Flushing Morphodynamic Thoughts

Peter Wilcock

July 31, 2024

- A reach-average model
- Some guidelines for modeling
- 1d vs 2d or 3d
- The flushing problem

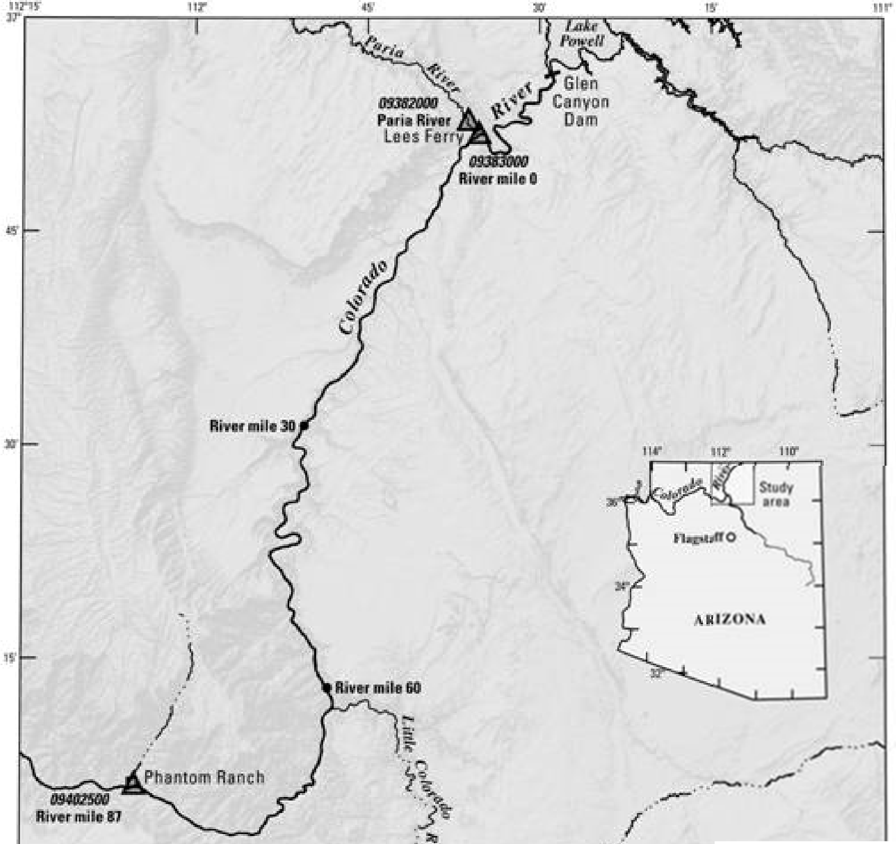
Peggy Johnson

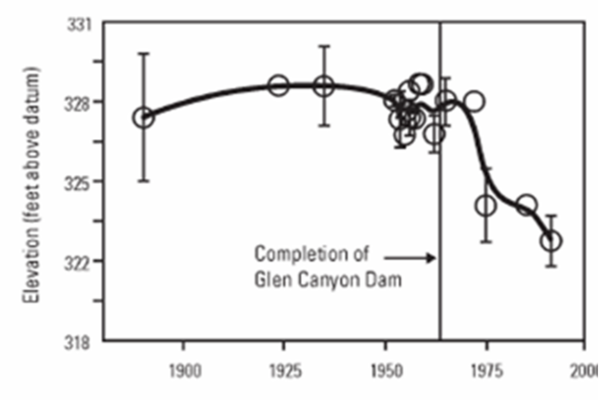
Flow and Transport Modeling to Support Decision Making in the Management of Glen Canyon Dam

Peter Wilcock
Johns Hopkins University

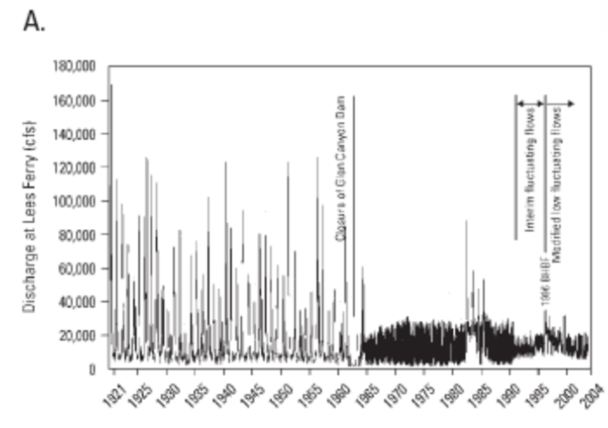
Stephen Wiele, Scott Wright
USGS

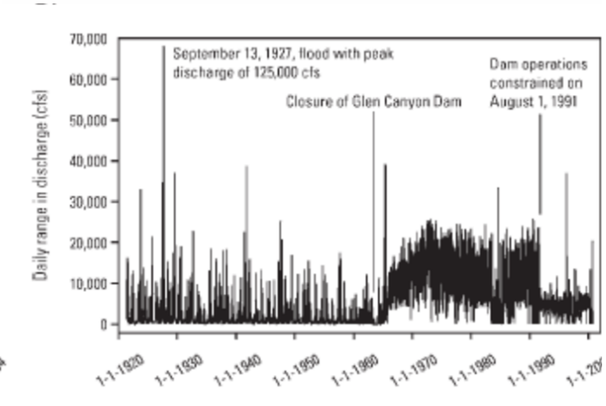
Wiele, S.M., P.R. Wilcock, P.E. Grams, 2007, Reach-averaged sediment routing model of a canyon river, Water Resour. Res., 43, W02425, doi:10.1029/2005WR004824.





2005 SCORE Report
USGS Circular 1282





The management issue

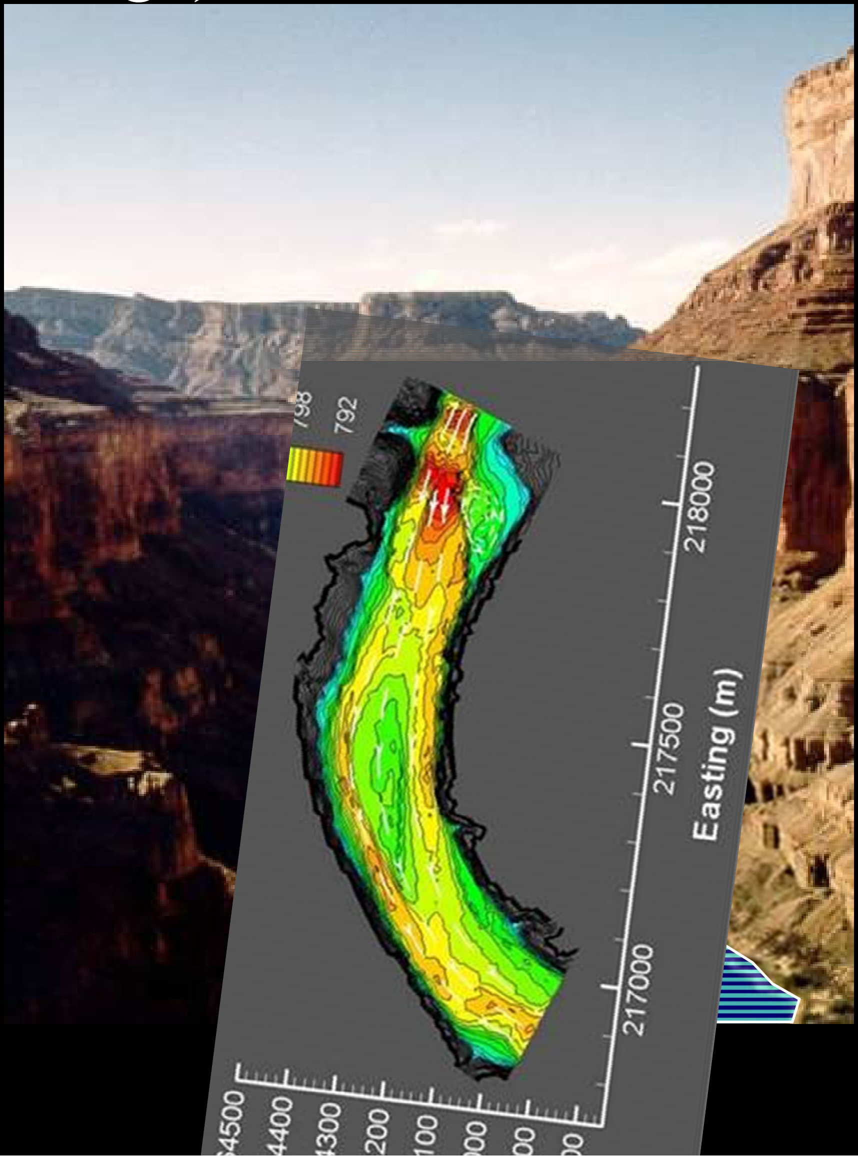
- Can sand bars be restored & maintained
  by modified dam operations (*alone*)?
  - high flow releases used to build bars,
  storing sand at high elevation
  (while also moving sand from the system)
  - low flows used to conserve tributary sand input
  until high flow release is possible
- Need simple operational guidelines &
  testable hypotheses

The science challenge: predict transport and storage of sand as fn(tributary inputs, discharge)

87 miles of complex channel geometry

Limited access

Most of the sand in eddies with erosion and deposition in recirculating flow



Options:

1d hydraulic routing model

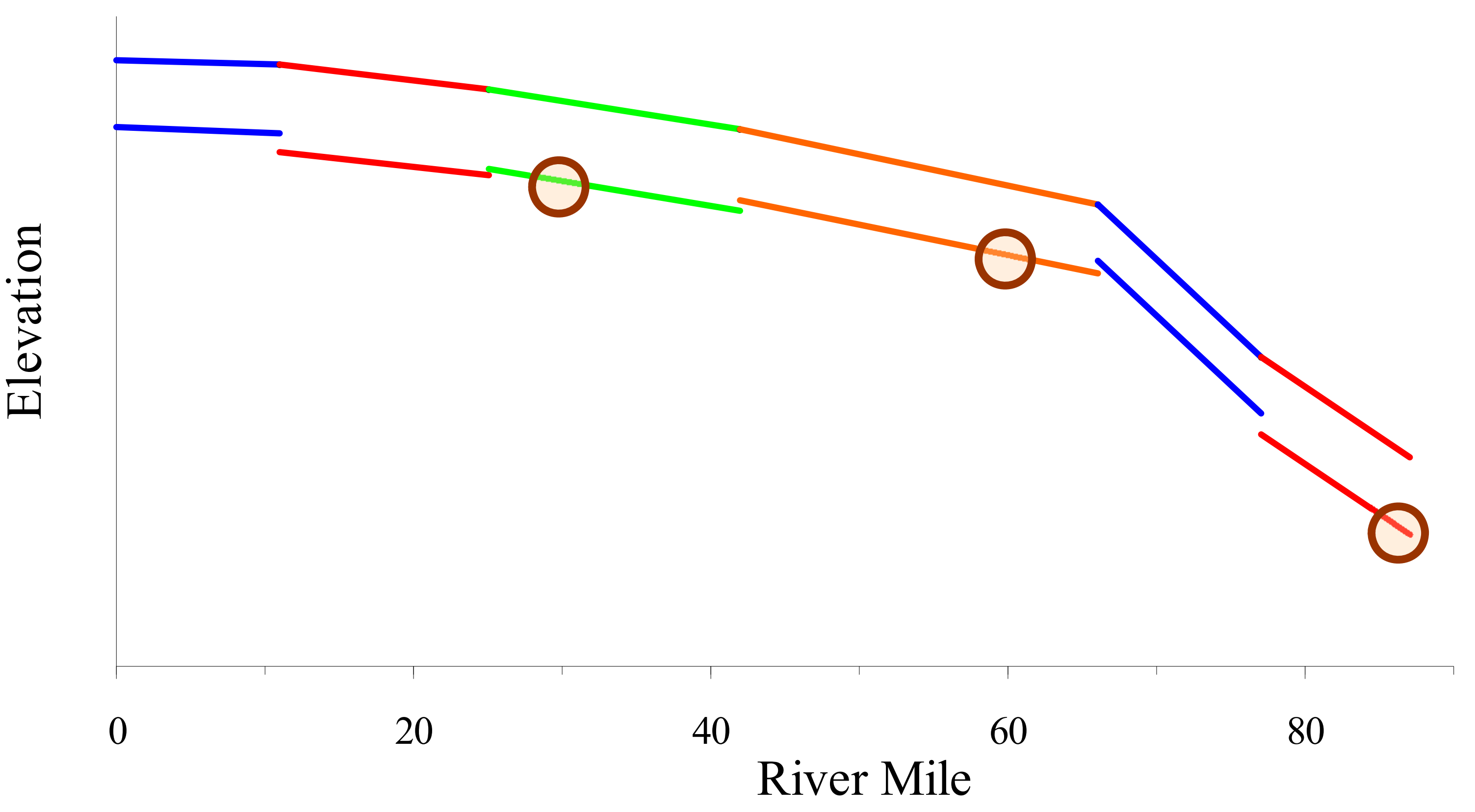
2d or 3d morphodynamic model

1d reach-averaged routing model with coupled sand storage fns

Key Model Elements

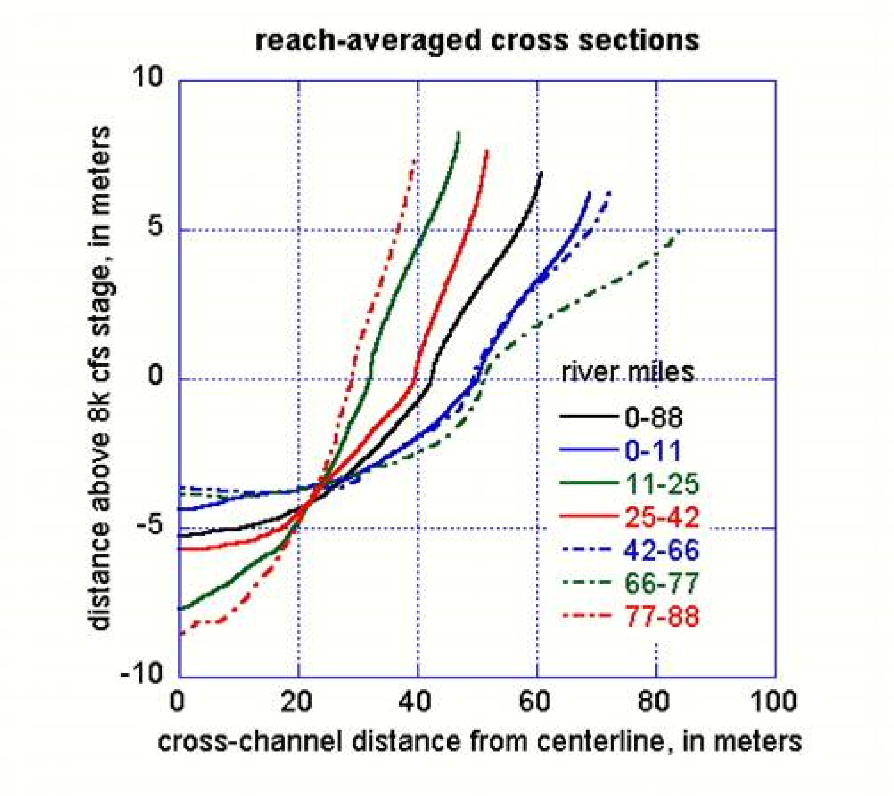
1) Reach-averaged channel geometry
    (complex channel shape, incomplete bathymetry)
    6 reaches: Paria R Confluence to Phantom Ranch (87 miles)
    pipe + pools
2) 1d unsteady flow model (significant daily fluctuations)
    existing reach-averaged flow model
3) Near-bed sand concentration
    (suspended sand transport over a cobble/boulder bed)
    develop independent relation for sand entrainment
4) Sand storage in eddies (cannot be captured in a 1d model)
    source/sink fns derived from 2d model applied to
    7 km-scale reaches @ 10 discharges & 3 sand concentrations
5) Testing: Fall/Winter 2004/2005

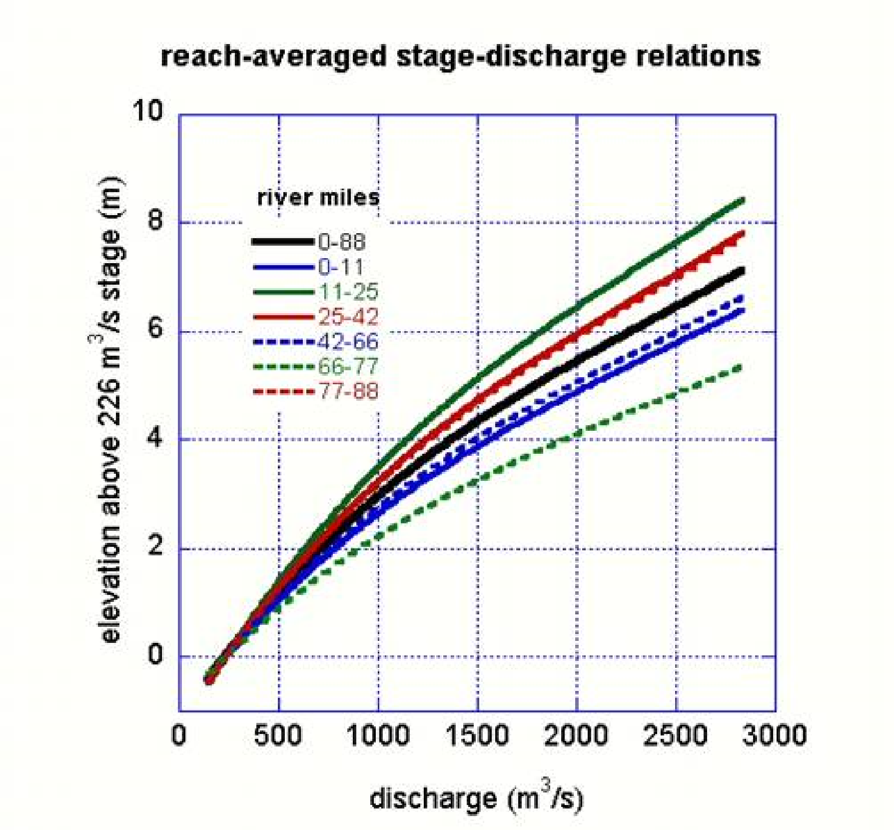
1. Reach-averaged channel geometry



1. Reach-averaged channel geometry

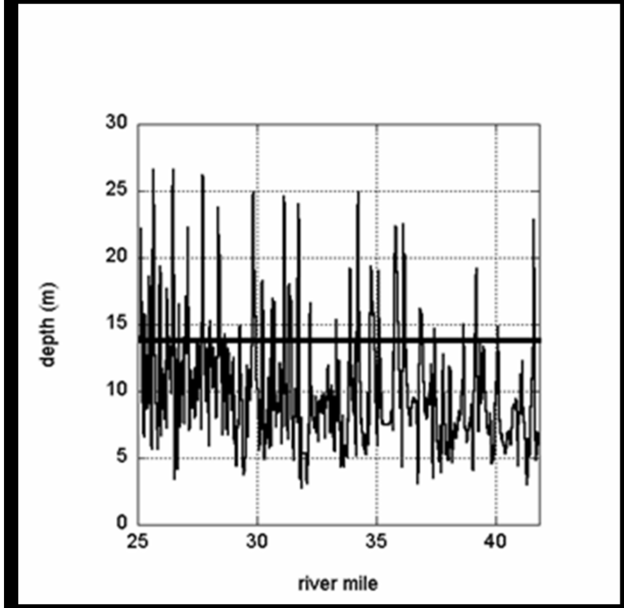
- Cross sections (Griffin, 1997)

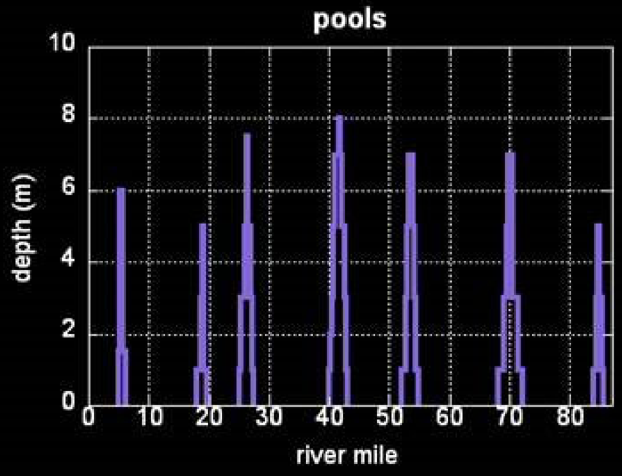


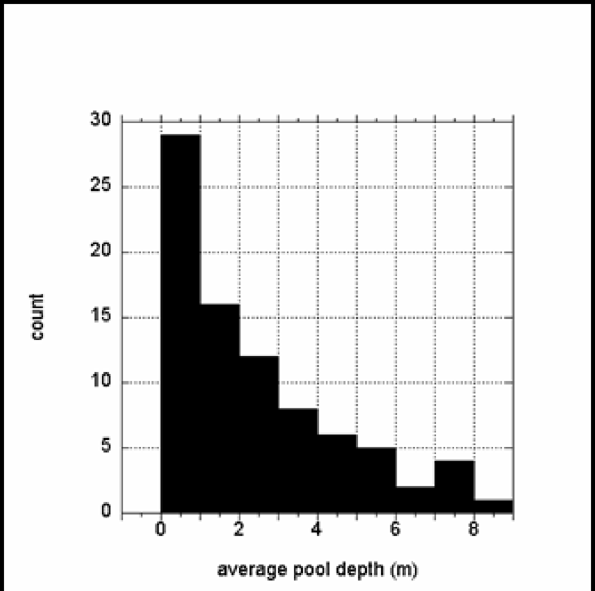


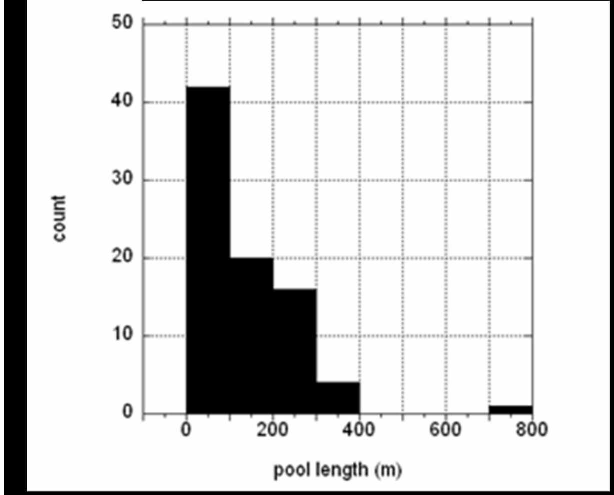
- Stage-discharge
(Wiele and Torizzo, 2003)

1. Reach-averaged channel geometry – Pools (Leopold, 1965, Randle and Pemberton, 1984)









2. 1d unsteady flow model

-- reach-averaged hydraulic geometry from

•streamflow gage records

•kinematic wave speed --

integrate function for wave speed

to get Q = f(A)

•dye study (Graf) for constant of

Integration

Wiele and Smith, 1996
Wiele and Griffin, 1997

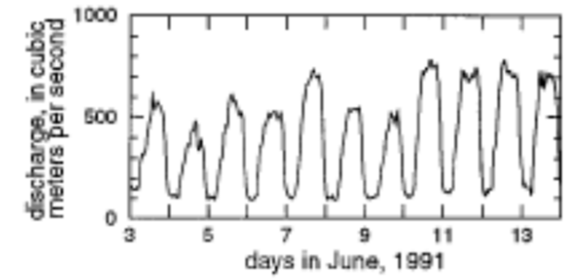


Figure 2. Typical hydrograph of releases from Glen Canyon Dam during peaking-power operation.

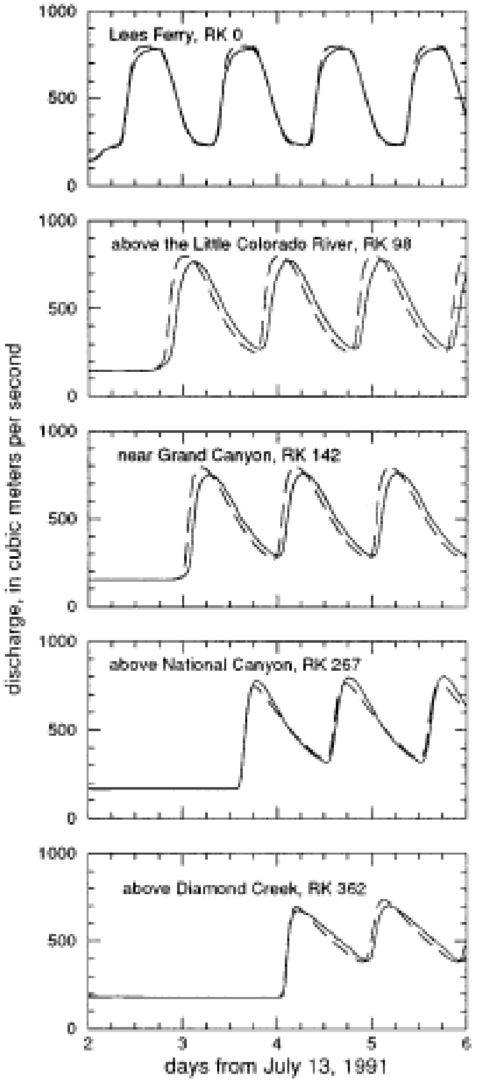
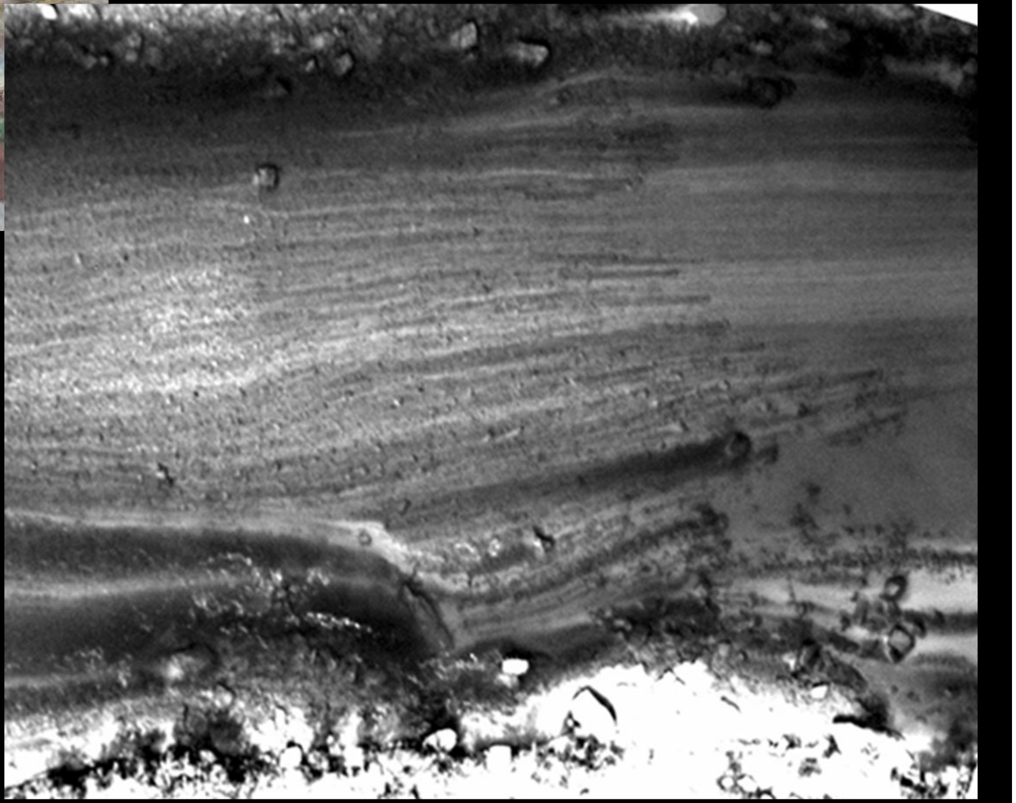
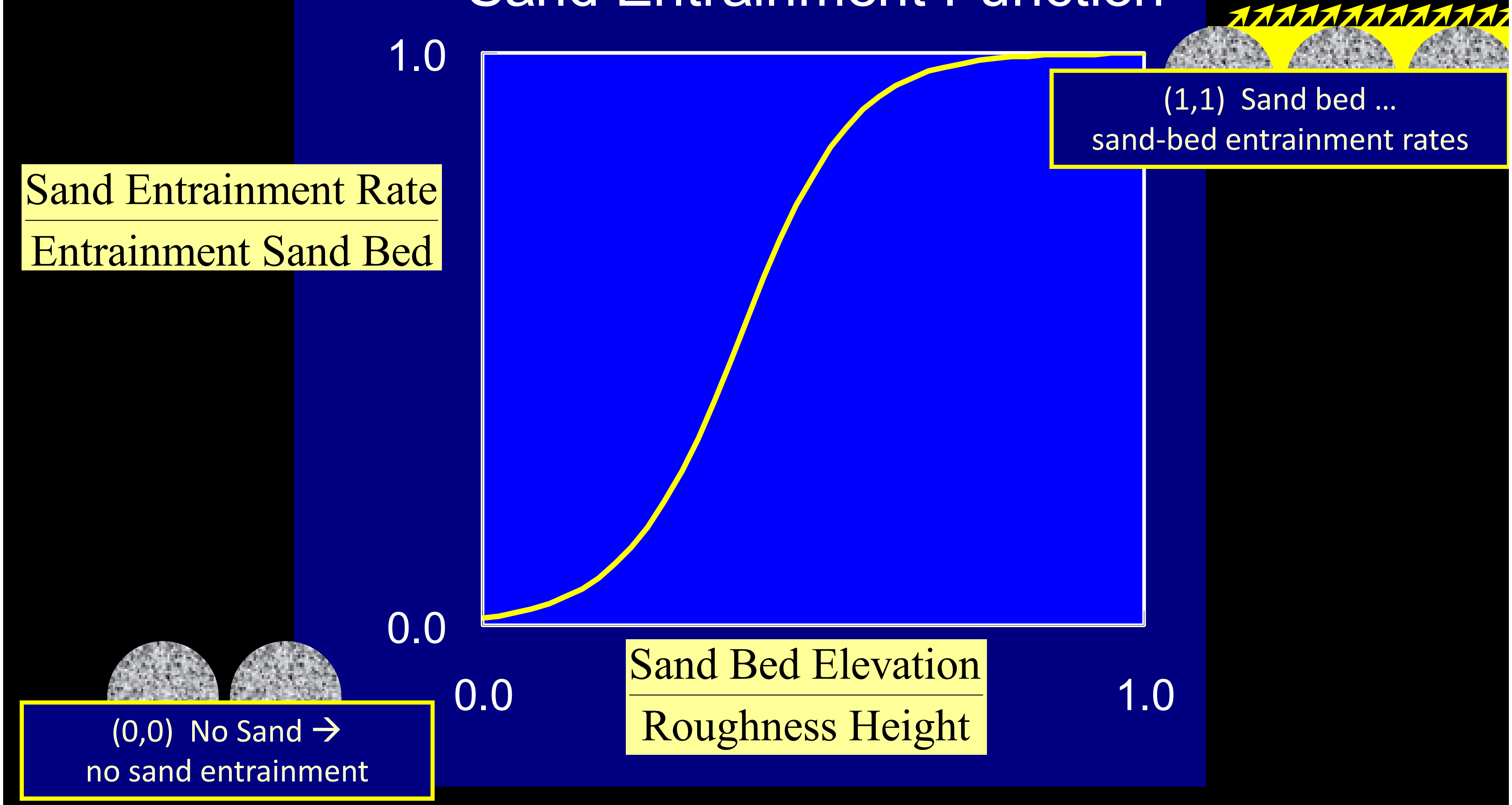


Figure 11. Calculated hydrographs (dashed lines) and hydrographs determined from stage-discharge relations (solid lines) at streamflow gaging stations for research flow F.

3. Near-bed sand concentration over a cobble/boulder bed



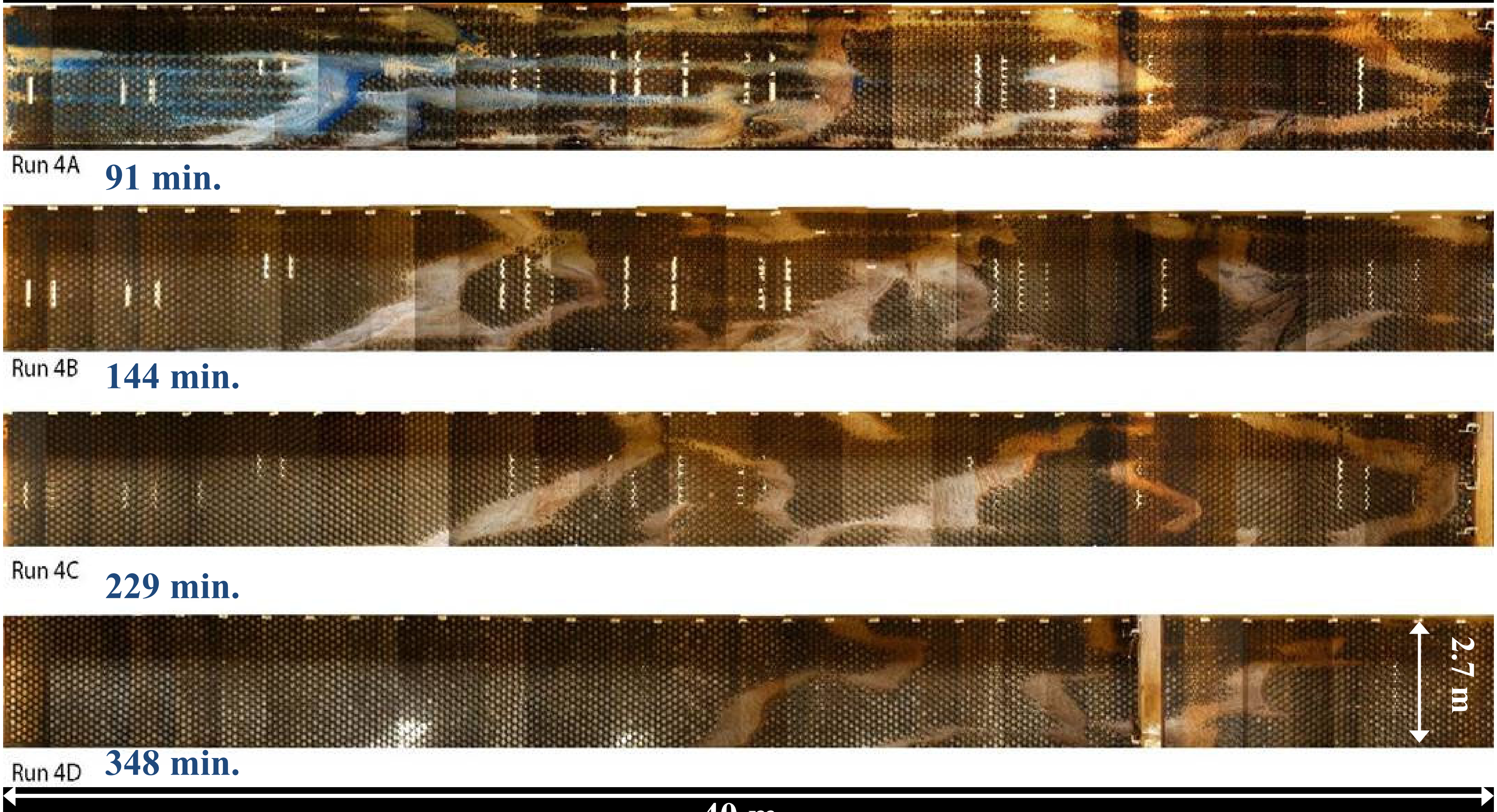
Sand Entrainment Function



(1,1) Sand bed …
sand-bed entrainment rates

(0,0) No Sand →
no sand entrainment

Main channel bed – Run 4



1 + 2 + 3 → Sand routing

- Calculated at local node (about ½-km apart) based on discharge, sand supply, and reach hydraulic properties
- Skin friction from Einstein decomposition
- Near bed sand concentration from Grams-Wilcock modification to Garcia-Parker relation
- Sand concentration from Rouse profile

Eddy erosion and deposition are invisible to this part of the model …

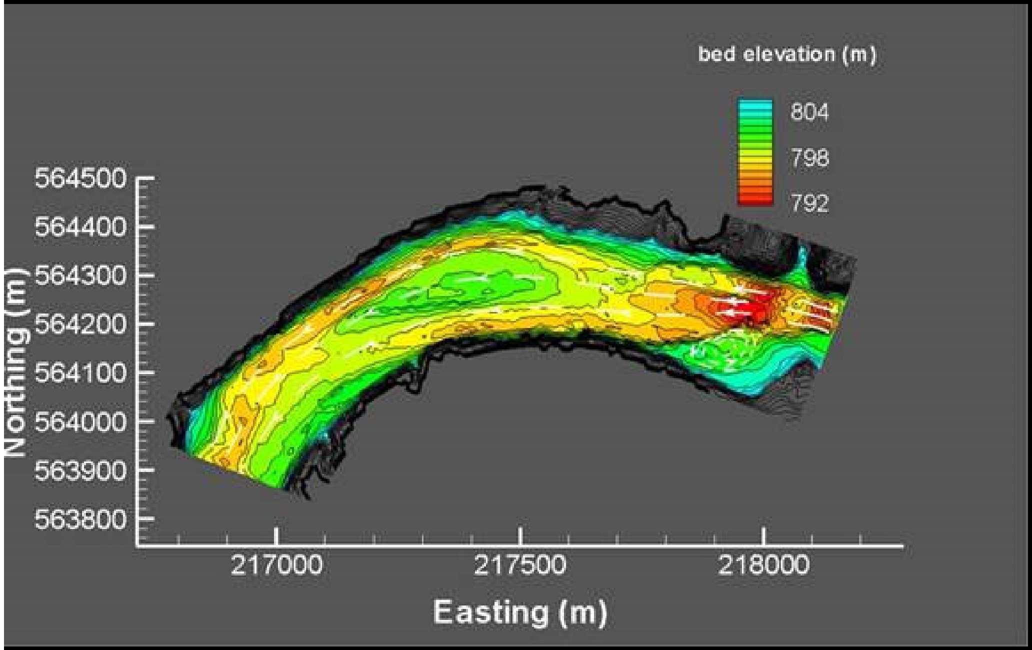
4. Sand erosion & deposition in eddies

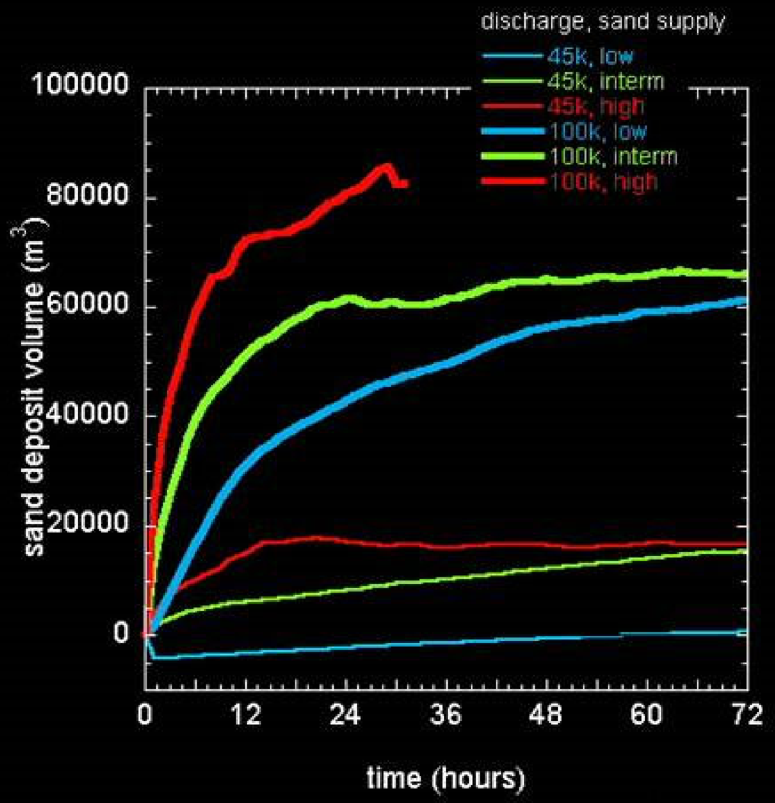
2d model of flow, sand transport, and bed evolution
applied to 7 km-scale reaches
@ 10 discharges & 3 sand concentrations
to develop source/sink functions

4. Sand erosion & deposition in eddies

calculate local flow & transport fields as function of discharge, sand supply, & initial sand volume

→ predict local sand deposition and scour



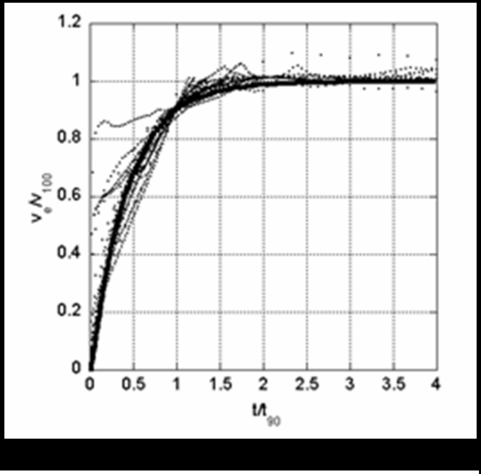


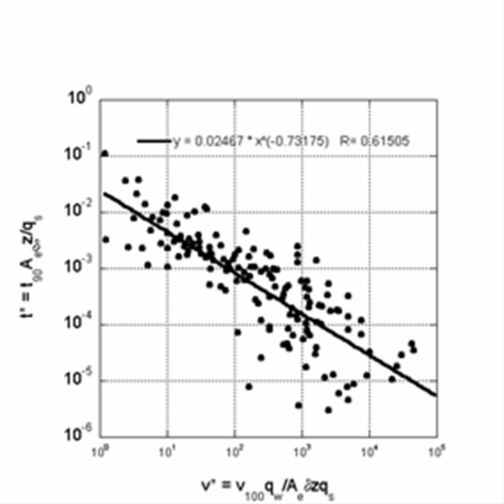
4. Dimensionless relations for sand deposition & scour

Eddy deposition

modeled as function of

- eddy properties
- discharge
- sand concentration
- **time (dv/dt)**

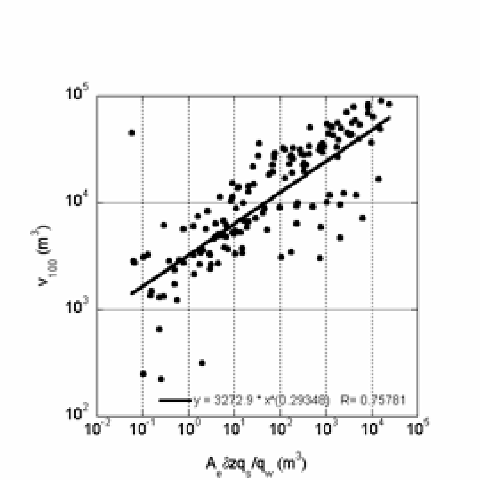




Eddy scour

modeled as a function of

- eddy properties
- discharge
- **change in discharge (dv/dq)**



For each time step in each model reach:

use summary eddy geometry to calculate sand additions and subtractions

1d morphodynamic modeling comments

Simpler topography (e.g. smoothed, or reach-averaged widths) may be more useful than more detailed topography *for the purpose of the model effort.* Adding detail does not help if you are not modeling at the fundamental granular scale.

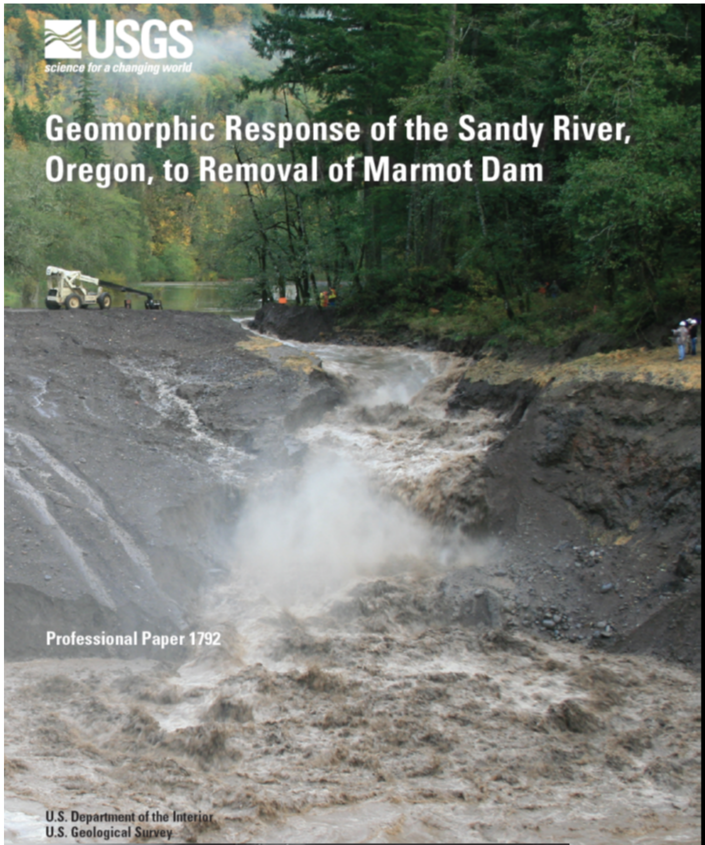
You cannot expect to capture the detail at any particular location, and should not believe the predictions at any single cross section. Rather, you hope to capture the broader trends that match observed behavior. This might be

(i) Dynamic equilibrium (no net scour or aggradation over full range of flows)
(ii) Observed large scale scour or aggradation
(iii) Observed sediment delivery to a reservoir
(iv) Broad alongstream trends in bed material grain size

Calibration, or ‘zeroing’ is ***everything*** in morphodynamic modeling.
Adjust the model until it ***behaves*** in accordance with observable attributes of the river.
As long as you have not built a physical unreasonable river, then you hope that model ***response*** to a perturbation will be similar to river ***response*** to the same perturbation.

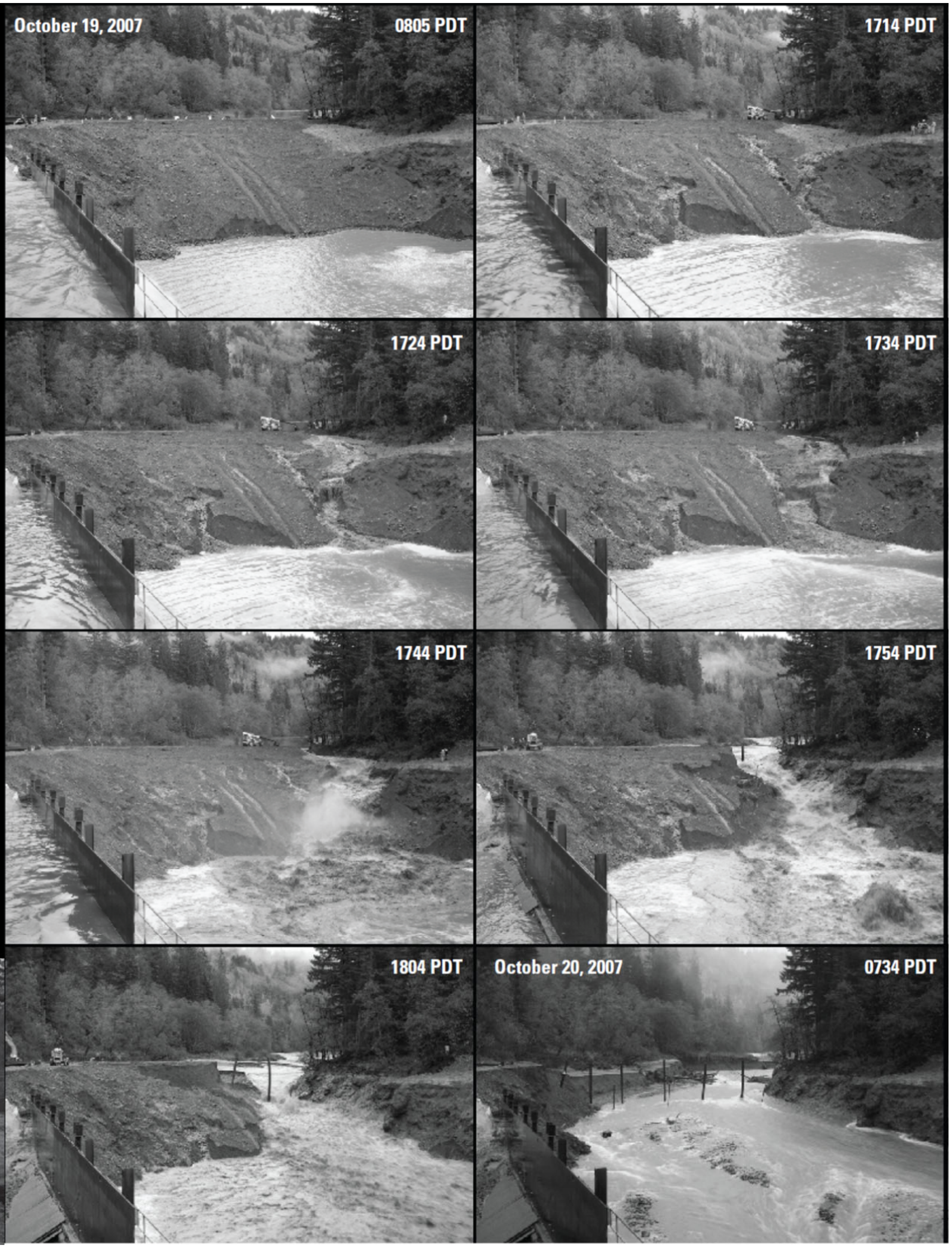
USGS
science for a changing world

Geomorphic Response of the Sandy River, Oregon, to Removal of Marmot Dam



Professional Paper 1792

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

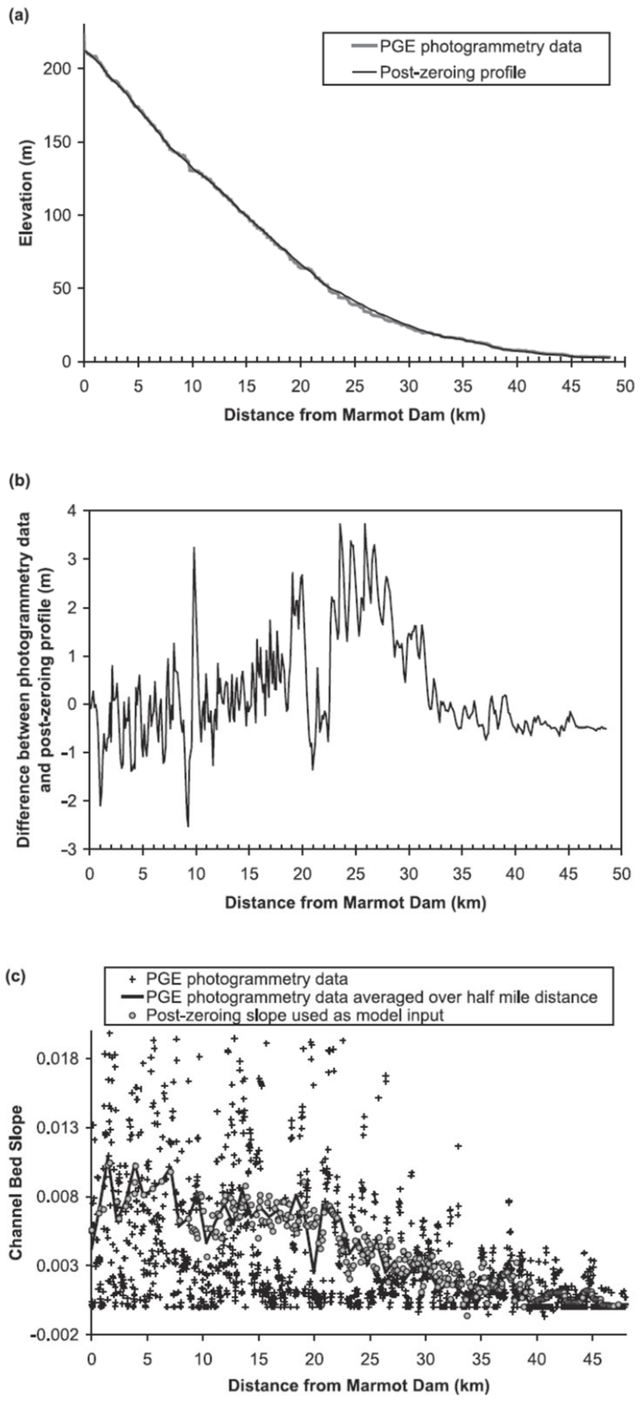


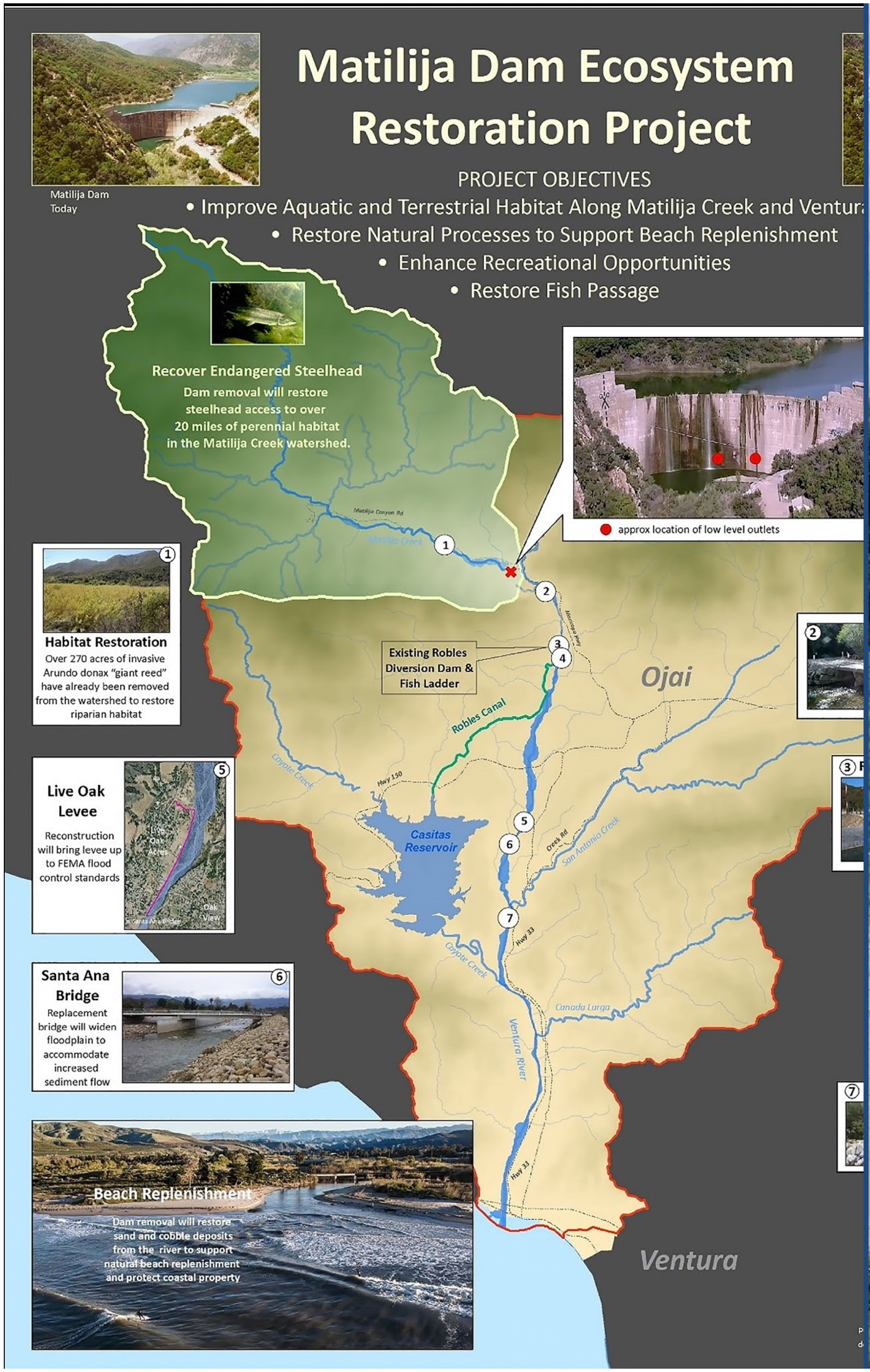
Comments on sediment transport model zeroing, with reference to Marmot Dam Model

The objective of a zeroing process is to adjust the model input parameters so that they approximately reproduce the existing quasi-equilibrium long profile under the assumed background conditions. One assumption, therefore, is [may be] that the modeled reach is in a quasi-equilibrium condition, in which some aggradation or degradation may occur following flood events, but the long-term cumulative channel aggradation or degradation is minimal. The zeroing process involves running the model repeatedly with the surveyed longitudinal profile as the initial condition and the recorded hydrologic condition and best estimate of sediment supply rate and grain size distribution as boundary conditions. During this process, certain input data such as channel width, sediment supply rate, and/or grain size distribution are adjusted iteratively until the model reproduces a quasi-equilibrium profile similar to that observed. The reproduced quasi-equilibrium longitudinal profile is then used as the initial profile for modeling future conditions such as evaluating sediment transport dynamics following dam removal herein or following channel reconstruction for restoration. Because this initial profile is in quasi-equilibrium state within the model, any deviations from this condition in the subsequent simulations are considered to result from the perturbation injected into the model input.

During the zeroing process for Marmot Dam removal sediment transport study, the following adjustments were made: channel width was adjusted by narrowing some of the excessively wide cross sections, long-term averaged sediment supply rate was adjusted within the range found during the literature review, and the abrasion coefficient of gravel particles was also adjusted based on published range so that the predicted grain size distribution and longitudinal profile under the current conditions were similar to observations.

Cui, Yantao, Scott R. Dusterhoff, John K. Wooster, Peter W. Downs, 2011. Practical Considerations for Modeling Sediment Transport Dynamics in Rivers. IN Andrew Simon, Sean J. Bennett, Janine M. Castro (eds), Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, Geophysical Monograph Series 194.





Matilija Dam Ecosystem Restoration Project

Matilija Dam Today

PROJECT OBJECTIVES

- Improve Aquatic and Terrestrial Habitat Along Matilija Creek and Ventura
- Restore Natural Processes to Support Beach Replenishment
- Enhance Recreational Opportunities
- Restore Fish Passage

Recover Endangered Steelhead
Dam removal will restore steelhead access to over 20 miles of perennial habitat in the Matilija Creek watershed.

● approx location of low level outlets

① **Habitat Restoration**
Over 270 acres of invasive Arundo donax "giant reed" have already been removed from the watershed to restore riparian habitat

Existing Robles Diversion Dam & Fish Ladder

⑤ **Live Oak Levee**
Reconstruction will bring levee up to FEMA flood control standards

⑥ **Santa Ana Bridge**
Replacement bridge will widen floodplain to accommodate increased sediment flow

Beach Replenishment
Dam removal will restore sand and cobble deposits from the river to support natural beach replenishment and protect coastal property

See also

A few Lessons Learned from Sediment Transport Modeling Projects

Yantao Cui
formerly of
Stillwater Sciences

Presented at 2011-05-25 ASCE EWRI Conference, Palm Springs

And

Cui Y., Dusterhoff S.R., Wooster, J.K., and Downs, P.W. (2011) Practical considerations for modeling sediment transport dynamics in rivers in Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, A. Simon, S.J. Bennett, and J.M. Castro, Editors, American Geophysical Union, ISBN 978-0-87590-483-2.

Comments on multidimensional modeling, with reference to Marmot Dam Model

1. Transport models are cross-section averaged; appropriate for 2d, 3d models?
2. Small errors in morphologic change add up over time
3. Model outcome sensitive to detailed local information (esp. grain size)
4. Model a short reach in detail or a long reach approximately? Importance of boundary conditions
5. Can decision support be better provided by simpler model?

There are three main limitations for multidimensional numerical models. First, while multidimensional modeling can usually realistically reproduce the flow field, the detailed relation between sediment transport and movement of sediment particles is not fully understood, and all the current sediment transport equations were developed based on data collected on a cross-section averaged basis. As such, topography predicted as a direct result of flow field (such as scour due to river bend) can often be realistically modeled, but the topography associated with complex sediment transport dynamics, such as the formation and development of alternative bars in a straight channel, may not be realistically reproduced. Second, attempting to model sediment transport dynamics in detail requires the collection of detailed field data, some of which are critical to the modeling but impractical to obtain in many situations or at a large scale. For example, simulating detailed topography in an area subject to channel erosion will require the knowledge of detailed grain size distributions and information with regard to where nonerodible material (such as bedrock and large boulders) is located and how deep it is beneath the surface. While it is possible to make some generalized assumptions about grain size distributions based on observations of the surface or bulk samples, it is impractical to know the locations and depth of the bedrock and large boulders, and without such information, the modeling results with regard to future topography would not have the desired resolution. Third, limitations in available computer resources will set upper bounds on the number of nodes permissible in a multidimensional model simulation, and because computational meshes cannot be overly distorted (i.e., the longitudinal dimension of the meshes cannot be too much larger than the lateral dimension), there are practical limits on the length of the river that can be simulated. This latter issue can introduce a further problem in that modeling short reaches may make the entire simulation domain dependent on boundary (especially downstream boundary) conditions, making the simulation results unreliable. This is generally not an issue in 1-D modeling because a 1-D model can be set to a significantly longer reach so that the interested area is beyond the influence of the model boundary.

The primary reason that multidimensional numerical modeling was not proposed at the time was that 1-D numerical modeling had satisfactorily answered all the important questions that the stakeholders and regulating agencies needed to know, with a few uncertainties addressed with contingency plans discussed earlier, allowing the stakeholders to reach an agreement. In addition, multidimensional simulations would have been limited to only a short period of time following dam removal, which was not the primary interest of the stakeholders.

Cui, Yantao, Scott R. Dusterhoff, John K. Wooster, Peter W. Downs, 2011. Practical Considerations for Modeling Sediment Transport Dynamics in Rivers. IN Andrew Simon, Sean J. Bennett, Janine M. Castro (eds), Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, Geophysical Monograph Series 194.

Some comments on flushing flows

Ecological Application: impact of bed material fines on salmonid eggs & emerging fry, and juvenile growth & mortality

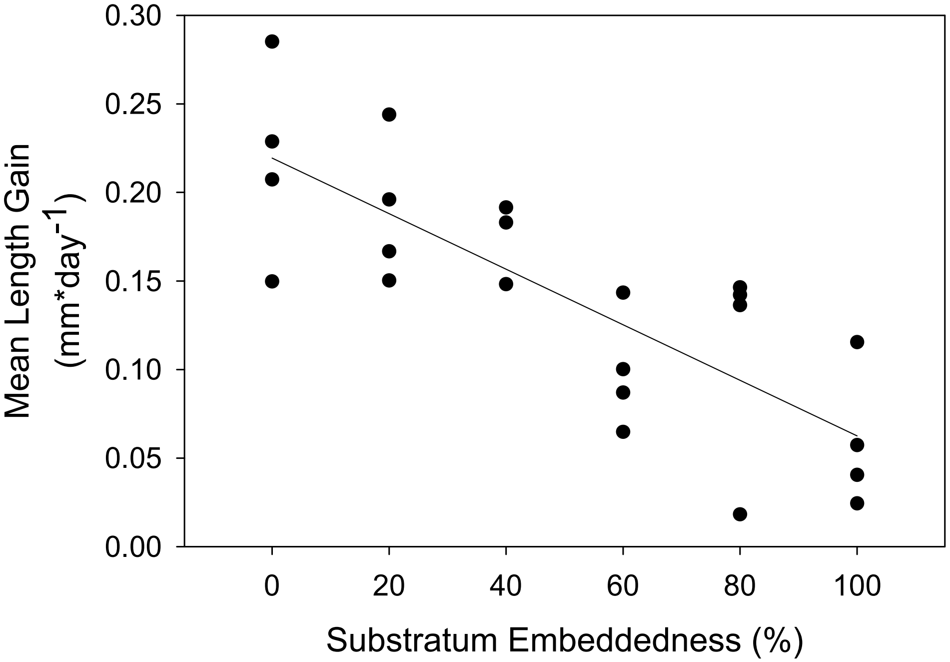
Effect of fine (< 2 mm) sediments on juvenile steelhead and the food webs that support them (Suttle, Power, Levine, McNeely, Sapp, Sorenson)

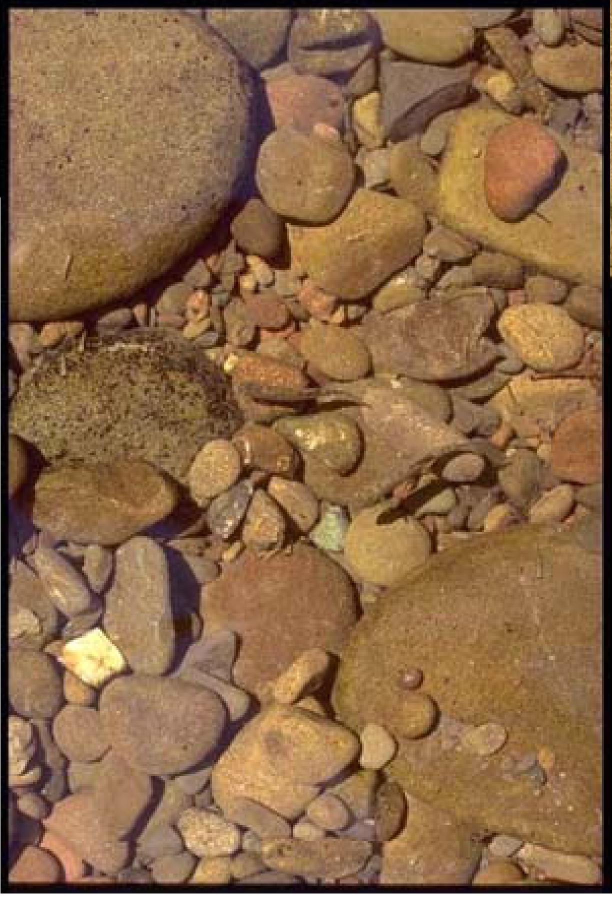
2 m x 0.5 m flow through channels

6 levels: 0, 20, 40, 60, 80 and 100% embedded

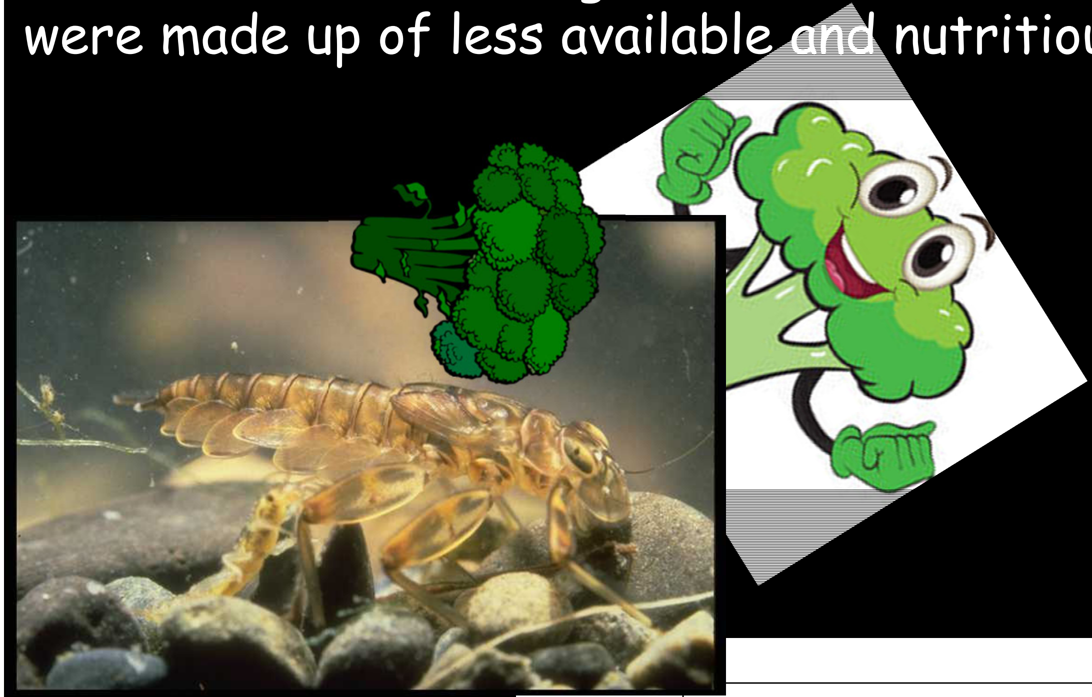
Replicated at 4 sites over ca. 4 km of S. Fk. Eel

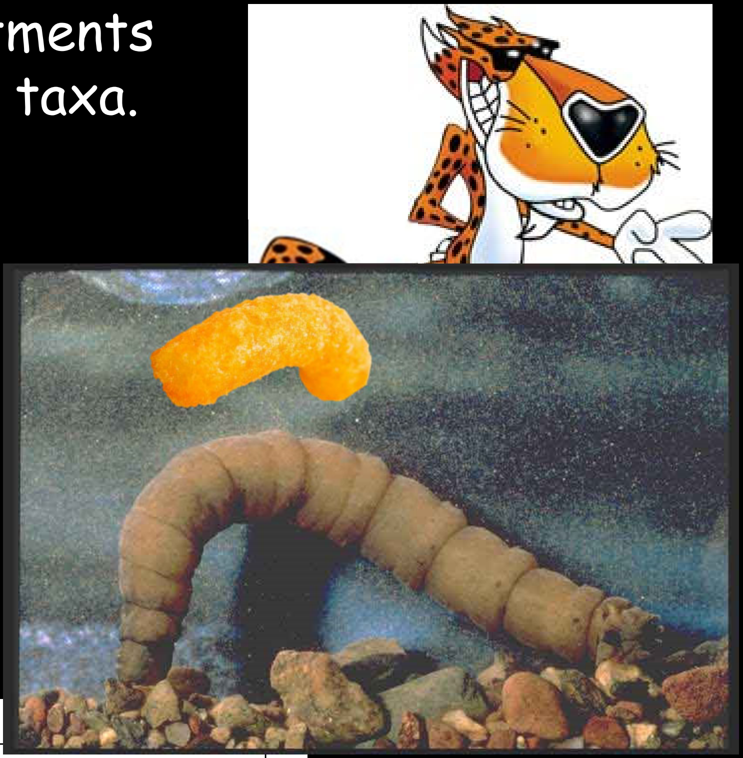
Growth in length and mass decreased linearly with proportion of fine sediment

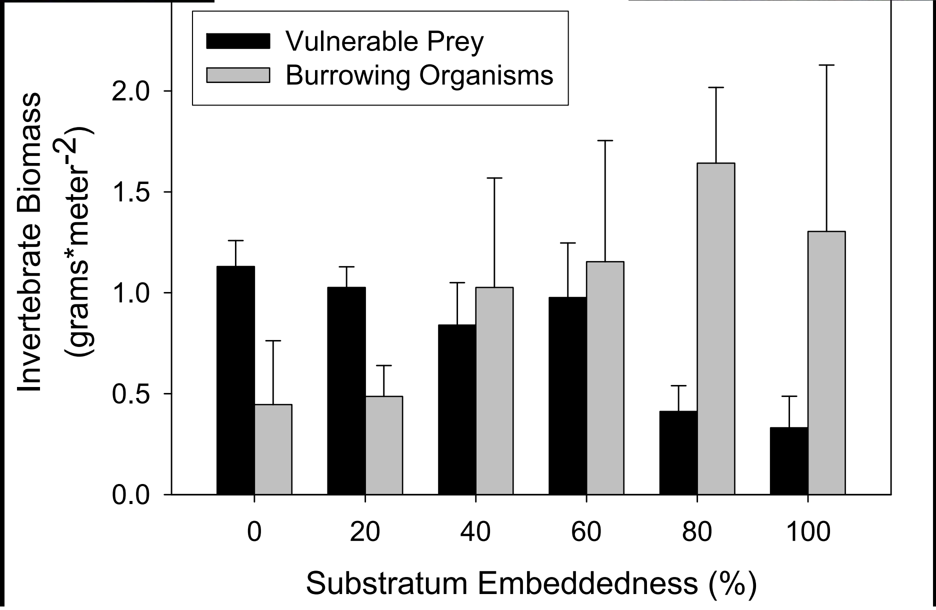




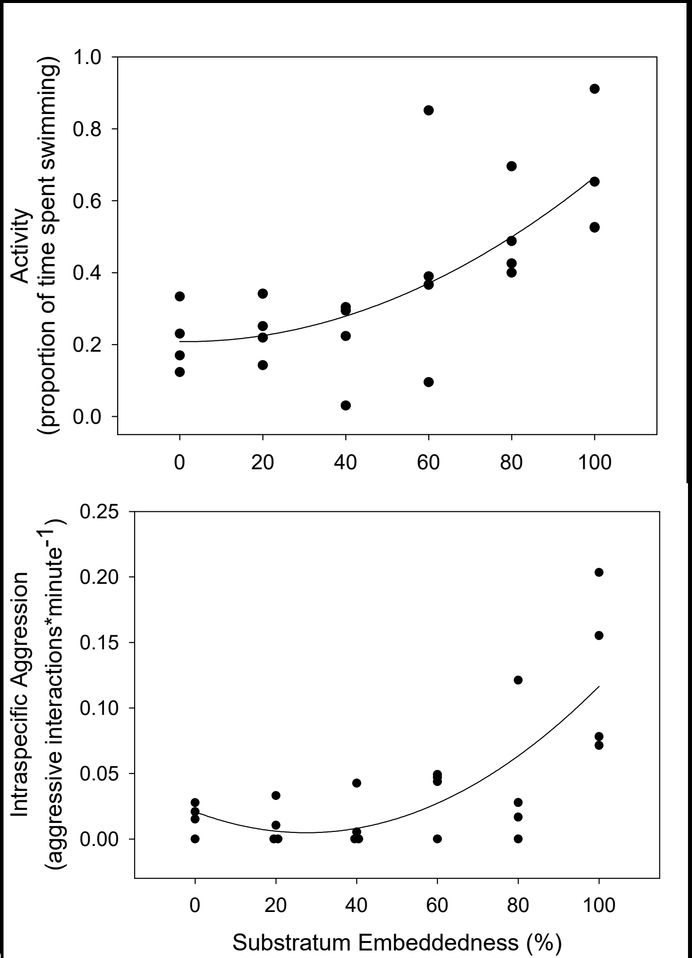
This occurred in part, because benthic invertebrate assemblages in embedded treatments were made up of less available and nutritious taxa.

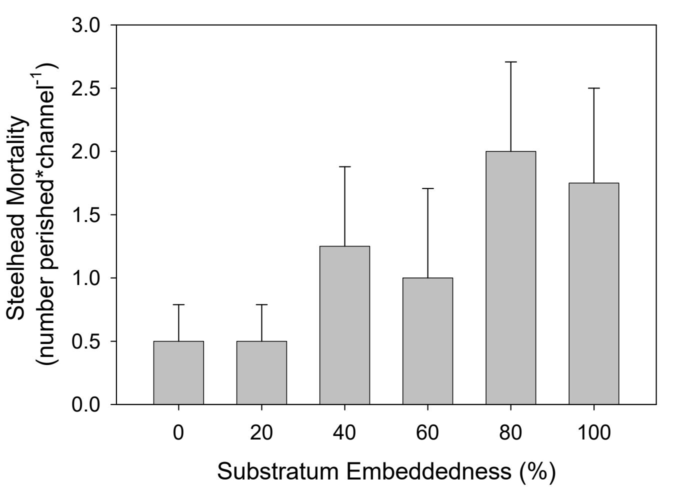






…and in part because fish were more active (and aggressive towards each other) on the flat, featureless beds in embedded treatments,





Mortality increased with embeddedness, and was associated with wounds from fighting.

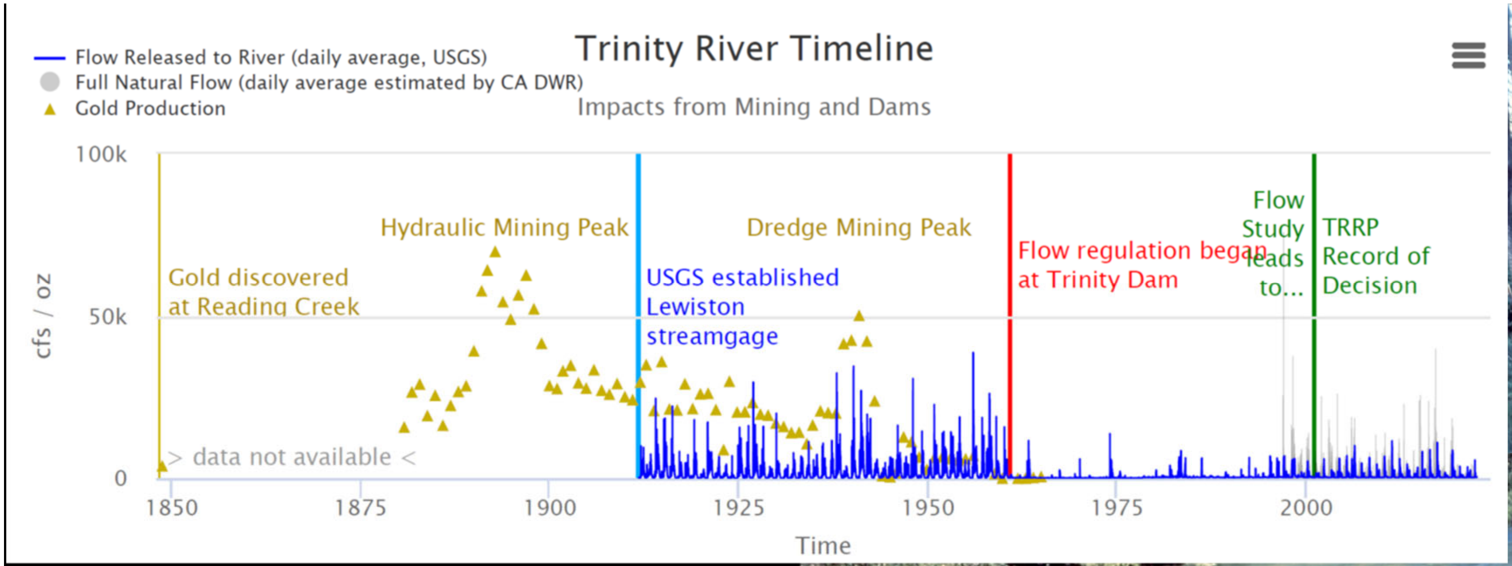
Ecological Application: reducing fines concentration in gravel-bed rivers

Solution: sufficient flow to entrain most of the bed surface (to flush the subsurface) **and** reduction of sand supply to below sand transport capacity

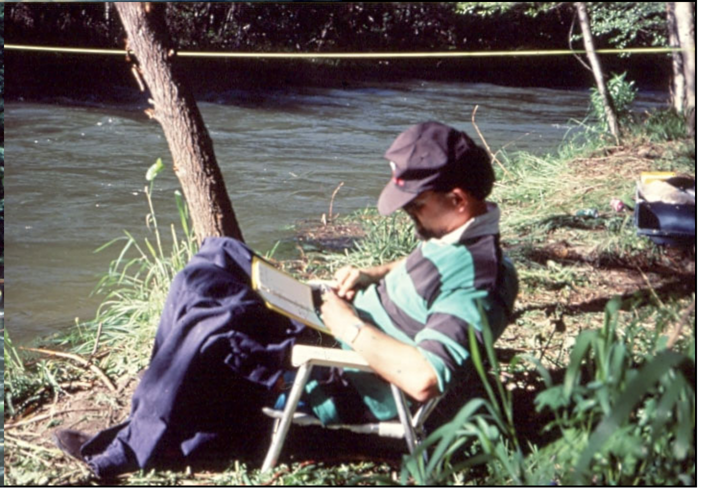
Note: *both* the **competence** and **capacity** elements of sediment transport are invoked here!

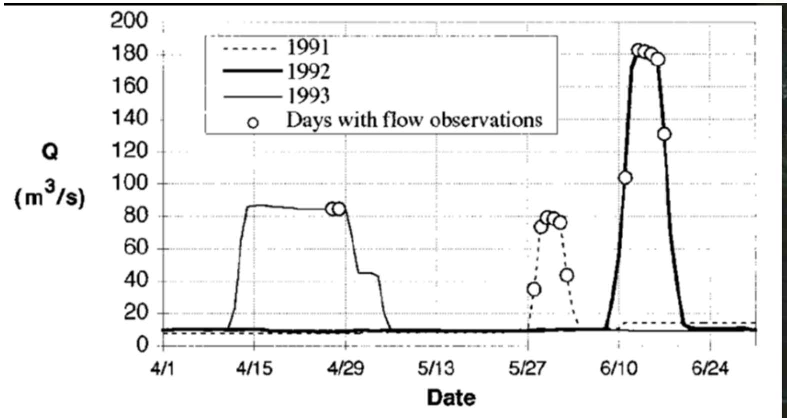
Flow Competence: flow must be high enough and last long enough to move most of the coarse grains on the bed surface

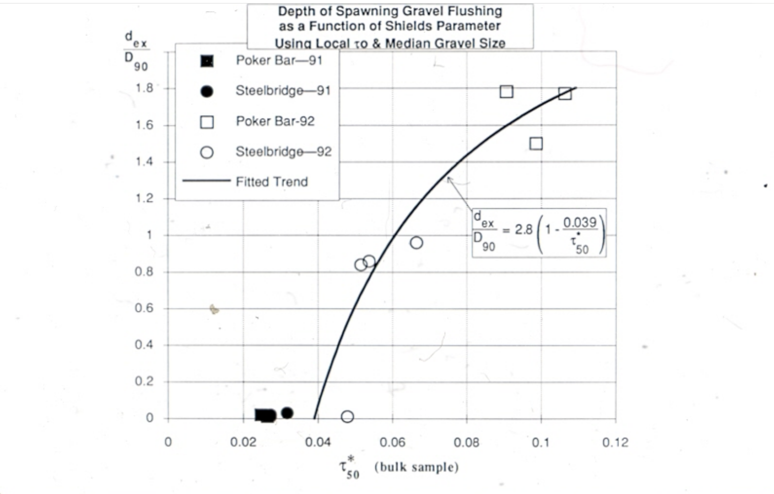
Transport Capacity: the reach must transport fines faster than the rate at which they are supplied


Trinity River Timeline
Impacts from Mining and Dams
Flow Released to River (daily average, USGS)
Full Natural Flow (daily average estimated by CA DWR)
Gold Production
100k
50k
0
cfs / oz
Gold discovered at Reading Creek
Hydraulic Mining Peak
USGS established Lewiston streamgage
Dredge Mining Peak
Flow regulation began at Trinity Dam
Flow Study leads to...
TRRP Record of Decision
> data not available <
1850
1875
1900
1925
1950
1975
2000
Time


5 29 '91







Bottom Line:
A flow of 6,000 cfs was sufficient to mobilize most of the gravel. Good for flushing IF the sand content of Trinity River can be reduced.

WATER RESOURCES RESEARCH, VOL. 32, NO. 9, PAGES 2911–2921, SEPTEMBER 1996

Specification of sediment maintenance flows for a large gravel-bed river

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Alan F. Barta
Intermountain Research Station, U.S. Forest Service, B

WATER RESOURCES RESEARCH, VOL. 32, NO. 9, PAGES 2897–2909, SEPTEMBER 1996

Observations of flow and sediment entrainment on a large gravel-bed river

Peter R. Wilcock,[1] Alan F. Barta,[2] Conor C. Shea,[3] G. Mathias Kondolf,[4]
W. V. Graham Matthews,[4] and John Pitlick[5]