Comparison of sediment-transport and bar-response results from the 1996 and 2004 controlled-flood experiments on the Colorado River in Grand Canyon

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Sandbars and other deposits of sand, silt, and clay are important because...

- Integral part of natural riverscape
- Provide riparian habitat, provide habitat for endangered native fish, protect archeological sites, and recreation

In the upstream 40% of Grand Canyon National Park, the amount of sand in the main channel and eddies has decreased by over 25% since the 1980s, in spite of the 1996 controlled flood experiment (Rubin et al, *EOS*, 2002; Flynn and Hornewer, *USGS-WRIR*, 2003; Schmidt et al., *GSA Special Paper*, in revision).
Effects of dam operations on sediment-transport

- Cut off ~94% of the sand formerly supplied to the Colorado River at the upstream boundary of Grand Canyon National Park (Topping et al., *WRR*, 2000)
- Removed seasonality in annual hydrograph (Topping et al., *USGS-PP*, 2003) by removing both base flows (when large volumes of sand would accumulate in the main channel) and flood flows (which eroded the accumulated sand from the channel, transferring part of it into eddy sandbars)
Sand-transport paradigm prior to the 1996 controlled-flood experiment

- Under normal powerplant releases from Glen Canyon Dam, tributary-supplied sand would accumulate in the main channel over multi-year timescales
- Accumulated sand could be transferred from the main-channel bed to eddies during controlled floods, increasing both the total area and volume of eddy sandbars
Sand-transport paradigm prior to the 1996 controlled-flood experiment

- Under normal powerplant releases from Glen Canyon Dam, tributary-supplied sand would accumulate in the main channel over multi-year timescales (FALSE; Rubin et al., EOS, 2002)
- Accumulated sand could be transferred from the main-channel bed to eddies during controlled floods, increasing both the total area and volume of eddy sandbars (ONLY PARTIALLY TRUE; Rubin et al., EOS, 2002)
Sand-transport paradigm prior to the 1996 controlled-flood experiment

- During year prior to 1996 controlled flood, tributary inputs of new sand were low and dam releases were moderate to high
- 1996 controlled-flood experiment conducted during period when river was relatively depleted with respect to sand

Reality

- Under normal powerplant releases from Glen Canyon Dam, tributary-supplied sand would accumulate over multi-year timescales (FALSE; Rubin et al., EOS, 2002)
- Accumulated sand could be transferred from the main-channel bed to eddies during controlled floods, increasing both the area and volume of eddy sandbars (ONLY PARTIALLY TRUE; Rubin et al., EOS, 2002)
During the 1996 controlled flood, ~3x the sand deposited in eddies above the stage associated with 8,000 ft³/s was eroded from eddies below this stage (Hazel et al., AGU Mono., 1999; Schmidt, AGU Mono., 1999). ~90% of the sediment exported was eroded from eddy sandbars (Hazel et al., JGR, 2006).
Design of 2004 controlled-flood experiment

• Keep dam releases relatively low (< 10,000 ft³/s) during September-November to allow the accumulation and retention of new tributary sand inputs in the channel

• If more than 800,000 metric tons of new sand were retained, follow this period of lower dam releases with a 60-hour release of 41,000 ft³/s in late November
More suspended sand in 2004
More suspended sand in 1996

Paria River

122-mile eddy

Lees Ferry gage (0-mile)

+ ~100%
+160 to +240%
+60 to +90%
-20 to -45%

Grand Canyon gage (87-mile)

National Canyon gage (166-mile)

above Diamond Creek gage (225-mile)

Glen Canyon Dam

Lake Mead

Little Colorado River
Lagrangian sampling

PARIA RIVER

LITTLE COLO. RIVER

CONCENTRATION (mg/l)

RIVER MILE

SILT & CLAY MEASURED DURING FIRST DAY OF 1996 FLOOD

SAND MEASURED DURING FIRST DAY OF 1996 FLOOD

SILT & CLAY DURING FIRST DAY OF PEAK FLOW IN 2004 FLOOD

SAND DURING FIRST DAY OF PEAK FLOW IN 2004 FLOOD
1996 controlled-flood experiment

No net change in sand volume downstream from 87-mile gage (0-mile)

Glen Canyon Dam
Paria River
Lees Ferry gage (0-mile)

National Canyon gage (166-mile)
122-mile eddy
Grand Canyon gage (87-mile)
Little Colorado River

Net erosion
Net deposition

Lake Mead
2004 controlled-flood experiment

- Net erosion
- Net deposition

Highest erosion rates upstream from here

Extremely slight net erosion between 87-mile and 225-mile

Slight net erosion

Lake Mead

Grand Canyon gage (87-mile)

above Diamond Creek gage (225-mile)

Paria River

Glen Canyon Dam

Lees Ferry gage (0-mile)

Little Colorado River

2004 controlled-flood experiment

Net deposition

Highest erosion rates upstream from here

Extremely slight net erosion between 87-mile and 225-mile

Slight net erosion

Lake Mead

Grand Canyon gage (87-mile)

above Diamond Creek gage (225-mile)
Sandbar topographic results

Compared to after the 1996 controlled flood

- Above river-mile 40, 50% of sandbars larger in volume and area above 8,000 ft³/s
- Between river-mile 40 and 87, only 18% of sandbars larger in volume and area above 8,000 ft³/s
- Between river-mile 87 and 225, only 31% of sandbars larger in volume and area above 25,000 ft³/s
Sediment-transport data indicate that >130,000 metric tons (>10%) of new sand in retention prior to the flood were deposited upstream from 30-mile Little Colorado River.

Net transfer of sediment into eddies during 2004 controlled flood: NEGATIVE

Net deposition from Lagrangian samp. trip: NEGATIVE

Interpolation of multibeam data yields +140,000 metric tons: POSITIVE

Grand Canyon gage (87-mile): NEGATIVE
Conclusions

- Because subsequent dam releases do not result in full recovery of lower-elevation parts of bars scoured during such floods, controlled floods conducted under sand-depleted conditions (1996) cannot be used to sustain sandbar area and volume.

- Substantial increases in total eddy-sandbar area and volume are only possible during controlled floods conducted under the sand-enriched conditions (2004) that follow large tributary floods.

- In future controlled floods, more sand than was available during the 2004 controlled-flood experiment is required to achieve increases in total eddy-sandbar area and volume throughout all of Marble and Grand Canyons.

- Tributary inputs larger than 1 million metric tons are relatively rare, therefore “more sand” can be achieved directly by augmentation from sand trapped in the reservoir impounded by Glen Canyon Dam, or perhaps indirectly by following each large tributary input of sand with short-duration controlled floods.