Integrated Fine-Sediment Monitoring in Grand Canyon: An Overview

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FIST

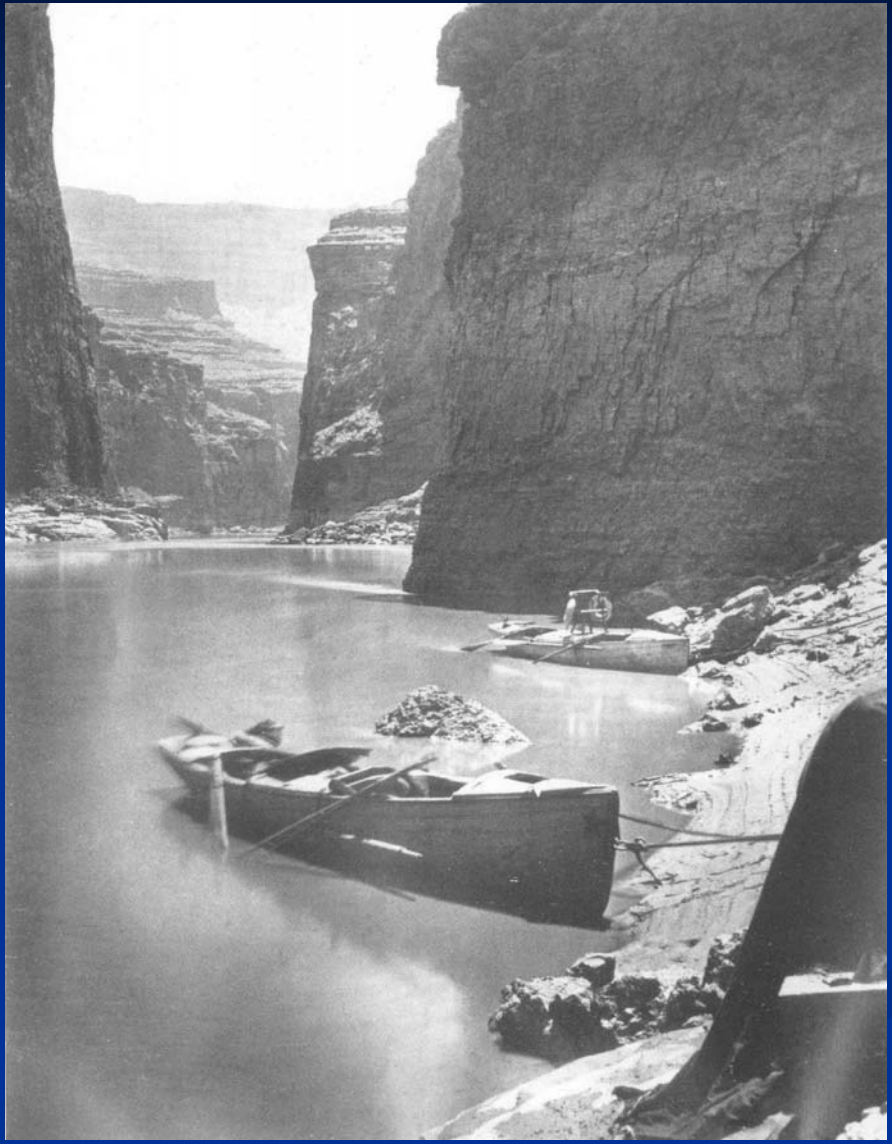
- U.S. Geological Survey (Rubin, Topping)
- Northern Arizona University (Hazel, Kaplinski)
- Utah State University (Schmidt)
- Grand Canyon Monitoring and Research Center (Melis)

Fine-sediment deposits in Grand Canyon

- Distinctive attribute of the pre-dam riverscape
- Campsites
- Architecture that creates stagnant flow and backwater habitat at some discharges
- Substrate for riparian ecosystem
- Deposits contain archaeological resources or contribute to stability of those resources
- Transport creates turbidity

NRC (Lewis committee) recommended that sand bars be 1 of 2 benchmarks indicators of ecological health of the river system

Badger Creek Rapids, 1920s



Marble Canyon, 1872

Sediment Budgets are a fundamental conceptual tool in organizing knowledge, establishing accuracy of existing measurement programs, and identifying future research needs

- input - output = Δ storage

- storage components
  - main channel bed
    - spawning habitat for trout
    - aquatic food base
  - banks
    - eddies
      - campsites
      - backwaters
      - archaeologic resources
      - fluvial marshes
    - linear channel margins
      - riparian vegetation, archaeologic resources, habitat

An Early Sediment Budget

(Dolan et al. 1974)

- “At Lees Ferry, the median suspended-sediment concentration has been reduced by a factor of about 200. Farther downstream, however, there is less reduction because of additional sediment from tributaries and from the continuing erosion of pre-dam terraces and of the channel bed; at the gauging station near Phantom Ranch the factor of reduction is about 3.5.”

- “Quantification of erosion rates and of the balance between sediment losses and deposition is difficult. Base-line studies have not been made, and there is no systematic measurement program.”

A Bleak Future Prognosis Based on a Sediment Budget *(Laursen et al. 1976)*

- "At present, the mean annual capacity of the river to carry beach-building material is about 12 million metric tons per year. The tributaries supply about 2.7 [million] metric tons of beach-building sediment per year. The difference of about 9 million metric tons per year must be obtained through scour of bed and/or banks."
- "… the beaches … could be in danger of being washed away since the transport capacity of the regulated river is in excess of the amount of beach-building material being supplied from the tributaries … How long they will last cannot as yet be estimated; certainly more than 10 years, probably less than 1000 years; but how much more or less than 100 years is a matter for continued study."

An Optimistic Alternative Future

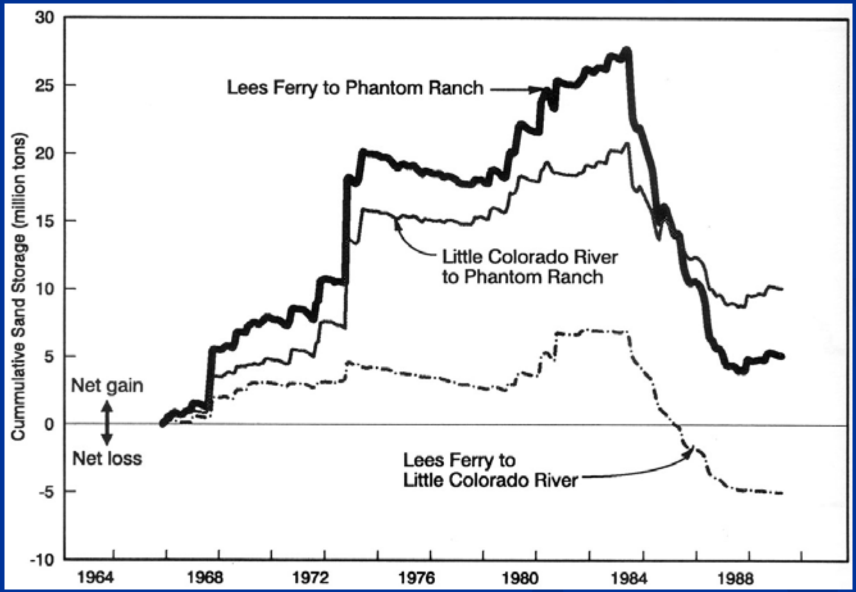
Prognosis Based on a Sediment Budget

(Howard and Dolan 1981)

- “The sand-size and finer sediment transported by the Colorado River is the most important size range both in terms of the extent of deposits and its relative abundance in the sediment load. Furthermore, the fine-grain sizes are the most conspicuously affected by Glen Canyon Dam.”
  - $\Delta S = LF + LC + PR + M(LC + PR) - GC$
- Used monthly transport data, assumed that transport relations did not change with time, assumed that bed was the major repository of sand (~75% of bed covered by sand), assumed that only minor changes in banks and eddy bars were occurring.
- “**Greatly reduced flood peaks since completion of Glen Canyon Dam have decreased the turbulence generated by rapids and hence transport capacity to the extent that an average of more than 1.5 m of sand has accumulated on the bed of the Upper Grand Canyon**.” (based on budget calculation and only calibrated by observations at the Lees Ferry and Grand Canyon gage cross-sections)

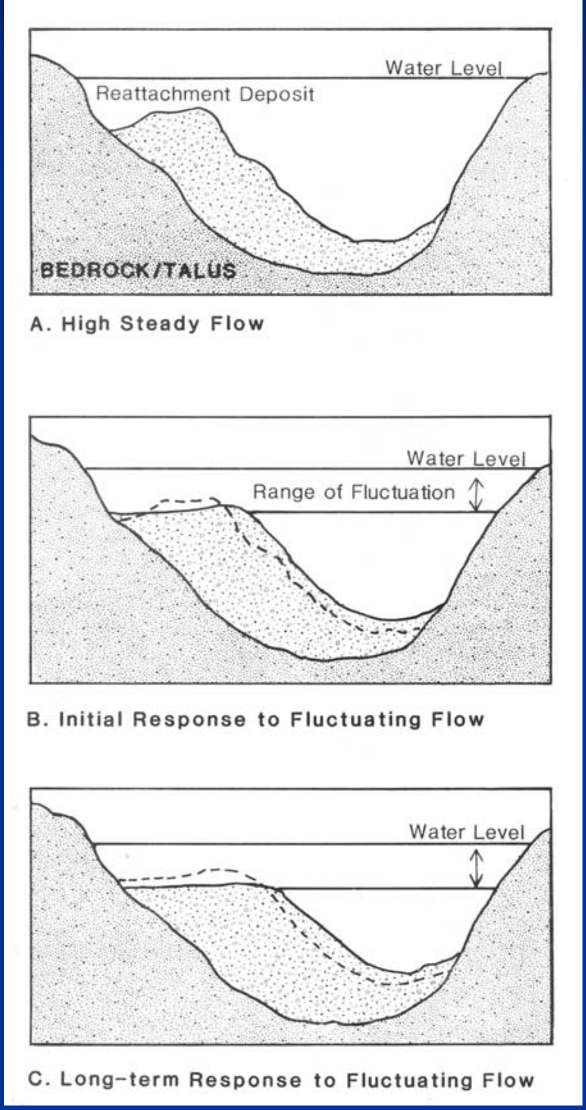
Continued Optimism: Fine Sediment Can Be Accumulated and Managed

- "A three-fold decrease in mean annual peak water discharge, plus the large contribution of sediment by tributaries, results in a surplus rather than a deficit of sediment." *(Andrews, 1990)*
- "… flow fluctuations and corresponding sand transport in the Colorado River can be managed to achieve a balance with long-term average annual sand inputs from the Paria River." *(Smillie et al., 1993)*



Final GCD EIS, 1995

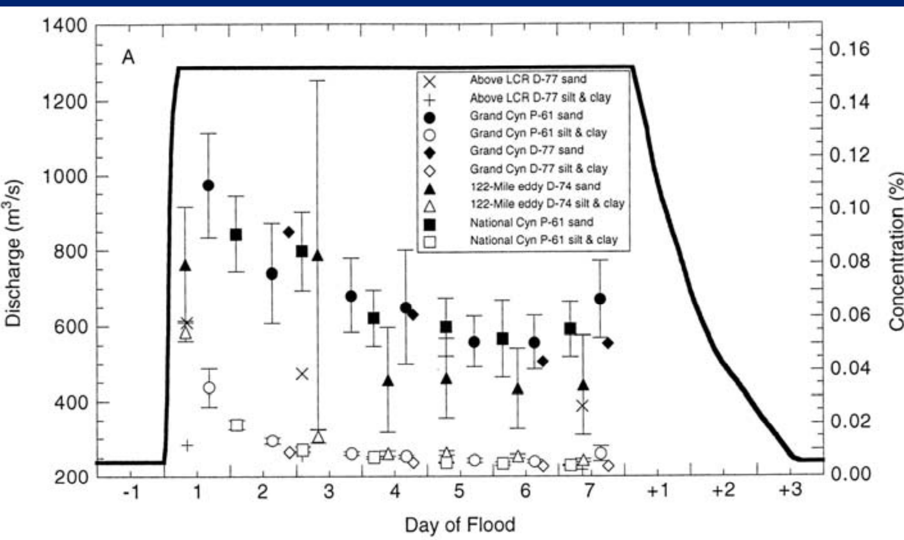
A Conceptual Model of Sediment Storage Unconstrained by Data

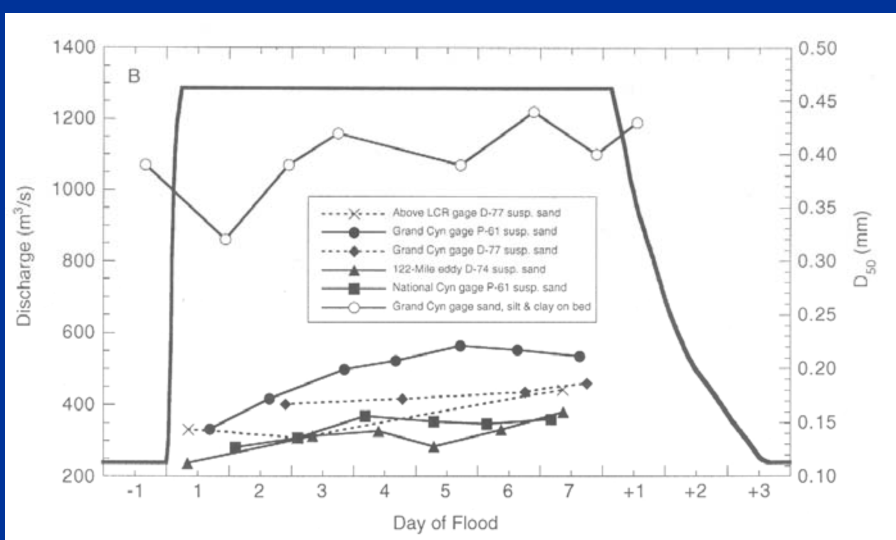


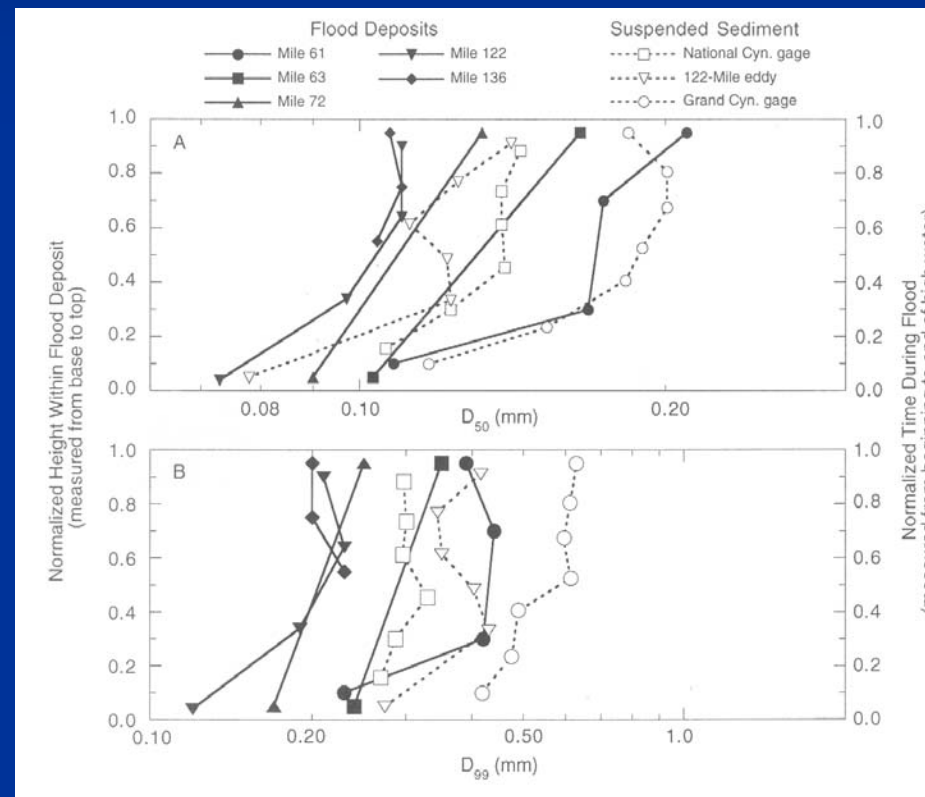
- This model was proposed as consistent with the calculated budget surplus and consistent with field measurements of beach erosion and bed measurements at two gages

(GCES, 1989)

Current Understanding:
Limited supply of fine sediment …
Rubin et al 1998; Topping et al. 1999, 2000)

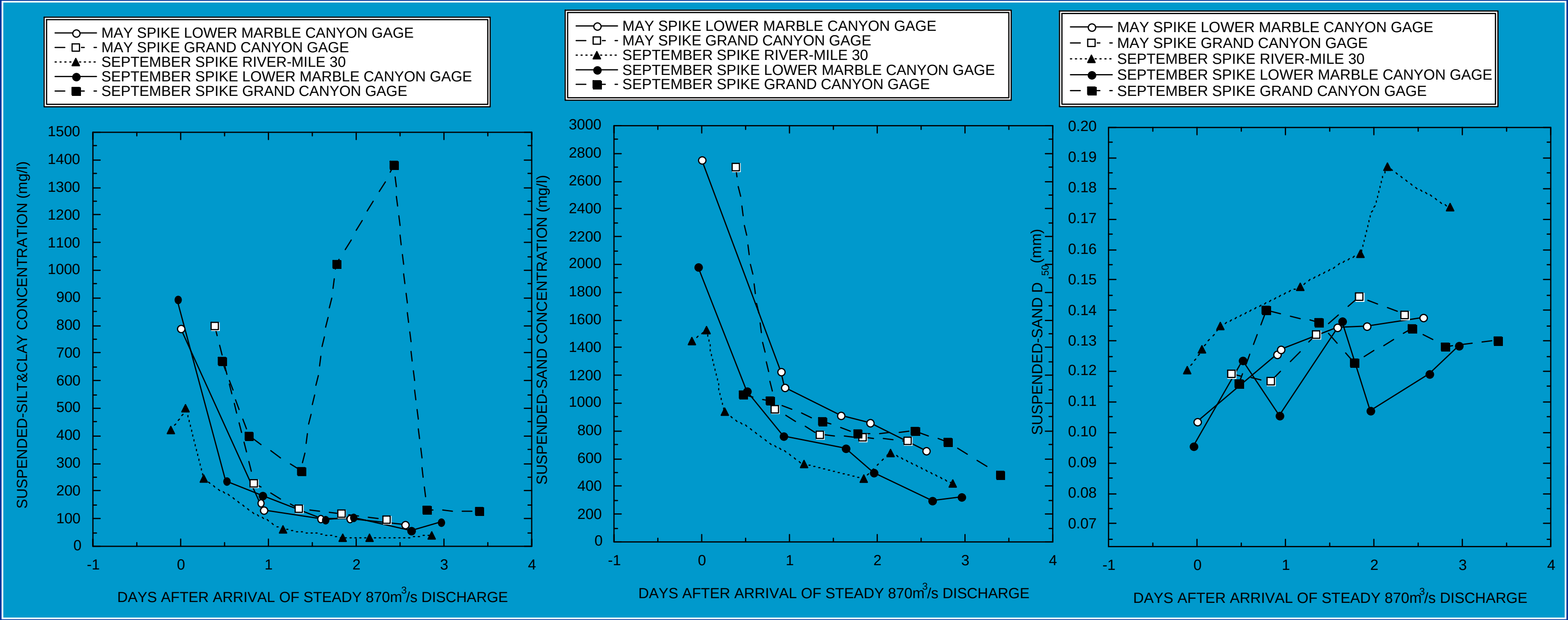




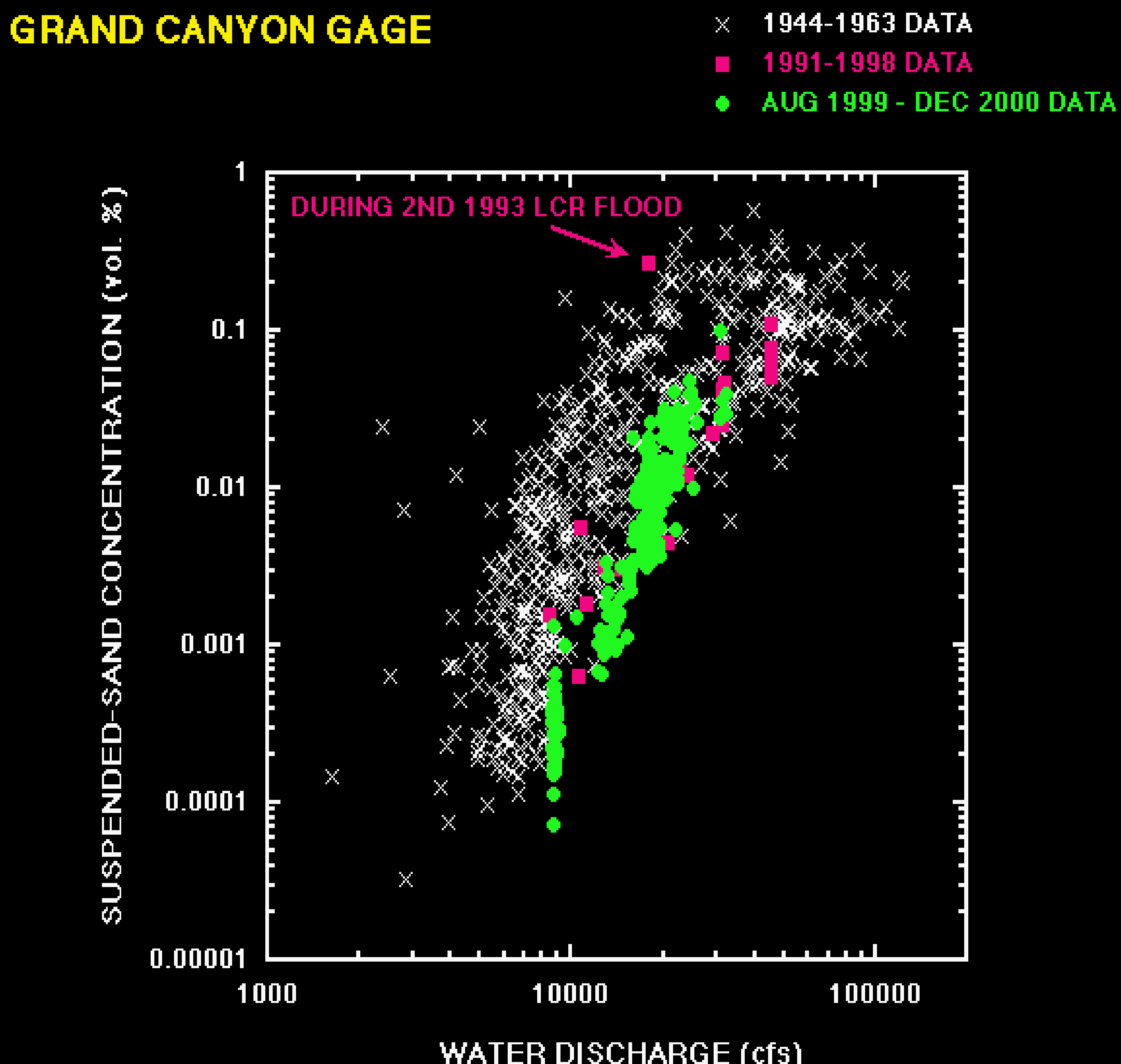


High sand concentrations were not sustained during high flows of the LSSF experiment

Suspended silt and clay concentrations | Suspended sand concentrations | Median size of suspended sand



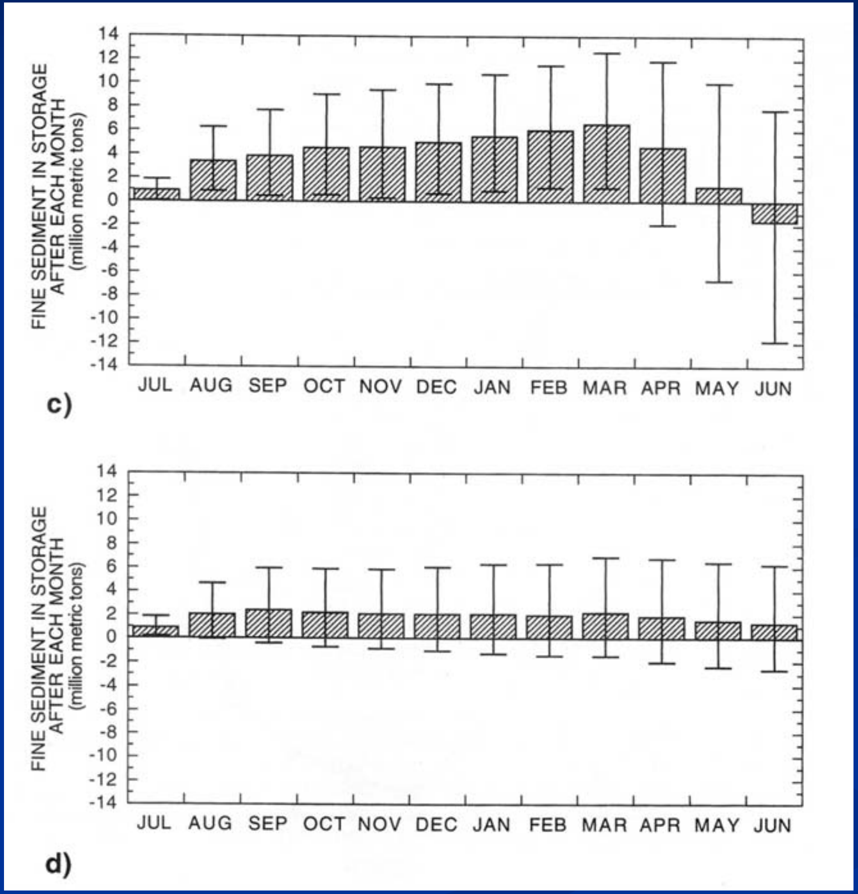
(D. Topping)


GRAND CANYON GAGE
1944-1963 DATA
1991-1998 DATA
AUG 1999 - DEC 2000 DATA
DURING 2ND 1993 LCR FLOOD
SUSPENDED-SAND CONCENTRATION (vol. %)
1
0.1
0.01
0.001
0.0001
0.00001
1000
10000
100000
WATER DISCHARGE (cfs)

... no persistent year-to-year accumulation ...

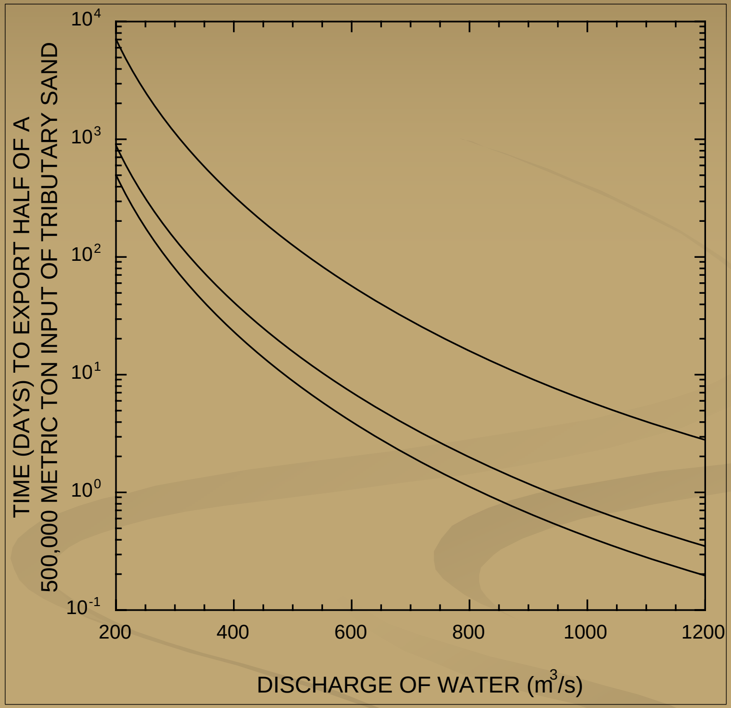
"In the average postdam year, fine-sediment storage in Marble Canyon and the upper Grand Canyon cannot be demonstrated for more than 2 months."

(Topping et al., 2000)



… and only short duration storage immediately after tributary floods

"Under normal dam operations, one-half of a 500,000 metric ton input of tributary sand is exported within a few weeks or months."



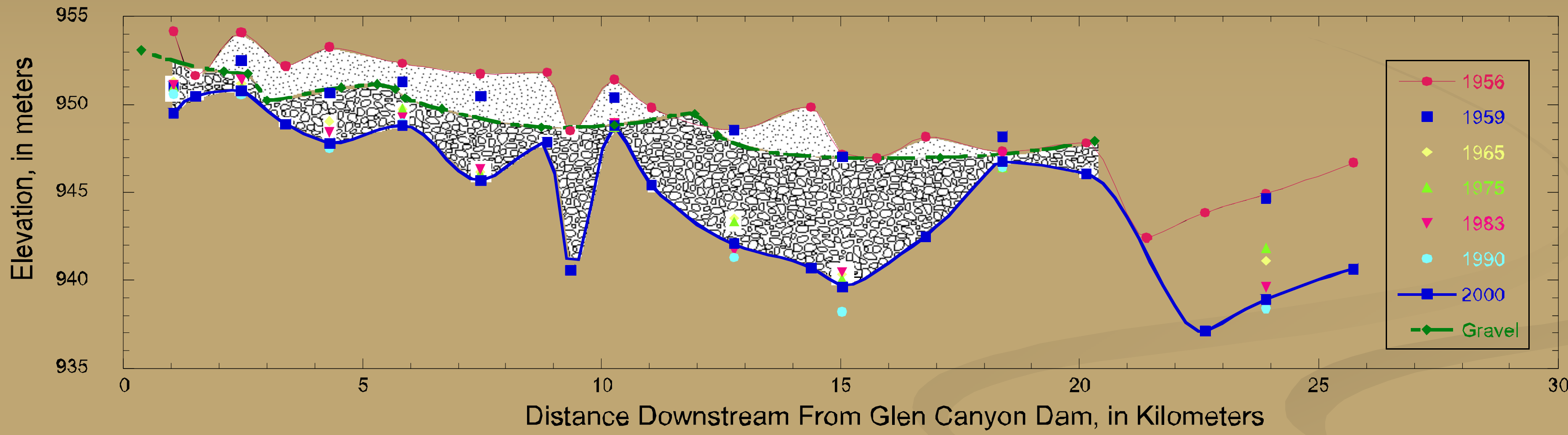
(Rubin et al. 2002)

Understanding the role of different components of sediment storage

- Bed
  - Estimates of the proportion of the bed covered by sand
    - 50%: pre-dam estimate at Grand Canyon gage (Topping)
    - 75%: post-dam estimate (Howard and Dolan, 1981)
    - 25%: post-dam estimate at Grand Canyon gage (Topping, based on Anima data)

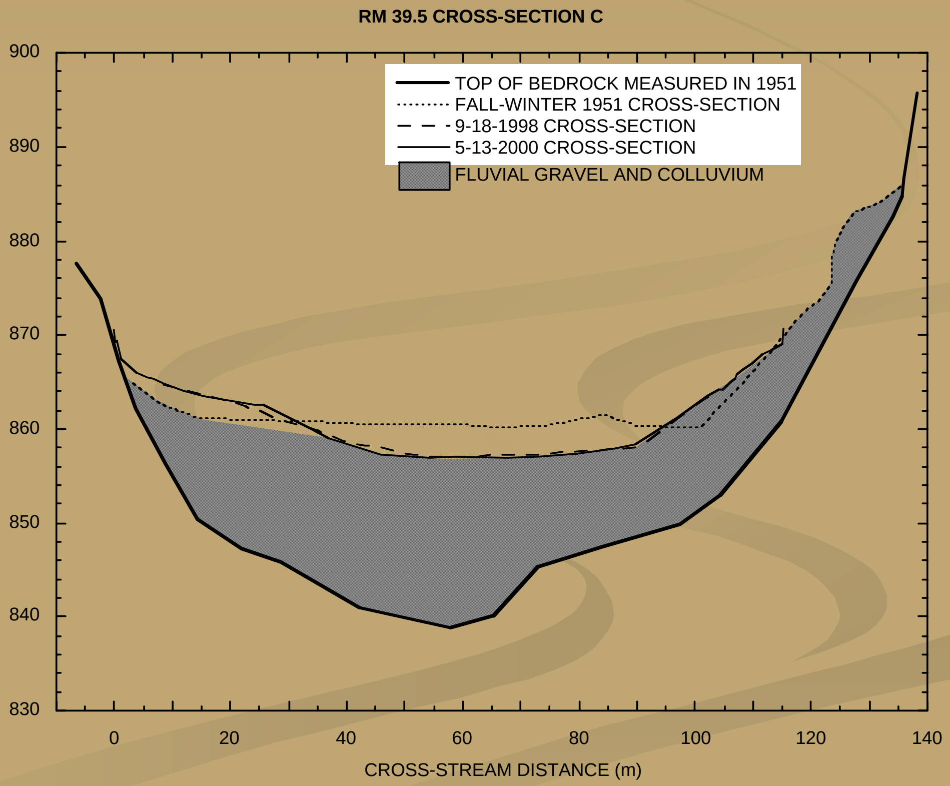
Substantial bed degradation in Glen Canyon (pools and riffles have scoured)

(Grams and Schmidt, 2002)

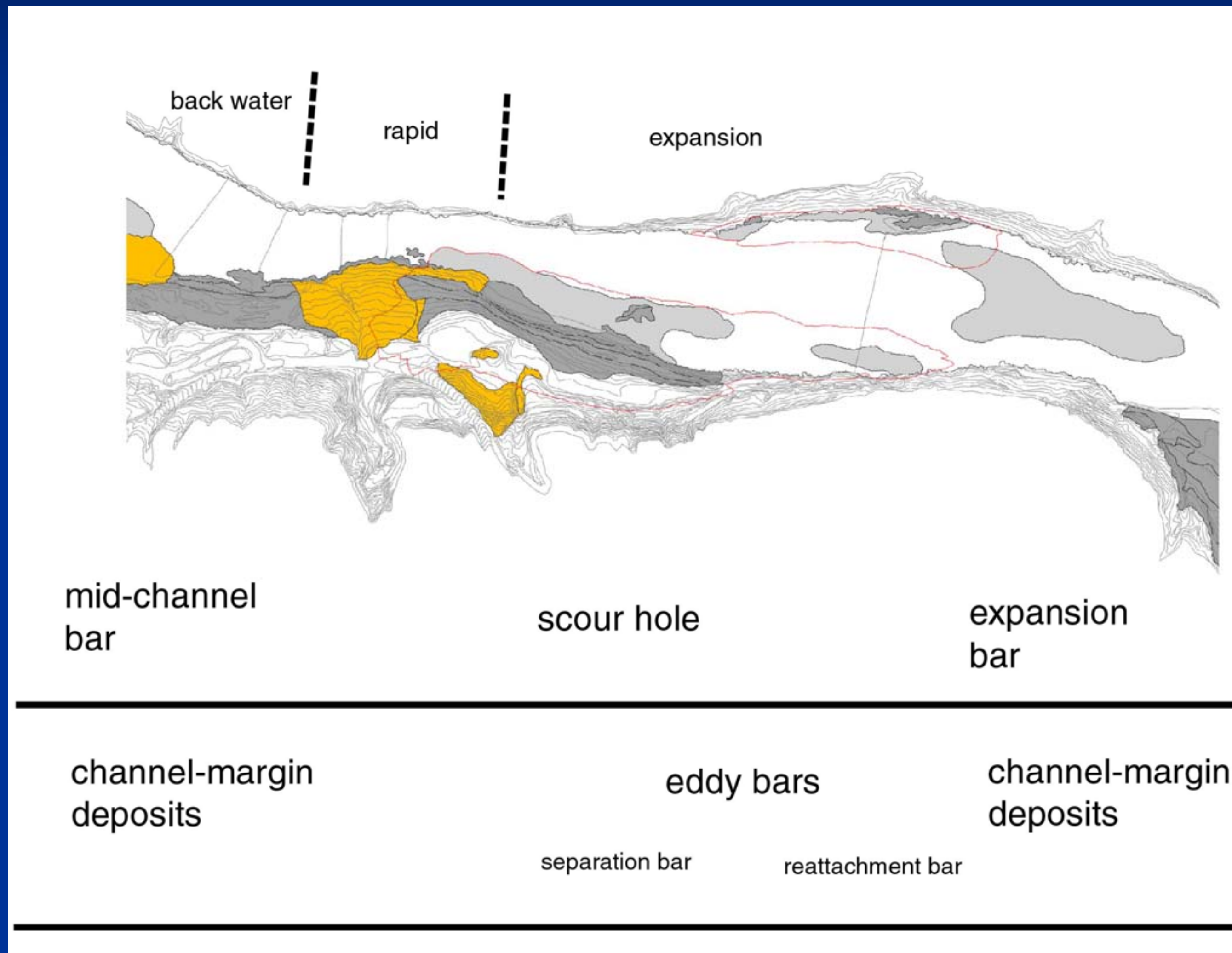


Location	Change, 1950-2000 (m^2)	Change, 1998-2000 (m^2)
RM 32.8 A	0	
RM 32.8 B	+8	
RM 39.5 A	-92	
RM 39.5 B	-95	0
RM 39.5 C	-101	-3
RM 39.5 D	-43	+10

In Grand Canyon, bed degradation restricted to pools. Some rapids are aggrading. *(Topping et al., unpubl.)*



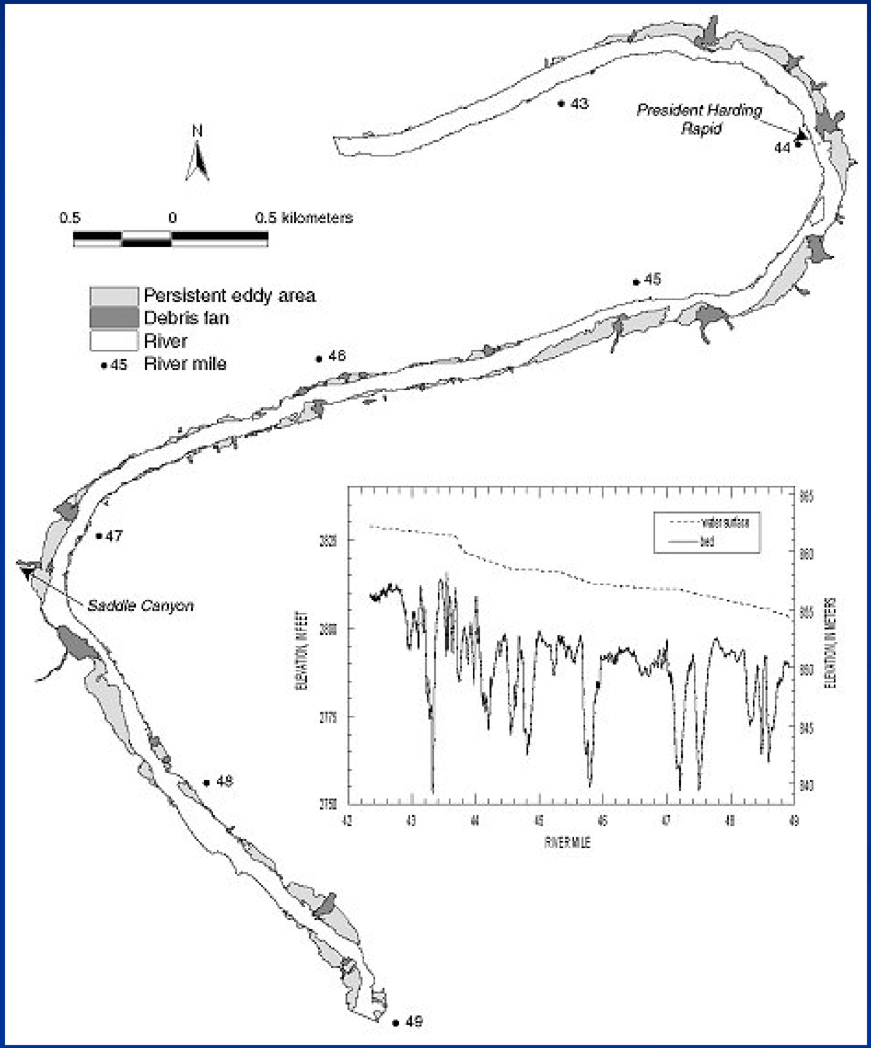
Where is the Sand Stored?



Implications of Whether the Bed or Eddies Are the Primary Repository of Sand

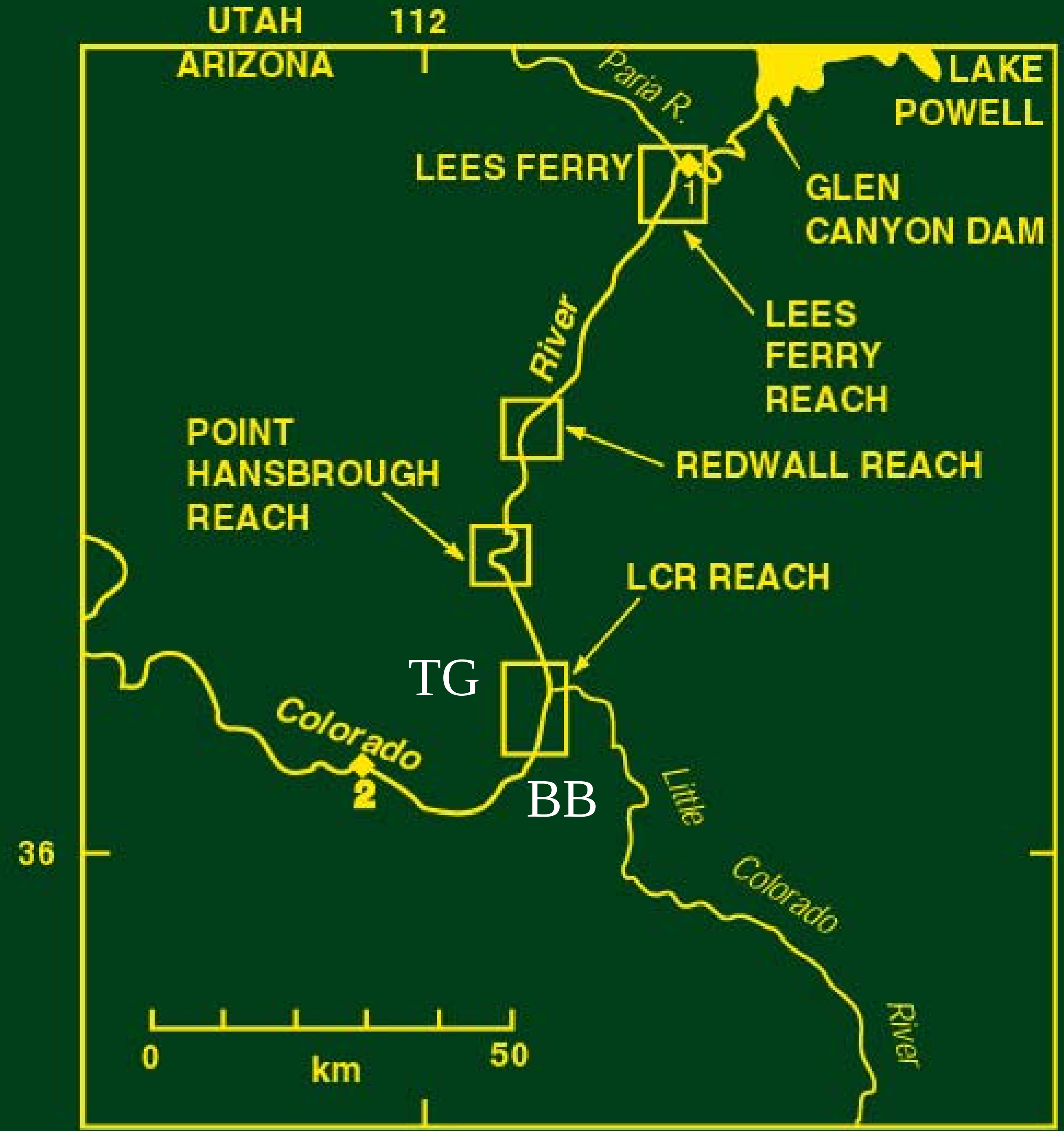
- If eddies are the primary storage site, then eddies in upstream part of Marble Canyon will be progressively eliminated in the face of a long-term and progressive negative sediment budget *(Rubin et al. 1994)*

Persistent eddies are unevenly distributed in the river corridor



Site map


AZ


UTAH
ARIZONA
112
Paria R.
LAKE POWELL
LEES FERRY
1
GLEN CANYON DAM
LEES FERRY REACH
River
REDWALL REACH
POINT HANSBROUGH REACH
LCR REACH
TG
Colorado
2
BB
Little
Colorado
River
36
0
km
50

Reach scale variation in eddy storage potential

	LF	RG	PH	TG	BB
Channel width (m)	110	74	100	114	103
# eddies per km	2.2	3.3	3.5	5.0	2.9
Median size, (m^2)	5900	3500	4800	6700	5700
Proportion of 1996 deposits in eddies	0.30	0.79	0.72	0.80	0.49

Sand Export from Marble Canyon during 1996 Flood

- Total export
  - sand: 670,000 +/- 30,000 Mg
    - 41% very fine (0.0625 - 0.125 mm)
    - 38% fine (0.125-0.25 mm)
    - 19% medium (0.25-0.50 mm)
    - 2% coarse and very coarse (>0.5 mm)
  - silt/clay: 120,000 +/- 10,000 Mg

- $\Delta S = I - O$
- thus, ΔS = ~800,000 Mg lost from Marble Canyon

Source: Topping

Total export from Marble Canyon, by source

- eddies
  - silt/clay110,000 Mg
  - sand: 490,000 Mg
- channel
  - silt/clay: 10,000 Mg
  - sand: 180,000 Mg

Source: Topping

Longitudinal Changes in Sources and Sinks during 1996 Flood *(Schmidt, 1999)*

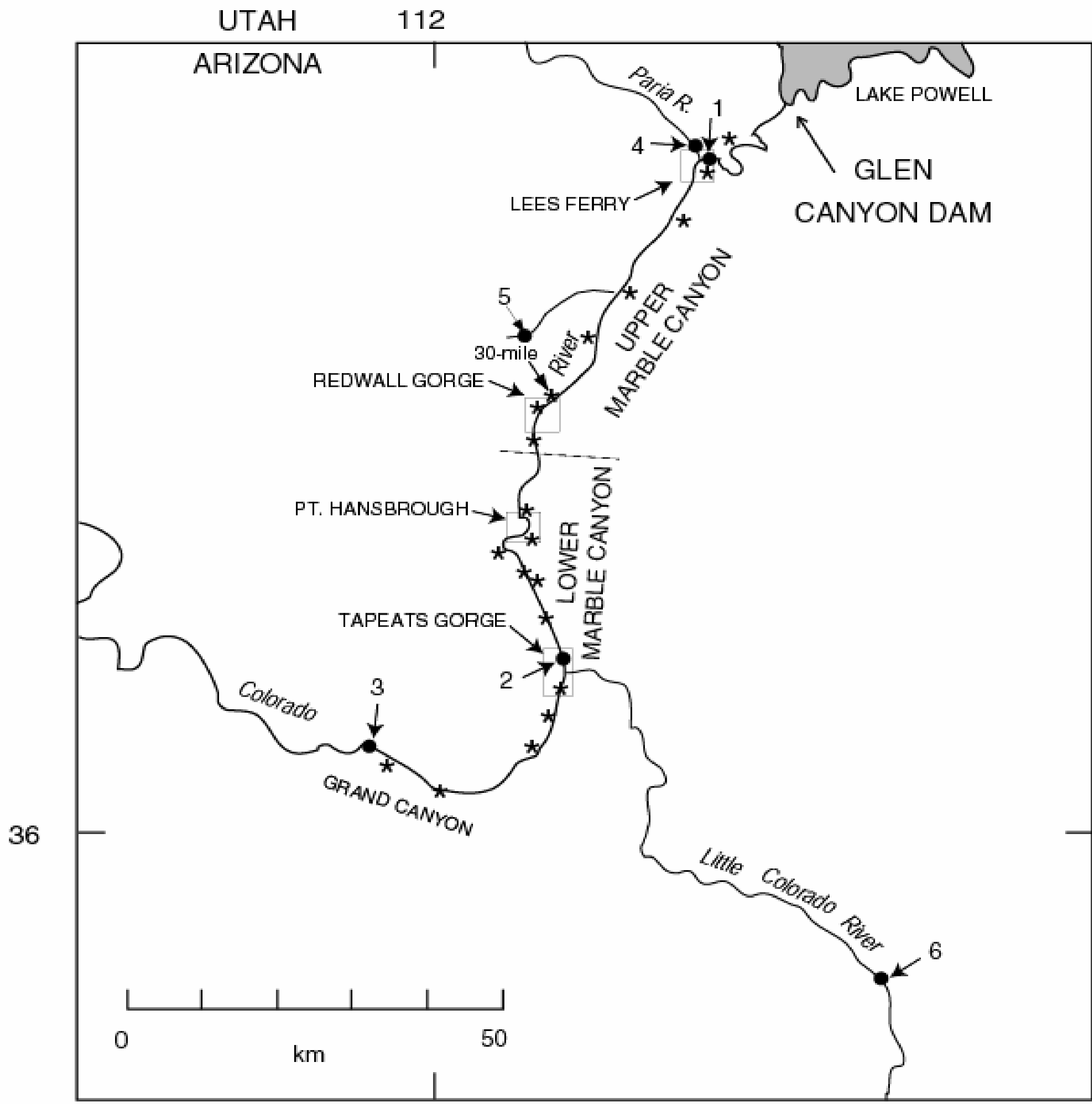
- Marble Canyon
  - Source
    - low elevation sand in eddies (-2.8 to -0.20 · 10^6)
    - channel (-0.98 to -0.86 · 10^6)
  - Sink
    - high elevation eddy sand (0.63 to 0.90 · 10^6)
    - high elevation sand on channel margins (0.06 to 0.18 · 10^6)
- Upper Grand Canyon
  - Source
    - channel (-2.1 to -0.89 · 10^6)
  - Sink
    - high elevation eddy sand (0.31 to 0.34 · 10^6)
    - high elevation sand on channel margins (0.04 to 0.13 · 10^6)

LSSF Data Collection

1,2,3,4,5,6 - gages

*** - detailed survey sites**

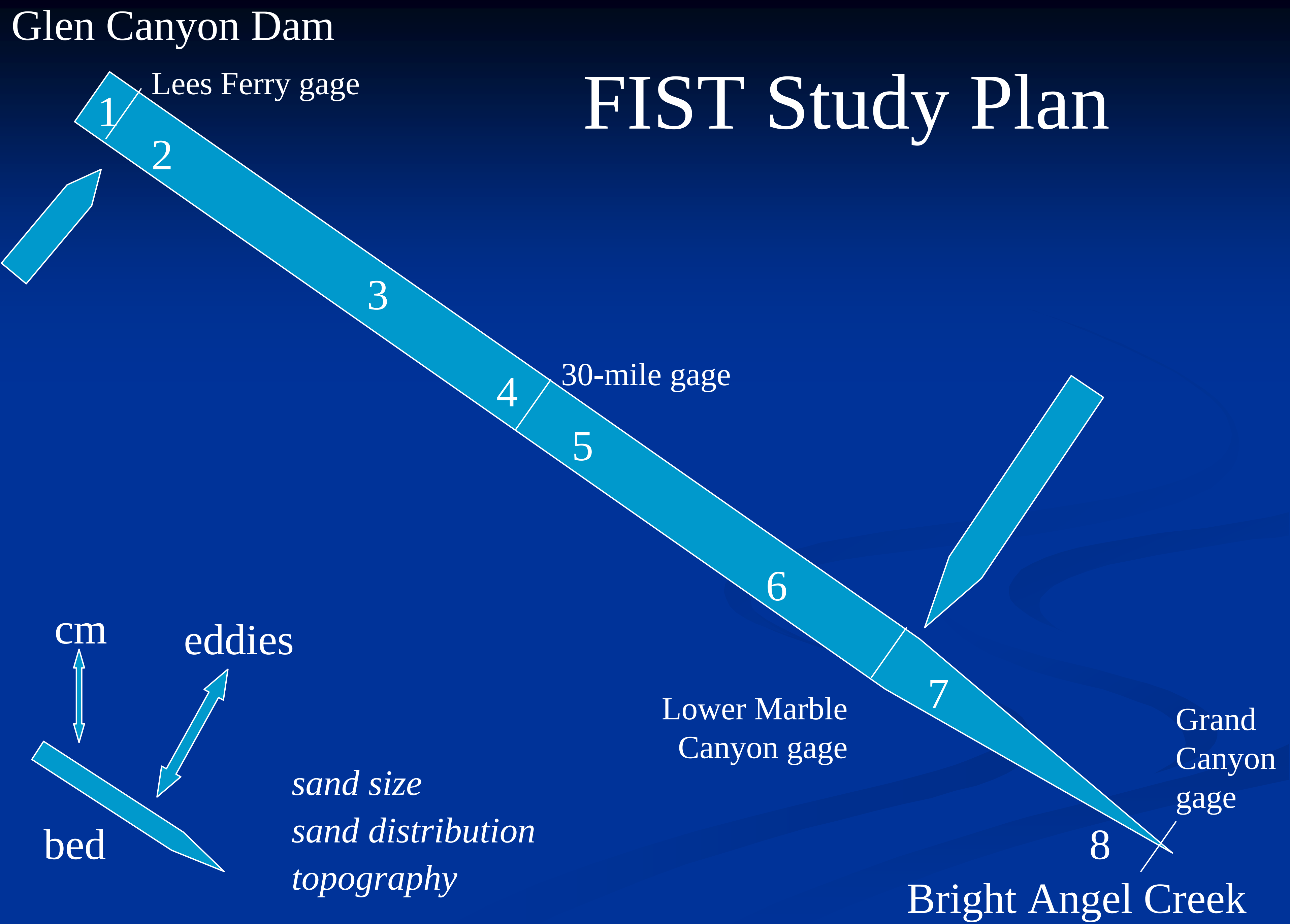
boxes - air photo analyses



Summary of the effects of the LSSF experiment on Marble and upper Grand Canyons

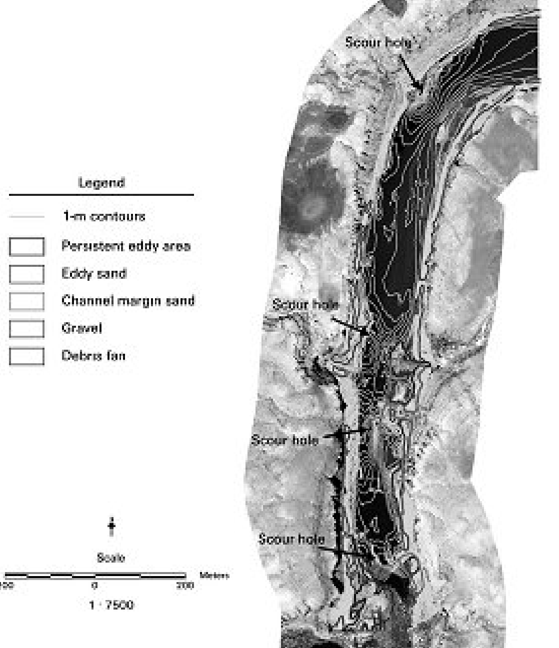
	Sand mass	Bed grain size	Reach-wide bar area	Mid-elev. bar area (n=19)	Low-elev. bar area (n=19)	Mid-elev. bar volume (n=19)	Low-elev. bar volume (n=19)
Marble Canyon							
1	↓						
2	↓			↑	↑	↑	↓
3	↓						
4	↑			↓	↑	↓	↑
5	↓	↑	nc	↑	↓	↑	↓
Upper Grand Canyon							
1	nc	↓ , ↑					
2	nc	↑		↑	↑	↑	↑
3	nc	↑					
4	↑	↓		↓	↓	↓	↓
5	nc	nc	↑	↑	↑	↑	↑

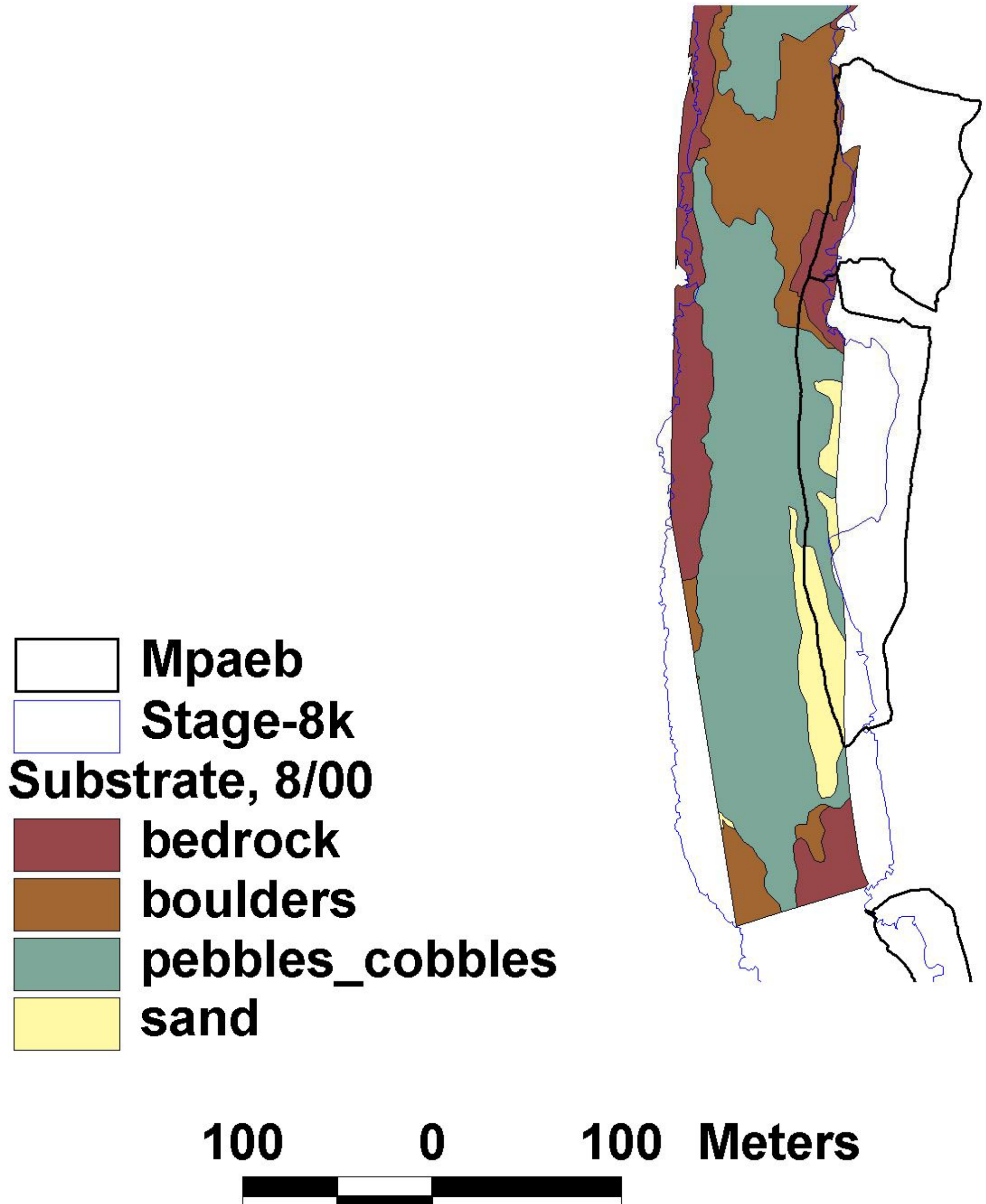
FIST Study Plan

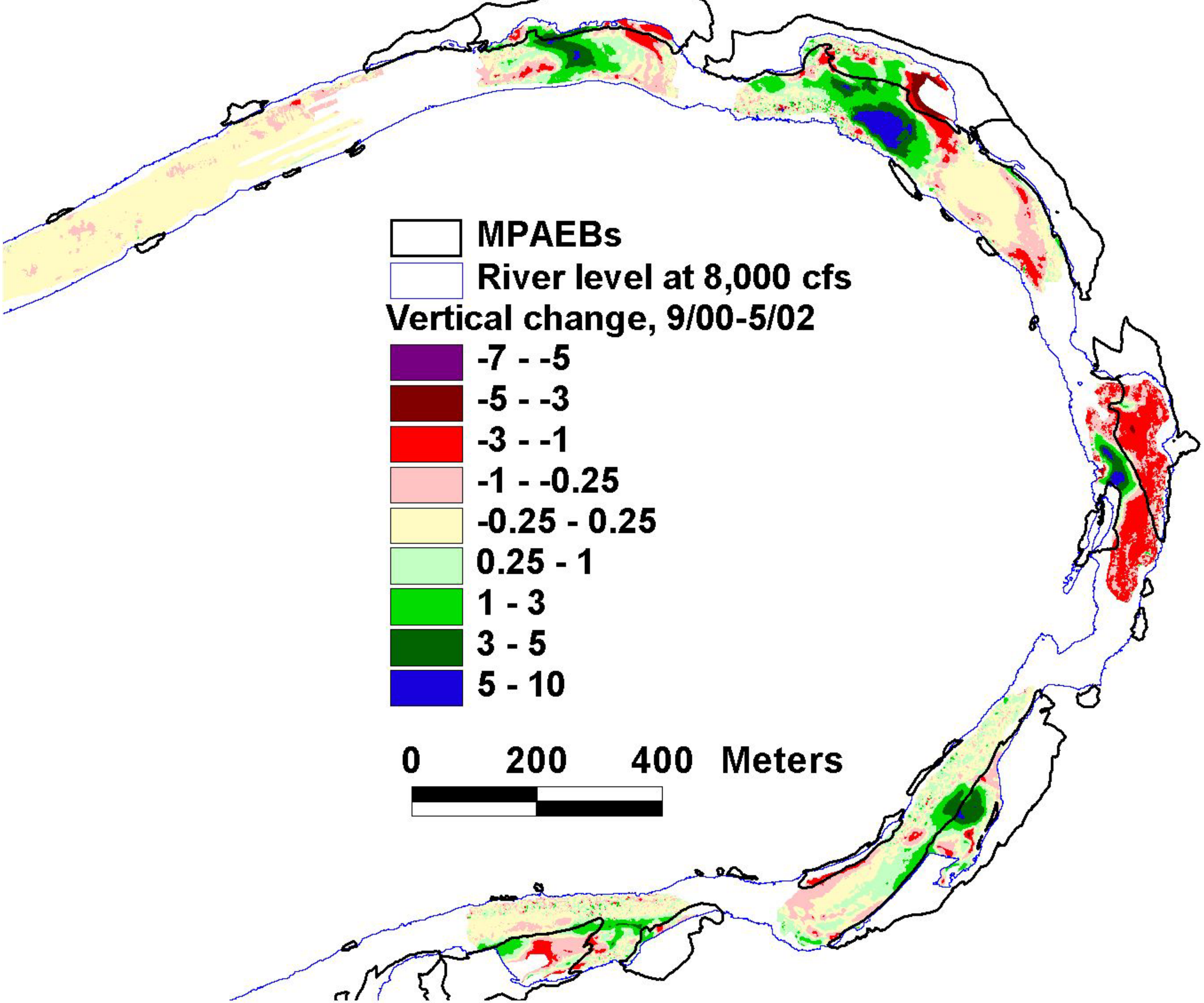


Hypotheses Under Evaluation in FIST

- The amount of fine sediment stored per unit length of river increases downstream
- The total amount of sand deposited in eddies during high flows increases downstream
- The amount of fine sediment stored on the bed increases downstream
- There is a downstream shift in sources and sinks associated with a downstream increase. The importance of eddies as the source of sand transported during floods decreases downstream.
- Total amount of sediment in storage and being exchanged with banks increases downstream.
- Progressive erosion will occur in the upstream part of Marble Canyon.


Legend
1-m contours
Persistent eddy area
Eddy sand
Channel margin sand
Gravel
Debris fan
Scour hole
Scour hole
Scour hole
Scour hole
Scale
Meters
1 : 7500


Mpaeb
Stage-8k
Substrate, 8/00
bedrock
boulders
pebbles_cobbles
sand
100 0 100 Meters


MPAEBs
River level at 8,000 cfs
Vertical change, 9/00-5/02
-7 - -5
-5 - -3
-3 - -1
-1 - -0.25
-0.25 - 0.25
0.25 - 1
1 - 3
3 - 5
5 - 10
0 200 400 Meters

What Have We Learned?

- Basic science must continue to reevaluate accepted paradigms that guide present river management.
- Sediment budgets must be refined by (1) measuring transport continuously and carefully, and (2) measuring storage changes comprehensively.