FLOODS IN THE GRAND CANYON: THE FIRST STEP TOWARDS UNDERSTANDING CRITICAL ECOSYSTEM PROCESSES BELOW GLEN CANYON DAM, AZ

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On March 26, 1996 the Department of the Interior and the Bureau of Reclamation embarked on a bold and innovative experiment to restore critical ecosystem processes in the Colorado River through the Grand Canyon. A controlled high flow of 1,274m3/s was released for seven days from Glen Canyon Dam to simulate a flood through the Grand Canyon. The experiment was designed to test our understanding of how flow regulates sediment erosion, transport and redeposition in the Grand Canyon and to further examine how the manipulation of flow might be used in a program to restore ecosystem features of the river that are dependent on basic geomorphic processes. The primary objective of the controlled flood was to mobilize the sediments from the bottom of the Colorado River channel and to redeposit them in the eddies and near-shore areas along the river corridor. Secondary objectives included restoration and rejuvenation of near-shore habitats for native fish, avifauna and insects. Prior to the controlled flood, scientists developed specific hypotheses for testing and identification of consistent and replicable sampling techniques and locations. The Glen Canyon Environmental Studies program coordinated the multi-agency effort including the research plan, logistics, geographic control system and bathymetric mapping to ensure consistency of data and integration into the GCES/Geographic Information System programs. Results show that the concept of controlled releases from dams is a feasible option for restoring critical ecosystem functions and habitats. Application of the scientific expertise gained through the GCES program to other river systems and impacted ecosystems will provide another valuable tool for the management of dams and controlled rivers.

KEY FINDINGS IN RESOURCE/STUDY AREAS

Over thirty specific studies were initiated as part of the Beach Habitat Building Flow program. All studies were designed to be linked together for evaluation of ecosystem change and response. Following are key initial findings in selected resource areas.

PHYSICAL SYSTEM

Changes in Sandbars and Camping Beaches

* Comparison of topographic and bathymetric surveys collected at 34 Colorado River sandbars before and after the flood showed that the sand bars had gained a significant amount of sediment following 7 days of constant 1,274m3/s. Sand bar volumes increased by an average of 53%. Sand was replenished to high elevation portions of bars where the most significant erosion

had occurred during interim flows. Bar deposition, however, was accompanied by only a slight increase in planimetric area from 5% to 7%. These results indicate that although sand was successfully redistributed to higher elevation on bars, the areal extent of the bars was only slightly increased. (NAU)

* At Kwagunt Bar (Mile 55.5), 68,000 m3 of sand were eroded from the channel and the eddy of which no more than 4,700 m3 contributed to bar building. Thus, no more than 7% of the sediment moved in that large eddy complex contributed to bar building. (NAU)
* Sand in recent flood deposits are decreasing. During the interim flows sand deposits decreased in size by an average of 7% per year. Rates of erosion are dictated by the amount of fluctuation and the base flow conditions. (NAU)
* Evolution of sand bar topography during the flood was faster than anticipated. Sand deposits, especially in the lateral separation eddies, aggraded and degraded by as much as 4 meters within less than 24 hours. (USGS)
* Subaqueous mass failures of steep portions of sand bars appeared to occur in the 10 eddies studied. (USGS)

Mainstem Sediment Transport

* A significant part of the total sediment erosion occurs during the rising limb of the hydrograph when sediment-transport capacity is increasing.
* Recent and massive scour during the beach habitat building flow was probably caused by unexpected rapid changes in eddy circulation. (USGS and GCES)
* In most eddies that were examined, deposits at the eddy separation and reattachment points grew and was eroded from the channel and along the outer margin of the eddy. (USGS)
* Changes in sand storage at a particular location are dependent upon local channel geometry and sand supply. (USGS)
* Sand was scoured from the deepest part of the channel and eddies and deposits were substantially rebuilt along the channel margins. (USGS and GCES)
* Sand transport rates initially were increased by a factor of ten then dropped off rapidly to the levels predicted by the sediment rating curves. The large pulse of sand in suspension contributed to the rapid deposition rates observed during the early parts of the flood.
* Reach averaged velocity during the flood was 1.8 m/s and ranged from 1.5 to 2.1 m/s. (USGS)
* Time-concentration curves of tracer dye were symmetrical indicating a normal distribution. Zones of stagnant water along the bed or banks are not significant in the Grand Canyon as they are in most other streams. (USGS)
* There was a net deposition of 0.5 to 2 m of sand at the eddy reattachment points. The middles of the eddies were generally scoured. (USU)
* Discharge rating models and sediment-transport and bed-evolution models are being tested with data collected during the flood and revised to improve the predictive capability for redistribution of sand by dam releases. (USGS)

Changes to Rapids

* Since the last dam release of magnitude similar to the 1996 controlled flood occurred in 1986, 25 debris fans were aggraded by debris flows. Significant changes occurred at Lava Falls and Crystal Rapids, increasing the navigational severity of the two largest rapids in Grand

Canyon. (USGS)

* Most of the debris fan reworking occurred during the rising hydrograph, particularly between 1,000 to 1,300 m3/s.
* The Lava Falls constriction widened from 34% to 42% and the aggraded area was reduced by 23%. The reworking at Lava Falls made the left run more serious but more steep (reduced by 0.6m). (USGS)
* Of 16 aggraded debris fans expected to be reworked during the controlled flood, 8 decreased 10% or more in size. Four debris fans had 1,900 m3 or more eroded by the controlled flood. Velocities through rapids either remained the same or, in the case of Lava Falls Rapid decreased by 50% as a result of the controlled flood. Both Lava Falls and Crystal Rapids became significantly easier for navigation as did most of the rapids involved. (USGS)
* As the interval between debris flows and reworking floods grows longer, aggraded debris fans are more difficult to rework because smaller dam releases cause particle suturing and interlocking. Debris fans should be reworked no more than 5 years after the debris flow if flood discharges are similar to the 1996 controlled flood. (USGS)
* In general, debris fans where stream power in the Colorado River is highest, changed more than other debris fans adjacent to riffles. (USGS)

Camping Beaches

* Large riverside sand deposits located above daily river fluctuations are used as campsites in Grand Canyon National Park. (GCES)
* Immediately after the flood a visual assessment was completed on known campsites. 50% increased in size, 39% remained the same and 12% were smaller. (GCES)
* 53 surveyed sites, beaches increased in area by an average of 57% over their pre-flood area. The flood created 82 campsites and destroyed 3. (GCES)
* Post-flood deposits cover a smaller area than do pre-flood deposits but their high elevation parts are much thicker and more extensive. (USU and NAU)

Backwater Habitats

* New backwater habitats were created due to changes in shape and extent of reattachment bars. (USU)
* Backwaters are dependent on the degree to which reattachment bars are created, the amount of deposition in the channel, and the volume of water that flows through a river system. (GCES)
* The flood scoured out return flow channels with sand floored channels and concomitantly rejuvenated those backwater habitats. (GCES)
* Backwater numbers increased by 20% immediately after the test flows and subsequently declined in numbers during the high releases during the summer of water year 1996. (GCES)

BIOLOGICAL SYSTEM

Geochemistry

* Flooding results in the biogeochemical rejuvenation of Colorado River ecosystems through the burial and accelerated decomposition of organic material. (NAU)
* The flood buried living and detrital organic matter under 0.2 to 0.95 m of sand. At the

measured sites, groundwater showed an increase in ammonium and non-purgeable organic carbon with decreases in dissolved oxygen. This is representative of increasing rates of microbial respiration in the beaches and a cycling of dissolved carbon from the beaches into the mainstem river. (NAU and GCES)

* The diel amplitudes of oxygen and pH cycles were decreased by 75% in the Lees Ferry reach due to scouring of the photosynthetic biomass by the flood. (USGS)
* The pH and dissolved oxygen in the Glen Canyon reach are controlled by photosynthesis and respiration. (USGS)

Fisheries

* No significant decreases in densities of non-native fishes resulted from the flood. Most non-native fish moved to submerged riparian vegetation and tributary mouth cover during the flood. (AGF and BioWest)
* Habitat selection was noted during the flood; juvenile humpback chub remained along the talus shorelines, speckled dace moved from riffles to debris fans, and fathead minnows moved from backwaters to tributary mouths. (AGF and BioWest)
* Radiotelemetry and netting studies indicated that many large native adult fish moved to low velocity vortices in large recirculation zones below large debris fans during the flood. (AGF, BioWest)
* No immediate negative impacts on the distribution, condition, densities, and health of the non-native trout fishery have been observed as a direct result of the flood. (AGF)
* The Cladophora food base was reduced in size during the flood. A composite shifting of the food base is occurring with Chara and Potomogeton taking over more of the Lees Ferry reach. A lag impact is occurring and monitoring will continue to evaluate the extent and significance to the overall foodbase (NAU)
* Densities of Gammarus were reduced by 65-70% at some sites in the Glen Canyon reach but were unchanged at others. Gammarus densities remained low in depositional environments for four months after the flood but returned to pre-flood levels on cobble bars. (AGF)
* Biomass of epilithon was unaffected by the flood, but densities of chlorophyll a were reduced. Standing stock of submerged aquatic macrophytes was severely impacted. (AGF)

Riparian Vegetation and Resources

* The population of many herbaceous species, especially annuals, are significantly reduced in the flooded areas. (NAU)
* Perennial herbaceous wetland species have recovered since the flood, especially Typha, Phragmites, and Carex. (NAU)
* With the exception of a small amount of damage from abrasion, the flood had a slightly positive effect on the woody perennial species, especially Salix. (NAU)
* Limited germination of tamarisk has occurred at the study sites. (NAU)

Endangered Species

* No direct impact occurred to the southwestern willow flycatcher nesting habitat as a result of the flood, however there has been a minor loss in the amount of understory vegetation. Continued monitoring is necessary to evaluate the significance to the species. (GCES and NPS)

* 31.5% of the primary Kanab Ambersnail habitat in the flood zone remained after the event. It was severely damaged by high velocity, debris laden flows. (GCES, NPS and FWS)
* Monthly Kanab Ambersnail population surveys for the study habitat patches revealed that the populations in the lower Vaseys Paradise site reached or exceeded the 1995 population levels by July 1996. This is due to the warm spring weather, and extended reproductive season. Vegetation in the impacted zone is recovering slowly. (GCES, NPS and FWS)
* Peromyscus spp. may be important predators on Kanab Ambersnails. (GCES, NPS and FWS)
* No impact was seen on the Peregrine Falcon populations
* A substantial loss of marsh vegetation associated with southwestern willow flycatcher nest sites occurred, approximately 36% reduction. Since some southwest willow flycatcher feeding occurs in marshes the importance of this impact continues to be evaluated.

Cultural Resources
* At three of the four study sites, sediments were deposited in the mouths of arroyos. At the fourth site, Lees Ferry, deposition did not occur because of lack of sediment, however the site did not sustain erosion. (Hopi)
* No impact was identified to the Hualapai Nation sacred tree at River Mile 209. (Hualapai)
* No direct impacts have been noted for any cultural sites along the river corridor as a result of the flood.
* Riparian resources in the lower Grand Canyon of importance to the Hualapai Nation were slightly reduced due to bank calving, inundation and burial of vegetation. The significance of the impacts remain to be analyzed. (GCES)
* At the Charles H. Spencer Steamboat, a net gain of sediment occurred, resulting in stabilization of the site.

Data Management
* The data collected during the controlled flood are being incorporated into the GCES Geographic Information System. The archiving of the data will result in a long-term data set for future monitoring and evaluation. (GCES)
* The hydrographic information is being integrated into the STARS model and the productivity model to provide for predictive tools for the future. (GCES)

SUMMARY

The forces controlling ecosystem response to periodic disturbance continue to be important elements in understanding impacts of dam operation. Our understanding of species composition, diversity, dynamics and stability of the Colorado River ecosystem through the Grand Canyon has taken a significant step forward with the controlled flood from Glen Canyon Dam. In the short time since the flood we have learned that the interactions among species depends on landscape and ecosystem level physical processes and that they may be as important as the anthropogenic impacts. Periodic controlled flooding is important if we are to maintain the dynamic nature of the Colorado River ecosystem through the Grand Canyon. Many elements of our understanding of the Colorado River were substantiated. Because there were unexpected results, as scientists

prepare to publish results and present them at scientific meeting it is clear that new knowledge is certain. This work can stand as a good example of rigorous science in the service of management. Planning of more frequent habitat maintenance flows, at or near powerplant capacity, requires completion of analysis and synthesis of information derived from this experimental flow.

The flooding has initiated a complex sequence of adjustments extending over a prolonged period of time with the lotic biotic community. Spatial, temporal and taxonomic variability of the lotic system are important considerations in developing paradigms of regulated flood releases.

The immediate short term impacts related to the flood are beginning to tell a story - a story that revolves around the relationships between flow and ecosystems. What is reported here is only part of the story. The short-term responses are precursors of what is to follow. The true value of the flood and the importance as a tool for long-term management of the dam and the Colorado River ecosystem will only be realized if the monitoring continues on the critical resources. The investment made in these studies will be squandered if only the short-term results are used to make decisions. The long-term response of the ecosystem must be evaluated if the value of the flood is to be realized.

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