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Sandbars and In-Channel Sand Storage: Short-Term Dynamics and Long-Term Trends

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Paul Grams and David Topping, Grand Canyon Monitoring and Research Center
Joe Hazel and Matt Kaplinski, Northern Arizona University

U.S. Department of the Interior
U.S. Geological Survey

The Question

Is there a “Flow-Only” operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

- A definitive answer requires precise definition of “restore and maintain.”
- Lacking that, we study and report on trends in sandbars and sand storage:
  - Do management actions (dam releases) build sandbars?
  - Can we expect these management actions continue to achieve the desired results indefinitely?

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Outline of Presentation

- Sandbar "dynamics"
  - Why do sandbars get bigger and smaller?
- Long-term trends in sandbars
  - Issues of sample size
  - Can we separate short-term dynamics from long-term trends?
  - What are the long-term trends?
- Trends in sand storage
  - How is this different from trends in sandbars?
  - Why does it matter and how will this knowledge inform management decisions?
  - How do we measure it?

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Preview

- Main Points
  - Sandbars above the 8,000 cfs stage at the NAU long-term monitoring sites
    - In Marble Canyon, most are smaller now than in 1990
    - In Grand Canyon, most are larger now than in 1990
  - Sand Storage
    - Floods and high flows deplete sand from storage
    - Tributary inputs put sand into storage
    - Need to repeat measurements over long reaches to understand long-term trends
- Key Concepts
  - The difference between sandbar response and sand storage
  - Sandbar response is a function of both hydrology and sand storage

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Sandbar Dynamics:

- Sediment enriched floods generally build sandbars at “high” elevations
- Sediment enriched low flows generally build sandbars at “low” elevations
- All non-enriched flows generally erode sandbars: higher flows do it faster
  - Rate of post-flood sandbar erosion positively correlated with flow and inversely correlated with tributary sand input
- The sandbars we measure when monitoring are a function both of sediment supply condition and recent flows

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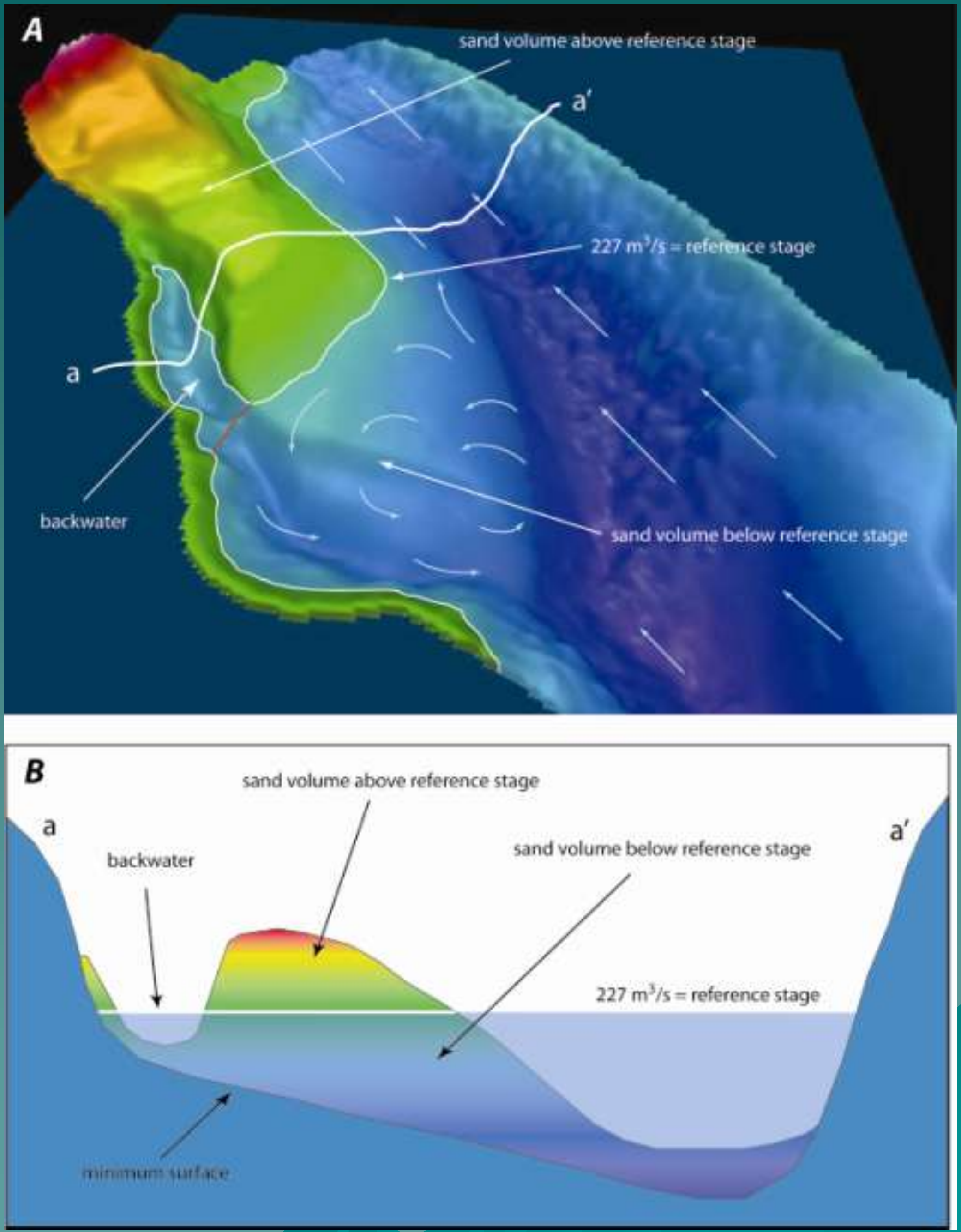
Hazel and others (2010); Schmidt and Grams (2011)

Anatomy of a Sandbar

~50 to 90% of the sand in Marble Canyon is stored in eddies. About 90% of the sand in eddies is stored below the stage elevation reached by a flow of 8,000 ft^3/s (Hazel et al., 2006, J. Geophys. Res., 11).

Why do sandbars change?

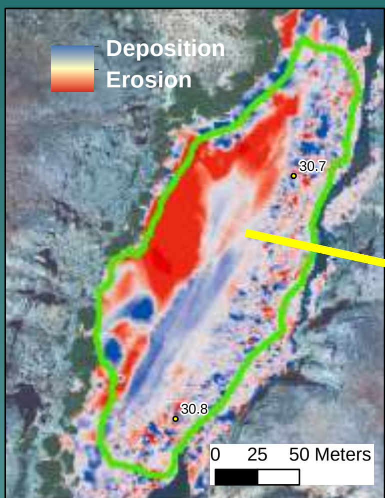
- Sand Supply
  - More sand → larger bars
- Hydrology (flow)
  - Sandbar morphology (shape) adjusts to flow
  - Some eddies may tend to gain sand at a certain flow while others lose sand at the same flow

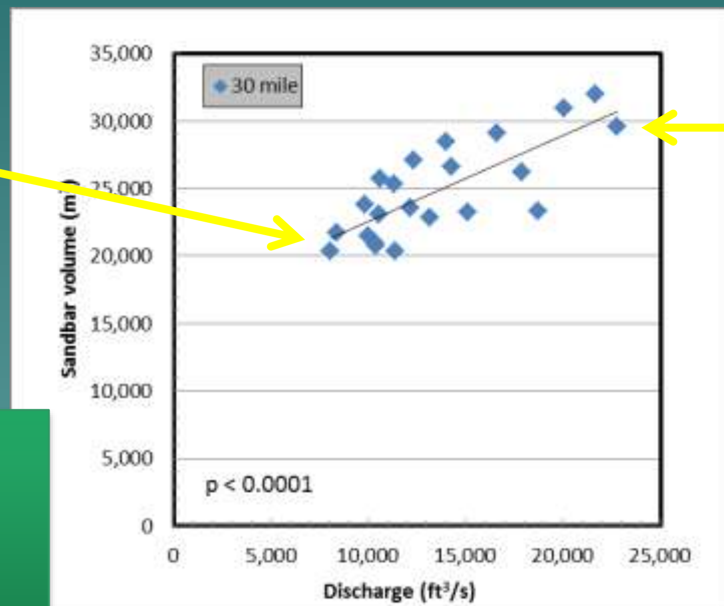


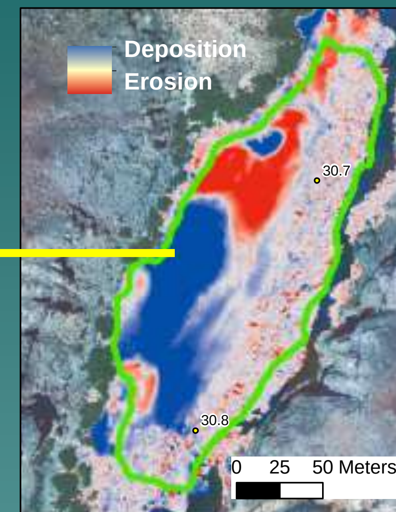
Grams and others (2010)

Discharge-dependent sediment redistribution: What does it mean?

More sand in eddy at higher flows







Small sandbar in period of positive sediment budget, but low discharge

Large sandbar in period of negative sediment budget, but high discharge

22 measurements from 1993 to 2008

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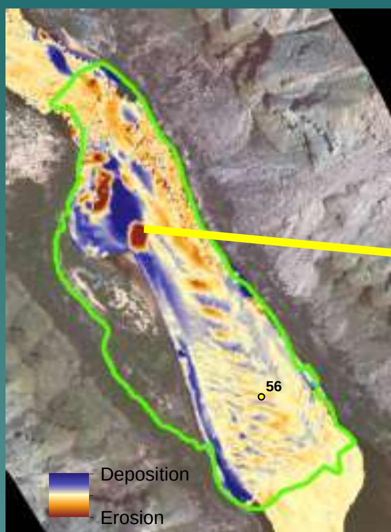
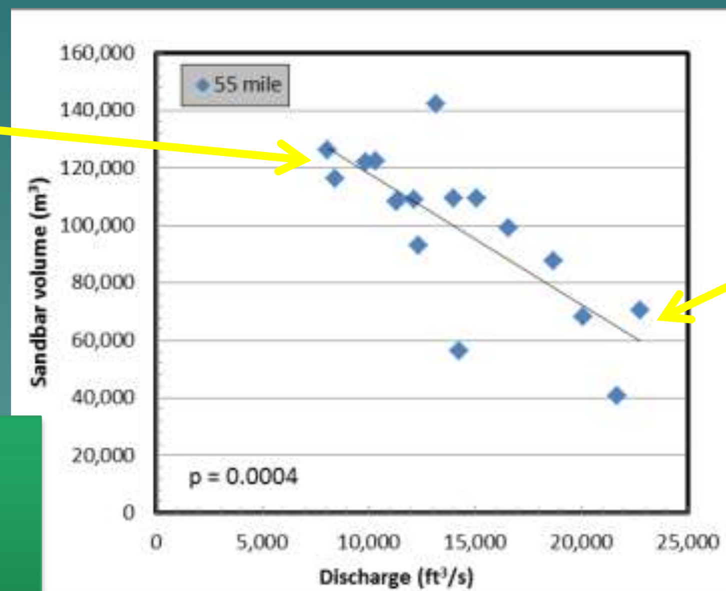
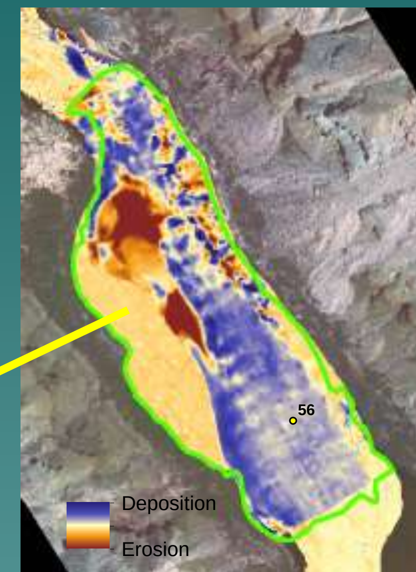
Preliminary Results -- Subject to Review and Revision

Discharge-dependent sediment redistribution

More sand in eddy at lower flows







Large sandbar in period of positive sediment budget, and low discharge

Small sandbar in period of negative sediment budget, and high discharge

17 measurements from 1996 to 2008

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RM 30 – Dynamic and “Collects” Sand at High Discharge

November 26, 2010 -- ~10,000 cfs

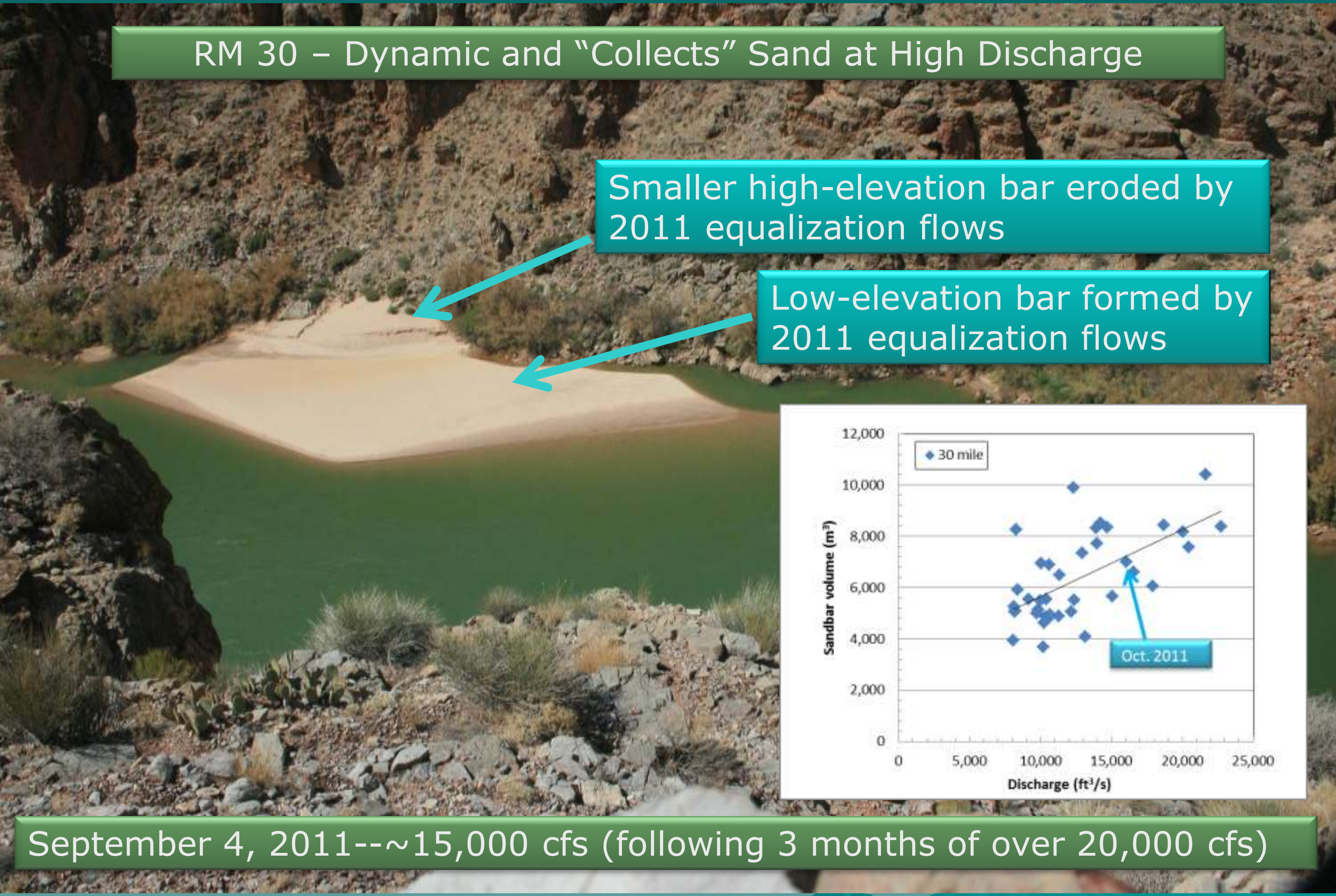
RM 30 – Dynamic and "Collects" Sand at High Discharge

August 8, 2011 -- ~25,000 cfs

RM 30 – Dynamic and "Collects" Sand at High Discharge

Smaller high-elevation bar eroded by 2011 equalization flows

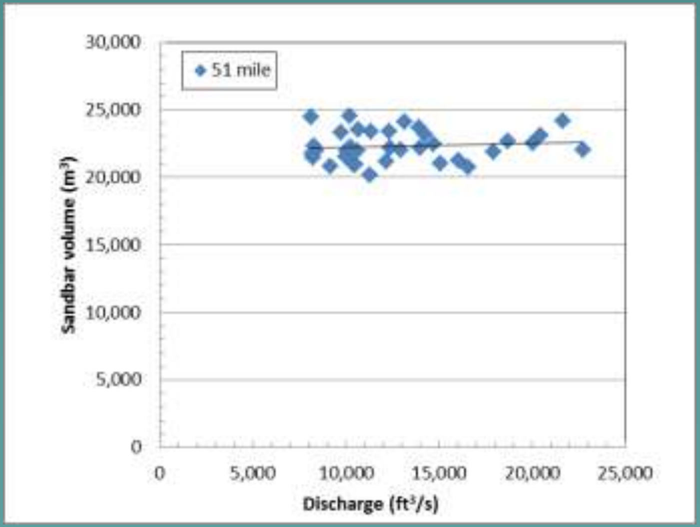
Low-elevation bar formed by 2011 equalization flows



September 4, 2011--~15,000 cfs (following 3 months of over 20,000 cfs)

RM 51 – "Can't get it to do anything"

- Does not respond differently to different flows
- Always about the same
- Need greater supply to build larger bar



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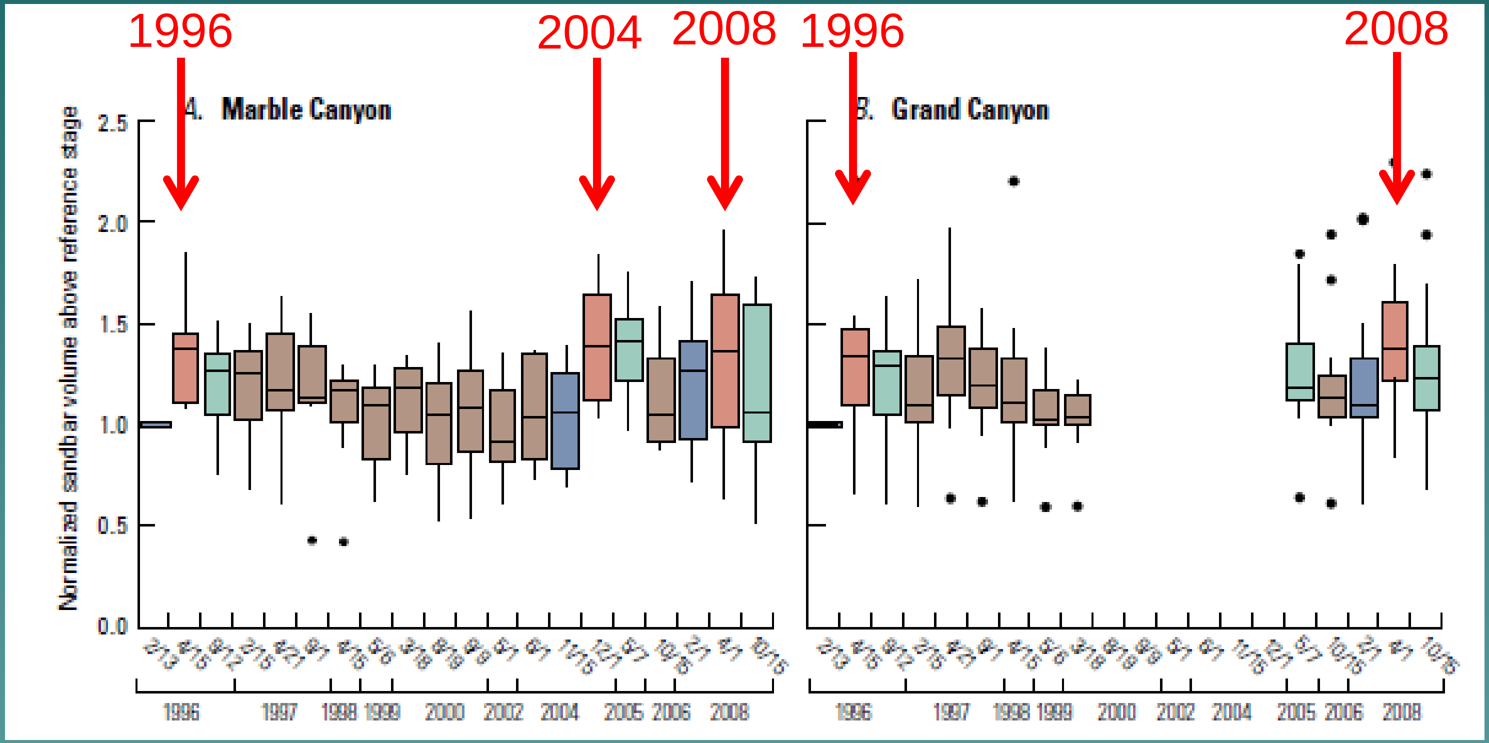
Floods cause increase in sandbar size at middle-and high-elevations:
Both supply and discharge are important

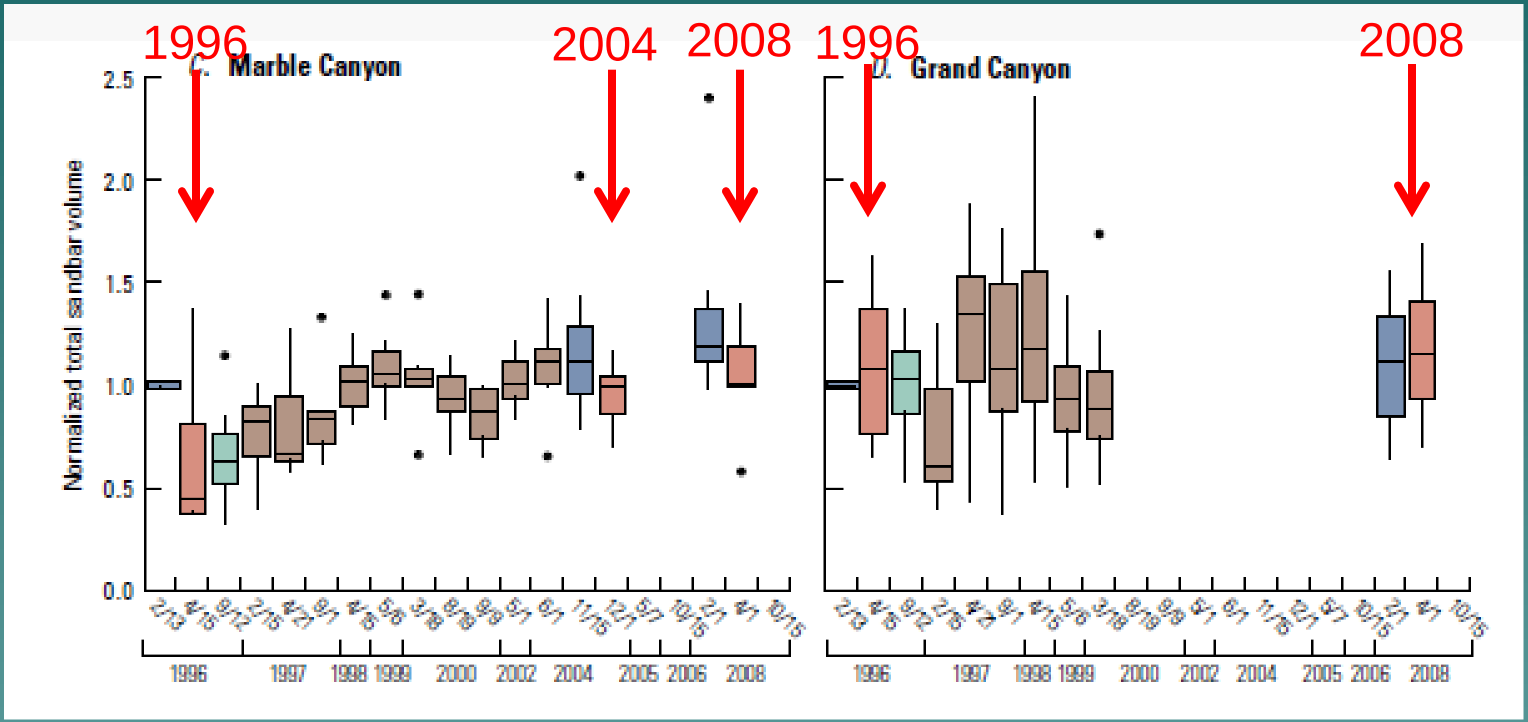


*middle- and high-elevation = above 8,000 ft^3/s stage

- 1996: high flow builds sandbars despite lack of supply
- 2004 and 2008: flow and supply work together for stronger bar building response

Hazel and others (2010); Schmidt and Grams (2011)

Floods cause decreases in sand storage at low-elevations: Discharge most important but supply makes a difference



*low-elevation = below 8,000 ft^3/s stage

- 1996: high flow greatly depletes low-elevation storage
- 2004 and 2008: much less depletion of low-elevation storage

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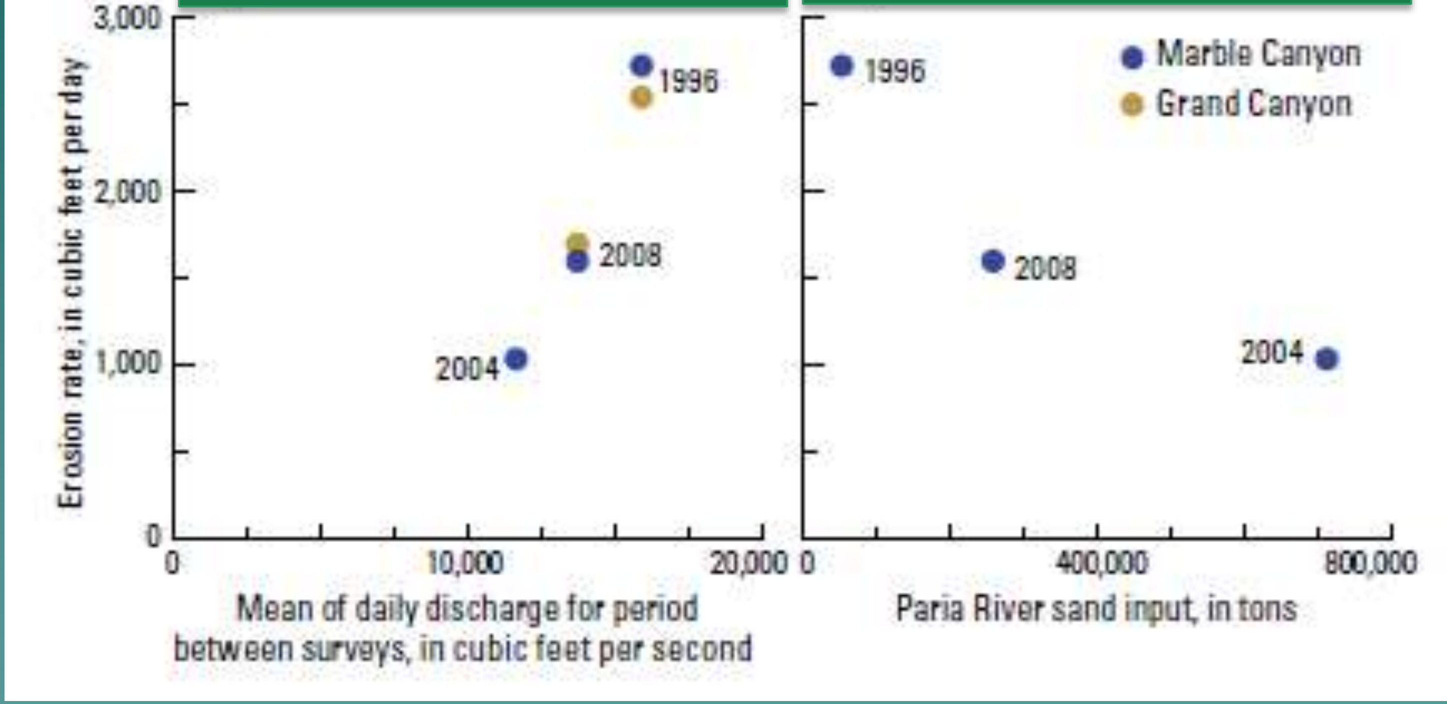
Hazel and others (2010); Schmidt and Grams (2011)

Sandbars erode following floods, but at different rates

Higher flows → higher erosion rates

Tributary resupply → lower erosion rates



- Both flow and supply affect sandbar deposition and erosion
- *Can we separate the two effects?*

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Grams and others (2010); Schmidt and Grams (2011)

Long-term Trends in Sandbars

- What is existing long-term dataset?
  - 24 sites for 1996 to 2008 total site storage change
  - 30 sites for 1990 to 2011 high-elevation storage change (above 8,000 cfs stage)
- How many sandbars are there?
  - Schmidt mapped 55 of the 140 km between Lees Ferry and Phantom Ranch
  - Found 183 eddies that have had at sometime between 1935 and 1996 a sandbar larger than 1000 m^2 in area
  - Extrapolated out, that means about 1600 such sites between Lees Ferry and RM 277
  - *We are monitoring fewer than 2% of the sites that have had sandbars at some time in the past*

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Schmidt and others (2004)

Long-term Trends in Sandbars

- Monitoring sandbars as campsites:
  - About 400-500 campsites between Lees Ferry and Diamond Creek that may be associated with sandbars
  - About 6% are long-term monitoring sites.

- Monitoring sandbars as backwaters:
  - About 880 potential backwater locations between Lees Ferry and Diamond Creek
  - Monitored all by inventory in 2008
  - Monitored 105 by topographic measurement in 2008
  - About 3% are long-term monitoring sites.

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Long-term Trends in Sandbars: What to do about undersampling

- Undersampling might be okay if we knew monitoring sites were representative
  - Sites might be representative for middle and high-elevation sand in Marble Canyon (next slide)
  - Don’t know about Grand Canyon
  - Probably not representative for low-elevation sand anywhere
- Initiated repeat mapping of long (~30-mi) reaches
  - Monitors all sandbars in reach
  - Also basis for long-term change in total sediment storage (more on this later)

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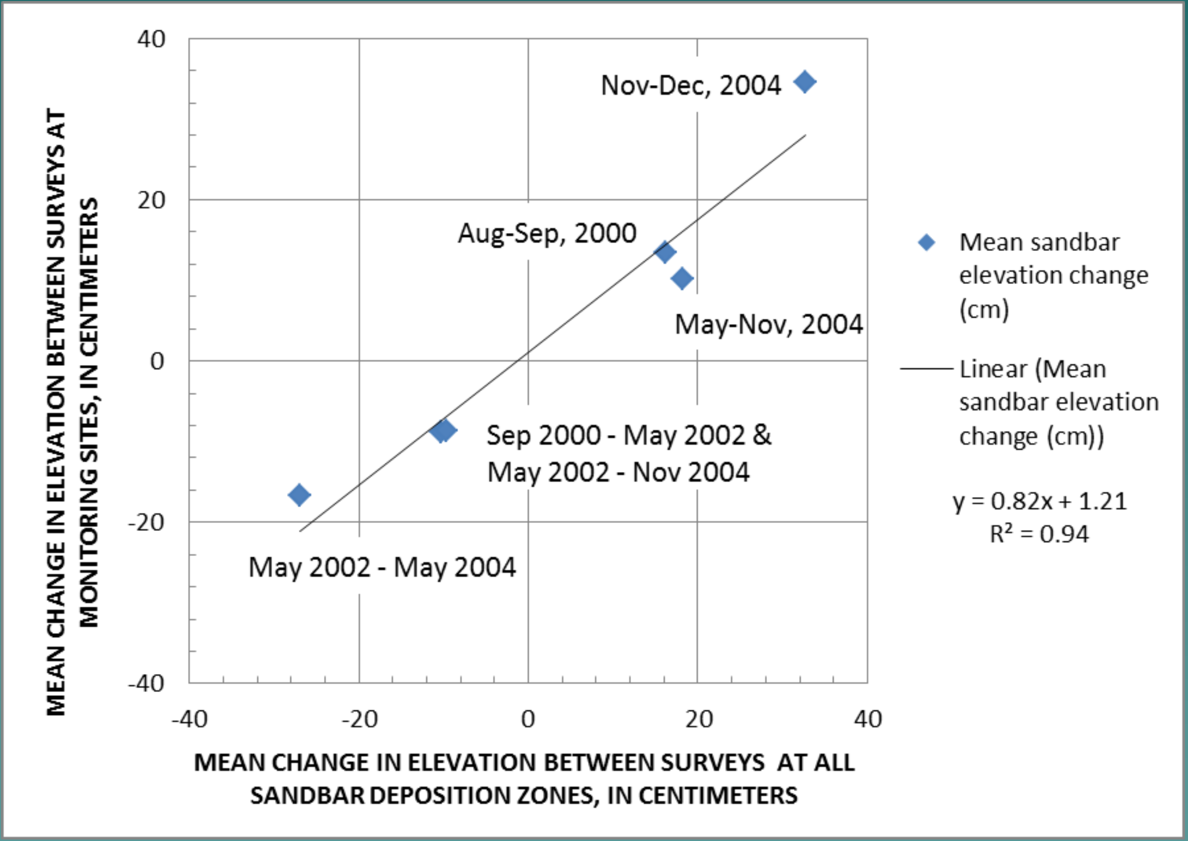
- *High-elevation sand – above 25,000 cfs stage*
- *Mid-elevation sand –8,000-25,000 cfs stage*
- *Low-elevation sand – below 8,000 cfs stage*

Sandbar Monitoring Sites Compared to all Sandbars in 6 Short Reaches

Positive correlation between response at monitoring sites and response for encompassing 2-mi reach (between RM 0 and 87)



Conclusion: *Monitoring sites provide a good representation of both sandbar erosion and sandbar deposition at relatively large eddy sandbars above the 8,000 cfs stage when averaged over long reaches.*

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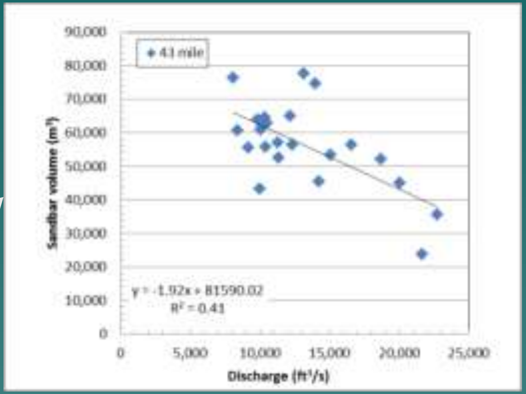
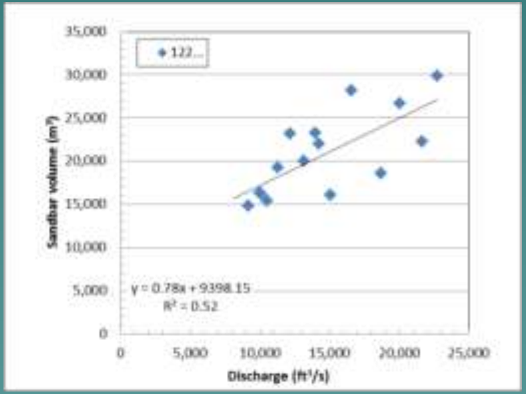
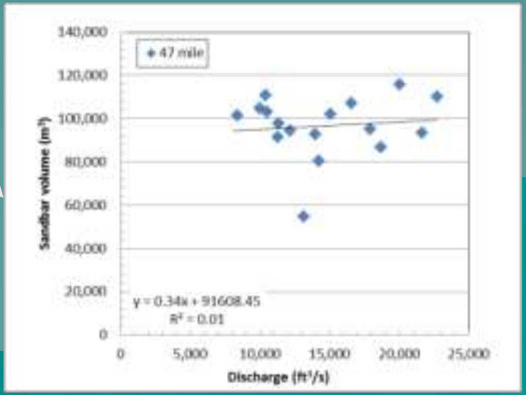
Preliminary Results -- Subject to Review and Revision

But the Discharge-dependence is still an issue

Slope of Q-V relation	All elev. (eddy & channel)	High and Mid-elev. eddy only
Negative ($p < 0.10$)	9	2
Positive ($p < 0.10$)	7	19
Flat	14	11







For sites with a known discharge dependence, we can address the bias

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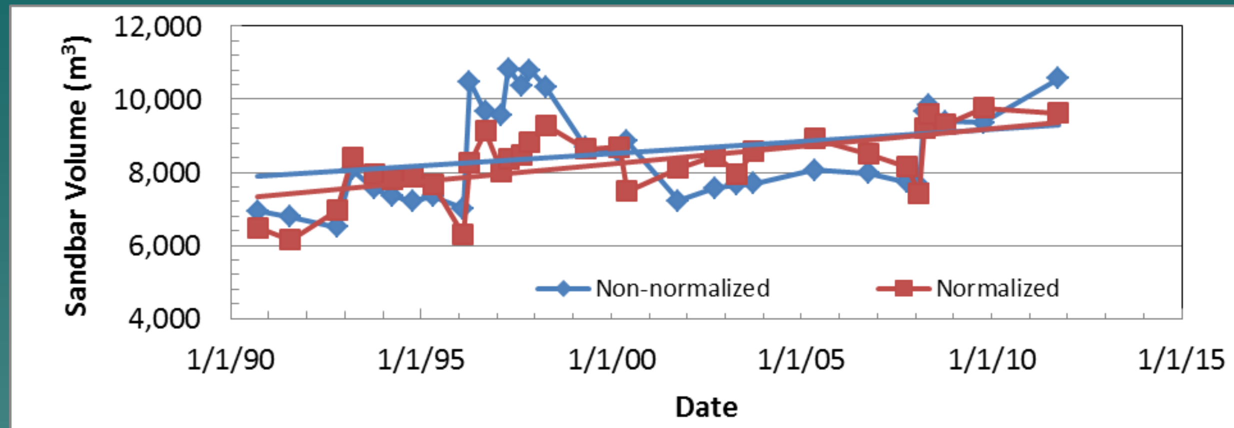
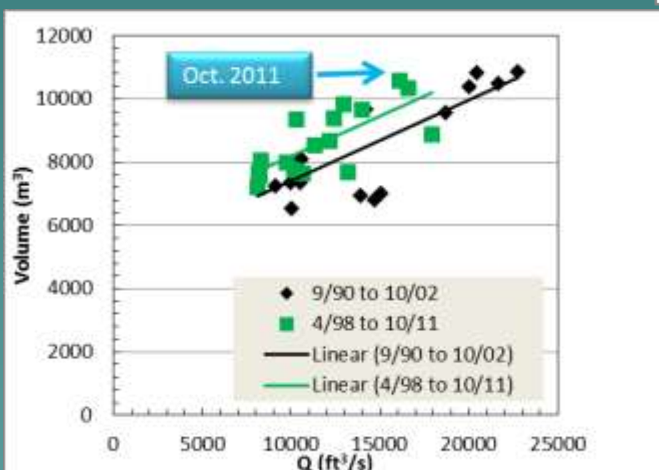
Sandbar with net increase in size: 122-mi





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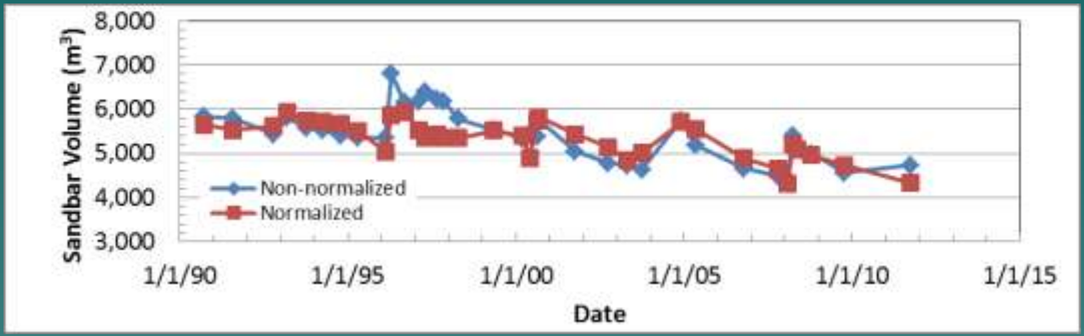
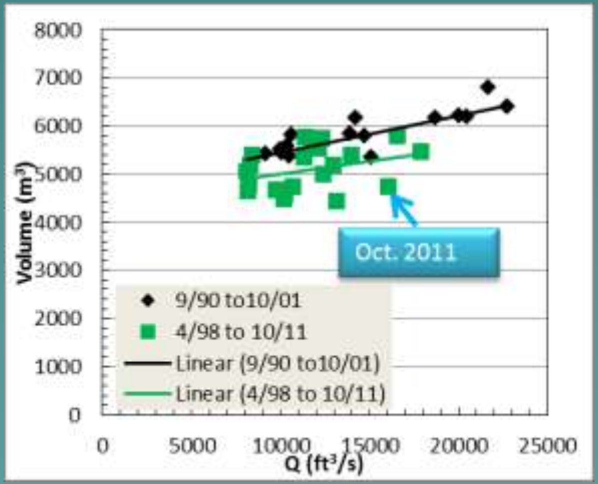
Sandbar with net decrease in size: 81-mi





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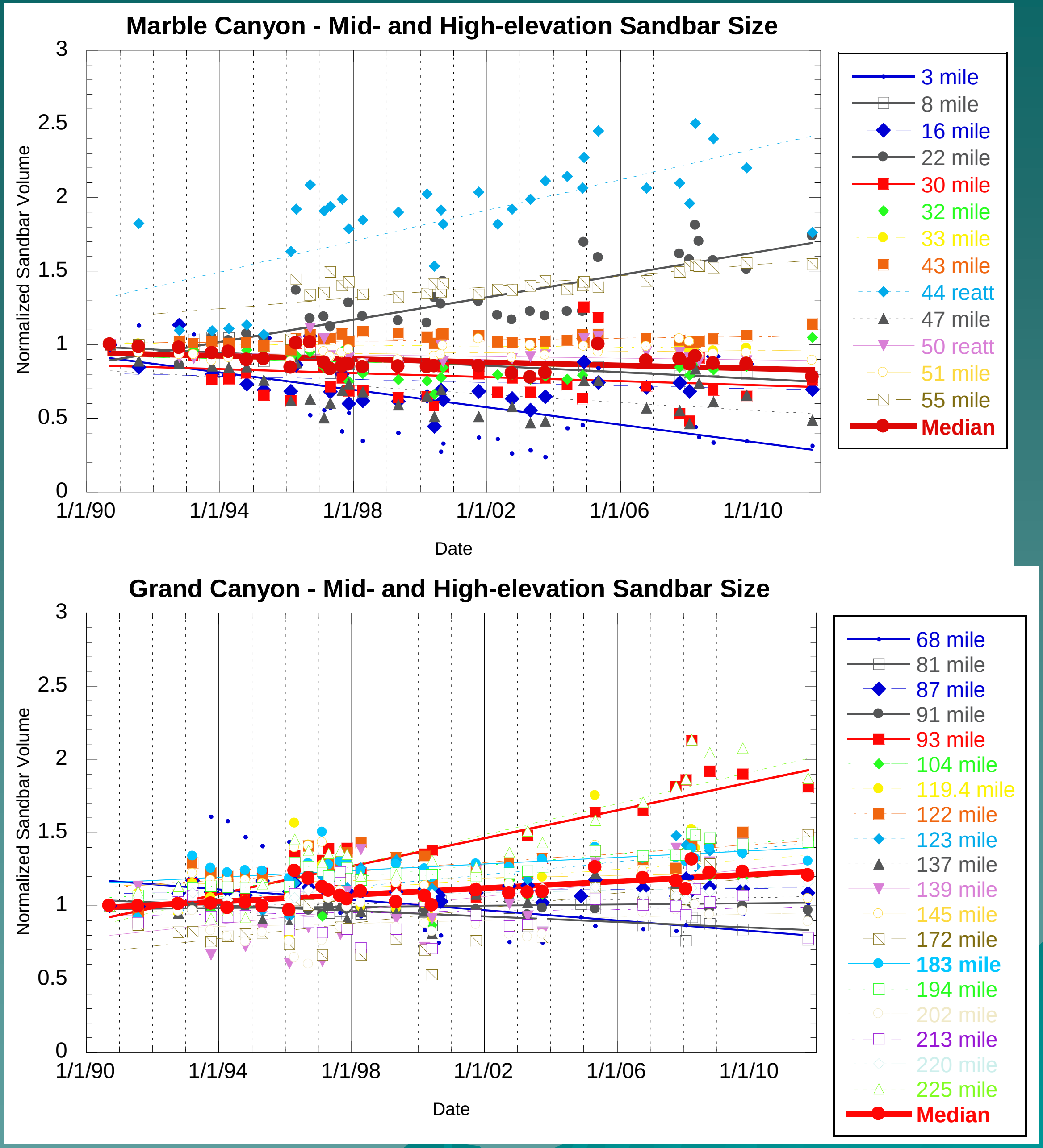
All 31 sites: Sandbar volume relative to 1990 and normalized to 12,000 cfs



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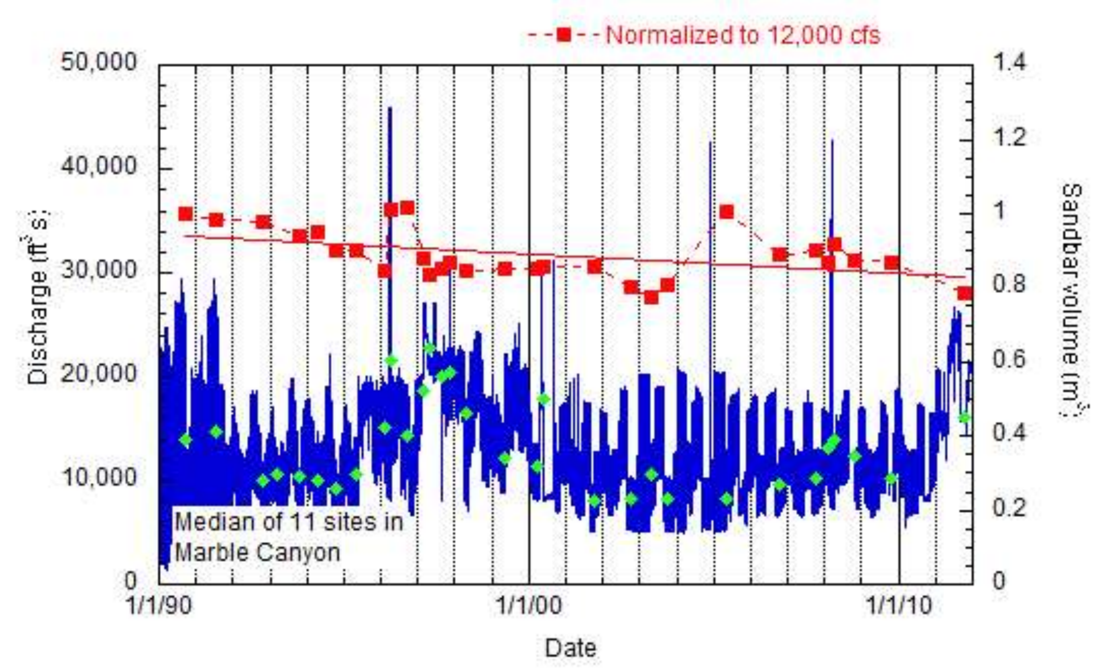
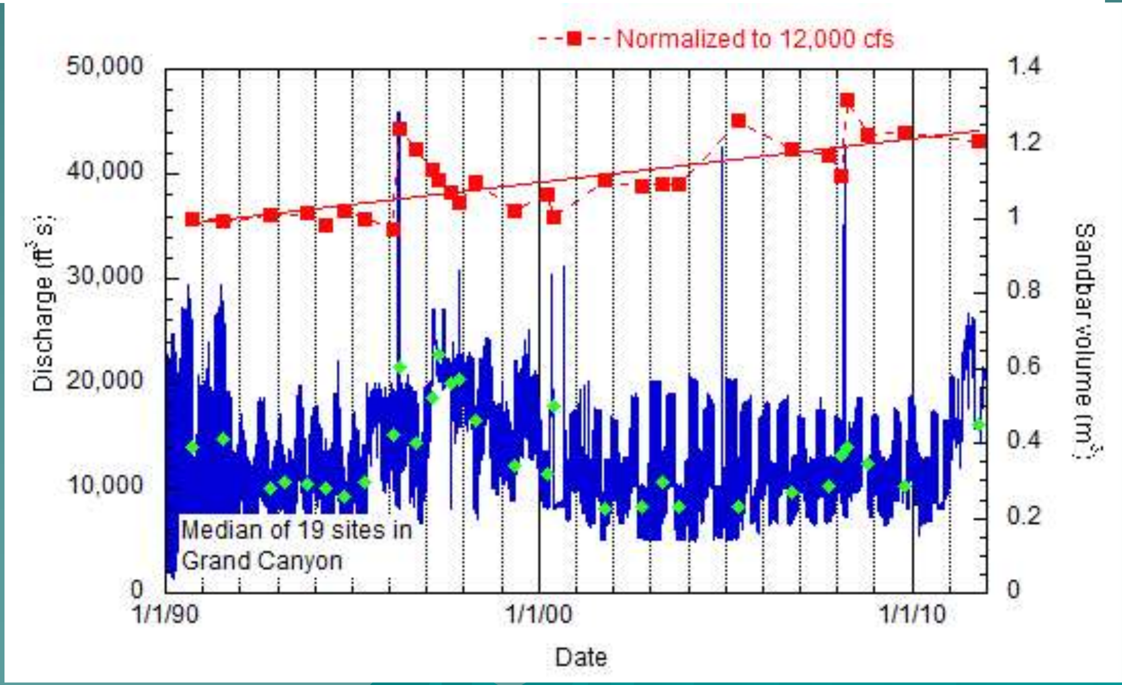
Median Value: Sandbar volume relative to 1990 and normalized to 12,000 cfs





Preliminary Results -- Subject to Review and Revision

Mid- and High-elevation Sandbar change at Sandbar Monitoring Sites: 1990-2011

Reach	Number of Sites	Number With Decreasing Trend	Number With Increasing Trend	Number no change
Marble Canyon	12	7	4	1
Grand Canyon	19	2	13	4
TOTAL	31	9	17	5

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Mid- and High-elevation Sandbar change at Sandbar Monitoring Sites: 2009-2011

Reach	Number of Sites	Number With Decreasing Trend	Number With Increasing Trend	Number no change
Marble Canyon	12	6	4	2
Grand Canyon	19	11	5	3
TOTAL	31	17	9	5

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What is the signal that drives changes in sandbars?

- The bed of the river (upstream eddies and pools in the main channel)
  - To build sandbars in eddies, you need an upstream supply on the bed of the river
  - If the supply is depleted, there will be fewer and smaller sandbars, like Glen Canyon and Hells Canyon on the Snake River
  - Even a flat long-term trend requires sand resupply

- High flows (and floods) deplete supply
- Inputs add supply

Long-term Trends in Sand Storage

- What is the cumulative long-term effect of repeated sand depletions and periodic resupplies by tributaries on sediment storage?
- Three possibilities:
  1) Declining storage: expect sandbar deposition and sandbar size to decline
  2) Constant storage: expect dynamically stable sandbars
  3) Increasing storage: expect dynamically increasing sandbars
- Until we can measure or estimate the long term trend, our predictions for the future of sandbars are only speculation

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Low-elevation Sandbar change at Sandbar Monitoring Sites: 1996-2008

Reach	Number of Sites	Number With Decreasing Trend	Number With Increasing Trend	Number no change
Marble Canyon	11	2	2	7
Grand Canyon	19	9	5	5
TOTAL	30	11	7	12

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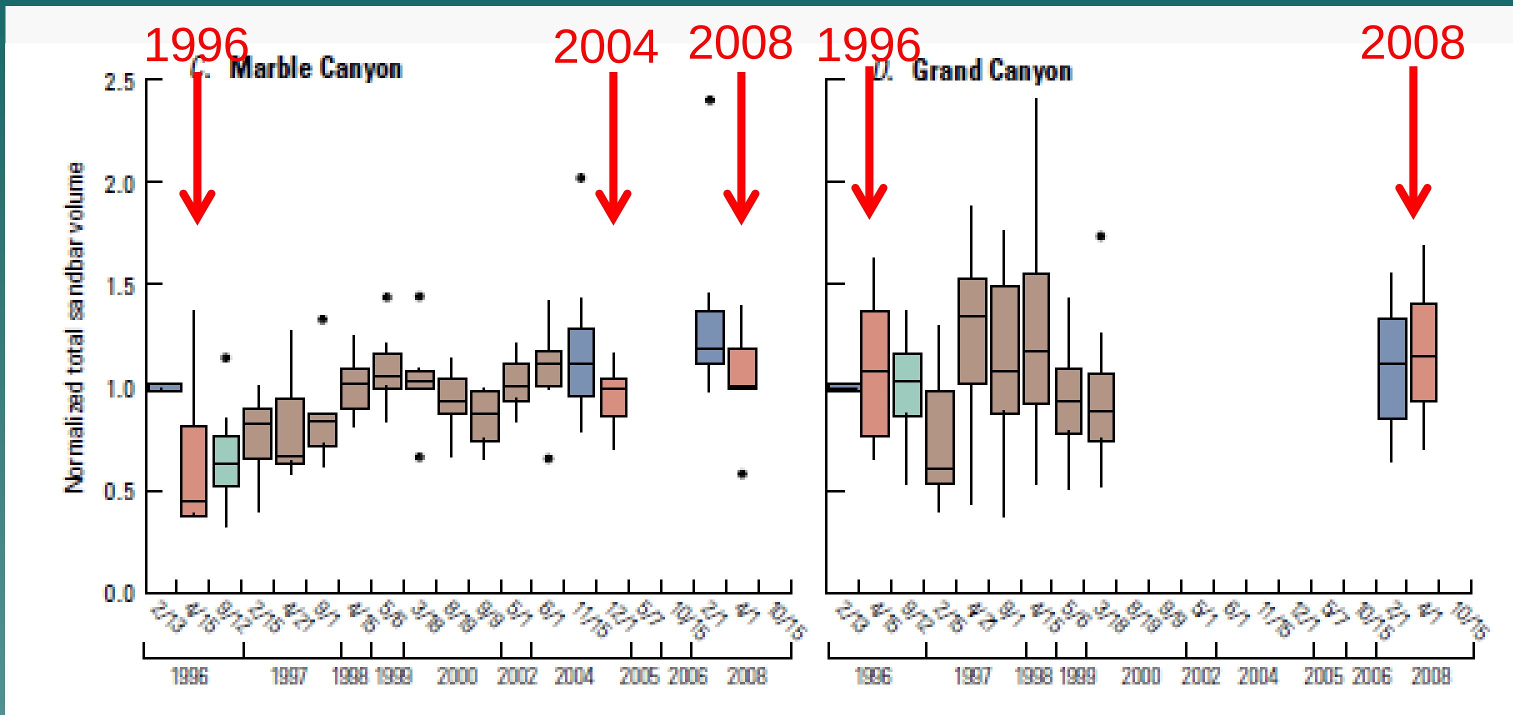
Preliminary Results -- Subject to Review and Revision

What can the NAU sandbar monitoring sites tell us about long-term trends in sediment storage?

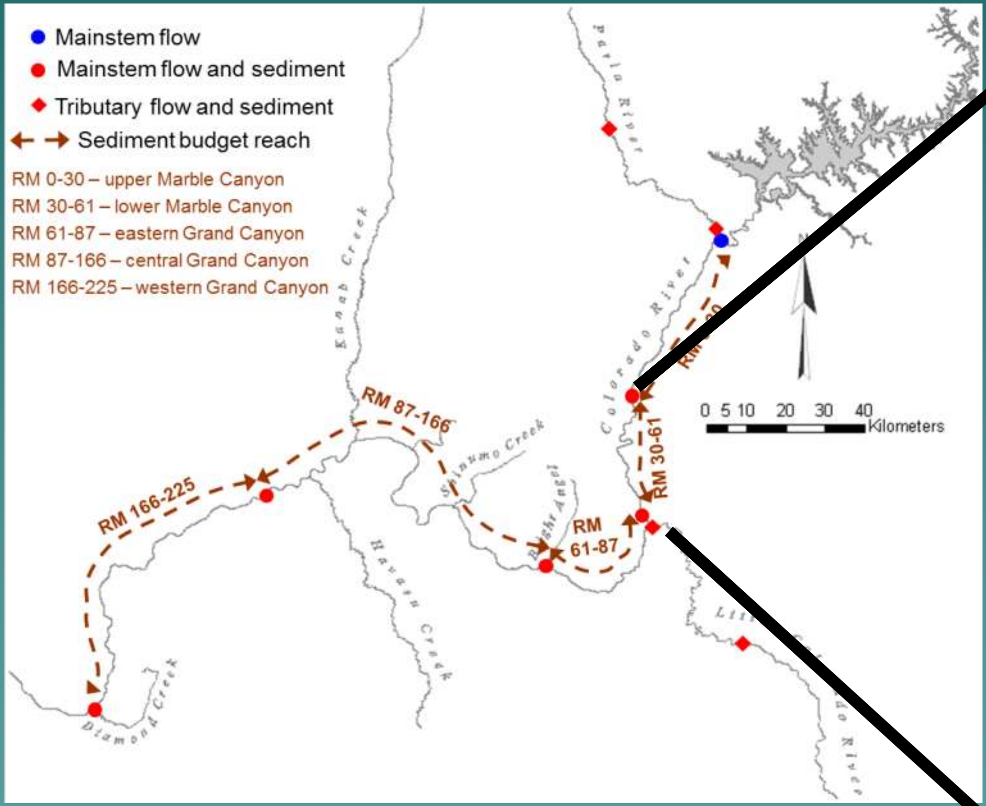


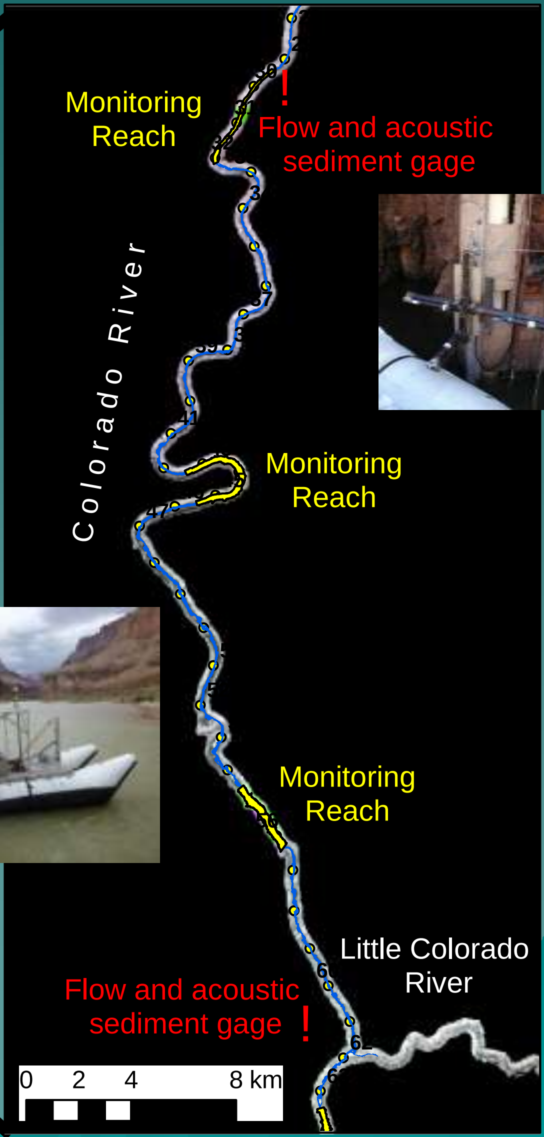
Reach	Number of Sites	Number Decreasing	Number Increasing	No change
Marble Canyon	11	2	2	7
Grand Canyon	19	9	5	5
TOTAL	30	11	7	12

They tell us about these sites: results can't be scaled up to longer reaches!

Hazel and others (2010); Schmidt and Grams (2011)

Reach-scale Sand Storage Change: First Attempt (aka FIST)





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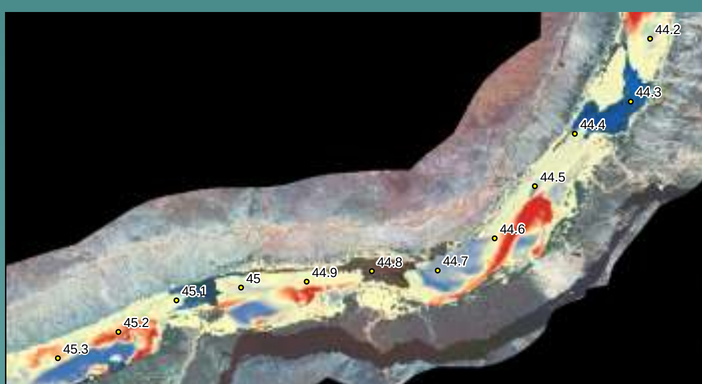
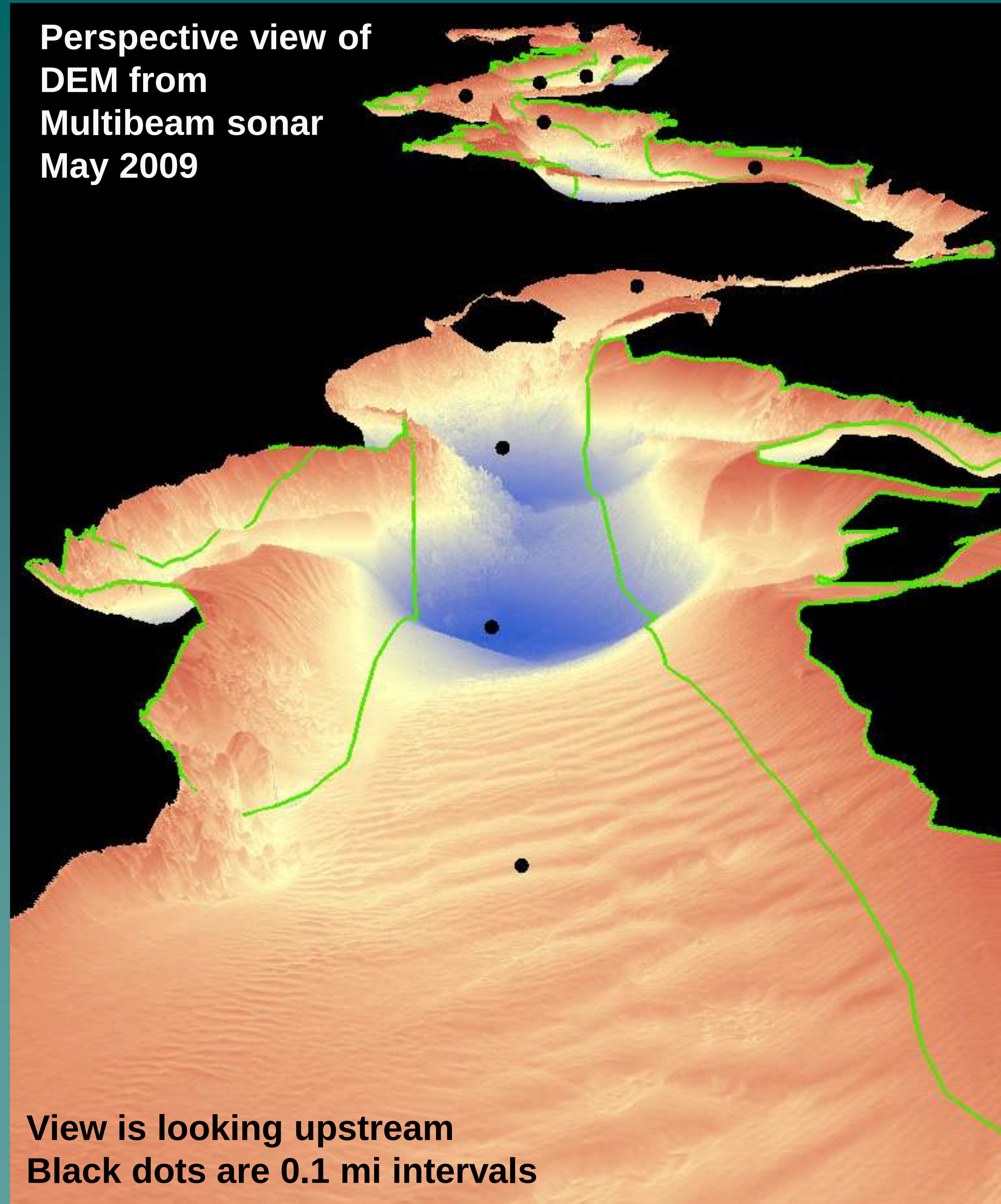
- Sediment flux record: 15 min
- Monitoring reaches: 6 surveys in 9 years

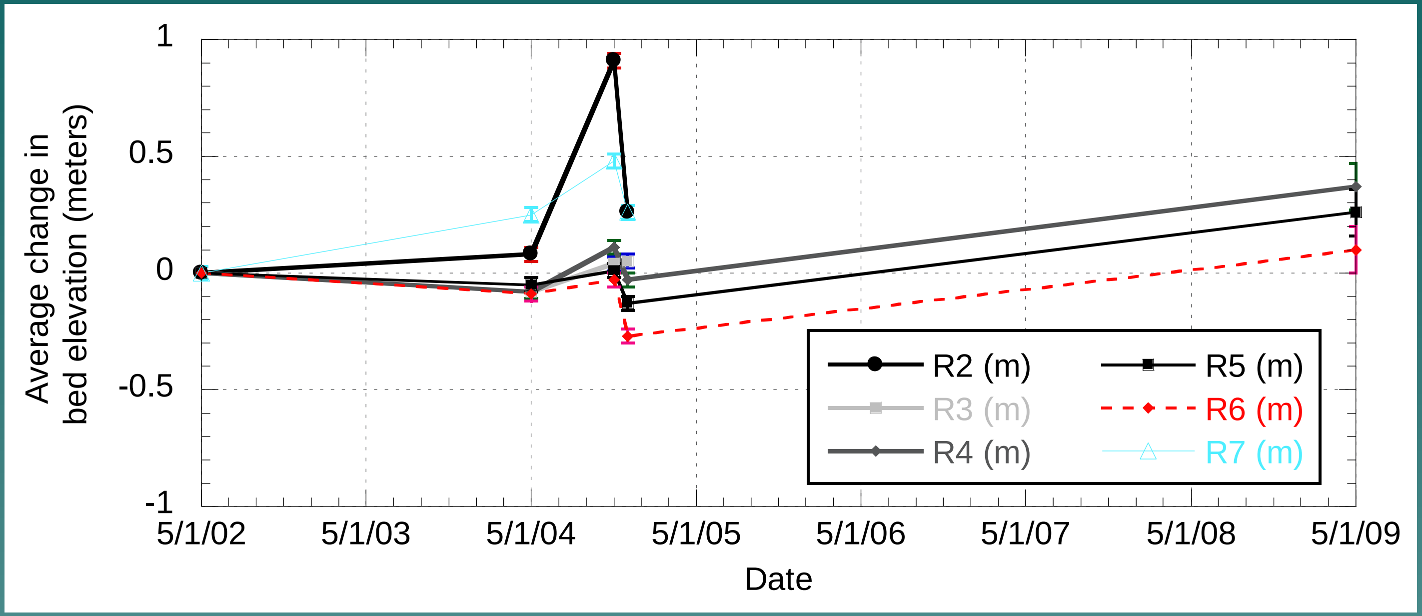
Mapping within monitoring reaches

- Make digital elevation models like this for each survey →
- Compute changes by differencing the two maps:





Storage change in short reaches: 2002 to 2009



- Reaches below tributaries show most accumulation leading up to 2004 flood and most loss during flood
- The three reaches measured in 2009 show accumulation between 2004 and 2009 (the remainder of the inputs that occurred before the 2008 flood)

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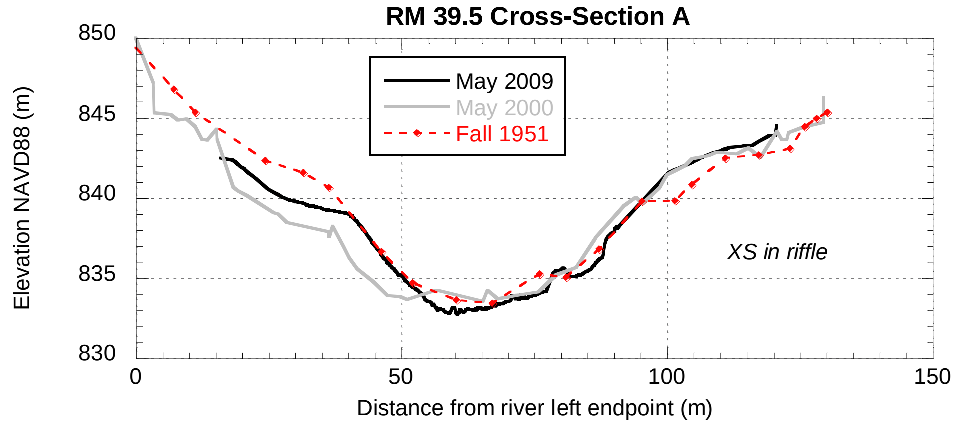
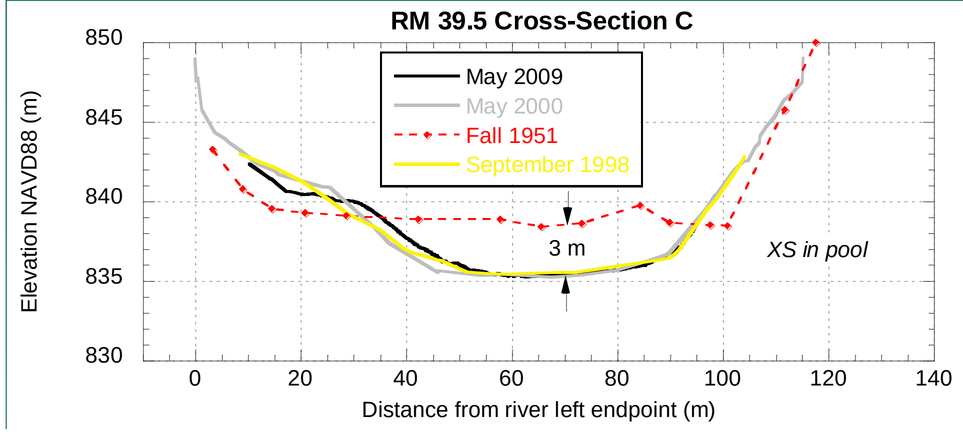
- 2002 to 2004: 6 reaches (13 mi in 66-mi reach)
- 2002 to 2009: 3 reaches (7 mi in 31-mi reach)

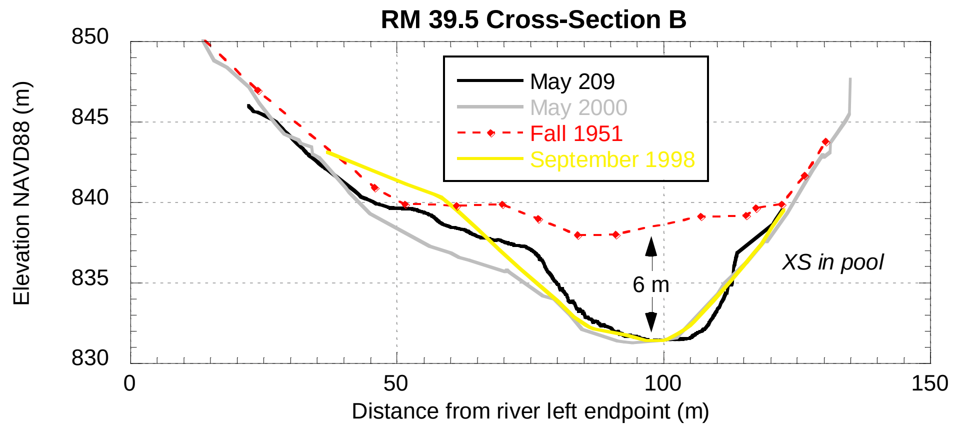
Preliminary Results -- Subject to Review and Revision

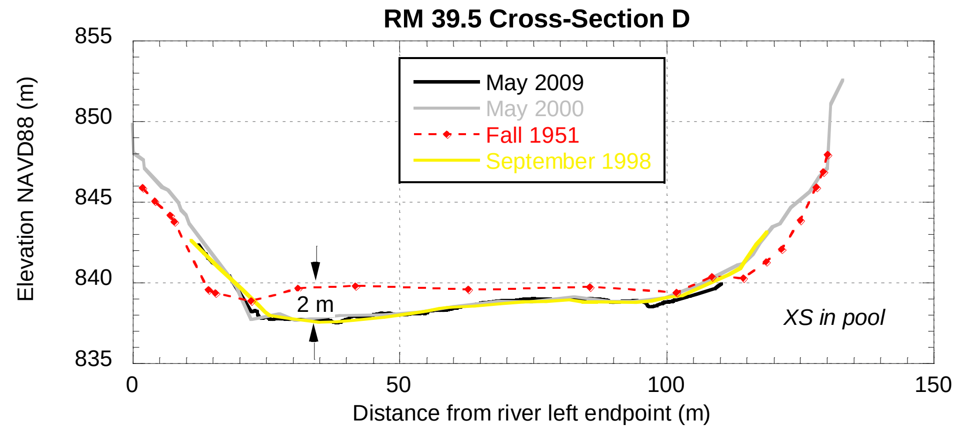
Perspective: Evidence for long-term sediment loss in Marble Canyon

The limited data that are available indicate sediment loss from pools between 1951 and 2000 (no major change 2000-2009)









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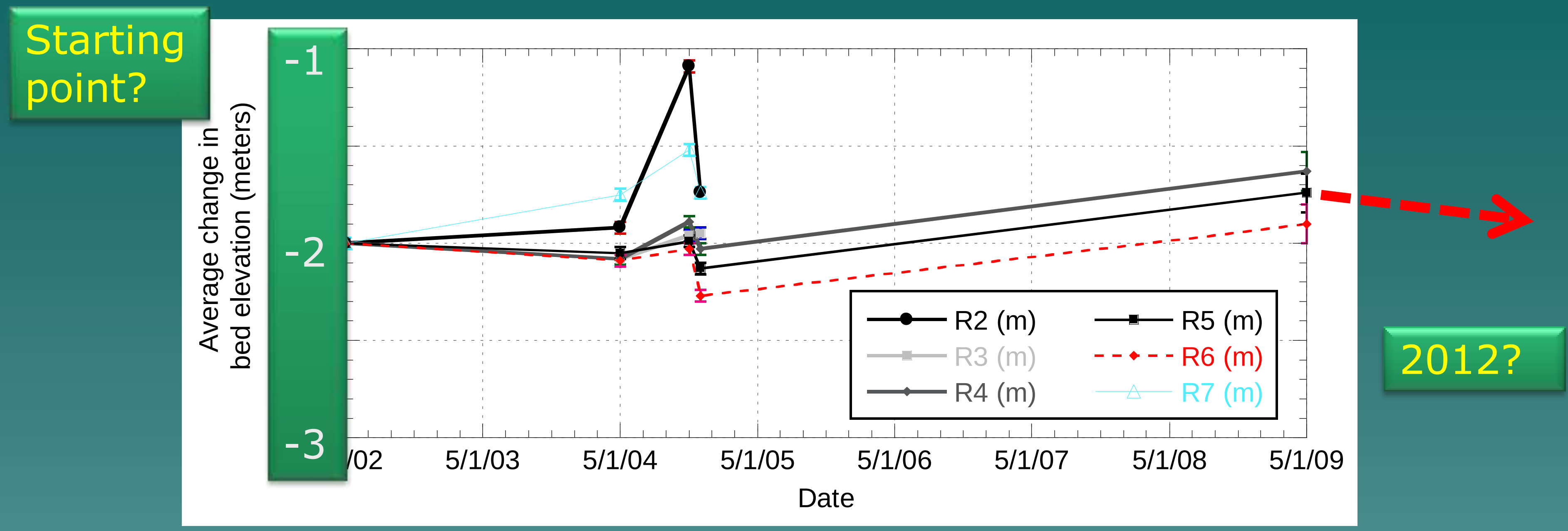
Storage change in short reaches: 2002 to 2009



- Reaches below tributaries show most accumulation leading up to 2004 flood and most loss during flood
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- 2002 to 2004: 6 reaches (13 mi in 66-mi reach)
- 2002 to 2009: 3 reaches (7 mi in 31-mi reach)

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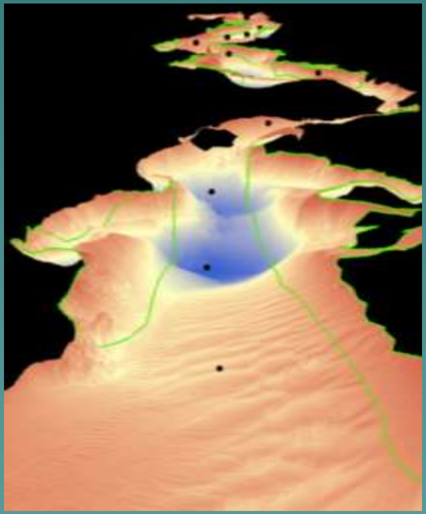
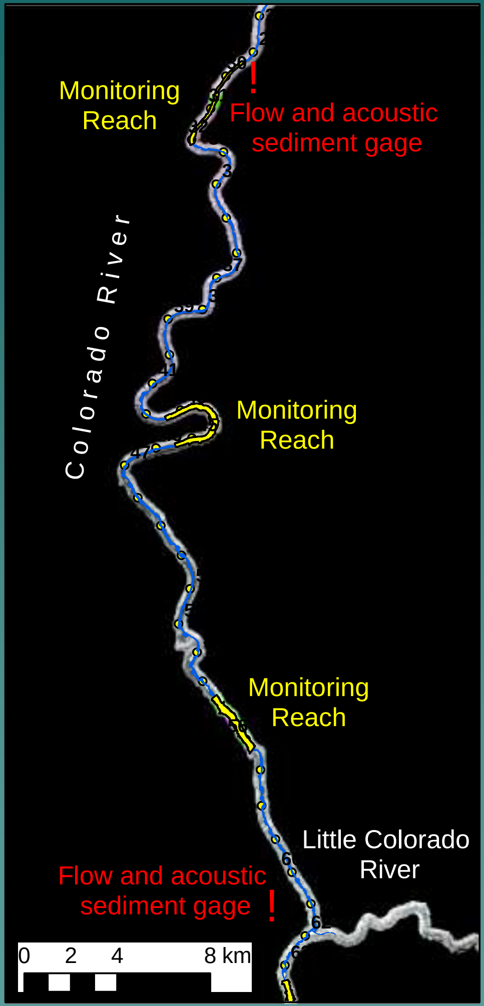
Reach-scale Sand Storage Change for RM 30 to RM 61: 2004 to 2009

- Repeat surveys:
  - + 521,000 metric tons in the three reaches monitored
  - Extrapolates to over 2 million metric tons for 30-mile segment





- Measurements of sand transport at gages:
  - + 220,000 metric tons for 30-mile segment

- The direction is correct (both positive), but our measurements of the bed indicate much larger change than is possible. WHY? ...

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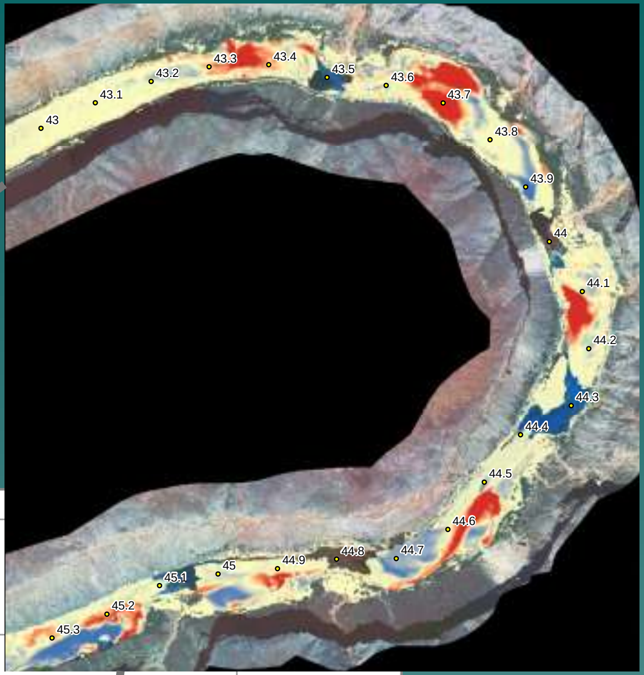
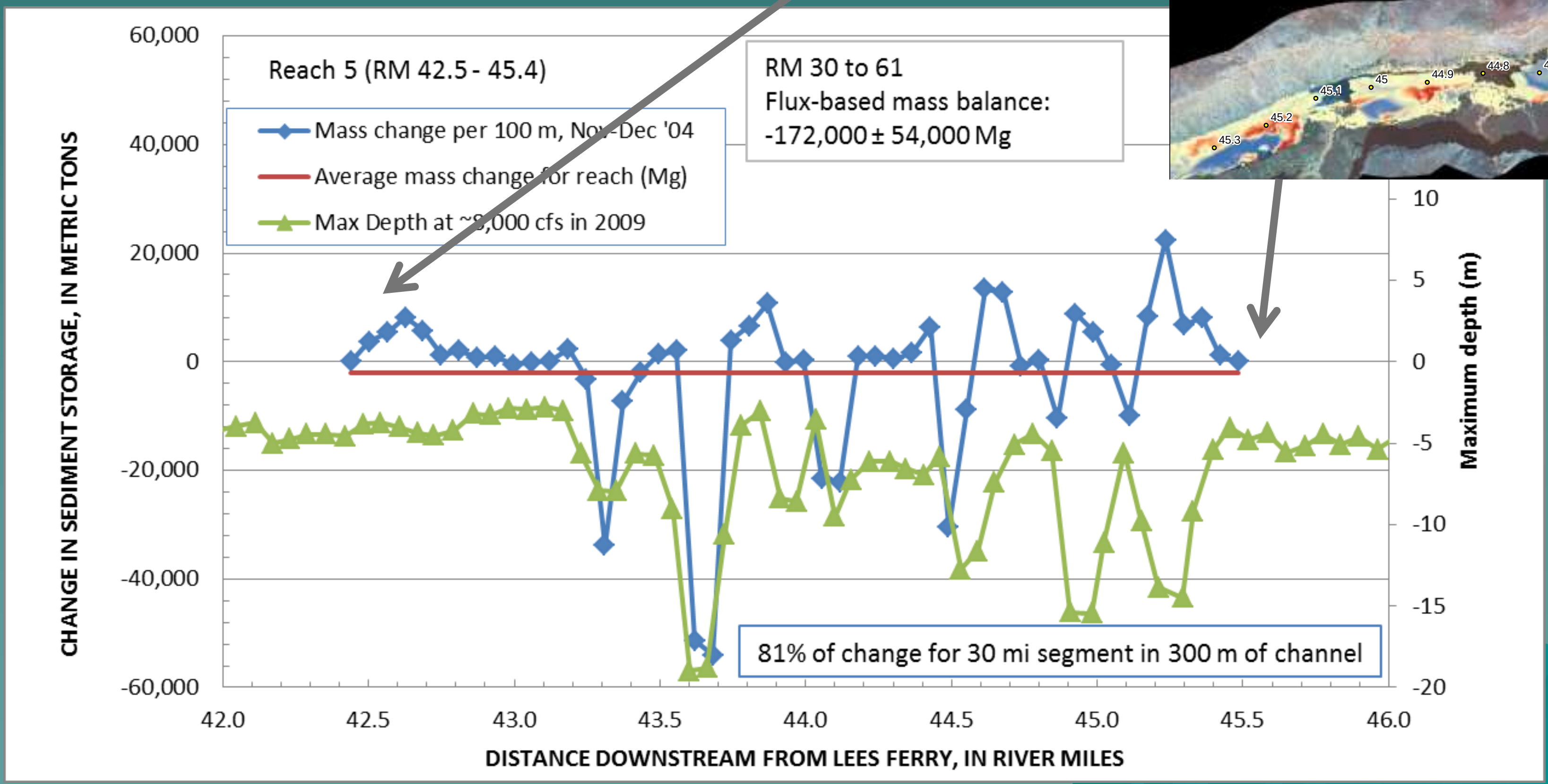
Sites of erosion and deposition are highly localized

The storage change in just a couple of pools matches the net storage change for an entire 50 km reach





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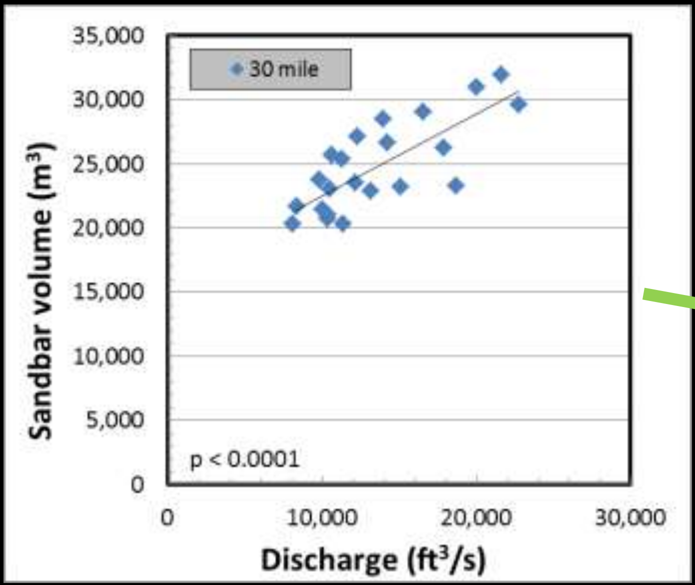
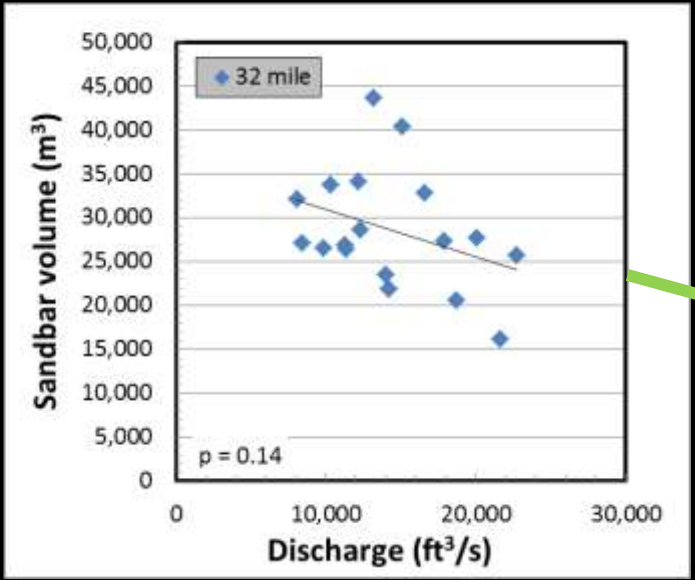
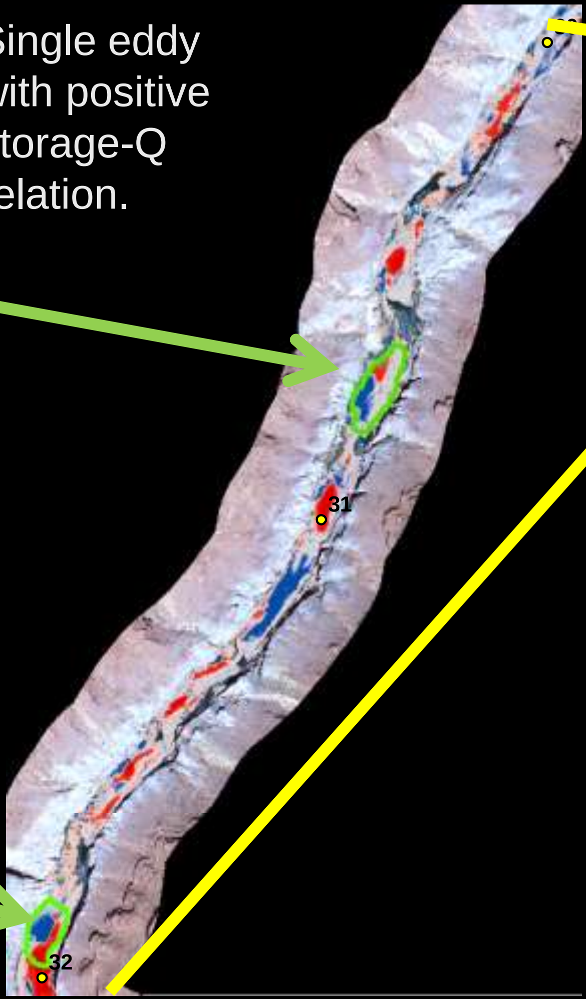
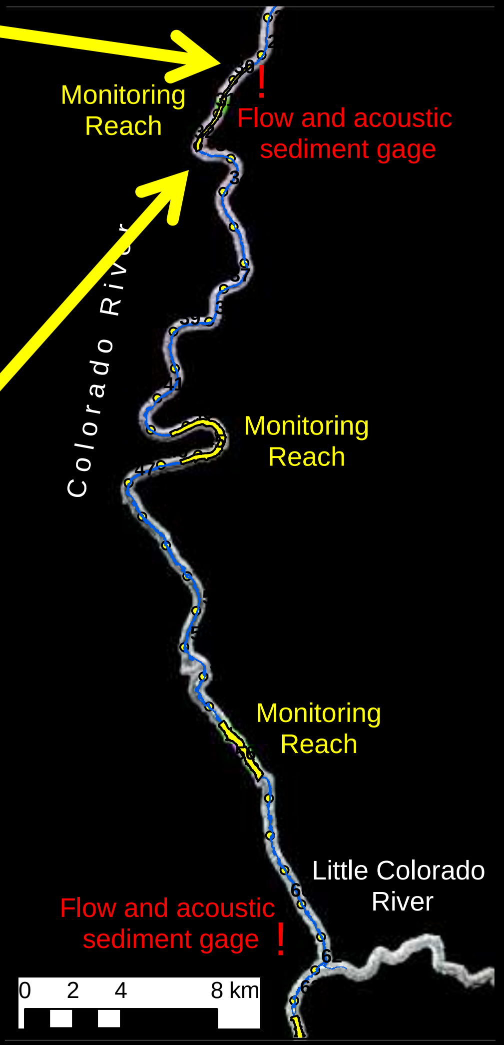
How long of a reach must be measured to eliminate local geometric effects?



Single eddy with positive storage-Q relation.







Single eddy with negative storage-Q relation.

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Conclusions – The sandbars you can see 1990 to 2011

- Hydrology (flow) causes redistribution of sand
- Supply
- Long-term trends in mid- and high-elevation sand at the long-term monitoring sites:
  - Marble Canyon (above LCR)
    - Majority of sites have less sand
  - Grand Canyon (below LCR)
    - Majority of sites have more sand
  - *Oct. 2009 to Oct. 2011 (equalization flows):*
    - 17 out of 31 sites have less sand
- *Caveat: very small sample size*

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Conclusions

- Sandbars above the 8,000 cfs stage at the NAU long-term monitoring sites
  - In Marble Canyon, most are smaller now than in 1990
  - In Grand Canyon, most are larger now than in 1990
  - *2009 to 2011 (equalization flows):* 17 out of 31 sites have less sand
- Sandbar response is strongly affected by hydrology at many sites (masks effects of storage).
- Sand in storage (the bank account) is needed to sustain bar building response (the ability of eddies to trap sand can be diminished by declining supply)
- Sand Storage
  - Floods and high flows deplete sand from storage
  - Tributary inputs put sand into storage
  - Need to repeat measurements over long reaches to understand long-term trends

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