Seismic Array Constraints on reach-scale bedload transport

Trinity River Array

Elevation
532 m
528 m
Node
Broadband

N

0 100 200 Meters

Trinity Dam Release

Salmon habitat

Gravel injection

Brandon Schmandt — THE UNIVERSITY OF NEW MEXICO. David Gaeuman — U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION
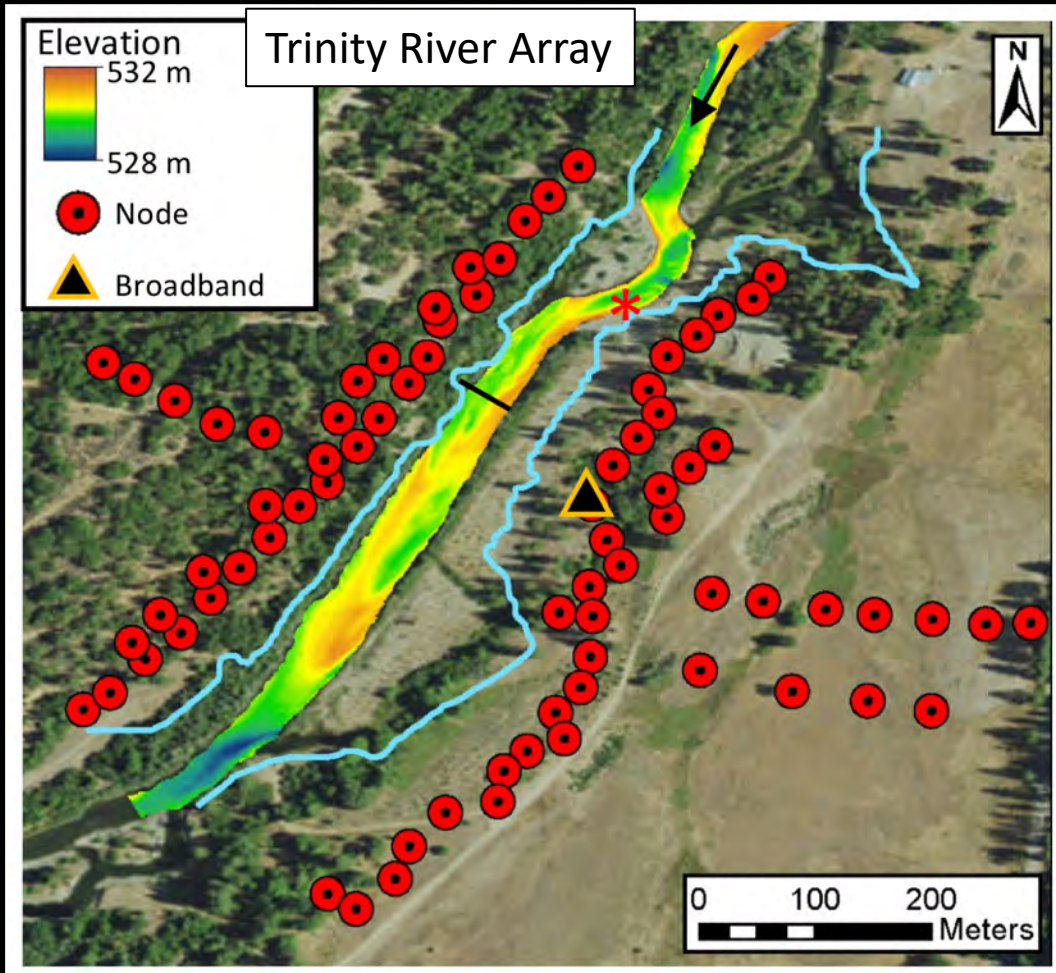
Motivations for quantitative measures of stream dynamics from outside the channel

Sediment transport by streams generally is the rate-limiting process for landscape evolution. Much work done during extreme discharge events, difficult to access the bed.
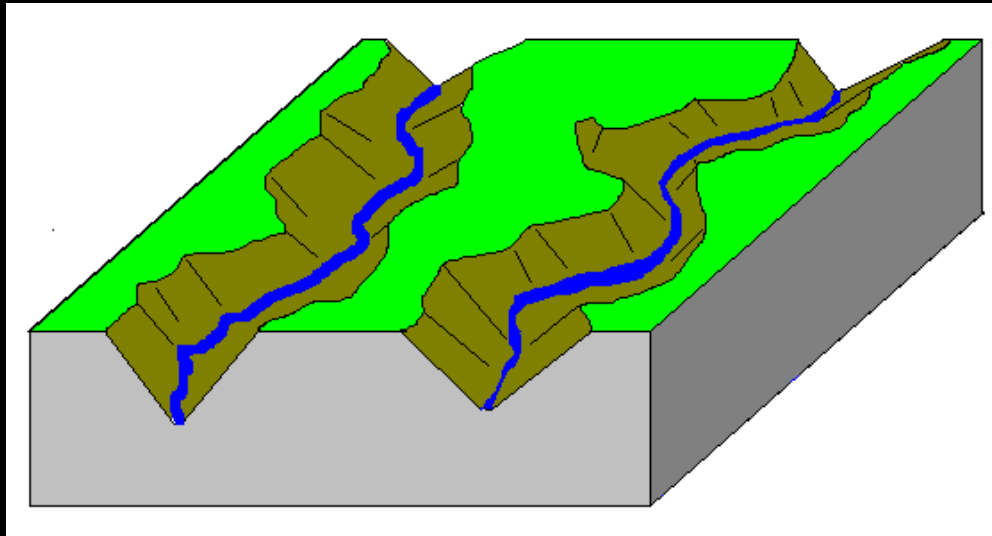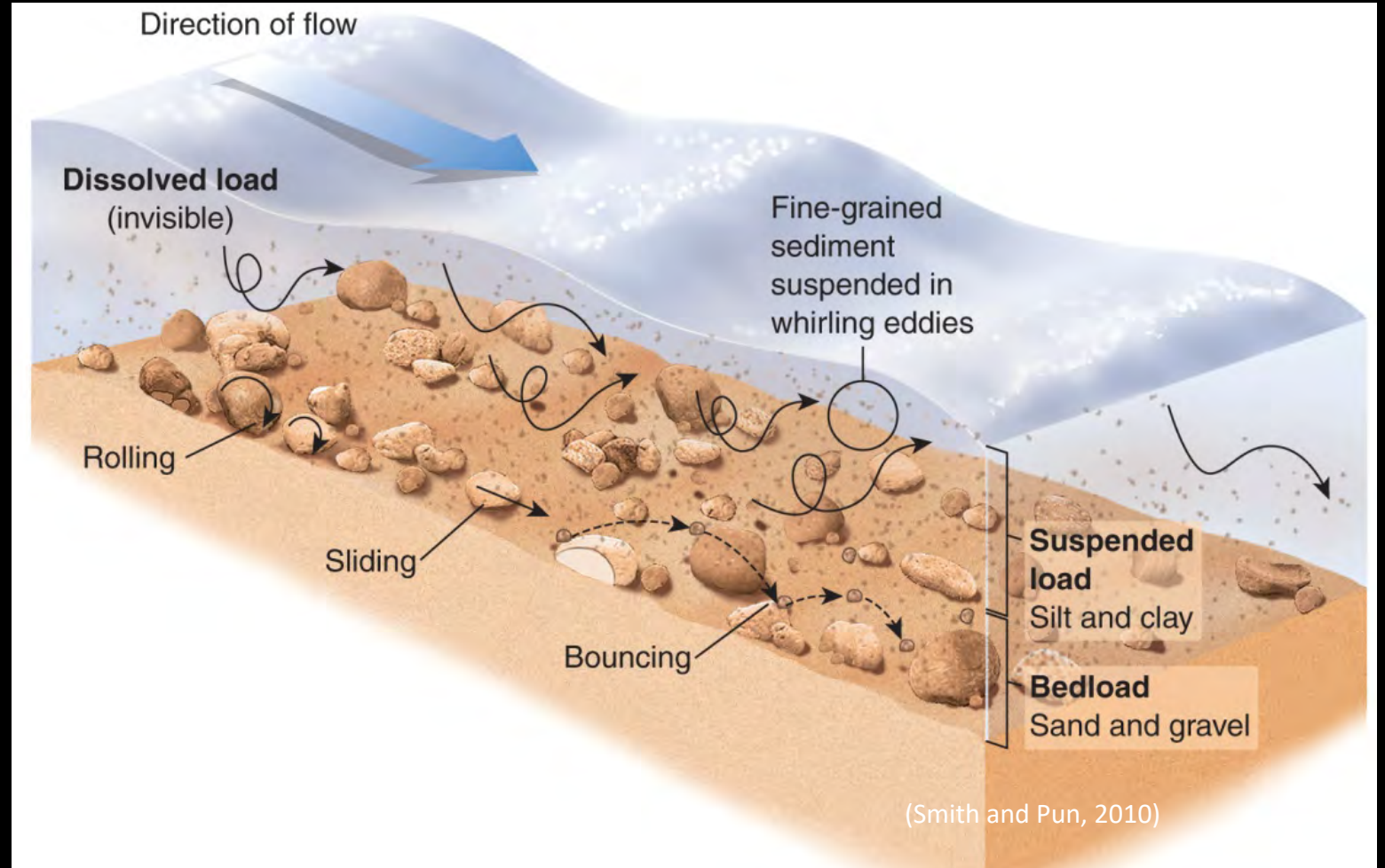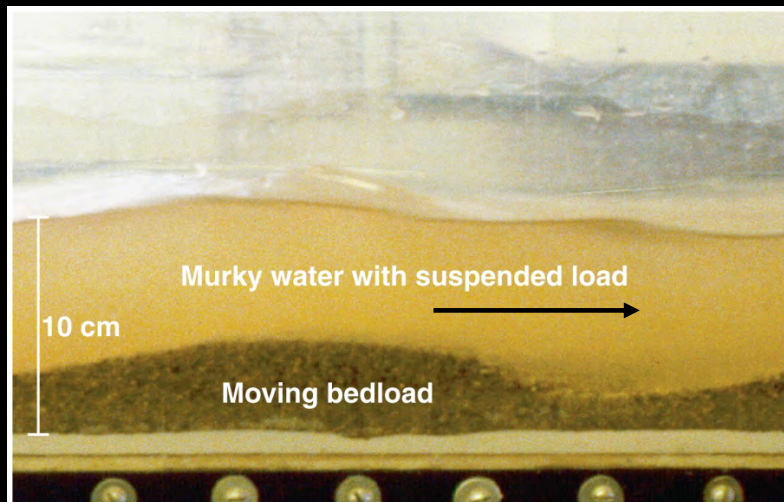
Management of watersheds

Sediment transport in regulated watersheds – balancing multiple uses and conserving habitats

The focus here is bedload

Direction of flow

Dissolved load (invisible)

Fine-grained sediment suspended in whirling eddies

Rolling

Sliding

Bouncing

Suspended load
Silt and clay

Bedload
Sand and gravel

(Smith and Pun, 2010)

Flume example

Murky water with suspended load

10 cm

Moving bedload

Because it's otherwise hard to measure the bottom of a river while it is actively being carried away, and rock collisions should be a tractable target for seismology

What can we measure?

It's particularly difficult/expensive to measure bed-load transport, but it is estimated to comprise ~2 to >50% of total sediment mass flux

An accurate but costly way to study bed-load transport in Switzerland, at the Erlenbach (e.g., Rickenmann et al., 2012)
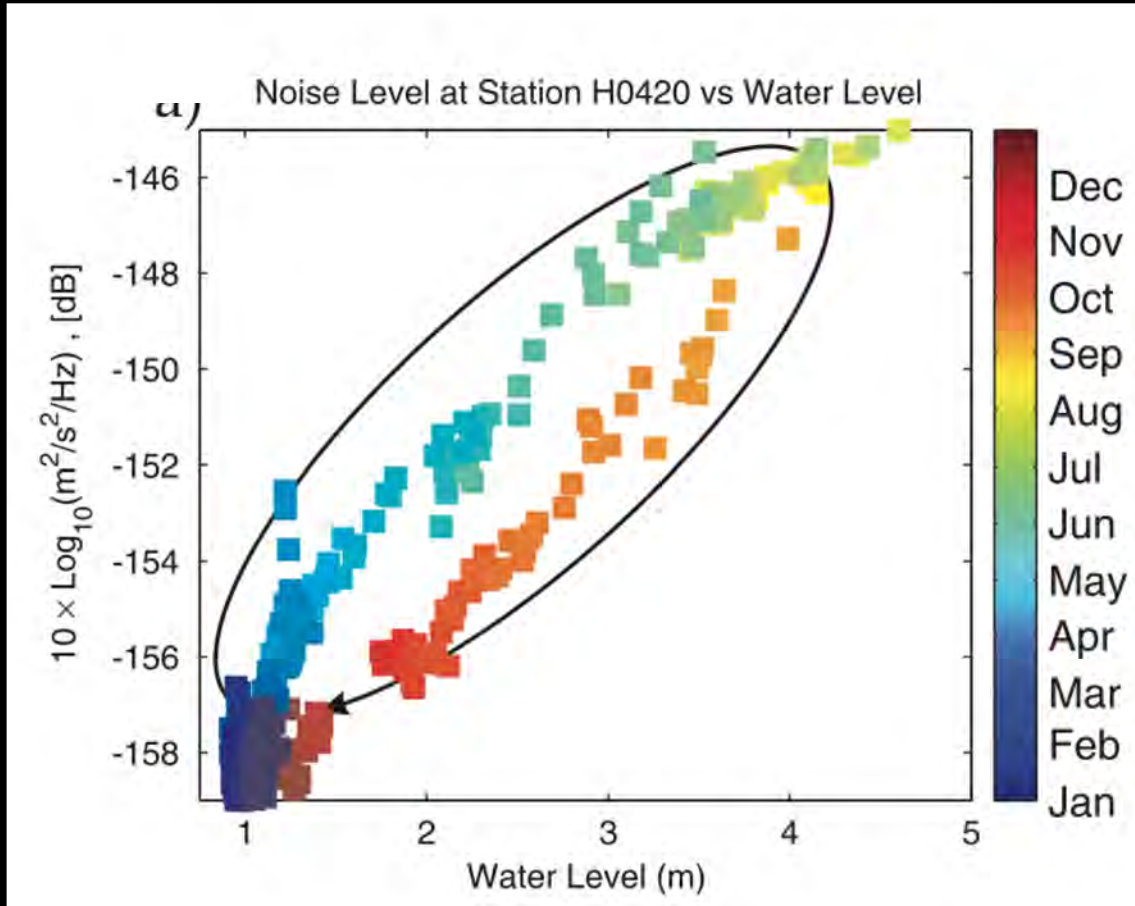
Not feasible to do this for many rivers…

Other common methods such as traps and force plates still not easy/cheap
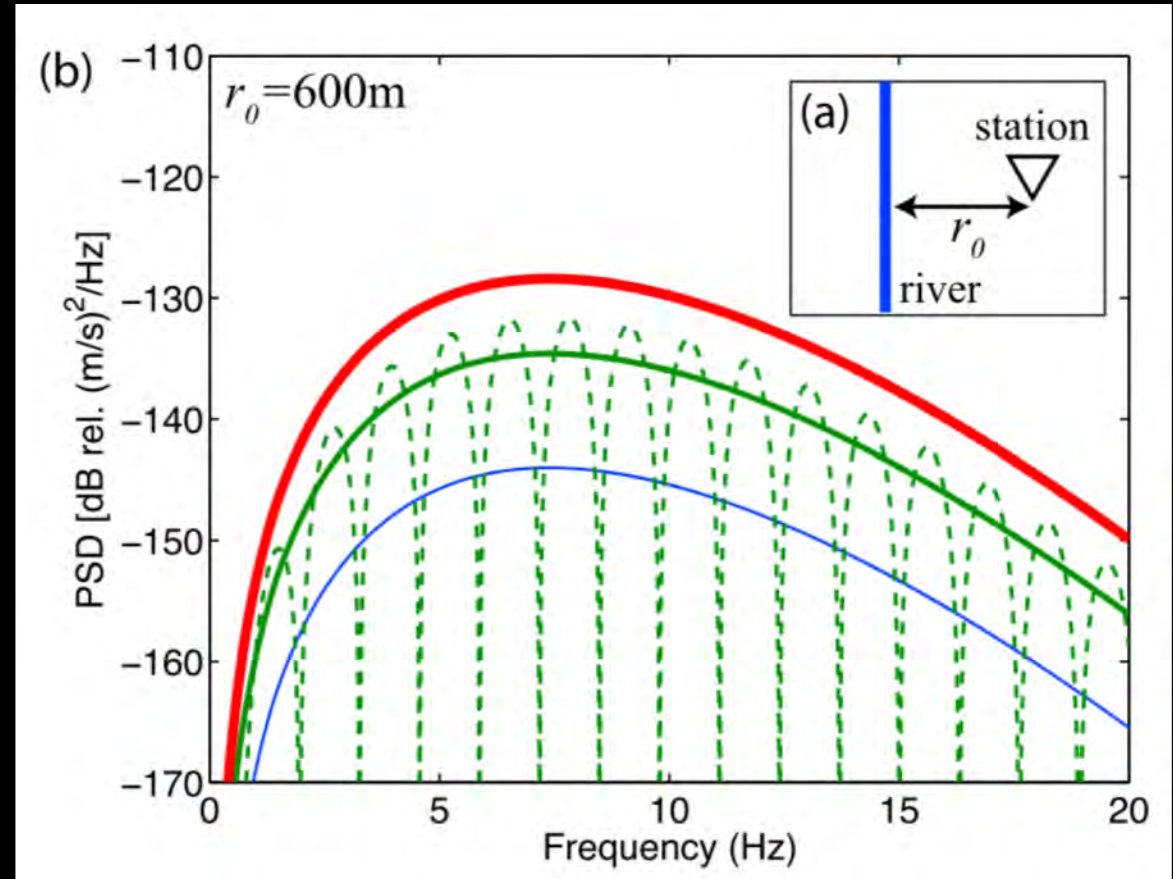
Listening to fluvial processes with seismology

- Some pioneering observation and modeling efforts

Burtin et al., 2008 – Trisuli River, Nepal

More bedload for given discharge at beginning of wet season? Possible changes in turbulence (Roth et al., 2017)?

Tsai et al., 2012 – analytic model of Hertzian impacts along a bedrock channel
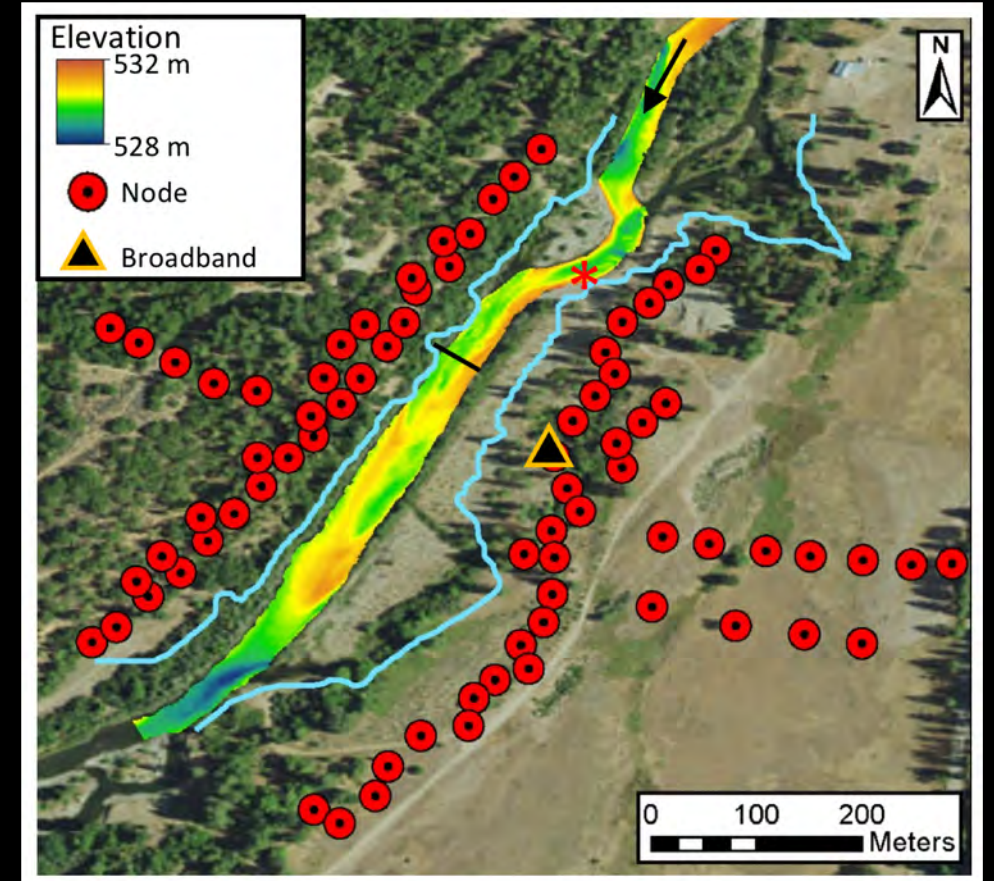
Listening to fluvial processes with seismology

Array with several L-22 seismometers in Grand Canyon

(Schmandt et al., 2013)

Array with ~100 nodes at the Trinity River in northern CA

(Schmandt et al., 2017)

Listening to fluvial processes with seismology

Array with several L-22 seismometers in Grand Canyon

Node array at the Trinity River in northern CA

Near threshold for any bedload movement, controlled floods designed to stimulate suspended load transport to maintain sandbars.

Good place to test if seismometers can detect onset and termination of small bedload flux.

Goal is to move as much bedload as possible with limited reservoir water. Controlled floods are augmented by gravel supply augmentation.

Good place to test seismic signal of higher bedload flux (~1000 tons/day) and response time scales to supply perturbations

(Schmandt et al., 2013)

(Schmandt et al., 2017)

Trinity River Restoration Program

- Multi-agency effort to restore the salmon fishery, physical geomorphology led by U.S. Bureau of Reclamation

- First impacted by hydraulic mining in 1800's, leaving abundant gravel tailings

- Later dam regulated discharge limited natural channel restoration since 1960

- Restoration effort ongoing since early 2000's, includes controlled floods for mechanical modification of the river channel
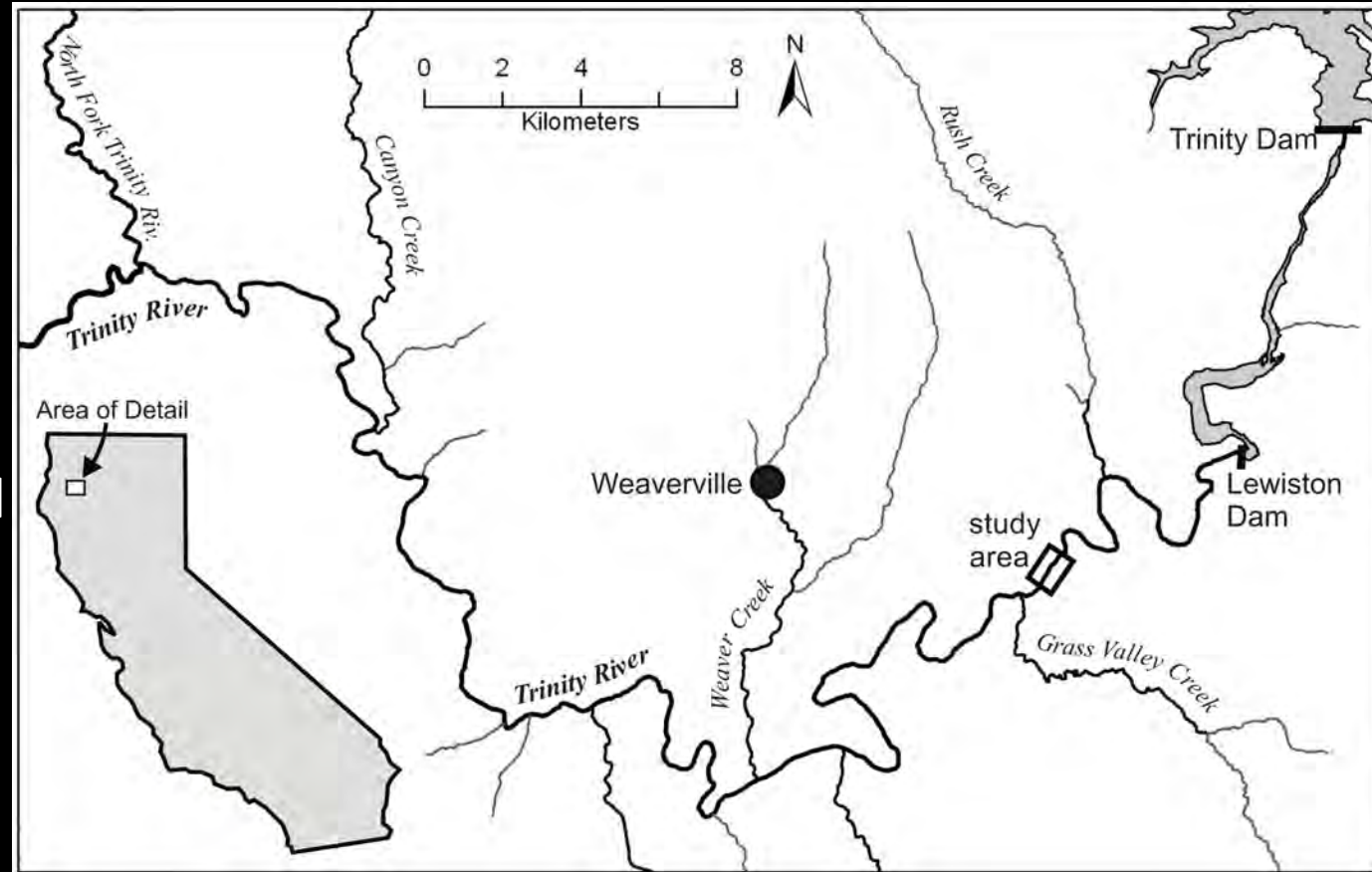
(Gaeuman et al., 2017)

Key Collaborators: David Gaeuman, Robert Stewart of USBR in Weaverville, CA (www.trrp.net)

Trinity River Restoration Program
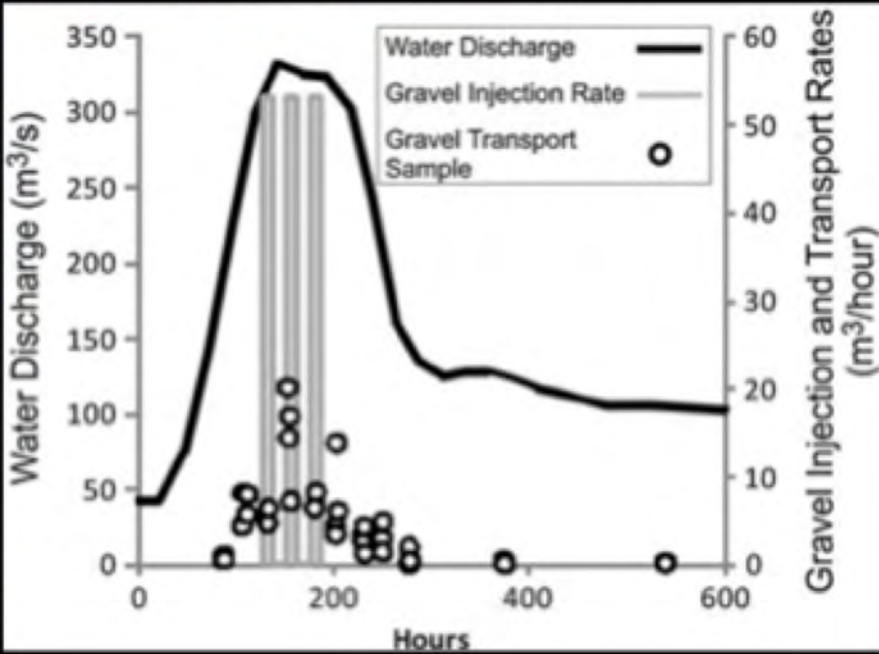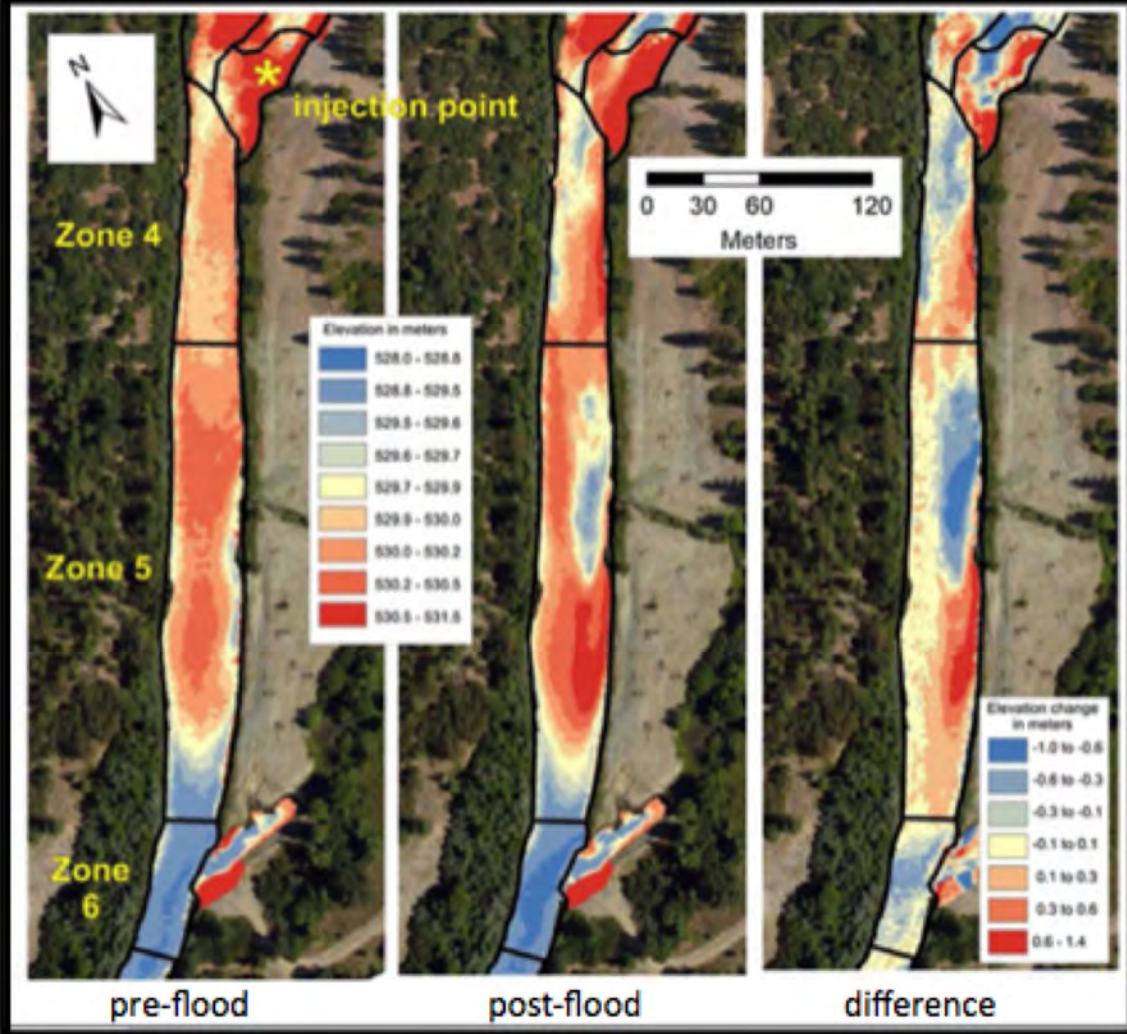
Physical sampling of bedload

Repeat bathymetry

Controlled gravel augmentation

Controlled flooding

(Gaeuman, 2011)

Key Collaborators: David Gaeuman, Robert Stewart of USBR in Weaverville, CA (www.trrp.net)

1. Unnatural channel constrictions due to gravel levees and tailings piles from hydraulic mining
2. Decades of low discharge due to water diversion for Great Valley farming

WesternMiningHistory.com

Photo 69. Carrville Gold Company Dredge, Trinity River District. This photo was taken on the upper Trinity River in Trinity County in 1940. Photo courtesy of Yuba Consolidated Industries.

TRRP goals include stimulating bedload transport to help restore channel's salmon habitat

A section of the alternating bar gravel bed river that is in a more natural state

Underwater video observations of gravel transport

Highest discharge is similar for the 2015 flood studied with the node array

Trinity River Node Array in 2015
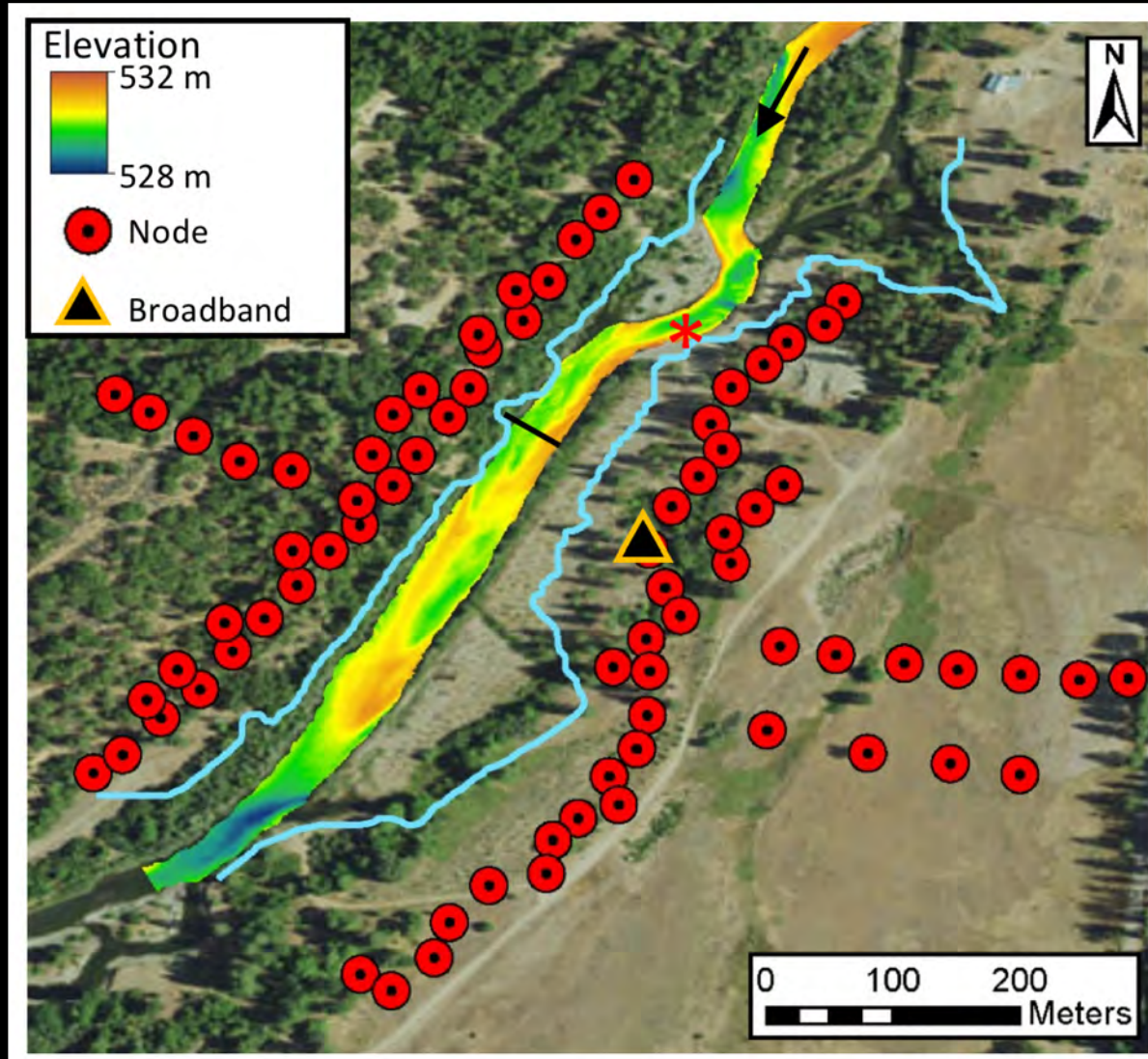
(Schmandt et al., 2017 Geology)

Lowden Ranch Array (largest of 4 sub-arrays)

~30 m spacing along a 700-m reach of the Trinity River

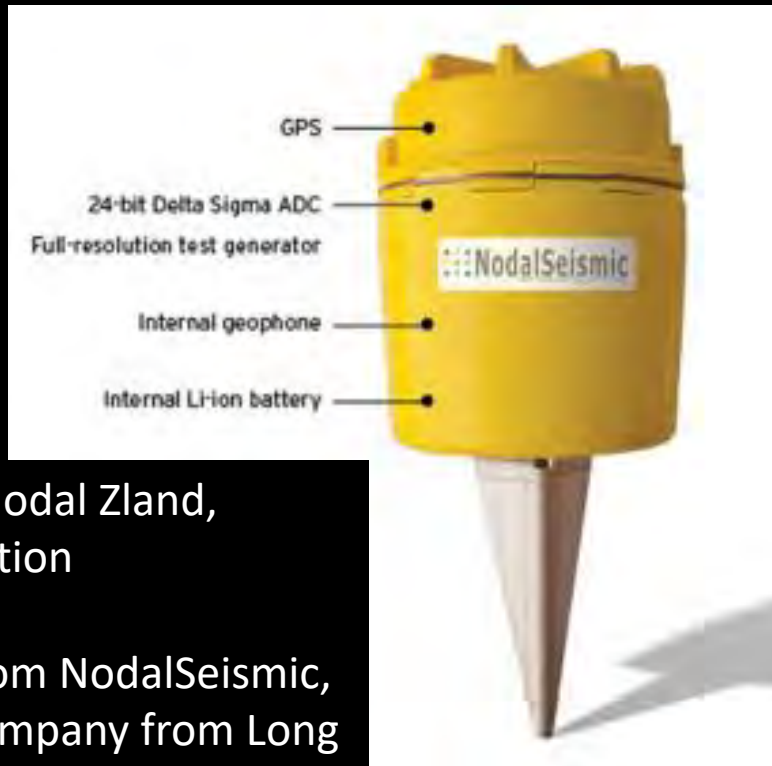Gravel injection site near upstream end and physical sampling transect near the middle

Only vertical component
2-week battery life
1st generation Fairfield Zland

Rented from NodalSeismic, service company from Long Beach, CA

Autonomous seismographs (nodes):
-cable-free
-GPS clock
-24-bit digitizer
-2-week battery life
-hard drive capacity

Fairfield Nodal Zland,
1st generation

Rented from NodalSeismic,
service company from Long
Beach, CA
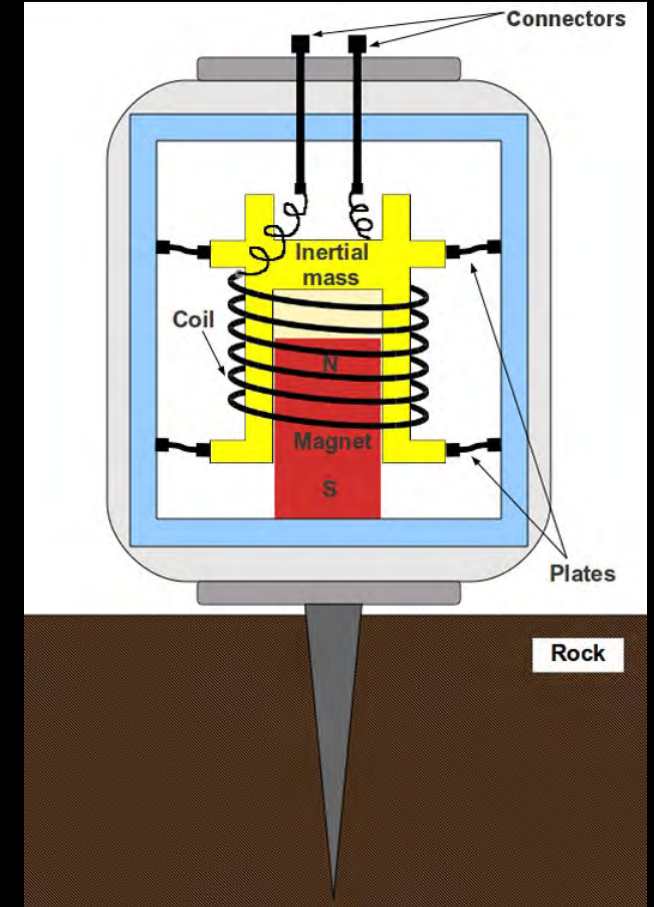
Geophone response peak at 10 Hz

Day of Year in 2015

(Schmandt et al., 2017 Geology)
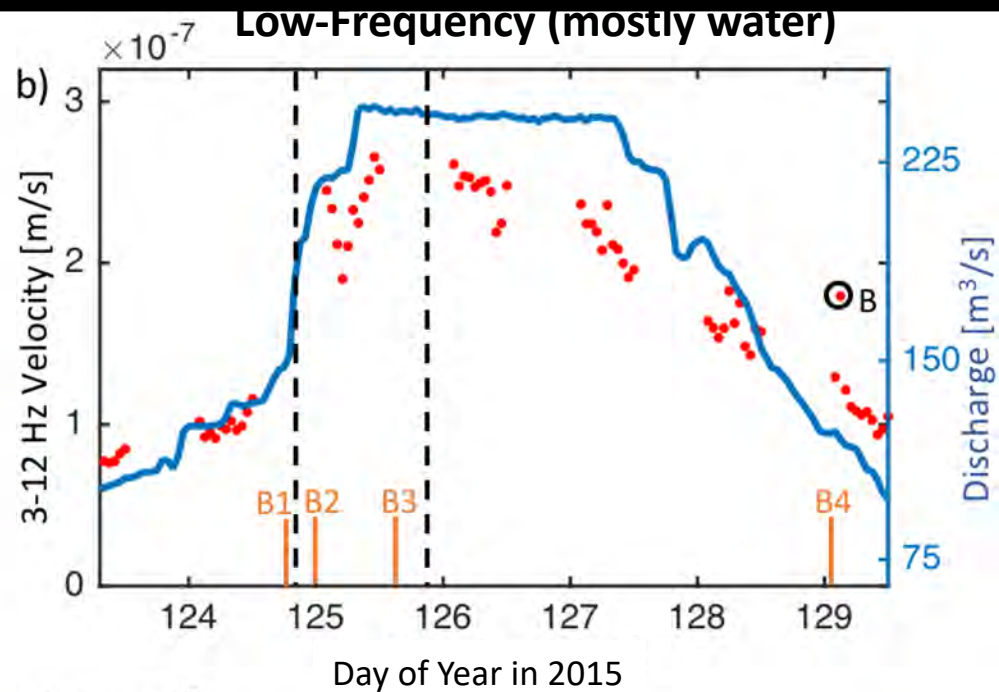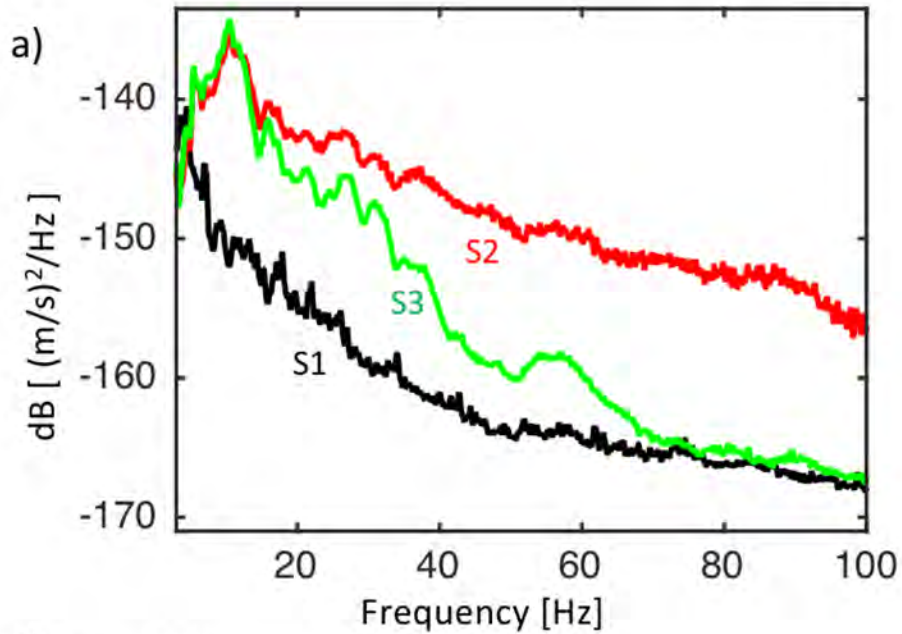
What frequency range is excited by bedload transport?
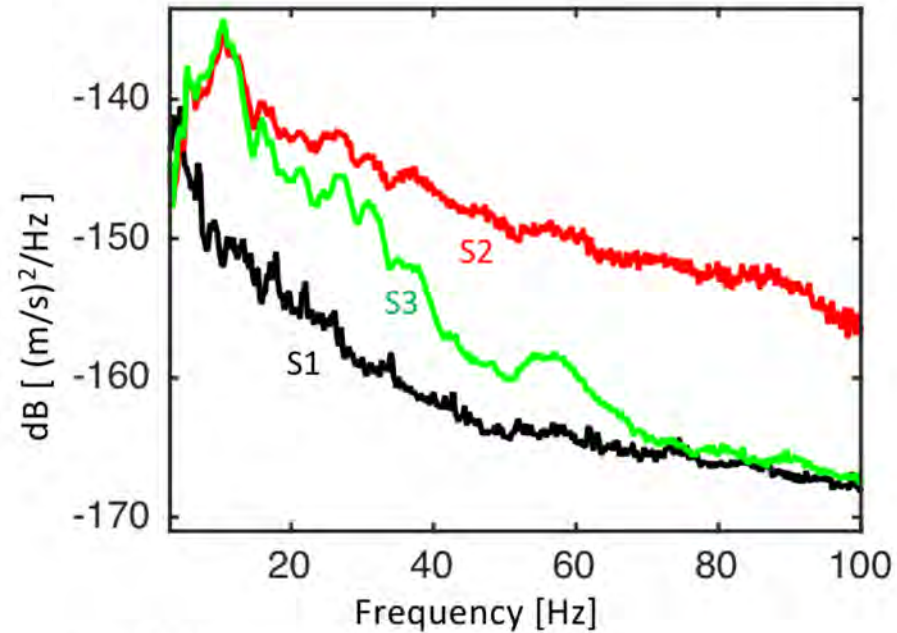
Gravel supply augmentation during constant water discharge directly identifies the shape of the local bedload spectrum
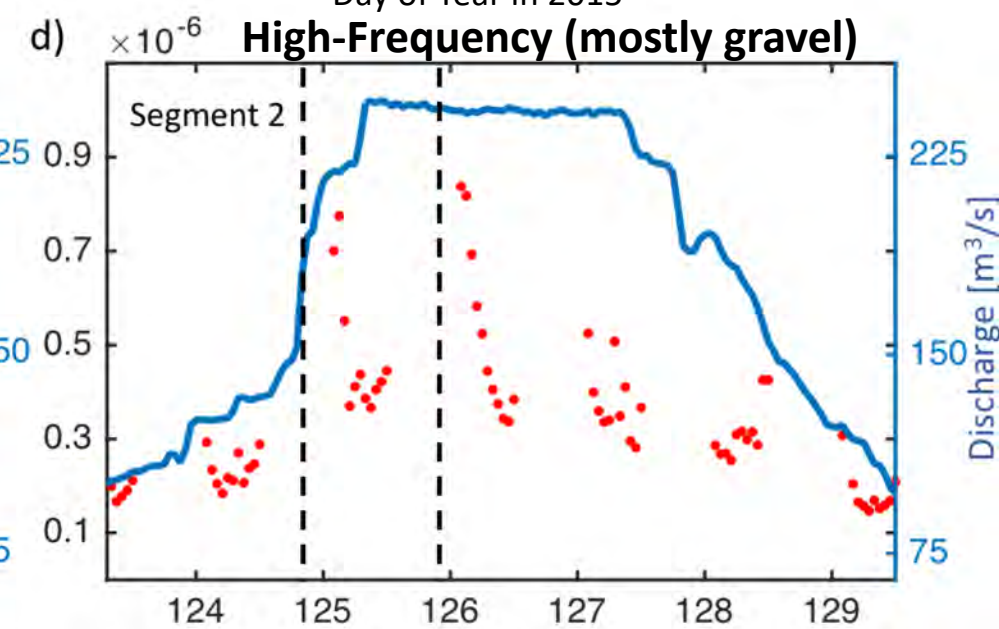
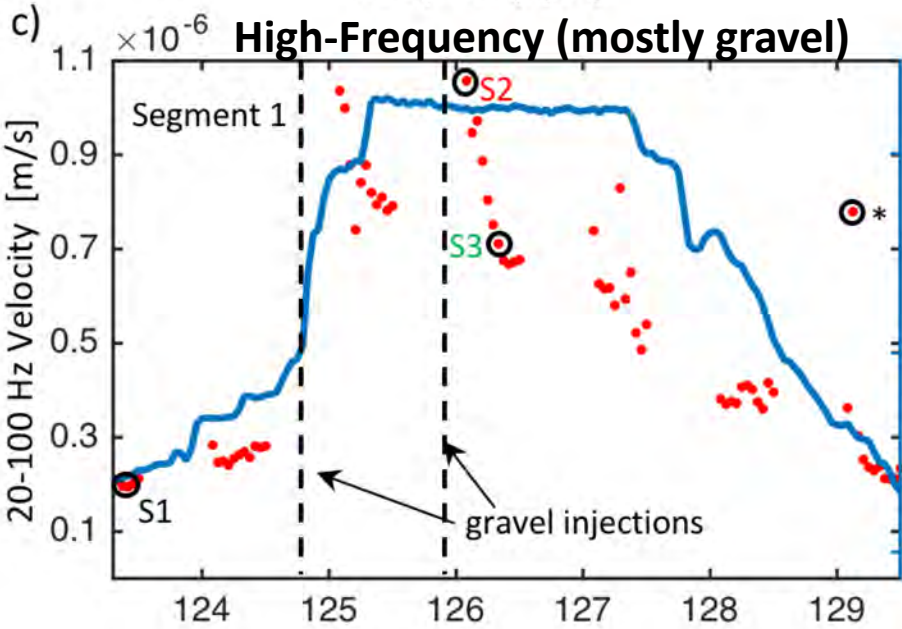Difference between S2 and S3 spectra shows bedload dominantly affects greater than 20 Hz spectrum

a)

b) Low-Frequency (mostly water)
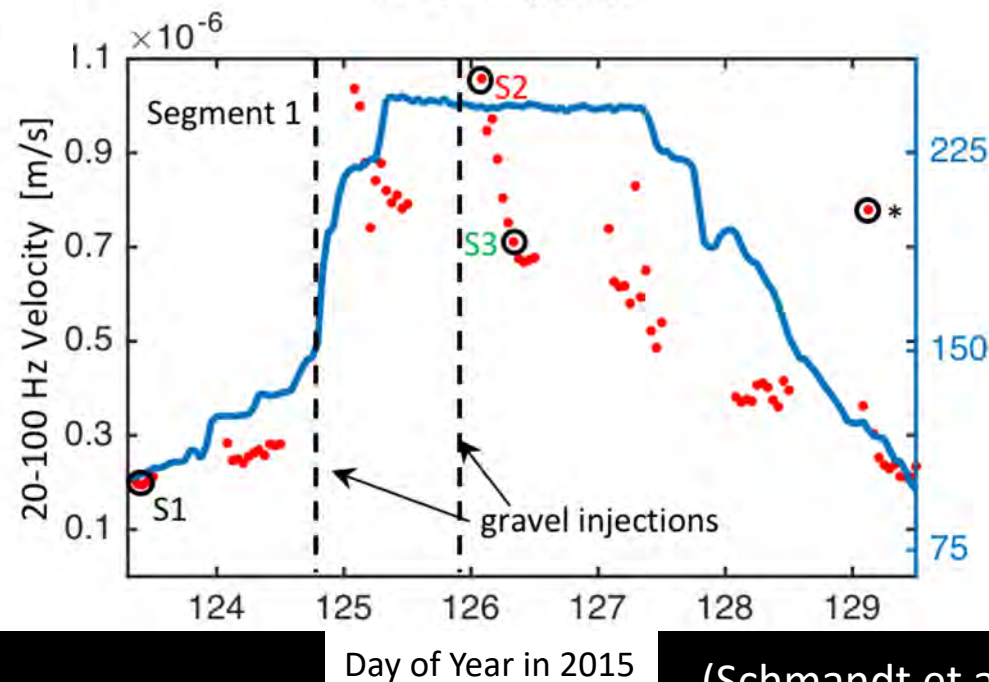
Smooth variations in low-frequency (<12 Hz) correlated with discharge

c) High-Frequency (mostly gravel)

d) High-Frequency (mostly gravel)

Day of Year in 2015

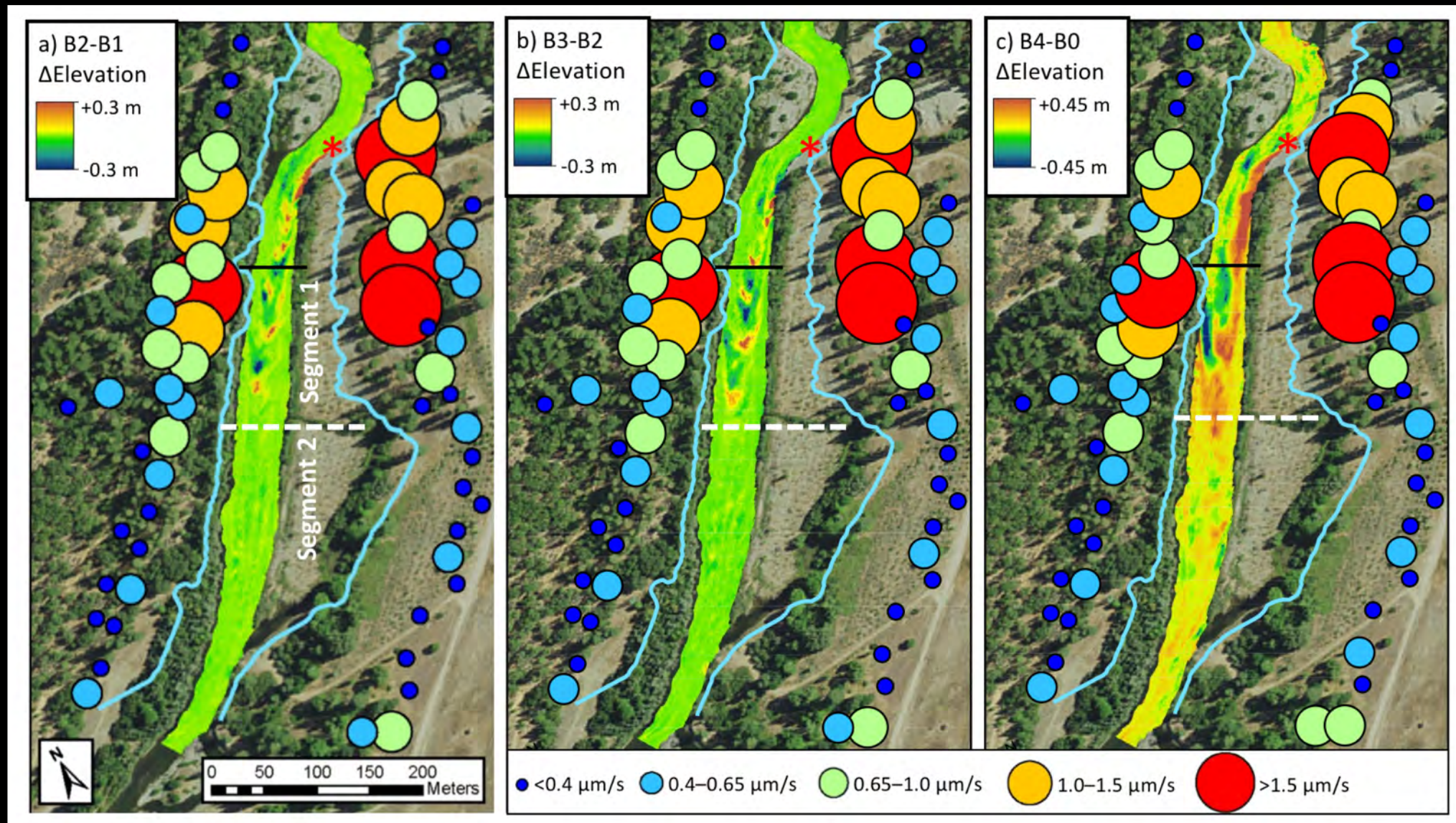High frequency (>20 Hz) responds to gravel augmentation for ~10 hours

After >10 hours the downstream segment produces about half the seismic power of the upstream segment

Schmandt et al., 2017 Geology

Spatial variability in bathymetric change and seismic amplitudes
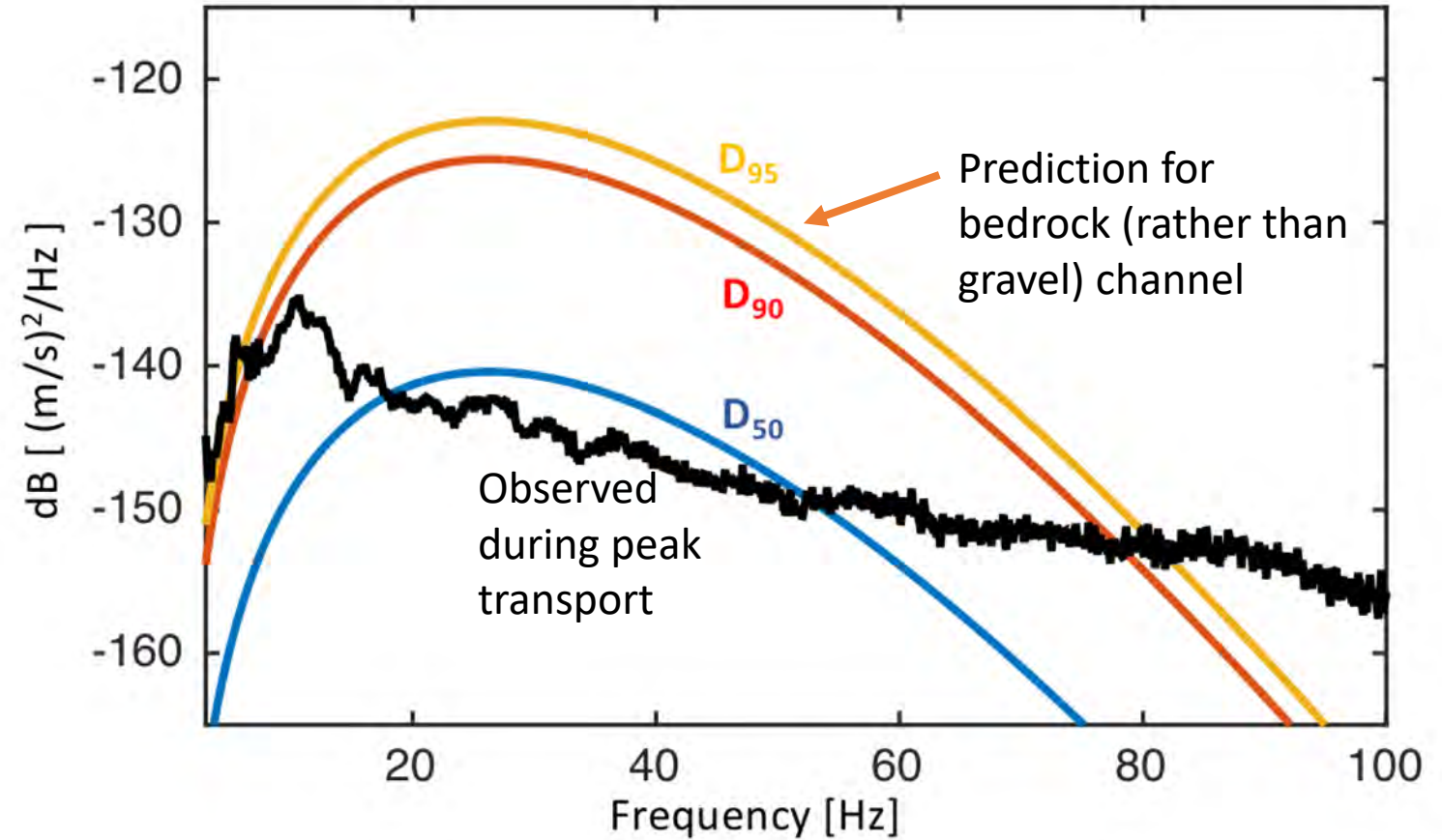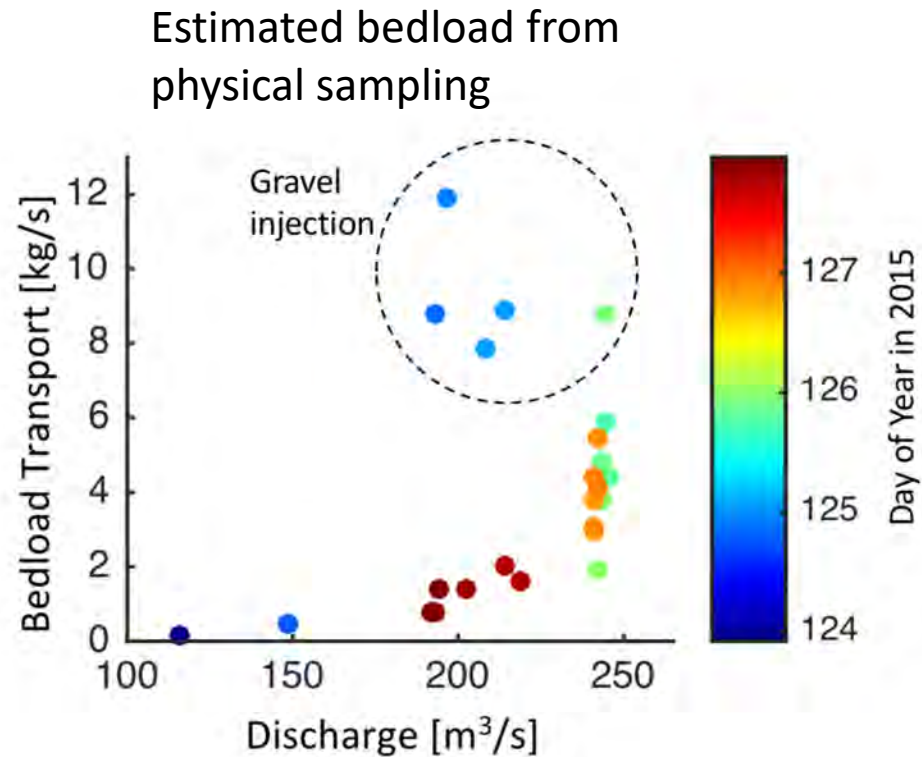
Before flood and gravel injection

After 2 gravel injections and flooding
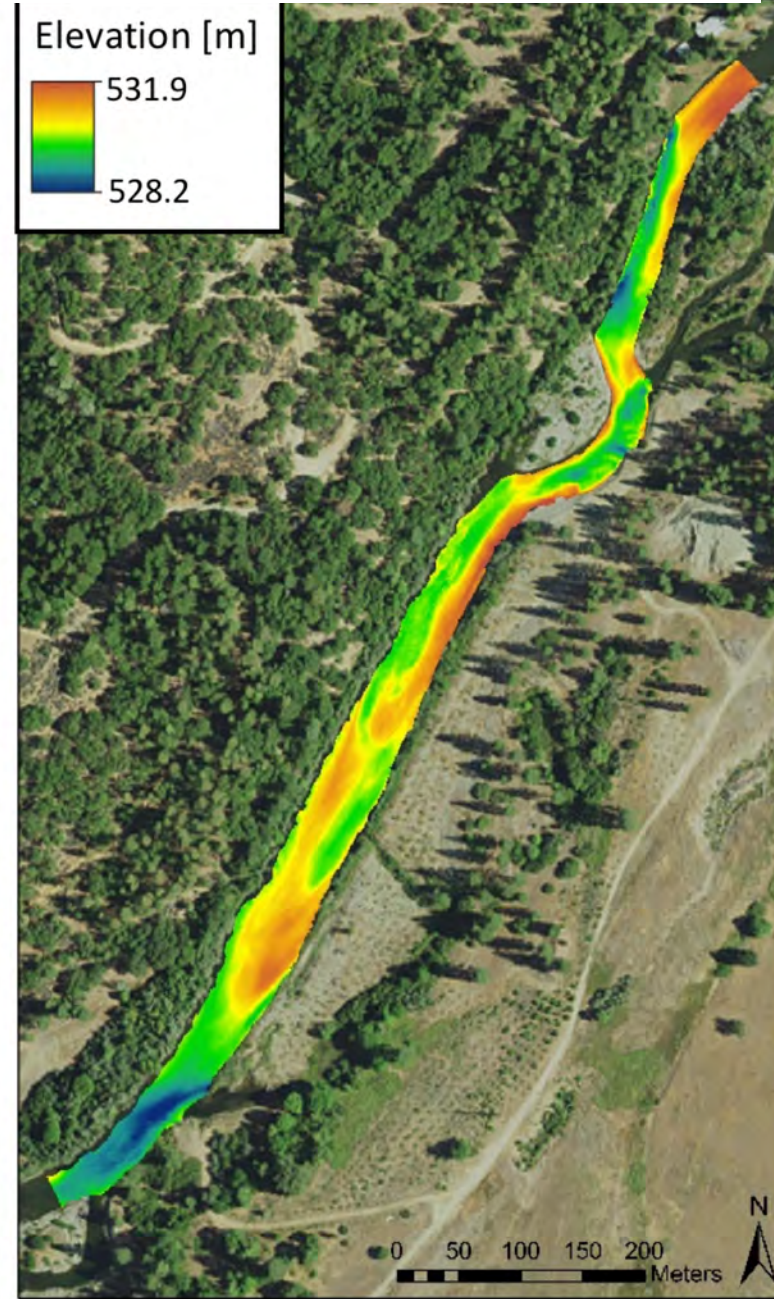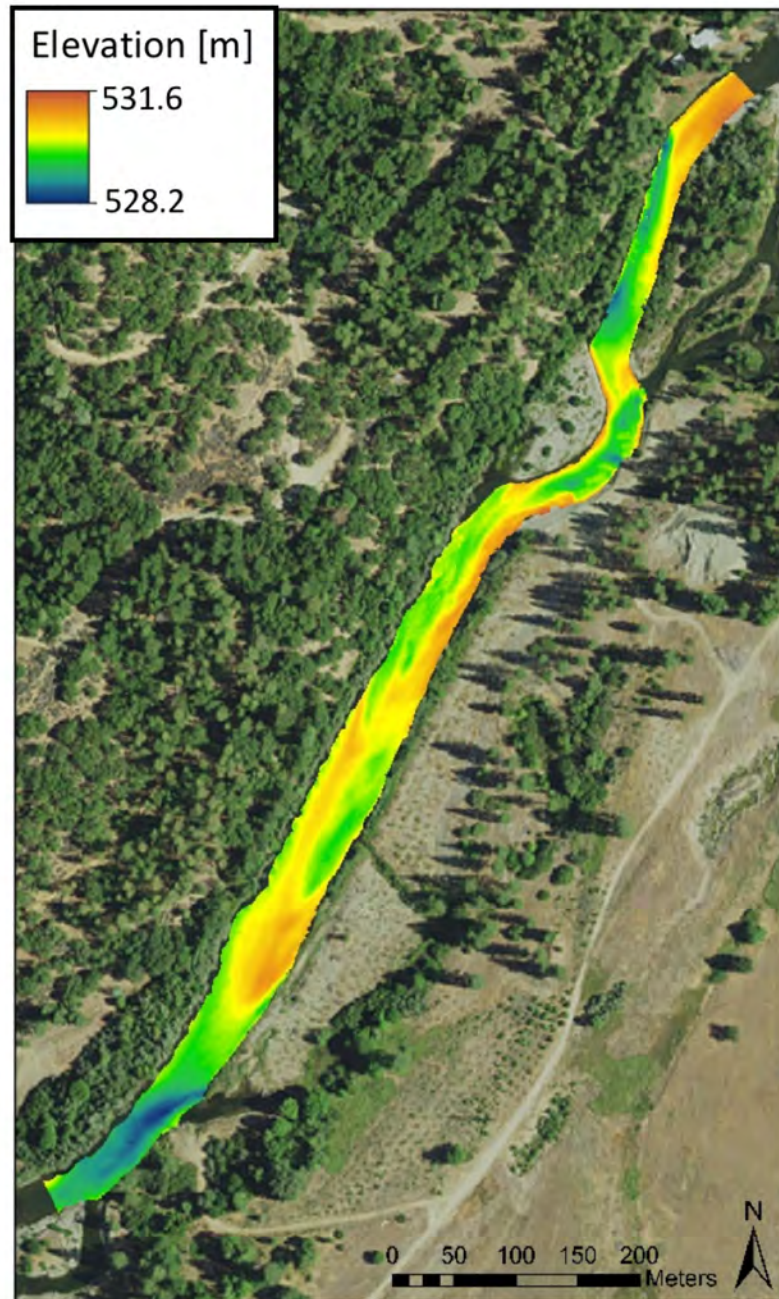
Steady alternating bar morphology with ~3 m of relief was not strongly modified during the high discharge event.

Migrating bedforms during event have maximum relief of ~0.3 m

Gravel bed channel produces ~15-20 dB lower power compared to predictions for bedrock channel signal

Estimated bedload from physical sampling

Prediction for bedrock (rather than gravel) channel

Observed during peak transport

Predicted bedload flux constrained by physical sampling and bathymetry changes, uses analytical model of Tsai et al. [2012]
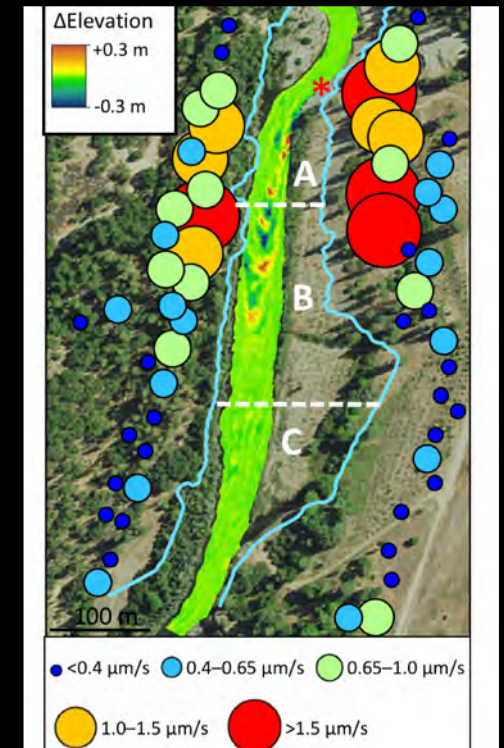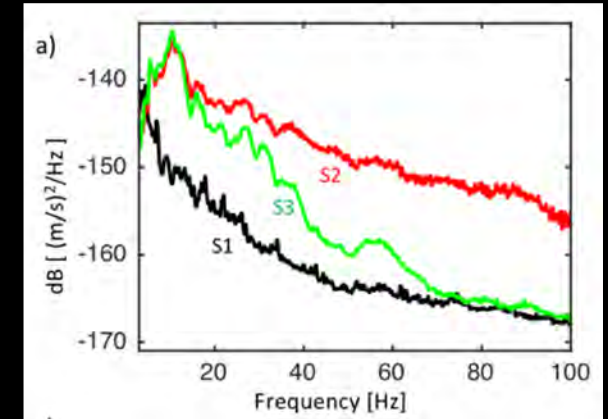
Seismic constraints on bedload transport at the Trinity River

- Time scale to adjust to supply perturbation, ~7-10 hours favors shorter higher discharge events

- Change in seismic amplitude coincident with along stream change from migrating gravel dunes to plane-bed saltation

- Potential to constrain dissipation of impact energy in alluvial versus bedrock channel segments
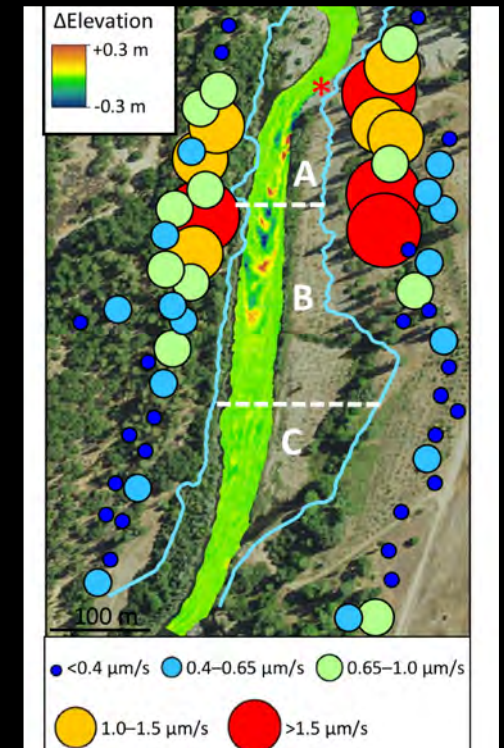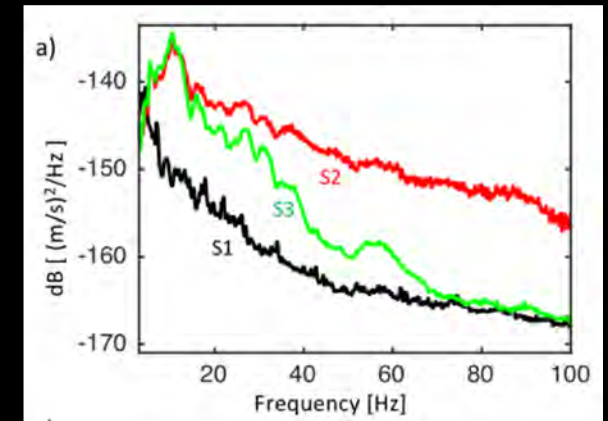
Seismic constraints on bedload transport at the Trinity River

Questions?

Hammer source amplitude decay