A Conversation about Dams …

… with the Texas Environmental Flows Science Advisory Board

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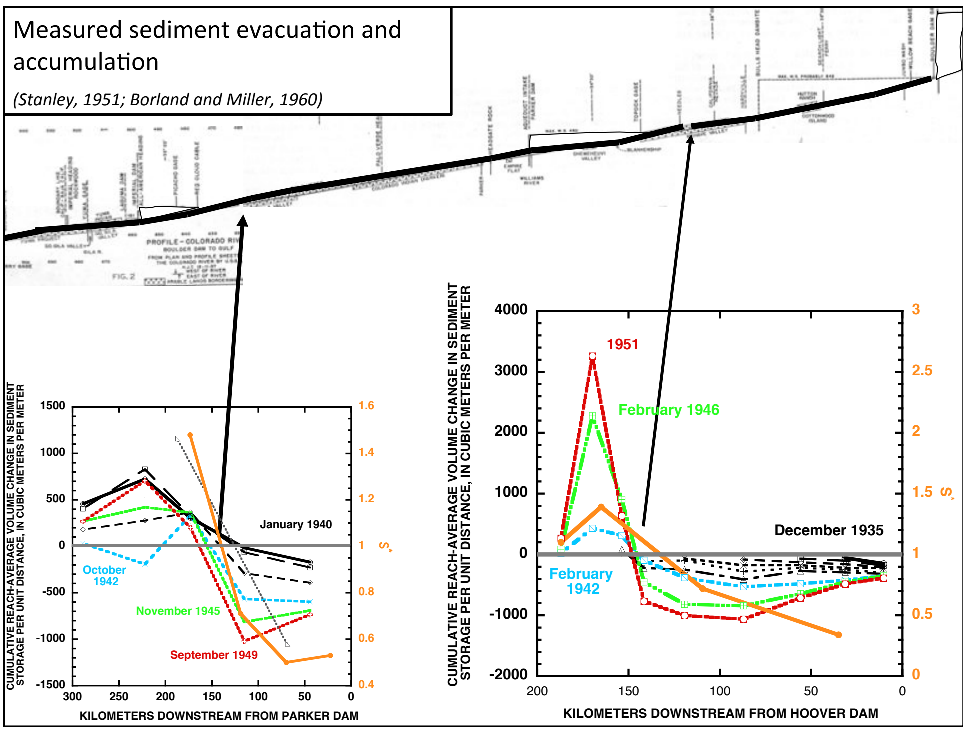
In general, what is the current "state of the science" with regard to sediment transport and channel shape/formation effects of construction and operation of major dams? (e.g. Is this a well-studied, well-understood topic or more of an area of research where hypothesis formulation and data collection/evaluation are more recent?)

Description, generalization, prediction, and metrics of downstream channel change: past work

- **Description (case studies)**
  - –
- **Generalization**
  - – Lagasse (1980); Williams and Wolman (1984)
- **Prediction**
  - Magnitude of incision
    - Komura and Simons (1967); Strand (1977)
  - Duration of adjustment process
    - Williams and Wolman (1984); Church (1995) after deVries (1975)
- **Metrics of Alteration**
  - Flow alteration
    - Richter at al (1996); Poff at al (1997)

Measured sediment evacuation and accumulation

(Stanley, 1951; Borland and Miller, 1960)



Previous efforts to generalize about dam impacts

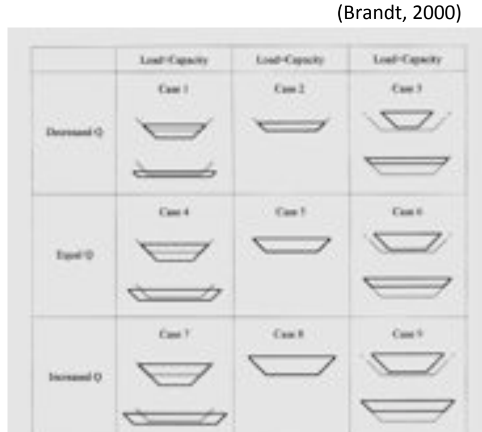
-
  -
  - narrowing
- *Magilligan et al. (2003, 2005); White et al. (2005)*
  - Characterization of changes in flow regime
- *Brandt (2000a, 2000b, 2000c)*
  - Identified 9 styles of change below dams
  - Predicted channel form
- *Grant et al. (2003)*
  - Fractional change in duration of sediment transporting flows
  - Ratio of downstream sediment supply to upstream supply

Efforts to anticipate changes in channel form rely on generalizations about the water/sediment balance

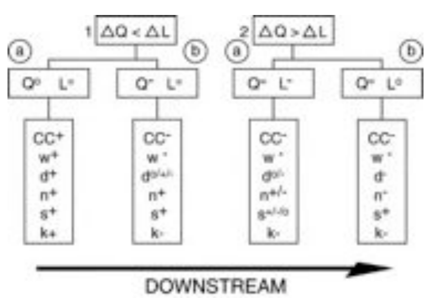
(Schumm, 1969)

$$Qw^- Qt^- \approx \frac{w^- L^- F^-}{P^+} S^{+/-} d^{+/-}$$

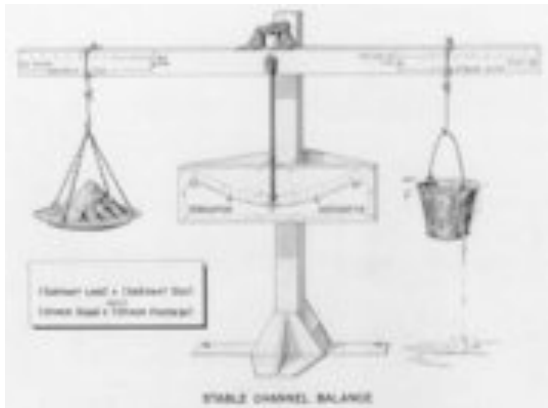
(Brandt, 2000)



(Petts, 2005)



Sediment mass balance: shift towards deficit or surplus



Borland's illustration of Lane's (1955) concept, drawn by Vitaliano

Factors that induce degradation below dams:

Reduced sediment supply

Fining of sediment supply

Factors that induce aggradation below dams:

Reduced floods or total stream flow

Coarsening of sediment supply

If there are comprehensive empirical studies, what are they showing? I.e. how much and what kind of changes downstream; how far downstream are changes evident (i.e. the role of tributary contributions); what effects, if any, have been identified with respect to downstream health of aquatic and riparian habitats; what are the major determinative factors with respect to river type, reservoir operation and/or time within which "new equilibrium" is established?

Are there any well accepted models for analyzing the above questions?

Three Metrics

- <u>Perturbation of the predam sediment mass balance</u>
  –
- <u>Likelihood of post-dam bed incision</u>
- <u>Potential for changes in width based on proportional change in annual floods</u>

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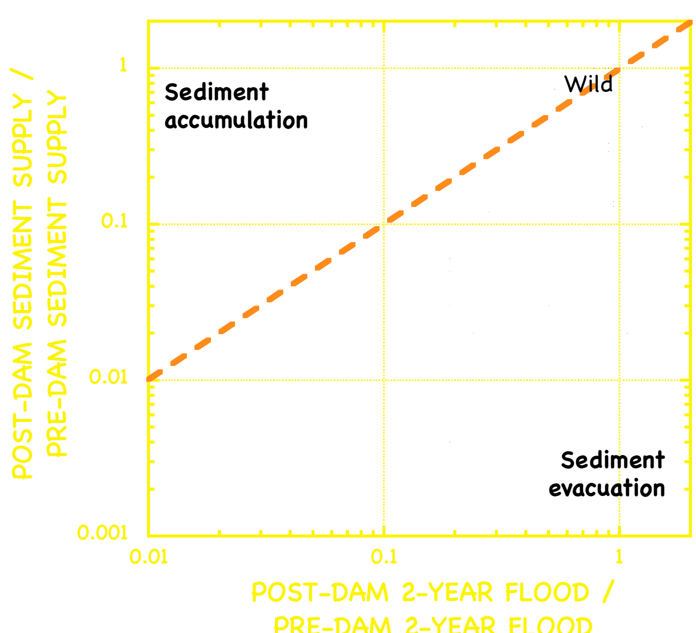
Metrics for assessing the downstream effects of dams

John C. Schmidt[1] and Peter R. Wilcock[2]



The Lane Balance, quantified almost 40 yrs ago by Henderson (1966, Open Channel Flow)

Einstein-Brown | depth-slope | continuity | Chezy

$qs^* \sim \;\; ^{*3}$ | $\tau \sim R\,S$ | $q = U\,R$ | $U \sim (R\,S)^{0.5}$

$qs \sim \tau^3 / D^{1.5}$ → $qs \sim (R\,S)^3 / D^{1.5}$

$q \sim R^{1.5} S^{0.5}$ → $R^3 \sim q^2 / S$

$qs \sim (q^2 S^2) / D^{1.5}$

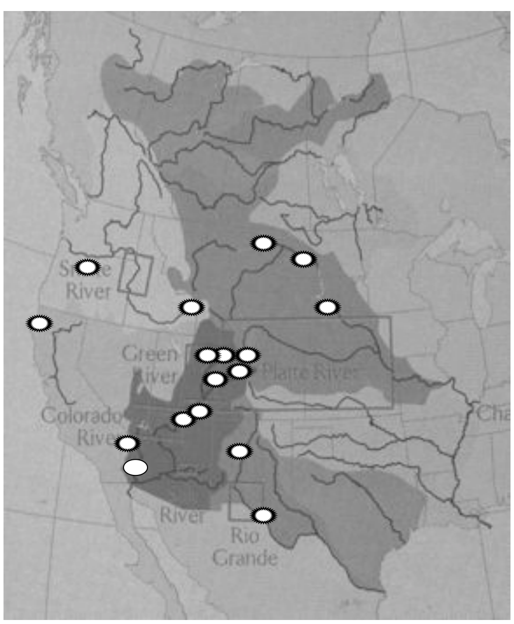
$S \sim (qs^{0.5} D^{0.75}) / q$

$$\frac{S_{post}}{S_{pre}} \propto \sqrt{\frac{qs_{post}}{qs_{pre}}}\left(\frac{q_{pre}}{q_{post}}\right)\left(\frac{D_{post}}{D_{pre}}\right)^{0.75}$$

$qs^* \sim qs / D^{1.5}$

$\tau^* \sim \tau / D$

$R \sim h$



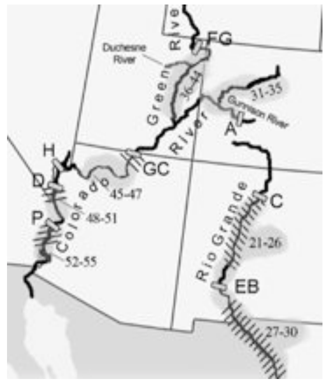
61 reaches of 6 rivers

- Missouri
- Rio Grande
- Colorado
- Trinity
- Snake, Deschutes

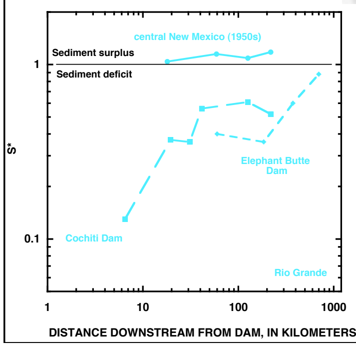
Perturbation of sediment mass balance caused by dams

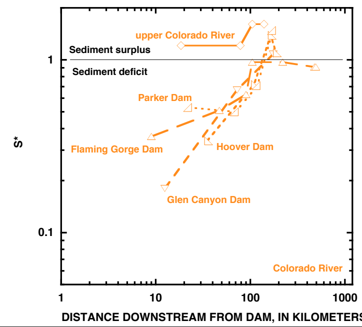
(red = S<1; sediment deficit)*
(green = S>1; sediment surplus)*
(blue= sediment balance indeterminate)

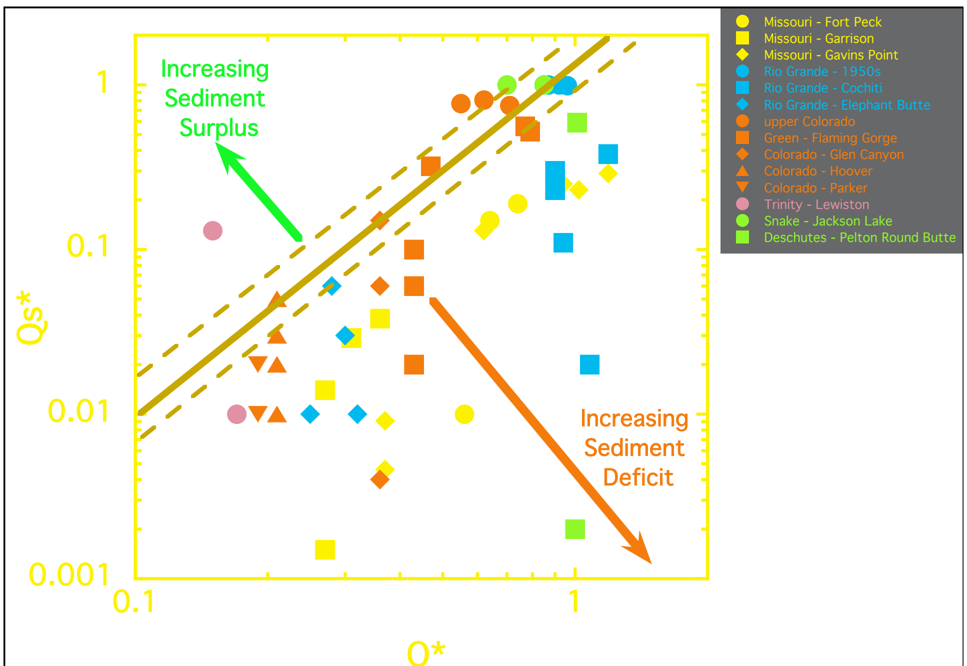
(hachure indicates zone of bed incision)



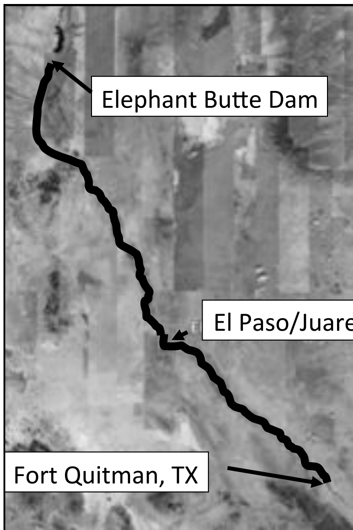
(Schmidt and Wilcock, 2008)







The perturbations vary widely



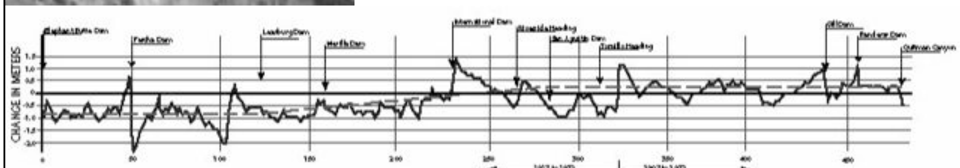
II. Bed Elevation Changes –

sediment deficit may, or may not, lead to bed incision

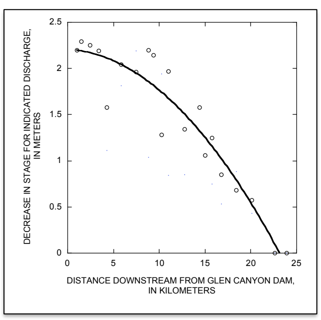
sediment surplus may, or may not, lead to bed aggradation

Downstream from Elephant Butte Dam, the upper river **incised its bed** as much as 1 m within 225 km downstream from Elephant Butte Dam between ~1917 and ~1933. Downstream from El Paso/Juarez, the bed **aggraded** about 0.25 m.

(Stevens, 1938)



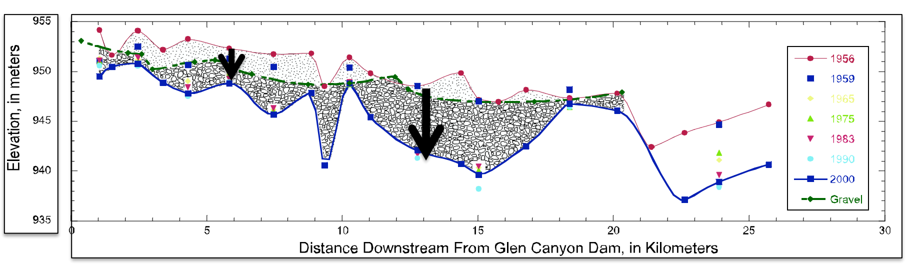
(Stevens, 1938)



… permanent shifts in stage-discharge relations

Bed incision under sediment deficit conditions depends on the grain size of the bed

In Glen Canyon, sediment deficit exists and bed incision has occurred ….



… converting a sand bed to a cobble bed.

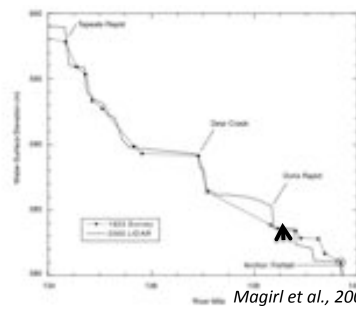
(Grams et al., 2007)

1956

1999

Under the same sediment deficit conditions in Grand Canyon …

… coarse bouldery rapids prevent bed incision. With low sediment supply and steep channel slope, mass balance deficit persists and available fine sediment is efficiently removed from system.



Magirl et al., 2005

III. Changes in channel width

Channels narrow wherever the annual flood regime decreases, regardless of whether in deficit or surplus.

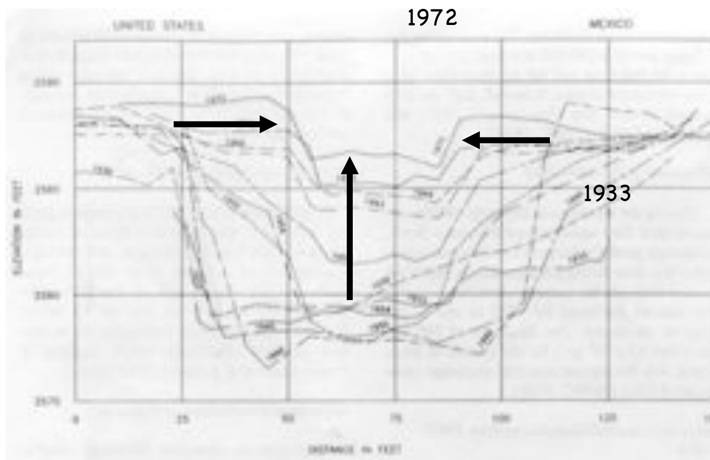
It is difficult to predict the magnitude of narrowing

Narrowing with sediment surplus and no bed incision
Narrowing with sediment surplus and bed incision

Narrowing with equilibrium conditions

Narrowing with deficit conditions and no bed incision
Narrowing with deficit conditions and bed incision

Sediment surplus – narrowing and bed aggradation

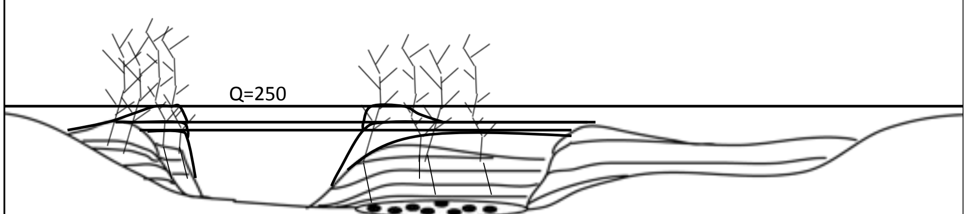


The Rio Grande above the Rio Cochos, near Presidio

Everitt (1993)

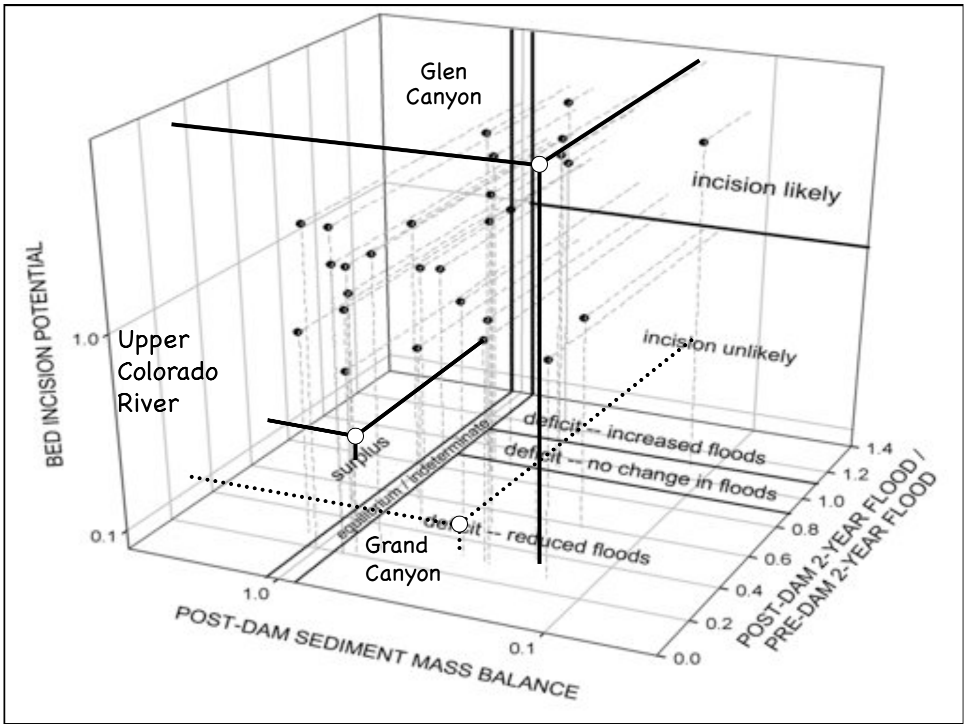
Invasive riparian vegetation enhances sedimentation, decreasing channel capacity, creating a positive feedback of enhanced vertical aggradation

Rio Grande / Rio Bravo – Big Bend

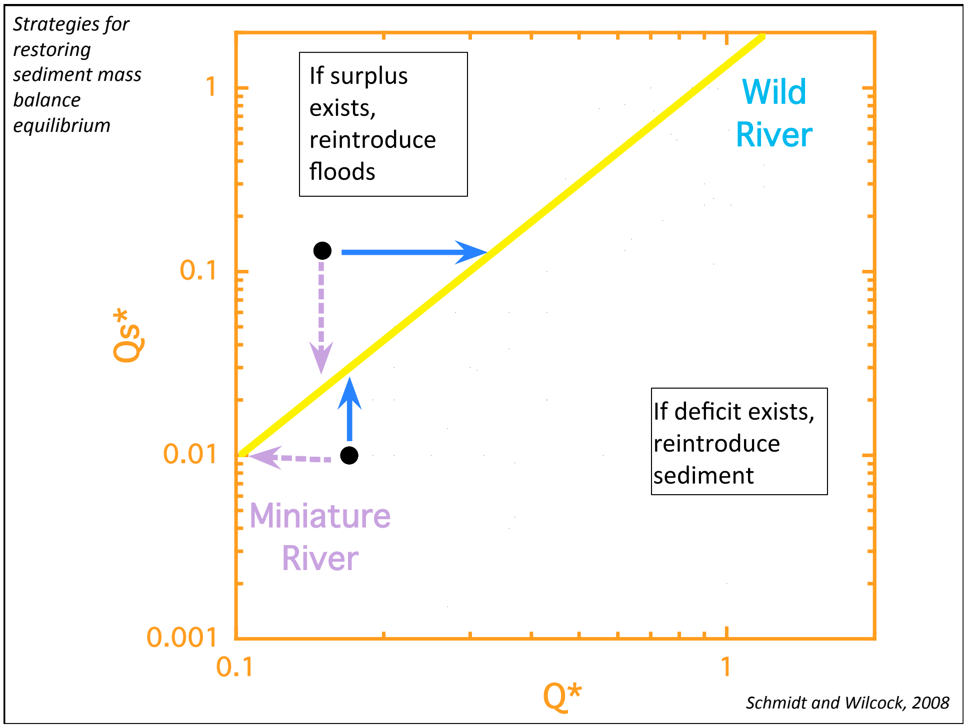


- Channel narrowing resulted in increases in stage
- Overbank deposition resulted in additional vertical floodplain accretion
- Dense vegetation increases sedimentation

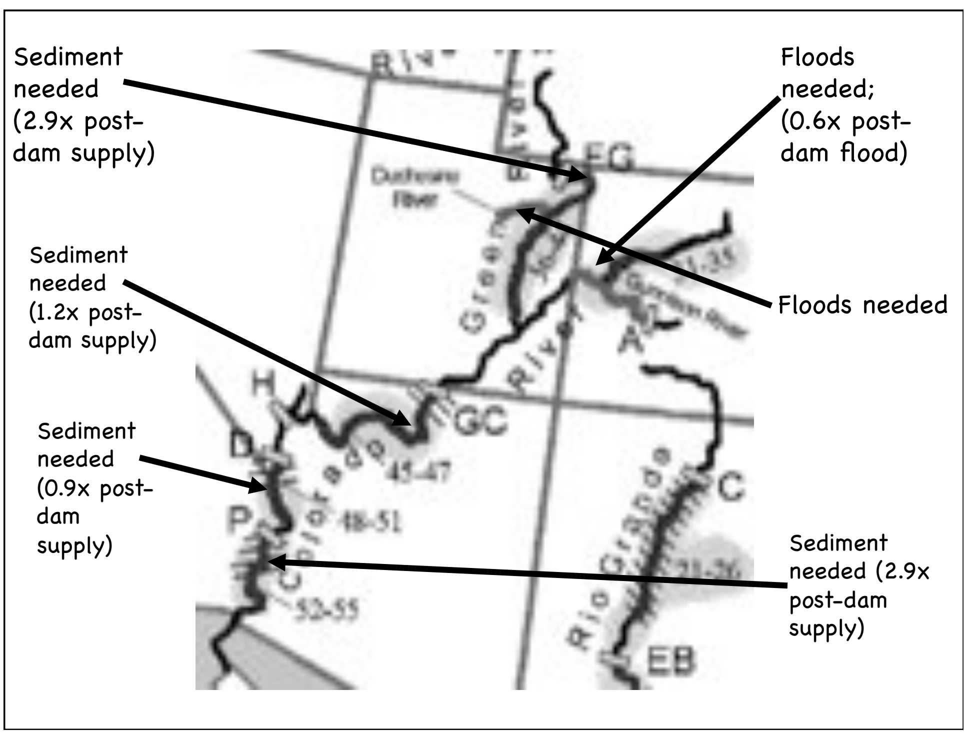
Dean and Schmidt, 2010



Are there any well accepted "rules of thumb" for the degree of alteration from historical flows with respect to preventing adverse effects of geomorphological/sediment transport changes? If so, what studies support these "rules of thumb"?



Strategies for restoring sediment mass balance equilibrium
If surplus exists, reintroduce floods
Wild River
If deficit exists, reintroduce sediment
Miniature River
Qs*
Q*
1
0.1
0.01
0.001
Schmidt and Wilcock, 2008



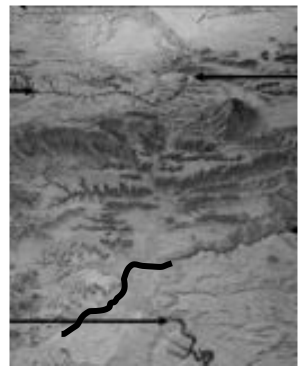
Sediment needed (2.9x post-dam supply)
Floods needed; (0.6x post-dam flood)
Floods needed
Sediment needed (1.2x post-dam supply)
Sediment needed (0.9x post-dam supply)
Sediment needed (2.9x post-dam supply)
FG
GC
Green River
Rio Grande
EB

The costs of adding sediment from Lake Powell into Grand Canyon

Addition of 4.3 x 10^6 Mg/yr by dredging and pipeline; *appraisal level cost estimates*

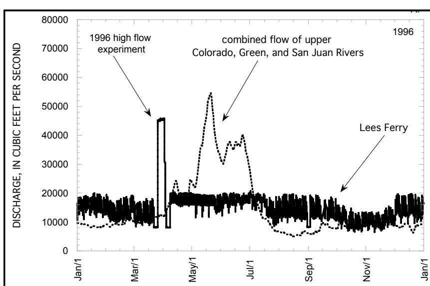
Slurry pipeline Navajo Canyon to Glen Canyon Dam ($220 million capital costs; $6.6 million annual operating cost)

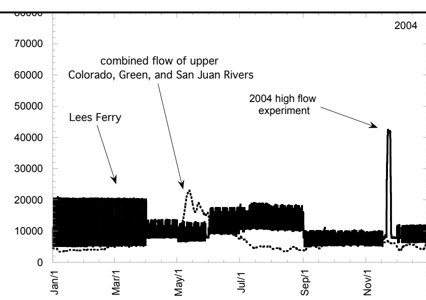
Slurry pipeline Navajo Canyon to Lees Ferry ($430 million capital costs; $17 million annual operating cost)



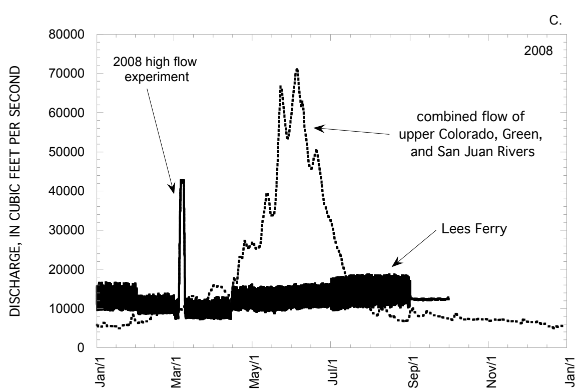
$44 million/yr is EIS estimate of cost reduced fluctuating flows

Randle et al, 2007

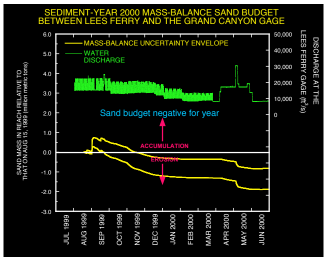




Constraints on reintroducing clear-water floods into a sediment deficit system



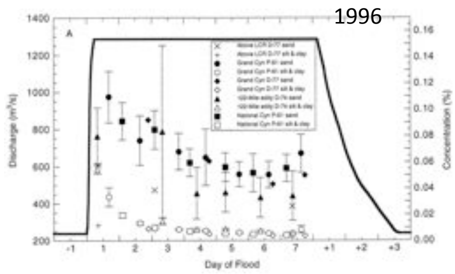
Natural and actual Lees Ferry flows

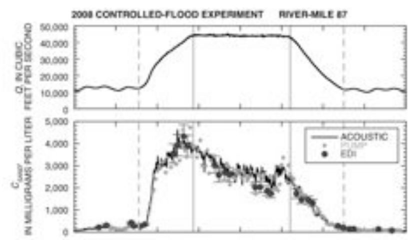


Maintaining positive mass balance is very hard without sediment augmentation

Topping, written commun.

Controlled floods quickly deplete the available supply.





2008

Change in suspended sediment concentration with time during two large dam releases

Topping, Rubin, various papers

Topping et al., 2010