover are expected to recover. Most small branches in the 0-0.5m zone in the dense *Tamarix* nest site stands were dead prior to the Test Flow, and we do not expect regrowth. Changes to nest stands as a result of the Test Flow occurred only in the inundation zone, in the lowest layer. It is unlikely that such effects exert detectable negative impacts on SWWF.

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51.5L	Pre	0.0278	0.0007	-	0.1455	36
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Upper Palisades Cr.	Post	0.2069	0.0800	-	0.3974	29
Cardenas Cr.	Pre	0.0000	0.0000	-	0.4590	6
Cardenas Cr.	Post	0.1667	0.0042	-	0.6411	6

Table 8: Change in the proportion of points without understory vegetation in the inundation zone before and immediately after the Test Flow. When all points surveyed during a site visit lacked vegetation, we computed a one-sided 97.5% confidence interval.

Site	Time	Mean	Lower 95% CL		Upper 95% CL	N of points
50.5L	Pre	0.6471	0.4651	-	0.8025	34
50.5L	Post	1.0000	0.8970	-	1.0000	34
51.5L	Pre	0.4444	0.2795	-	0.6191	36
51.5L	Post	0.7784	0.6084	-	0.8989	36
Upper Palisades Cr.	Pre	1.0000	0.8804	-	1.0000	29
Upper Palisades Cr.	Post	1.0000	0.8804	-	1.0000	29
Cardenas Cr.	Pre	0.6250	0.2448	-	0.9147	8
Cardenas Cr.	Post	1.0000	0.6309	-	1.0000	8

Impacts to Associated Marshes: Analysis of aerial photography demonstrated a 7% decrease in marsh vegetation at the 50.5L SWWF nest stand as a result of the Test Flow (Table 9). This marsh is dominated by *Juncus* spp., *Typha* sp., *Phragmites australis*, *Agrostis stolonifera*, *Baccharis emoryi*, *Tamarix ramosissima* and other wetland and riparian species. The vegetation of this site was recovering rapidly as early as two weeks after the test flow. Comparison of April, March and September 1996 aerial photographs demonstrate the limited impacts on the nest stand, but more substantial impacts on the associated marsh due to minimal scour of the underlying bar. The marsh continued to decrease in size six months after the test flow, losing 15% of its pre-flow area by September.

Table 9: Area of marshes (ha) associated with nest stands at the four SWWF nest sites in upper Grand Canyon, from 1:4800 black and white aerial photographs (see Figs. 2K-M, 3K-M, 4K-M, and 5A-C). Percent change from pre-flow area shown in parentheses.

Site	Pre-Flow	Immediately Post-Flow	Six Months Post-Flow
50.5L	0.193	0.180 (-7)	0.165 (-15)
51.5L	0.239	0.068 (-72)	0.060 (-75)
Upper Palisades Cr.	0.531	0.192 (-64)	0.206 (-61)
Cardenas Cr.	0.349	0.336 (-1)	0.369 (+6)

Aerial photographic analyses demonstrated a 72% decrease in vegetation cover at the 51.5L SWWF nest stand site (Table 9). The vegetation at this marsh is dominated by *Phragmites australis* (a rhizomatous grass species), *Typha* sp., and *Juncus acutus*, and aerial cover loss here was largely due to burial under newly deposited sediment. Comparison of March, April and September 1996 aerial photographs demonstrated the limited impacts on the nest stand and the

substantial impacts on the associated marsh, due to heavy scouring and erosion. This marsh decreased in size six months after the test flow, losing 75% of its pre-flow area by September.

Aerial photographic analyses demonstrated a 64% decrease in marsh vegetation cover at the Upper Palisades site SWWF nest stand as a result of the Test Flow (Table 9). The vegetation at this marsh was composed of *Juncus* spp. and *Salix exigua* and the loss here was largely due to scour at the river's edge and burial under newly deposited sediment. Aerial photographs from March, April, and September 1996 demonstrate the limited impacts on the nest stand and the more substantial impacts on the associated marsh from burial. Marsh area increased rapidly in the six months following the Test Flow as new vegetation has recolonized the bar surface, which was scoured of vegetation, but not substantially eroded. This marsh increased in size six months after the test flow, regaining 3% of its pre-flow area by September.

Aerial photographic analyses demonstrated a 1% decrease in marsh vegetation at the Cardenas Creek SWWF site as a result of the Test Flow (Table 9). The Cardenas Creek increased in area beyond its pre-flow limits by 6% by six months after the Test Flow (Table 9). The vegetation at this site is dominated by *Phragmites australis*, which recovered quickly from flooding throughout the river corridor. This marsh increased in size six months after the test flow, exceeding its pre-flow area by 6% by September.

NPS SWWF Monitoring

During the 1996 breeding season, there were six river trips completed to survey for SWWF territory occupancy and to monitor nesting attempts. The trips occurred during an 11-week period to allow for detection of early migrant birds, documentation of nesting attempts, and any associated successful reproduction. The dates of the trips were: 6-20 May, 29 May-9 June, 17-28 June, 1-8 July, 10-16 July, and 21 July.

Based on results of previous SWWF monitoring during the 1980's and from 1992-1995, the 1996, NPS survey efforts were focused between Saddle Canyon (Mile 46) to Cardenas Marsh (Mile 71), and from miles 190-198. These areas represent the best potential SWWF habitat between Lees Ferry and Diamond Creek.

During 1996, early surveys documented six singing males between Saddle Canyon and Cardenas Marsh. However, later surveys revealed that three of the six singing males detected during early May had moved to other unknown areas, and of the three remaining males, only one had paired. One unpaired male remained on territory from 31 May until at least 13 July, while the other remained from 31 May until at least 20 June.

The single breeding pair was located at the 50.5L site within three meters of the successful 1995 nest site. A total of 9 days were spent monitoring this nest site. The female was confirmed incubating 3 SWWF eggs on 1 June, and an unknown number of eggs again on 12 June. However, on 20 June the nest was abandoned and 2 SWWF eggs remained and one broken shell was found below the nest. On 3 July, a second nest was found 4 m from the first nest and the female incubating one egg and two newly hatched nestlings present. Subsequently, two nestlings

9-10 days old were still in the nest on 6 July, and on 21 July the adults were seen foraging busily in the vicinity of the nest in mid-morning, but no fledglings were actually detected. It is likely that at least one of the nestlings observed on 6 July successfully fledged.

CONCLUSIONS

The 1996 Test Flow had little, if any, biologically important impact on the Grand Canyon SWWF population or its nesting habitat. Marshes associated with the nest site stands were reduced in area by 1% to 75%; however, marshes are resilient and should recover relatively rapidly. We conclude that if there were any short-term impacts to the Grand Canyon SWWF, those impacts were not detectable. Similarly, no long-term impacts of the 1996 test flow on the Grand Canyon SWWF population are anticipated.

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Glen Canyon National Recreation Area survey of terrestrial avifauna in Glen Canyon and potential effects of the 1996 controlled flood

John R. Spence

ABSTRACT

Walking surveys to detect bird species and individuals were conducted between March 18 and April 5, 1996, in patches of riparian vegetation adjacent to the Colorado River in Glen Canyon. In all 25 surveys were conducted before, during and after the 1996 controlled flood release. Mean individuals, species, ground gleaners and tree gleaners all declined significantly after the flood. Mean time/patch in survey effort was not significantly different before or after the flood. The early spring period of the study suggested that mitigation was unlikely to have been the principle cause of this decline. Reasons for the declines may have been related either to loss of river edge habitat or reductions in the resource base (prey items, seed and fruits) which may have been swept away during the flood.

Mitigation and flood effects on cultural resources

Janet R. Balsom

ABSTRACT

The Bureau of Reclamation conducted an experimental habitat building flow in late March and early April of 1996. The experimental habitat building 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 in an especially important area of study since many of the terraces are of relatively recent origin and contain buried cultural remains. Although the flow was expected to provide system-wide mitigation to most cultural sties, field verification of these predicted results was needed.

The National Park Service (NPS), Glen Canyon National Recreation Area (GLCA) and Grand Canyon National Park (GRCA), initiated a program of both monitoring and mitigation of archaeological sites that could potentially be effected by the experimental flow. The program entailed enhanced monitoring at 36 archaeological sites and mitigation activities at another eight locations along the Colorado River corridor. A variety of monitoring and mitigation actions were taken, ranging from terrace mapping, repeat photography, drainage cross sectioning, aerial photography, and inundation modeling, along with traditional data recovery methods. The overall findings of the cultural resources studies done in conjunction with the 1996 experimental habitat building flow strongly suggest that the flow had either no effect, no adverse effect, or a beneficial effect on cultural resources. These findings support our original premise that habitat building flows can offer a system-wide mitigation for cultural resources caused by sediment depletion related to both the operation and existence of Glen Canyon Dam.

Channel margin deposit aggradation and archaeological site stabilization

Michael Yeatts

ABSTRACT

In the spring of 1996, the Bureau of Reclamation conducted a historic event: an experimental manmade flood was released from Glen Canyon Dam through Glen and Grand Canyons. This presented the opportunity to examine the effectiveness of high flows to elevate sediment into the mouths of ephemeral arroyos that drain the margin (terrace) deposits along the Colorado River. These types of arroyos have been identified as one of the contributing sources of erosion to cultural resources in the river corridor, and therefore, mechanisms which will limit their formation and expansion are identified in the GCDEIS as critical for maintaining the cultural resource sites *in situ*.

The objectives of this study were two-tiered. First, the ability of a planned high flow to elevate sediment onto the margin deposits, thereby filling in the mouths of the ephemeral arroyos needed to be evaluated. Second, assuming sediment deposits were realized, then determining the retention of these through time was to be monitored. If sediment was deposited in the arroyo mouths, but failed to remain for any length of time, their effectiveness at stabilizing the terrace deposits, and the cultural resources that these deposits contain, would be minimal.

Four study sites were selected (river miles -0.5, 65.7, 71.3, and 71.4) to quantify the results of the high flow. These sites are all characteristic of the locations in which cultural resources are being impacted by ephemeral arroyo erosion, and represent a range of potential depositional environments. Mapping at these sites was conducted prior to and following the high flow with the aim of accurately characterizing the topography to 0.25 meters. This was felt to be accurate enough to quantify the effects of the high flow, and still be achievable in a reasonable length of time. Repeat mapping will then be used to follow the changes in the new deposits through time.

The high flow produced sediment deposition at three of the four study sites, filling in the mouths of the arroyos. As was expected, the Lees Ferry site, being in a particularly sediment starved portion of the river, received no deposition. Even more significantly, however, it did not experience erosion which potentially could exacerbate arroyo downcutting. Sediment was deposited at all three of the downstream study sites. Since the post-high flow mapping, visits have been made to the downstream sites in September, 1996 and February, 1997. The first visit identified little change other than some reworking of the new deposits by wind. During the February visit, it was noted that all of the arroyos had flowed and that the sand plugging the arroyo at river mile 71.4 had been breached. The new deposits at the other two study sites were still intact within the arroyos. This April, the three downstream arroyos will be again mapped in order to quantify the changes that have occurred over the course of the year since the high flow. Assuming the new deposits are essentially intact, they will continue to be monitored in order to determine their effective life span.

Effects of Colorado River test flow experiment on Hualapai and Southern Paiute traditional ethnobotanical resources

Loretta Jackson, Cynthia Osife, and Arthur M. Phillips, III

ABSTRACT

For the past five years, the Hualapai and Southern Paiute Tribes have carried out research on ethnobotanical resources along the Colorado River as an important part of their overall monitoring and research programs through Glen Canyon Environmental Studies. This work has included taking tribal elders on river trips and conducting interviews on traditional uses of native plants in the Colorado River Corridor. Some 80 species of plants have been identified as having cultural significance to one or both tribes. These efforts are ongoing, and additional plants are constantly being added to the cultural database. Recently, the programs for both tribes have included taking youth on the trips along with elders, so the youth can learn about their cultural heritage from the elders while in the Grand Canyon.

In 1995 and 1996 monitoring programs were developed which included assessment of culturally significant plants along the river. Although the ethnobotanical resources identified by elders included species present on desert slopes, side canyons, and springs as well as along the Colorado River, riparian plants predominate, and the emphasis on plant monitoring has been along the river. The condition of plants at selected Traditional Cultural Properties (TCP) sites is assessed using standard botanical sampling techniques, and is used as an indication of the overall health of the sites.

The test flow experiment provided an opportunity to study the effects of flooding, deposition, and erosion on plant resources along the Colorado River. The Hualapai Tribe selected five TCP sites for monitoring within their portion of the Canyon: National Canyon, Granite Park, Diamond Creek, Bridge Canyon, and Spencer Canyon. At each site, three line intercept plant transects were established before the flood. They were re-read shortly after the flood to assess its immediate effects, and again six months later to assess recovery of plants after the summer growing season.

The Southern Paiute Consortium established plant study sites as part of its overall monitoring program in July, 1995. The data collected when transects and plots were initially installed at these sites was used as baseline pre-test flow data. Sites affected by the flood were evaluated in May, 1996, providing post-flood data. Study sites, considered TCPs by the Southern Paiute Tribes, included Jackass Canyon, Nankoweap Canyon, Kanab Creek, Mile 178 R, Whitmore Wash petroglyph site, Mile 198 R, and Spring Canyon. The sites were not re-visited in the fall of 1996.

Both tribes consider the ancient Goodding willow on the shore at Granite Park to be an important ethnobotanical and historic landmark. The willow was stabilized prior to the flood and its condition was subsequently monitored and evaluated.

The propensity of riparian systems to undergo periodic severe perturbation by flooding, and to recover with renewed vigor, was illustrated by the information gathered at study sites established for ethnobotanical evaluation. Plant transects sample a portion of the overall cultural concerns represented by each site as a comprehensive TCP site. Studies established for test flow evaluation will be continued as a part of long-term monitoring programs by the Hualapai and Southern Paiute Tribes.

Effects of Colorado River test flow experiment on Hualapai traditional ethnobotanical resources

Arthur M. Phillips, III, and Loretta Jackson

EXECUTIVE SUMMARY

Abstract

Hualapai Cultural Resources studied the effects of March, 1996 Glen Canyon Dam experimental flows on ethnobotanical resources at five sites on Hualapai traditional lands in the Grand Canyon. The study design included plant transects which were installed prior to the flood, re-read after the test flow, and read a third time approximately six months later. In addition, stabilization actions on historical and prehistorical resources were carried out at Granite Park. Research provided information on the effects of high releases on ethnobotanical cultural resources at sites which have Traditional Cultural Property (TCP) significance to the Hualapai people.

INTRODUCTION

The Hualapai Tribe has a special interest in the Grand Canyon and the Colorado River because the lower part of the Grand Canyon is included in Hualapai Traditional Lands. The current Hualapai Reservation includes 108 miles of the Grand Canyon on the south side, from river mile 165 to mile 273. Protecting and enhancing the natural, cultural, and economic interests of the Hualapai Tribe in this area is an issue to which the tribe attaches extremely high importance (Mapitis, 1982; Hualapai Tribe, 1993, 1994). Studies undertaken in the past few years have focused on the ethnobotanical resources of the canyon, and 46 plant species were recognized as having cultural significance to the Hualapai people during three ethnobotanical river trips conducted in the lower Grand Canyon in 1994-95 (Phillips, 1994, 1995; Hogan, 1995). Rich in its botanical resources, the inner gorge of the Grand Canyon supports more than 900 species of plants, and the greatest diversity is in the lower, or western, portion of the canyon (Phillips et al., 1987).

The Hualapai Cultural Resources Division evaluated the effects of the experimental flood on ethnobotanically significant resources and the overall environment at five sites in the Lower Grand Canyon deemed by the Hualapai people to have particular cultural significance. Results of this project are reported in Phillips and Jackson (1996). Sites selected are National Canyon delta (RM 166.5 L), Granite Park (RM 209 L), Diamond Creek (RM 225.5 L), Bridge Canyon delta (RM 235 L), and Spencer Canyon delta (RM 246 L). All of these sites were visited and interviews with elders were conducted during one or more of the Hualapai ethnobotanical river trips.

Methods

Short-term plant monitoring was initiated prior to the experimental flood with the installation of a series of three line intercept transects at each study site. This method is appropriate for rapid assessment of potentially large changes in Grand Canyon beach and riparian zone vegetation such as those that were anticipated from experimental flood releases.

Transects started at a point at or above the maximum water depth anticipated for the experimental flow, and were set using a 50-meter tape extended across the beach or riparian zone to the water's edge at the pre-spike time of installation. Sites were selected to include individuals of as many cultural plant species as possible at each study area; a total of 15 ethnobotanically significant species occur on the transects (see Appendix A). Transects were marked at the upper end at a relocatable point above the high water line. After the flood, they were relocated using a compass bearing, supplemental relocation points unlikely to be disturbed by high water, and photography.

The three transects at each site were placed so as to sample different sections of the beach or delta, representing different depositional and erosional regimes present at the site. The placement of transects depended upon finding endpoints which could be relocated. The tape was placed from the endpoint to the water's edge, perpendicular to the shore. At two sites, other alignments were selected in order to include certain culturally important species in the monitoring regime and take advantage of various aspects of site morphology.

The line-intercept method is a standard method for quickly and efficiently collecting quantitative vegetation data (Mueller-Dombois and Ellenberg, 1974; Bonham, 1989). Line intercept transects have also been used as a method for monitoring ethnobotanical resources in the Grand Canyon by the Southern Paiute Consortium (Stoffle et al., 1995). A meter tape is laid from the upper endpoint to the water's edge, with the 0 point away from the river. A vertical, two-dimensional plane extending from ground level to the top of the vegetation canopy is defined by the tape. Starting from the 0 end of the tape, each individual plant which hangs over the tape, or "breaks the plane," is measured by reading the interval along the tape through which the plant intercepts the plane. The beginning and endpoint of each such intercept is recorded for each individual biennial and perennial plant.

The individual intervals recorded for each species are added, giving a total intercept for each species along the transect. The ratio of the intercept for a particular species and the sum of intercepts for all species gives a value known as per cent cover for each species present on the transect.

The key to accurately comparing vegetation changes at the three readings is the placement of the tape in exactly the same position each time. Photography was used to facilitate relocation; photos taken at the initial and subsequent readings document the end points, additional fixed points, and the placement of the transect with respect to key individual plants and clumps of vegetation along the line. Matching photos taken at the post-flood readings provide visual documentation of changes in plants, sediment deposition, and erosion attributable to the flood and the subsequent six month recovery period.

Granite Park Willow

An ancient Goodding willow along the Colorado River shoreline at the boat docking area at Granite Park has stood at the site for perhaps 150 to 200 years. It appears as a mature plant in photos from the second Stanton expedition in 1890 and the USGS survey in 1923 (the latter photo was published in Turner and Karpiscak, 1980). Undoubtedly it also provided shade and

shelter for Native American parties, both Hualapai and Southern Paiute, living at and visiting Granite Park in the 19th century.

During the past 15 years the health of the tree has been gradually declining. The trunk is hollow and has split. The shore has been gradually eroding around the base of the tree, and its roots are being exposed more and more next to the river. Sediment erosion has steadily been steepening the gradient of the slope into the eddy, exposing the tree's roots and reducing the area available for roots on the river side. These relentless processes have reduced the vigor of the tree, and it has lost some of its main branches. Its growth during recent years has begun later in the season than is normal, and its growth has primarily consisted of short sucker branches sprouting from the main trunk. Insects have taken advantage of its reduced vitality and have infested the growing leaves and branches. It has held on remarkably, but its condition has steadily declining.

As a first step in an effort to save the tree, and reverse its declining condition, stabilization prior to the controlled flood was one of the tasks scheduled as part of cultural resource mitigation efforts at Granite Park in March, 1996. The purpose of these efforts was to prevent further erosion of sediment from around the base of the tree during the experimental flood, stemming the steady erosion of the beach which appears to have been a major cause for the present unhealthy condition of the old willow. The area around the base of the tree was built up using tons of rocks from the Granite Park Canyon debris fan, and dozens of buckets of sand were added to stabilize the rocks.

RESULTS

National Canyon

Sites upstream from Diamond Creek were visited in early March, 1996. Three transects were established at National Canyon beach, two from high points on the delta to the shore and one from a point on the talus slope above the lower beach to the edge of the beach. The post-flood reading was on May 16, and the site was re-visited on November 4 for the six-month reading.

Flood waters encroached some 35 m horizontally from the pre-flood shoreline, resulting in deposition of sand up to 60 cm deep in the upper portion of the flooded zone and scouring along the river. Vegetation cover was reduced up to 76% but recovered to 40% of the pre-flood level in November. Six months after the flood, the shoreline had been restored to its original position or somewhat beyond, depending on water releases. The exotic bermuda grass and salt cedar showed the largest increases during the recovery period.

Granite Park

Granite Park transects were installed on March 1-2, 1996. Two transects were placed upstream from the main camp area, and the third transect was set upstream from the mouth of Granite Park Canyon, in the lower part of Granite Park. The site was revisited on May 21, and the follow-up reading was on November 4.

The transects showed contrasting effects from the flood. The upstream transect was the least affected of all, with only minor deposition in the upper portion of the flood zone and minor loss of plants. The middle site documented the largest deposition event at Granite Park, with sand 1.5 m thick deposited 7.4 m into the river. Much of this dune had eroded by November; arrowweed and scouring rush buried by the sediment had grown through more than 1 m of the remaining sediment to re-establish their presence. The lower half of the third transect was lost to erosion during the flood. Vegetation increased between the post-flood and fall readings, with camelthorn and Bermuda grass showing the greatest increases.

Granite Park Willow

The tree survived the flood, and when observed in May it appeared to be healthier than it has been in many years. It was fully leafed out and branches had grown vigorously during the spring. There was a minimal amount of sand deposition around the tree during the flood, and much of the sand placed on the upstream side in March had been removed by the flood. Perhaps the rocks prevented serious erosion of the pre-existing sand. There was a thin deposit of sand on the downstream side of the tree, and the rocks were not removed by the flood waters.

The tree was still in full leaf and looking vigorous in November, but there appeared to have been some erosion of rocks placed along the shoreline prior to the flood. Roots of the tree in the water appeared to be more exposed than they were in May. This may be a result of the high water over the summer rather than the flood, and will require ongoing monitoring to assess the effects on the tree.

Diamond Creek

Transects were established at Diamond Creek and at downstream sites March 22-23, 1996, during the 8000 cfs flow immediately prior to the flood. Two of the transects are upstream from the main beach area, and the third transect is about 10 m downstream from the mouth of Diamond Creek. The Diamond Creek transects were re-read during the 8000 cfs flow following the flood, on April 7-8. The fall reading was on October 6-7.

The effects of the flood at Diamond Creek contrasted in different parts of the beach, depositing a new sand beach in the upstream part of the delta and severely eroding the shoreline in the lower part. The upstream transects were extended more than 10 m by the deposition of a new sand deposit within the river channel, most of which was eroded during the summer. The lower half of the third transect was lost to erosion during the experimental flood. Beach morphology effects were more pronounced than vegetation changes at all three of the Diamond Creek sites.

By October the outer portions of the sand bar deposited by the flood had been entirely removed at the upstream transect and partially eroded at the second site. A major flash flood in Diamond Creek on September 7-8 caused a large debris deposit downstream from its mouth, across the lower end of the downstream transect, filling in the area eroded by the experimental flood and reversing its erosional effects in a local area that happened to include the transect.

Bridge Canyon

This site at the mouth of Bridge Canyon Creek, a permanent stream with well developed riparian vegetation along its banks, has been important in ethnobotanical studies with Hualapai elders (Jackson, 1994; Phillips, 1994, 1995; Hogan, 1995). Transects were placed near the mouth of Bridge Canyon, in the lower camp area, and at the downstream end of the beach. Installation of the Bridge Canyon transects was on March 23, 1996; post-flood reading was April 7-8, and fall reading was October 6-7.

Because of the constriction of the river channel at Bridge Canyon delta water depths during the flood and amount of sediment deposited were the greatest of all the sites. The upstream portion of the delta above Bridge Canyon Creek, although inundated, appeared to have been little affected by either deposition or scouring. Transect 1 was entirely inundated, as was the entire forward part of the delta back to the base of the upper terrace. On the lower beach the sand was up to 12 m deep, rising steeply from the shore to a narrow crest, then falling off toward the talus at the back of the beach. The deep dune deposit continued downstream to cover the lower end of the beach, previously a rocky talus. Two unstable sand shelves with eroding vertical banks were present in the days immediately after the flood.

At the time of the fall reading unstable deposits along the shore had been mostly removed by high water releases during the summer, restoring the pre-flood shoreline. Large dunes, still mostly bare of vegetation and somewhat modified by wind, remained on the lower beach. Vegetation recovery was confined mostly to the side stream riparian community along Bridge Canyon Creek and the emergence of arrowweed from under deep sediment deposits. Camelthorn appeared for the first time along a Bridge Canyon transect at the fall reading.

Spencer Canyon

Spencer Canyon is one of the most important TCP sites in the Grand Canyon to the Hualapai people. It was a focal point for ethnobotanical studies carried out with Hualapai elders in 1994 and 1995 (Phillips, 1994, 1995; Hogan, 1995; Jackson, 1994).

Spencer Canyon was subjected to severe flooding in early 1993 and again in 1995. The 1993 flood removed most of the riparian vegetation along the canyon floor, and the 1995 flood removed plants that had begun the recovery process after the flood two years before. The second flood deposited a debris fan into the Colorado River channel; this deposit had been truncated but not removed at the time of the experimental flood. The high releases of 1996 washed over the lower portion of the debris fan but had little erosive effect on the steep outer edge of the fan.

Transects were established at Spencer Canyon beach next to the cliff at its upstream end, through a riparian strip at the lower end of the sand bar, and along the wall at the downstream end of the Spencer Canyon debris fan. The third transect was marked by points along the wall, and did not extend to the shore of the Colorado River.

The Spencer Canyon transects all showed less overall sediment deposition than any other site. Scouring caused substantial loss of mostly juvenile plants on Spencer Creek delta. The 1993 and 1995 flash floods had a much greater impact on vegetation at the mouth of the creek than the experimental flood, which reversed re-vegetation only in the outer parts of the delta. By October the temporary reversal in recovery from the flash floods had been erased as riparian and wet marsh species obscured any indication of the extent of experimental flood waters. Vegetation growth during the summer was as much as 2 m.

DISCUSSION

The fifteen line intercept transects installed to monitor the effects of the experimental flood on Hualapai ethnobotanical resources at five TCP sites showed a variety of changes due to the high water. Effects included severe erosion, removal of plants by scouring and substrate removal, deep sand deposition, and burying. In some cases there was virtually no effect. All of the sites showed both erosional and depositional effects, often at different places on the same transect.

Riparian communities are well adapted to periodic disturbance by flooding. Renewal of eroded sediments along shorelines, scouring out of stagnant return channels, scarification and water-borne dissemination of seeds, and removal of excess dead brush are all potential positive effects of flooding on riparian communities. Most riparian species are well adapted to periodic catastrophic habitat disturbance. Non-riparian plant species less well adapted to perturbation may not recover from the effects of habitat destruction or deposition of new sediment following a flood event.

Many years of stability in a riparian habitat, without perturbation, may lead to senescence of a community made unhealthy by lack of periodic renewal. Without disturbance, soil nutrients are used up, new seedlings cannot germinate through thick duff, and dead wood chokes the dense, shaded habitat. Prior to the closing of the gates of Glen Canyon Dam silt-laden spring floods occurred every year or two, probably causing many of the same changes in the riparian zone, with greater amplitude, observed as a result of the 1996 experimental flood.

Six months after the experimental flood, when the transects were re-read in October and November, 1996, 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 with much shoreline sediment lost to the river by high summer water releases from Glen Canyon Dam. Upper beach deposits remained somewhat unstable and were kept that way by wind action. There was a general trend toward habitat stabilization compared to the visits immediately after the flood.

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 at the end of six months. Increasers included some shrubs such as a seepwillow on transect 3 at Bridge Canyon which appeared to have been killed but at the last reading recovered to show few adverse effects

from the flood, and numerous examples of arrowweed and scouring rush which were buried in sand by the flood and after a few weeks grew through more than 1 m of sand to become re-established on the newly deposited sediment.

3. Two exotic species were the most consistent increasers in the first six months after the flood. Bermuda grass, an exotic species whose main growing season is the warm months, was introduced from Africa as a drought-tolerant and alkali-resistant species (Cronquist et al. 1977), and has been increasing on Grand Canyon beaches for some time. Although it is valuable as ground cover stabilizing sediments, its aggressive colonization may adversely affect less competitive natives. Also increasing after the flood and perhaps invading new sites was camel-thorn, an exotic species from the Near East and eastern Mediterranean region (Barneby 1989). This spiny perennial herb grows clonally in large patches and is difficult to eradicate due to its deep, strong rhizomatous root system. Its range along the Colorado River increased following the flood of 1983, when its seeds were carried and widely deposited by the river. Increases in these two exotics, particularly the latter, may be considered a negative effect of the experimental flood.

4. The historic Goodding willow at Granite Park appeared healthier than it had been for several years during the 1996 growing season. Stabilization efforts involving additions of tons of rock and sand around its base in March, 1996 slowed erosion, and the tree was not adversely affected by the experimental flood. Possible loss of stabilization materials and erosion of the underwater bank at the shoreline during the summer of 1996 was cause for concern.

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Appendix A

Ethnobotanically significant plant species occurring on transects established at five TCP monitoring sites on Hualapai lands in the lower Grand Canyon. Sites: NC=National Canyon, GP=Granite Park, DC=Diamond Creek, BC=Bridge Canyon, SC=Spencer Canyon.

Species	Common Name	Transects
Acacia greggii	Catclaw acacia	NC3, GP1, BC1
Acourtia wrightii	Arizona cotton	NC3
Alhagi camelorum	Camelthorn	GP2,3
Artemisia ludoviciana	Water sage	NC1, 2, BC3
Baccharis salicifolia	Seepwillow	GP3, DC1,3, BC1, 2, 3,
	SC2, 3	
Baccharis sarothroides	Desert broom	NC1, 2, 3, GP1, 3
Gutierrezia microcephala	Snakeweed	NC3
Lycium fremontii	Fremont wolfberry	NC3
Nicotiana trigonophylla	Indian tobacco	BC1
Prosopis glandulosa var. *torreyan*	Torrey mesquite	GP1, 2, 3
Salix exigua	Coyote willow	SC3
Tamarix chinensis	Saltcedar, tamarisk	NC1, GP1, 2, 3, DC1, 2, 3,
		BC1, 2, SC1, 2, 3,
Tessaria sericea	Arrowweed	GP1, 2, 3, DC1, 2, BC1, 2
Typha latifolia	Broad-leaved cattail	SC3
Ziziphus obtusifolia	Gray thorn	NC3

Campsite area changes

Lisa Kearsley

ABSTRACT

Large riverside sand deposits located above daily river fluctuations are used as campsites in Grand Canyon National Park. Since completion of Glen Canyon Dam in 1965, these deposits have degraded while campsite use has increased. Concern on Glen Canyon Dam's effects on campsites and other resources in the Grand Canyon precipitated an effort to reintroduce flooding, an integral component of the pre-dam river. In March 1996, an experimental "flood" consisting of a week-long discharge well above normal dam operations was released from the dam as part of a research experiment primarily designed to restore high elevation sand deposits in the Grand Canyon. Preliminary studies had indicated that this flood would help move sediment to higher elevations thus expanding campsite availability. The present study evaluates the effects of the experimental flood on campsite number, size, and longevity.

Campsites were evaluated in three ways. First, we quickly assessed flood-induced changes to 92% (200/218) of all established campsites. Second, we documented and when feasible measured new flood-created sites two weeks and six months after the flood. Third, we mapped campsite area for 53 established campsites two weeks before, two weeks after, and six months after the flood. The rapid assessment data show that half (50%) of the campsites increased substantially in size, 39% remained the same, and 11% became smaller. The test flow created 82 and destroyed 3 campsites. More than twice as many campsites per mile were created above the Little Colorado River (LCR), a major tributary that flows into the mainstem, than below it and in wide "non-critical reaches" versus narrow "critical reaches." Six months after the flood, 45% (37/82) of the new deposits were no longer useable as campsites. New campsite loss was primarily attributed to erosion of the newly deposited sediment but also to inaccessibility of otherwise sufficiently large sediment deposits due to their steep slopes along the river. The remaining new sites were on average half their 2-week post-flood size. The 53 established sites that were mapped increased in area on average by 57% two weeks after the flood. After six months most had decreased in size so that all measured sites were on average 22% larger than they were prior to the flood.

The test flow irrefutably increased the number, size, and, consequently, capacity of campsites in the Grand Canyon. It also reversed the trend of slow degradation that occurred during non-flood years. However, degradation of these new deposits occurred fairly rapidly. Because of this rapid erosion, the benefits to campsites caused by these types of floods will likely subsist for only a portion of the 5-year planned flooding for future dam management. Nevertheless, temporary increases in sand bar size such as those found in this study benefit the recreational use of campsites considerably and are conducive to a more natural river system.

Grand Canyon River Guides Adopt-a-Beach

Kate Thompson, Kelly Burke, and Andre Potochnik

EXECUTIVE SUMMARY

Abstract

The announcement of the 45,000 cfs test flood release through Grand Canyon sparked the interest of river guides in hands-on documentation of the changes in Colorado River sand bars ("beaches"). During a program of repeat photography called Adopt-a-Beach, commercial river guides took photos of 44 selected beaches and answered research questions about them, prior to and immediately following the test flood and throughout the commercial boating season (April to October, 1996).

The results of the study show 82% (36 of 44 sites) of the beaches photographed gained sand visibly, 11% (five sites) stayed about the same, and 7% (three sites) lost sand, because of the test flood. After observing the initial effects of the 45,000 cfs release, the guides documented four processes that eroded the beaches. The most significant of these were the interim fluctuating flows, followed by visitation, wind, and finally side canyon flash floods. From before the test flood until the end of the 1996 season, 80% of the beaches studied showed an overall net gain in sand, 11% showed a net loss, and 9% remained or returned to the same.

These results are supported by the conclusions of the sand bar survey project of Kaplinski and others (in press). They showed an average volume increase in sand of 176% for 93% of sand bars surveyed, due to the test flood. The results of Kearsley and Quartaroli (1997) differ, but their work focused on assessing change in campable area, rather than volume of sand. The guides comments refute the social conclusion in the Kearsley and Quartaroli report, that steep beach fronts left by the test flood made camps inaccessible. Guides generally considered the replenished condition of the beach well worth the scramble up the beach face and more consistent with natural conditions along undammed rivers.

The series of photographs of campsites showed that beaches with steep fronts slowly eroded to a gentle slope over the summer, as people tracked the sand downslope while loading and unloading boats. This suggests that human visitation is assisting in stabilizing the beach fronts. However, any reduced rate in erosion due to a gentler beach slope must be compared to the loss of sand into the eddy as pushed downslope by people.

The Adopt-a-Beach program can continue to address questions about beaches such as: (1) What will be the effects of high-flow releases in years of high lake levels? (2) How will the new maximum flows of 25,000 cfs affect beach shape and size? (3) Will the beach fronts remain at gentle slopes or begin to retreat as cutbanks reform? and (4) How will the new beaches fare in the long run?

INTRODUCTION

The operation of Glen Canyon Dam directly influences the Colorado River's ability to deposit, shape, and maintain sand bars in Grand Canyon. River guides have watched these sand bars decrease in size, height, and number as releases from the dam have diverged dramatically from pre-dam flows. The guides' interest in "beaches" stem not only from intimate daily use, but from recognizing these sand deposits as indicators for overall health of the river ecosystem.

Guides depend on sand deposits for camping and lunch stops. Even with user limits, the number of river trips has made that resource vital, especially in critical areas where beaches are scarce and in high demand (Kearsley and Warren, 1993). The beaches also form the substrate for communities of plants, invertebrates, and vertebrates, including obligate species such as riparian birds (Carothers and Brown, 1991). Grand Canyon beaches nurture unique biologic diversity, preserve ancient cultural features, and foster our enjoyment of these resources.

Prompted by guides, their passengers, and many others, the Bureau of Reclamation began the Glen Canyon Environmental Studies (GCES) in 1982. The studies show that sand bars can be replenished at higher elevations above the river by releasing flows larger than the standard daily discharges (Hazel and others, 1993; Kaplinski and others, 1994; Schmidt and Graf, 1990; Hereford and others, 1993). Because sand bars are accumulations of sand settling out of water, the water level determines the elevation of the deposit. In the Glen Canyon Dam EIS that resulted from the studies, scientists and managers agreed to release an experimental "beach/habitat-building flow" of 45,000 cfs for seven days, March 26 - April 1, 1996 (the "test flood"). This discharge level was designed to remobilize sand stored in the eddies and the main channel and deposit some of it as higher elevation sand bars.

The size and shape of many sand bars reflects the dynamics in recirculation zones (eddies) formed by debris fans constricting the river channel (Schmidt and Graf, 1990). During a flood release, sand may be eroded from an individual bar if the debris fan is overtopped and the sand bar is subjected to erosive downstream current. Otherwise, sand may be deposited in the enlarged eddy created just below the fan (Webb and others, 1989; Schmidt, 1990).

In 1983, a flood release of 97,000 cfs built many beaches (Brian and Thomas, 1984). However, most eroded back to their pre-1983 size during the erosive, high flows of 1984-86, and the high fluctuating flows that followed (Hereford and others, 1993; Kearsley and Warren, 1993). Hence, researchers are concerned with the longevity of sand bars formed by the test flood.

Many river guides observed changes during the mid-eighties and offered these observations to researchers as anecdotal evidence on GCES research trips. When the test flood release was scheduled for March-April 1996, river guides working with Grand Canyon River Guides, Inc. (a volunteer, non-profit organization) started a program of repeat photography called Adopt-a-Beach to document changes they would see. The guides would be on site much more often than any of the scheduled research science trips. Also, they could see first-hand, processes such as wind deflation, trampling, flash flooding, and calving of beach faces, which erode and reshape beaches. Thus, the goal of this project is to provide purely qualitative,

anecdotal evidence about the effects of the test flood and the subsequent impacts on sandbars during the 1996 commercial boating season. Also, the study adds to the collection of photographs for campsite documentation by Kearsley and Quartaroli (1997) and complements sand bar and eddy studies by Parnell and others (in prep).

Methods

Data Collection

Grand Canyon River Guides selected 44 representative beaches (sand bars commonly used as campsites) in three "critical" reaches of the Colorado River. Critical reaches are narrow sections of river corridor with few, small, or high-demand beaches. The three reaches defined in our study are Marble Canyon (RM 8-42), Upper Granite Gorge (RM 75-116), and Muav Gorge (RM 131-167) (Figure 1). These are the same critical reaches defined for the campsite study of Kearsley and Quartaroli (1997). Twenty-two beaches were observed by both studies, which employed slightly different methods. Kearsley and Quartaroli photographed and measured campable space of these beaches on three research trips: in March before the test flood, in April just after the test flood, and in September, 1996.

In our study, river guides participating in the program volunteered to take photos using disposable 35mm cameras and record specific observations of individual beaches every time they passed them. For consistency between the two studies, Kearsley and Quartaroli provided photo stations and pre-flood photos for 22 beaches they had previously photographed. Where possible, guides used those stations. For the remaining 22 beaches, we set up photo stations on trips in March 1996, prior to the test flood. Logistical difficulties resulted in three sites with no pre-flood photo. In these cases, several guides were interviewed in order to glean their knowledge of beach changes from pre- to post-flood conditions.

For each photo rematch, guides first took a photo of a sheet displaying date, time, and estimated flow level. On the reverse of the data sheet, they answered a series of descriptive questions about observed changes and processes (see Appendix A).

Data Analysis

At the end of October 1996, the photos and data sheets were assembled in chronological order per site. We compared photos for each site, looking for changes in beach size and shape above the approximate 20,000 cfs level. Specifically, we identified rocks and vegetation as reference points in each photo to recognize apparent sand loss or gain. In this way we could evaluate relative amounts of cutbank retreat, slope changes, and surface scouring.

We compared the guide comments and compiled them into a spreadsheet along with our assessed changes that we observed from the photos. We used Kearsley and Quartaroli (1997) area measurements of campsites for comparison to what guides reported. No obvious discrepancies were found between the two studies for the 22 overlapping sites.

We grouped the data into three categories of change: beaches that increased in size, beaches that decreased in size, and beaches that remained the same size. We then analyzed and calculated the number of beaches that showed size change for three time periods: (1) from pre- to post-flood (March to April); (2) during the commercial boating season (April to October); and (3) from pre-flood to the end of the commercial boating season (March to October). These time divisions allow us to identify the processes that affect beach size over time, and finally to assess beach longevity at the end of the commercial boating season.

Results

We analyzed a total of 284 photographs, out of over 350 photos received from guides and scientists for the 1996 commercial boating season. The photo chronologies ranged from three to 14 photos per beach, spanning from shortly before the test flood to the end of the commercial boating season in mid October. Photographs with accompanying data and comments averaged one per month per beach. This collection provides the basis for the following results which are summarized for three separate periods: (1) results from the test flood, (2) results from subsequent processes during the summer months, and (3) net results at the end of the season. Because the mission of Adopt-a-Beach is to evaluate beach "health" over time, we based much of our analysis on apparent beach volume change, with a lesser emphasis on campable area.

Test-Flood Results (March to April)

Photo observations and adopters comments show that of 44 sites, 82% (36 beaches) visibly gained a large volume of sand immediately following the flood release. Only 11% (5 beaches) stayed about the same, and 7% (3 beaches) lost sand. All adopted sites aggraded vertically, including the three that lost some beach frontage: 110 Mile, Ross Wheeler, and Upper National.

In comparison, the study of Parnell and others (in prep.), which contrasts pre-flood topographic surveys with post-flood surveys, shows that 93% of their 33 studied sand bars increased in volume above the 15,000 cfs level, which is the April-to-October average daily maximum flow. Volumes increased an average of 176% for all their sand bars, on which new sand was deposited as 1-2 meters of vertical gain. Sixty-two percent of the sand bars expanded in area by an average of only 7% for each bar. Although none of their study sites overlap with ours, this result substantiates our observations that beaches generally increased in height much more than in area.

Studies by Kearsley and Quartaroli (1997), which focused on campable area above the approximately 20,000 cfs level, infer that campsites generally increased in area following the test flood. Using their data from "established campsites" within the three critical reaches, we calculated that 62% of all their study beaches significantly increased in campable area due to the test flood. However, only 50% of the 22 beaches that coincide with our study increased; 27% decreased and 23% stayed the same. Although their study is directed at measuring campable area as a valuable resource, their data do not necessarily reflect gain in sand volume. "Campable area" excludes vegetation or slopes too steep to camp on. This may explain why their results show a smaller percentage of beaches that increased compared to our study or the study of Parnell and others (in prep.).

Most guides reported that camping was generally easier on the beaches that gained sand because the quality of beaches improved, in spite of the difficult hike up many steep slopes. Only 11% of guides complained of harder camping on these beaches because of steepness or height of the cutbank. For the three beaches that were eroded by the test flood, guides reported that camping was harder because of reduced area.

Summer Results (April to October)

Beach change through the summer months was often witnessed first-hand and noted by most participating guides, as well as documented by photographs. By the end of the season (mid-October), 30% of the beaches remained intact with minimal changes, whereas 70% showed some kind of decrease (Figure 2).

Results of Parnell and others (in prep.) indicate a more pronounced, system-wide effect through the summer. From mid-April to September, they show that the volume of sand decreased by an average of 44% per beach above the 15,000 cfs level at 91% of their sites. Many of the guides reported that camping was harder on beaches that lost sand because less space was available than just after the test flood, and more rocks were being exposed.

River guides were concerned about the sustainability of the beaches through the summer. Therefore, most of them systematically documented processes which helped shape or change beaches. In many cases, sites were affected by more than one process. The main forces that reportedly impacted beach size were identified as summer fluctuating flows, wind, people, flash floods or gullying from rainfall, and unknown processes. For three sites, North Canyon, Hance, and Kanab Creek, some of the sand loss was unexplained and could not be determined from photo observations. We summarized and ranked these processes by the percentage of beaches within each of the critical reaches that were altered by each process (Figure 3).

Figure 3 shows that fluctuating flows reportedly had the most erosive effect on beach size. Daily fluctuating flows of 15,000 to 20,000 cfs characterized the flow regime throughout most of the summer months, with the exception of lower weekend flows. The percentage of beaches noticeably cut back by the summer flows ranged from 55% to 80%, depending on the reach. From May to July, guides commented that the erosive action of fluctuating flows incised steep cutbanks into these beaches. These cutbanks generally retreated up beaches and became taller through much of the summer. By September, however, most cutbanks had become subdued, and steep beach fronts had evolved to more gentle slopes.

The next most commonly reported impact to beach shape was trampling by people. When separated per reach, reports of this process contributed to an average of 18% to 41% of beaches decreasing in size through the summer (Figure 3). Sand was progressively pushed down steep slopes, accounting for minor beach front retreat. This helped lessen overall steepness of beach fronts, which many guides found to be beneficial as it afforded easier access to camping.

Guides reported that wind was active in reshaping most beaches by mounding sand on the surface and deflating cutbanks. This process contributed to a size decrease on 19 to 35% of

beaches, when reports were averaged per reach (Figure 3). The only repeatedly recorded, detrimental effect was surface scour, which visibly exposed rocks on the surface.

Flash floods and gullying from rainfall, which are tangible events easily recognized in camps, accounted for sand loss on five beaches (Figure 3). Three of these lie within a five-mile section of Muav Gorge. Flash floods scoured large quantities of sand from Nautiloid and Olo Camps, whereas Schist, Kanab, and Matkatamiba Camps showed minor gullying.

We used either September or October photographs, and corresponding data collected by guides to evaluate end-of-summer beach-front stability. An estimated 84% of beach fronts achieved quasi-stability, indicated by a gentle slope and low-water bench extending into the eddy. A few guides suggested that calving of beach faces in early summer may have initiated beach stability. By late summer, many guides had reported on the processes that formed gentle beach-front slopes, and suggested that people were pushing sand downhill simply through visitation and camping. Several photo series where people are actively trampling beach fronts when loading and unloading boats can be seen in the photo series in the Boatman's Quarterly Review (Thompson and others, 1997, p. 19-21). Each of the beach-front slopes in the photos appears to become successively more gentle until the fall season, when they finally appear to stabilize as maximum flows were reduced to below 20,000 cfs.

End-of-Season Net Results (March to October)

The results show a net gain in sand, from before the test flood in March/April to the end of the 1996 commercial boating season in October, for over 80% of the study beaches. Eleven percent of beaches suffered a net loss, mainly from the combination of the test flood and summer flows. Nine percent of beaches remained or returned to the same beach as before the test flood.

Our observations generally support the results of Parnell and others (in prep.) regarding volume change. Despite the system-wide decreases recorded in September as compared to April volumes, sand bars in their study still showed a net gain from pre-flood time (February) to September. During this time, 93% of sand bars increased, with an average volume gain of 97%.

However, our compiled observations are notably different from the results of Kearsley and Quartaroli (1997). Based upon their measurements in March and September, only 45% of the 22 camps that coincide with our study showed a net increase in area. These sites averaged a net gain of 22% in area (Kearsley and Quartaroli, 1997). Comparatively, 82% of the same 22 camps were reported by guides to have increased in size by the end of the commercial boating season.

We divided out end-of-season change for each of the three reaches (Figure 4) in order to see any concentrated net results. Marble Canyon was originally expected to be impacted the most by regulated flows following the test flood, yet 100% of the beaches show a net end-of-season increase. Conversely, most of the net decreases occurred in the Upper Gorge reach where four beaches (25%) were visibly cut back, two of which were eroded by the test flood.

SUMMARY AND CONCLUSIONS

In short, river guides feel that the test flood was tremendously successful at depositing large amounts of sand on highly used beaches, such as the beaches adopted for this study. The test flood had deposited enough sand that erosive processes during the summer months did not strip away most of the sand that beaches had gained. Beach deposits system wide seem to be in moderately good condition after one commercial boating season, despite the erosion of sand bars during the summer. This conclusion agrees with Parnell and others (in prep.), who conclude that the new beaches are mostly "still there" (Matt Kaplinski personal communication).

Campable area markedly decreased over the summer, as Kearsley and Quartaroli's (1997) work shows; yet, river guides generally feel that campsites still are in better condition and contribute to a more pristine river experience than before the flood. However, it is imperative to evaluate the longevity of these beaches through continued photo monitoring and observations of beach change for several years.

Almost all guides commented about the steep slopes and cutbanks initially following the flood, yet they generally concluded that camping was easier because of the new sand and larger camp size. As the season progressed many steep slopes graded to gentler and apparently more stable ones, affording easier access for camping. Therefore, we feel beach steepness is not a negative result of the test flood. Rather, it is a typical beach shape that forms when flood waters subside, and in fact is a common geomorphic characteristic in many natural, undammed, dryland rivers (Graf, 1988).

A hypothesis that needs to be further explored is that beach fronts become more stable if their slopes are reduced to lower angles. Trampling by people may cause some erosion of the beach front, but more importantly human visitation may be contributing to beach-front stability by lessening beach slope. If this is true, then quasi-stability of beach fronts may be achieved at a faster rate, with visitation during the commercial boating season. However, we would need to estimate the amount of sand that accumulates in eddies as a result of sand migrating downslope. Then we could weigh the benefits of slope stability enhanced by people against erosion caused by them. Unfortunately, any new regime of fluctuating flows can still undercut or remove sand. Alternatively, stability may be enhanced by lower discharge releases in the fall.

Most beaches ended up with a net gain in sand by the close of the commercial boating season, despite erosion during the summer season. Beaches that decreased were mostly concentrated in the Upper Gorge. It may be premature to speculate about why beaches decreased mostly in this reach. However, two camps, Hance and Crystal which are both upper pool deposits, decreased as a result of the summer fluctuating flows. This suggests that deposits such as these may be more susceptible to erosive qualities of higher flows, and should be closely monitored in the future especially in light of the newly elevated maximum flow constraint of 25,000 cfs set in the Final GCDEIS Record of Decision. A flow increase such as this could cause beaches to lose their apparent stability as they re-equilibrate to the higher flow through further erosion. In addition, any emergency flow releases above 20,000 cfs and below the 45,000 cfs test flood may entirely remove many of the newly created beaches.

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The effects of the 1996 beach/habitat-building flow on observed and reported boating accidents on the Colorado River in Grand Canyon National Park

Linda M. Jalbert

EXECUTIVE SUMMARY

Abstract

The purpose of this study was to ascertain the risks and potential impacts to boaters running the Colorado River at flows around 45,000 cfs, compared to "normal" daily flows. The data collected during the beach/habitat-building flows of March 27 through April 2, 1996, were added to a database of information collected during various flows during GCES I and GCES II. The data from the 1996 study indicated a relationship between certain accident variables and trip management actions. However, the information from the spring 1996 experimental flows indicate no greater risk of an accident than at other studied flow levels.

The information gathered from the boater interviews suggests that while the 45,000 cfs flow presents certain risks and limits camps in some areas of the canyon, the flood flows enhanced the overall quality of the visitor experience. Like the beach/habitat-building flows of Spring, 1996, other "special" management flows are common to all alternatives in the Glen Canyon Dam Environmental Impact Statement (GCDEIS). Because the specified flow regimes are scheduled yearly with the Annual Operating Plan for the Colorado River, the National Park Service should consider specific actions for managing recreational use for those periods where management directed flow regimes occur.

INTRODUCTION

Flows from Glen Canyon Dam have a great affect on users of the Colorado River. These effects can be both positive and negative, and have the potential to define the quality of the river running experience. The Grand Canyon Protection Act, along with numerous pieces of legislation relating directly to Grand Canyon National Park, identifies critical values for which Glen Canyon National Recreation Area and Grand Canyon National Park were established. Included within these values is the visitor's recreational experience. Specific attributes include safety while running rapids, time for side hikes, and availability of campsites.

Recreation research conducted during Phase I and II of the Glen Canyon Environmental Studies (GCES I and II), indicated that the value of the white-water boating experience is sensitive to the volume of water released by Glen Canyon Dam. The attribute and contingent value surveys conducted for GCES I further indicated that both higher (>45,000 cfs) and lower (<10,000 cfs) flows reduce the enjoyment of the Grand Canyon boating experience (Bishop, et. al., 1986).

Other studies addressed public concerns about the effect of dam operations on boating safety (Brown and Hahn, 1987; Jalbert, 1992). Investigators have collected and analyzed several kinds of data addressing the relative hazard associated with running rapids at different flow levels and

during fluctuating flows. Individual studies included surveys of commercial white-water guides and noncommercial trip leaders (Bishop, et. al, 1986), analysis of National Park Service records of boating accidents (Underhill, et. al, 1986; Jalbert, 1992), and observations of boats running rapids at different river flow levels (Brown and Hahn, 1987; Jalbert, 1992). The various studies converged on the conclusion that river flow levels are related to boating accident rates in a statistically reliable manner.

The relationships between accidents and flows reported for both Phase I and II of the GCES were statistically reliable, supported by other types of data (expert judgement, historic records, direct observations), and showed a consistent pattern. At this point, we are confident that the relationships are real. Interpreting the practical significance of the results is not as straightforward. Questions that must be answered by managers and boaters concern visitor safety as it relates to the overall recreational experience and risk management.

While boaters have indicated that they find some flow levels "too risky," they also believe that challenge and danger are an integral part of the white-water experience (Brown and Hahn, 1987 and Bishop, et. al., 1986). At the same time, managers must consider policies and responsibilities for risk management. During the flood flows of 1983 (in excess of those in 1996), NPS managers closed the river to boaters during the highest flows (over 92,000 cfs). This management action suggested recognition that NPS managers do have a responsibility for risk management. The limits or the basis for such responsibility, however, have yet to be defined.

Since the experimental flood flow is a management action recommended through the GCDEIS, and is expected to continue on a five year cycle, the NPS needs to ascertain potential impacts on recreational users of the Colorado River. Direct observation and the systematic analysis of data provided a basis, along with input of professionals and experienced boaters, from which the necessary management actions can be determined.

Objectives and Hypotheses. The primary objectives of the study were to assess the effects of the controlled flood flows on boating safety, and how safety affects the recreational experience for boaters in Grand Canyon National Park. Specific to these overall objectives were to: (1) observe and record boating incidents (accidents or actions taken to avoid accidents, such as portaging or lining) at six rapids during the experimental flood flow period; (2) review NPS case incident files on boating related accidents to determine correlation between flood flows and accident rate; (3) combine the new data with the data from Phase I and II set and carry out an analysis of the relationship between flows and trip management, trip characteristics, and accidents; and, (4) conduct interviews with commercial and noncommercial trip leaders to obtain information regarding the effects of various flows on trip attributes.

The hypotheses tested were: (1) the experimental flood flows (45,000 cfs) have no affect on boating accident rates at major rapids; and (2) the experimental flood flows have no affect on river trip attributes.

RESULTS

Observed Boating Accidents

A combined total of 61 trips with 900 people were observed at all rapids. This accounted for all the commercial and noncommercial trips that were on the river during the experimental flow period. It was also noted that nearly all the individual trips were observed at at least three different rapids. A number of research trips were also in the canyon during this period, but many were stationed at different research locations and were not traveling. Of the total observations, nine were research trips.

The experimental flow patterns affected the entire river system, not just individual rapids. Although individual rapids respond differently to flows, most of the analyses address the effect of flows on accident rates for all rapids taken together.

Averaged Accident Rates. To provide a context for the analyses, the general rate of various accidents averaged across all observed rapids was determined. These rates might be considered the average risk one incurs for any serious rapid in the Grand Canyon, averaged across all boat types for the experimental flow.

When averaged across all rapids, 4% of the boats flipped. When looking at an averaged rate per rapid, less than 1% of the boat population flipped "per rapid." Four accident variables (lose control of oar, flip, person overboard/swim, and injury) and two risk management activities (walking and portaging boats around rapids) were observed. Incidents of hitting rocks and equipment damage were not observed.

Actual Rate of Incidence. During the 1996 experimental flow period, observers recorded a total of 17 different accident variables including flips, losing control of an oar, person overboard, and injuries requiring evacuation. The overall accident rate was .068, or roughly 7% of the boats on the river experienced some type of accident. Another 2.4% of the boats avoided the risk of accident by walking around the rapids. The actual total incidents was 23, and the overall rate of incidence was .093 or 9.3% of boats observed.

Observers recorded a total of ten flips: five oar rafts, four kayaks and one inflatable kayak or "ducky." Flips were observed at all rapids except House Rock and Crystal. Passengers were observed walking around Hance and portaging kayaks around Lava Falls Rapids. Injuries were observed at Hance and Crystal Rapids, and occurred on a small oar raft and motor rig respectively.

Overall, the rate of incidence was highest for small oar-powered rafts, although not significantly when compared to other non-motorized boats. The actual number of separate incidents was almost the same for large rafts (6), small rafts (7), and kayaks (6). The lowest rate of incidence was experienced by motorized rafts.

When looking at rate of incidence for commercial versus noncommercial trips, it could be noted that one of the five raft flips involved experienced commercial guides. It should also be noted that the highest percentage of use was noncommercial (excepting research) during the experimental flow period.

Comparison of data to previous studies. Analysis of data for determining the rate of incidents during the experimental flow period is reported for all trip types across all rapids. This provides a context for comparing the data to the results of the GCES I (Brown and Hahn, 1987) and GCES II (Jalbert, 1992) studies.

The rate of incidence was determined for each flow category. In the baseline study, a hierarchial Analysis of Variance was used to determine which variables are related to flow level. Table 1 shows the proportion of boats having an accident across all rapids observed for each flow category.

Table 1: Observed Boating Accidents: Proportion of boats having an accident in each flow category, compared across all studies (1987, 1992, 1996).

	Low (<9k)		Medium (9-15.9k)	High (16-31.5k)	Flood (>31.5k)	
	'87	'92	'87	'87	'87	'96**
Lost Control of Oar*	.06	.06	.09	.07	.06	.05/.01
Boat Struck Rock*	.13	.11	.09	.02	.02	.00/.00
Person in Water	.02	.00	.04	.05	.08	.01/.00
Boat Flipped*	.02	.00	.02	.03	.08	.02/.04
Equipment Damaged	.00	.01	.02	.02	.02	.00/.00
Injury*	.00	.00	.00	.00	.02	.01/.05
Boat Lined/Portaged*	.02	.00	.05	.03	.13	.02/.00
Passengers Walked*	.00	.13	.12	.08	.11	.00/.01

*Variable is significantly related to flow ($p<.05$). **The 96 rates are split to compare directly with the 1987 rates which include data for Crystal and Lava Falls rapids only. The second figure in the split is the overall rate for comparison across flow levels.

In the baseline study, investigators looked at accident rates for specific rapids known for difficulty in navigation and higher risk. At Crystal Rapids, where they had the most information for flood flows, it was found that all accident variables were significantly related to flows. Brown and Hahn also found a striking relationship between flow levels and either walking around Crystal Rapid, or portaging or lining a boat. These activities substantially increased from low to flood flows. During that flood flow study period, roughly 4% of the boating population elected to avoid the risk of accident by having passengers walk around the rapid. In comparison, during the 1996 flood flow period, no passengers were observed walking around Crystal Rapids or portaging or lining boats.

At Lava Falls Rapids, Brown and Hahn found that four accident variables were related to flow levels: losing control of oar, hitting rocks, amount of time in water, and walking around rapids. Results also showed that the rate for time in water and walking around rapids increased with flows. In comparison, during the 1996 flood flow period, no passengers walked around the rapid, two kayakers portaged, and the individual who flipped was in the water for more than 5 minutes, at least until the time he was out of sight (and rescued by a downstream research group).

When comparing the data for Crystal and Lava Falls Rapids for the 1987 and 1996 flood periods, the rate of incidence for the recent experiment was significantly less than the baseline, especially for persons in water, flips, and portaging boats or walking around the rapid.

Reported Accidents

A chi-square analysis of the recorded versus expected accident distributions for the April 1995 to April 1996 study period showed no significant relationship between accident occurrence and flow range ($X^2 = 3.44$, $p>.05$). Table 2 summarizes the variables used for analysis.

In the one year period ending April 2, 1996, 17 on-river accidents were reported. These accidents took place while traveling on the river, as compared to the other dozens of accidents that are incurred by river passengers in camp or while hiking (off river). During the last year, the mean discharge from Glen Canyon Dam was in the medium to high flow categories for a great portion of the time. Thirteen of the 17 accidents or 76% of the reported accidents occurred during that time.

The accident rate across all flows for the reported period was .45% (.0045 boats per day having an accident). The reported accident rate during the experimental flood flow period was .67% (.0067 boats per day having an accident).

Table 2: Reported Boating Accidents: Percent of total Grand Canyon boating accidents vs. percent of total boat-hours in each flow range category, and recorded vs. expected boating accidents by flow category for April 2, 1995 through April 2, 1996.

	Low (<9,000)	Medium (9-15,999)	High (16-31,500)	"Flood" (>31,500)
Percent of total Grand Canyon accidents	5.9	41.2	35.3	17.6
Percent of total boat-hours in each flow	11.6	33.8	41.4	13.2
Recorded Accidents	1	7	6	3
Expected Accidents	1.97	3.86	7.04	2.24

CONCLUSIONS

The combined results of observed and reported boating accidents for the 1996 experimental flood flows confirm the null hypothesis that there is no significant relationship between the 45,000 cfs flows and increased boating accidents. In other words, the data shows that there is no significantly greater risk at 45,000 cfs than other flows. This information substantiates the findings of the previous studies which concluded: (1) that a relationship does exist between certain types of incidents and certain flows, and (2) that personal injury is not necessarily related to the 45,000 cfs experimental flows.

The most recent data from the observed accident study indicated that certain types of accidents are related to flood flows, but were not statistically or practically significant. The data also showed that accident rates were lower for the 1996 experimental flows than for the previous study flood flows at Crystal and Lava Falls Rapids as reported by Brown and Hahn in 1987. The 1987 results were obtained during flows slightly above powerplant capacity (i.e., between 31,500 - 33,000 cfs). The findings of the current study, when compared to the 1987 study, suggests that there is a greater likelihood of accidents occurring at flows between 31,500 and 33,000 cfs (i.e., powerplant capacity) than at the 45,000 cfs flow. This finding is potentially significant given that the GCDEIS recommends "habitat maintenance" flows at or near powerplant capacity on a yearly basis.

When comparing the accident rates across flow levels, Brown and Hahn found that flows in the range of 10,000 to 17,000 cfs appear to be the safest. Earlier studies showed that as flows increase, actions to avoid rapids, such as walking or portaging boats increases. The current observations indicated a relatively low combined rate of risk avoidance. One might argue that in a period of 10 years (i.e., since 1986, when flows were commonly at or above flood levels), the general population of boaters has either become more skillful in negotiating rapids at flood flows, or, have become more willing to take risks in negotiating rapids. It should also be noted that a Trip Attribute Study Bishop, et. al (1987), found that commercial trip leaders are more likely to walk passengers around rapids than private trip leaders. During the recent study, the greater proportion of users on the river were private river trips, which may explain why the rate of walking or portaging was lower.

Recorded interviews and anecdotal information from boaters indicated an array of opinions regarding the affects of the flows on their experiences and specific trip attributes. Most boaters appeared excited about the opportunity to run the Colorado River through the Grand Canyon during the flood flows. A few boaters on the other hand, were anxious and felt "overwhelmed" by the power and speed of the river. Several trip leaders indicated difficulty in locating camps in the Marble Canyon section of the river. Several trips were managed in order to run the bigger rapids specifically during the experimental flood flows, by taking layover days waiting for the river to rise.

Management Implications. As stated in the GCDEIS, the National Park Service (NPS) recreation management objectives for the operation of Glen Canyon Dam are to provide for recreational experiences along the river corridor that do not diminish natural or cultural resource values and protect and preserve environmental and wilderness conditions that

contribute to quality recreation experiences. While the Colorado River through Grand Canyon is not designated wilderness, it is potential wilderness and is managed as such.

The NPS management policies recognize that "park visitors must accept wilderness largely on its own terms ..., and must accept certain risks ... that are inherent in the various elements and conditions that comprise a wilderness experience ..." Research has indicated that one of the attributes of an excellent or almost perfect river trip most often identified by river runners is a wilderness experience (Bishop, et.al., 1987, and Shelby et. al., 1992).

The presence of Glen Canyon Dam does not preclude wilderness designation, but dam operations can have an influence on the wilderness setting. The NPS will not eliminate or unreasonably control risks that are normally associated with wilderness, but it will strive to provide users with general information concerning possible risks, recommended precautions, minimum-impact use ethics, and applicable restrictions and regulations. To that end, every effort should be made to educate users to known conditions, and how to best manage their river trips based on these conditions.

Flows from Glen Canyon Dam are no longer controlled by natural occurrences; they are controlled by Reclamation and the laws governing release of water from the Upper Basin to the Lower Basin states. The planned flood flows are, therefore, a deliberate management action as opposed to a natural phenomenon. As such, the NPS does have an obligation to provide river users with general information concerning possible risks and recommendations for avoiding risks or precautionary measures for managing trips more safely under those conditions. These cautionary notes should be internal to NPS management of recreational users of the river and should not interfere with wilderness experiences of the users.

The greatest concern for recreational use during planned beach/habitat-building flow are the health and safety of visitors. Secondary to this is the visitor experience. The GCDEIS calls for specific flow regimes for beach building and habitat maintenance. These "special" flows are common to all alternatives and will likely become part of the preferred alternative and the Record of Decision for the EIS. Because the specified flow regimes are scheduled yearly within the Annual Operating Plan for the Colorado River, the NPS should evaluate options for managing recreational use for those periods where management directed flow regimes occur. While Grand Canyon National Park does not guarantee flow regimes, it is not unreasonable to presume that flows will be within the range of powerplant release. River permittees, therefore, had an expectation of a certain range of flows which did not occur because of a management action. Education of the possibilities of flows and allowance within the Grand Canyon permit system should be explored in the next revision of the River Management Plan.

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Glen Canyon Dam beach/habitat-building test flow--An *ex post* analysis of hydropower cost

David A. Harpman

EXECUTIVE SUMMARY

Prior to construction of Glen Canyon Dam, the Colorado River transported tremendous amounts of sediment through Glen and Grand Canyons. Since dam construction, downstream tributaries has provided the only source of sediment. Operation of the dam to produce peaking power results in hourly fluctuations in release and river stage. Historically these fluctuations were constrained only by the physical limitations of the power plant. The resulting fluctuations have been shown to significantly affect aquatic resources and sediment deposits on the channel margins. The elimination of large sediment laden floods has prevented the replenishment of high predam terrace deposits.

A 7-day controlled flood was conducted at Glen Canyon Dam in late March and early April of 1996 for research purposes. This short duration high release was designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. The goal was to test hypotheses about sediment movements and the response of aquatic and terrestrial habitats to controlled flood events.

There were two sources of economic and financial impact associated with the beach/habitat-building test flow--changes in the timing and amount of hydropower produced and the costs of the research associated with this experiment. The purpose of this report is to describe the economic and financial impacts of the test flow on the hydropower system. Research on the physical and biological aspects of this experiment is estimated to have cost an additional $1.5 million. These research costs are not considered in this document.

The annual amount of water released from Glen Canyon Dam during water year 1996 did not change as a result of the experimental flow. However, an additional 409,000 acre-feet of water were released during the months of March and April. Of this amount, approximately 217,000 acre-feet of water bypassed the power plant during the test and the opportunity to generate 109,000 megawatt hours (MWhr) of electricity was foregone. Since water was reallocated to accommodate the test flow, there were hydropower effects across the entire water year.

The economic impacts of the test flow are measured by the dollar value of real resources committed by the United states, including the additional use of fuels such as gas and coal. As shown in Table EX1, the economic cost of the test flow was approximately $2.520 million. This represents a 3.3 percent decline in the economic value of hydropower produced during the year.

The financial cost, or impact on Western Area Power Administration's net revenue, is dependent on interpretation and implementation of section 1807 of the Grand Canyon Protection n Act of 1992. If the

costs of the test flow are determined to be reimbursable, or repayable by project beneficiaries--primarily power users, the financial cost to Western and it's customers will be $2.524 million. This represents a 2.5 percent decline in net revenue. As shown in Table EX1, the potential effect of the test flow on Western's Salt Lake City area Integrated Projects (SLCA/IP) wholesale power rate is $0.02/MWhr which represents a 0.1 percent increase. An increase in Western's SLCA/IP wholesale power rate could potentially cause an increase in the retail rates of end use power consumers. This is particularly true for small system power users who are heavily dependent on Federal power. The potential increase in small system retail rates is estimated to be $0.01/MWhr which represents a 0.01 percent change.

If the costs of the test flow are determined to be nonreimbursable, there will be no financial cost to Western and no impact on either wholesale power rates or small system retail rates. In this event, the incidence of the cost of the test flow is shifted to all taxpayers in the United States.

Table EX1. Summary of economic and financial impacts of the experimental test flow on the hydropower system.

	Water Year 1996	Water Year 1996 adjusted to exclude spill reduction measures
Economic Impacts (million $)	2.520	1.300
[1]Financial Impact (million $)	2.524	1.179
[1]SLCA/IP rate impact ($/Mwhr)	0.02	0.01
[1]Small system retail Rate impact ($Mwhr)	0.01	0.01

[1] Financial costs, wholesale and retail rate impacts are dependent on interpretation and implementation of section 1807 of the Grand Canyon Protection Act of 1992. These costs may or may not be realized. See text for further details.

The impact of the test flow during water year 1996 was, in part, influenced by additional release during the months of April, may, and June designed to reduce the risk of an uncontrolled spill at lake Powell. If a spill occurred, the resulting high flows might erode newly reformed sediment deposits. Since the longevity of these sediment deposits, is, in itself, a significant research question, a spill would have masked the effects of the experimental flood and decreased the scientific value of the experiment.

If risk of spill reduction releases had not been made in April, May, and June, the cost of a beach/habitat-building flow would have been less than experienced during water year 1996. A sensitivity analysis of the test flow, exclusive of these spill reduction measures, was undertaken. The results are shown in the

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second column of Table EX1. As shown there, independent of these risk of spill reduction releases, the economic cost of the test flow would have been approximately $1.3 million and the financial cost would have been less than $1.2 million.

The estimated economic and financial costs of the water year 1996 test flow on the hydropower system reflect existing hydrologic conditions, the timing and design of the experiment, and current conditions in the electric power market. This experiment reduced the economic and financial value of the power produced at Glen Canyon Dam during the water year by 3.3 and 2.5 percent respectively. The preliminary physical and biological results of this experiment indicate that controlled floods may be an effective tool for use in the management of the Colorado River in Glen and Grand Canyons. Future periodic beach/habitat-building flows are planned. Depending on the magnitude and duration of these flows, hydrologic conditions at the time, and conditions in the electric power market, the costs of future beach/habitat-building flows may be less than or greater than those of the water year 1996 experiment. Clearly, the tradeoff between the hydropower costs of such flows and the benefits to the downstream ecosystem must be carefully weighed.

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THE FLOOD EXPERIMENT: PERSPECTIVES FOR THE FUTURE

Lawrence D. Garrett

The flood experiment represented a major success in both management and science. It is a management success in that stakeholders and managers created the opportunity to both protect and enhance resources in the riverine corridor as prescribed in the Grand Canyon Protection Act and the Glen Canyon Dam Environmental Impact Statement. It is a success in science in that the action was designed also as a experiment, that considered the delicate interactions of various resources and resource attributes in the system. The experiment, therefore, was in many ways an ecosystem experiment.

The Beach/Habitat-Building Flow experiment then establishes a strong basis for all future research in the Canyon. It has established a perspective of adaptive management and science that will be improved upon through critical cooperation of the Adaptive Management Work Group, the Technical Work Group, and the Grand Canyon Monitoring and Research Center.

The three primary perspectives that are gained and will become critical missions of the new programmatic direction are as follows:

1. Involvement of stakeholders in defining information needs and recommending dam operation changes for resource enhancement to the Secretary,

2. Evaluating resource attribute change and interactive resource relationships in the Canyon as a holistic ecosystem, rather than an aggregation of resource components.

3. Implementation of extensive outreach programming and information exchange to stakeholders to assure that stakeholders are fully cognizant of all resource implications of changing dam operations.

To ensure continued involvement of stakeholders in defining information needs the Grand Canyon Monitoring and Research Center (GCMRC) has developed all of its research plans from stakeholder objectives and information needs.

The design of all future monitoring and research in the Grand Canyon Monitoring and Research Center is based on the ecosystem science paradigm. This science paradigm will integrate in time and space our understanding of resource interactions, both in the riverine corridor and in Lake Powell.

Incorporated in all future programs will be aggressive programs on technology exchange from the Center to all stakeholders. This special outreach programming will make available annually data, analysis and scientific recommendations for resource improvements.

WELCOME AND OPENING REMARKS FOR THE 1997 GLEN CANYON DAM BEACH/HABITAT-BUILDING FLOW SYMPOSIUM

Dr. Dennis Fenn

Several challenges exist for the scientists at this workshop. The first challenge is to identify the comprehensive changes that occurred in individual resource attributes due to the experimental flood. A second challenge is to interact as colleagues to determine what of these individual resource attribute changes are related to other resources and other resource attributes. The final challenge is to work with managers and other stakeholders to understand the implications of these interrelated changes on the quality of the total ecosystem of resources, and how this information can be used to assist managers and stakeholders in defining appropriate management guidelines to benefit ecosystem health through time.

As a manager of science programs in the National Park Service, the National Biological Service, and now in the U.S. Geological Survey, I have learned the importance of transitioning from a single agency science perspective to a multi agency science perspective. Your effort here, as is ours in BRD, is to transition to a multi agency science and management perspective that must relate impacts and opportunities to a broad cross-section of stakeholders.

In the past decades, we have recognized as science managers that our research must adapt the following improvements to be more successful:

1. Research must be driven by stakeholder issues, opportunities and concerns.

2. Research must approach its solutions on the basis of ecosystems, rather than disaggregate functions or elements of a system.

3. Researchers and managers must work hand-in-hand to assure appropriate application of findings.

In many ways, the Biological Resources Division (BRD) national model for involving stakeholders in identification of information needs, strongly emulates the Glen Canyon Adaptive Management Program. Programs of the BRD, for example in the Everglades, utilizes various aspects of the Adaptive Management Program in conducting research and implementing findings.

We have determined that management of natural resources programs using adaptive management and science approaches can provide optimum protection, management and use of public resources in the western United States. This program will contribute strongly to our efforts in this arena.

MERGING ECOSYSTEM SCIENCE AND ADAPTIVE MANAGEMENT

Dr. Mark Schaefer

The synthesis of existing science to be presented today on the Beach/Habitat-Building Flow experiment, is a watershed in science and management activities on public lands in the West. It is a watershed, because this experiment, developed by stakeholders and scientists, represents the first time a major river corridor in the United States has been deliberately flooded for scientific and resource protection objectives.

The Secretary is extremely pleased at the Glen Canyon Dam Adaptive Management Program, which has been endorsed by managers, stakeholders and scientists. We see this symposium as a critical example of how management and science can work together to offer solutions to the managers of western riverine facilities, to provide important environmental, social and economic enhancements in western public resources. Although we cannot return the great Colorado to its original raging spring flows, which carried extensive, nutrient-rich sediments throughout the Canyon, we can, as with this Beach/Habitat-Building Flow, reintroduce some processes of the original wild river.

The Bureau of Reclamation, National Park Service and other groups are to be applauded for recognizing in the early '80s, the need for extensive science to document the impacts of operation of the Glen Canyon Dam on the Colorado River and potentially Lake Powell resources. The science efforts of the BOR's Glen Canyon Environmental Studies program was critical in development of the state-of-the-art Environmental Impact Statement on operation of Glen Canyon Dam.

The Grand Canyon Protection Act and the Glen Canyon Dam Environmental Impact Statement has spawned a new approach in management and science interaction. This approach, the Adaptive Management Program, clearly articulates the need to utilize our best science to implement protection, management and use of resources affected by operation of the Glen Canyon Dam. The intent to utilize new science, as it comes available, to modify dam operating strategies to ensure resource protection and enhancement over time, is a bold step in public resource protection and management. The Adaptive Management Work Group, the Transition Work Group, and the Grand Canyon Monitoring and Research Center will prove through time to be critical agents for the protection of critical camping beach resources, endangered species such as the Humpback Chub and the Kanab Ambersnail, and Native American Tribal resources such as traditional cultural properties.

The Beach/Habitat-Building Flow experiment is looked upon as the initial experiment in the new Adaptive Management process. It is fully expected that the Adaptive Management Work Group, working closely with the Grand Canyon Monitoring and Research Center, will through time, both protect and enhance the valuable resources in the Colorado riverine corridor and Lake Powell.

USBR REMOTE SENSING AND GEOGRAPHIC INFORMATION GROUP D-8260 EXECUTIVE SUMMARY ON MAPPING THE CONTROLLED FLOOD EVENT

An Executive Summary

Presented to

Grand Canyon Monitoring and Research Center

By

USBR Remote Sensing and Geographic Information Group

March 1997

TASK HISTORY

Prior to the flood, our lab was involved in using a geographic information system (GIS) as a predictive tool to model the inundation that would occur at 45,000 cfs at 14 sites of interest. This information was used by the Glen Canyon Environmental Studies (GCES), the National Park Service (NPS) and US Fish and Wildlife Service (USFWS) in mitigating and planning for the experimental flood.

During the flood our research task for the Beach/Habitat-Building Test Flow was to map and quantify the area gained or lost by alluvial deposits, eddys, and new high water vegetation for rivermile 61.5 through 72 (monitoring site #5) and four small study areas (Hidden Slough, Cathedral Wash, Badger Creek and Kwagunt Marsh). Due to budget constraints, prior to the flood event we worked with GCES and Utah State University (USU) to help the University to achieve its research goals. Our lab agreed to develop USU's raw mapping product into digital layers using a portion of the money allocated to our budget.

After the flood, our lab was contracted by the Glen Canyon National Recreation Area (GCNRA) to map the impacts of the 45,000 cfs flood event on alluvial deposits and cut banks for five selected sites. GCNRA will report on the findings of this work.

We intend to focus on each aforementioned task with an executive summary throughout the remainder of this paper.

PREDICTIVE MAPPING USING EXISTING GIS DATA

At the request of the GCES office the BOR Remote Sensing and Geographic Information Group (RSGIG) developed a methodology to model and plot the area of inundation that would occur within small sites at a flow release of 45,000cfs along the Colorado River. The plots produced from this effort were used by GCES, NPS, GCNRA and USFWS for mitigation and pre-flood planning.

Vasey's Paradise and 3 other areas down river from Lees Ferry defined as endangered species habitat or archeologically sensitive were mapped. Figure 1, Vasey's Paradise plot of the modeled 45,000cfs flow may be found as a foldout at the back of this report. In addition, 10 particularly sensitive areas containing cultural and natural resources prioritized by GCNRA were also mapped up river from Lees Ferry.

METHODOLOGY

The predicted surface elevation lines of 45,000cfs were generated using the existing GIS data sets of:

1) 5,000cfs surface elevation line
2) 15,000cfs surface elevation line
3) 30,000cfs surface elevation line
4) ½ meter topography

A simple linear interpolation was performed between the different surface elevations to predict the 45,000cfs surface elevation at each prioritized site. The assumption was made that their is a direct correlation between flow and surface elevation, given that the largest site mapped was no more than 400 meters in length. To confirm the validity of the estimated surface elevations, the STARS model was used to compute water surface profiles at a steady flow of 45,000 cfs. Of the sites tested, GIS generated surface elevations were within ½ meter of surface elevations computed by the STARS model.

CONCLUSION

This exercise was proof positive of how beneficial an online geographic information system data base can be in a multi-agency research effort such as this. Existing digital information was used in a real-time scenario to provide answers to researchers and managers in the justification and planning for the flood event.

MAPPING CHANGE IN VEGETATION, ALLUVIAL DEPOSITS AND BACKWATERS DUE TO THE CONTROLLED FLOOD EVENT

We proposed to use data developed from aerial photography, acquired by GCES during the 1996 pre-flood and post-flood events to map and analyze change within site #5 and four small selected areas, Hidden Slough, Cathedral Wash, Badger Creek and Kwagunt Marsh.

Our primary objective was to monitor change by quantifying the area gained or lost by alluvial deposits, hydrologic features, and new high water vegetation within the aforementioned sites. These data will also provide information as to change in geologic and hydrologic structure and, thus, support the research of other scientist.

HYPOTHESIS

The planned 45,000cfs flood event is expected to affect the existing condition of the new high water vegetation, alluvial deposits, and hydrologic features downstream of the Glen Canyon Dam.

METHODOLOGY

1) Field work during the pre and post-flood events was performed to ground truth and map data. Data sets were delineated and classified onto mylar overlays registered to the aerial photography.
2) A transfer scope was used to rectify and georeference the data sets to mylars registered to the 1990 1:2400 orthophoto basemaps. Using a dense network of survey control common to both the aerial photography and the orthophotos will ensure horizontal accuracy of between 1 and 2 meters relative to the orthophoto base map.
3) These data then were scanned and classified, creating a digital product available for analysis using a geographic information system.

It is important to note that a contingency plan was developed to collect data if a fixed wing aerial photography mission could not be flown do to bad weather. Helicopter videography was chosen as the backup methodology and was flown pre-, during and post-flood. Due to a limited time window the first flight line of the post-flood photo mission had to be flown before the standardized flow of 8,000 cfs could be reached, this photography collected included the Kwagunt Marsh site. Therefore, still frames from the pre- and post-flood videography were used in the generation of the Kwagunt Marsh data. The digital data collected from the videography was georeferenced using a second order transformation of 25 control points.

CONCLUSION

As the result of the work done within the aforementioned sites 5 map plots were generated along with quantitative results representing change in alluvial deposits, hydrologic features, and vegetation. Figure 2, a plot depicting the "Tanner" portion of monitoring site 5 can be found as a foldout at the back of this report. Similar plots were generated for the Hidden Slough, Cathedral Wash, Badger Creek and Kwagunt Marsh study sites as well.

The quantitative results of the pre- and post-flood work follows:

1) Monitoring site #5 rivermile 61.5 to 72
    a. Cobble Bar = Insignificant change
    b. Sand Bar = 21% increase
    c. NHW Vegetation = Insignificant change
    d. Eddy = 29% decrease
    e. Isolated Pool = 71% increase

2) Badger Creek Rapid rivermile 8
    a. Cobble Bar = Insignificant change
    b. Sand Bar = Insignificant change
    c. NHW Vegetation = Insignificant change
    d. Eddy = Insignificant change

3) Cathedral Wash rivermile 2.5 to 3.2
    a. Cobble Bar = Insignificant change
    b. Sand Bar = 20% decrease
    c. NHW Vegetation = Insignificant change

d. Eddy = Insignificant change

4) Hidden Slough rivermile -6.5
   a. Sand Bar = Insignificant Change
   b. NHW Vegetation = Insignificant change
   c. Eddy = 40% increase
   d. Isolated Pool = 20% decrease

5) Kwagunt Marsh rivermile 55.5
   a. Sand Bar = 80% increase
   b. NHW Vegetation = 20% decrease
   c. Eddy = 29% decrease
   d. Isolated Pool = 77% decrease

The photogrammetric work done on each site has proven the hypothesis of change brought about by the flood event to be true. It is interesting to note that the increase in sand bars occurred more so in the Kwagunt Marsh and monitoring site 5 sites than in the upper sites. This correlates with the larger stored sediment budget down river. The values defined for the smaller sites cannot be interpolated beyond their plotted boundaries because of their limited size.

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