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Is there enough sand?

Evaluating the fate of Grand Canyon sandbars

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Motivation

- Science Symposium Panel: Several were declaring it a lost cause and that sediment augmentation is needed

- Knowledge Assessment Workshop: Primary question identified for sediment was “Is there a ‘flow-only’ (non sediment augmentation) operation that will rebuild and maintain sandbar habitats over decadal time scales?”

Goal here was to take a “big picture” approach to try to answer the question, Is there enough sand?

Approach

- **Define and evaluate the "best case scenario", in terms of hydrology and dam operations for rebuilding and maintaining sandbars (we call this scenario "optimal operations")**

- **Why this approach?**

  - **It's the logical first step - If the "optimal operations" don't "work", then non-flow measures may be evaluated. If the "optimal operations" do "work", it sets the upper bound for expectations and leads into more complex scenarios**

  - **The "optimal operations" are the easiest to analyze with available information, leading to the least uncertainty**

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Definition of "optimal operations"

Sand transport is non-linearly related to water discharge. It follows that lower flows transport less sand, and for a given flow volume, steady flows transport less sand than fluctuating flows.

Thus, for maximizing sand retention:

- "optimal hydrology" is minimum releases (8.23 MAF*)
- "optimal flows" are steady year-round
- result: 8.23 MAF steady = 11,400 cfs

Any accumulation would be below 11,400 cfs stage. Redistribution to higher elevations is required by periodic high flows (we assume an annual high flow with a hydrograph shape dependent on the supply condition for a given year)

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* This analysis was done before shortage criteria

Approach

Framework for analysis is the annual sand budget for Marble Canyon

$$\Delta M = M_{in} - M_{out}$$

M_{in} is tributary inputs, M_{out} is export

Redistribution of sand to bars can only happen if accumulation occurs during “intervening operations”:

$$\Delta M_{io} = M_{in} - M_{io}$$

If $\Delta M_{io} > 0$, then some fraction can be redistributed to bars

First step is to evaluate potential accumulation during intervening operations, ΔM_{io}

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Annual tributary inputs

$$\Delta M_{io} = M_{in} - M_{io}$$

M_{in} – annual tributary inputs

Paria ~ 1,500,000 metric tons per year
(Topping et al., 2000)

Others ~ 290,000* metric tons per year
(Webb et al., 2000)

Total ~ 1,800,000 metric tons per year

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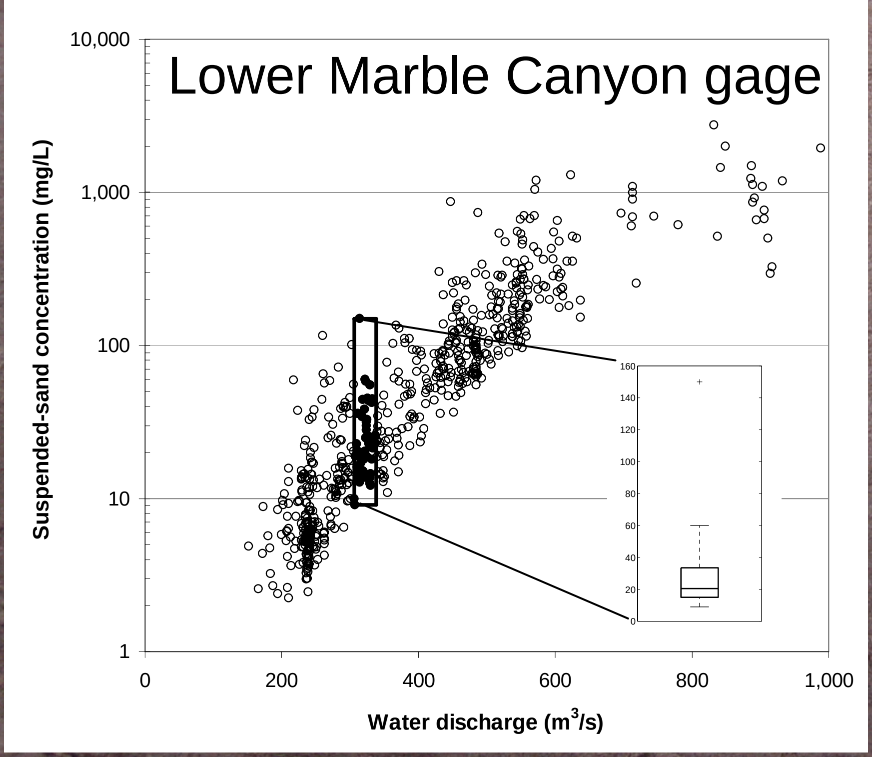
* recent data indicate this may be as much as a factor of two high

Annual export (non high flow)

$$\Delta M_{io} = M_{in} - M_{io}$$

M_{io} – annual export (non high flow)

To compute M_{io}, we need to estimate the sand concentration at 11,400 cfs



Using available data (and professional judgment) we estimated ~ 50 mg/L

Thus, M_{io} ~ 500,000 metric tons per year

Annual accumulation

$$\Delta M_{io} = M_{in} - M_{io}$$

ΔM_{io} = 1,800,000 – 500,000 = 1,300,000 metric tons per year

The “optimal operation” has the potential to accumulate about 1,300,000 metric tons per year (on average)

This sand would be below the 11,400 cfs stage; requires redistribution to higher elevations by high flows

How much can be retained in sandbars?

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High flow redistribution

As pointed out by Rubin et al. (2002), high flows are a “double edged sword” because, in order to redistribute sand to higher elevation, a substantial quantity must be exported:

$$\left(F_b + F_c + F_e\right)\Delta M_{io}$$

Fraction transferred to bars (F_b)

Fraction left behind in channel (F_c)

Fraction exported (F_e)

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High flow redistribution

Estimates of F_b

- Topping et al. (2006b) estimated that ~10-20% of the available tributary sand retained in the upper 50 km of Marble Canyon was still in the reach following the 2004 high flow event, presumably in sandbars

- Though the 1996 high flow event resulted in an overall net loss of sediment from sandbars (Schmidt, 1999, Hazel et al., 2006), there was a gain in high-elevation volume that was ~20% of the losses from the low-elevation portions of sandbars and the channel

- Hazel et al. (2006) estimated the potential active storage in sandbars in Marble Canyon to be ~13,000,000 metric tons, which is ~20% of the total pre-dam fine sediment load (sand and finer)

we chose F_b ~ 0.15

High flow redistribution

$$Sandbar\ \ accumulation = F_b \Delta M_{io}$$

Thus, we estimate that ~200,000 of the ~1,300,000 metric tons of accumulated sand could go towards bar-building. Since this is based on “optimal” operations, it can be considered the upper bound for expectations

If gains are maintained until the next high flow (an implicit assumption in our approach), response would be cumulative through time

How does this compare to post-dam erosion rates?

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Post-dam erosion rates

For Marble Canyon, we have relatively good estimates:

- In April-May 1965, ~16,000,000 metric tons was eroded from Marble Canyon (Rubin and Topping, 2001) – if 10% came from sandbars, this equates 1,600,000 metric tons which is about 8 times our estimated potential annual accumulation

- Schmidt et al. (2004) and Hazel et al. (2006) estimated the loss of fine sediment from sandbars from the pre-dam era through the 1990s to be ~6,000,000 metric tons. Over the approximately 40 years since dam construction, this equates to an average annual erosion rate of ~150,000 metric tons per year

potential accumulation ~200,000

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Conclusions

- The “best case scenario” for hydrology and dam operations has some viability for rebuilding and maintaining sandbar deposits
- The maximum rate at which sandbars could potentially be rebuilt is comparable to their erosion rate over the ~40 years since dam construction
- Deviations from “optimal conditions” (e.g. wetter hydrology, fluctuating flows) will decrease the rate of accumulation or result in net erosion
- The largest uncertainty is in estimating F_b. Can high flow hydrographs be “optimized” to promote sandbar building while minimizing export?

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Future work

- **Variable hydrology** – we assumed minimum releases (8.23 MAF) – if releases are higher, export increases and less sand is available for building sandbars. The difficulty in analyzing these scenarios is predicting future hydrology.

- **Fluctuating flows** – To evaluate a year-round steady flow, one discharge and one concentration are required. To evaluate fluctuating flows, hourly hydrographs, relations between discharge and sand concentration, and time series of tributary inputs are required. We are working on models to do this (LTEP), but they are not quite ready.

- **Optimized high flow hydrographs** – Need models capable of evaluating various hydrograph scenarios and supply conditions.

Final comments

Is there a ‘flow-only’ (non sediment augmentation) operation that will rebuild and maintain sandbar habitats over decadal time scales?

We think so, yes…

But, it is likely dependent on low volume releases

And, it will take time even under "optimal operations"

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