A morphodynamic model to evaluate long-term sandbar rebuilding using controlled floods

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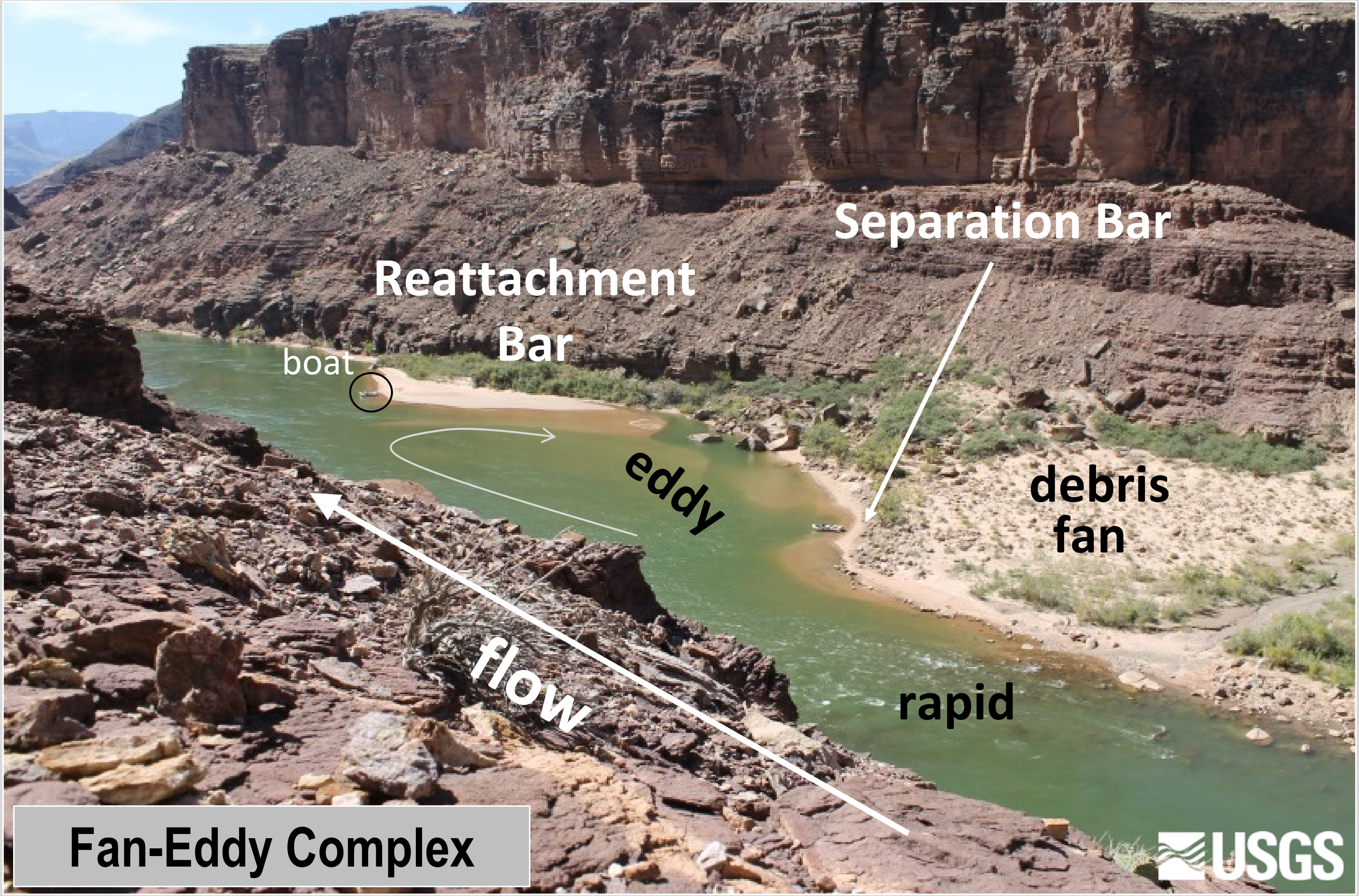
USGS science for a changing world

Reattachment bars are the focus of the modeling approach



Controlled Floods

Example sandbar (22-mile) showing sand deposition during the 2013 controlled flood, followed by bar-edge erosion and sand re-deposition at lower elevation during post-flood fluctuating flows.

Background

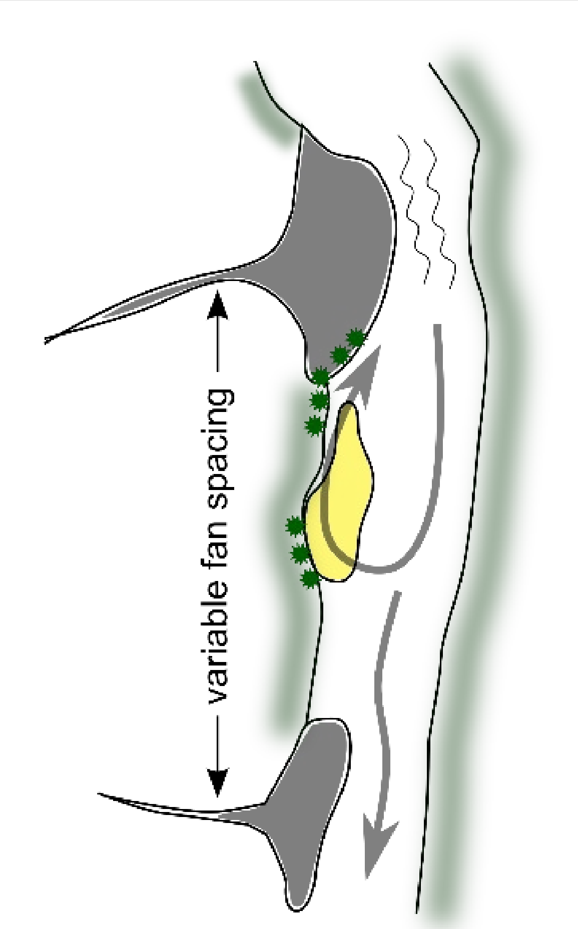
- Controlled floods have occurred during a period of increasing vegetation establishment following the 1980s floods (e.g. Sankey et al., 2015)
- The degree of vegetation encroachment reflects the hydraulics of longer reaches

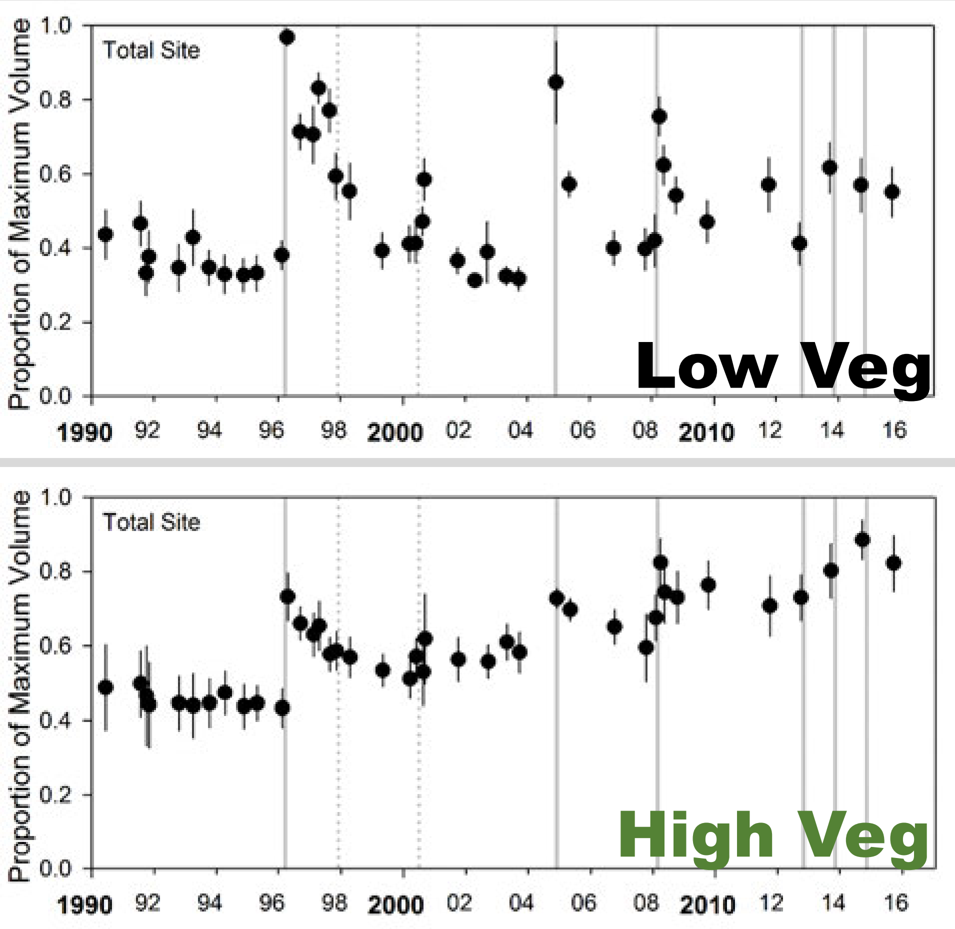
Narrower reaches
Larger range in stage

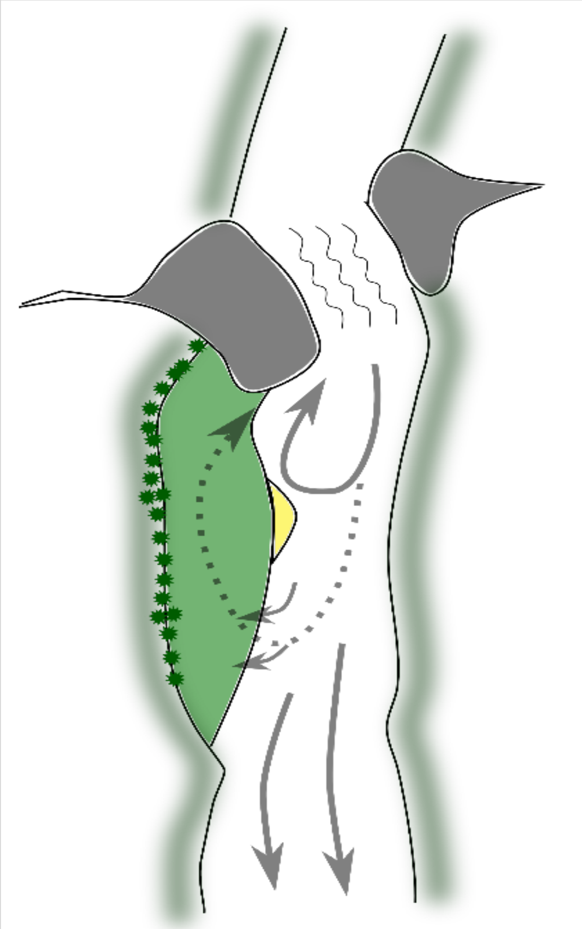
Sandbar Groupings

(Mueller et al., 2018)

Wider reaches
Smaller range in stage

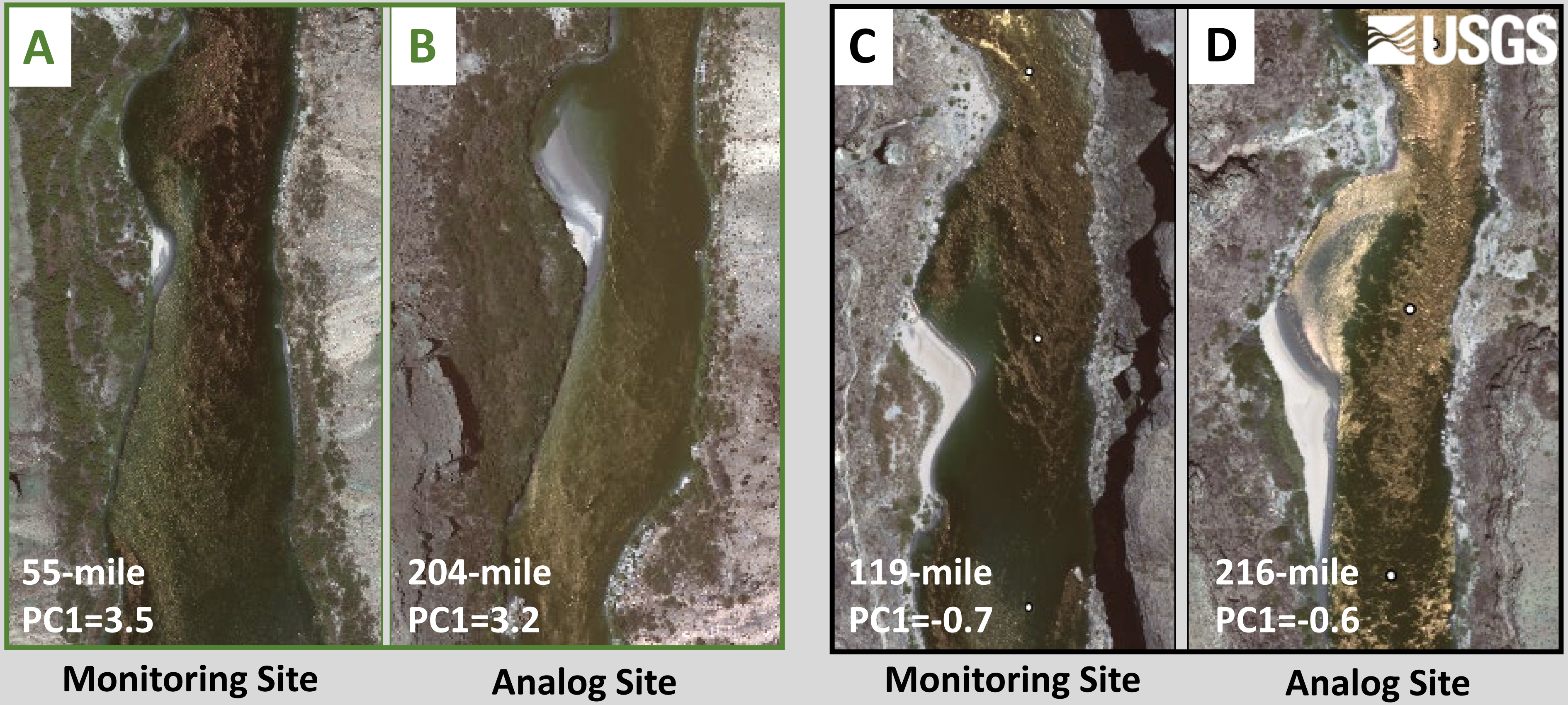




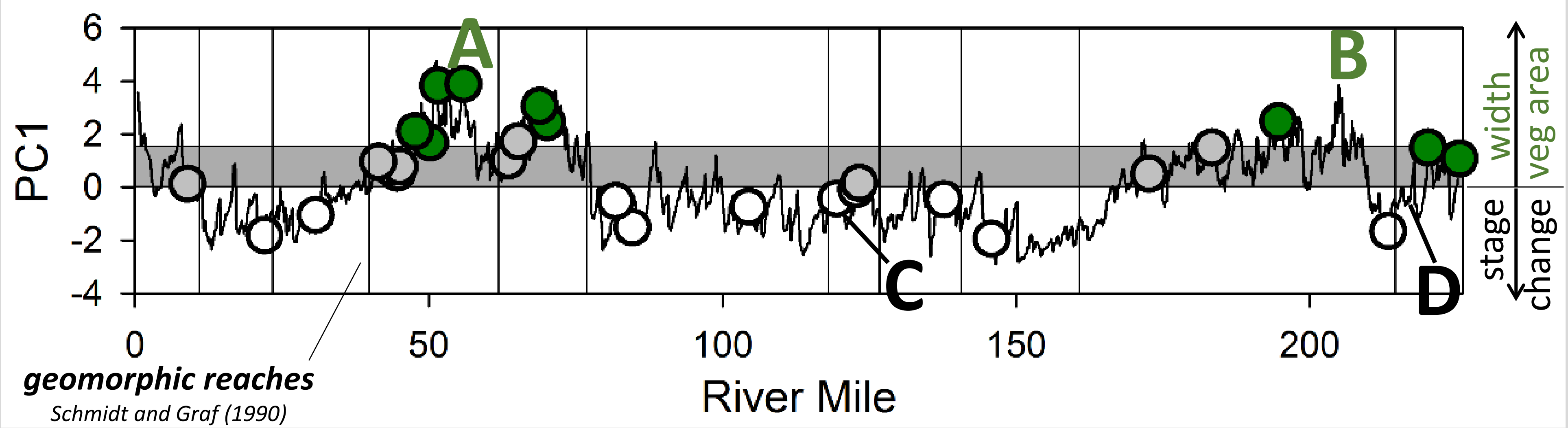


Minimal vegetation encroachment,
More dynamic

Significant vegetation encroachment,
More Stable

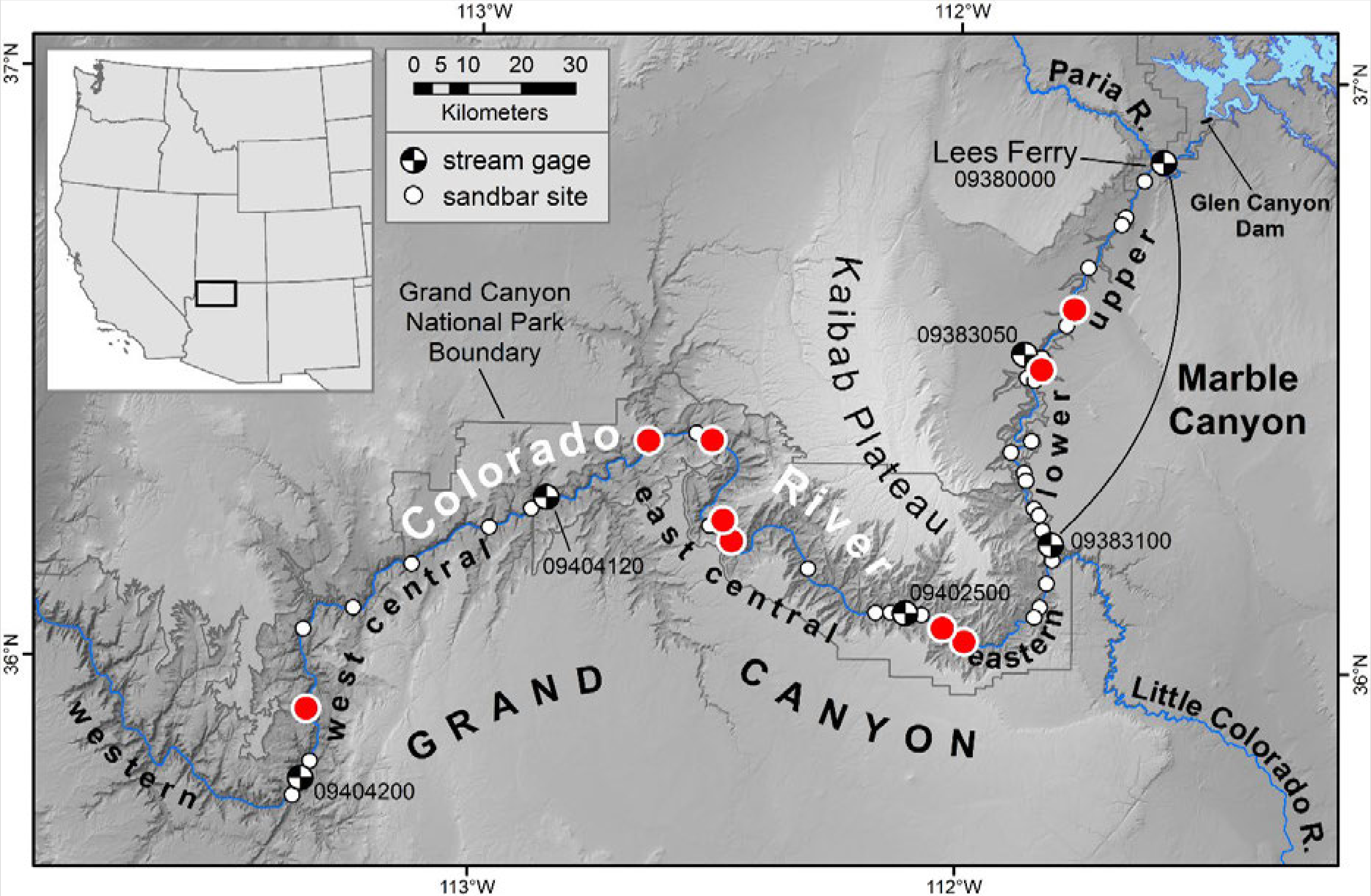


Long-term monitoring sites have analogs throughout the canyon

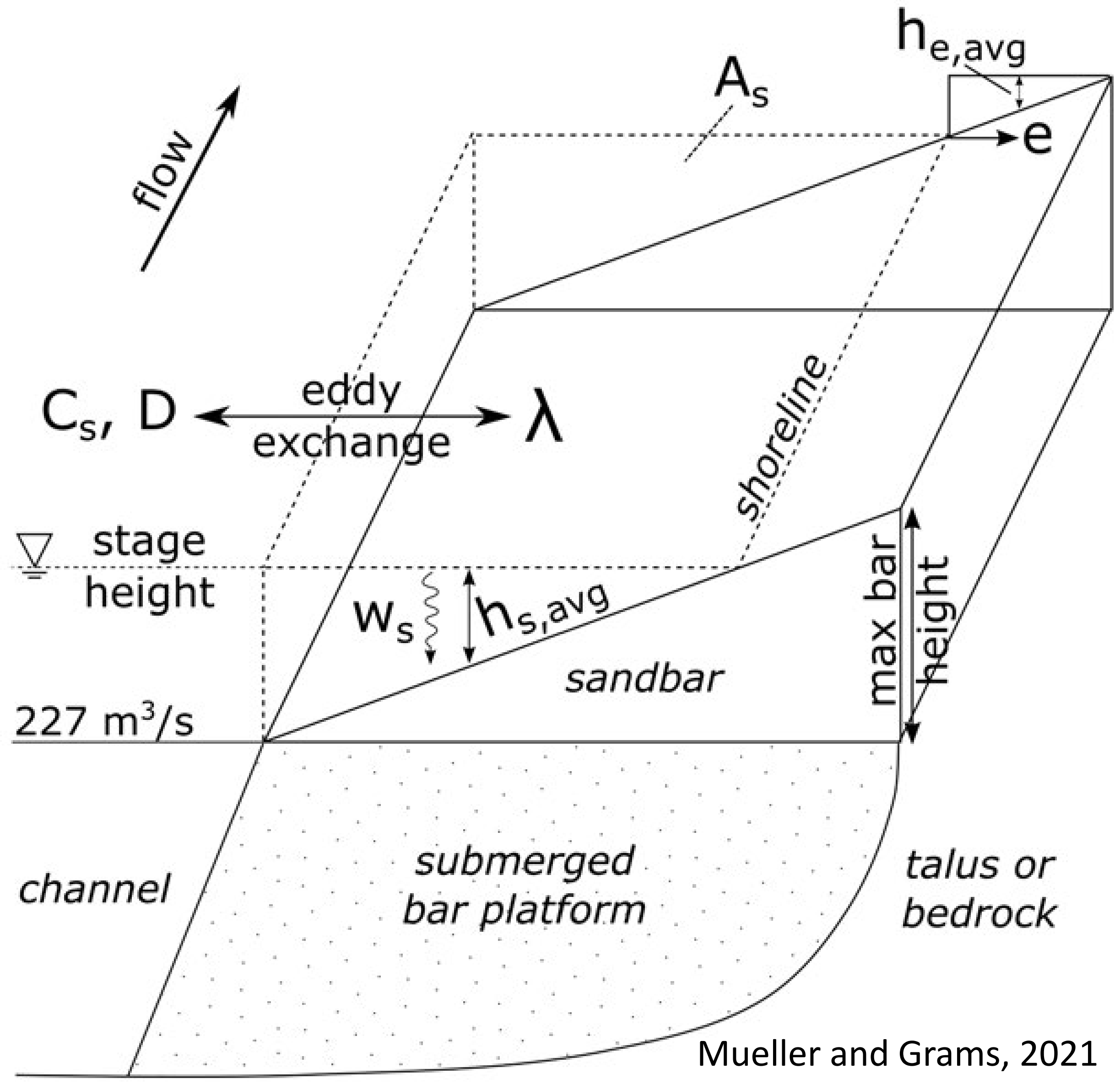


More of the canyon is narrow
("critical reaches")

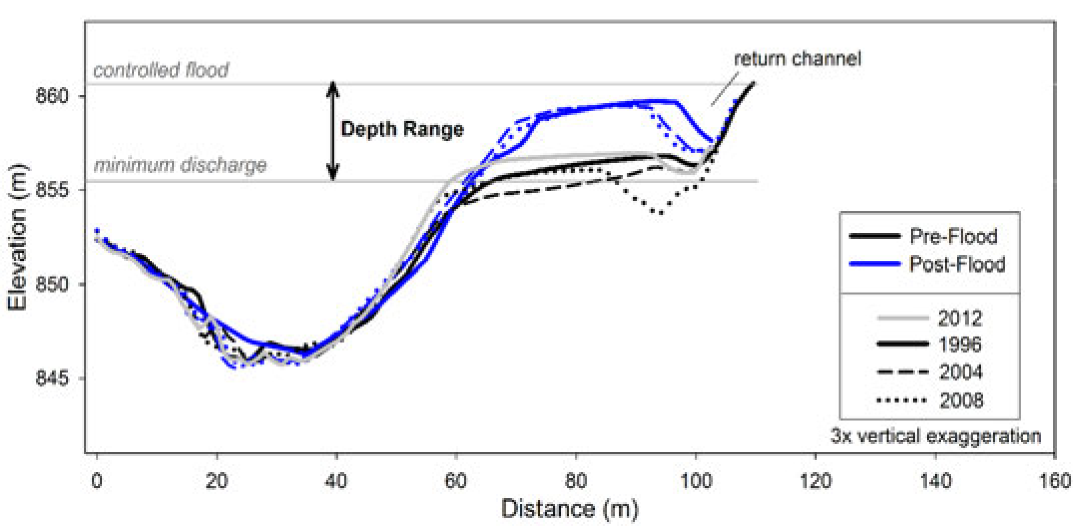
Location of sandbars used to parameterize the model



Morphdynamic Model



Mueller and Grams, 2021



Eddy Exchange and Sandbar Erosion

λ: Eddy exchange coefficient

- the fraction of the eddy volume exchanged with the main channel per second

e: erosion rate parameter

- two models: exponential decay with total volume and height/length of exposed bar

Parameters **optimized** to match the measured data using a Nelder-Mead approach

Validated by censoring data from the calibration set

Key model equations

(after Andrews and Vincent, 2007)

Suspended sand flux into eddy:

$q_{s,in} = \lambda V_e C_s$ Mass/time

Deposition rate in eddy:

$S_d = w_s C_e$ Mass/area

Mass balance in eddy:

$\lambda V_e C_s = \lambda V_e C_o + w_s C_e A_e$

Total flux in = flux out + deposition

$C_e = \frac{C_s + C_o}{2}$ Linear approximation

Rearrange:

$$S_d = w_s C_e = \frac{\lambda h_{s,avg} w_s C_s}{\lambda h_{s,avg} + \frac{w_s}{2}}$$

Compute volume change using gage data and erosion equation

$$\frac{dVol}{dt} = \frac{w_s \lambda h_{s,avg} C_s}{\frac{w_s}{2} + \lambda h_{s,avg}} \frac{A_s}{(1-\phi)} - E$$

For an "average" bar:

bars are normalized by their maximum measured values

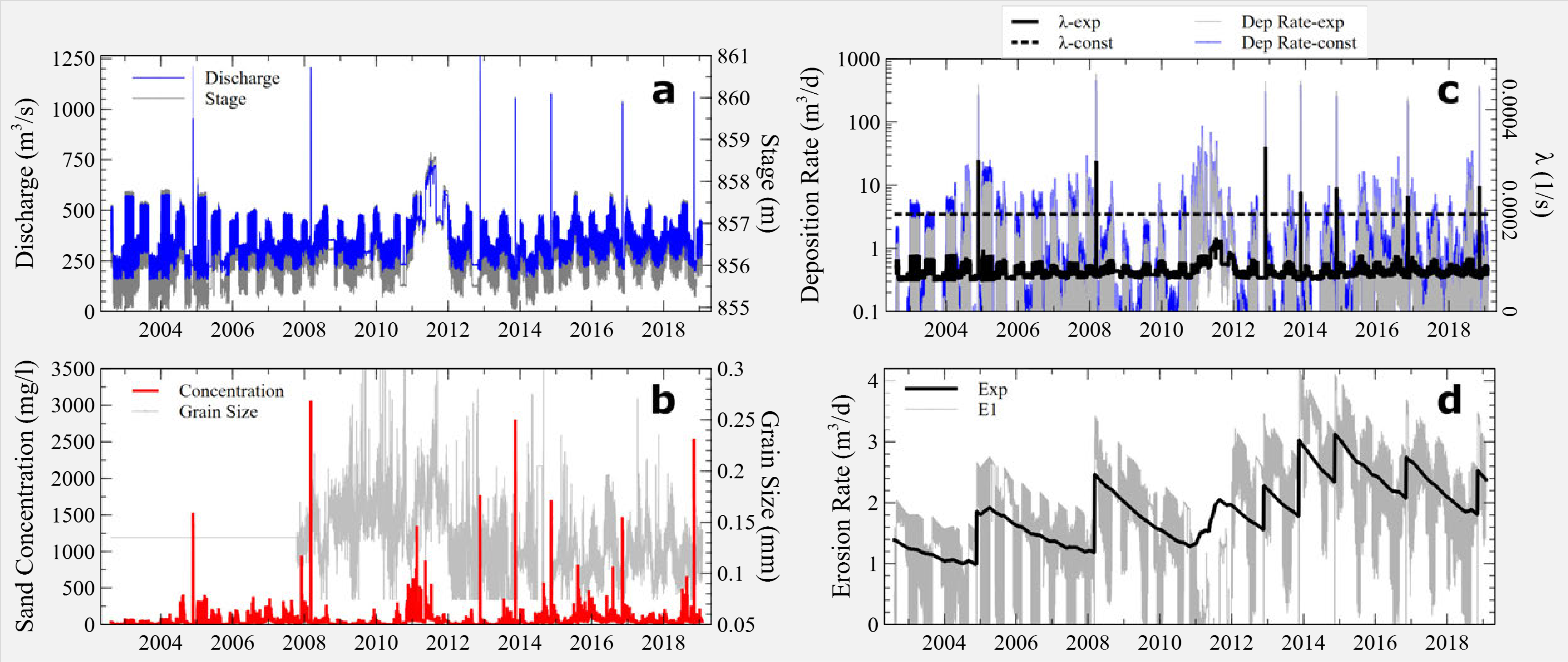
Sandbar Location	average area (m^2)	average volume (m^3)	maximum area (m^2)	maximum volume (m^3)
022r	2469	3285	3105	4098
030r	2828	3347	3871	6069
081l	1993	737	2101	1412
084r	959	475	1025	625
119r	3090	3495	3717	5412
122r	4433	3936	5507	5521
137l	3486	2300	3662	3063
145l	880	665	935	1126
213l	2023	2468	2248	4188
average	*2462*	*2301*	*2908*	*3502*

Input Data (from USGS gage)

Colorado River near 30 mile (09383050)

https://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09383050

Model Results



The model utilized data routinely measured at gages

Model Results: 2002-2019

A Morphodynamic Model to Evaluate Long-Term Sandbar Rebuilding Using Controlled Floods in the Grand Canyon

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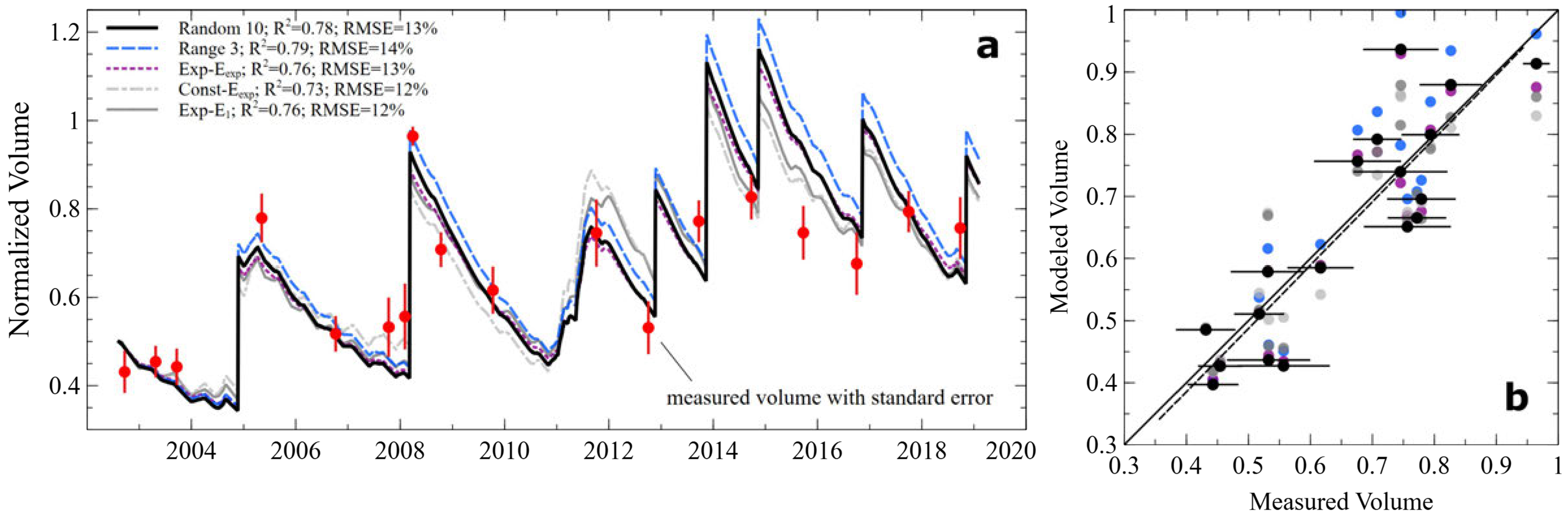
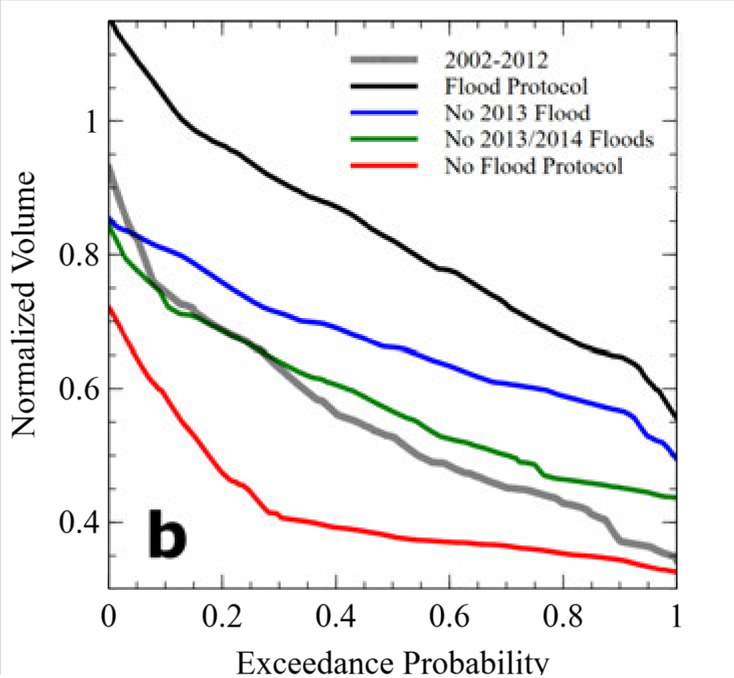
Geophysical Research Letters

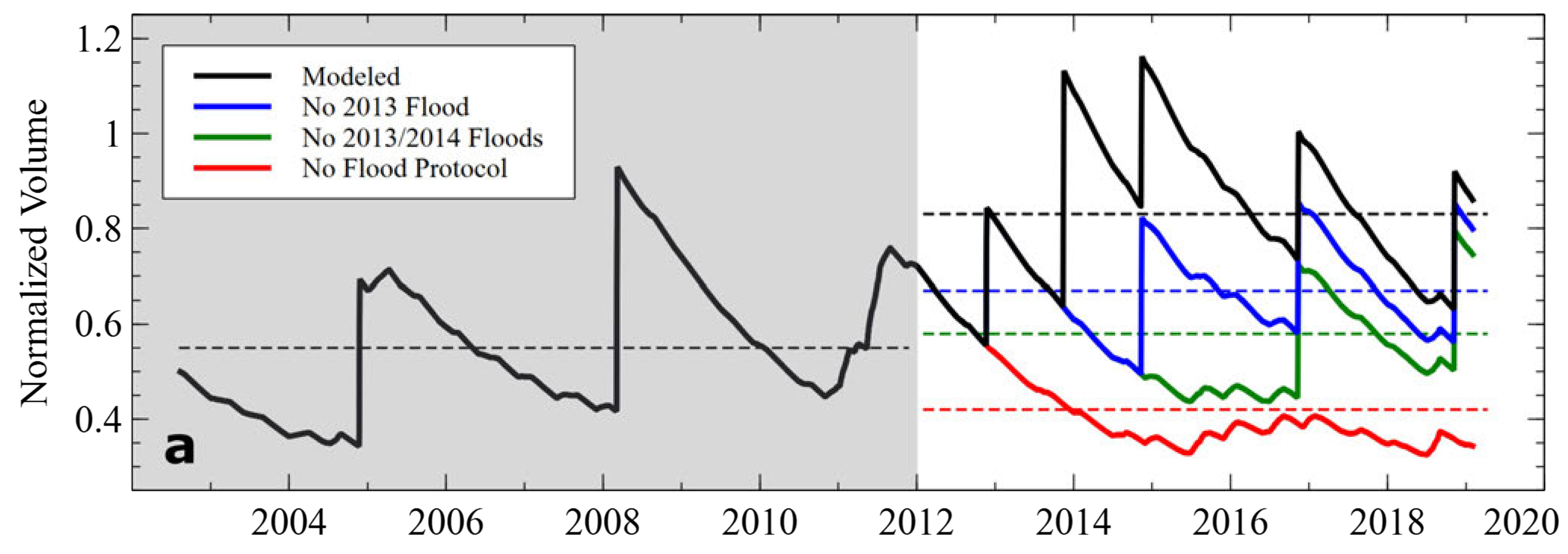


Mueller and Grams, 2021

Post-hoc Modeling of the Controlled Flood Protocol

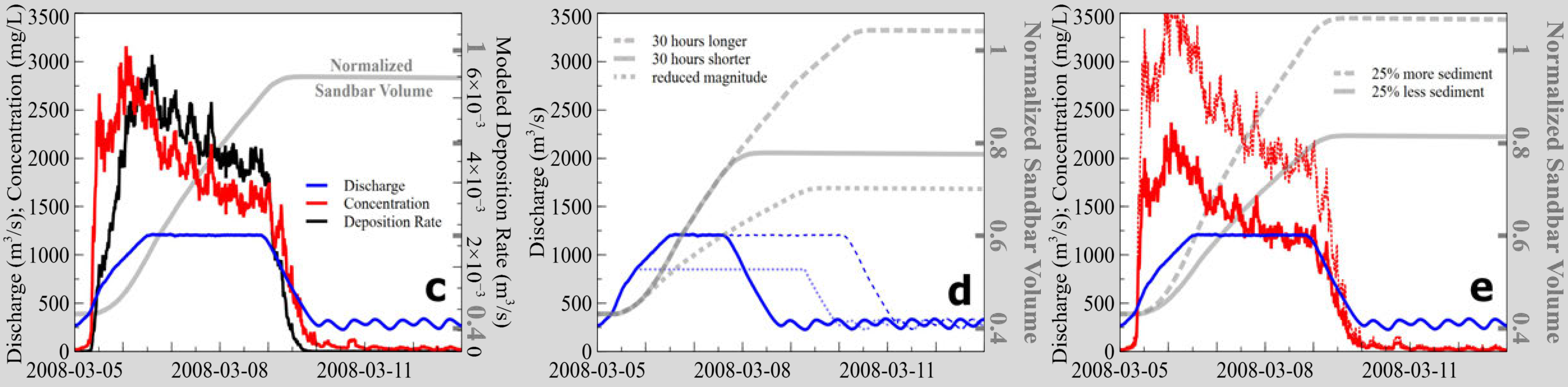


Mueller and Grams, 2021



Hypothetical Flood Scenarios

flood size and sediment supply both key factors



2008 Flood: Measured

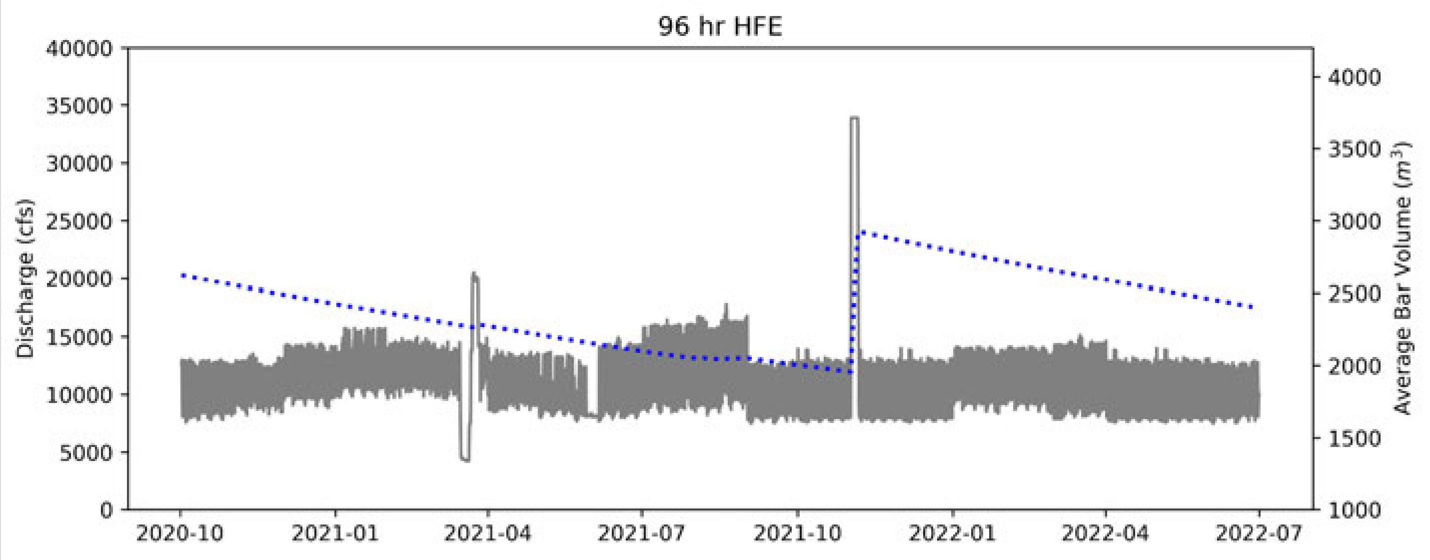
Magnitude/ Duration

Sediment Supply/ Concentration

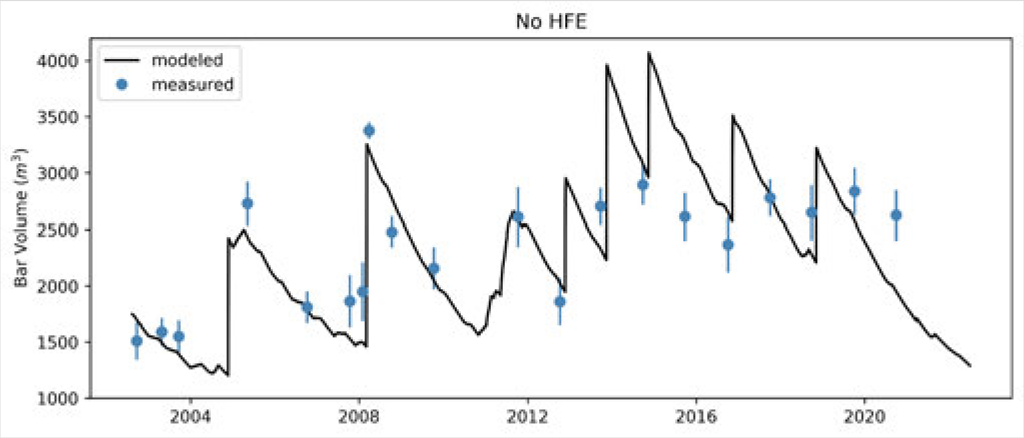
Mueller and Grams, 2021

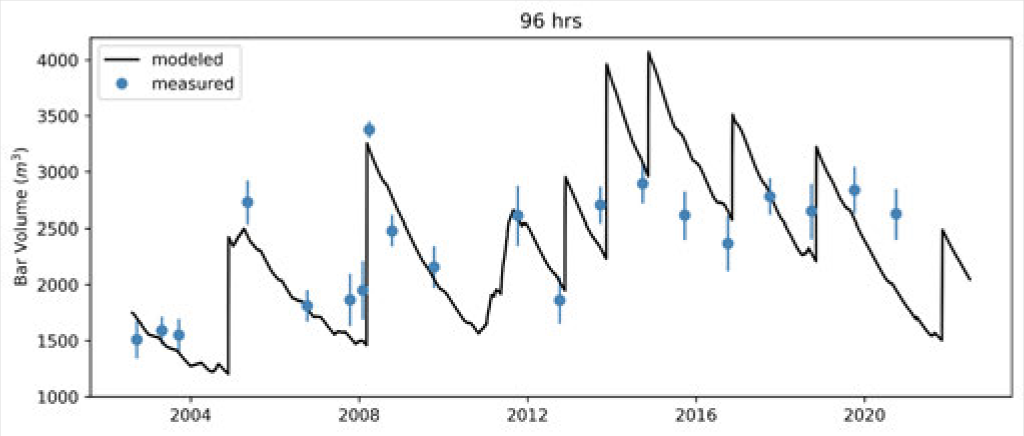
(15-40% bar size decrease under reduced scenarios)

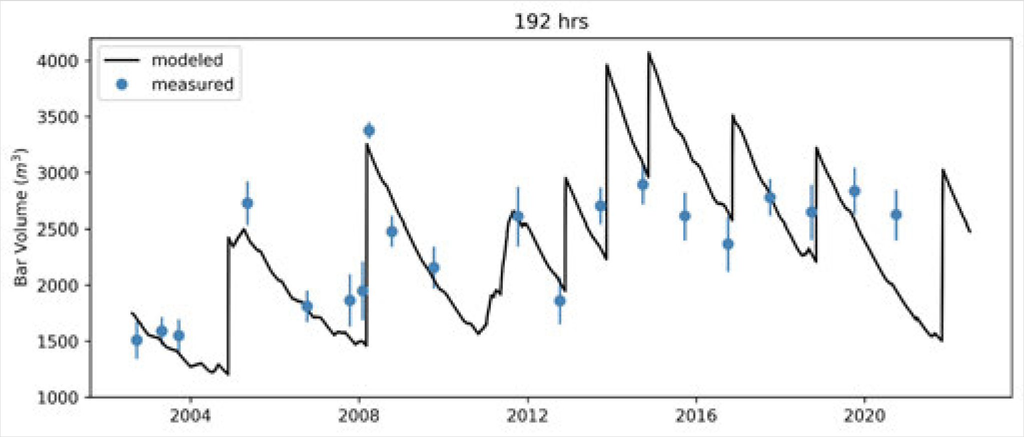
2021-2022 Scenarios



Using the Wright et al. (2010) model for sediment concentration



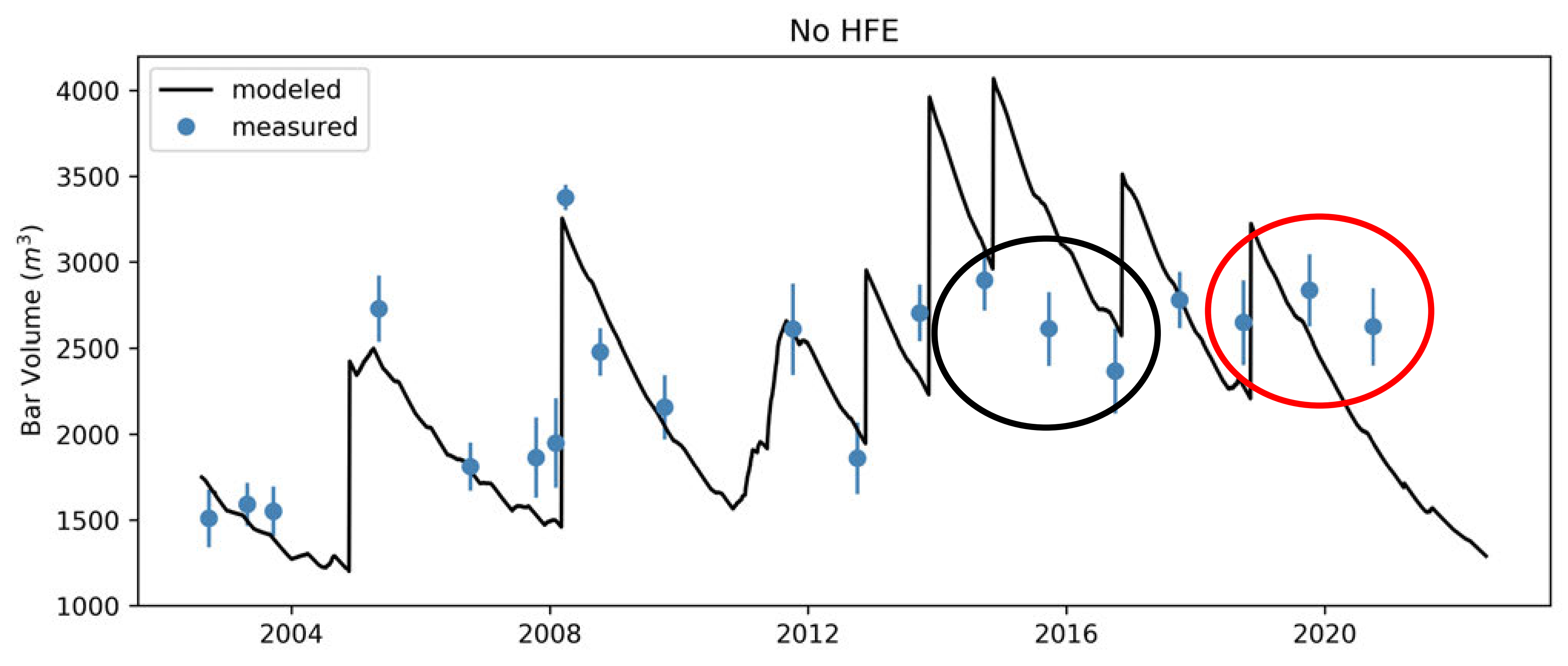




Preliminary data, do not cite

2021-2022 Scenarios

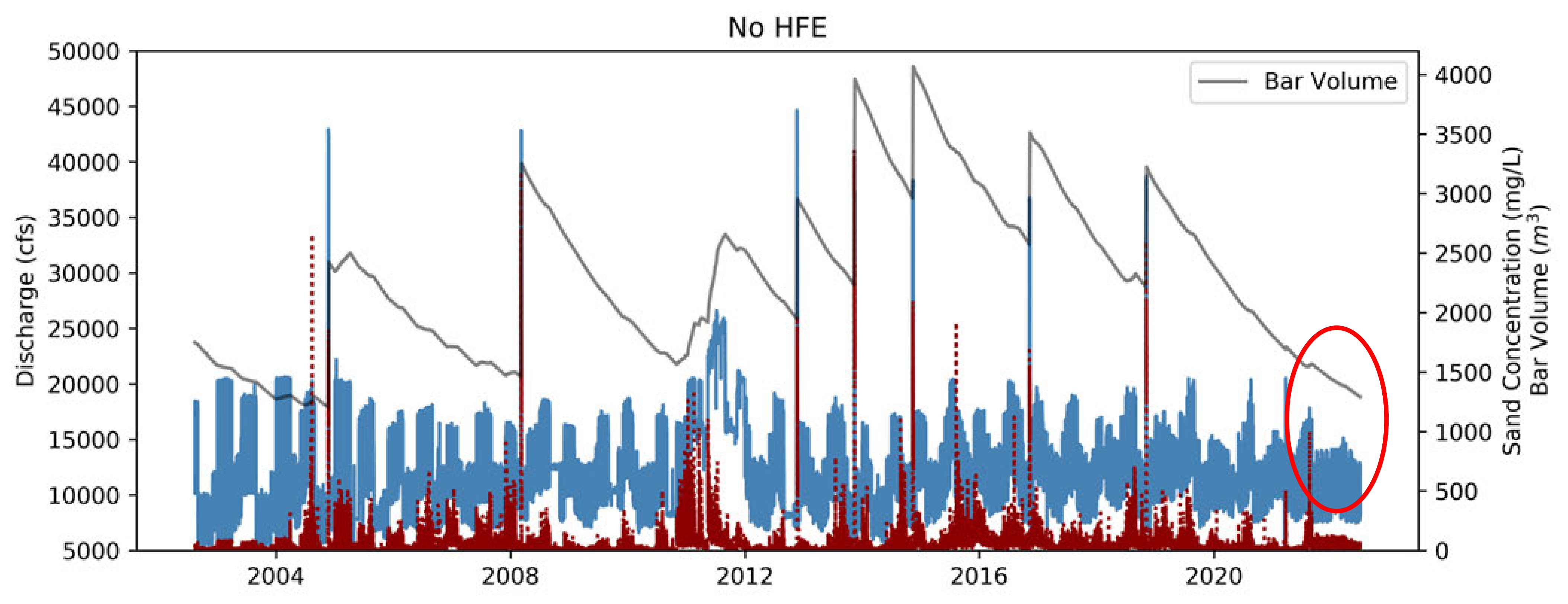
overpredicts **underpredicts**



Measured data is more variable in the early period, likely related to the timing of surveys

Preliminary data, do not cite

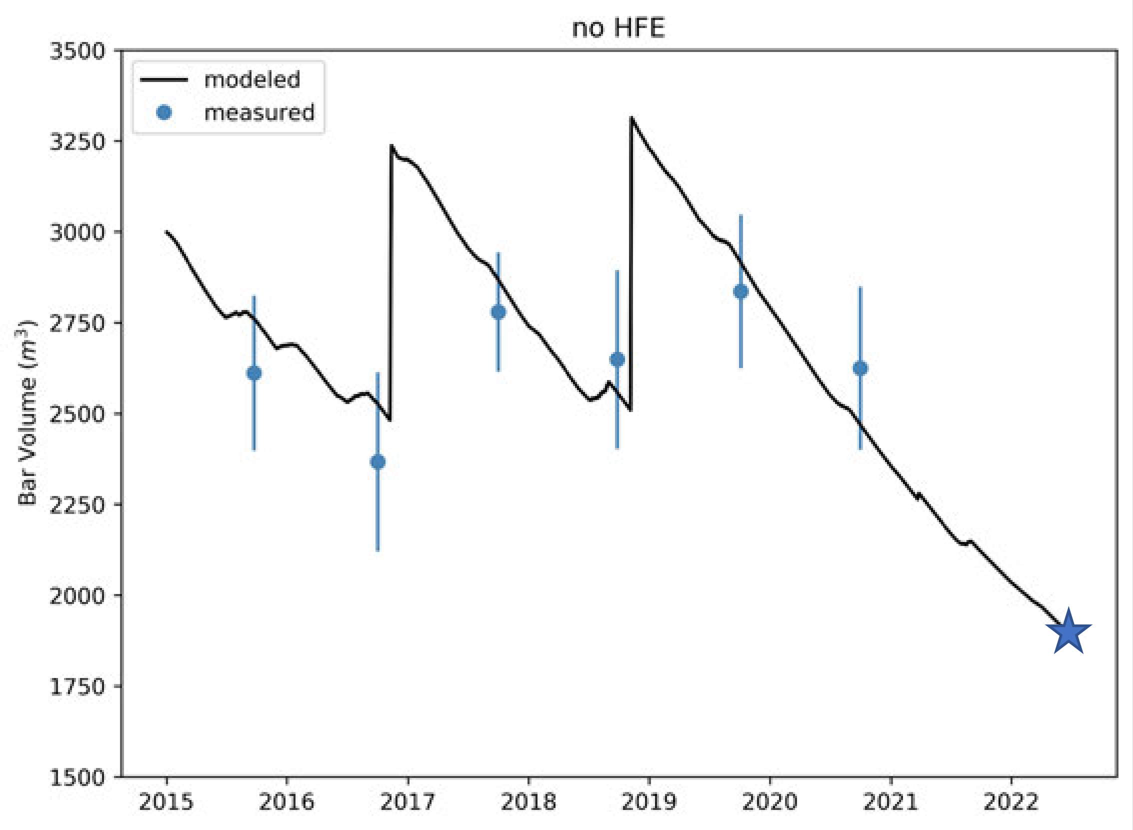
Anticipated low release volumes lead to continued erosion (in the model)

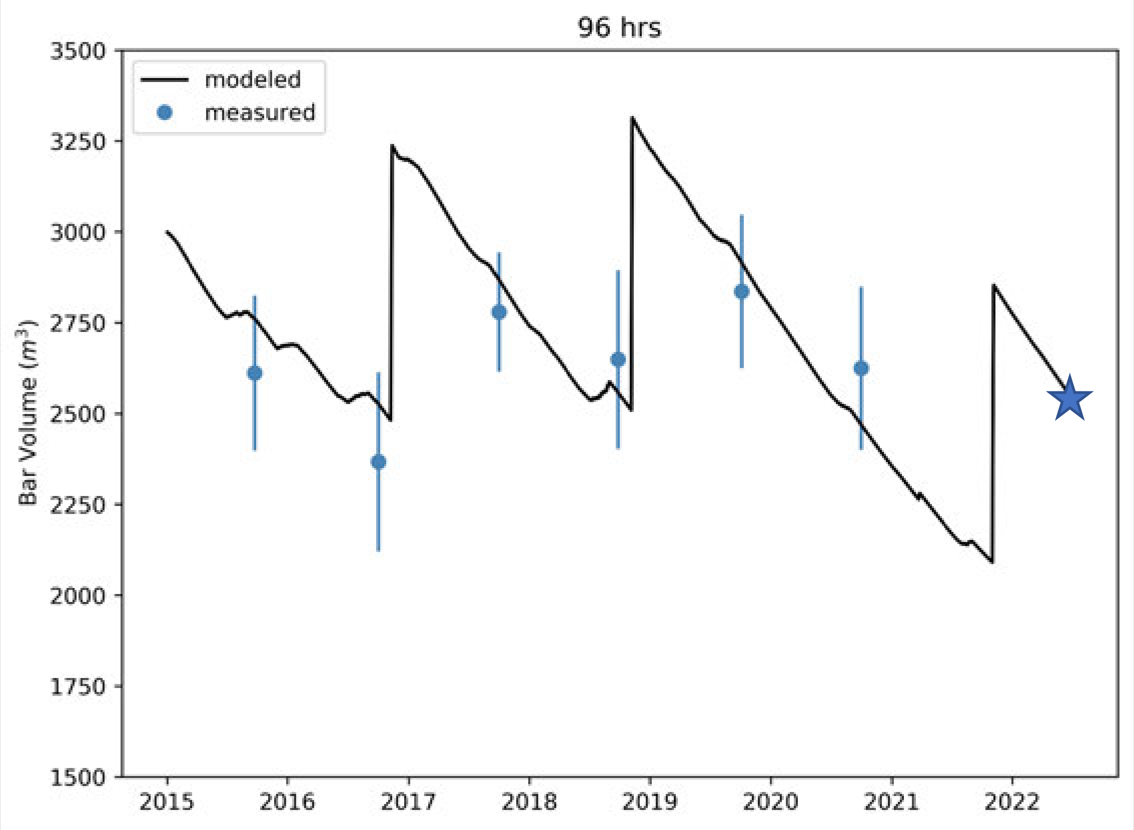


May need to re-parameterize if flows or bar conditions (i.e. vegetation) are considerably different than calibration period

Preliminary data, do not cite

Re-calibrated model (2015-2020) improves the fit to the more recent data





~33% increase

Both **erosion** and **eddy exchange** parameters were **slightly lower** than in the original model

Preliminary data, do not cite

Sandbar Timelapse (courtesy of Ryan Lima)

Conclusions

- The model is simple, but is physically-based and captures major changes in bar size
- Model input utilizes the high-resolution sediment concentration data at gages
- Provides a useful tool for rapid scenario modeling because it is based on extensive measured data (flow and sediment conditions; sandbar surveys)
- Simple erosion models likely miss important processes, some of which (vegetation, mass failure) can be difficult to quantify

Future Work

- Couple sandbar model with hydropower generation model
- Explore better approaches to erosion modeling
- Incorporate effects of vegetation on stabilizing portions of bars

Acknowledgements

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