Project 2: Streamflow, Water Quality, Sediment Transport, and Sand Budgets in the Colorado River Ecosystem

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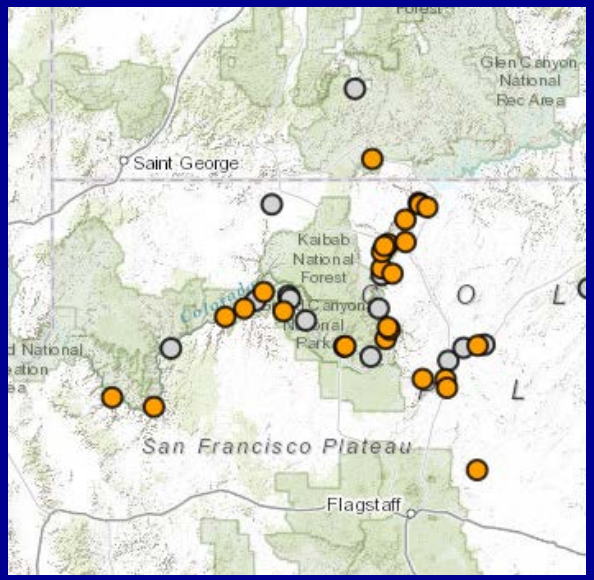
Project Overview

We collect, post, and analyze the following data at stations located through the Colorado River Ecosystem, including key tributaries…



- Stage
- Discharge
- Water temperature
- Salinity (specific conductance)
- Turbidity
- Dissolved Oxygen
- Suspended- and bed-sediment data
- Sediment loads (silt and clay loads and sand loads)
- User-interactive sand budgets in 6 reaches from Lees Ferry to Lake Mead
- User-interactive duration-curve tool for any continuous parameter

All other GCDAMP-funded projects use these data, and data from this project inform LTEMP

Citation for data and plots on most slides:

U.S. Geological Survey, 2018, Discharge, sediment, and water quality monitoring, Grand Canyon Monitoring and Research Center: accessed on January 14, 2018, at http://www.gcmrc.gov/discharge_qw_sediment/.

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The USGS team

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Work completed under 2015-2017 TWP to address the following fundamental science question…

How do operations at Glen Canyon Dam affect flows, water quality, sediment transport, and sediment resources in the Colorado River Ecosystem?

- All required monitoring data collected, processed, and posted to the web, including those data used to design and evaluate the Nov. 2014 and 2016 HFEs
- Substantial improvements to the project website at https://www.gcmrc.gov/discharge_qw_sediment/, including the release of user-interactive duration-curve plotting tool
- 10 peer-reviewed interpretive papers published (see list in Annual Report)
- 1 additional peer-reviewed journal article accepted for publication and four others in various stages of prep. and/or journal review

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Key drivers of sand transport and storage in the Colorado River Ecosystem

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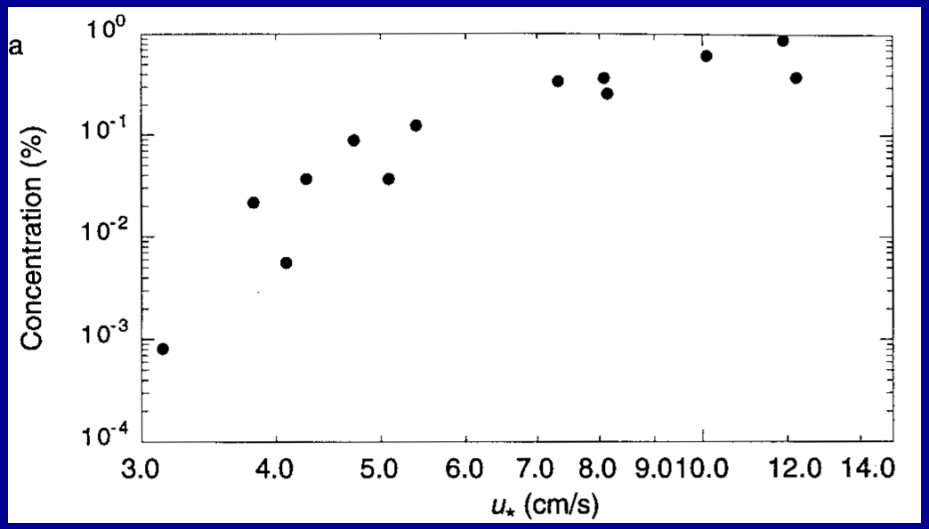
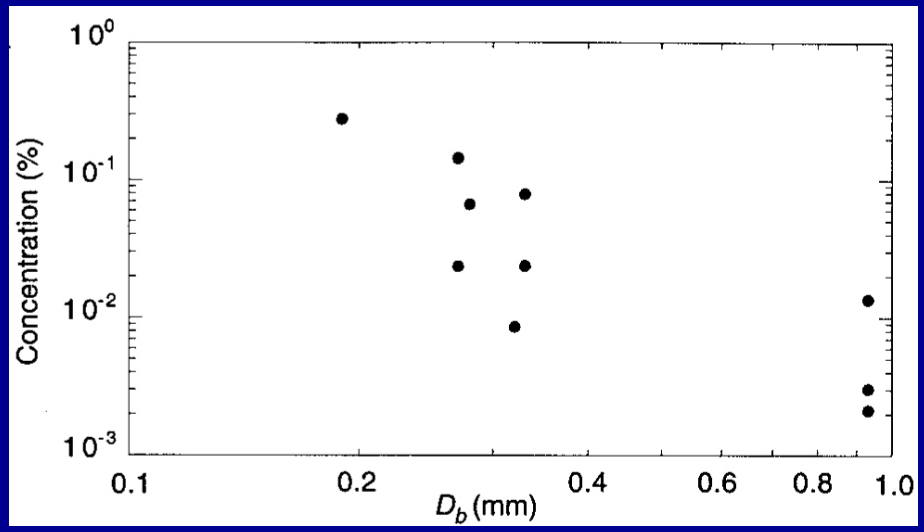
Sand concentration can be "regulated" by changes in flow and changes in bed-sand grain size (Rubin and Topping, *WRR*, 2001)



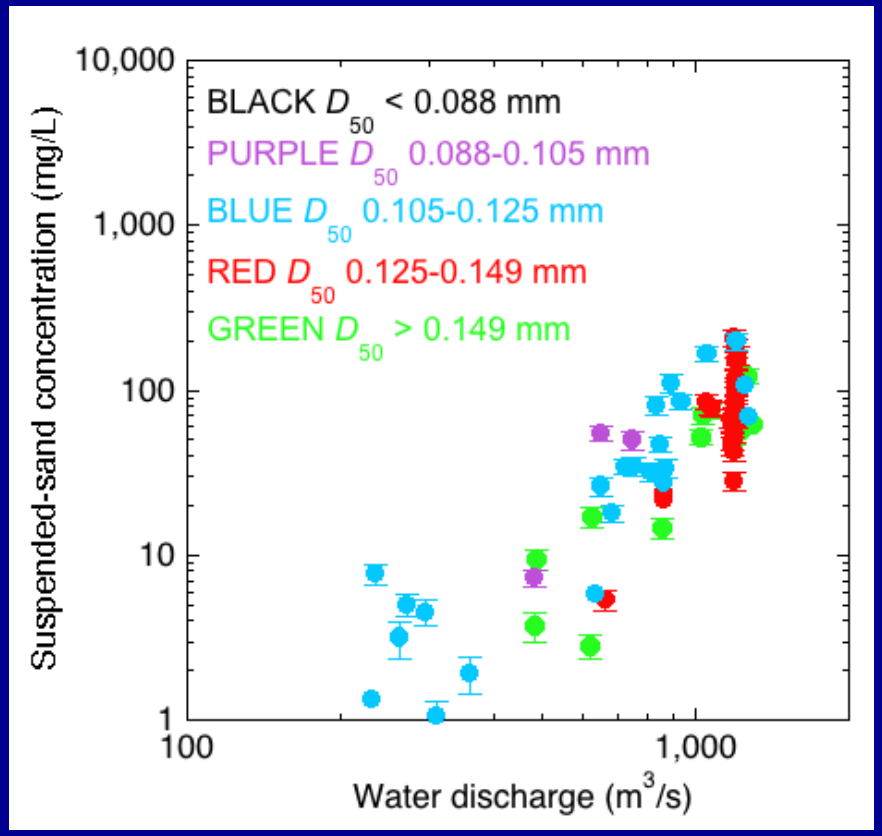


Increase in flow (discharge) with constant bed-sand grain size leads to increase in sand concentration

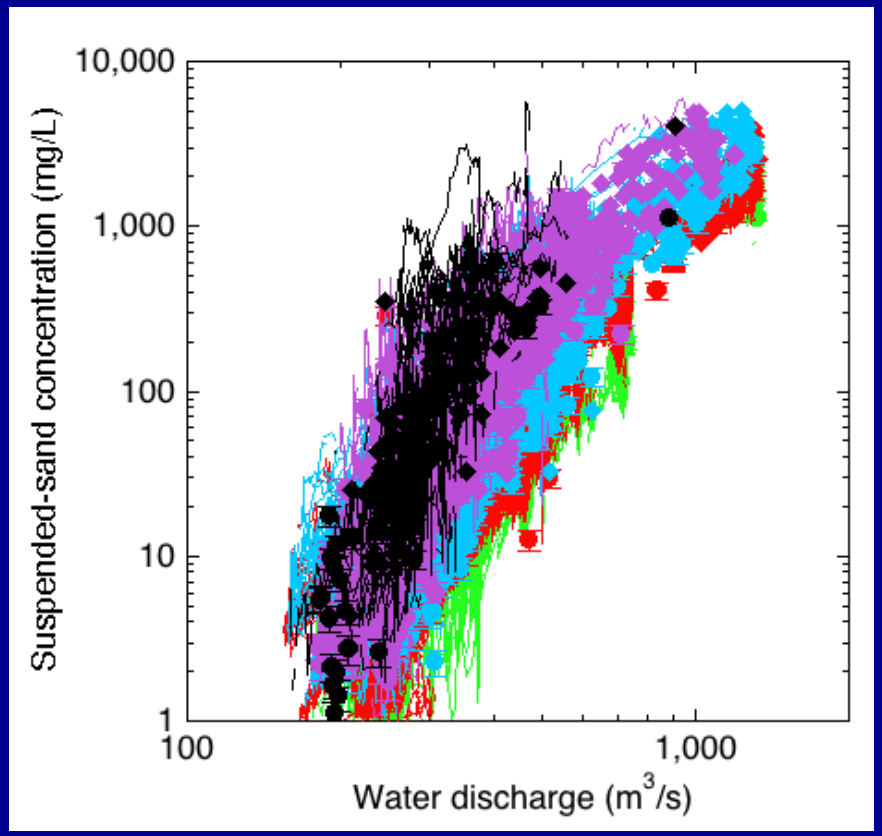
Increase in bed-sand grain size under constant discharge leads to decrease in sand concentration

Rubin and Topping (2001) plots of data from flume experiments of Guy et al. (1966)

α-analyses indicate that although changes in discharge generally regulate sand concentration, changes in bed-sand grain size play an important and sometimes dominant role in regulating suspended-sand concentration throughout the Colorado River in the CRE, including upstream from the Paria River at Lees Ferry



Lees Ferry gage (RM 0)



Grand Canyon gage (RM 87)

Data from USGS (2018)

Why is this the case?

1. Median size of tributary sand supply is finer than antecedent bed-sand grain size in Colorado River

- Flux-weighted mean D_{50} of Paria River sand supply was 0.133 mm among 3,256 physical suspended-sediment samples collected from 1996 through 2017
- Mean D_{50} of bed sand at RM30 was 0.336 mm among 85 cross-sectionally averaged measurements made from 1998 through 2017
- Minimum D_{50} of bed sand at RM30 was 0.165 mm and maximum D_{50} of bed sand at RM30 was 0.435 mm among these measurements

Data from USGS (2018)

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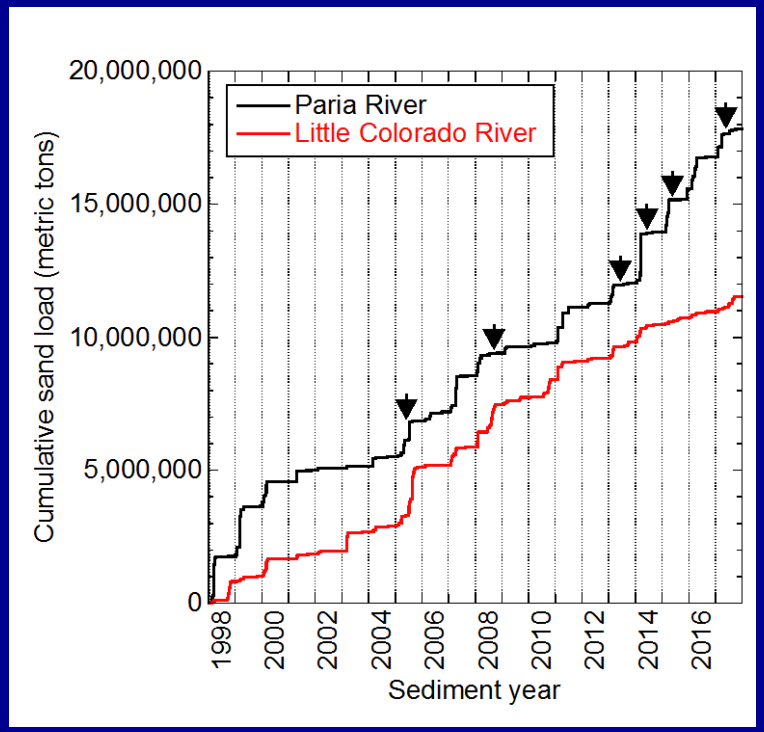
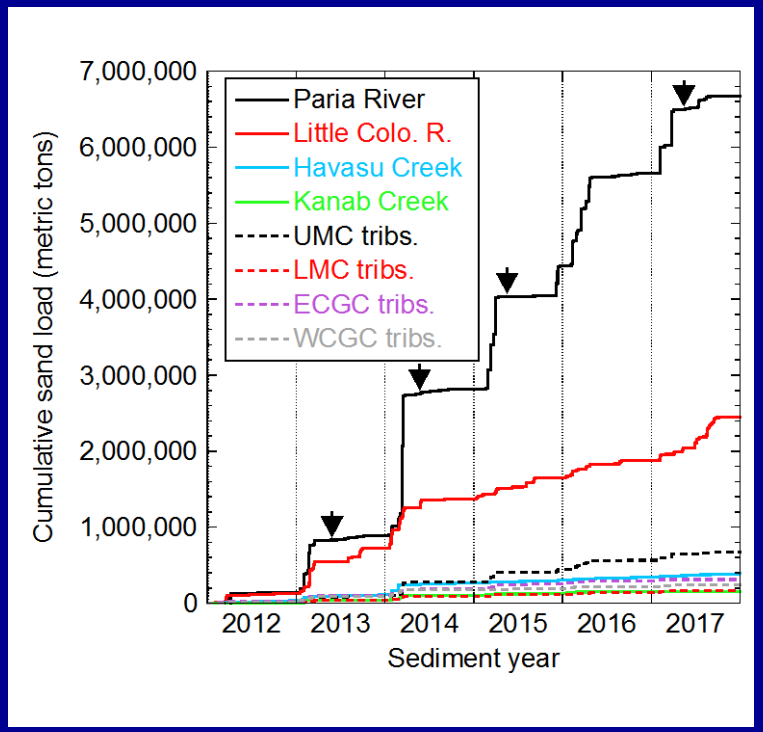
2. Tributary sand supply is highly episodic, with long periods of tributary quiescence when the discharge of the Colorado River is relatively high





- Long periods of time between tributary floods for bed to be winnowed
- Over last ~5 years, Paria River sand supply has been above average and the LCR sand supply has been below average
- Large sand-supplying floods in Paria River and LCR are poorly correlated
- Measurements indicate Paria River and LCR are only large suppliers of sand

Data from USGS (2018)

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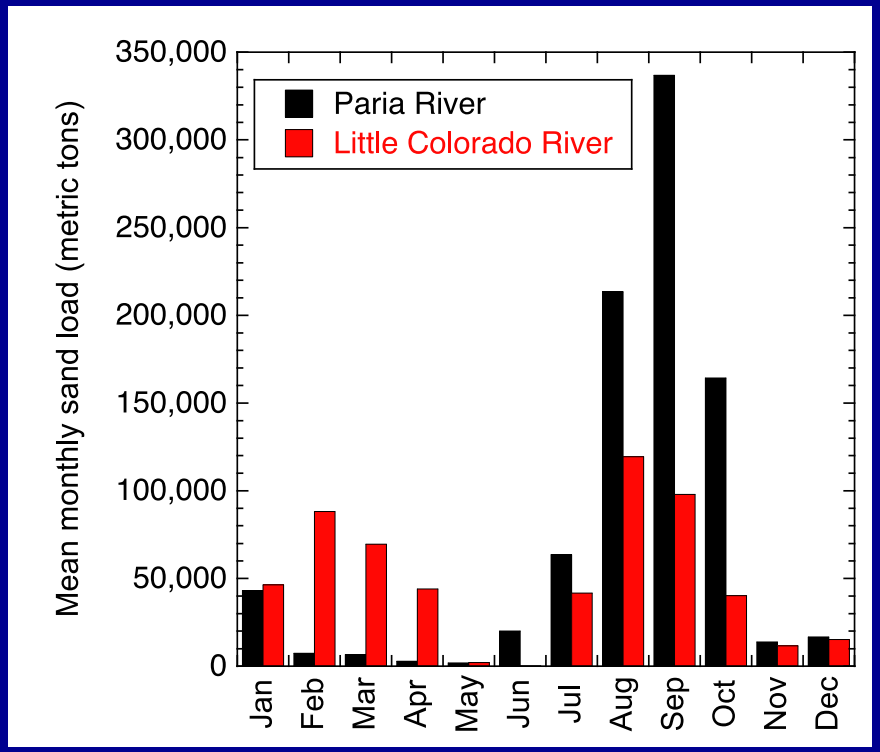
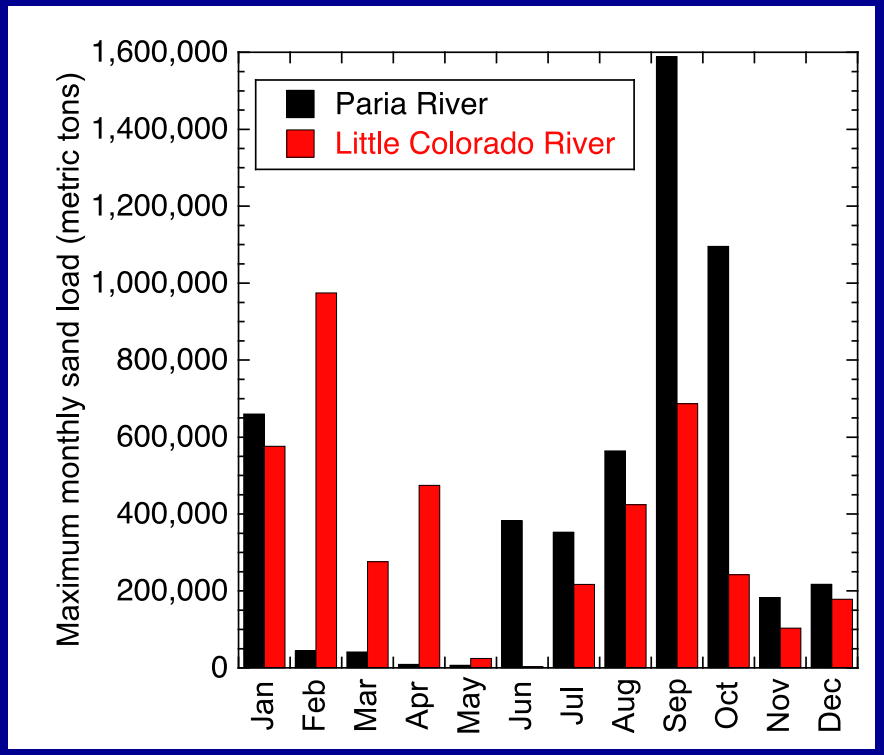


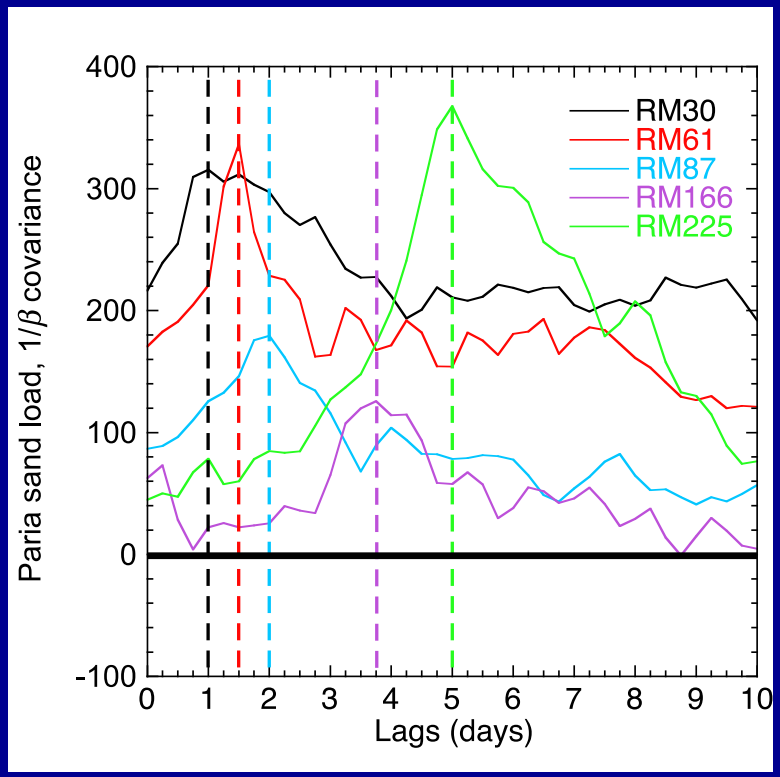


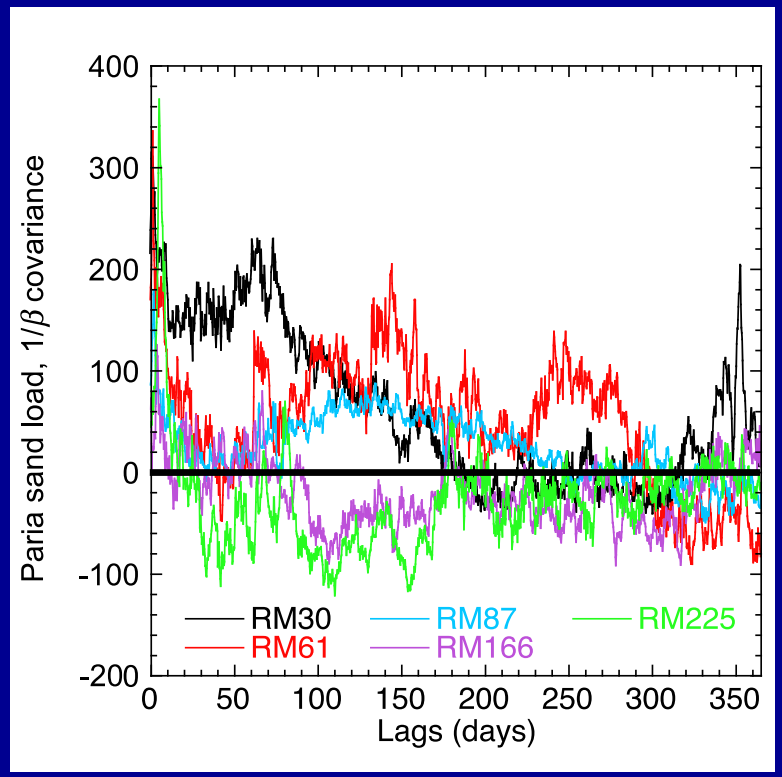
- **Almost all large Paria River floods occur during August through October**
- **Only two large Paria River floods have occurred in the winter during the last 20 years (January 2005 and December 2010)**
- **Thus, spring HFEs may only rarely occur because the HFE trigger in the LTEMP is reset on December 1**

Data from USGS (2018)

- **Lagged covariance analysis of 6-hour Paria River sand loads and Colorado River bed-sand grain size indicates that large Paria River floods generate sand waves with leading edges that migrate throughout the CRE within ~5 days**

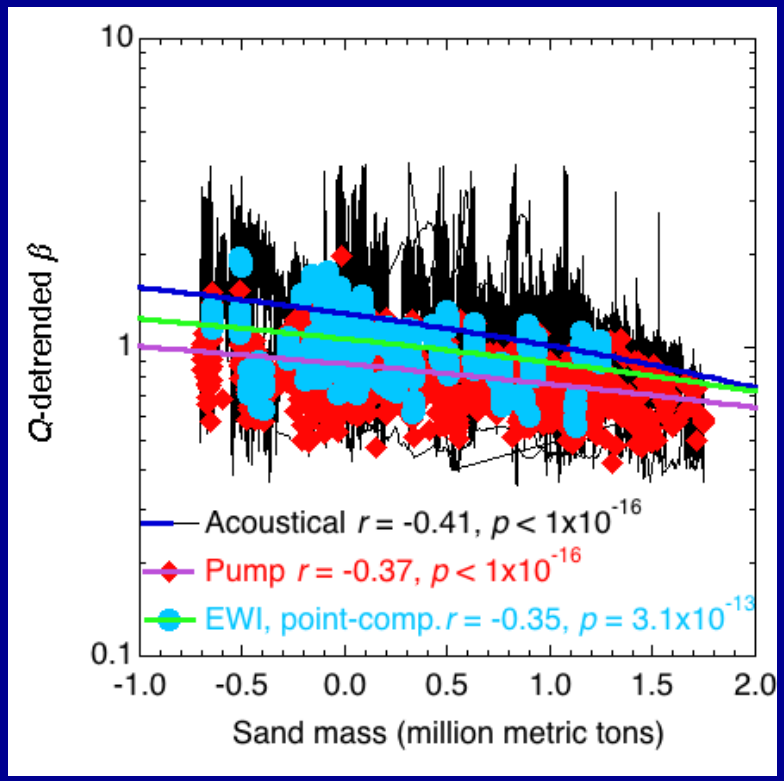
- **The sand waves generated during these floods cause fining of the Colorado River bed sand that persists for ~170 days after these floods in upper Marble Canyon, and over ~250 days in lower Marble Canyon and eastern Grand Canyon**



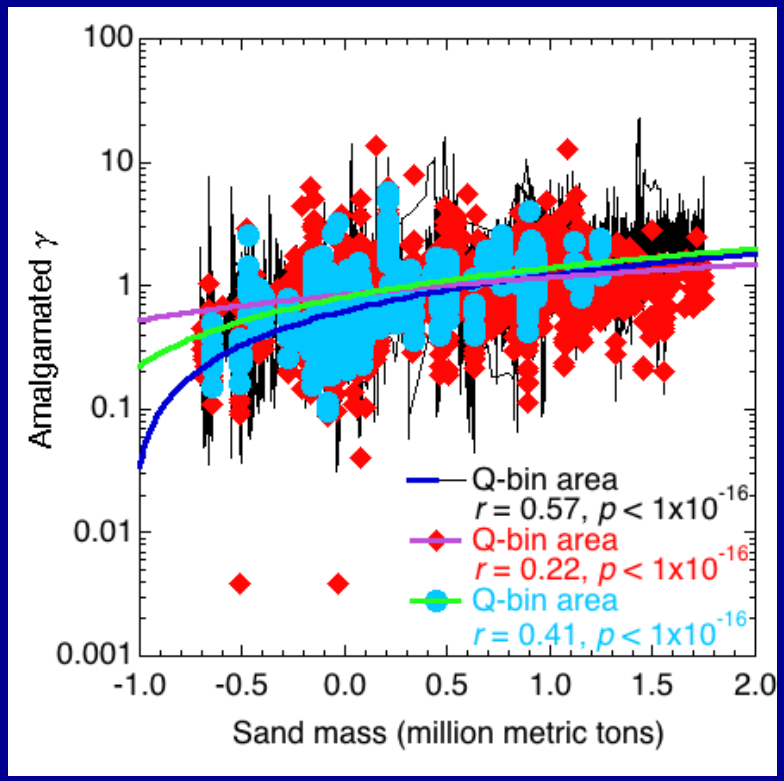


Analysis after Rubin and Topping (2001, 2008) and USGS (2018)

Downstream migration of sand waves leads to bed-sand grain size that is inversely correlated with sand storage and bed-sand area that is positively correlated with sand storage (FINER BED = MORE SAND IN STORAGE)



Nondimensional RM30 bed-sand grain size and Upper Marble Canyon sand budget



Nondimensional RM30 bed-sand area and Upper Marble Canyon sand budget

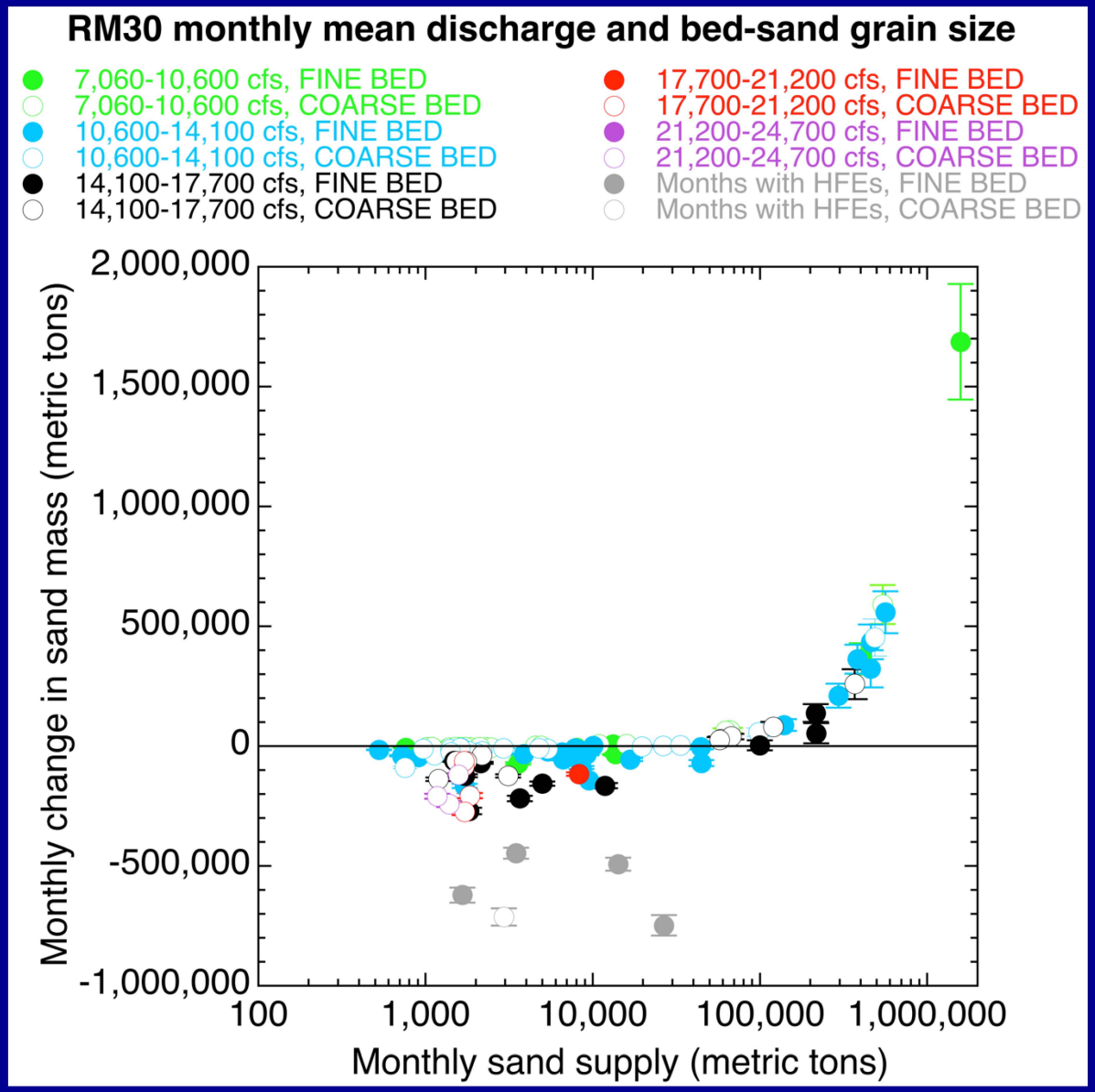
Analysis after Rubin and Topping (2001, 2008), Topping et al. (2010), and USGS (2018)

As sand storage increases…the bed-sand fines…leading to increased suspended-sand concentrations and increased sand export, thus self-limiting the amount of sand in storage

Colorado River near Grand Canyon, AZ, 09402500

Movie courtesy of David M. Rubin

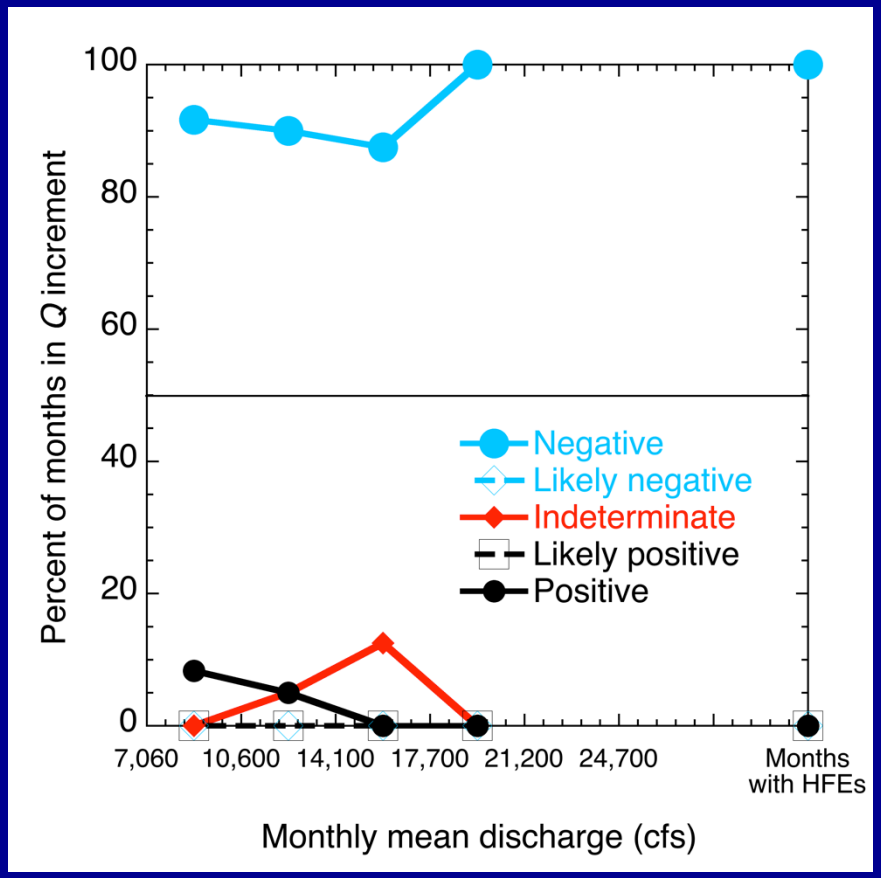
Monthly upper Marble Canyon sand budget is typically negative unless Paria River monthly sand load exceed 100,000 metric tons



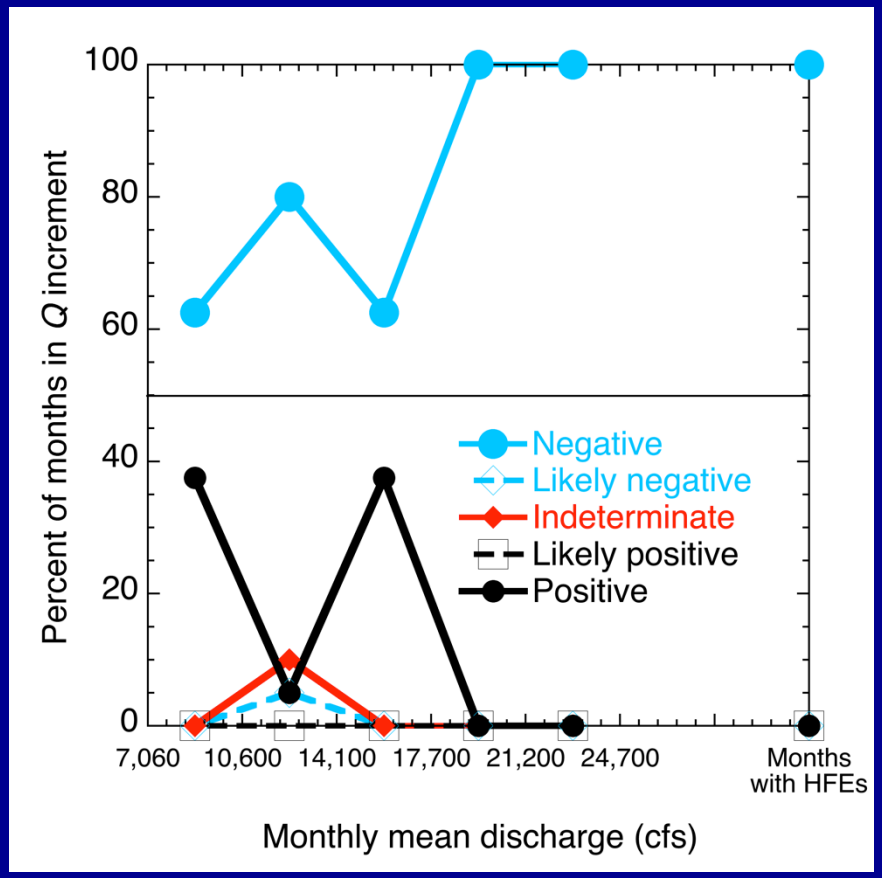
Analysis after Rubin and Topping (2001, 2008) and USGS (2018)

For cases where the Paria River month sand load <100,000 metric tons, monthly upper Marble Canyon sand budget tends to be "less negative" when bed-sand grain size is relatively coarse *(and amount of sand in storage is small)*

When monthly mean bed-sand grain size is finer than the 10-year median value…



When monthly mean bed-sand grain size is coarser than the 10-year median value…



Analysis after Rubin and Topping (2001, 2008) and USGS (2018)

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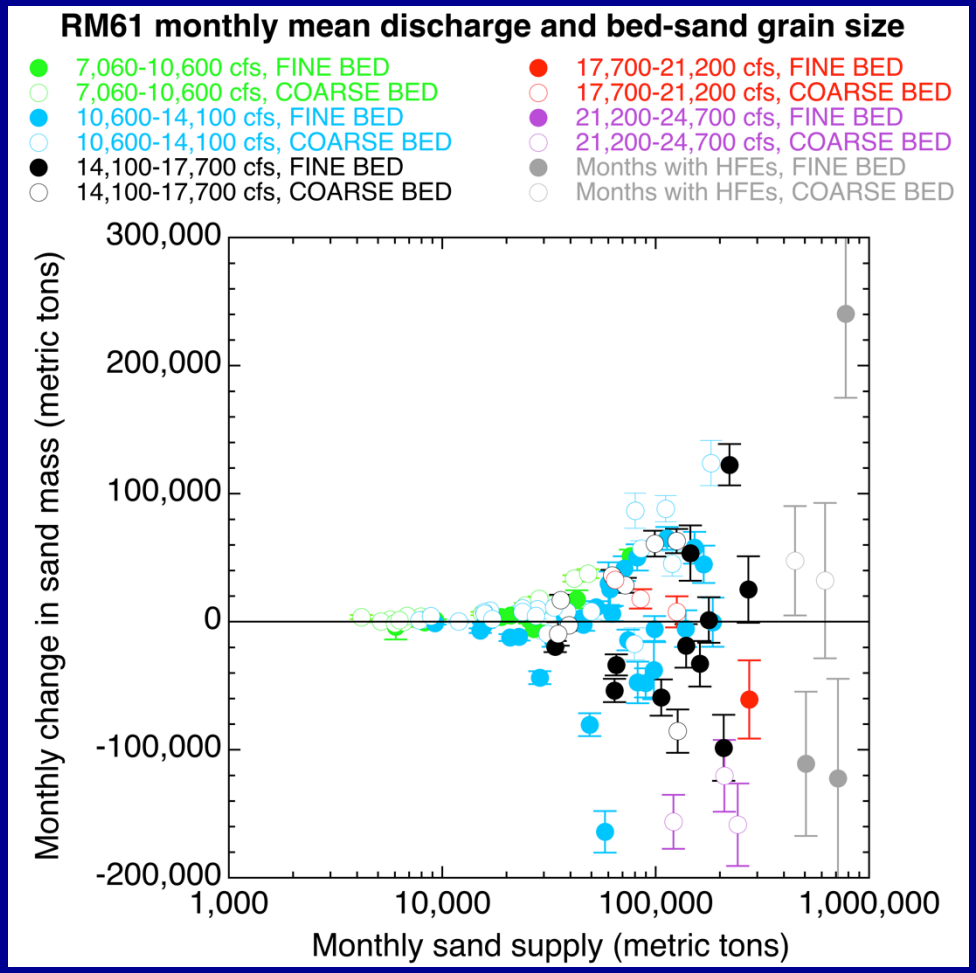
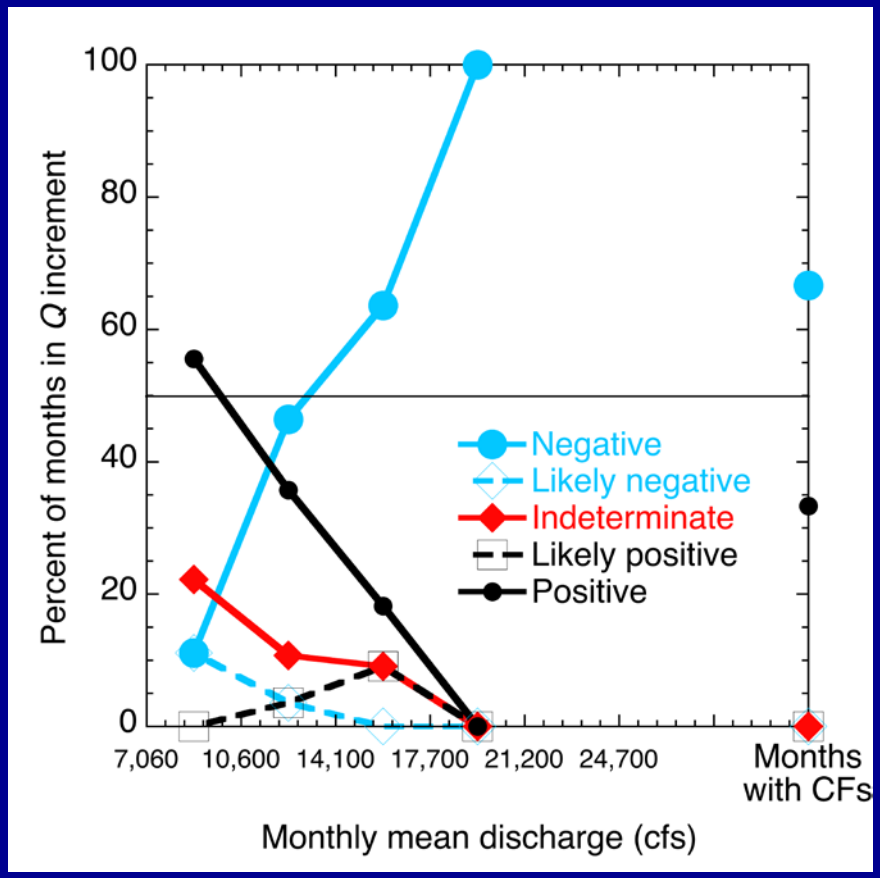
- **Monthly lower Marble Canyon sand budget tends to be negative, including during HFEs, when monthly mean discharge exceeds ~14,100 cfs and bed sand is fine *(and amount of sand in storage is large)***
- **Monthly lower Marble Canyon sand budget tends to be positive, including during HFEs, when monthly mean discharge is less than ~21,200 cfs and bed sand is coarse *(and amount of sand in storage is small)***



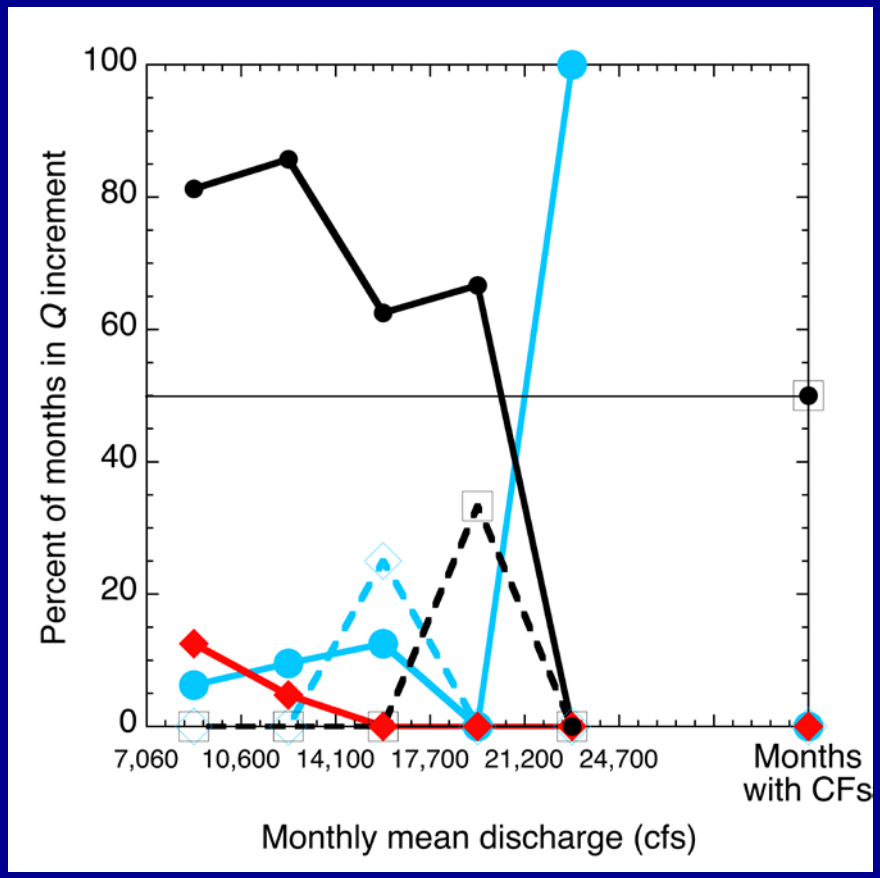
Analysis after Rubin and Topping (2001, 2008) and USGS (2018)

Although the monthly lower Marble Canyon sand budget remains positive under much higher discharges when bed-sand is coarse *(and amount of sand in storage is small)*, it is only generally positive when monthly mean discharge < 10,600 cfs

When monthly mean bed-sand grain size is finer than the 10-year median value…

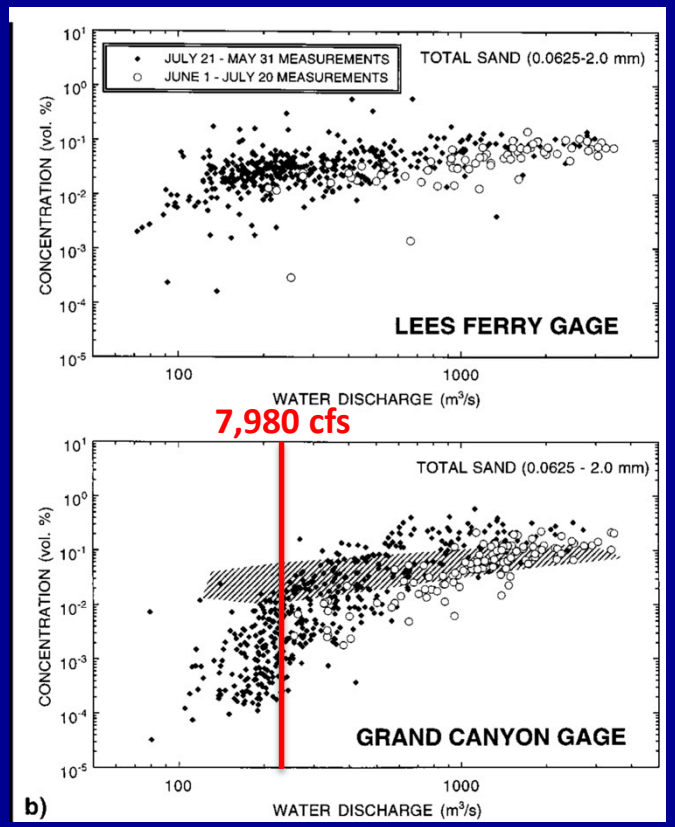


When monthly mean bed-sand grain size is coarser than the 10-year median value…

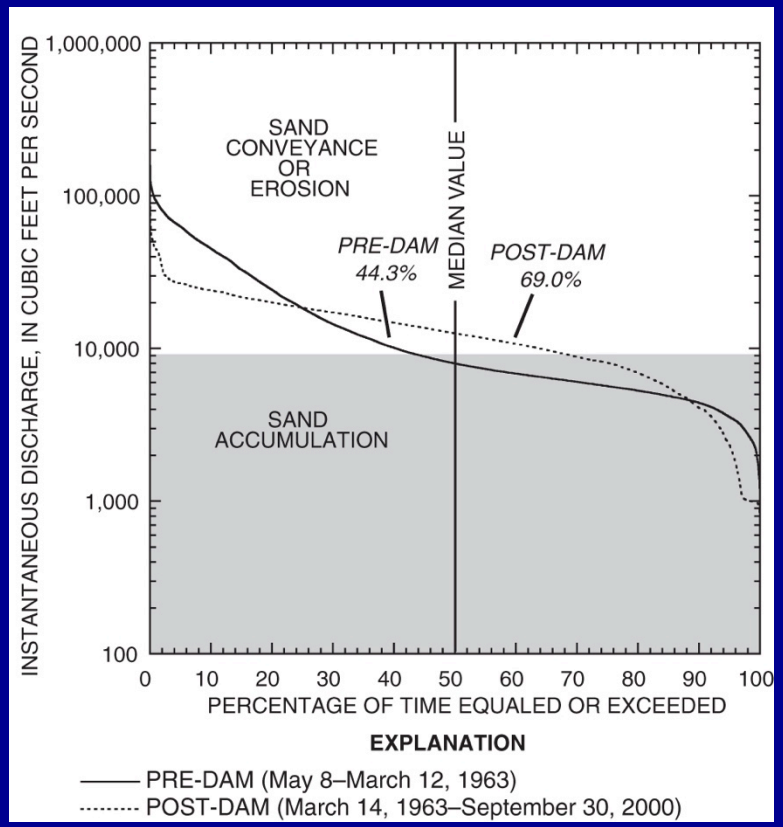


Analysis after Rubin and Topping (2001, 2008) and USGS (2018)

Even though pre-dam sand storage was also grain-size-limited, seasonal sand storage capacity was much larger because discharges < 7,980 cfs occurred half of the time



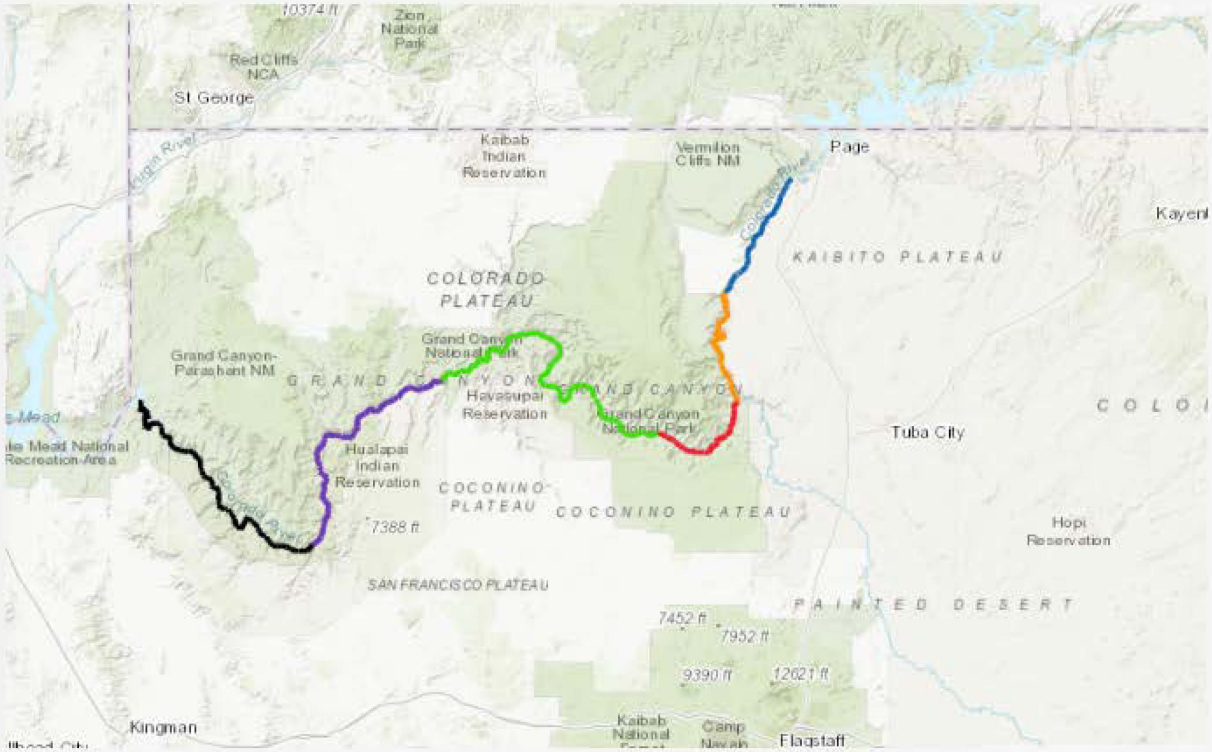
Topping et al. (*WRR*, 2000a)



Topping et al. (*USGS-PP, 2003*)

Pre-dam transition from sand accumulation to conveyance occurred above ~9,000 cfs

Grand Canyon Reaches



Reaches

Upper Marble Canyon
(Colorado River at Lees Ferry, AZ to Colorado River near river mile 30)

Lower Marble Canyon
(Colorado River near river mile 30 to Colorado River above Little Colorado River near Desert View, AZ)

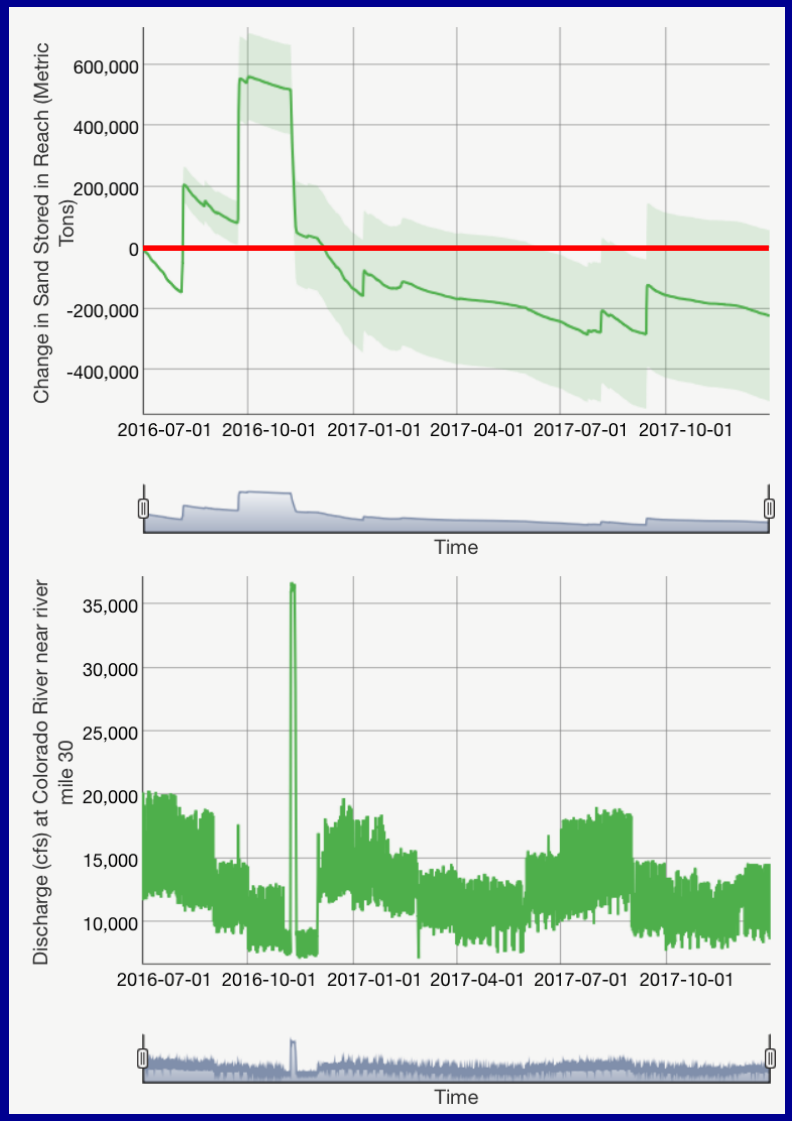
Eastern Grand Canyon
(Colorado River above Little Colorado River near Desert View, AZ to Colorado River near Grand Canyon, AZ)

East Central Grand Canyon
(Colorado River near Grand Canyon, AZ to Colorado River above National Canyon near Supai, AZ)

West Central Grand Canyon
(Colorado River above National Canyon near Supai, AZ to Colorado River above Diamond Creek near Peach Springs, AZ)

Western Grand Canyon and the Lake Mead Delta
(Colorado River above Diamond Creek near Peach Springs, AZ to Pearce Ferry near river mile 280)

Upper Marble Canyon
7-1-2016 to 1-1-2018



Change in Sand Mass

Zero Bias Value: **-220,000 Metric Tons**

Upper Uncertainty Bound: 58,000 Metric Tons

Lower Uncertainty Bound: -500,000 Metric Tons

Plots and values from USGS (2018)

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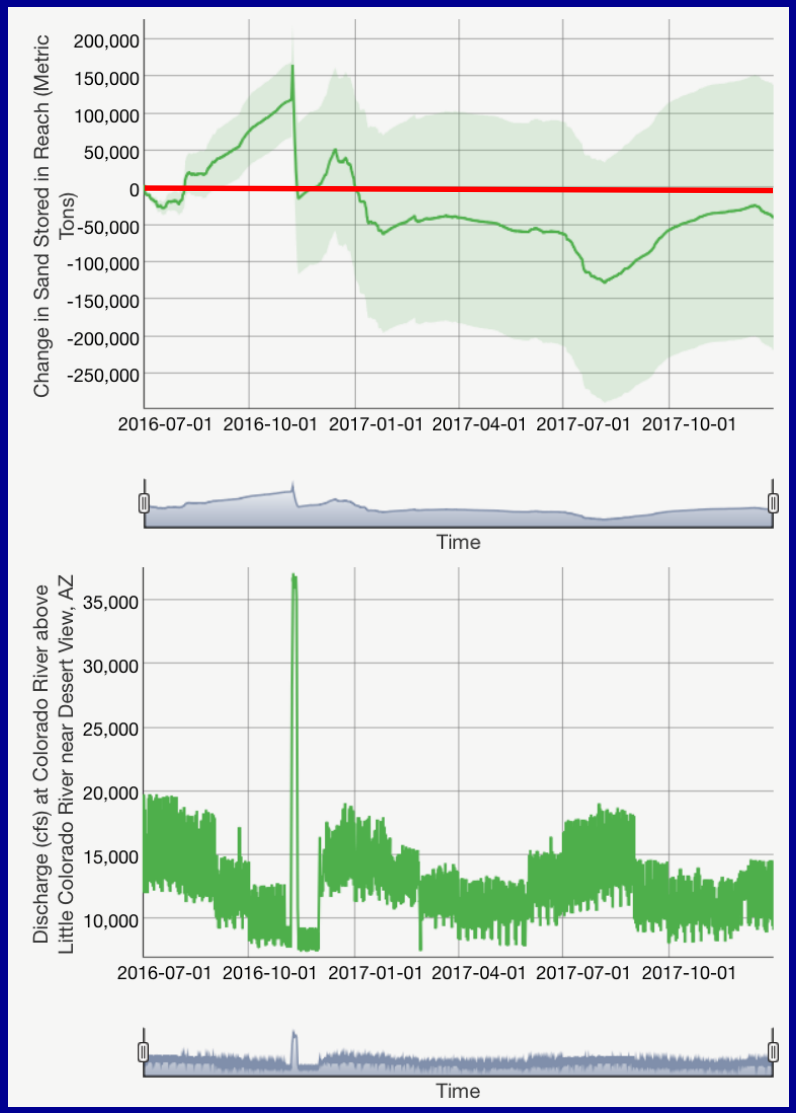
Lower Marble Canyon
7-1-2016 to 1-1-2018



Change in Sand Mass

Zero Bias Value: **-40,000 Metric Tons**

Upper Uncertainty Bound: 140,000 Metric Tons

Lower Uncertainty Bound: -220,000 Metric Tons

Plots and values from USGS (2018)

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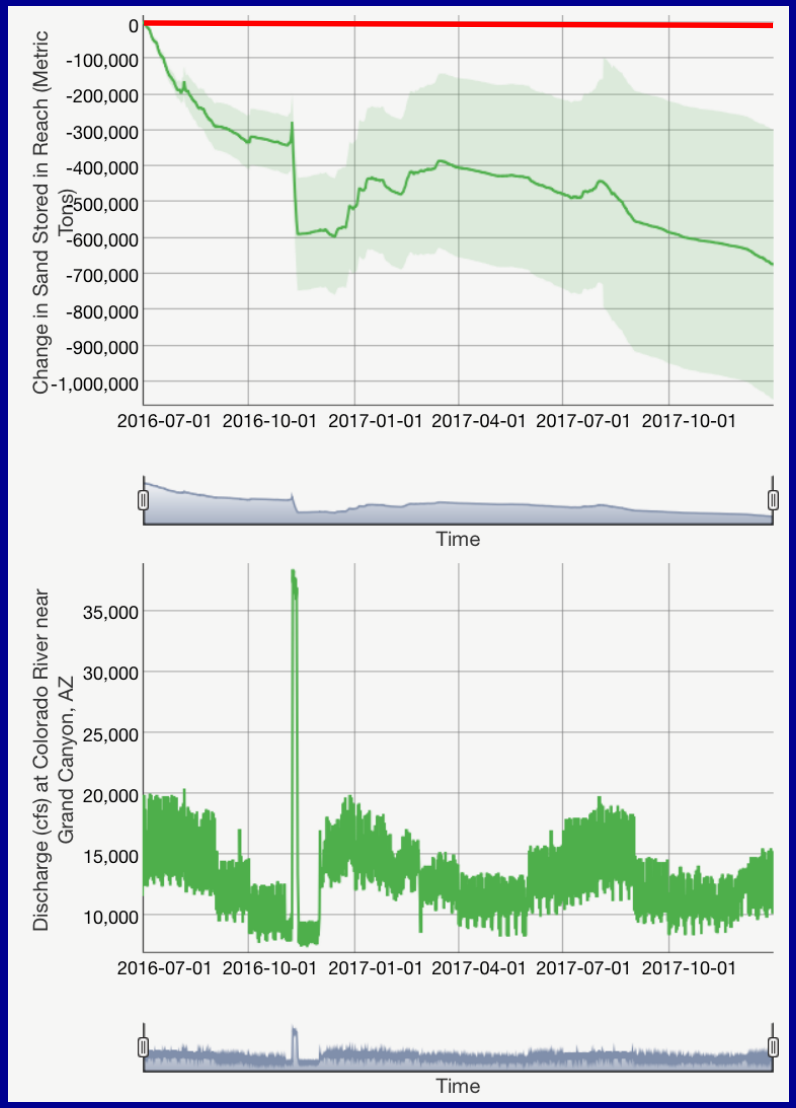
Eastern Grand Canyon
7-1-2016 to 1-1-2018



Change in Sand Mass

Zero Bias Value: **-670,000 Metric Tons**

Upper Uncertainty Bound: -300,000 Metric Tons

Lower Uncertainty Bound: -1,000,000 Metric Tons

Plots and values from USGS (2018)

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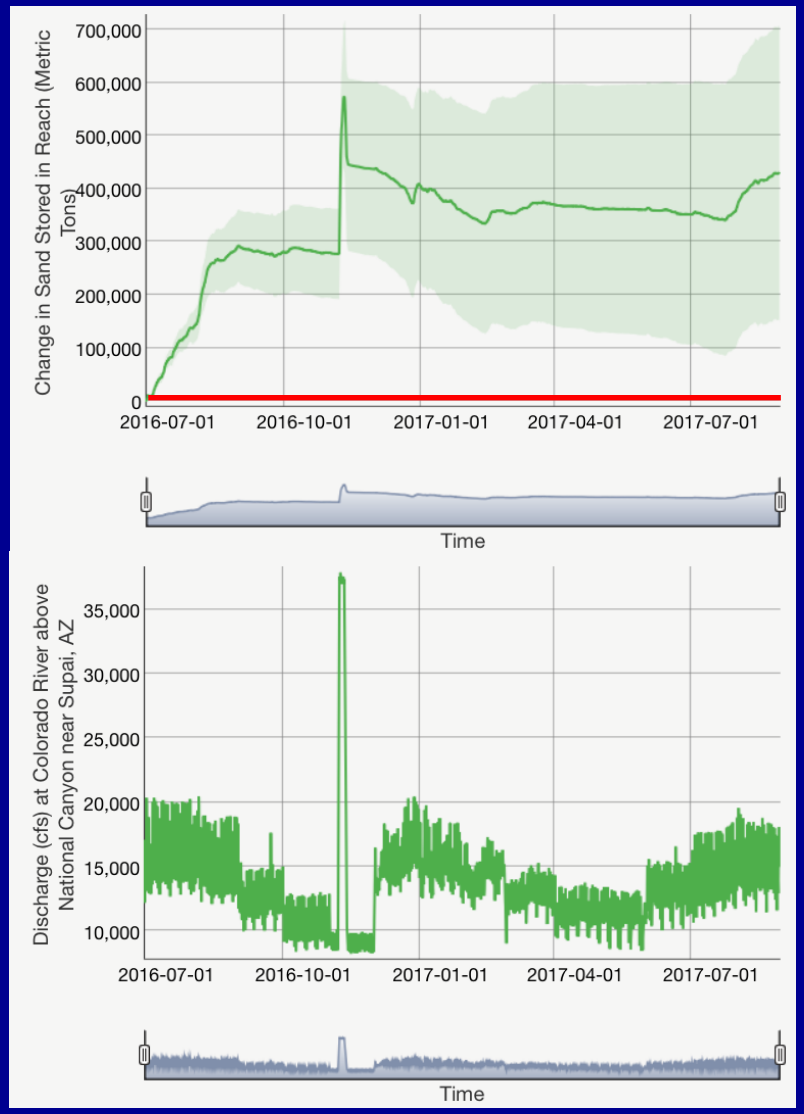
East Central Grand Canyon
7-1-2016 to 8-31-2017



Change in Sand Mass

Zero Bias Value: **430,000 Metric Tons**

Upper Uncertainty Bound: 700,000 Metric Tons

Lower Uncertainty Bound: 150,000 Metric Tons

Plots and values from USGS (2018)

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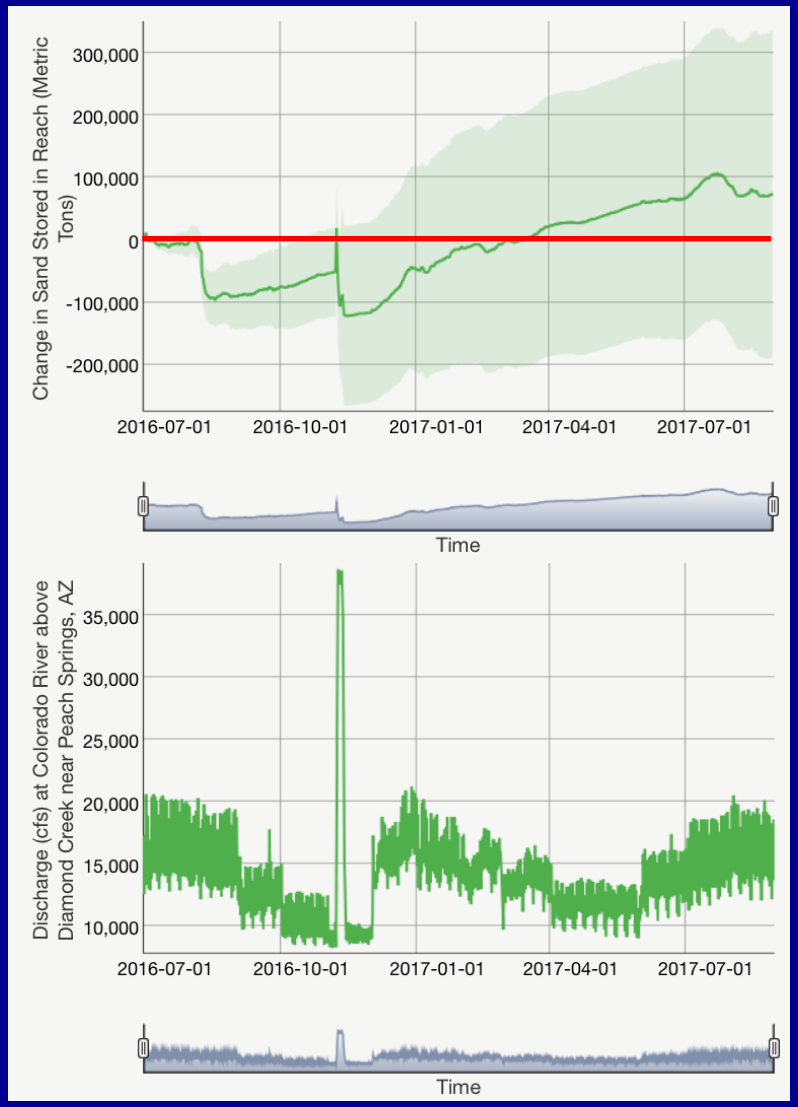
West Central Grand Canyon
7-1-2016 to 8-31-2017



Change in Sand Mass

Zero Bias Value: **75,000 Metric Tons**

Upper Uncertainty Bound: 340,000 Metric Tons

Lower Uncertainty Bound: -190,000 Metric Tons

Plots and values from USGS (2018)

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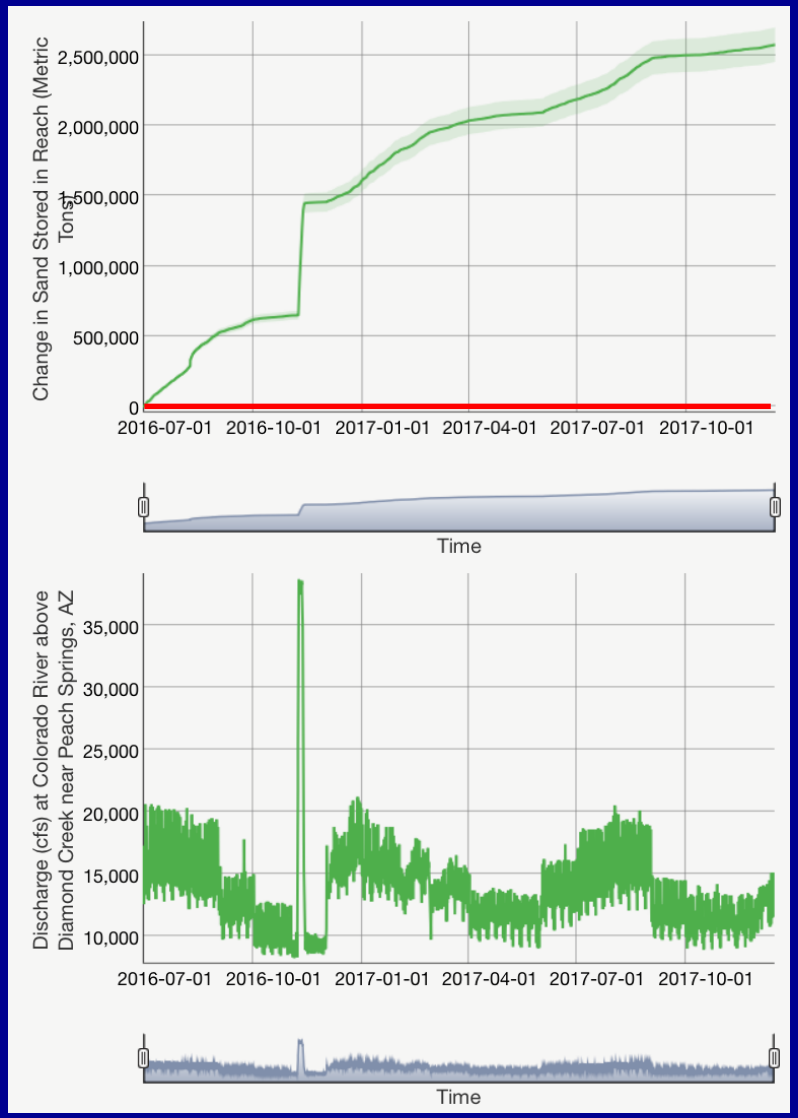
Western Grand Canyon and the Lake Mead Delta

7-1-2016 to 12-16-2017



Change in Sand Mass

Zero Bias Value: **2,600,000 Metric Tons**

Upper Uncertainty Bound: 2,700,000 Metric Tons

Lower Uncertainty Bound: 2,500,000 Metric Tons

Plots and values from USGS (2018)

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Although sandbars have generally been built in each reach during the 2004, 2008, 2012, 2013, 2014, and 2016 HFEs…

These controlled floods have had different systematic effects on the sand budget in some reaches as a function of the antecedent bed-sand grain size

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Conclusions

- Sand storage is grain-size-limited in the post-dam Colorado River under the relatively high discharges (i.e., >8,000 cfs) that are always released by Glen Canyon Dam
- Sign of upper Marble Canyon sand budget is typically negative unless Paria River has had a recent large flood
- Bed-sand grain-size regulation of sign of monthly sand budget becomes more important downstream from upper Marble Canyon
- Spring HFEs will be triggered only rarely because large Paria River floods are extremely rare in the winter and early spring
- Annual Marble Canyon sand budgets are negative at annual mean discharges >11,300 cfs (8.2 MAF) unless Paria sand inputs exceed 1.1 million metric tons, then budgets are negative when annual mean discharges >13,400 cfs (9.7 MAF)
- Annual Grand Canyon sand budgets are also negative at annual mean discharges >11,300 cfs (8.2 MAF) unless Paria + LCR sand inputs exceed 2 million metric tons, then budgets remain positive until annual mean discharges >14,800 cfs (10.7 MAF)
- It remains unclear whether sand resources are sustainable except during periods when Paria River and LCR sand inputs are above average and dam releases are relatively low (i.e., <13,400 cfs or 9.7 MAF)

Thank you