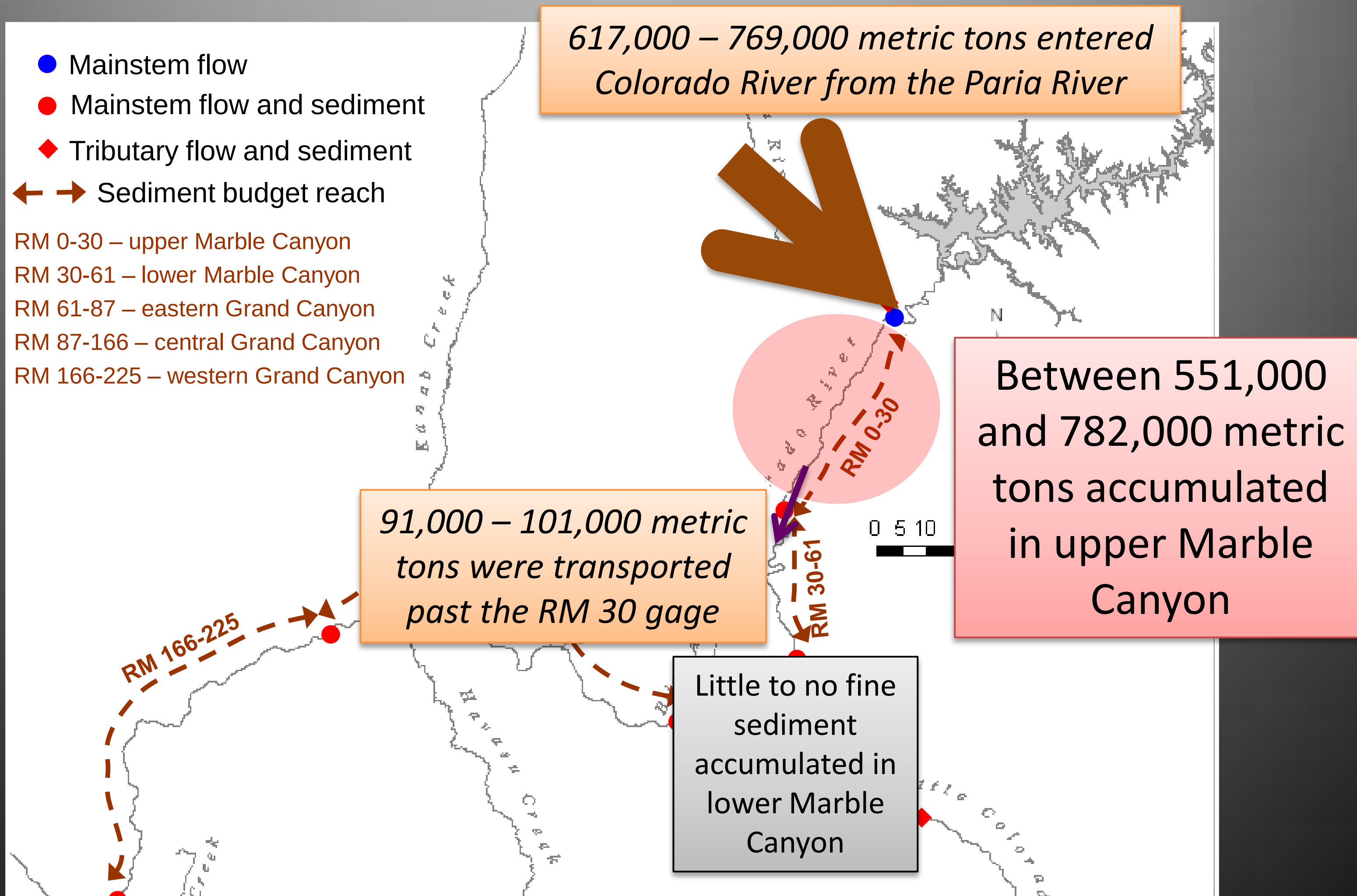
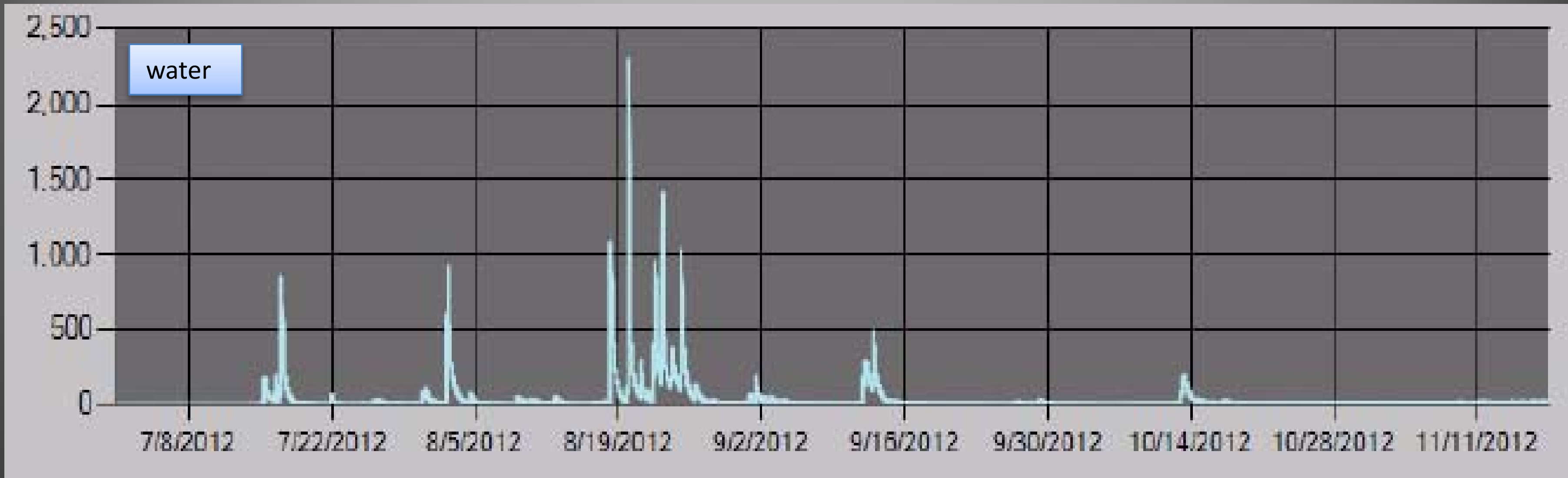
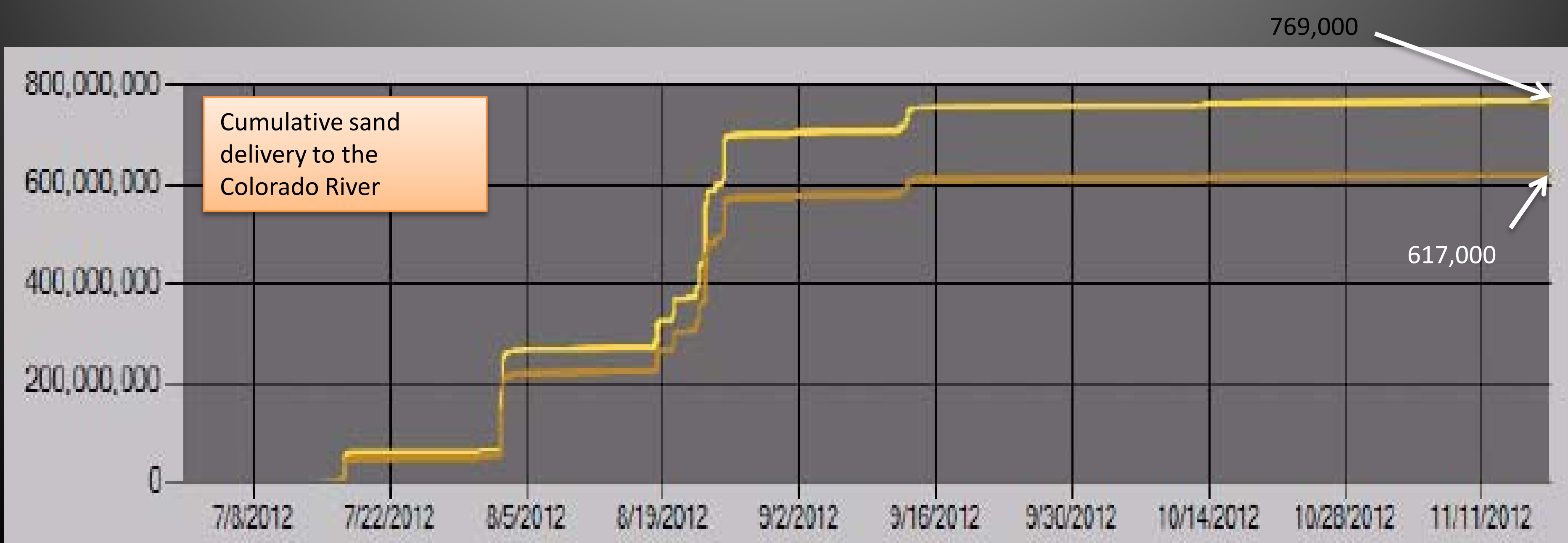
Between July 1 and November 17, 2012, …

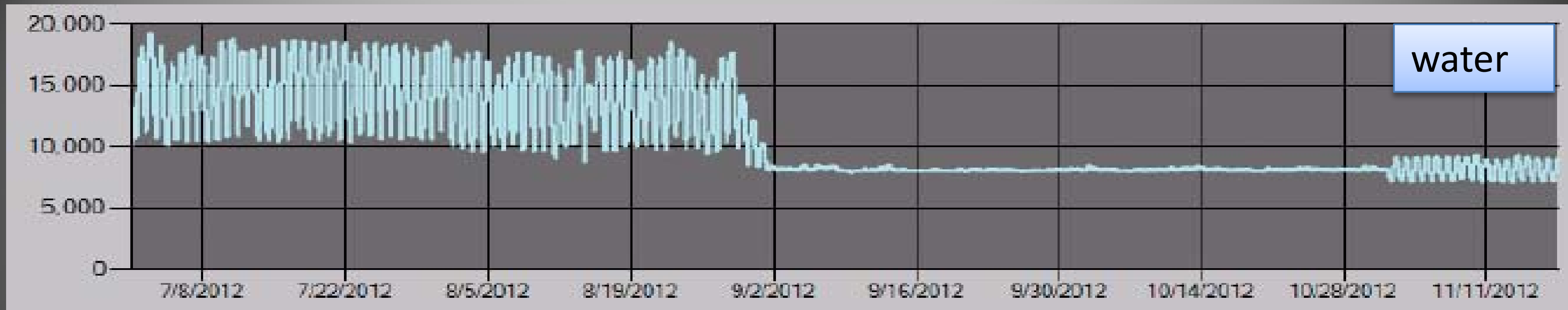


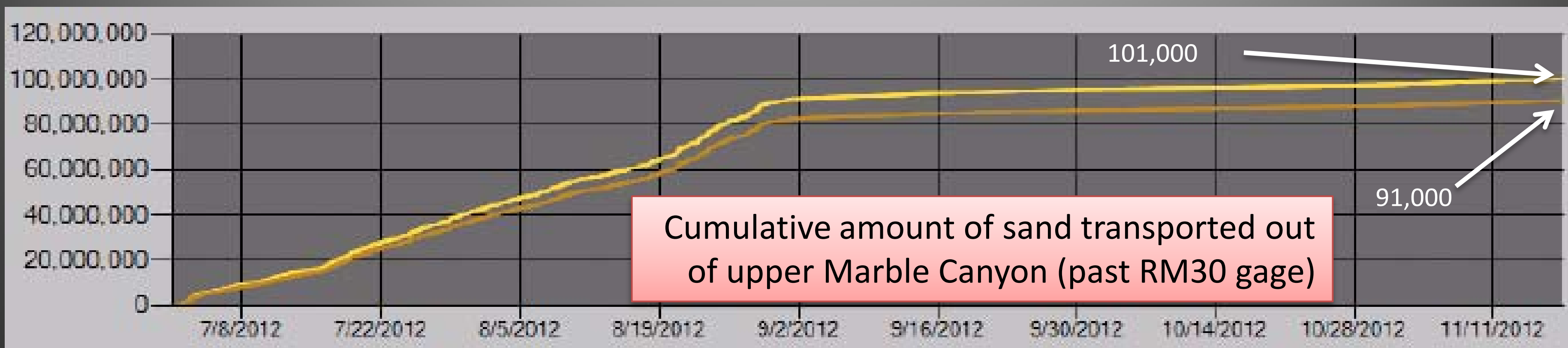
<u>Mass balance prior to 2004 and 2008 HFEs</u>
July 1 to November 2004: 275,000 – 491,000 metric tons
December 2004 – March 2008: 567,000 – 1,823,000 metric tons

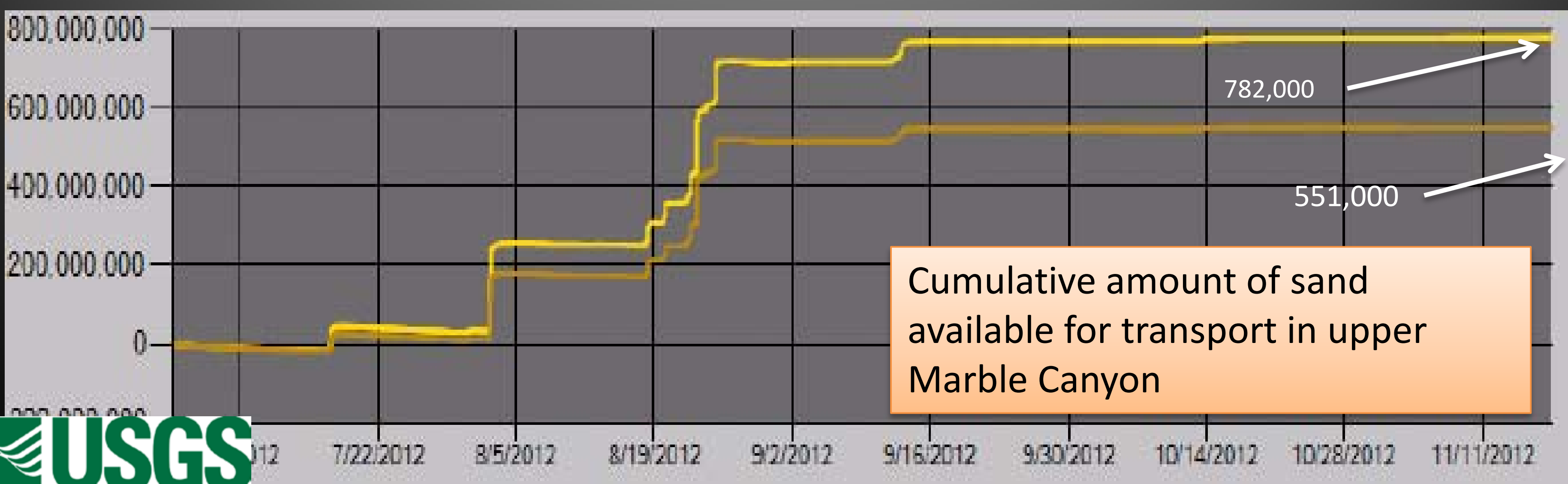
Paria River at Lees Ferry











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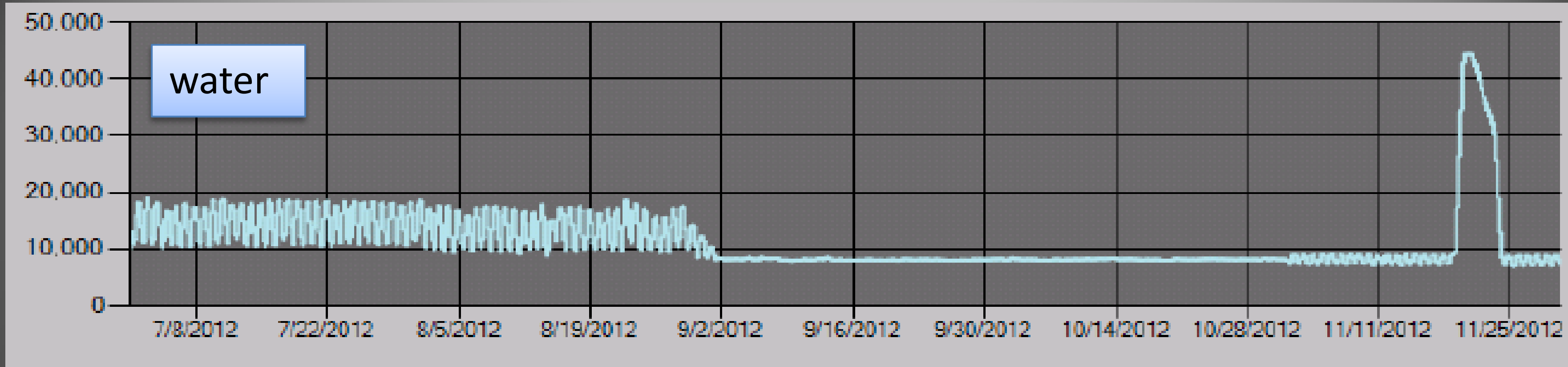
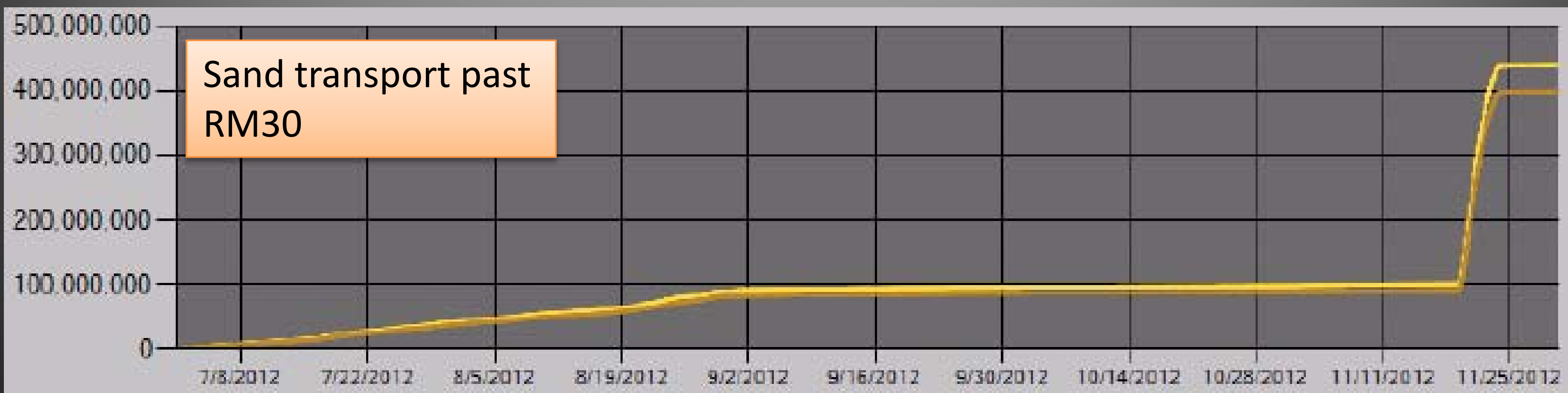
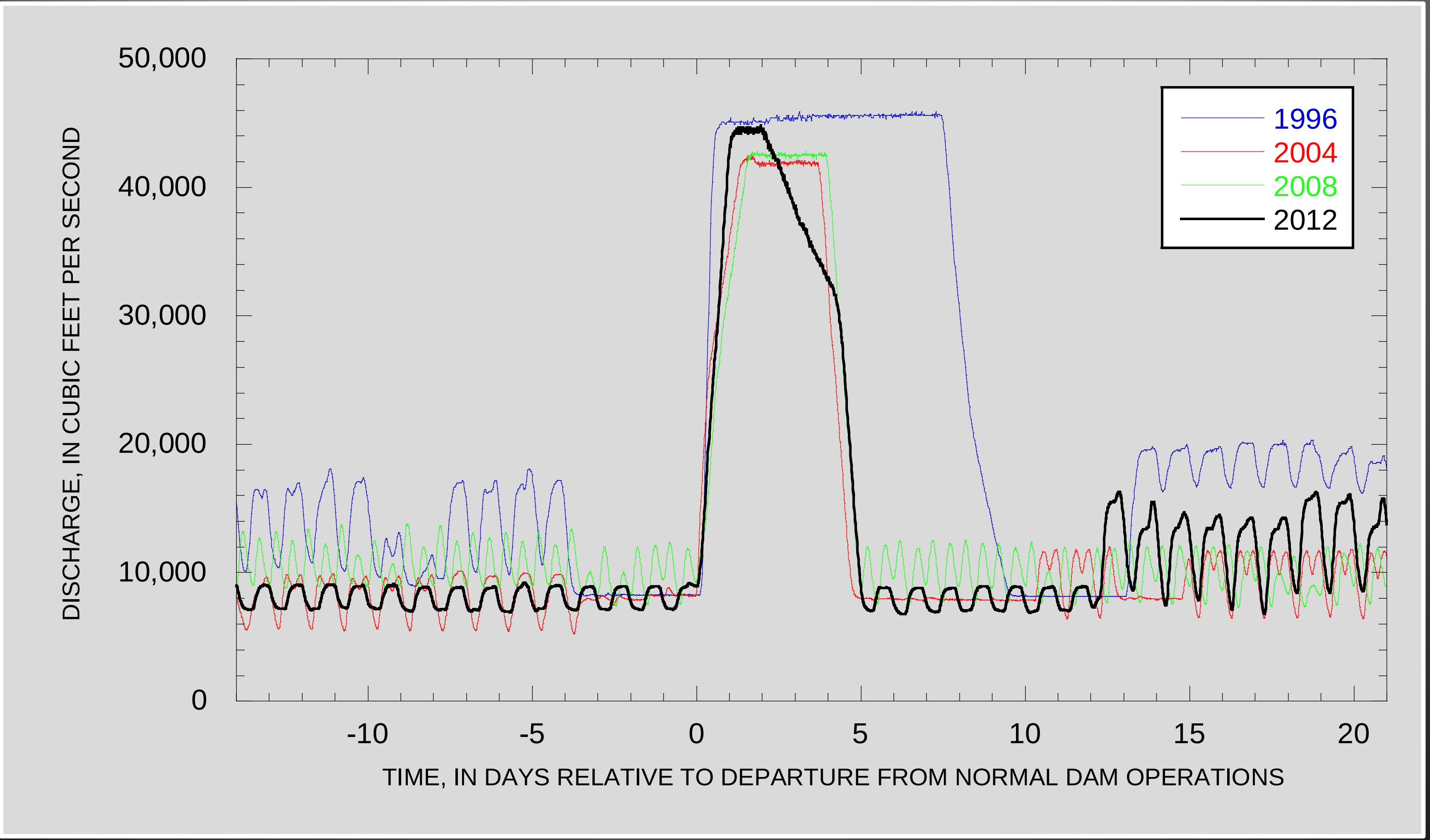

water
50,000
40,000
30,000
20,000
10,000
0
7/8/2012
7/22/2012
8/5/2012
8/19/2012
9/2/2012
9/16/2012
9/30/2012
10/14/2012
10/28/2012
11/11/2012
11/25/2012

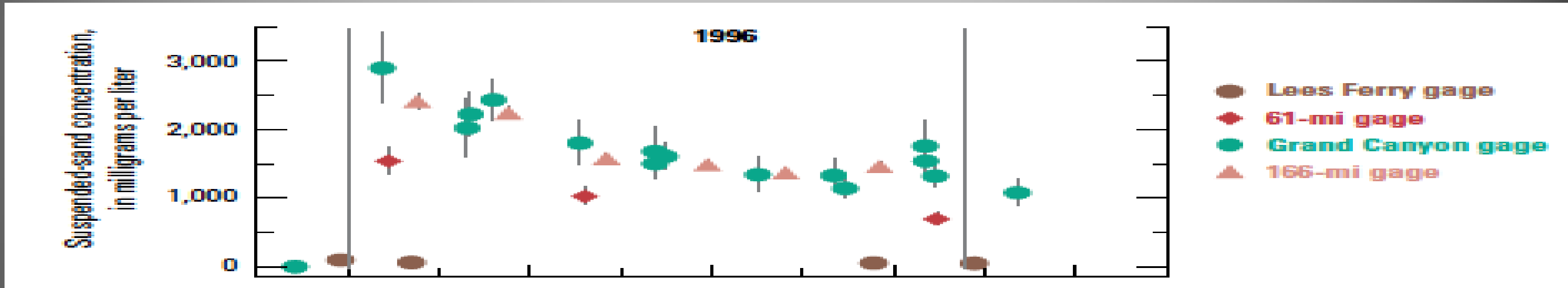

Sand transport past RM30
500,000,000
400,000,000
300,000,000
200,000,000
100,000,000
0
7/8/2012
7/22/2012
8/5/2012
8/19/2012
9/2/2012
9/16/2012
9/30/2012
10/14/2012
10/28/2012
11/11/2012
11/25/2012

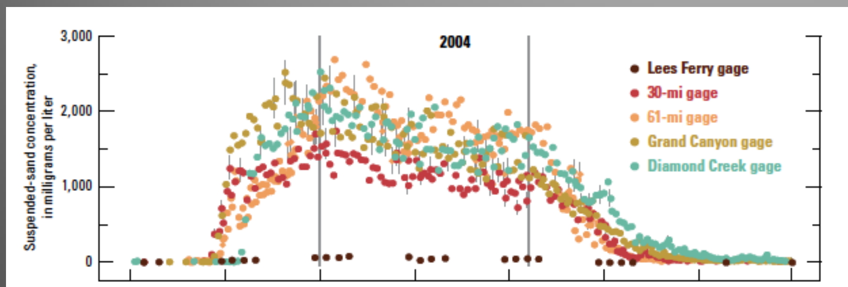

Sand mass balance in upper Marble Canyon
800,000,000
600,000,000
400,000,000
200,000,000
0
477,000
212,000
7/22/2012
8/5/2012
8/19/2012
9/2/2012
9/16/2012
9/30/2012
10/14/2012
10/28/2012
11/11/2012
11/25/2012

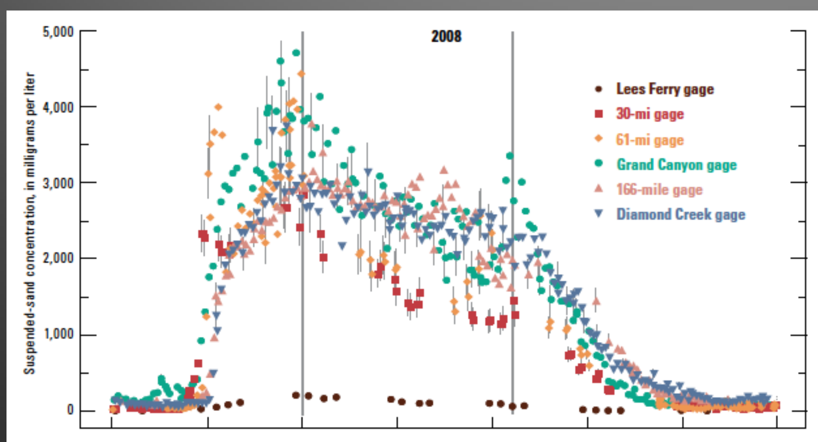
2012 Controlled Flood



- 24 hr. upramp from 7,000 to 43,400 ft^3/s
- 24 hr. peak at 43,400 ft^3/s
- 53 hr. downramp from 43,400 to 31,200 ft^3/s
- 24 hr. downramp from 31,200 to 7,000 ft^3/s

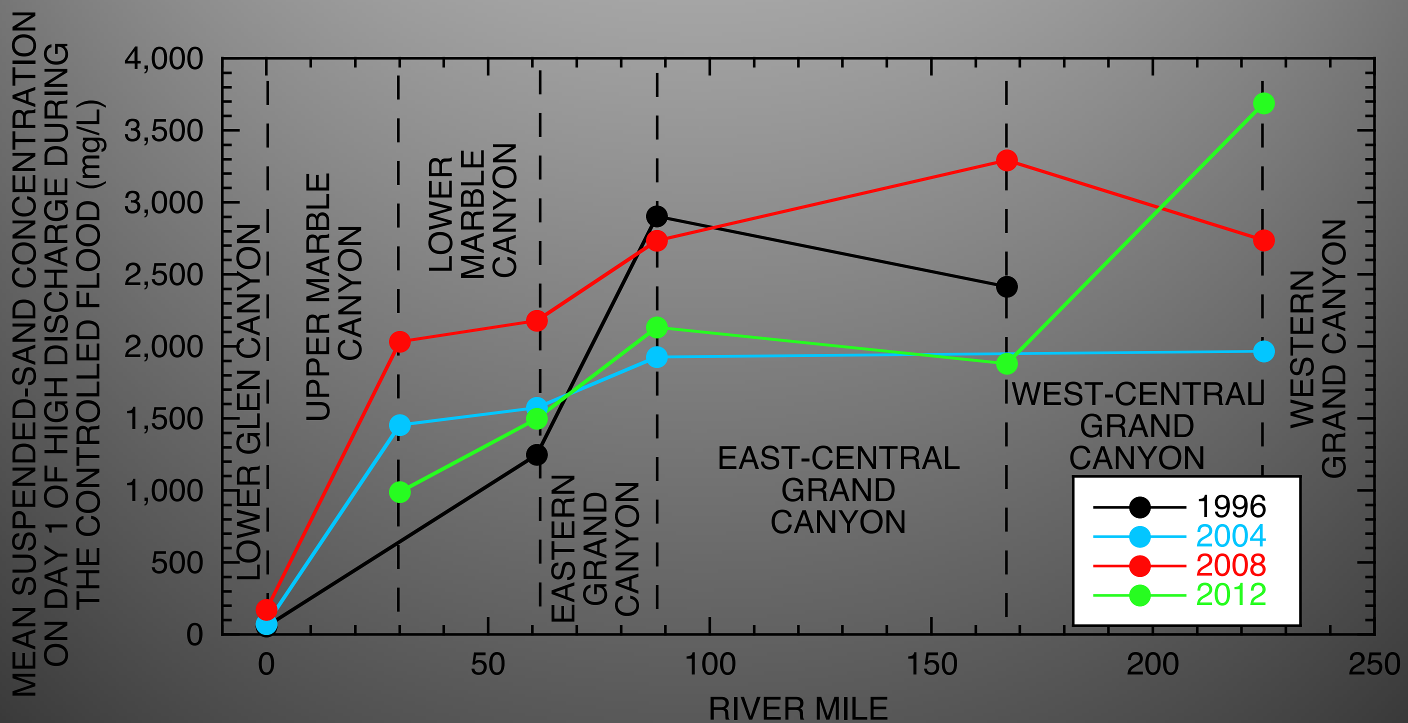




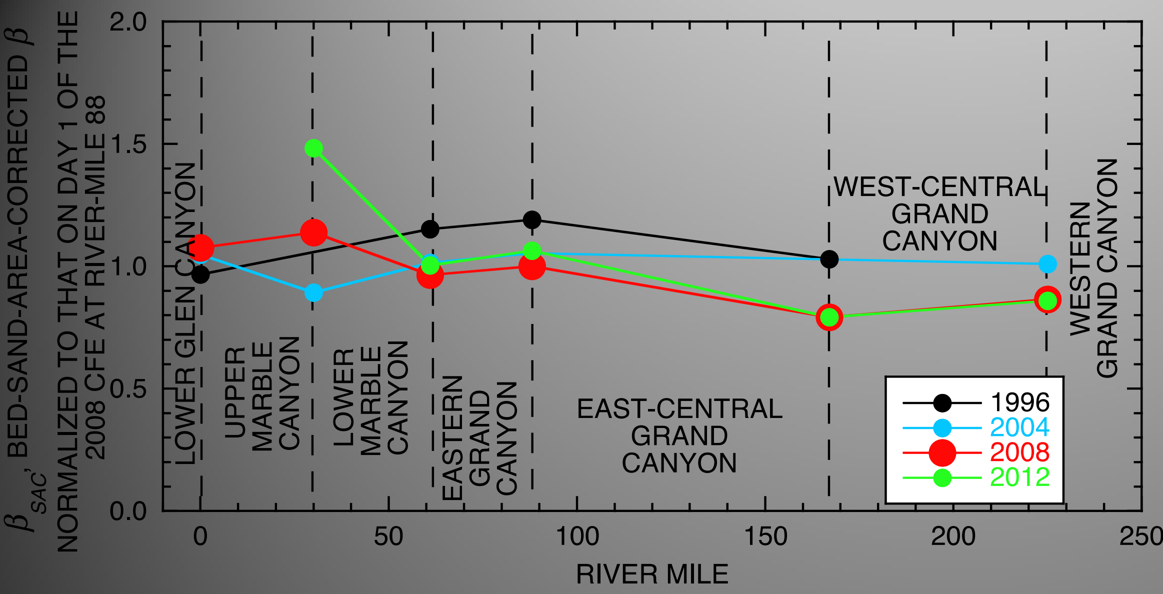


Deposition rates of sand in eddies are primarily determined by the concentration of sand transported by the river. Concentrations change with time.

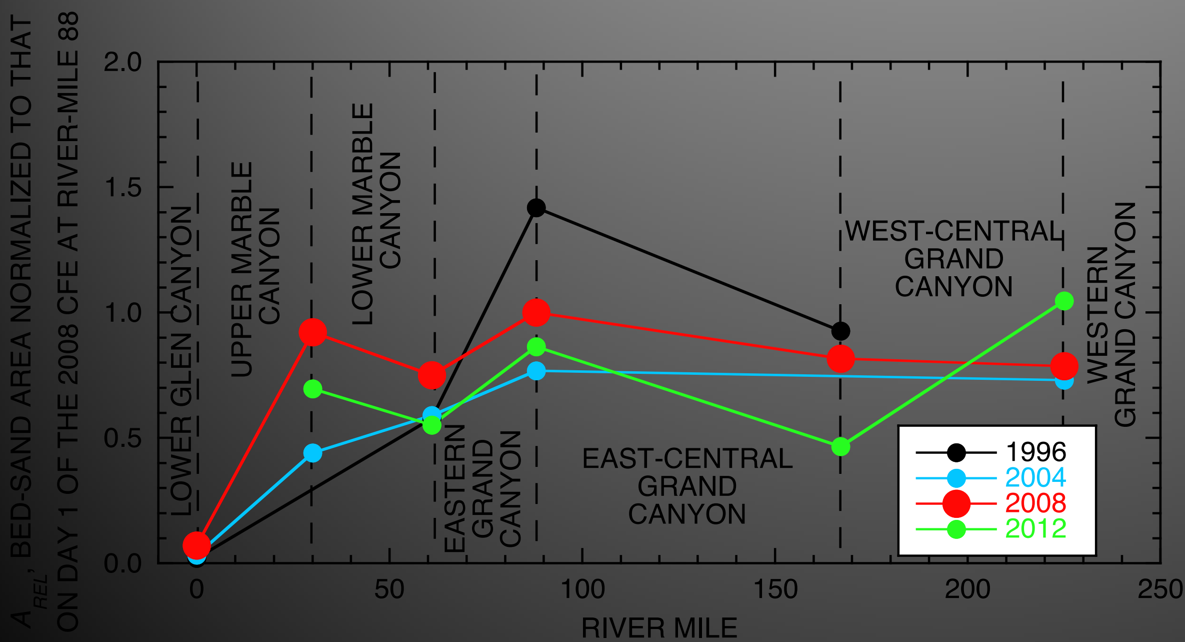
Suspended-Sand Concentration on Day One of Flood



(after Topping and others, *USGS OFR 2010-1128*, 2010)

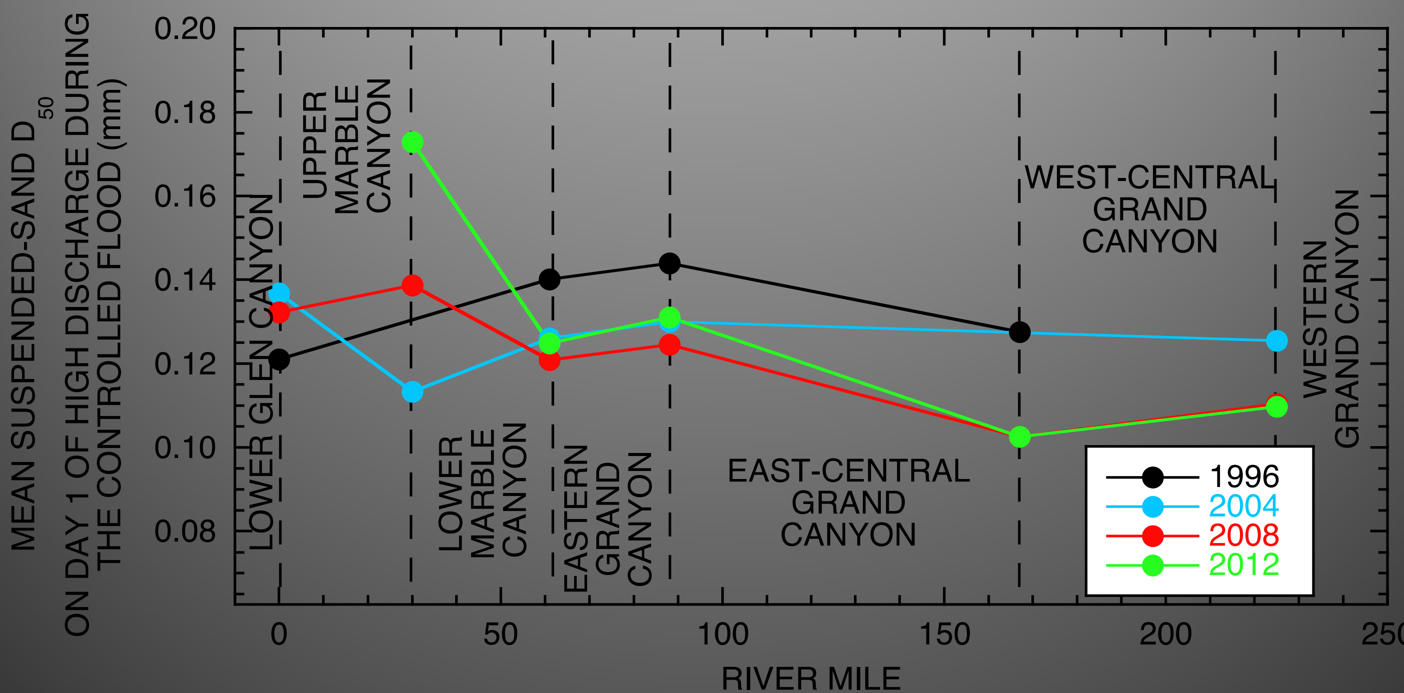


Bed-sand median grain size



Bed-sand area (amount)

Suspended-sand median grain size



(after Topping and others, *USGS OFR 2010-1128*, 2010)

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Sand-concentration ranking of controlled floods

RM 0	RM 30	RM 61	RM 87	RM 166	RM 225
2008	2008	2008	1996 ≈ 2008	2008	**2012**
2004	2004	2004 ≈ **2012**	**2012** ≈ 2004	1996	2008
1996	**2012**	1996		**2012**	2004

- 75% of sand-concentration rankings agree with bed-sand area (amount) analysis
- Only 40% of sand-concentration rankings agree with bed-sand grain-size analysis
- Mass-balance sand budgets should teach us more...

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Sand mass-balance context

Shown are changes in sand mass (metric tons)

Period of budget	Upper Marble Canyon	Lower Marble Canyon
July 2002 - pre2004 flood	330,000 ± 194,000	-280,000 ± 110,000
pre2004 flood – pre2008 flood	900,000 ± 640,000	290,000 ± 350,000
pre2008 flood – pre2012 flood	-1,500,000 ± 620,000 (mostly during May-August 2011)	-12,000 ± 430,000
July 2012 – pre2012 flood	670,000 ± 120,000	18,000 ± 15,000
during 2012 flood	-320,000 ± 13,000	-78,000 ± 36,000

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Relations between sand mass balance and sand concentrations during controlled floods

	Upper Marble Canyon		Lower Marble Canyon	
	Cumulative post-July 2002 sand mass before flood (metric tons)	% of sand concentration during 2004 flood	Cumulative post-July 2002 sand mass (metric tons)	% of sand concentration during 2004 flood
2004 flood	**330,000**	**100%**	**-280,000**	**100%**
2008 flood	**1,230,000**	**140%**	**10,000**	**140%**
2012 flood	**-270,000**	**68%**	**-2,000**	**95%**
post 2012 flood	**-590,000**		**-80,000**	

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flow

bed sand area

bed sand area

$$\frac{\Delta \eta}{\Delta t} \propto -\frac{\Delta\left(u_*^{4.5} h A_b D_b^{-2.5}\right)}{\Delta x}$$

- Spatial decrease in “flow” leads to deposition

- Spatial increase in bed-sand grain size leads to deposition

- Spatial decrease in bed-sand area (amount) leads to deposition

- Greatest deposition rates occur in eddies when greatest flow “deceleration” occurs between channel and eddy, and sand in upstream channel is as fine as possible and amount on upstream channel bed is relatively large

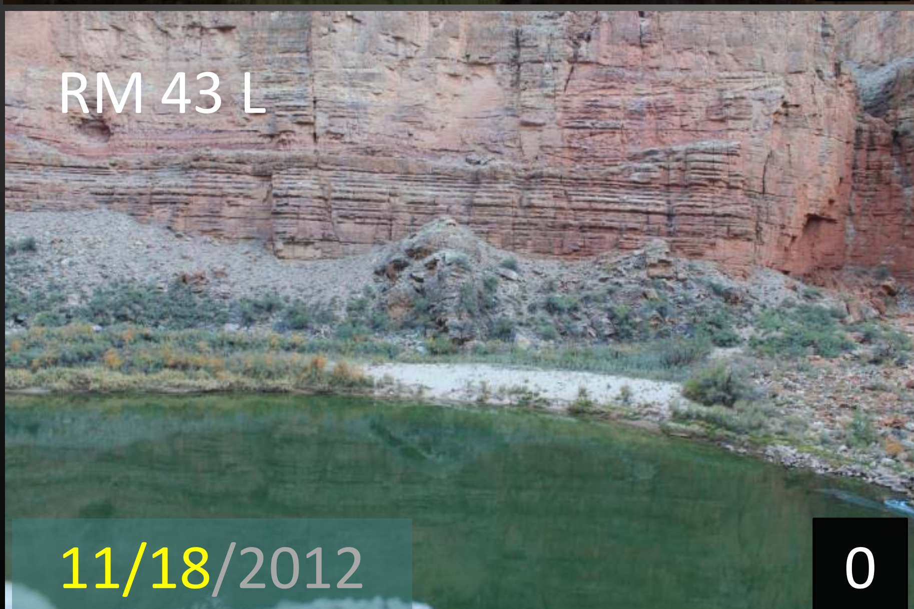
Substantial Gain (18 sites)


RM 9 L
11/18/2012
0
11/24/2012
1
RM 16 L
11/18/2012
0
11/24/2012
1

Grand Canyon River Guides
Adopt-a-Beach Site

Shinumo
Wash Camp
RM 29.4 L

No Substantial Change(12 sites)



Substantial Loss (3 sites)

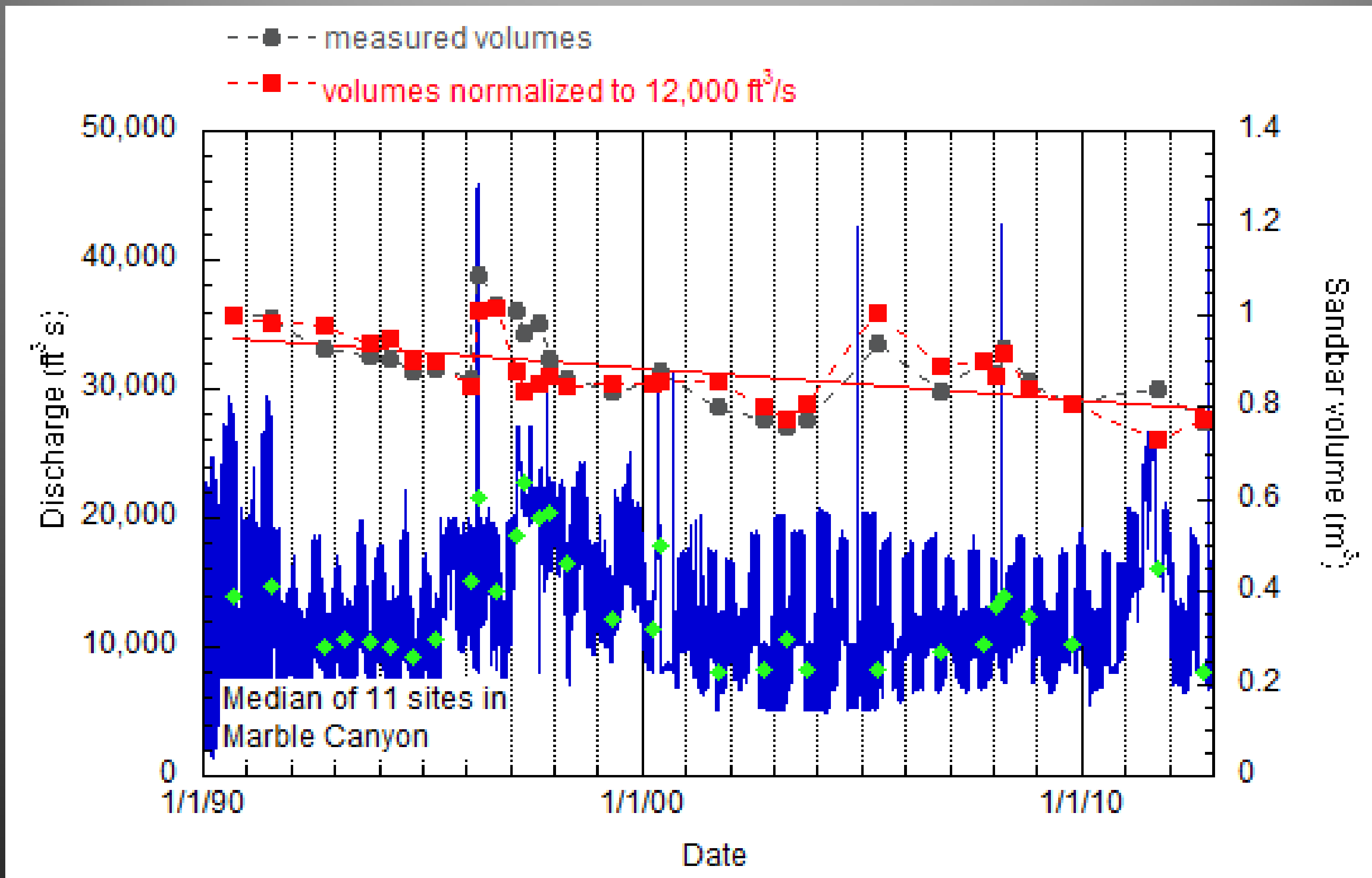
Sandbar Response to 2012 HFE based on Analysis of Images from Remote Cameras

- Summary of evaluations at 33 sites for 2012 HFE response
  - Substantial Gain (deposition): 18 sandbars (55% of sites)
  - No substantial change: 12 sandbars (36% of sites)
  - Substantial Loss (erosion): 3 sandbars (9% of sites)
- Downstream trends
  - All sites between RM 0 and RM 32 increased
  - Downstream from RM 32, split between sites of noticeable gain and no change, with a few showing noticeable loss

Comparison of Response Among 4 Controlled Floods: 1996, 2004, 2008, 2012

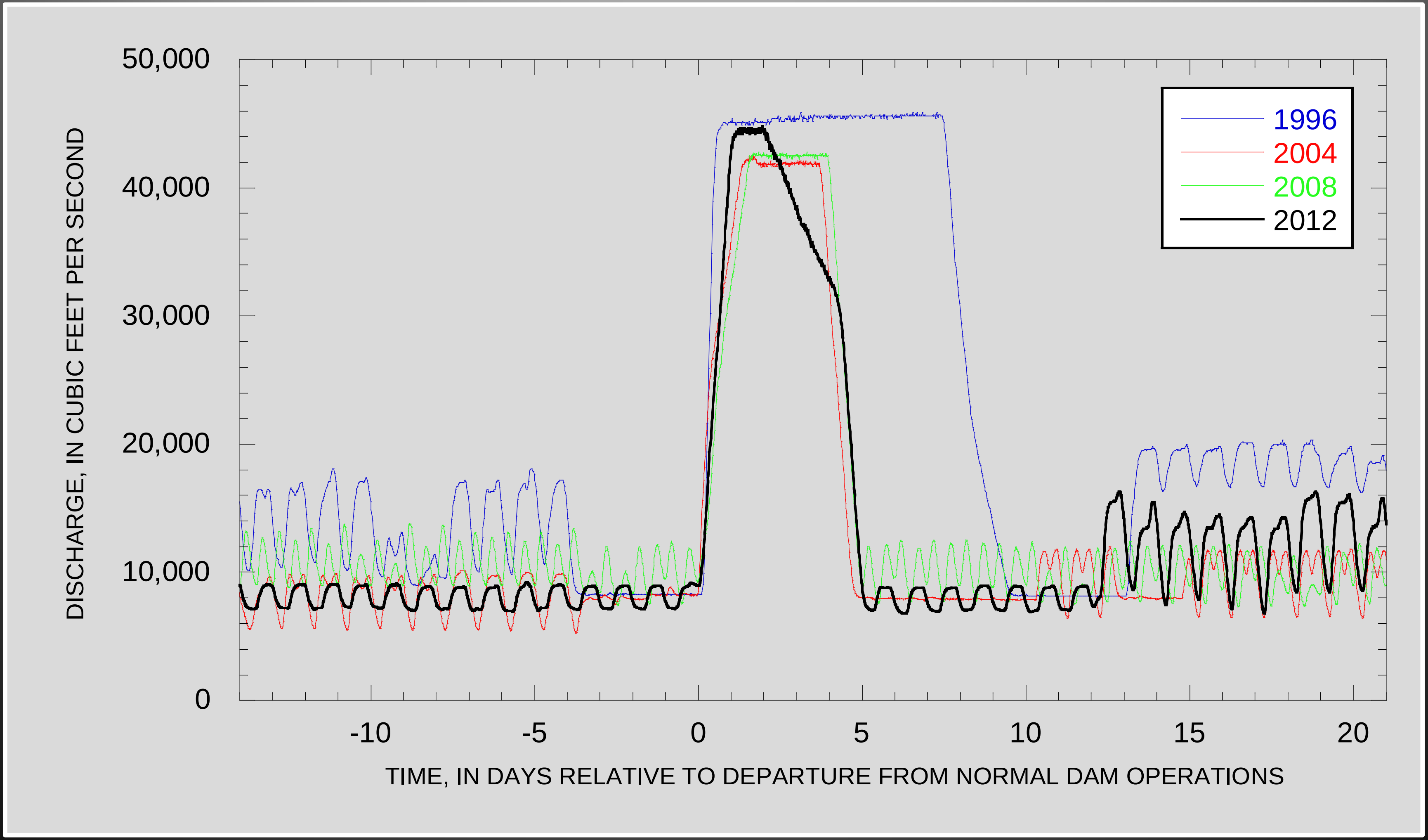
- 15 sites with cameras present during all 4 events
  - In each year, a few sites did better, a few not as well, nothing stands out, too few sites to make any general conclusions
- 26 sites with cameras present in 2008 and 2012
  - Sandbar larger in 2012: 4 sites, 3 above RM 32
  - Sandbar smaller in 2012: 7 sites
  - Sandbar about the same in 2012: 15 sites

Sandbars in Marble Canyon before 2012 Controlled Flood

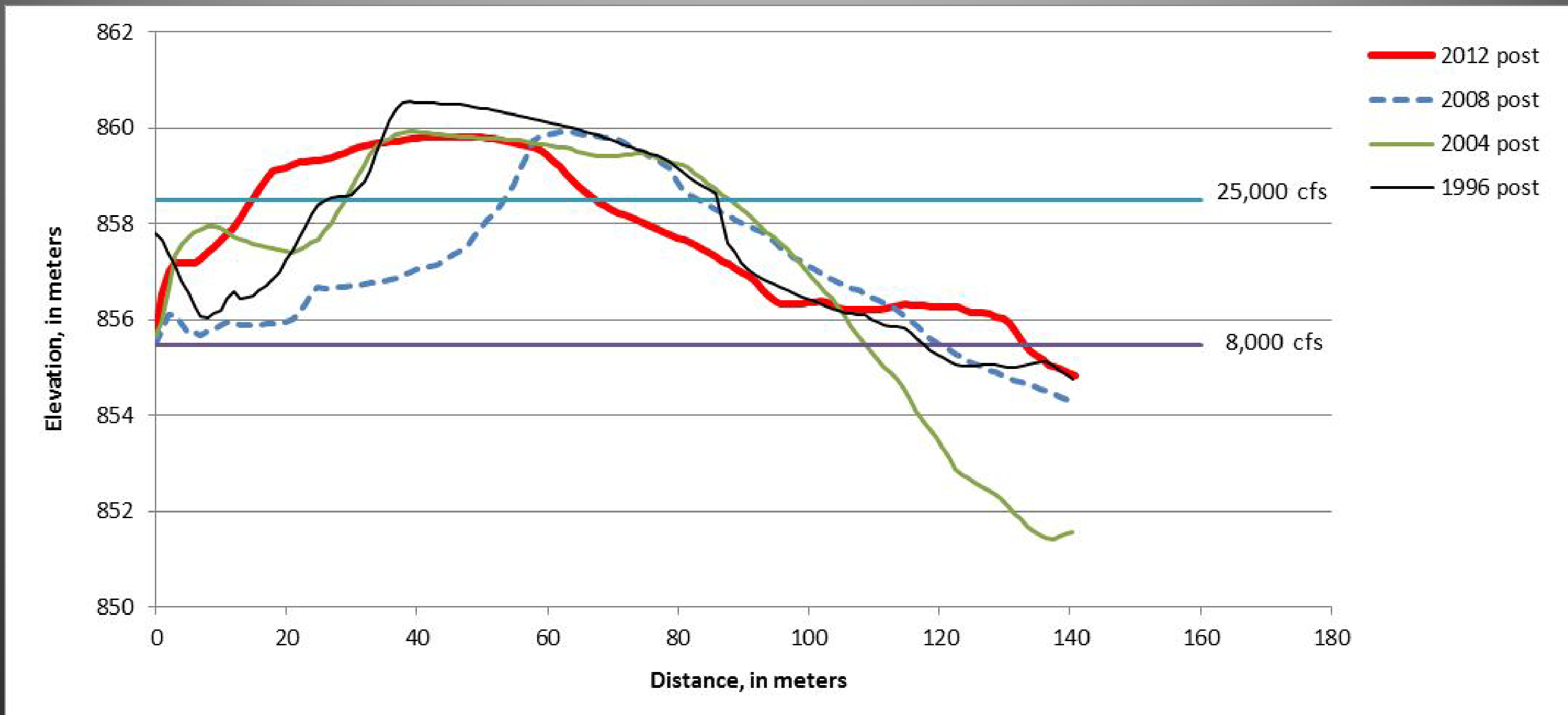


- *Some increase between October 2011 and October 2012*
- *Both 2011 and 2012 are low relative to early 1990's and post-flood surveys*

What is the effect of changing the hydrograph of the high flow?



Sandbar Shape – RM 30

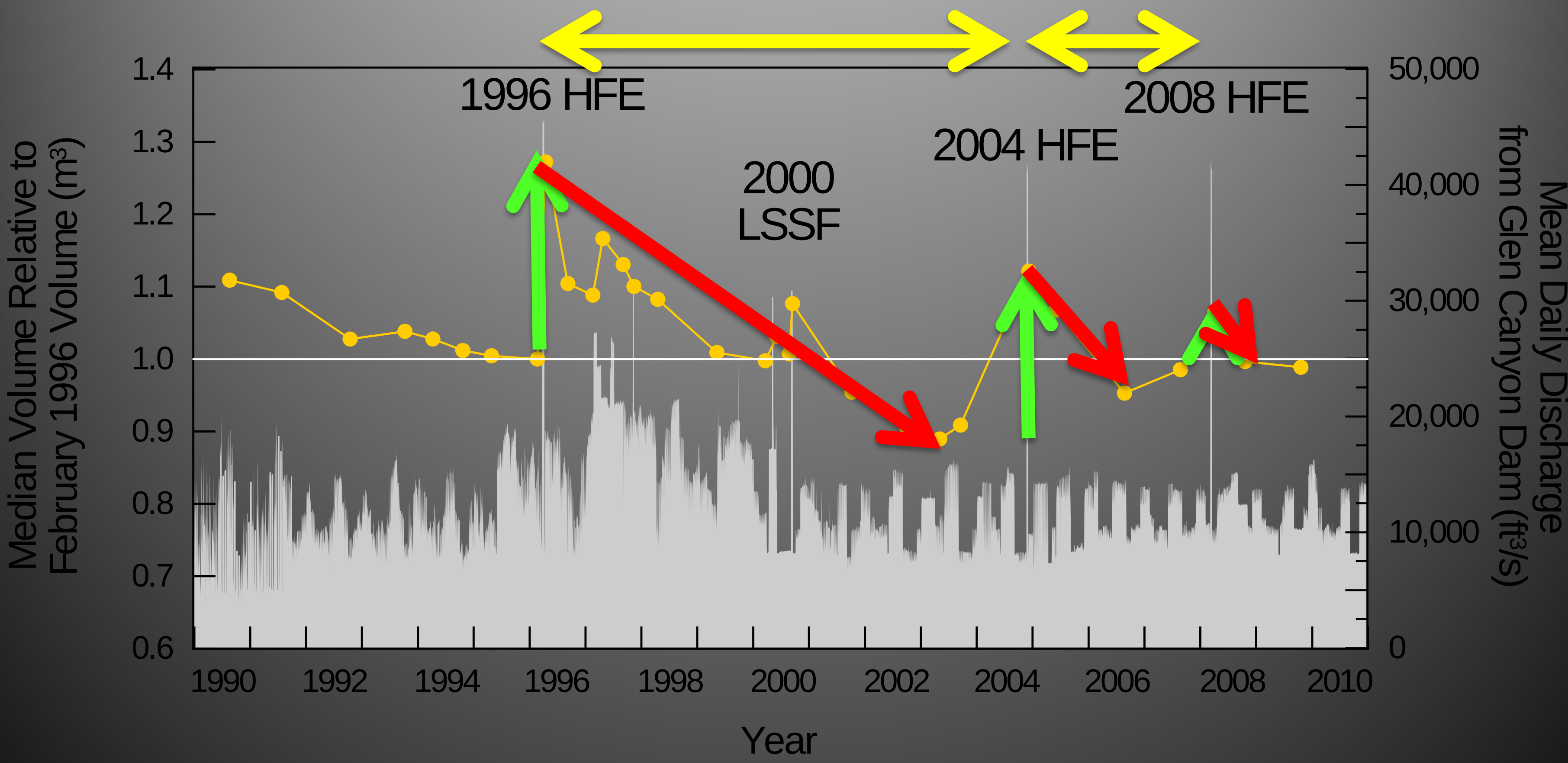


- Slope from bar crest to 8,000 cfs level less steep than other floods
- For 3 sites with post-flood surveys and large reattachment bars, the area of newly deposited bar above the 8,000 cfs stage with slope less than 8 deg. was larger in 2012 than previous floods

Conclusions

- 2012 flood resulted in sandbar building, as observed in previous controlled floods
- Bar building not as widespread as 2008
  - But likely stronger than 2008 in upper Marble Canyon
- Effect of slower rate of flood recession
  - Not a dramatically different response
  - May have resulted in bars that are less steep in a few locations
  - Need more observations, numerical modeling, and probably controlled laboratory experiments to better understand the effect of hydrograph shape

Long-term average size of sand deposits along the channel margin depends on **how much deposition occurs during each flood**, **how much erosion occurs between each flood**, and **how frequently the floods occur**



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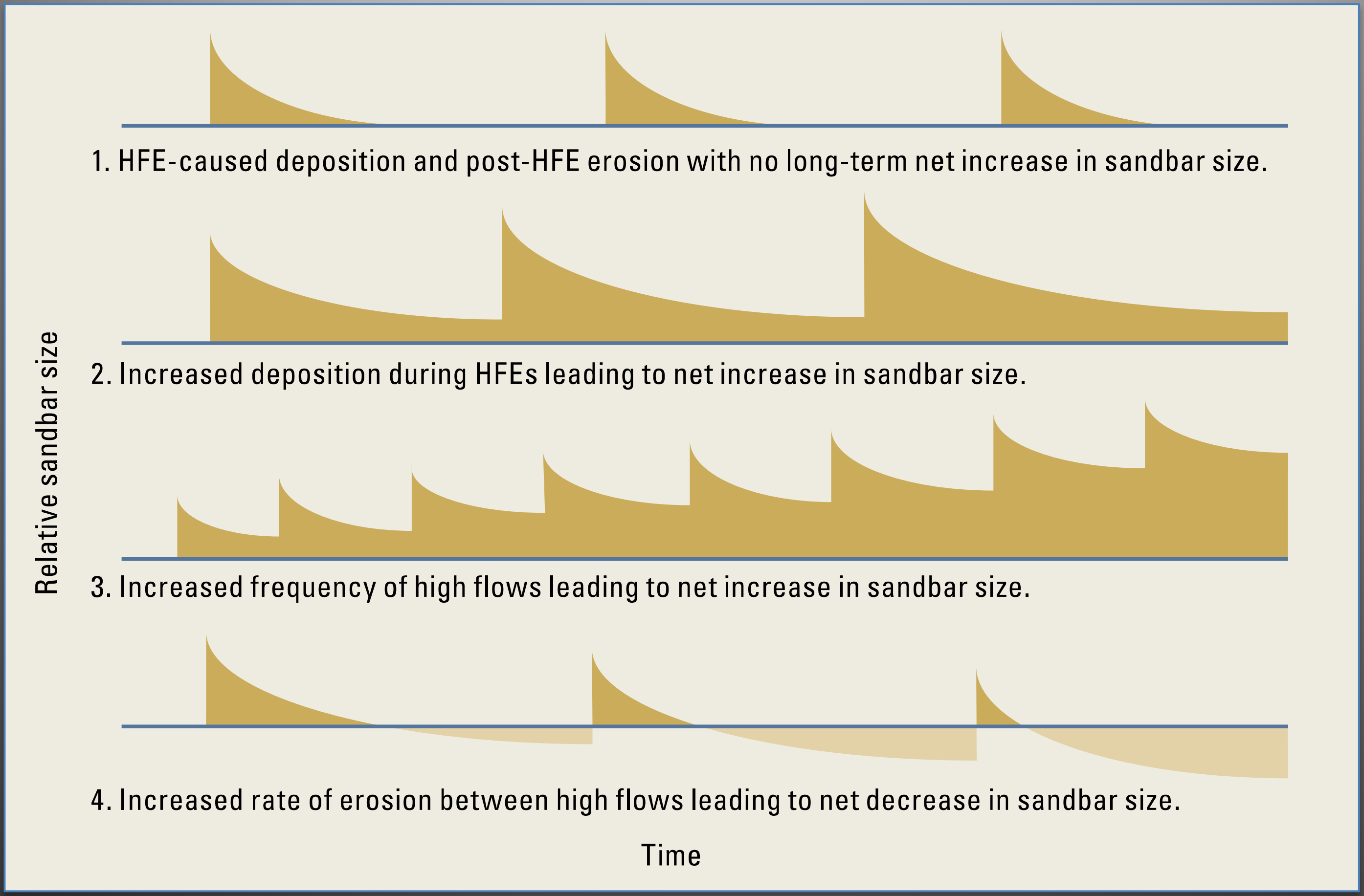

These are all hypothetical trajectories of long-term sand bar change. We are hoping for the best, which can be accomplished by any scenario where the aggregate amount to sand deposited by floods exceeds the aggregate amount of erosion that occurs in the intervening times.