Exploring Climate Controls on Hyporheic Zone Dynamics and Feedbacks Between Sediment Distribution, Riverbed Bioclogging, Infiltration, and Microbial CO_2 Production

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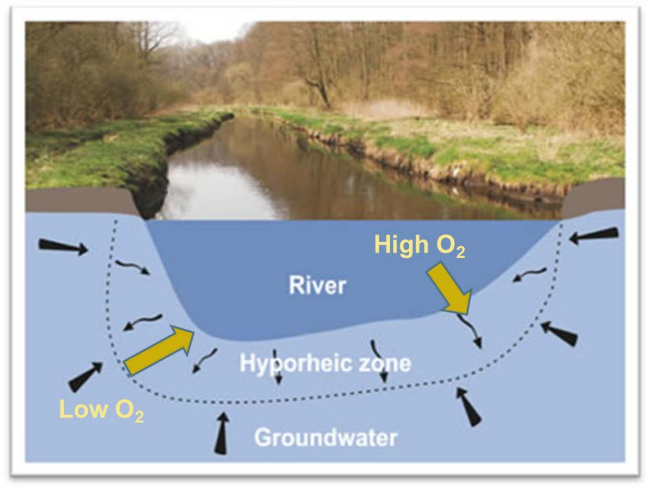
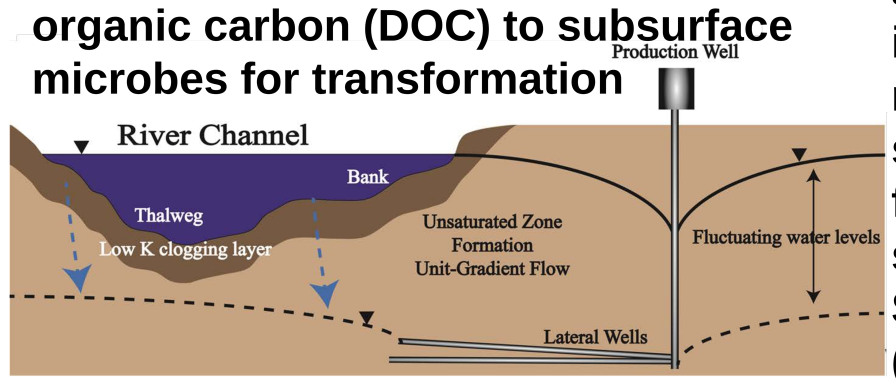
ABSTRACT

In regions worldwide, losing rivers are common and can introduce feedbacks affecting total transport of infiltration and nutrients. Permeability decline from hyporheic zone bioclogging is one feedback that is thought to depend on climatic events that control riverbed sediments, primary productivity, infiltration, and subsurface gas production. Results from a previous analysis show strong bioclogging controls on infiltration leading to dynamic permeability that depend on river gaining versus river losing conditions.**



River life-cycles are an important component of this cycle as they typically represent a sink of CO_2 gas from the atmosphere. When benthic organisms decay, however, this provides a source of dissolved organic carbon (DOC) to subsurface microbes for transformation back to CO_2. Net CO_2 and other greenhouse gas (GHG) fluxes from the surface-subsurface interface are highly dependent on synergistic hyporheic flows, infiltration rates, and transformations. Both surface and subsurface metabolism, leading to bioclogging is not well quantified in river-aquifer zones. Nor are their interactions understood in rivers that have variable surface-water flow regimes from climate perturbations such as the El Niño Southern Oscillation (ENSO).

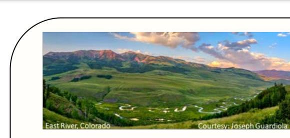


CONCEPTUAL MODEL & STUDY SITES

Managed System

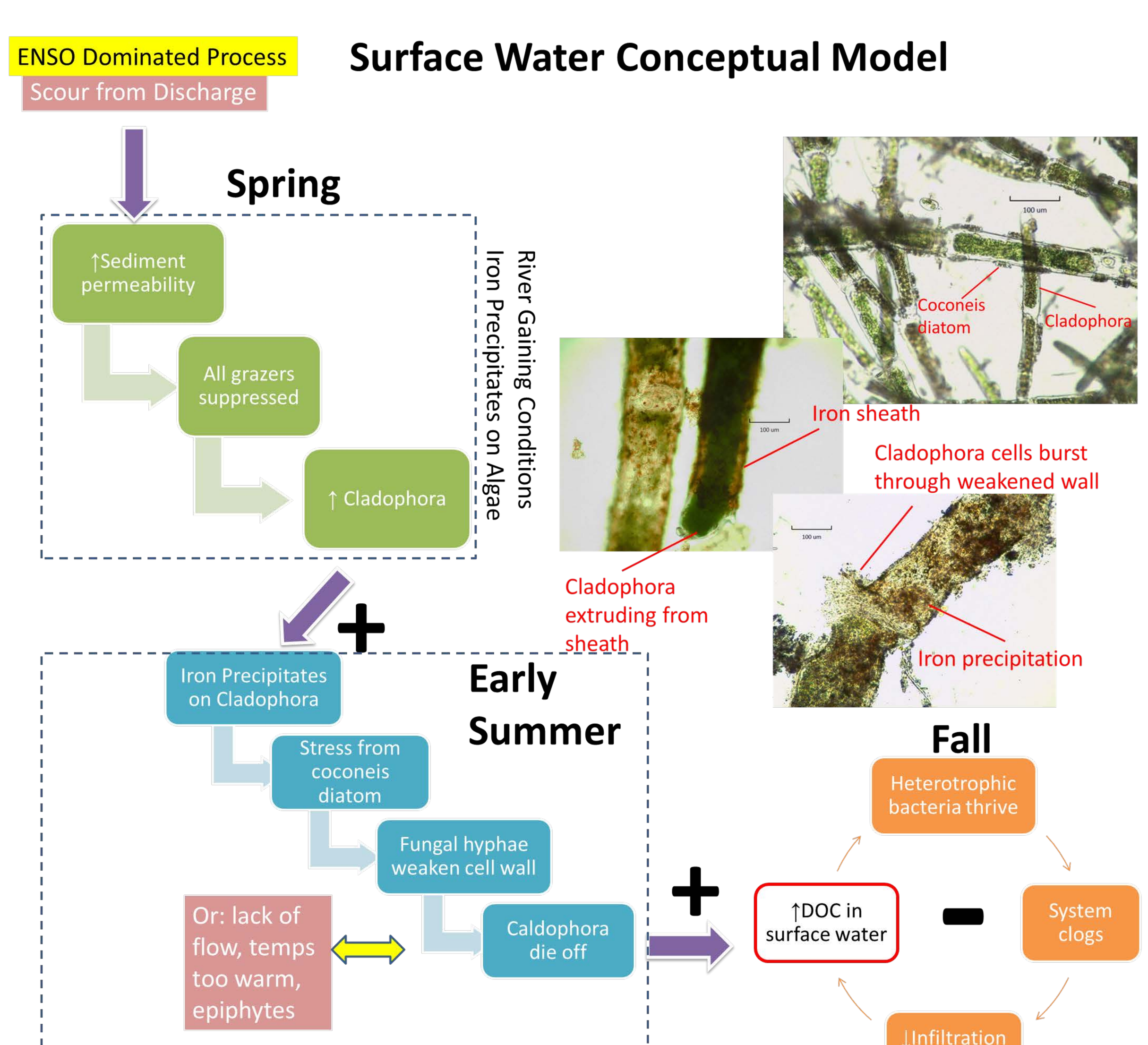
Russian River, CA
Riverbank Filtration
Mediterranean climate
Losing river

Natural System



East River, CO
SFA Watershed (Upper Colorado)
Semi-arid, Montane climate
Horizontal fluxes

How do coupled hyporheic hydrological-biogeochemical feedbacks range between these conditions?



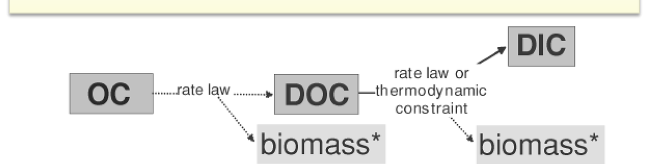
HYPOTHESES & METHODS

To test the effect of large scale climate-controls on biogeochemical fluxes, we simulated riverbed biological growth and hyporheic zone carbon dynamics using 1D/2D MIN3P numerical models, allowing a range of initial grain size distributions (GSD) to represent ENSO control of riverbed scour.

Wet year end-member: ↑Q, ↑K, ↑Φ

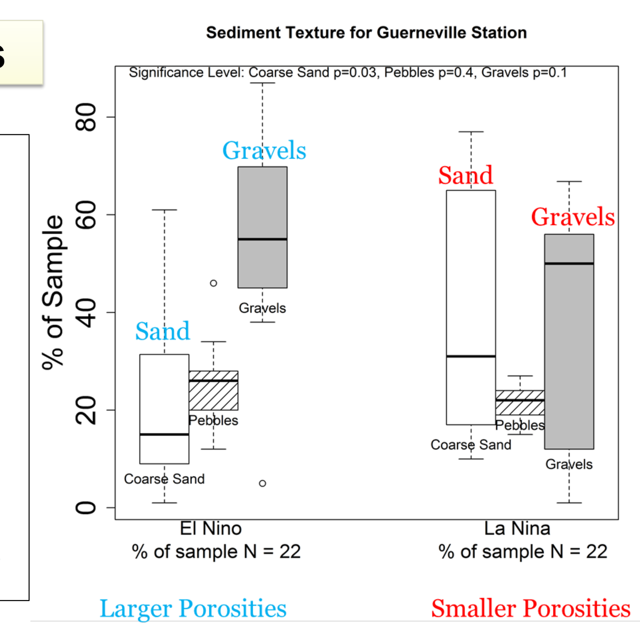
Dry year end-member: ↓Q, ↓K, ↓Φ

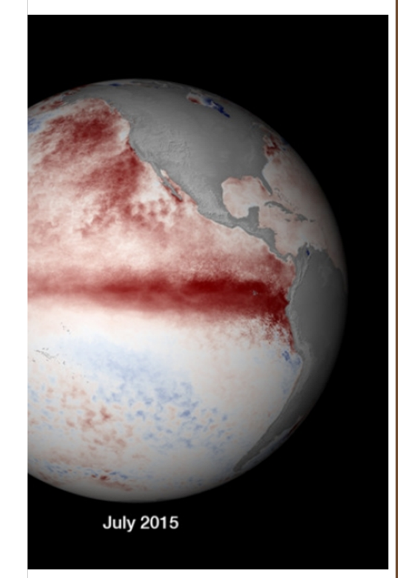
Monod Kinetics



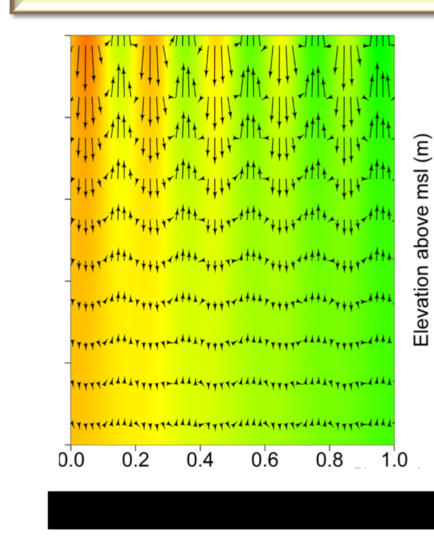
Modeled Processes

- Disconnection
- Pumping
- Initial GSD
- Topography
- Bioclogging from DOC, NO_3
- Fe(III) precipitation
- Ecological boundary





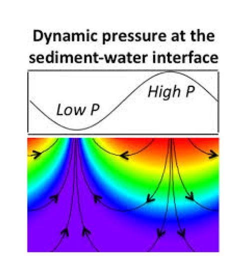
HORIZONTAL & VERTICAL HYPORHEIC FLUXES



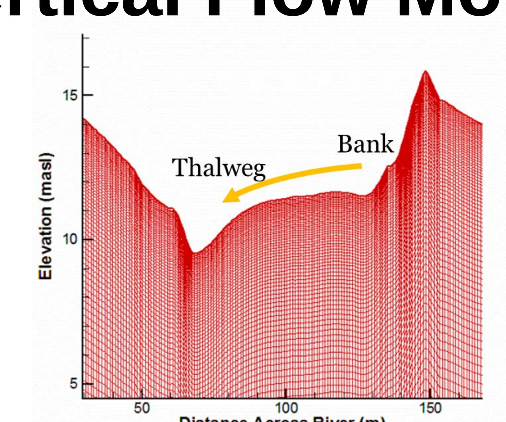
Horizontal Hyporheic Flow Model

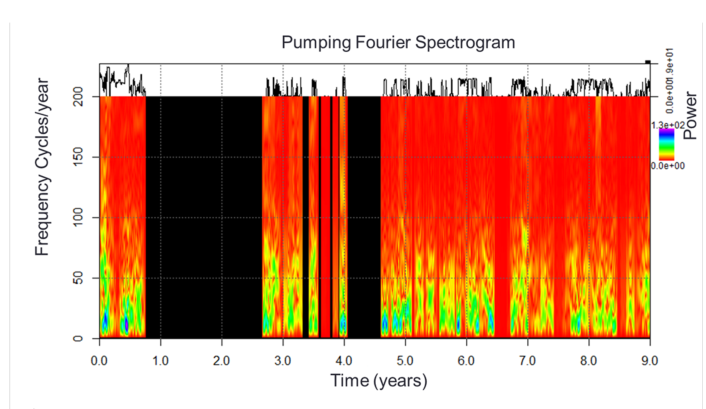
$$h_m = 0.28\frac{U^2}{2g}\begin{cases}\left(\frac{H/d}{0.34}\right)^{3/8} & H/d \le 0.34\\ \left(\frac{H/d}{0.34}\right)^{3/2} & H/d \ge 0.34\end{cases}$$

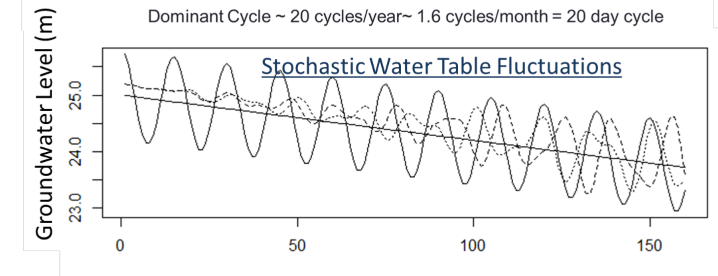
*Elliot & Brooks (1997) Upper Head Boundary



Vertical Flow Model







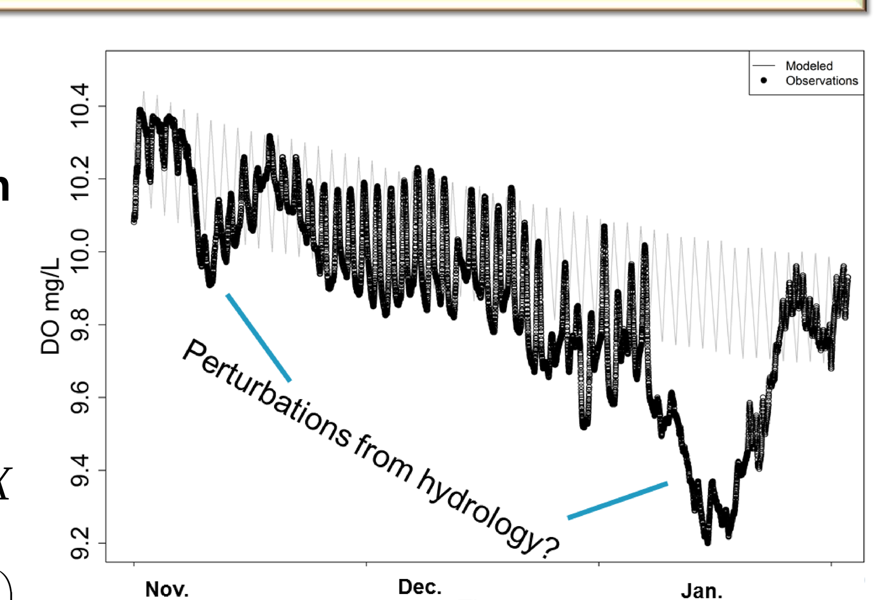
SIMULATING AN ECOLOGICAL BOUNDARY

Dissolved oxygen was quantified from Primary Productivity (P), Respiration (R), Diffusion (D), and Heterotrophy (H):

Dissolved Oxygen Model

$$\frac{dX}{dt} = D(X_s - X) + P - R - HX$$

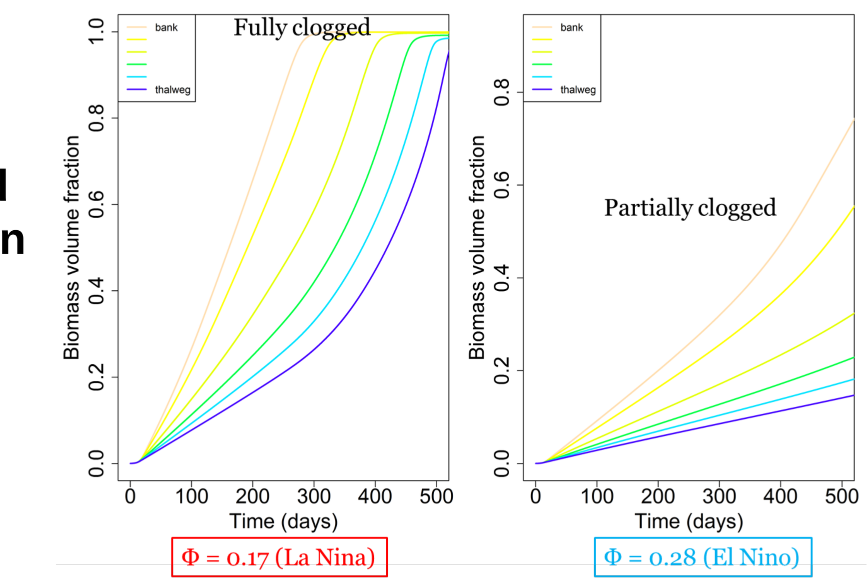
$$P(z) = \frac{P_{max}}{kz}\ln\left(\frac{L_s + \sqrt{\left(\frac{P_{max}}{\alpha}\right)^2 + L_s^2}}{L(z) + \sqrt{\left(\frac{P_{max}}{\alpha}\right)^2 + L(z)^2}}\right)$$

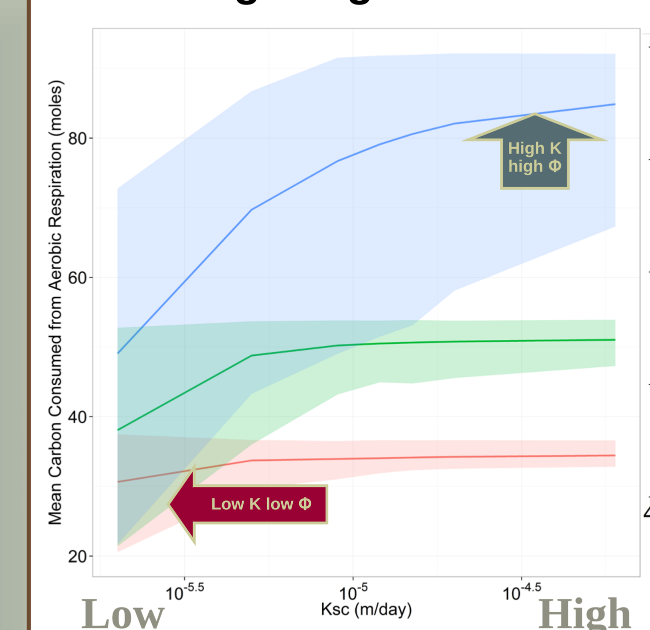


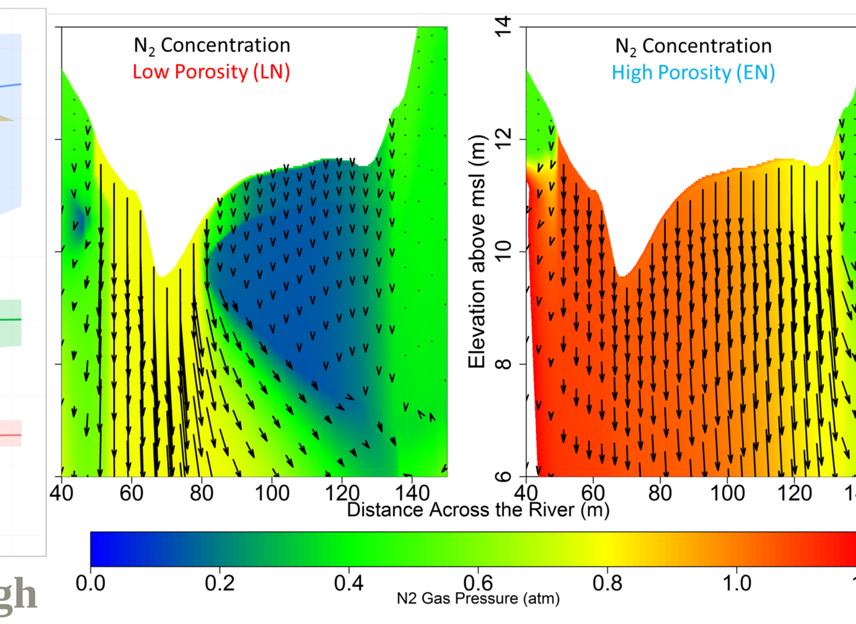
Surface water quality data from the Pump House Location in the Upper East River watershed in Colorado. DO provided as ecological boundary to MIN3P.

BIOCLOGGING RESULTS

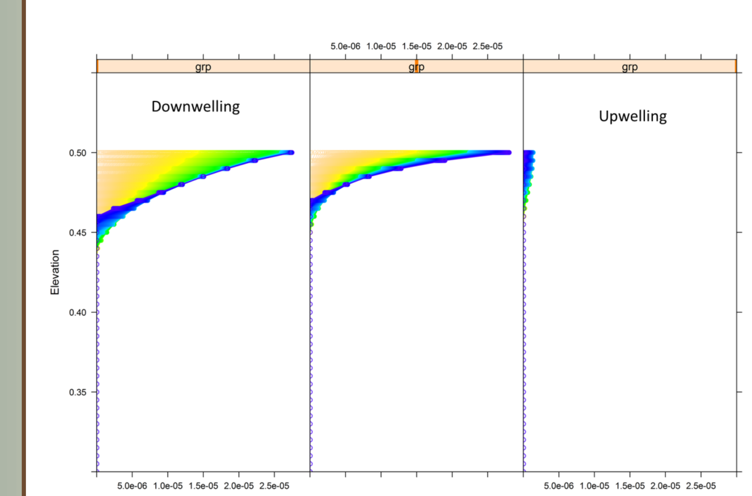
- Spatially variable C, N transformation
- Aerobic respiration and anaerobic denitrification are a function of sediment structure
- Redox-stratified microbial communities feedback into surface ecological growth





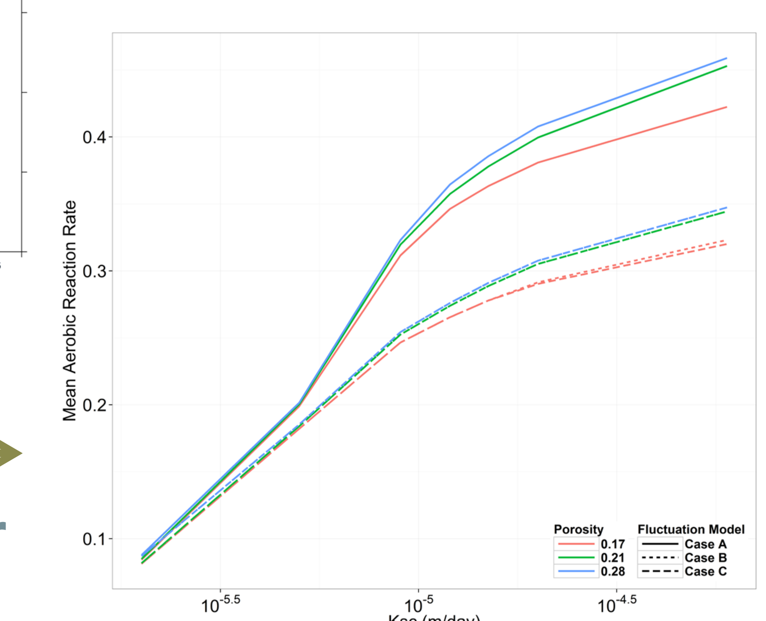


IMPLICATIONS FOR NUTRIENTS & METALS



Mackinawite Precipitation (FeS)

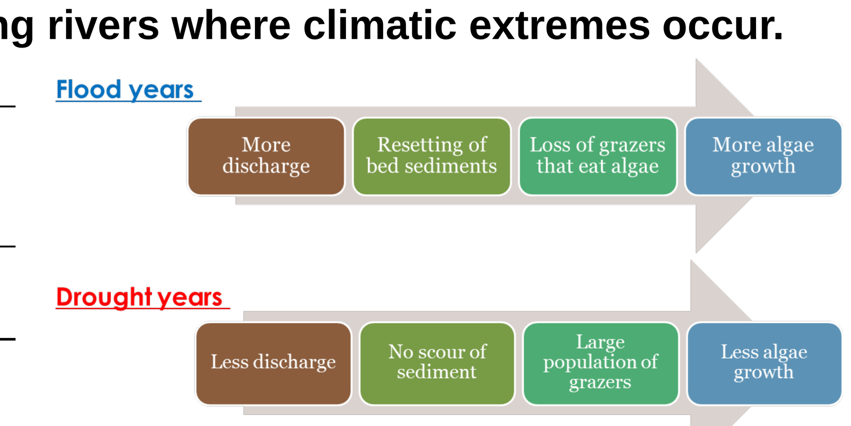
Reaction rates vary with sediment conditions and water table fluctuations



CONCLUSIONS

Our work links climatic perturbations of surface water discharge as a major control on riverbed sediment GSD, bioclogging, and subsurface transformations. Results show that GHG production is not only a function of surface ecology, but linked to the statistics of extreme climatic events that control riverbed initial conditions. These results provide a new understanding of nutrient cycling and hotspot bioclogging in losing rivers where climatic extremes occur.

	Moles Carbon Consumed	Moles Nitrate Consumed
Generic Boundary	406.0	26.0
Ecological Boundary	402.0	50.7



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**Newcomer, M. E., S. S. Hubbard, J. H. Fleckenstein, U. Maier, C. Schmidt, M. Thullner, C. Ulrich, N. Flipo, and Y. Rubin (2016), Simulating bioclogging effects on dynamic riverbed permeability and infiltration, *Water Resour. Res.*, 52,

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