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GCMR-700

September 18, 2000

MEMORANDUM

To: Kathleen Wheeler

From: Barry D. Gold

Subject: Summary of Recent Sediment related Research Findings

A few months ago I sent you five published scientific papers that presented the results of recent sediment-related research sponsored or conducted by GCMRC. At that time you asked that we prepare a summary of those papers for your information. I asked Ted Melis, the GCMRC Program Manager for Physical Resources and the sediment researchers whose work we were citing to develop a summary memo. While the attached memo was reviewed by myself and Randy Peterson it represents the researcher's own perspectives on their recent findings.

Their conclusions could have important implications for the Glen Canyon Dam Adaptive Management Program. They challenge the two hypotheses on which the EIS and ROD were based. First they challenge the notion that sand can be stored in the channel bed over a number of years and then once sufficient accumulation has occurred it can be redistributed through a Beach/Habitat- Building Flow. Rather, they argue that the sand which enters the system from tributary events is transported downstream relatively rapidly. Second, they postulate that the fraction of sand that is remaining will not be sufficient to build bars and provide a positive sand balance.

The implications for their findings for sediment resources only are: (1) that releases above peak-power-plant discharge may need to be conducted immediately after substantial inputs of sand from tributaries; and (2) flows following sand inputs from tributary events should be maintained at 8,000 to 10,000 cfs to maximize sediment storage until peak power-plant discharges can be implemented.

Their findings also suggest two hypotheses that will need to be evaluated based on the data collected from the GCMRC long-term monitoring program. One is that the system will exist in the post-dam era in some sort of degraded equilibrium as compared to the pre-dam sediment balance. The other is that the system will continue to experience a long-term loss of sediment.

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MEMORANDUM

August 29. 2000

To: Barry D. Gold, Chief, Grand Canyon Monitoring and Research Center

From: David M. Rubin and David J. Topping, U.S. Geological Survey
John C. Schmidt, Utah State University
Joe Hazel, Northern Arizona University

Re: Summary and Discussion of Recent Research Findings Related to Dam Operations and Sand Bar Resources of the Colorado River Ecosystem

Background

Sand bars are an essential component of the Colorado River ecosystem downstream from Glen Canyon Dam. They create habitat utilized by endangered fish; they contain and protect an array of Native American cultural resources; they provide campsites used by recreational boaters; and they are a distinctive attribute of the pre- and post-dam river landscape. Improving and maintaining sand bars below the dam is a fundamental long-term management objective of the Grand Canyon Protection Act, the Operation of Glen Canyon Dam Final Environmental Impact Statement, and the Glen Canyon Dam Adaptive Management Program (See Attachment 1).

Sand bars and sandy banks of the Colorado River in Grand Canyon are maintained by the sand that is transported through the canyon. The high-elevation parts of these sand bars (those parts at elevations above peak power-plant discharge) can be constructed only by flows that exceed peak power-plant discharge (i.e. flows greater than 31,000 cfs); in the absence of such high flows, these high-elevation areas are eroded by lower flows or canyon winds or are rapidly colonized by both native and exotic vegetation. Flows above peak power-plant discharge are necessary to maintain these high-elevation sand bars, but are effective only when the river contains sufficient sand resources.

Evaluating restoration and sustainability of sand resources is a complicated problem that involves sand storage on the Colorado River's bed, tributary resupply of sand, sand deposition induced by flows above peak power-plant discharge, erosion and transport of sand during normal power-plant operations, and recolonization by vegetation. Improving or sustaining sand resources is a difficult challenge because Glen Canyon Dam traps all of the sediment from the upper Colorado River, resulting in an approximate 94% reduction (relative to pre-dam inputs) in the amount of sand supplied to the Colorado River at the upstream boundary of Grand Canyon National Park.

With respect to restoration and sustainability of sand bars, the Secretary of the Interior's 1996 Record-of-Decision (ROD) for operations of Glen Canyon Dam is based primarily on two hypotheses:

(1) that much of the sand introduced to the Colorado River by tributaries downstream from Glen Canyon Dam can accumulate in the channel over multiple years if dam releases do not exceed average volume, and

(2) that flows above peak power-plant release (such as the 45,000 cfs flow in 1996) can effectively move that accumulated sand from the channel bed to bars, thereby rebuilding sand bars that are eroded by typical dam releases.

Recent Findings

Work conducted since the 45,000 cfs release in 1996 has shown that the first hypothesis on which the 1996 ROD was based is false and that the second hypothesis is only partially true. The 45,000 cfs release in1996 increased the amount of sand at high elevations (Figure 1), but the sand that was deposited at high elevations came largely from the lower portions of the sand bars (Schmidt, 1999) and not from the channel bed as originally hypothesized.

Under the dam operations imposed by the 1996 ROD, most newly input sand is not stored on the channel bed for long periods of time (Topping et al., 2000a; Topping et al., 2000b). Flows above peak power-plant release cannot take advantage of multiple years of sand accumulation, because substantial multi-year accumulation of sand does not occur. Instead, this sand is transported downstream relatively rapidly. The time required to export (transport downstream past the Grand Canyon gage) one-half of a 500,000 metric ton input of tributary sand (the contribution of a typical, moderate, Paria flood) varies from less than one week (for dam discharges of 25,000-30,000 cfs) to roughly one year (for discharges of 10,000 cfs), as illustrated in Figure 2.

The time required to export the second half of a tributary input is greater than for the first half (for a constant water discharge), because the second half is coarser, as a result of winnowing of the bed (Topping et al., 2000b; Rubin and Topping, in press). The remaining half, however, is not necessarily sufficient to enable both bar-building and a positive sand balance. For example, the 45,000 cfs release in 1996 exported 700,000 metric tons of sand from Marble Canyon in one week. Thus, a release above peak power-plant discharge is a double-edged sword: high discharges are indispensable for rebuilding high-elevation parts of bars, but high discharges deplete sand resources rapidly (Figure 2). Conducting a release above peak power-plant discharge when recent tributary sand inputs are greatest will tend to minimize the negative impact on the sand resources.

Since the 45,000 cfs release in 1996, six kinds of sediment and topographic data have been examined: sediment input and output, changes in grain size of sand on the river bed, changes in sand-bar size, geomorphic mapping, and changes in channel cross-sections. Some of these studies document rapid export of tributary sand (transport past the Grand Canyon gage), whereas others demonstrate a lack of substantial multi-year accumulation of sand, especially in upper Marble Canyon:

• Both measurements and calculations of sediment input and output have shown that most fine sediment (sand, silt, and clay) introduced by tributaries is exported within a few months (Topping et al., 2000a; Topping et al., 2000b). For example, field measurements show that most sediment introduced by floods on the Paria River in September, 1999, was exported within 6 weeks. On a longer time scale (August 11, 1999 to May 14, 2000), the Paria supplied approximately 0.8 million metric tons of sand to the Colorado River, while roughly twice this amount of sand (1.5-2 million metric tons) was exported past the Lower Marble Canyon gage.

• Changes in grain size of sand on the river bed also demonstrate rapid export of tributary sand. The bed was measurably enriched in finer sand as a result of Paria floods in September, 1998 (median grain size of Paria River sand is 0.11 – 0.13 mm). When sampled next (May, 1999), most of the new fine-grained sand on the bed had been winnowed (Topping et al., 2000b). The remaining sand in the channel was generally too coarse to be transported onto the high-elevation areas of sand bars.

• Topographic surveys of 11 sand bars in the first 76 miles downstream from the dam document a continuing depletion of sand-bar area from 1991 to 1999 (Figure 1A). High flows in 1996 and 1997 temporarily reversed this trend but did not halt the continuing decrease in sand-bar area. The sand bars (above 20,000 cfs) were 22% smaller in surface area in 1999 (Figure 1A), although they contained 2-3% more sand than in 1991 (Figure 1B).

• Topographic surveys of 35 sand-bar sites documented scour of sand during the 45,000 cfs release in 1996, followed by net accumulation (J. Hazel, personal communication). Comparison with tributary-input data for the same time, however, indicates that most of the observed accumulation occurred when there was no substantial tributary sand input.

• Repeated surveys of channel cross-sections from 1991 to 1999 have shown relatively large and rapid fluctuations in the amount of sediment present (M. Flynn and N. Hornewer, personal communications). These fluctuations are interpreted to represent temporary storage and subsequent down-river transport of sediment. These studies have not detected multi-year accumulation of sediment.

• Analysis of bed-elevation data at the historical Marble Canyon dam sites suggests considerable loss of sediment from the 1950's to the present. Not only does the post-dam river contain less sand than the pre-dam river, but the remaining sand is generally coarser (Rubin and Topping, in press).

• Geomorphic mapping indicates that deposition of the 45,000 cfs release in 1996 was least near Lees Ferry and was greatest downstream from the Little Colorado River (Schmidt et al., 1999; H. Sondossi, personal communication). The magnitude of "improvement" is greatest further downstream where more tributaries have delivered fine sediment to the channel. Thus, the "improvement" caused by any specific release above peak power-plant discharge differs both temporally and spatially, depending on how enriched or depleted a particular reach is at the time.

Implications for Current Management Actions

The features listed above characterize a system where increases in sand abundance result not from incremental multi-year accumulation but rather from temporary storage of individual tributary inputs. In such a system, where increases in sand abundance are temporary, the goal for building sand bars should be to exploit tributary inputs as soon as possible, because the volume of sand available for bar-building is greatest immediately after large tributary inflows. To be effective in rebuilding sand bars, releases above peak power-plant discharge should occur soon after these tributary inflows, before the new sand is lost downstream (Figure 2).

Large Paria tributary inflows typically occur during late summer and early fall. Under the rules of the 1996 ROD, however, releases above peak power-plant discharge cannot be implemented on a schedule that takes advantage of such inputs. If a release above peak power-plant discharge cannot be scheduled immediately following a tributary input, another option might be to maintain low flows until a release above peak power-plant discharge could be implemented; the low flows would reduce the amount of sand lost downstream. The magnitude of an acceptable low flow that limits the rate of sand export depends on the volume of sand introduced by tributary flooding, the length of time following the tributary input, and what loss of sand downstream is considered acceptable. At dam releases that are typical of recent years, half of the sand introduced by a tributary flood can be exported within days or weeks (Figure 2). Retention of sand for more than a few months requires sustained dam releases at the lower discharges currently permitted under the ROD (8,000 -10,000 cfs).

Recommendations for Future Management Actions

Even if rules for releases above peak power-plant discharge are revised to allow scheduling during or shortly after periods of sand inputs, the objectives of improving or sustaining the desired abundance, form, and function of sand bars may still not be possible because the long-term sand supply from tributaries in critical reaches may be too small. The 76-mile reach downstream from Glen Canyon Dam has but one large sand source: the Paria River. The supply of sand from the Paria River is only about 6% of the sand that was supplied to this reach prior to the construction of Glen Canyon Dam. Natural floods from the Paria River may be too infrequent and too small to restore sand resources in this critical upstream reach, which includes the 60-mile length of Marble Canyon within Grand Canyon National Park.

Altering the timing of releases above peak power-plant discharge (or drastically reducing the dam's discharge until such flows can be released) may be insufficient to rebuild sand resources above existing levels or to achieve sustainability at present levels; additional monitoring will be required to see if these options are successful. If alternative timing of releases above peak power-plant discharge proves to be insufficient for sand-bar management goals, then other more effective alternatives should be evaluated.

One approach would be to selectively add sand downstream of the dam. This alternative ("sediment augmentation") was considered and eliminated during the Operations of Glen Canyon Dam EIS process. We are unaware of engineering feasibility studies of such a program, but sediment by-pass is an attribute of some recently built dams, as well as harbors and estuaries. A review of sediment pipeline technology is included on the EPA web site, http://www.epa.gov/glnpo/arcs/EPA-905-B94-003/B94-003.ch5.html. Addition of enough sediment (continuously, seasonally, or perhaps only during releases above peak power-plant discharge) would offer greater flexibility in dam operations, and it is conceivable that such an approach might cost less than imposing new constraints on dam operations. It is possible that sediment augmentation, substantial seasonal modification of flows released from Glen

Canyon Dam, or both, might be able to restore the sand resources in the Colorado River ecosystem in Grand Canyon National Park without more extreme actions.

Conclusions

The post-dam Colorado River is depleted in sand resources relative to the pre-dam river. The existing management strategy permitted under the ROD is failing to restore sand resources in the ecosystem in Grand Canyon National Park. The bars are continuing to decrease in surface area, and no long-term retention of tributary sand has been detected.

Our opinion, based on the information presented in this summary, is that any of the following approaches will have a significantly greater likelihood of success in restoring or retaining sand resources in the Grand Canyon ecosystem:

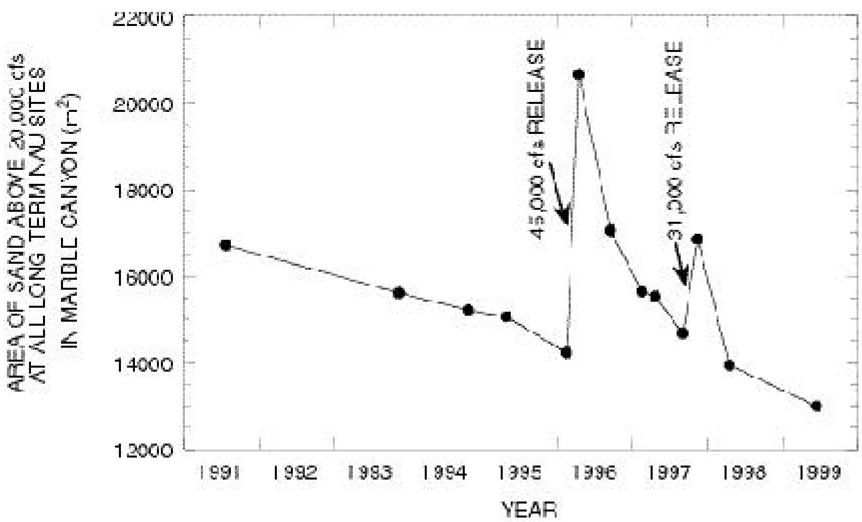
(1) Implement releases above peak power-plant discharge immediately after substantial inputs of sand from tributaries.

(2) Maintain low flows following sand inputs until releases above peak power-plant discharge can be implemented.

(3) Add sediment downstream from the dam.

Dam operations of the last decade must have caused one of the following possible effects on sediment resources in the Colorado River ecosystem: sediment resources were enhanced or replenished relative to conditions in the early-to-mid 1990's, sediment resources were maintained in a degraded (post-dam) condition, or long-term export and loss of sediment resources is continuing. Distinguishing between such possibilities has been—and should continue to be—an important function of the GCMRC Adaptive Monitoring Program. The research reviewed above demonstrates that current operations are failing to increase sediment resources. At least one significant measure of sediment resources, surface area of sand bars above 20,000 cfs, documents continuing depletion of sand resources.

A



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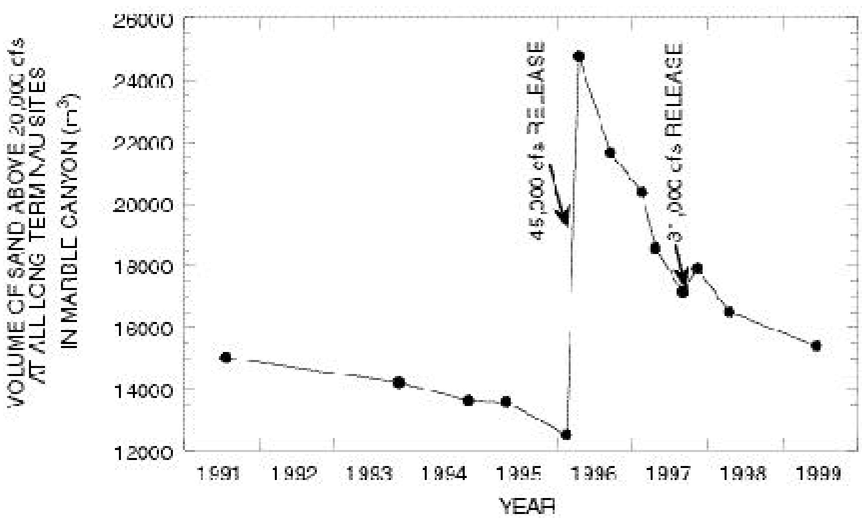

Figure 1. Changes in sand-bar surface area and volume at all 11 long-term Northern Arizona University study sites in Marble Canyon. **A**. Surface area of sand bars decreased by 22% from 1991 to 1999 despite temporary increases caused by high releases in1996 and 1997. **B**. Volume of sand bars in 1999 was 2-3% greater than in 1991.

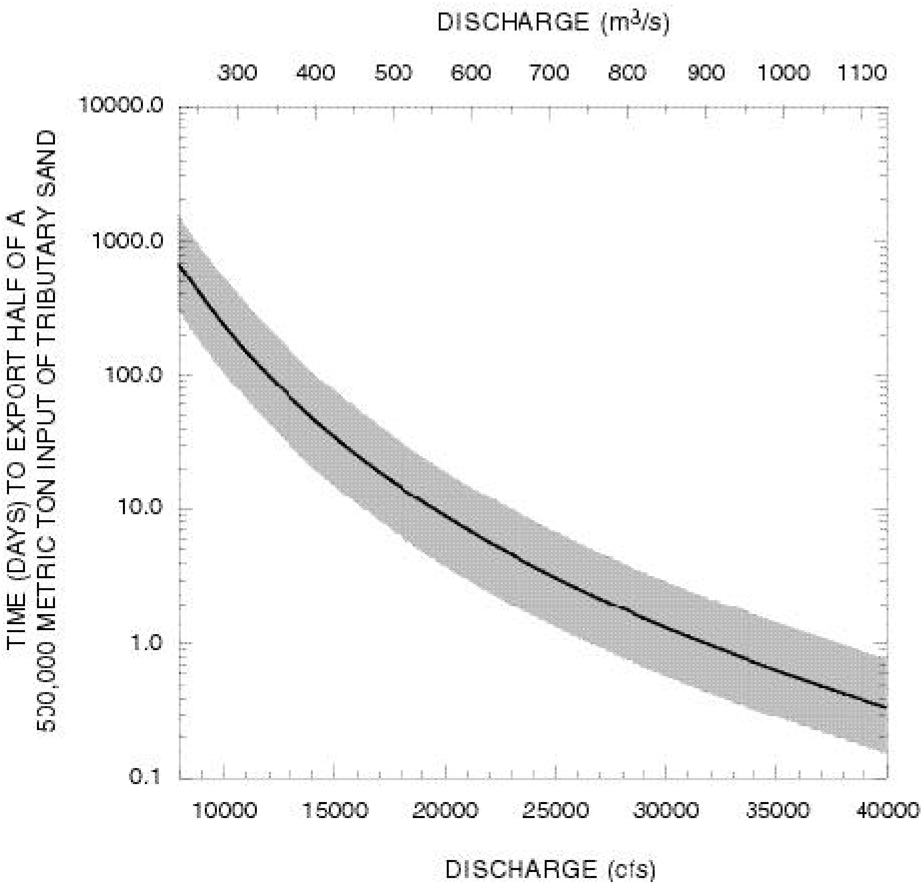

Figure 2. Calculated time to export one-half of a 500,000 metric ton input of tributary sand past the Grand Canyon gage. Calculations are based on sediment-transport data collected at the Grand Canyon and above LCR gages during the 1990's. The upper limit of the shaded area (slowest export) is calculated using the average suspended-sediment concentration for each specified discharge; the lower limit of the shaded area (most rapid export) is calculated for high concentrations of suspended sediment at each discharge; the solid line in the center of the shaded band is calculated using concentrations that decrease through time from high values (during and immediately following tributary inputs) to mean concentrations (after half of the tributary sand has been exported). At the upper range of dam operations, half of the sediment is exported within a few days; multi-year accumulation is only likely to occur if discharge is restricted to less than 8,000-10,000 cfs. To maximize the benefit of sand supplied by tributaries, releases above peak power-plant discharge should be implemented as soon as possible after tributary input events.

References

Rubin, D.M., Anima., R.A., and Nelson. J.M., 1997, Sedimentologic and hydraulic observations of depositional processes during the 1996 experimental high flow: Proceedings of the Grand Canyon Monitoring and Research Center's 1997 Symposium on the Glen Canyon Dam Beach / Habitat-building flow, p. 9.

Rubin, D.M., Nelson, J.M., and Topping, D.J., 1998, Relation of inversely graded deposits to suspended-sediment grain-size evolution during the 1996 flood experiment in Grand Canyon: Geology, v. 26, p. 99-102.

Rubin, D.M. and Topping, D.J., 1999, Seasonal and Multi-Year Sediment Balance in the Colorado River Downstream from Glen Canyon Dam: Colorado River Ecosystem Science Symposium, Grand Canyon, AZ.

Rubin, D.M., and Topping, D.J., in press, Quantifying the relative importance of flow regulation and grain-size regulation of suspended-sediment transport (α), and tracking changes in bed-sediment grain size (β): Water Resources Research.

Schmidt, J.C., 1999, Summary and synthesis of geomorphic studies conducted during the 1996 controlled flood in Grand Canyon, *in* Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A., eds., The 1996 controlled flood in Grand Canyon: Washington, D.C., American Geophysical Union, Geophysical Monograph 110, p. 329-342.

Schmidt, J.C., Grams, P.E., and Leschin, M.F., 1999, Variation in the magnitude and style of deposition and erosion in three long (8-12 km) reaches as determined by photographic analysis, *in* Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A., eds., The 1996 controlled flood in Grand Canyon: Washington, D.C., American Geophysical Union, Geophysical Monograph 110, p. 185-203.

Topping, D.J., 1997, Flow, sediment transport, and channel geometric adjustment in the Grand Canyon, Arizona gage reach of the Colorado River during the 1996 Grand Canyon flood experiment: Proceedings of the Grand Canyon Monitoring and Research Center's 1997 Symposium on the Glen Canyon Dam Beach / Habitat-building flow, p. 20-22.

Topping, D.J., Rubin, D.M., Nelson, J.M., Kinzel, P.J., III, and Bennett, J.P., 1999, Linkage between grain-size evolution and sediment depletion during Colorado River floods, *in* Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A., eds., The 1996 controlled flood in Grand Canyon: Washington, D.C., American Geophysical Union, Geophysical Monograph 110, p. 71-98.

Topping, D.J., Rubin, D.M., and Schmidt, J.C., 1999, Why knowing real-time sediment inputs from tributaries is important: Colorado River Ecosystem Science Symposium, Grand Canyon, AZ.

Topping, D.J., Rubin, D.M., and Vierra, Jr., L.E., 2000a, Colorado River sediment transport 1. Natural sediment supply limitation and the influence of Glen Canyon Dam: Water Resources Research, v. 36, p.515-542.

Topping, D.J., Rubin, D.M., Nelson, J.M., Kinzel, III, P.J., and Corson, I.C., 2000b, Colorado River sediment transport 2. Systematic bed-elevation and grain-size effects of sand supply limitation: Water Resources Research, v. 36, p. 543-570.

Attachment 1. Management objectives for sediment resources within the Glen Canyon Dam Adaptive Management Program are stated as follows in the June 10, 1998 Management Objectives document adopted by the Adaptive Management Work Group.

SEDIMENT RESOURCES

Goal: to maintain a range of sediment deposits over the long-term, including an annually flooded bare-sediment (unvegetated) active zone, a less frequently flooded vegetated zone, terraces (within the 45,000 cfs river stage), and backwater channels. Managing sediment resources will be on a reach-scale basis. Should significant and localized adverse impacts occur, site-specific mitigation would be considered.

Definition: Sediment resources include a broad array of material, ranging from suspended fines to coarse gravels. Primary interest relates to both material in suspension, which affects benthic capability, as well as stored sediment in beaches and channel margins, which affects recreation.

MANAGEMENT OBJECTIVES

MO 1: Maintain a long-term balance of river-stored sand to support maintenance flow (in years of low reservoir storage), beach/habitat-building flow (in years of high reservoir storage), and unscheduled flood flows. Maintain system dynamics and disturbance by annually (in years which Lake Po well water storage is low) redistributing sand stored in the river channel and eddies to areas inundated by river flows between 20,000 cfs and maximum power plant capacity.

MO 2: As a minimum for each reach, maintain the number and average size (area and thickness) of sandbars and backwaters between the stages associated with flows of 8,000 and 45,000 cfs that existed during the 1990/91 research flows.

MO 3: Periodically increase the average size of sandbars above the 20,000 cfs river stage and number and average size of backwaters to the amounts measured during the high period of 1990/91 or the 1996 test of the beach/habitat-building flow in as many years as reservoir and downstream conditions allow.

M) 4: Maintain system dynamics and disturbance by redistributing sand stored in the river channel and eddies to areas inundated by river flows up to 45,000 cfs in as many years as possible when BHBF hydro logic and resource criteria are met.

RECREATION

MANAGEMENT OBJECTIVES

MO 2: Maintain flows (under approved operating criteria) and sediment processes that create an adequate quantity, distribution and variety of beaches for camping, as long as such flows are consistent with management of natural recreation and cultural resource values (other natural resource values).