MODELING 101

Scott Wright
(many others have contributed to the content of this talk)

Colorado River Knowledge Assessment
February 1, 2012

What is a "model"?

Models attempt to reproduce things we observe in nature

Models rely on our understanding of the underlying laws – thus, models and theory are closely linked

Many observations have motivated theory and models in science:

- An apple falling on your head (Newton's laws of motion)
- Planet's moving through the sky (Kepler's laws)
- Global changes in climate (GCMs)
- Native species declines (population models)
- Stock market trends (financial markets models)
- Election results (exit polling and extrapolation)
- And, of course, sand transport in Grand Canyon

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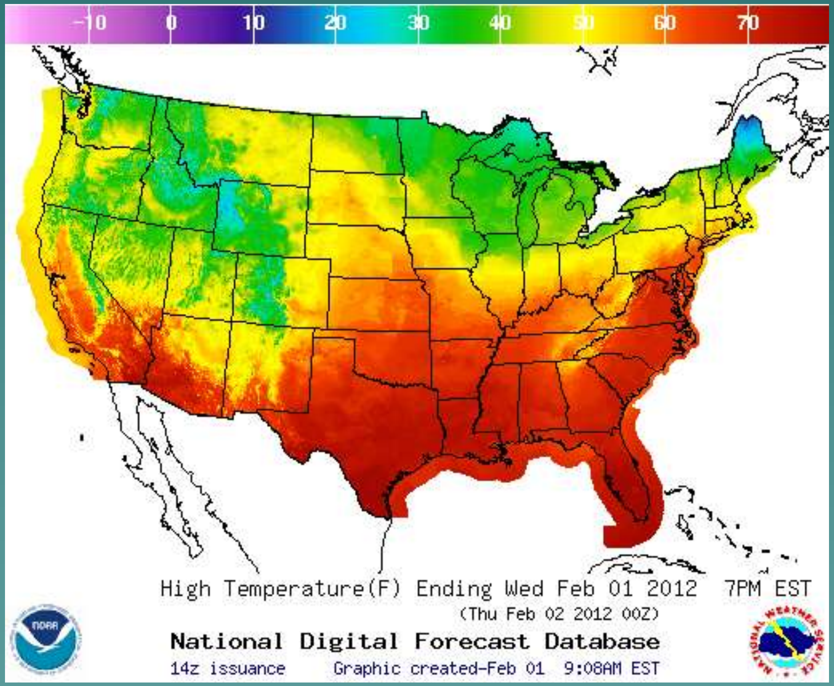
Models are everywhere in our society

Why do we construct models?

1) To try to explain our observations (along with theory)

2) TO MAKE PREDICTIONS!

Weather forecasting is one of the most popular applications of models



Today: Mostly sunny, with a high near 75. East wind at 5 mph becoming south.

Tonight: Partly cloudy, with a low around 42. West southwest wind around 6 mph becoming calm.

Thursday: Sunny, with a high near 70. Calm wind becoming west southwest around 6 mph.

Thursday Night: Mostly clear, with a low around 41. West wind 5 to 7 mph becoming northeast.

Friday: Sunny, with a high near 70. Northeast wind between 4 and 7 mph becoming calm.

Friday Night: Mostly clear, with a low around 42.

Saturday: Sunny, with a high near 71.

Saturday Night: Mostly clear, with a low around 43.

Sunday: Mostly sunny, with a high near 73.

Sunday Night: Partly cloudy, with a low around 43.

Monday: Mostly sunny, with a high near 74.

Monday Night: Partly cloudy, with a low around 45.

Tuesday: Mostly sunny, with a high near 74.

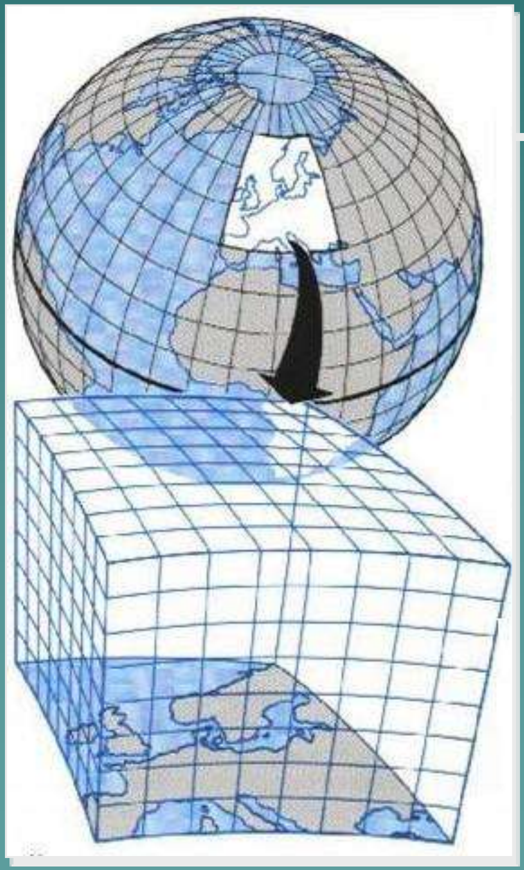
Models come in many shapes and sizes

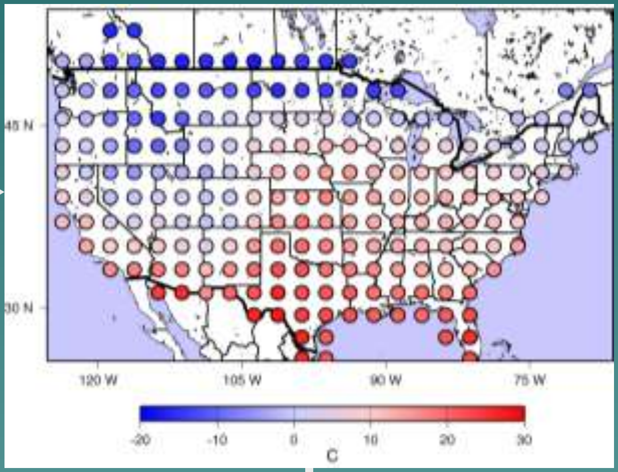
Models are always tailored to a particular type of prediction because there are computational limits to what can be done

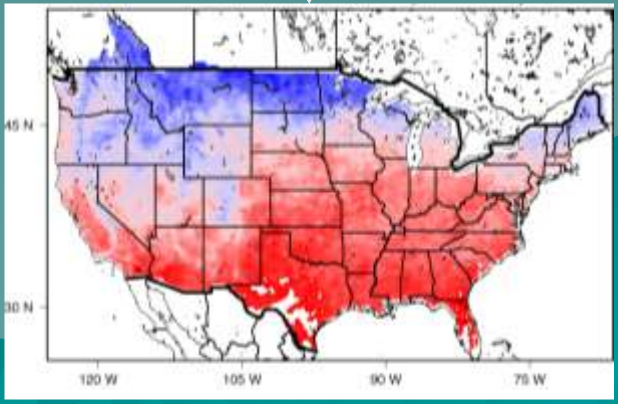
For example:

Global models provide broad scale predictions of climate

Other models are used to downscale the results to finer scales







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Physics-based models in fluid mechanics

All models emanate from mass conservation and
Newton's 2nd law: F = ma (no, really)

Applied to fluid mechanics, the most general forms are:

Mass conservation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Force balance (F=ma)

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + g_i$$

We CAN solve these equations. However, it is impractical for almost all geophysical flows. The physics must be simplified to construct useful models. These simplifications are the essence of modeling

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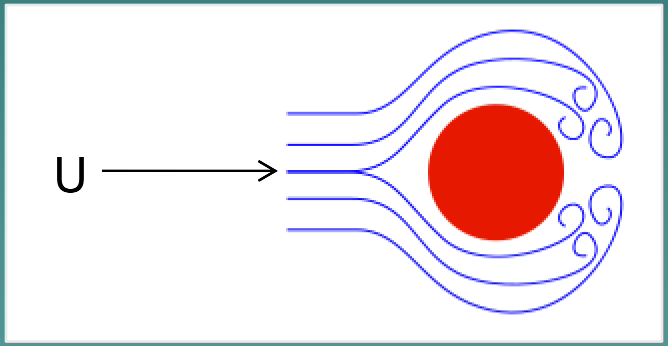
Models we can use

A simple model that captures the important processes is always better than a complicated one. Simple models are easier to interpret and apply

Classic example: drag force, F_D, on an object



Complex flow can be simulated and used to directly compute drag

But a much simpler model works:

$$F_D \sim C_D U^2$$

Experiments were used to estimate C_D for a wide range object shapes

Simple models with empirical coefficients require more data

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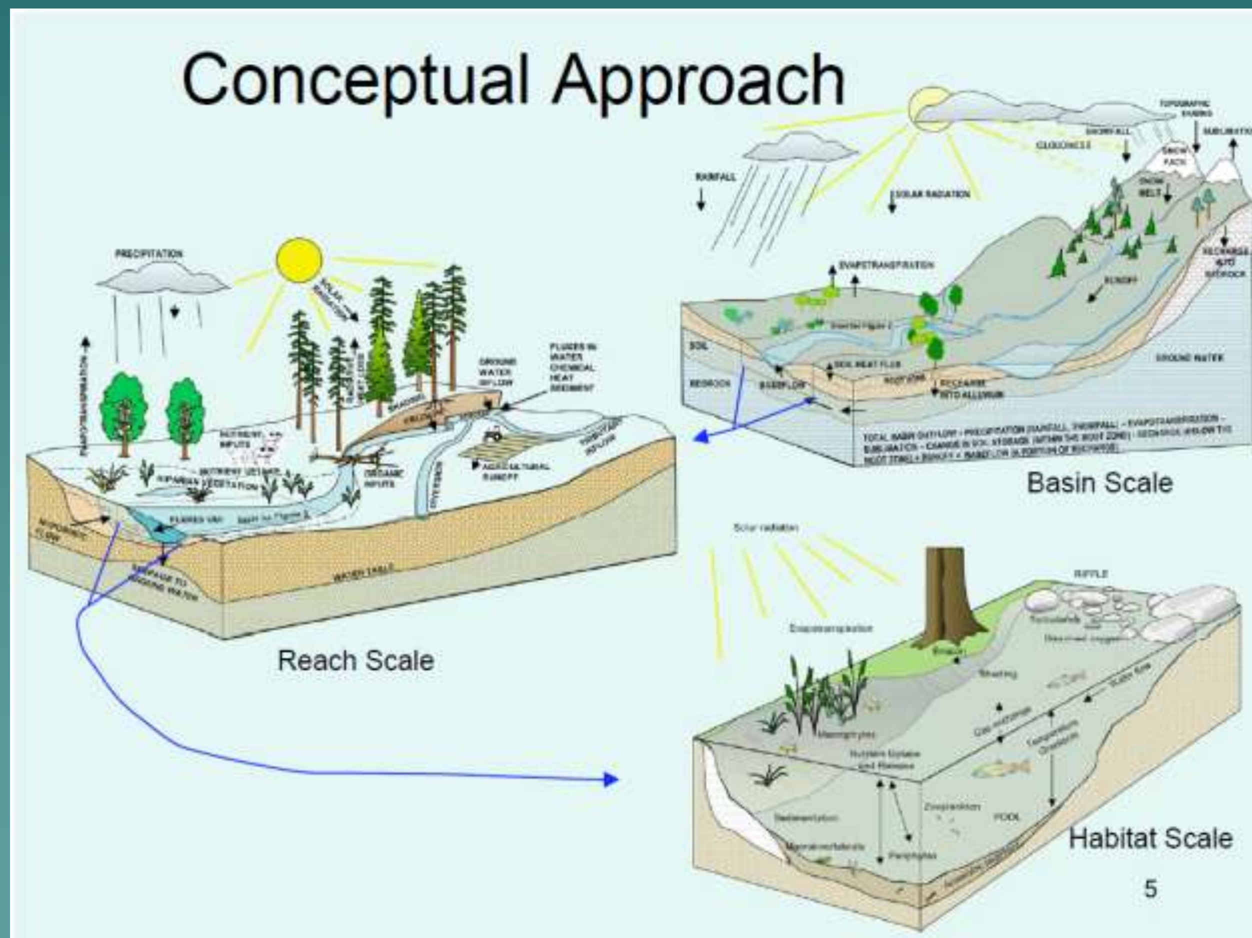
Scale issues in river modeling

A recent trend is to construct a suite of linked model that "cascade" from coarse to fine scales

Each scale requires a different approach (more or less simplifications)

Models are then linked together to cascade down the spatial scales

What is the impact of climate change on fish habit?



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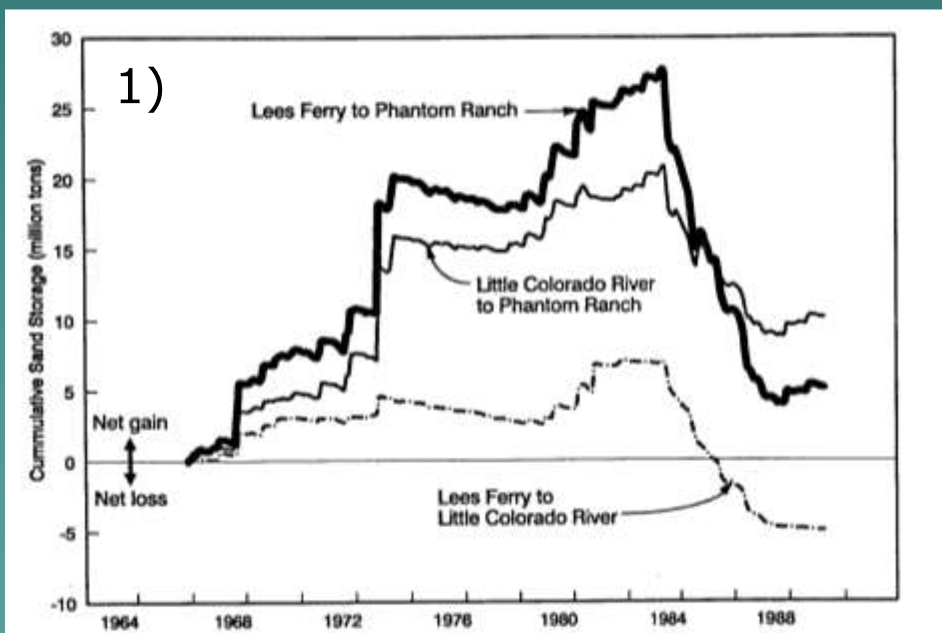
Grand Canyon sand models

Two main modeling goals:

1) Predict changes in the amount of sand in the canyon over time (months to years)

2) Predict changes in sandbar size during floods (days to weeks)



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Grand Canyon sand models

Both types of models are based on the same basic physics:

Force balance for the fluid (water):

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + g_i$$

Mass conservation for the sediment (Exner):

$$B_a(1-\lambda_p)\left[\sigma + \frac{\partial \eta}{\partial t}\right] = -I_Q \frac{\partial Q_s}{\partial x}$$

$$B_a(1-\lambda_p)\frac{\partial (L_a F_{bk})}{\partial t} = -I_Q \frac{\partial Q_{sk}}{\partial x} + F_{Ik}\left[I_Q \frac{\partial Q_s}{\partial x} + B_a(1-\lambda_p)\frac{\partial L_a}{\partial t}\right]$$

Model 1) requires drastic simplifications

Model 2) requires modest simplifications

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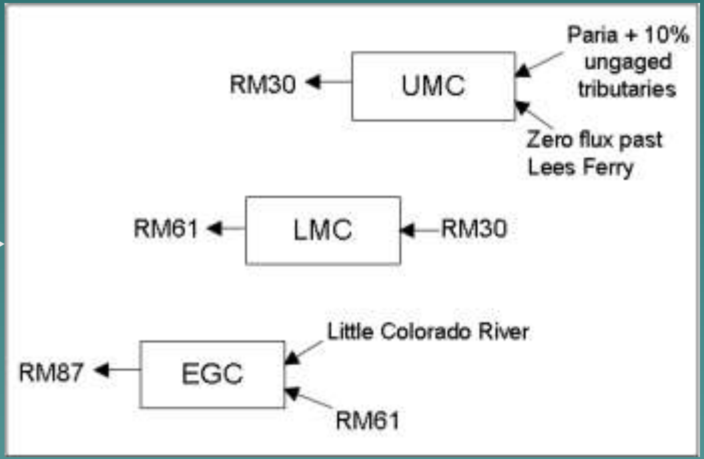
Model 1: sand routing

We want to model sand budgets in long reaches over long time scales

Primary simplification: spatial averaging over long reaches



The model reaches are equivalent to Topping's sand budget reaches

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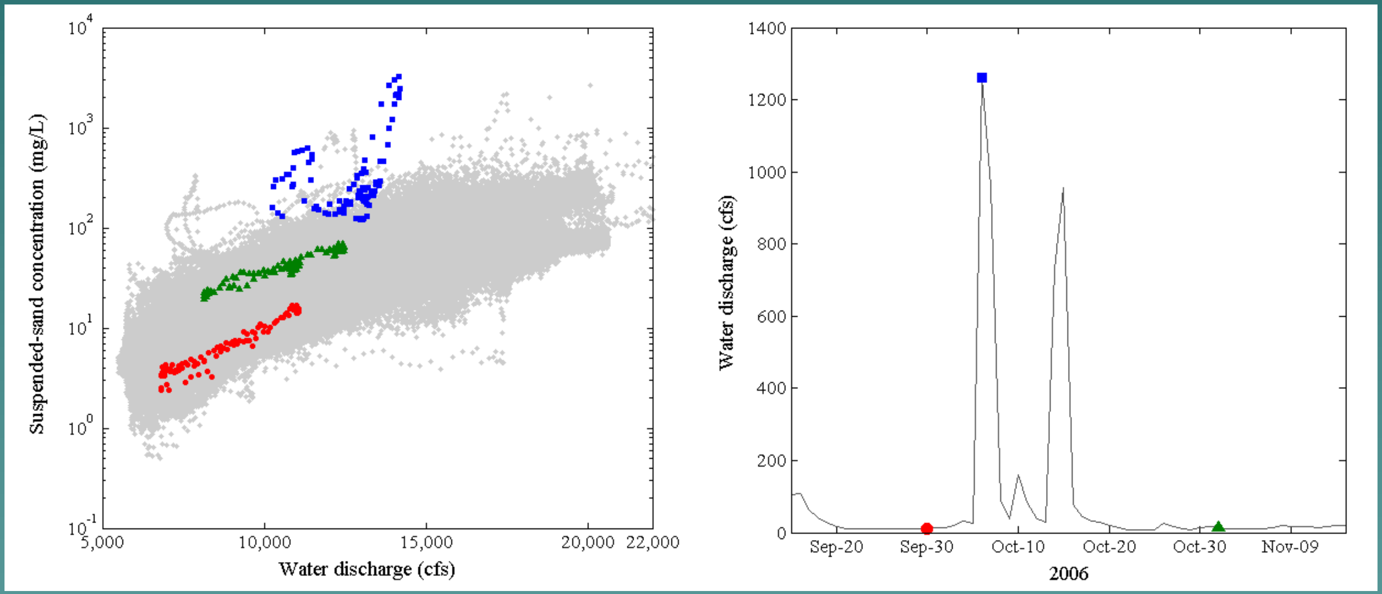
Model 1: sand routing

Caution: It IS possible to oversimplify the problem

For example, the EIS assumed that sand concentration was not dependent on sand supply, but only on discharge



The most important aspect of this model is that it retains dependence of sand concentration on supply (grain size on the bed). Rubin-Topping research changed the paradigm

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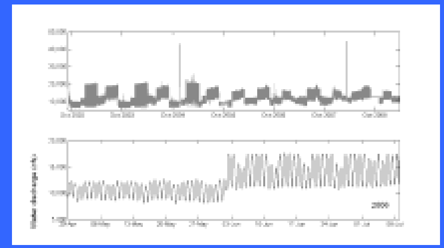
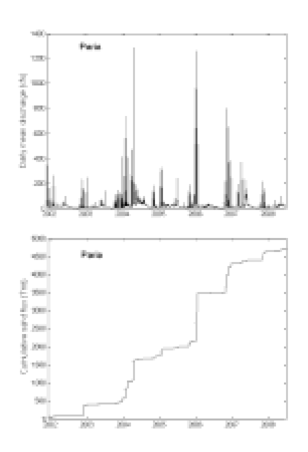
Model 1: sand routing

Model concept

Mainstem flows
for the reach



Paria sand inputs,
by grain size



Export predicted
based on flow,
grain sizes in reach

sand volume by grain size in reach

Model applies mass conservation to keep track of the volume of each grain size in reach

$$(1-\lambda_p)B\frac{\partial H_s}{\partial t} = -\frac{\partial Q_s}{\partial x}$$

$$(1-\lambda_p)B\frac{\partial}{\partial t}(H_s F_{bi}) = -\frac{\partial Q_{si}}{\partial x}$$

$$C_i = F_{bi} A Q^L D_i^K$$

$$Q_{si} = C_i Q$$

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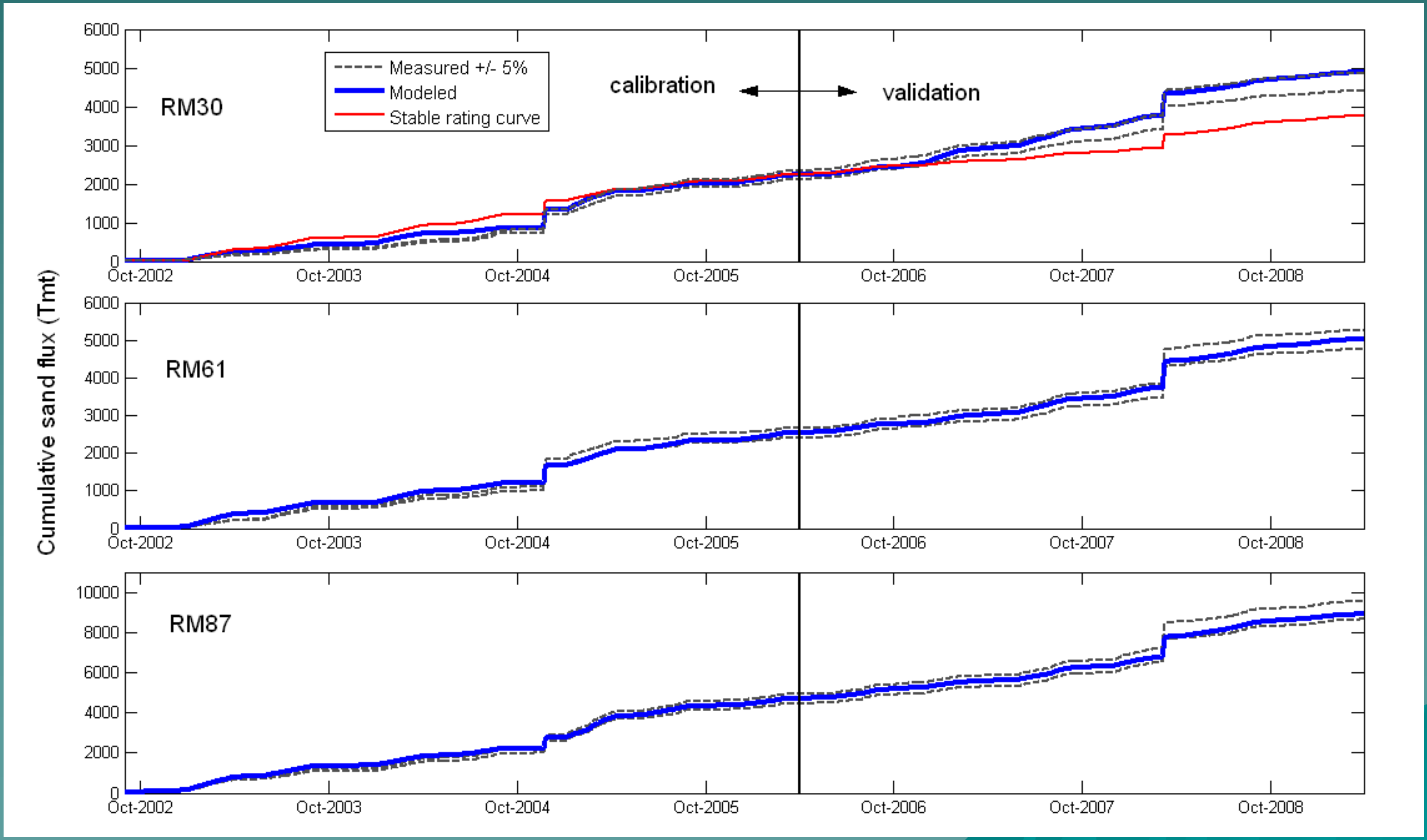
These equations can be solved very efficiently

Model 1: sand routing

Model has been calibrated and validated using sand transport data from Topping's monitoring program



Model 1: sand routing

If you want more details on the model:

Wright, S. A., D. J. Topping, D. M. Rubin, and T. S. Melis (2010), An approach for modeling sediment budgets in supply-limited rivers, Water Resour. Res., 46, W10538, doi:10.1029/2009WR008600.

WATER RESOURCES RESEARCH, VOL. 46, W10538, doi:10.1029/2009WR008600, 2010

An approach for modeling sediment budgets in supply-limited rivers

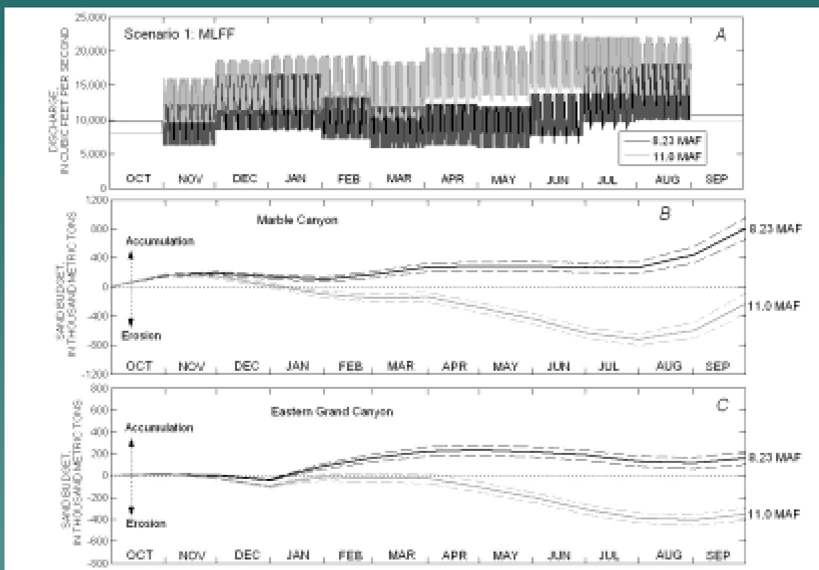
Scott A. Wright,[1] David J. Topping,[2] David M. Rubin,[3] and Theodore S. Melis[2]

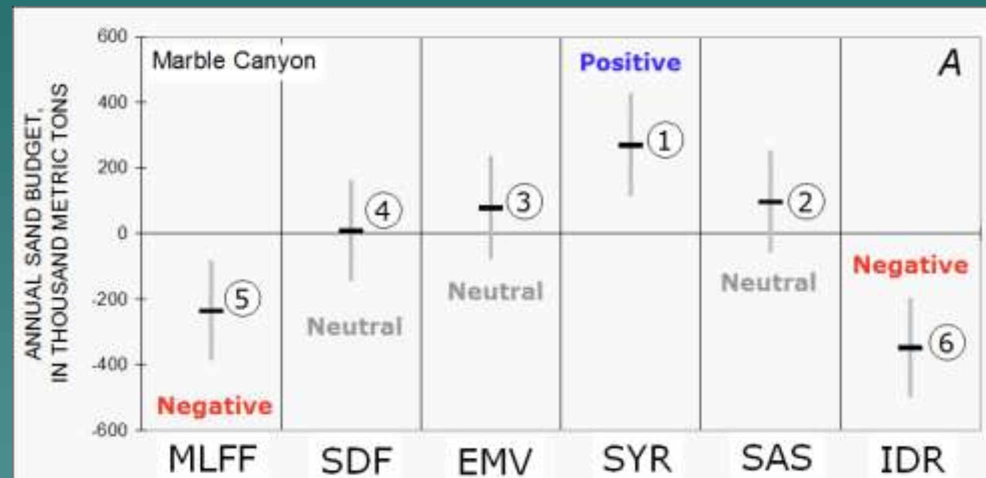
Received 1 September 2009; revised 11 June 2010; accepted 18 June 2010; published 28 October 2010.

[1] Reliable predictions of sediment transport and river morphology in response to variations in natural and human-induced drivers are necessary for river engineering and management. Because engineering and management applications may span a wide range of space and time scales, a broad spectrum of modeling approaches has been developed, ranging from suspended-sediment "rating curves" to complex three-dimensional morphodynamic models. Suspended sediment rating curves are an attractive approach for evaluating changes in multi-year sediment budgets resulting from changes in flow regimes because they are simple to implement, computationally efficient, and the empirical parameters can be estimated from quantities that are commonly measured in the field (i.e., suspended sediment concentration and water discharge). However, the standard rating curve approach assumes a unique suspended sediment concentration for a given water discharge. This assumption is not valid in rivers where sediment supply varies enough to

Model 1: sand routing

Model has been applied to make predictions for various hydrologic and dam operations scenarios (WY 2011)





Evaluation of Water Year 2011 Glen Canyon Dam Flow Release Scenarios on Downstream Sand Storage along the Colorado River in Arizona

By Scott A. Wright and Paul E. Grams

Abstract

This report describes numerical modeling simulations of sand transport and sand budgets for reaches of the Colorado River below Glen Canyon Dam. Two hypothetical Water Year 2011 annual release volumes were each evaluated with six hypothetical operational scenarios. The six operational scenarios include the current operation, scenarios with modifications to the monthly distribution of releases, and scenarios with modifications to daily flow fluctuations. Uncertainties in model predictions were evaluated by conducting simulations with error estimates for tributary inputs and mainstem transport rates. The modeling results illustrate the dependence of sand transport rates and sand budgets on the annual release volumes as well as the within year operating rules. The six operational scenarios were ranked with respect to the predicted annual sand budgets for Marble Canyon and eastern Grand Canyon reaches. While the actual WY 2011 annual release volume and levels of tributary inputs are unknown, the hypothetical conditions simulated and reported herein provide reasonable comparisons between the operational scenarios, in a relative sense, that may be used by decision makers within the Glen Canyon Dam Adaptive Management Program.

Wright, S.A., and Grams, P.E., 2010, Evaluation of Water Year 2011 Glen Canyon Dam flow release scenarios on downstream sand storage along the Colorado River in Arizona: U.S. Geological Survey Open-File Report 2010-1133, 19 p.

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Model 1: sand routing

Model has been applied to make predictions of the frequency of floods for the recent Environmental Assessment

Table 4. HFEs to be conducted for the moderate hydrology, moderate sediment trace.

Month of Potential HFE	HFE No.	Peak Magnitude (ft^3/sec)	Peak Duration (hrs)
4/1/2010			
11/1/2010	6	45,000	24
4/1/2011			
11/1/2011			
4/1/2012	2	45,000	72
11/1/2012	2	45,000	72
4/1/2013	1	45,000	96
11/1/2013	8	45,000	1
4/1/2014			
11/1/2014			
4/1/2015	1	45,000	96
11/1/2015			
4/1/2016	8	45,000	1
11/1/2016			
4/1/2017			
11/1/2017	1	45,000	96
4/1/2018			
11/1/2018	1	45,000	96
4/21/2019			
11/1/2019	6	45,000	24

RECLAMATION

Managing Water in the West

Environmental Assessment

Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020

Grand Canyon sand models

Two main modeling goals:

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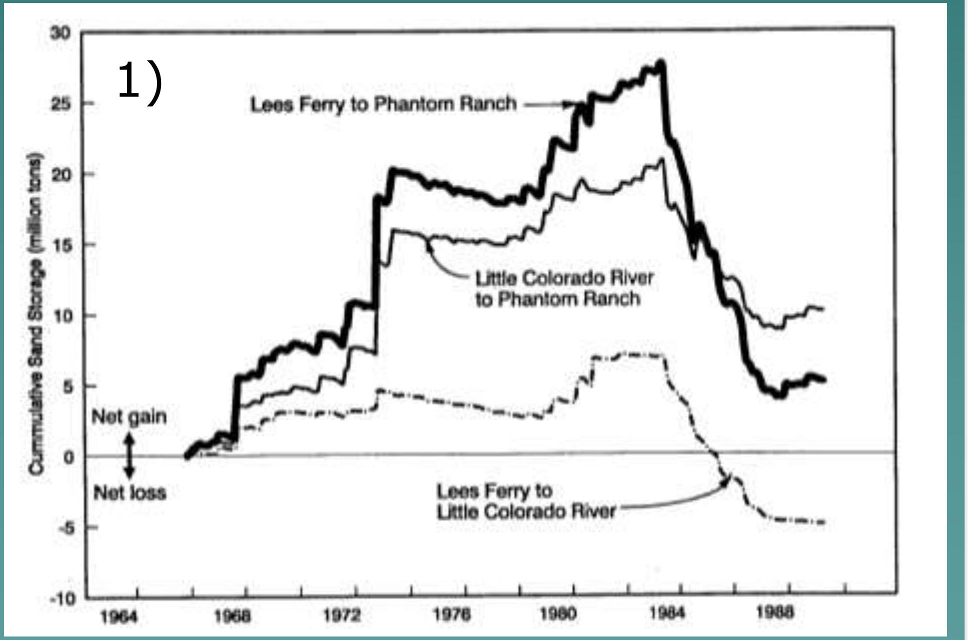

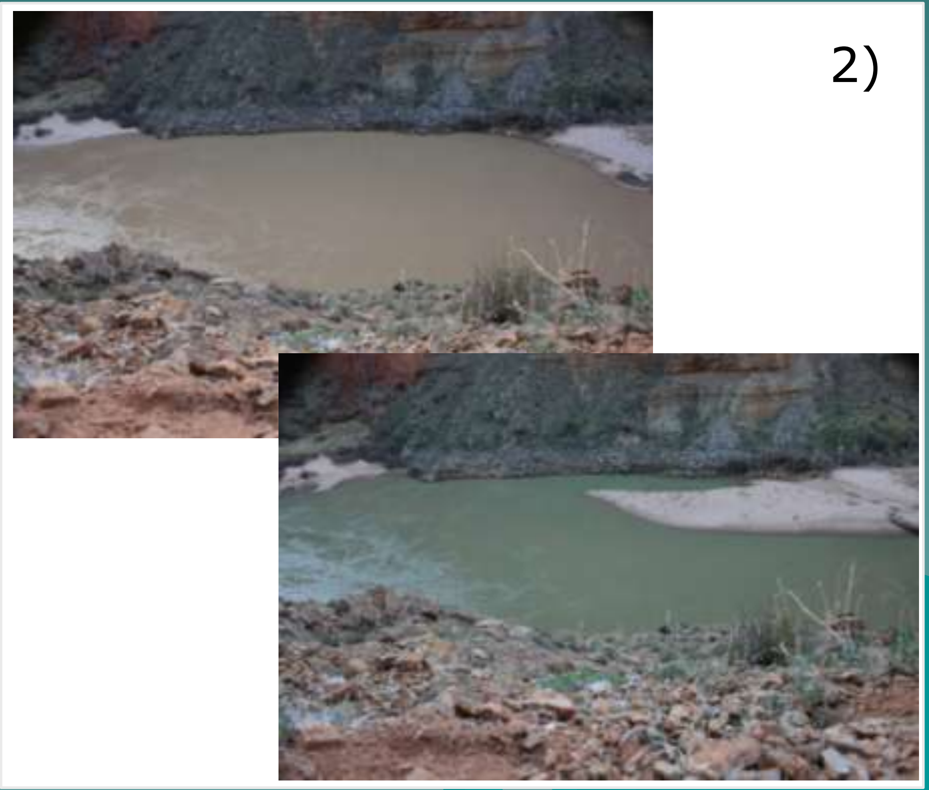

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Model 1) requires drastic simplifications

Model 2) requires modest simplifications

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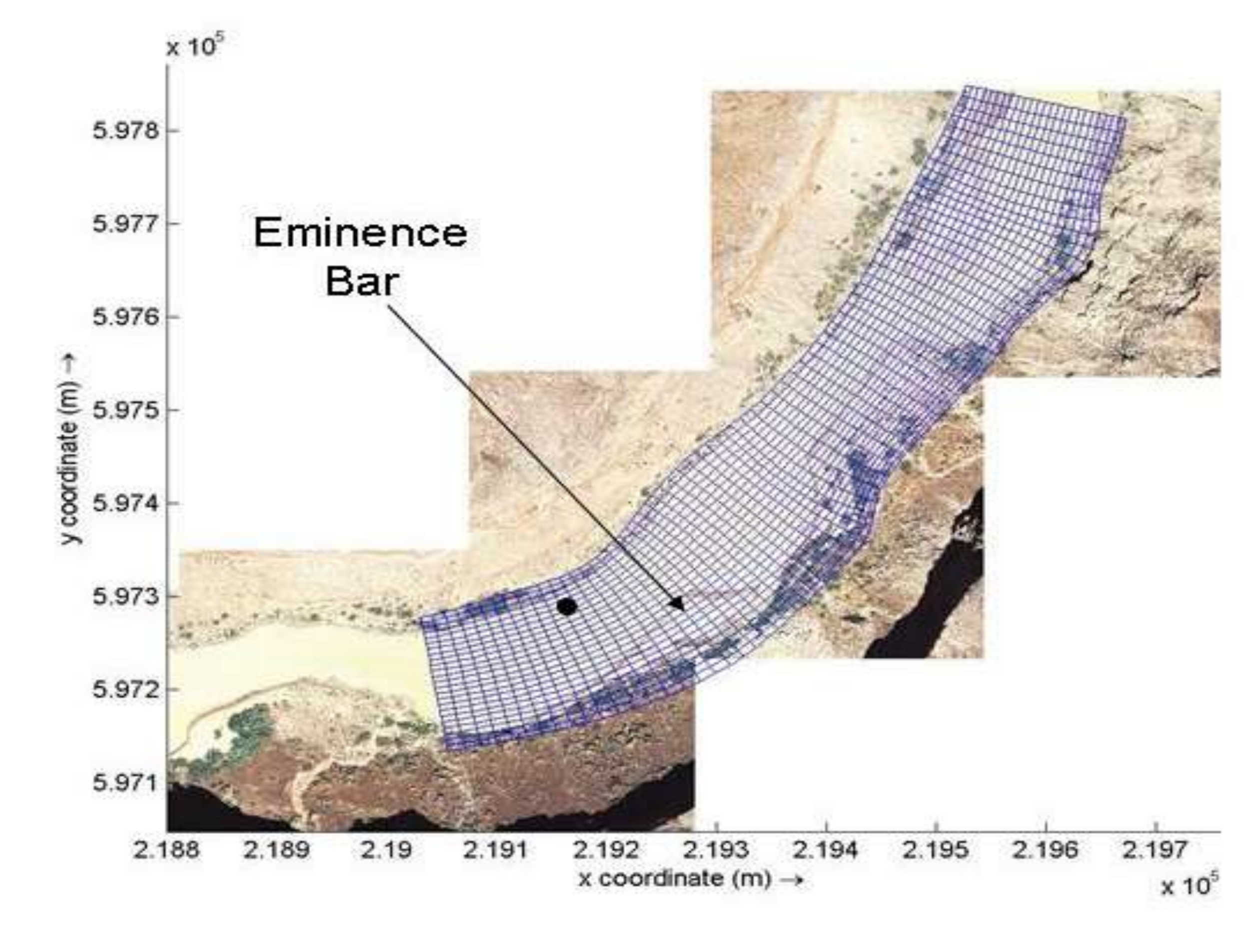
Model 2: sandbar evolution

Instead of 3 long reaches, equations are solved for meter scale grid cells

The complexity of eddy flows means we must retain most of the physics in the basic equations – this imposes computational limits



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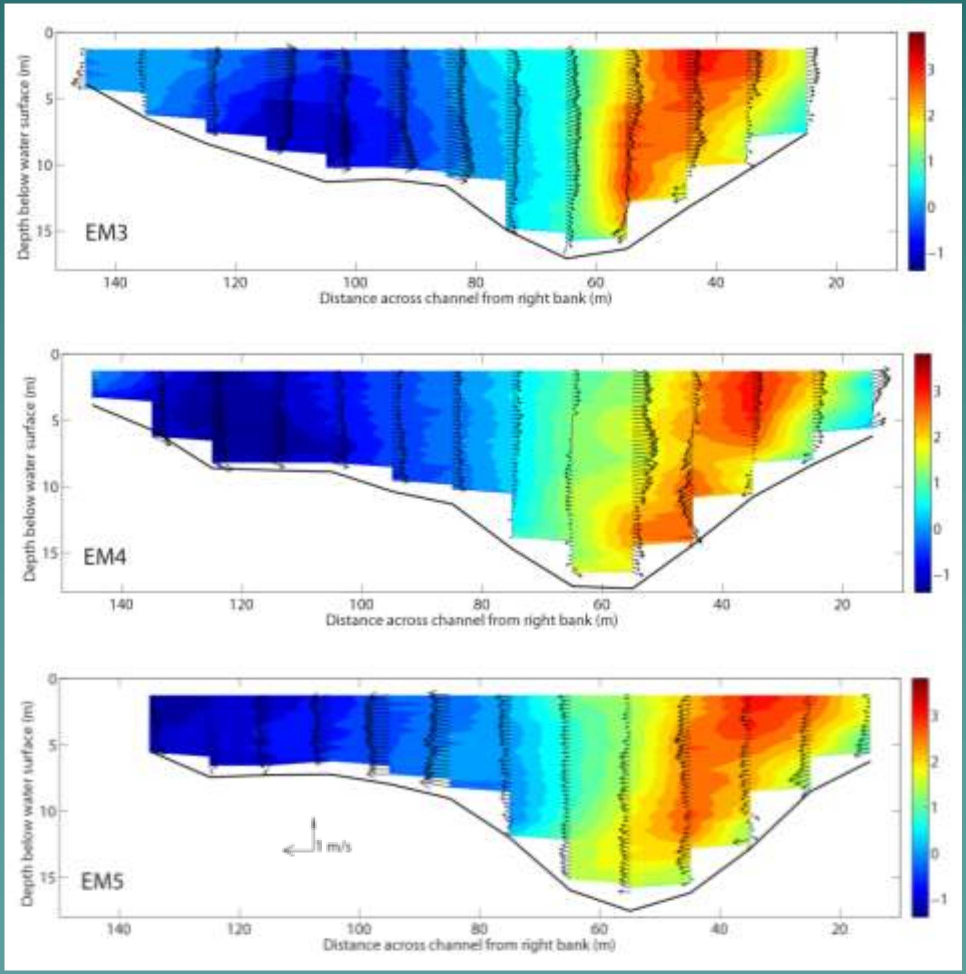
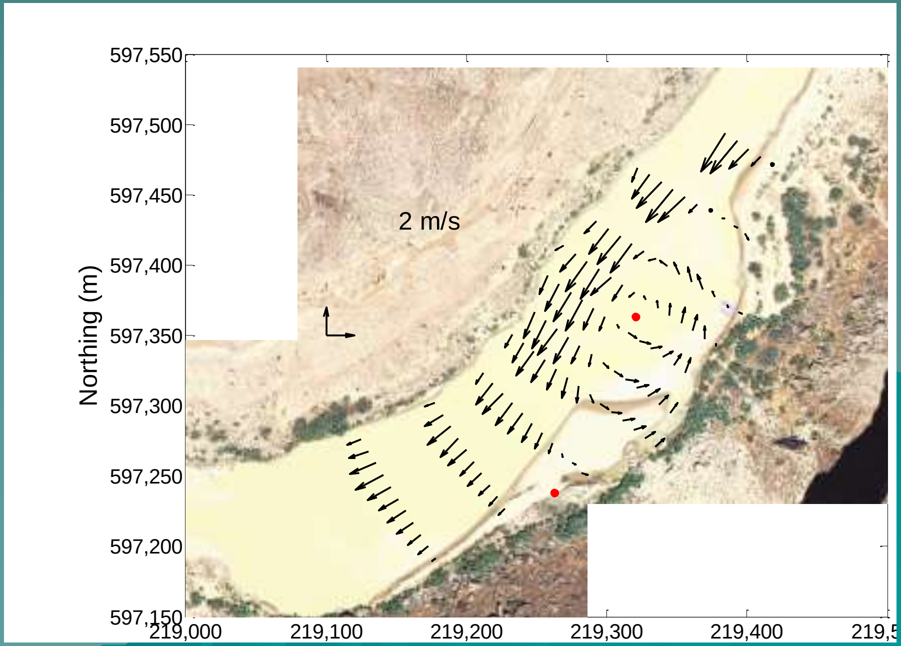
Model 2: sandbar evolution

Even the most physically-based models require calibration. However, the tuning knobs are smaller than for empirical models

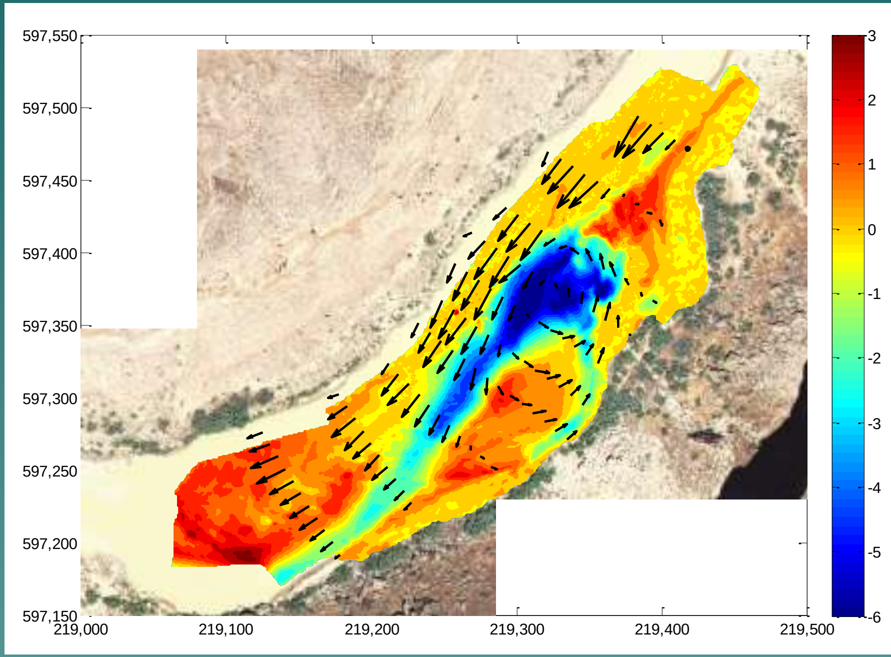


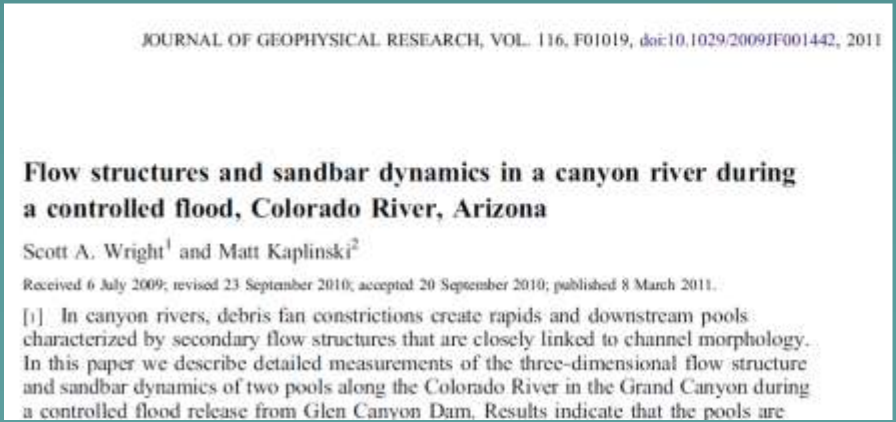
We mapped the detailed velocity structure in 2 eddies during the 2008 flood



Model 2: sandbar evolution

We also mapped erosion and deposition in the same 2 eddies





JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, F01019, doi:10.1029/2009JF001442, 2011

Flow structures and sandbar dynamics in a canyon river during a controlled flood, Colorado River, Arizona

Scott A. Wright[1] and Matt Kaplinski[2]

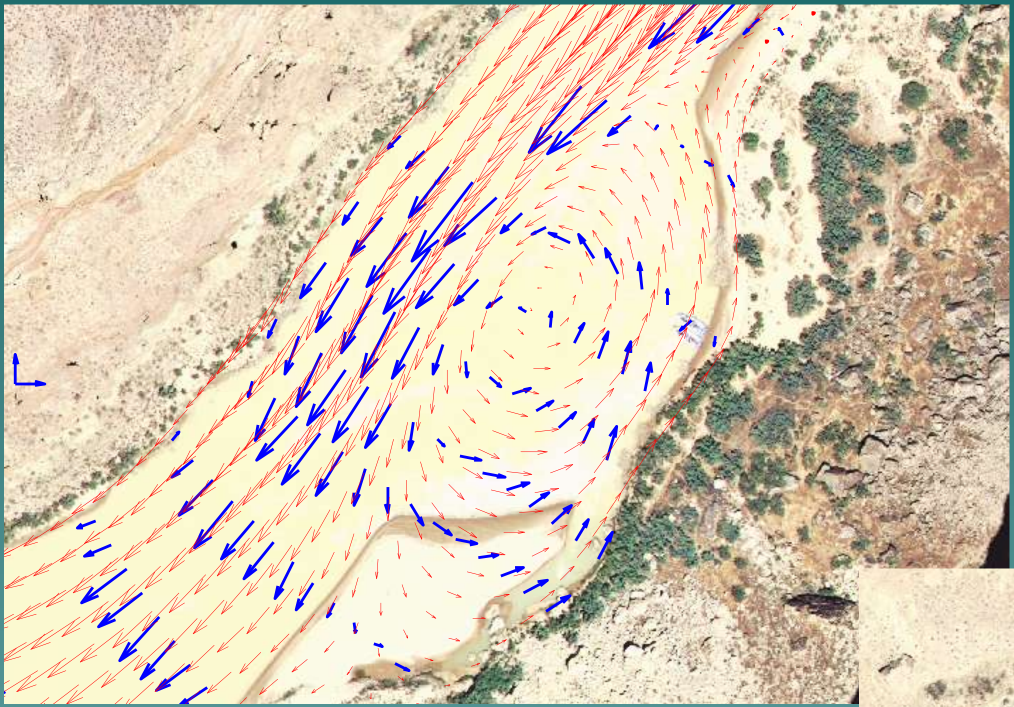
Received 6 July 2009; revised 23 September 2010; accepted 20 September 2010; published 8 March 2011.

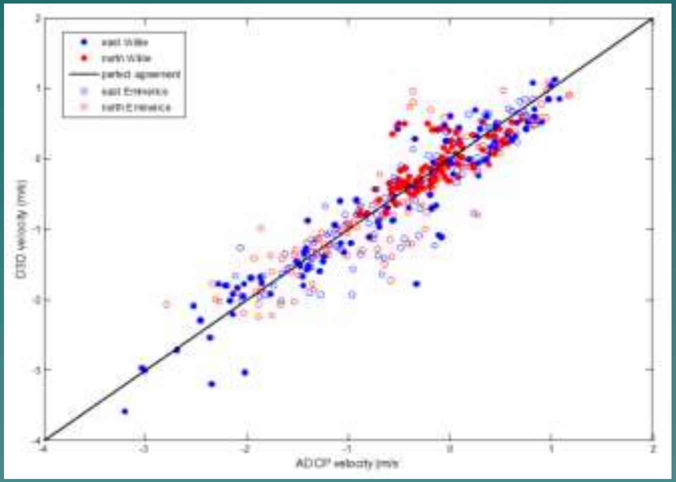
[1] In canyon rivers, debris fan constrictions create rapids and downstream pools characterized by secondary flow structures that are closely linked to channel morphology. In this paper we describe detailed measurements of the three-dimensional flow structure and sandbar dynamics of two pools along the Colorado River in the Grand Canyon during a controlled flood release from Glen Canyon Dam. Results indicate that the pools are

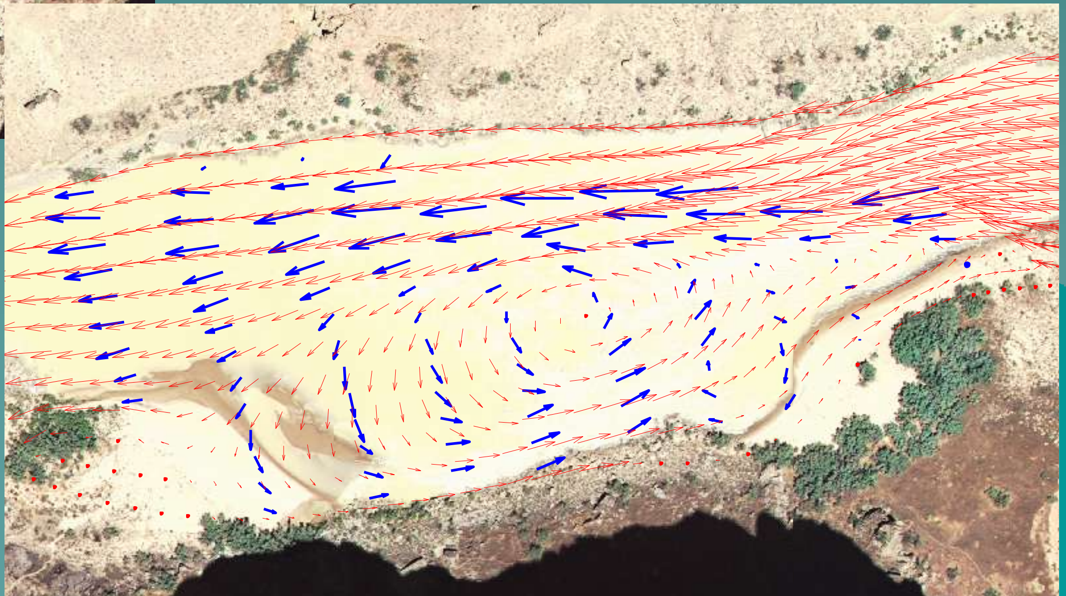
Wright, S. A., and M. Kaplinski (2011), Flow structures and sandbar dynamics in a canyon river during a controlled flood, Colorado River, Arizona, J. Geophys. Res., 116, F01019, doi:10.1029/2009JF001442.

Model 2: sandbar evolution

The Delft3D model can reproduce velocity fields pretty well







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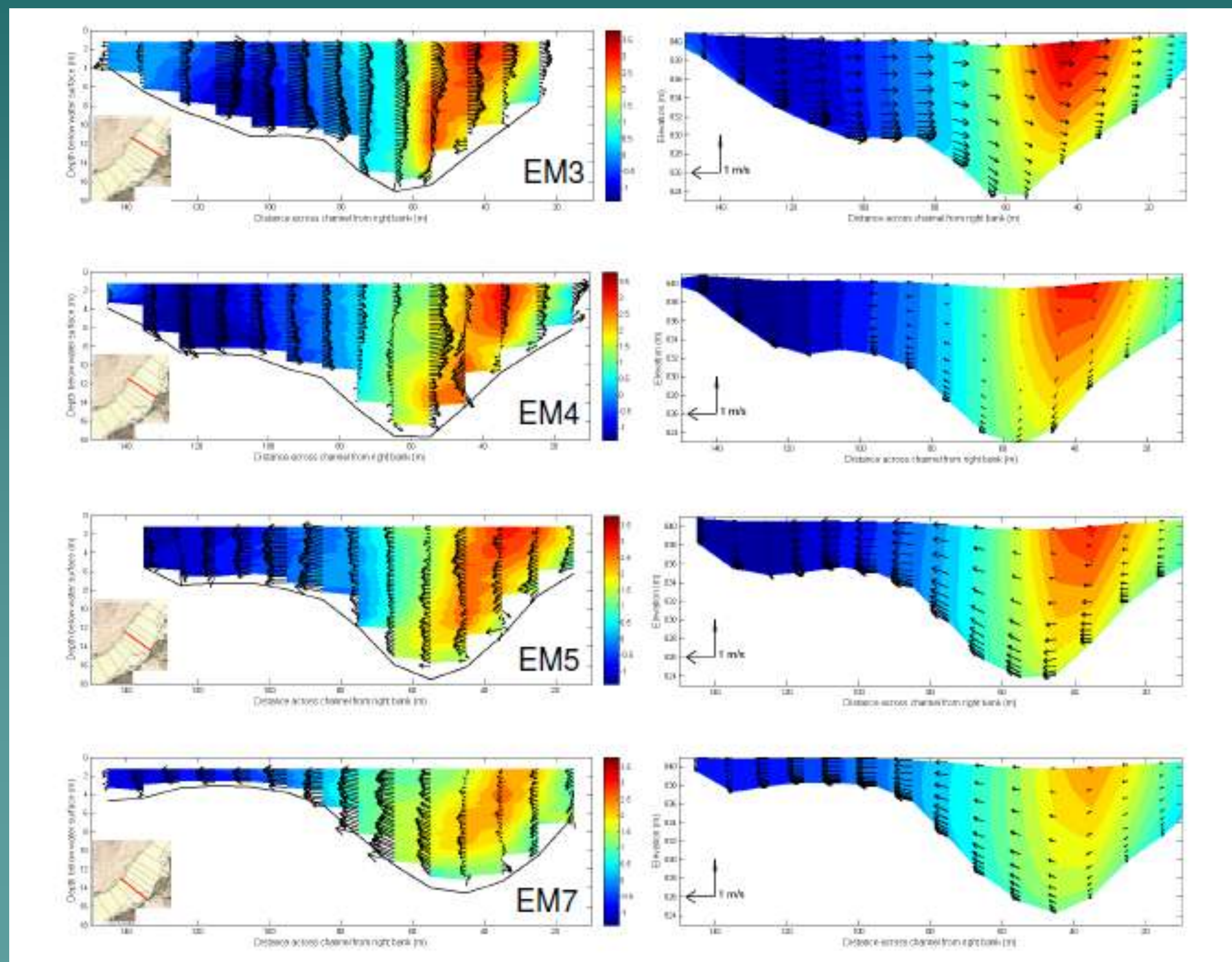
Model 2: sandbar model

Most three-dimensional velocity structures are also reproduced

Measurements Model



That’s the good news…

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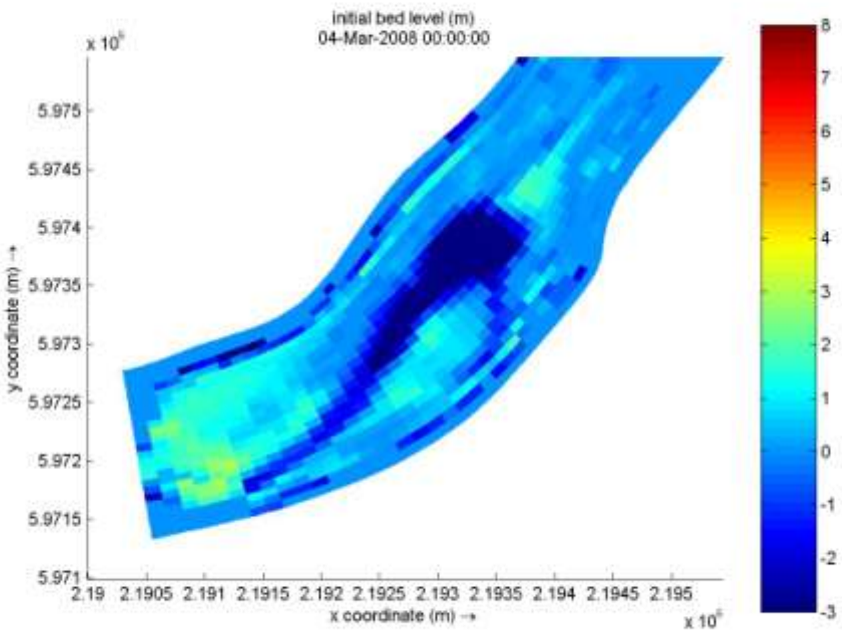
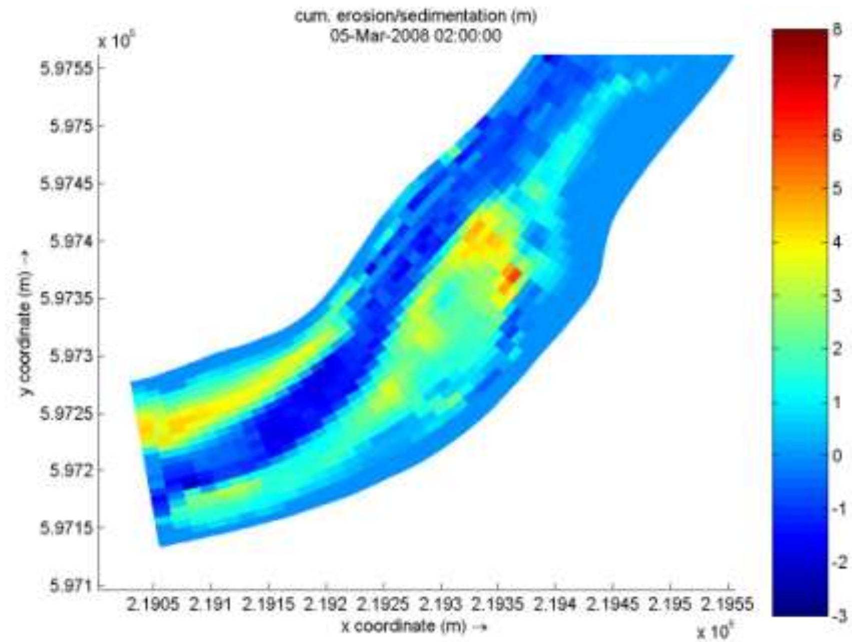
Model 2: sandbar evolution

Models have not been successful at reproducing erosion and deposition rates – the model predicts WAY too much deposition in the eddy and along the banks

Measurements

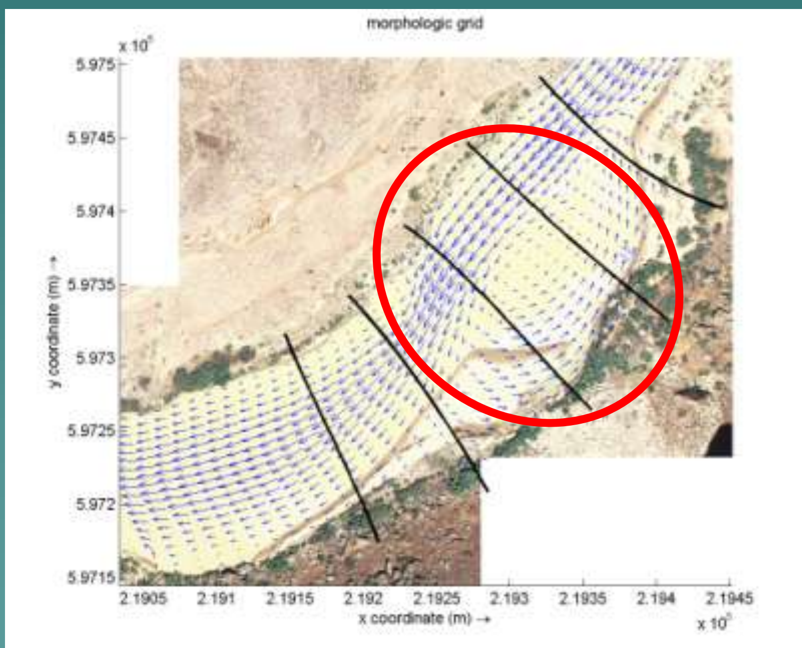


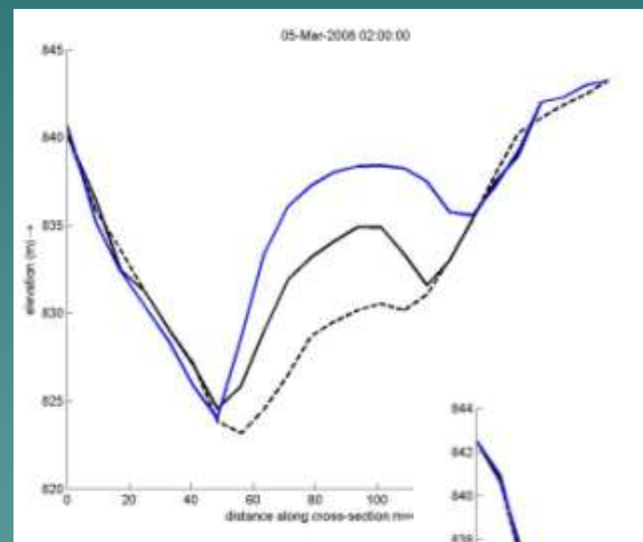
Model

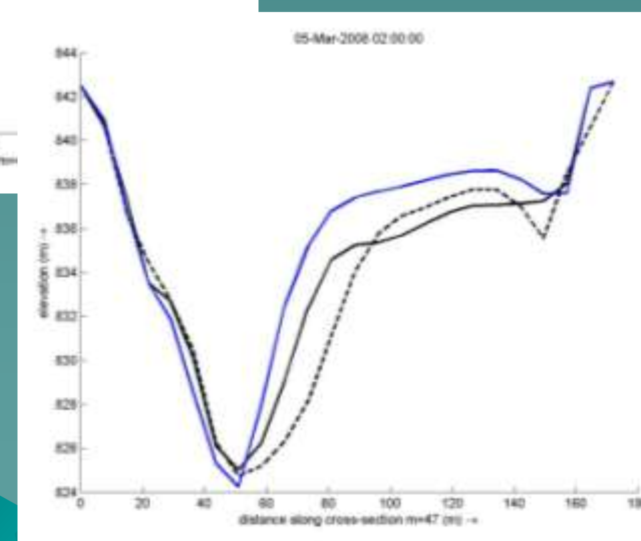


Model 2: sandbar evolution

We are working with the model developers to try to solve this problem. We are also testing other models to try to isolate the issue with Delft3D







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What I hoped you learned

- ✓ Models are everywhere. You cannot escape them
- ✓ Even when we can write down the fundamental physical laws, models almost always require simplifications because of the scales of interest. Simple models are always better than complex ones
- ✓ Because of the work of Rubin, Topping, and others, we've been able to construct a sand routing model that is simple but retains the essential physical processes. This model has been a useful tool for the program
- ✓ We can model the velocity fields in eddies fairly well. However, our formulation for sandbar evolution is not quite correct. We are working to figure out why this is the case

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Questions?