RECLAMATION

Managing Water in the West

Sediment Analysis for Glen Canyon Dam High Flow Experiment Protocol Environmental Assessment

Upper Colorado Region, AZ

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3.2 Qualitative Sandbar Assessment

The model only considers sand mass balance; it does not differentiate between sediment in the channel and sediment in the sandbars. However, anticipated sandbar response to an HFE can be concluded from the literature available on previous high flows. To date, there have been three high-flow experiments as well as three habitat-maintenance flows, which can be considered smaller discharge high-flow experiments. A quick summary of the high-flow experiments is displayed in Table 5 and described below.

Table 5. Previously conducted high flow experiment parameters.

Date	Peak Magnitude (ft^3/sec)	Peak Duration (hr)
March-April, 1996	45,000	168
November, 1997	30,700	48
May, 2000	30,700	72
September, 2000	30,700	96
November, 2004	42,000	60
March, 2008	42,500	60

The 1996 HFE was conducted without a recent tributary input. The HFE resulted in increases to sand volume at elevations around the 25,000 ft^3/sec water surface elevation and scour to lower elevation eddies. "*Results from the 1996 controlled flood experiment indicate that, during sediment-depleted conditions, sand deposited at higher elevation in downstream eddy sandbars is derived from the lower-elevation parts of upstream sandbars. Thus, controlled floods conducted under these conditions result in decreases in total eddy-sandbar area and volume (especially in Marble Canyon)*" (Topping et. al. 2006). It is not recommended to run future HFEs when these is no recent tributary sediment input and the channel sediment is depleted since it will erode sediment from long-term eddy storage (Hazel et. al. 2006a).

The 1997 high flow of 30,700 ft^3/s was conducted in November after Paria River flooding in August and September (Hazel et. al. 2000). The flow did not completely inundate the sand bars and the net bar thickness above 25,000 ft^3/sec did not increase. This was due to erosion of the existing high-elevation deposits offsetting any new deposition.

In 2000, another set of powerplant capacity flows (30,700 ft^3/s) were released during the low summer steady flows (LSSF) experiment. Unfortunately, there were little tributary sand inputs during 2000. Still the May and September 2000

HFEs did significantly increase volume and area of fine sediment in the eddy sandbars between the 8,000 ft^3/sec elevation and the 25,000 ft^3/sec elevation (Schmidt et. al. 2007). Changes above 25,000 ft^3/sec elevation were insignificant because these elevations were not deeply inundated. The volume below the 8,000 ft^3/sec water surface elevation decreased. Comparing the September 2000 HFE with the 1996 HFE shows that "*6 times less sediment was deposited as high-elevation eddy bars and channel-margin deposits, during the lower-discharge September 2000 Powerplant Capacity Flow, and a greater percentage of sediment was exported from Marble Canyon*." (Hazel et. al. 2006).

For the 2004 HFE, it was estimated that about 0.63 million metric tons of sand was supplied from the Paria River in the previous year (Topping et. al. 2010). The 2008 HFE had 1.12 million metric tons of sand. In 2004, the sandbars in Upper Marble Canyon were larger in total volume and area than after the 1996 flood. However, in Lower Marble Canyon, only 18% of the sandbars were larger in total volume and area above the 8,000 ft3/sec elevation than following the 1996 flood (Topping 2006). This was due to the fact that most of the new tributary sand in the system was located in Upper Marble Canyon when the HFE was conducted.

Based on monitoring surveys, the 2008 HFE deposited sand above the elevation reached by 25,000 ft^3/sec at nearly every study sight (Hazel et. al. 2010). Sandbars did not have a consistent response to the HFE, the total eddy thickness change are from -1.88 m to 1.13 m. Often, deposition above the 8,000 ft^3/sec elevation was offset by erosion below this elevation. The results showed that the total-site sand volume was greater for the 2008 HFE than for the 1996 and 2004 HFEs (Hazel et. al. 2010). In addition, there was less erosion at low elevations and in the main channel than from the 1996 and 2004 HFEs.

There was not a consistent response from every sandbar in Marble Canyon. The increases that are presented for total sand volume do not represent the site specific changes. There were four styles of sandbar change documented in the 2008 HFE response (Hazel et. al. 2010). The most common response was Style 1 (45%), which is characterized by a net increase in sand volume above and below the 8,000 ft^3/sec elevation. Style 2 (37%) is characterized by an increase in volume above the 8,000 ft^3/sec elevation, and degradation below this stage. Style 3 (16%) is characterized as net erosion at all stages and Style 4, which occurred at 1 site, is erosion above the 8,000 ft^3/sec stage and deposition below (Hazel et. al. 2010).

Using the comparison of the HFEs several lessons were discovered to be implemented of future HFEs. These are:

- A higher magnitude of flow will produce a larger sandbar response. Using a stage-discharge relationship developed for multiple locations within Marble Canyon (Hazel et. al. 2006b), the predicted stage increase is 3.5 feet between 31,500 ft^3/sec and 45,000 ft^3/sec. Therefore the sand can be deposited in higher available space for larger magnitude HFEs.

- The antecedent conditions are an important factor in the sandbar response. The three flows above 42,000 ft^3/sec resulted in increases in sandbar volume above the 8,000 ft^3/sec water surface elevation. Even though levels of sand enrichment were different for the three flows, the sandbar volume above 8,000 ft^3/sec was similar in Marble Canyon (Grams et. al. 2010). However, the 1996 flood *"resulted in a large net decrease in the total sand volume contained at the study site in Marble Canyon, while the 2004 and 2008 controlled floods resulted in smaller decreases in total sand volume"* (Grams et. al. 2010). Therefore, lesser enrichment results in greater erosion from the lower elevation portions of the eddies and degradation of the overall sand balance. This may not be a concern when HFEs are occurring many years apart and there is time to increase the sand balance with tributary inputs. However, if HFEs are happening once or twice per year, the overall sand balance and sand in the lower portions of the eddies becomes more of a concern.

These lessons were applied to the protocol that was set up for the EA. Based on the sandbar responses from previous HFEs, sand will be transported from lower eddy elevations to the higher elevations. The sandbars will begin to erode following an HFE. After the 2008 flood the median sandbar volume had returned to pre-HFE values in Marble Canyon 6 months after the HFE. The rate of erosion after each HFE differed and was "*positively correlated with the magnitude of average dam releases and inversely related to the magnitude of Paria River sand inputs for Marble Canyon*" (Grams et. al. 2010). The 2004 HFE has the lowest erosion rates while the 1996 HFE had the highest. These results provide motivation to conduct HFEs often to reverse the erosion that will inevitably occur. No experiments have been conducted where HFEs could potentially occur as often as every six months, monitoring and tracking the results and effects from repeated HFEs will be necessary.

Based on the literature summarized above, the HFEs recommended to occur by the modified sand budget model will cause an increase in the sand volume above the 8,000 ft^3/sec water surface elevation. Some sediment will be eroded from the lower eddies, but this amount will be minimized based on previous tributary sand inputs ensuring the system is not depleted. The redistributed sand will erode in the months following the HFE and the rate will be dependent on dam releases and any new tributary sand inputs.

A concept discussed in the existing literature is accommodation space, which is defined as the amount of space any one sandbar has to store sand. The success of frequent HFEs will depend on how much accommodation space is emptied from the previous HFE and available for sand storage in the next HFE. Depending on the rate of erosion there may be a diminishing rate of return on conducting multiple and consecutive HFEs. However, if the erosion rate is rapid, there may always be enough accommodation space in the sandbars to make an HFE efficient and successful at redistributing the sand to higher elevations. It is unknown how the system will react to frequent HFEs or multiple consecutive HFEs.

4 Conclusions

For the EA being produced by Bureau of Reclamation, the number of future HFEs (estimated frequency, magnitude, and duration) that could potentially occur was needed. A protocol was developed to determine when the conditions were feasible for an HFE to occur based upon past scientific monitoring and analysis. The protocol states that an HFE should be conducted when the increased flows will not cause a negative sand budget for the current accounting period. In addition, the HFE should be maximized for magnitude and duration to redistribute as much available sand as possible. A sand budget model developed by USGS (Wright 2010) was modified based on the protocol.

Future hydrology and sediment input traces were generated and used to run nine simulations in the modified sand budget model. Based on these, a HFE is performed in 56% of the potential implementation windows. Of these HFE's, 92% had a peak magnitude of 45,000 ft^3/sec. Typically HFEs occur in groups; 80% of the predicted HFEs had an HFE in the neighboring accounting periods. In the model, the occurrence of an HFE can be triggered by a certain level of sediment regardless of the hydrology. For the nine traces, the average monthly Paria sand load that always resulted in an HFE was 500,000 metric tons.

Based on the literature, the HFEs recommended by the modified sand budget model will cause an increase in the sand volume above the 8,000 ft^3/sec water surface elevation. Some sediment will be eroded from the lower eddies, but this amount will be minimized based on previous tributary sand inputs ensuring the system is not depleted. The redistributed sand will erode in the months following the HFE and the rate will be dependent on dam releases and any new tributary sand inputs.