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

David J. Topping (USGS)
David M. Rubin (USGS)
John C. Schmidt (USU)
Joseph E. Hazel, Jr. (NAU)
Theodore S. Melis (USGS)
Scott A. Wright (USGS)
Matt Kaplinski (NAU)
Amy E. Draut (USGS)
Michael J. Breedlove (USU)

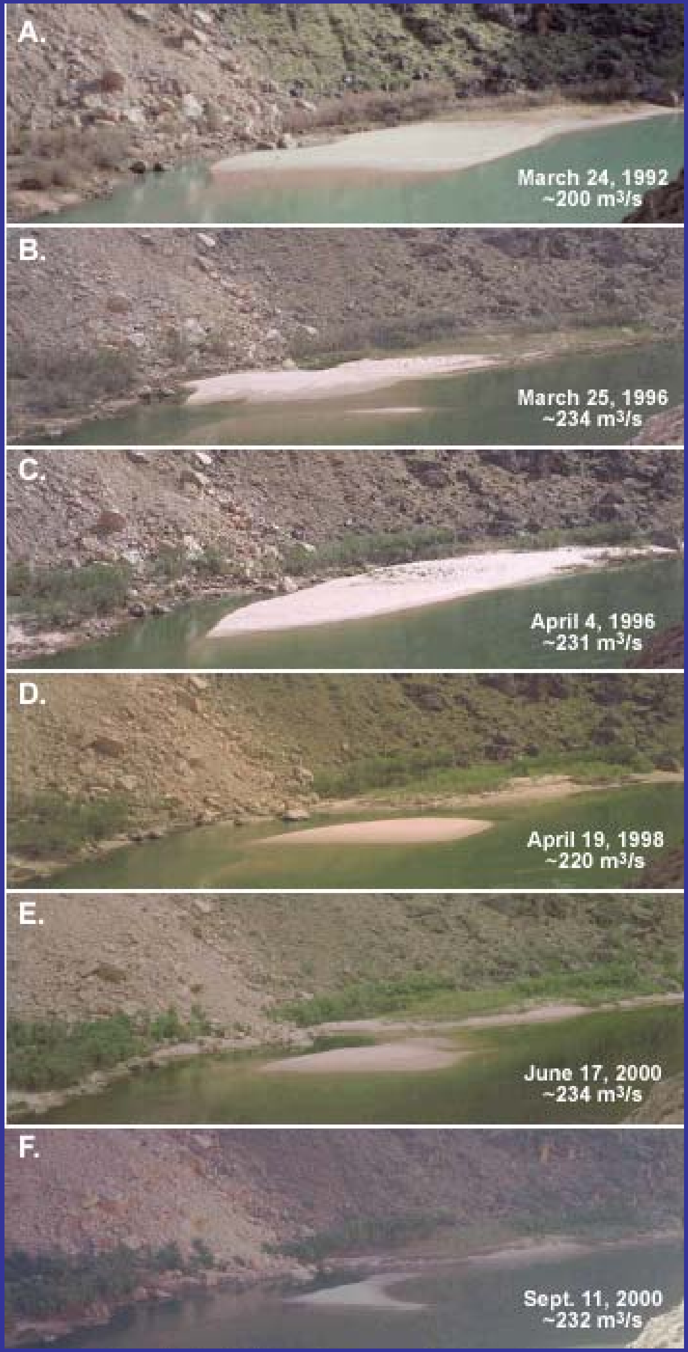
published 2006 in Proceedings of the 8th Federal Inter-Agency Sedimentation Conference

USGS
science for a changing world

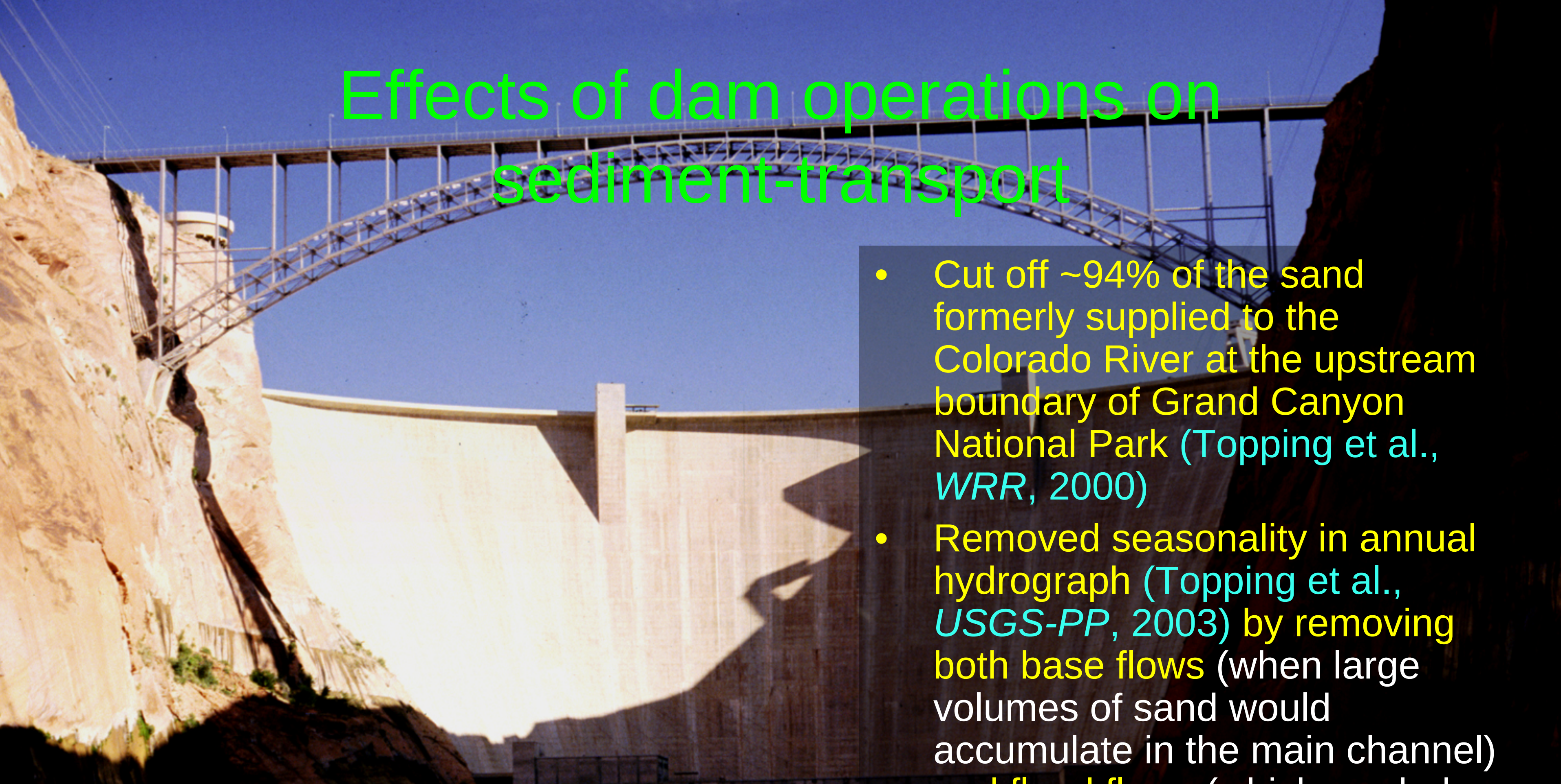
Sandbars and other deposits of sand, silt, and clay are important because...

- 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).

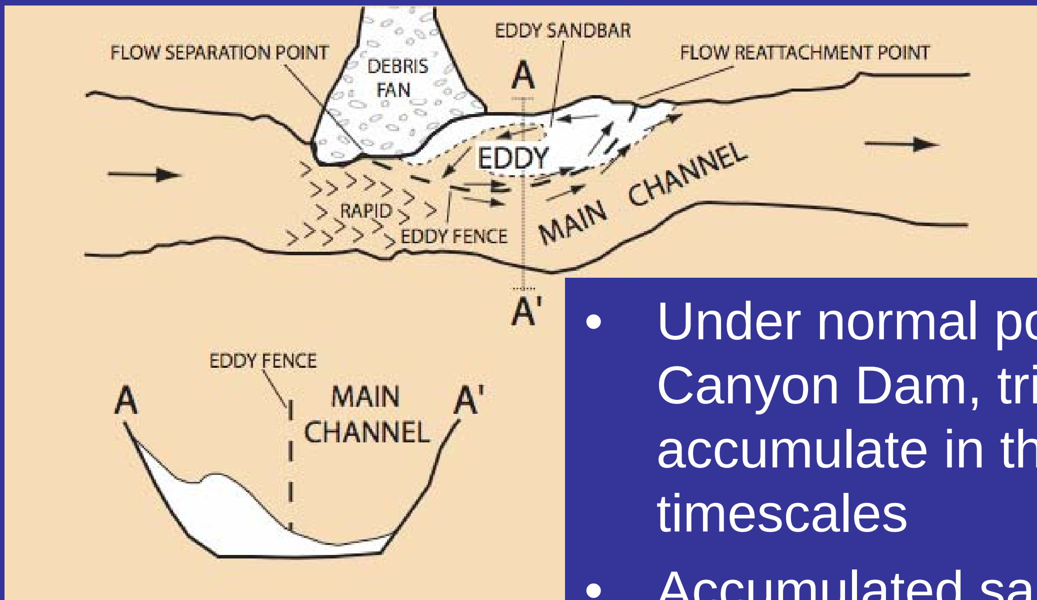


Effects of dam operations on sediment-transport



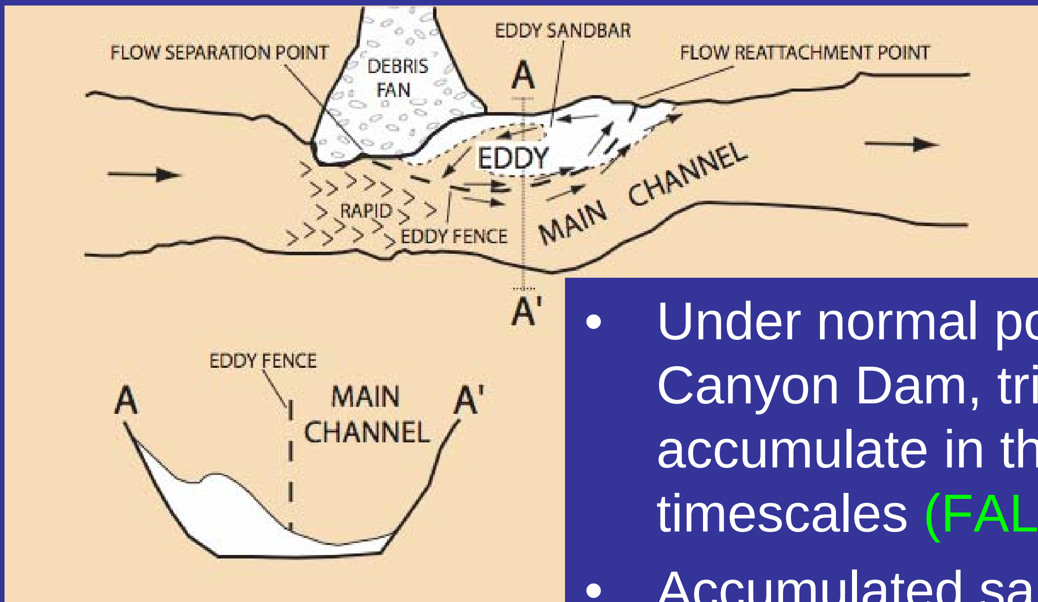
- Cut off ~94% of the sand formerly supplied to the Colorado River at the upstream boundary of Grand Canyon National Park (Topping et al., *WRR*, 2000)
- Removed seasonality in annual hydrograph (Topping et al., *USGS-PP*, 2003) by removing both base flows (when large volumes of sand would accumulate 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



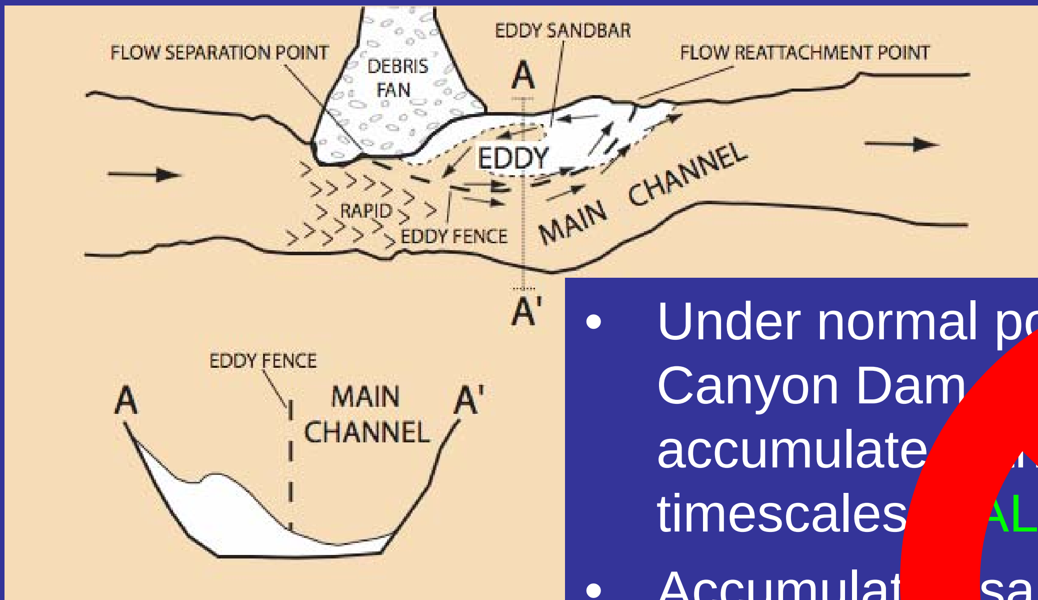
- Under normal powerplant releases from Glen Canyon Dam, tributary-supplied sand would accumulate in the main channel over multi-year timescales
- Accumulated sand could be transferred from the main-channel bed to eddies during controlled floods, increasing both the total area and volume of eddy sandbars

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



- Under normal po… …ases from Glen Canyon Dam …utary-suppli… …and would accumulate … …ain channel… …er multi-year timescales … …ALSE… …ubin et al., … …S, 2002)
- Accumulat… sand co… …e trans… …ed from the main-chan… bed to edd… …durin… …ontrolled floods, incre… …ng both the … …a and volume of eddy sandb… (ONLY PA… …LLY TRUE; Rubin et al., *EOS*, …

Reality

- 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

Site 55.5R

Before and after 7-day 45,000 ft³/s 1996 controlled flood

3/26/96

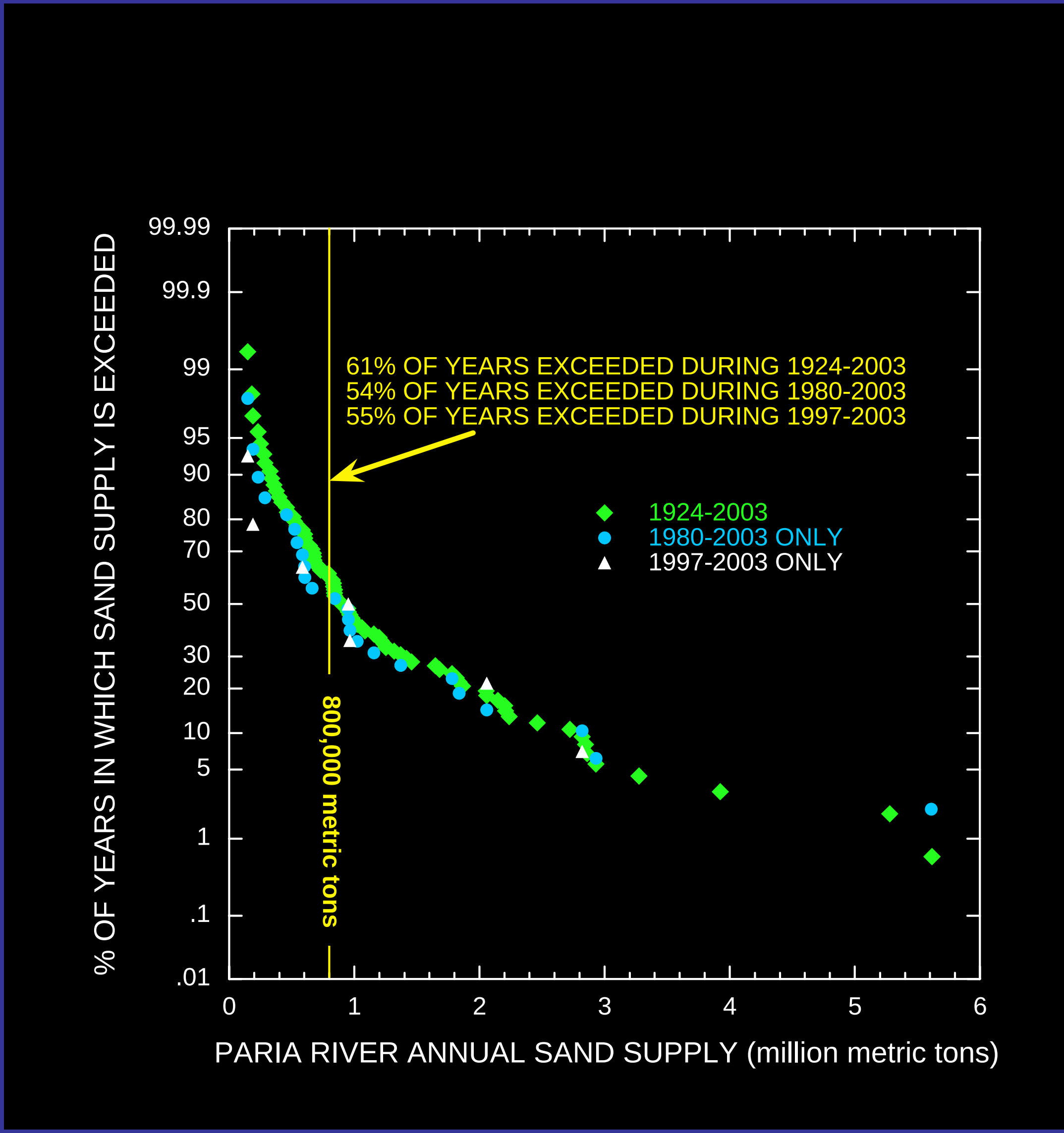
4/07/96

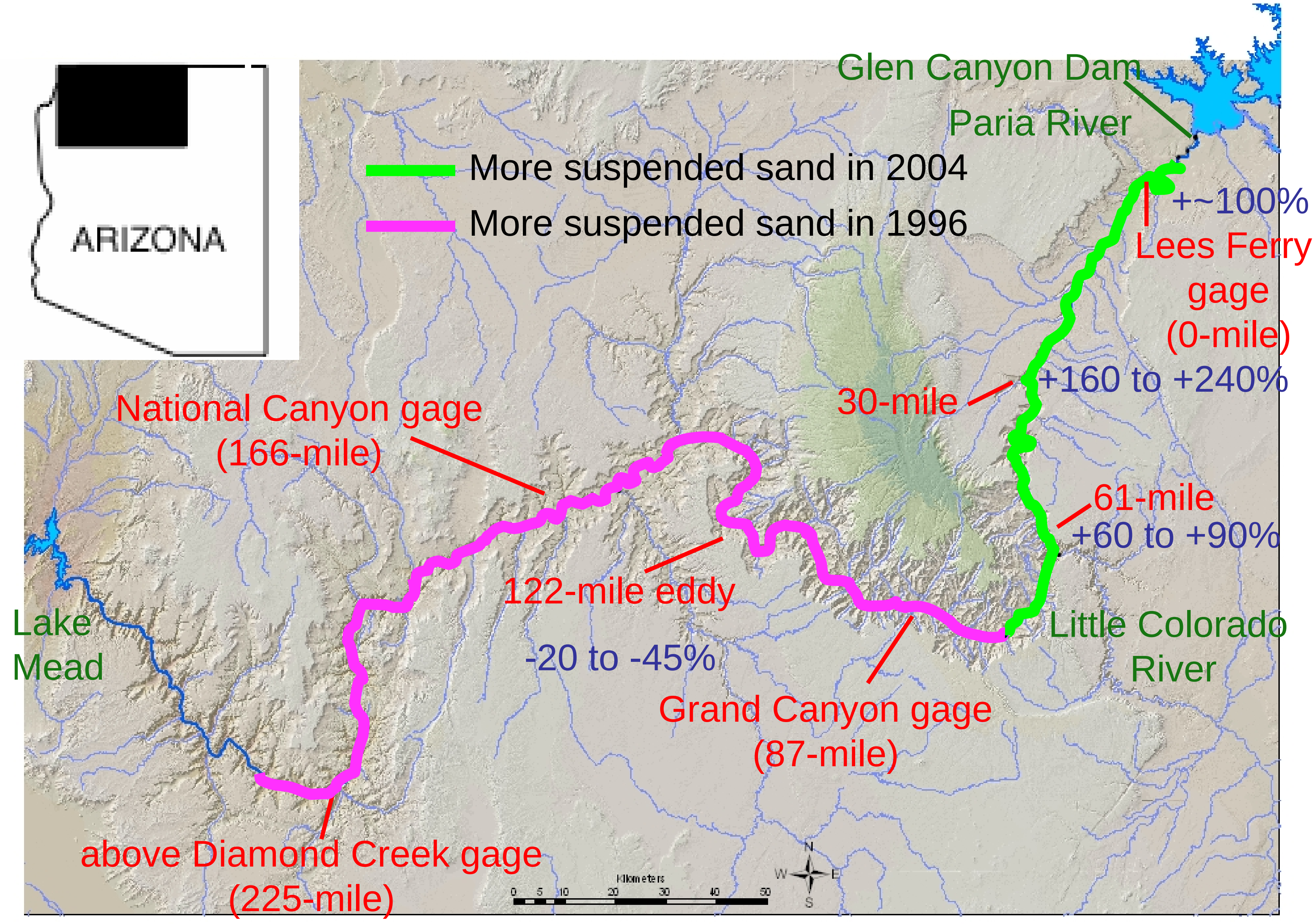
During the 1996 controlled flood, ~3x the sand deposited in eddies above the stage associated with 8,000 ft³/s was eroded from eddies below this stage (Hazel et al., *AGU Mono.*, 1999; Schmidt, *AGU Mono.*, 1999). ~90% of the sediment exported was eroded from eddy sandbars (Hazel et al., *JGR*, 2006).

Design of 2004 controlled-flood experiment

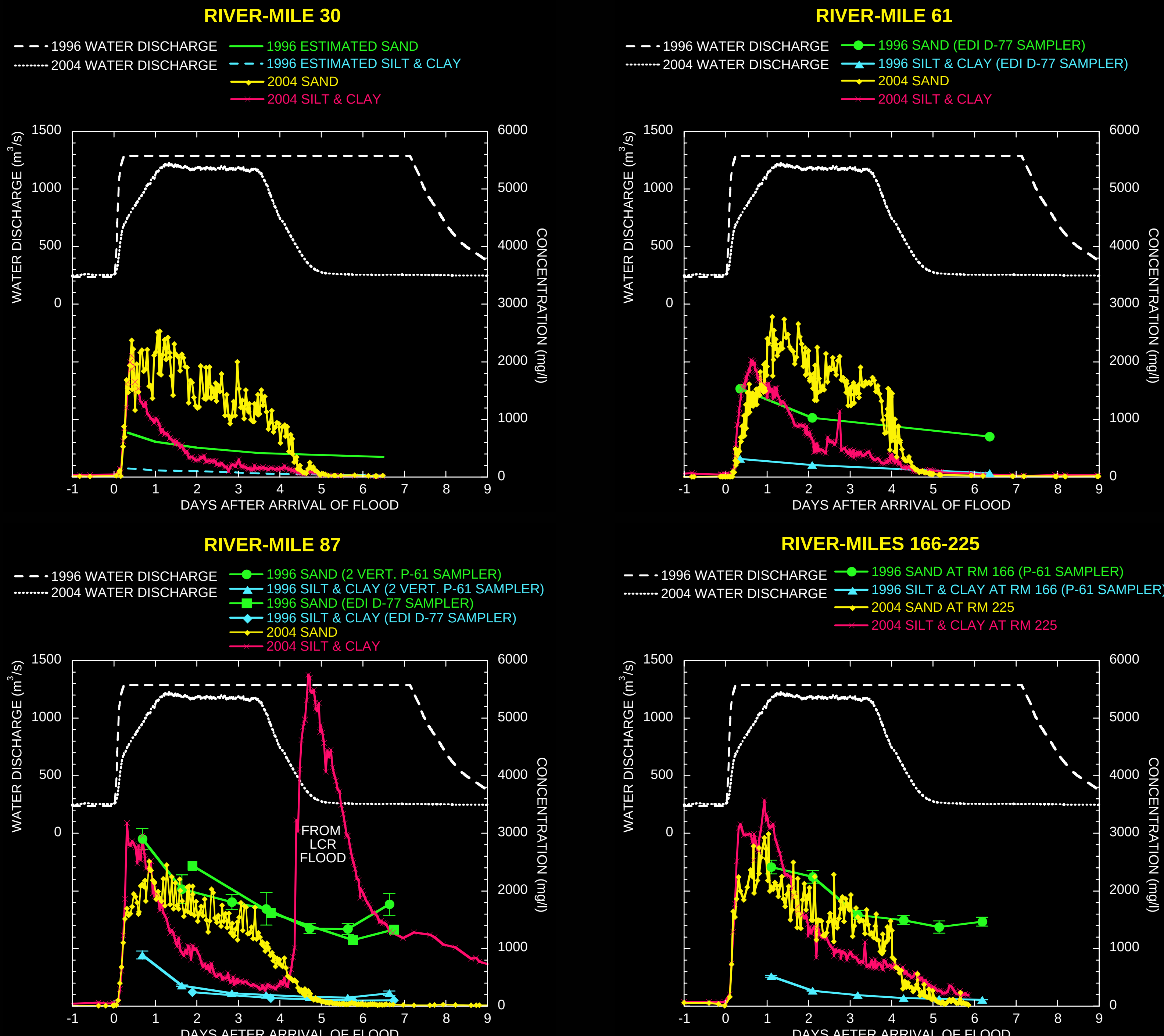
- Keep dam releases relatively low (< 10,000 ft^3/s) during September-November to allow the accumulation and retention of new tributary sand inputs in the channel

- 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 ft^3/s in late November



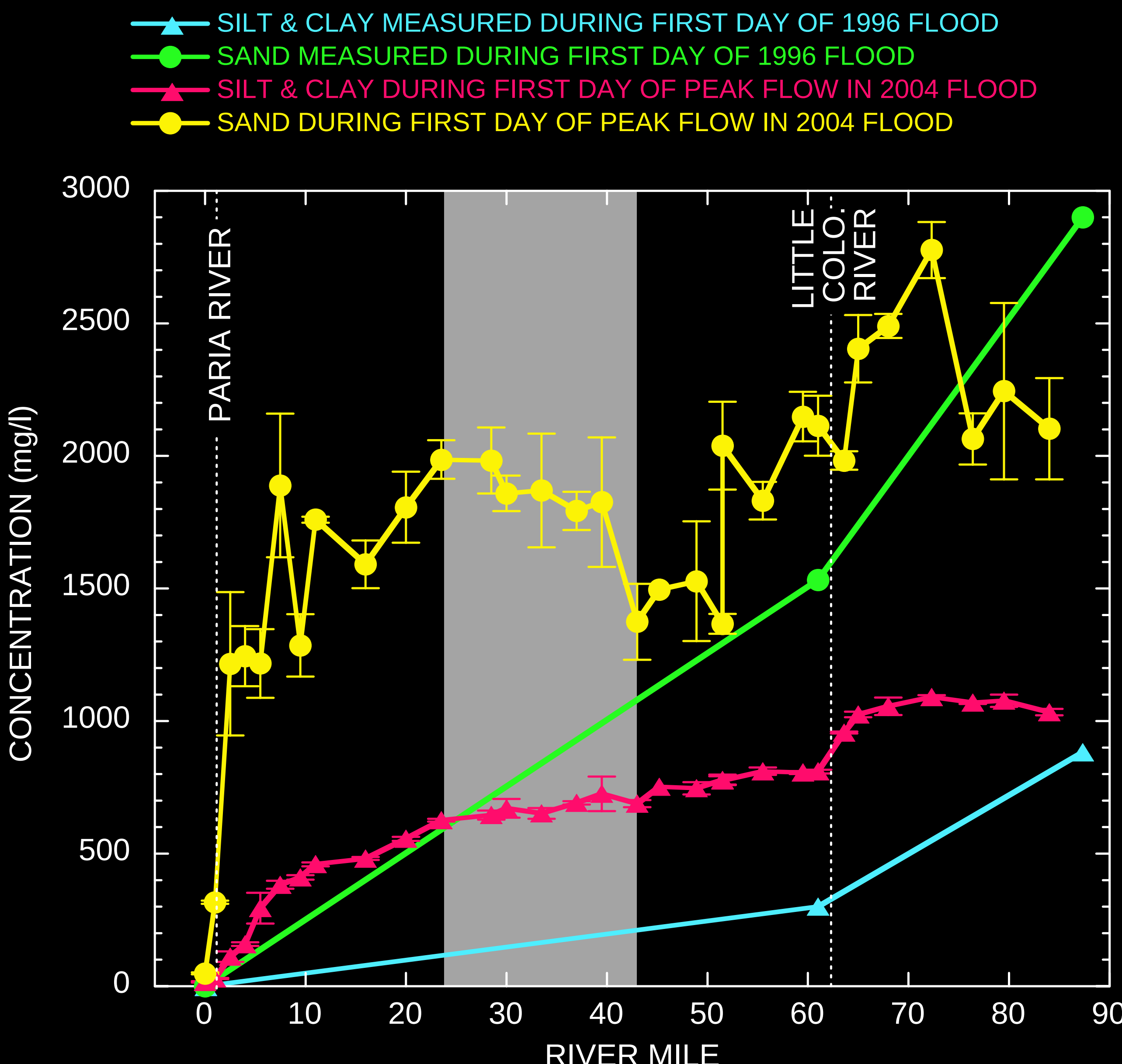


ARIZONA
Glen Canyon Dam
Paria River
More suspended sand in 2004
More suspended sand in 1996
+~100%
Lees Ferry gage (0-mile)
30-mile
+160 to +240%
National Canyon gage (166-mile)
61-mile
+60 to +90%
122-mile eddy
Lake Mead
Little Colorado River
-20 to -45%
Grand Canyon gage (87-mile)
above Diamond Creek gage (225-mile)
Kilometers
0 5 10 20 30 40 50
N
W
E
S

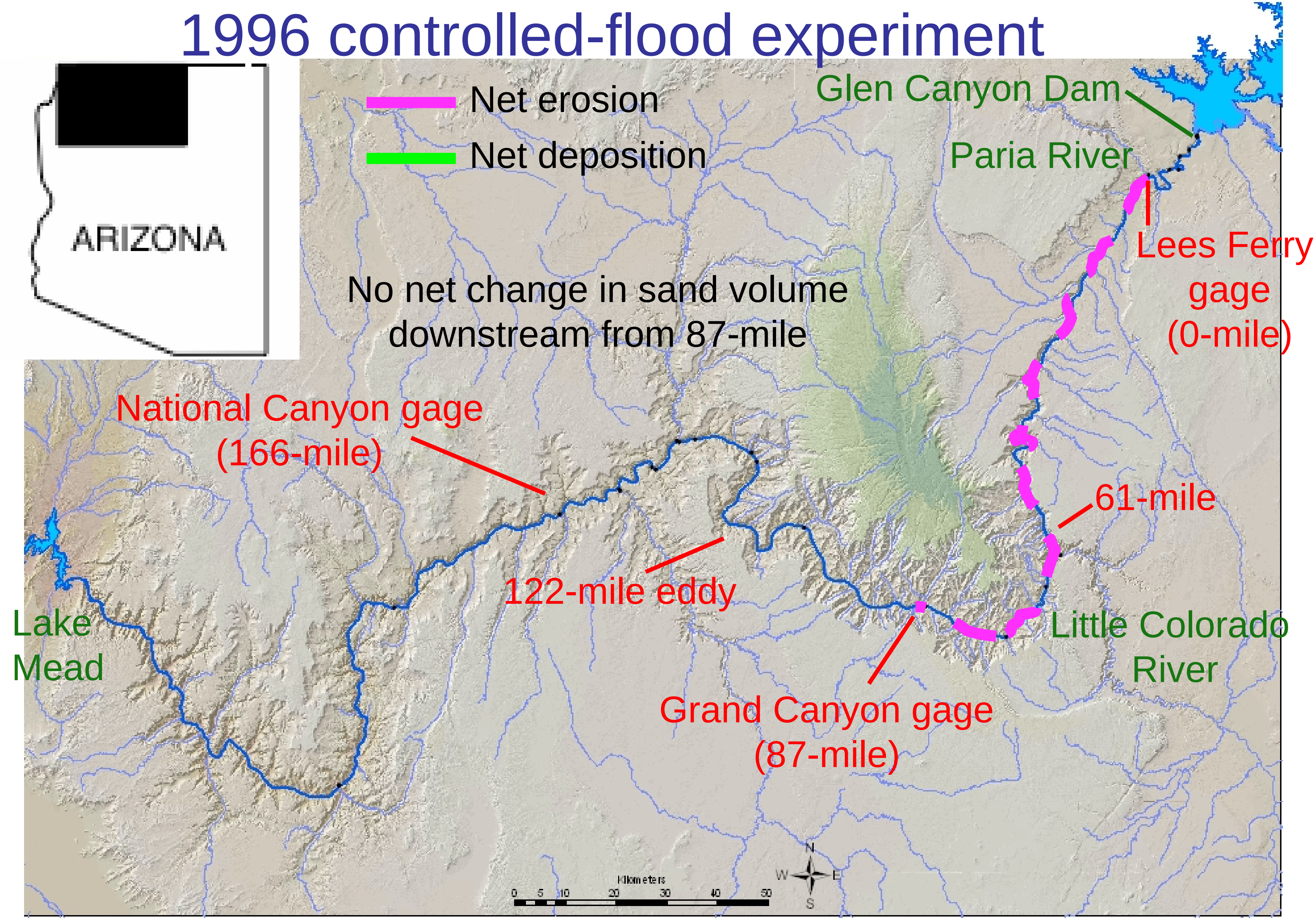


RIVER-MILE 30
1996 WATER DISCHARGE
2004 WATER DISCHARGE
1996 ESTIMATED SAND
1996 ESTIMATED SILT & CLAY
2004 SAND
2004 SILT & CLAY
WATER DISCHARGE (m3/s)
CONCENTRATION (mg/l)
DAYS AFTER ARRIVAL OF FLOOD
RIVER-MILE 61
1996 WATER DISCHARGE
2004 WATER DISCHARGE
1996 SAND (EDI D-77 SAMPLER)
1996 SILT & CLAY (EDI D-77 SAMPLER)
2004 SAND
2004 SILT & CLAY
WATER DISCHARGE (m3/s)
CONCENTRATION (mg/l)
DAYS AFTER ARRIVAL OF FLOOD
RIVER-MILE 87
1996 WATER DISCHARGE
2004 WATER DISCHARGE
1996 SAND (2 VERT. P-61 SAMPLER)
1996 SILT & CLAY (2 VERT. P-61 SAMPLER)
1996 SAND (EDI D-77 SAMPLER)
1996 SILT & CLAY (EDI D-77 SAMPLER)
2004 SAND
2004 SILT & CLAY
FROM LCR FLOOD
WATER DISCHARGE (m3/s)
CONCENTRATION (mg/l)
DAYS AFTER ARRIVAL OF FLOOD
RIVER-MILES 166-225
1996 WATER DISCHARGE
2004 WATER DISCHARGE
1996 SAND AT RM 166 (P-61 SAMPLER)
1996 SILT & CLAY AT RM 166 (P-61 SAMPLER)
2004 SAND AT RM 225
2004 SILT & CLAY AT RM 225
WATER DISCHARGE (m3/s)
CONCENTRATION (mg/l)
DAYS AFTER ARRIVAL OF FLOOD

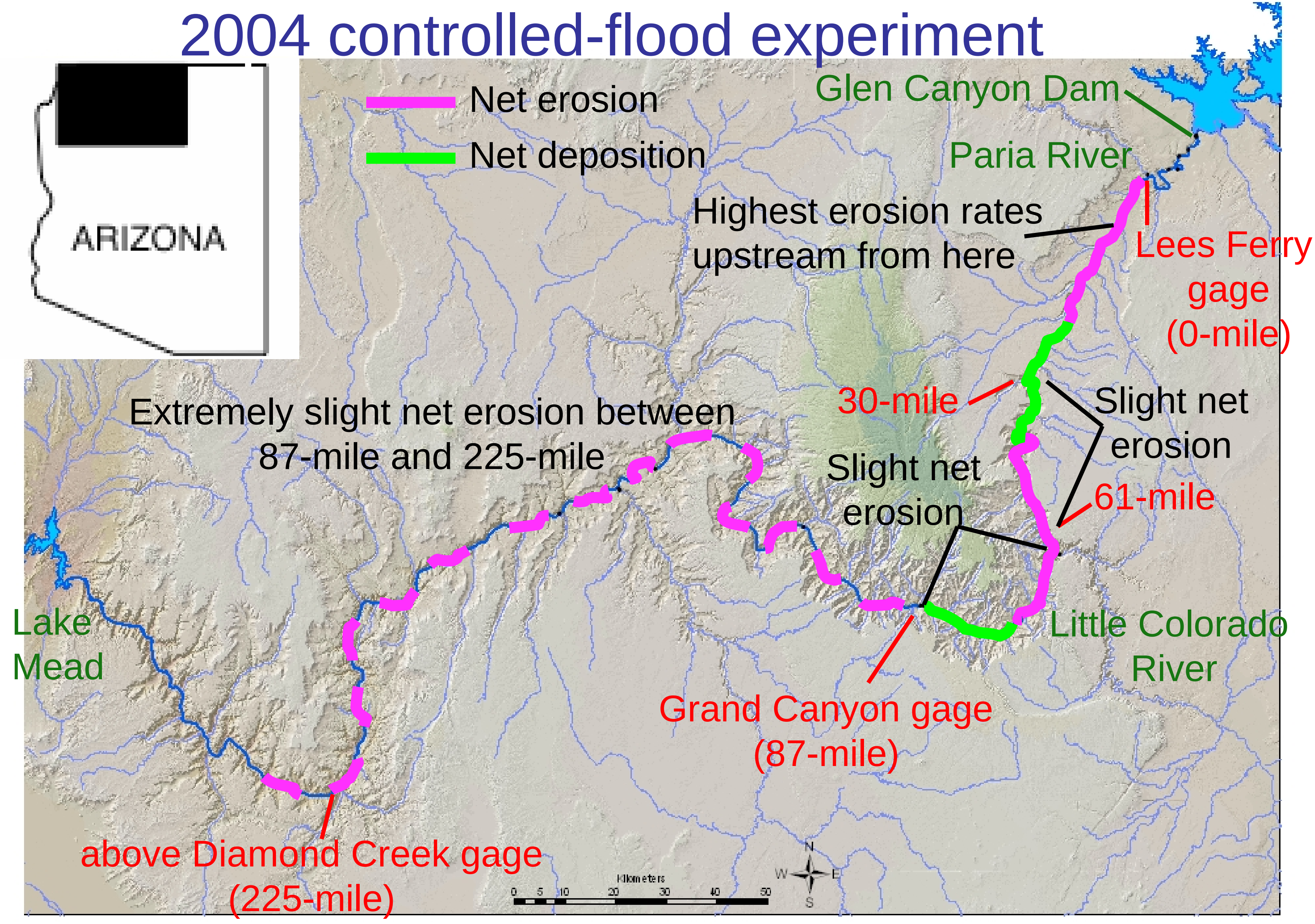
Lagrangian sampling

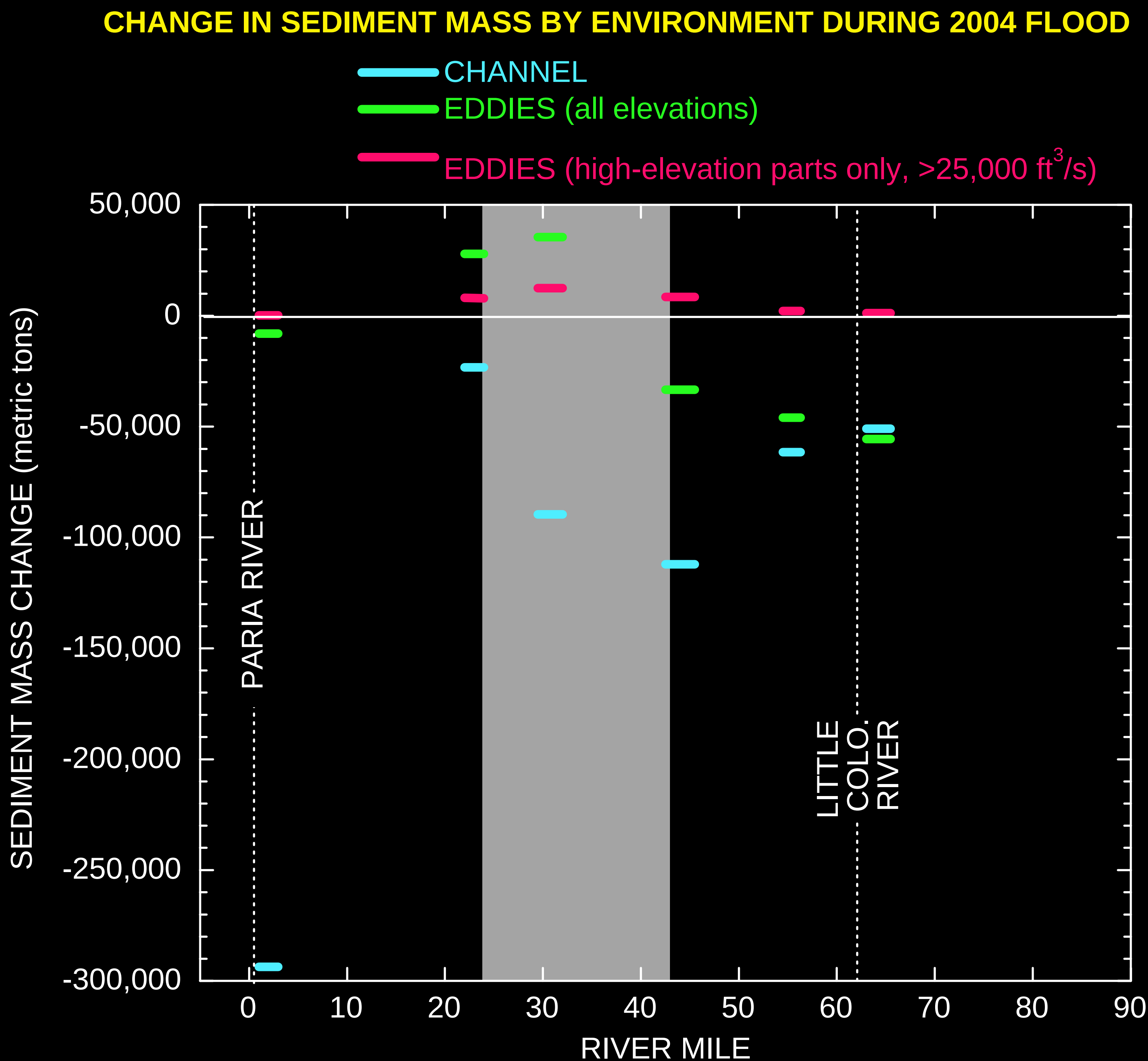


1996 controlled-flood experiment



2004 controlled-flood experiment





CHANGE IN SEDIMENT MASS BY ENVIRONMENT DURING 2004 FLOOD
CHANNEL
EDDIES (all elevations)
EDDIES (high-elevation parts only, >25,000 ft3/s)
SEDIMENT MASS CHANGE (metric tons)
50,000
0
-50,000
-100,000
-150,000
-200,000
-250,000
-300,000
PARIA RIVER
LITTLE COLO. RIVER
0
10
20
30
40
50
60
70
80
90
RIVER MILE

Sandbar topographic results

Site 21.8R

11/20/04

11/27/04

Site 55.5R

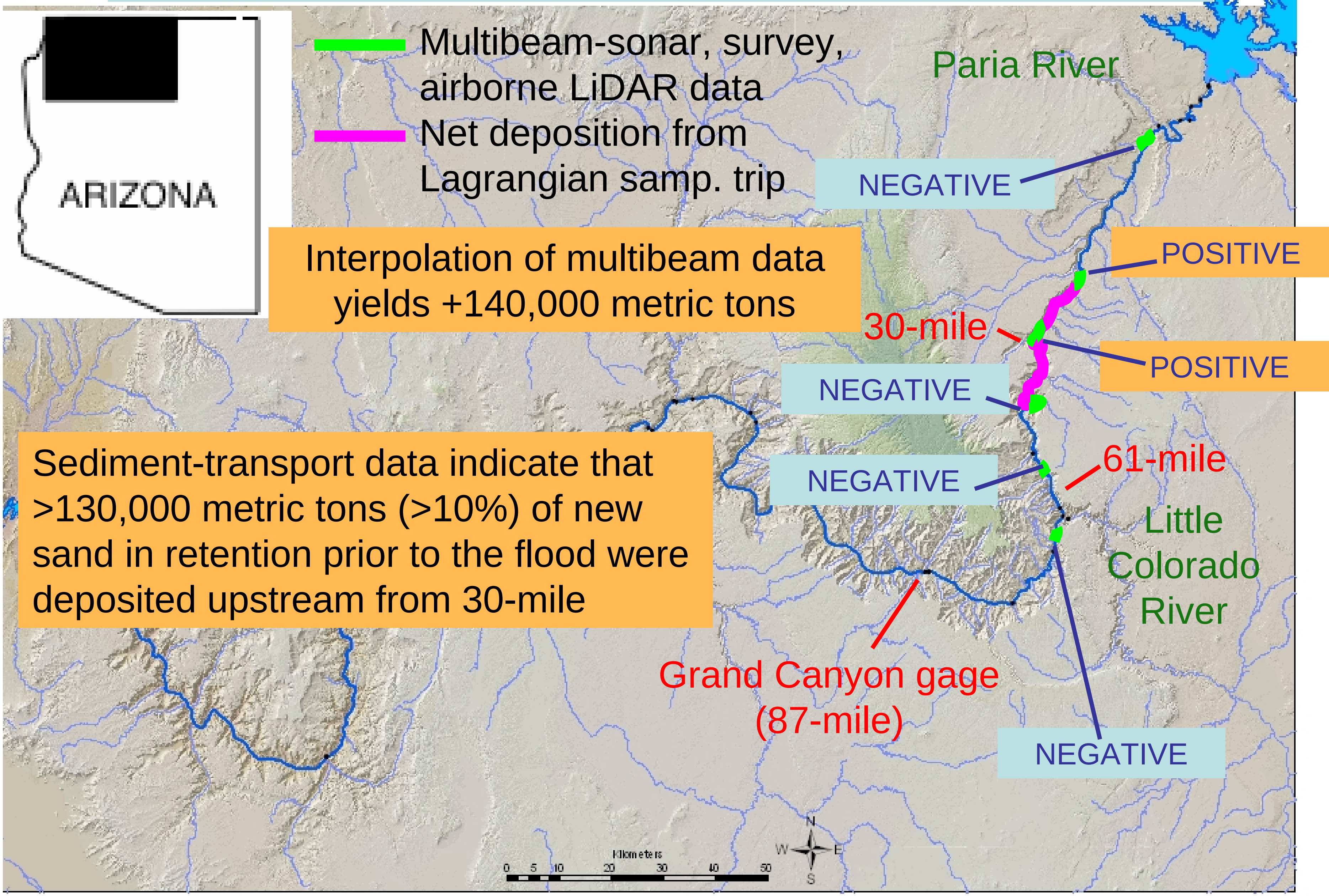
11/20/04

11/28/04

Compared to after the 1996 controlled flood

- Above river-mile 40, 50% of sandbars larger in volume and area above 8,000 ft^3/s
- Between river-mile 40 and 87, only 18% of sandbars larger in volume and area above 8,000 ft^3/s
- Between river-mile 87 and 225, only 31% of sandbars larger in volume and area above 25,000 ft^3/s

Net transfer of sediment into eddies during 2004 controlled flood



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