TESTING THE EFFECTS OF A SHORT-DURATION 60,000 CFS SPIKE FLOW AND SUBSEQUENT LOAD-FOLLOWING OPERATIONS AT GLEN CANYON DAM

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The Glen Canyon Technical Working Group's (TWG) ad-hoc group on testing alternative beach/habitat-building flows sent a letter to the Grand Canyon Monitoring and Research Center (GCMRC) that proposed an experimental beach/habitat-building flow in excess of 45,000 cfs with subsequent load-following operations. In this paper, we explore the merit of this proposal and the hypothesis-testing approach that could be used to determine the effects of such an experiment.

BACKGROUND

Floods are natural events that control the size and shape of a river. Construction of Glen Canyon Dam in 1963 ended the natural cycle of flooding that occurred in the Colorado River through Grand Canyon. Prior to construction of the dam, the average annual peak discharge of the Colorado River in Grand Canyon was approximately 93,400 cfs. Such flows scoured a large amount of sediment (mostly sand) from the river bottom and channel margins and deposited this sediment at higher elevations along the river banks, leaving it above the water level after floods receded. Over time, these sediment deposits would erode and sediment would be returned to the river channel, but over the long term would be maintained by the natural cycle of flooding.

The annual scour-and-fill process maintained large sand bars along the river banks, kept sand clear of vegetation, and reduced constriction of the river from debris fans. Regulation of flows in the Colorado River by Glen Canyon Dam has reduced the frequency and magnitude of annual floods. Consequences of river regulation include reduction in the area of beaches, increased encroachment of vegetation along shorelines, and a build-up of debris fans. The Glen Canyon Dam EIS identified a preferred alternative that included scheduled, short-duration, high-flow releases (above the powerplant capacity of 31,500 cfs) from the dam (called beach/habitat-building flows) to help alleviate some of the undesirable changes that have resulted from dam operations (Bureau of Reclamation 1995).

In March and April of 1996, a controlled high-flow release from Glen Canyon Dam was made to evaluate the effects of such a flow on environmental conditions, including sediment resources. Under this experiment, a release of approximately 45,000 cfs was maintained for an 8-day period.
The peak was preceded and followed by three days of steady releases of approximately 8,000 cfs before resuming normal operations consisting of low-fluctuating flows. Although this high-flow release exceeded the normal maximum powerplant release of 31,500 cfs, it was only about half the magnitude of the pre-dam average annual spring peak.

Sand storage changes in the channel after the high-flow release ranged from a gain of 118 m^2 just downstream of the Paria River confluence to a loss of 637 m^2 downstream of the Little Colorado River confluence (Konieczki et al. 1997). Analyses of sand bars and daily photographic records collected during the high-flow release indicated that there was significant redeposition at higher elevations of sand that had been stored in the main channel (Hazel et al. 1997). This pattern of redeposition occurred throughout the Grand Canyon, regardless of geomorphic reach or bar type and resulted in an average increase in sand bar volumes of 48%. The volumes of sand bars located above the elevation of 14,000 cfs flows increased by 176%. Thus, the experimental high-flow release resulted in sand bars that were higher than before the release. Although high-elevation sand deposited by the experimental release was still present following 6 months of normal Glen Canyon

Dam operations, the upper bar zone decreased by an average of 18% as cutbanks retreated at an elevation corresponding to the stage of the maximum daily flow during the post-peak period. Measurements of cutbank retreat indicated that the erosion rate would be highest under steady releases of long duration (Hazel et al. 1997).

From the perspective of improved sediment management, the 1996 beach/habitat-building flow could be considered successful since in-channel sediment was mobilized and redeposited to higher elevations on sandbars and beaches. Under the adaptive management strategy being used for management of the Grand Canyon ecosystem, the Glen Canyon Technical Working Group must consider whether changes to the operational regime used during the 1996 beach/habitat-building flows could provide even greater benefits. Changes to the magnitude and duration of peak flows and alterations of the pre- and post-peak fluctuation regimes should be considered. Changes that allowed main-channel sediments to be redeposited at higher elevations and that reduced the rate of erosion of the toe of the deposited sand would be of greater value as this would reduce the frequency with which such releases would be required. Since these high releases can adversely affect some resources, a reduction in frequency could be beneficial.

PROPOSED BEACH/HABITAT-BUILDING RELEASE PATTERN

We propose that the Technical Working Group consider implementing an experimental beach/habitat-building flow that provides a peak flow of a greater magnitude than the 1996 flows and that this spike flow be followed with a period of fluctuating flows. Specifically, we propose that a peak release of 60,000 cfs be made for a period shorter than 8 days between January 1 and July 31, 1999 and that this peak release be followed by load-following releases ranging from 4,000 cfs less to 4,000 cfs greater than the designated mean flow. The rationale for and expected results of each of these aspects of the experimental release are discussed below.

Higher Peak Flow

A 60,000 cfs spike flow is expected to remove a greater amount of sediment from the channel bed and channel margins than the previous 45,000 cfs experimental release. In addition, the higher energy of the 60,000 cfs release would exceed the incipient motion discharge for larger sediment particles and these larger particles would be mobilized. The 45,000 cfs release did little to scour existing vegetation from sand bars (Kearsley and Ayers 1997) or rejuvenate backwater habitats (Parnell et al. 1997). The 60,000 cfs release should be more effective in performing these two functions.

Some of the sediment mobilized by a 60,000 cfs release would be deposited at higher elevations and some would be transported out of the system and deposited in the Lake Mead delta. Observations of the effects of the 1996 experimental release indicated that sediment was deposited at the 45,000 cfs elevation, and it is anticipated that the proposed release would deposit sediment at the 60,000 cfs level. Deposition of sediment at a higher elevation is expected to result in greater conservation of sediment resources because these deposits would be further isolated from the erosive effects of normal dam operations.

Shorter Duration of Peak Flow

Shortening the peak duration from an 8-day period is proposed because observations during the 1996 experimental release indicated that most sediment was moved during the first days of the peak release. In addition, as the experiment progressed, the size of sediment particles that were mobilized and deposited increased (Rubin et al. 1997). These observations demonstrate the relationship between flow, sediment grain size, and transportability. They also indicate that most in-channel and channel-margin sediment with an incipient motion discharge of 45,000 cfs or less was mobilized during the initial days of the spike flow and either deposited at high elevations or transported out of the system. In essence, the channel became armored for that particular flow level. It is expected that such will be the case for the higher release as well, but as mentioned above, larger sediment particles would be transported by the higher flow and sediment transport could occur over a period longer than a few days. We suggest that the duration of the peak release not be determined prior to the experiment, but rather be based on field measurements of suspended sediment taken as the experiment progresses. Shortening the peak duration to only that needed to achieve maximum sediment conservation would be desirable because cost savings would be accrued and adverse ecological impacts (e.g., to trout) reduced if the duration of flows above powerplant capacity was minimized.

Fluctuating Flows Following the Peak

Hazel et al (1997) predicted that erosion of newly deposited sand would be highest under steady flows. For this reason, we believe that the potential sediment-conservation benefits of following the peak release with a fluctuating flow regime should be investigated. Because the proposed flows would place sand higher than the 1996 flows, it is anticipated that when flows are dropped back to normal operational levels, less of the newly deposited sand would be affected by subsequent daily fluctuations related to load-following. However, normal operations following the spike flow would continue to erode the toe of sand deposits. Existing observations suggest that fluctuations would serve to redeposit eroded sand to levels of the maximum daily release and minimize the rate of erosion.

TESTING THE EFFECTS OF THE EXPERIMENTAL RELEASE

The purpose of the proposed experiment is to test specific hypotheses regarding several aspects of the beach/habitat building flow release pattern; specifically, the magnitude and duration of the spike flow and subsequent operations.

Because each of these aspects of the release pattern are expected to affect different, discrete components of sediment-transport processes in the canyon, we feel that a hypothesis-testing approach can be applied that separates the effects of each aspect of the experimental regime. The proposed experimental release pattern has been developed from specific observations and predictions resulting from the 1996 experimental release of 45,000 cfs followed by a steady release. The proposal contains more than one modification to the previous experiment and, thus, comparisons to previous results has been perceived as more complicated. However, a focused monitoring program that tests very specific hypotheses will allow robust statistical comparisons.

This experiment is being proposed in its present configuration where more than one aspect of the 1996 release is being modified in order to capitalize on information gathered in 1996 and to maximize the number of hypotheses tested. Successful completion of the experiment requires the presence of adequate sediment resources and suitable hydrologic conditions. These required conditions limit the number of years in which spike flow experiments can be successfully performed. Recently, the Adaptive Management Work Group recommended hydrologic criteria for triggering a beach/habitat-building flow. It is expected that these trigger criteria would result in beach/habitat-building flows during 1 out of 6 years. In addition, for the experiment to be successful, sufficient sediment must be available in the channel and channel margins for transport. Recent storm events have produced significant in-channel sediment deposits below the Paria River confluence. Thus, if hydrological conditions in 1999 meet the hydrologic trigger criteria, there is the opportunity for testing the various sediment-conservation hypotheses presented in this paper. Performing an experimental release pattern that contains several elements of interest would accelerate the adaptive management process.

A number of hypotheses can be successfully and unambiguously tested using the proposed experimental release pattern. Although several are suggested here

(Table 1), the purpose of this paper is not to provide a comprehensive experimental design or monitoring program for the proposed experiment. The efficacy of a higher peak release should be monitored by determining (1) the elevation, depth, and areal extent of sediment deposits, (2) the grain-size distribution of deposited sediment particles, (3) rates of vegetation removal, and (4) changes in return-current channel backwater conditions. We suggest that measurements be made during the peak release to determine when suspended sediment concentrations fall off significantly, and at that time releases be reduced to the mean operating level. These measurements would enable determination of the appropriate duration of a 60,000 cfs spike flow without releasing more water than is needed. The effects of fluctuating flows should be monitored by measuring the rate of sediment bar erosion.

Table 1. Examples of Important Measurements and Hypotheses for the Proposed Experimental Release Pattern.

Element of Release Pattern	Measurements	Hypotheses
Higher peak release	Elevation, depth, and areal extent of sediment deposits	Sediment deposited during experimental release will be at higher elevation, greater depth, but similar areal extent compared to the 1996 release.
	Grain-size distribution of deposited sediment particles	A greater percentage of larger sediment particles will be deposited compared to the 1996 release.
	Rate of vegetation removal	A greater percentage of existing vegetation will be removed compared to the 1996 flow.
	Changes in return-current channel backwater conditions	Backwaters will increase in depth and areal extent compared to the 1996 release.
Shorter duration release	Suspended sediment	Suspended sediment concentrations will fall off significantly after several days, but the duration of high suspended sediment will be longer than in 1996.
Fluctuating flows	Rate of sediment bar erosion	Rate of sediment erosion will be less than that observed under steady conditions in 1996.

It is important to note that direct comparisons to the results of the 1996 spike flow will be difficult for any experimental release because of the importance of antecedent conditions (particularly effects on sediment availability). Conditions at the start of the next experiment will not be the same as they were at the start of the 1996 experiment. In fact, the effects of the 1996 experiment itself will linger for several more years. Thus, the notion that only one parameter (e.g., magnitude) should be varied in the next experiment relies on the erroneous assumption that a direct comparison of results will be possible. For any experiment, comparisons to the 1996 test flow will have to be made cautiously and take into account differences in the availability of sediment and any other relevant factors (e.g., vegetation cover).

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