Hyporheic flux and antecedent flow conditions influence the retention and release of fine sediment and nutrients from streambeds

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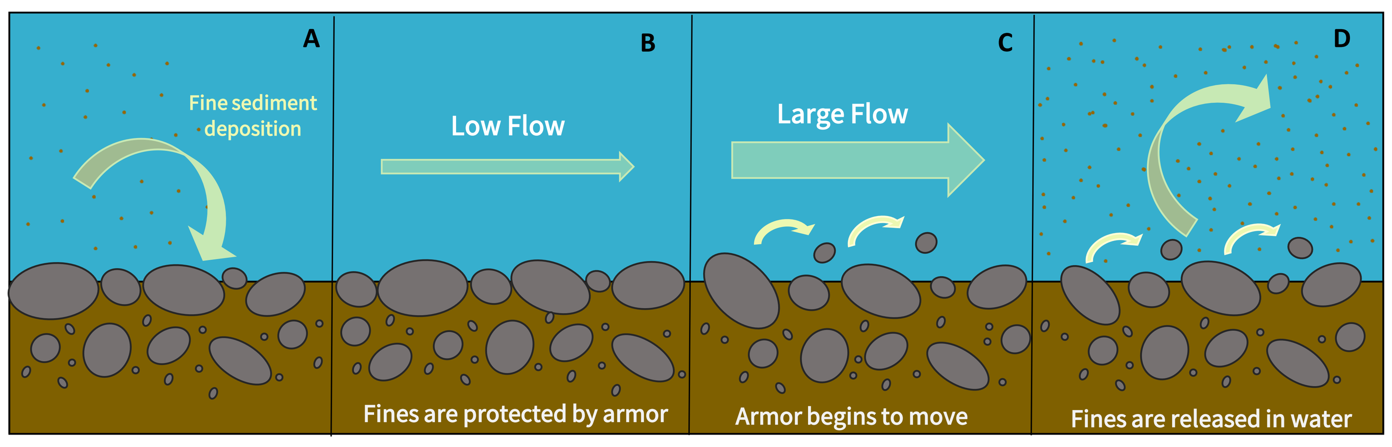
Environmental System Science Program

Introduction

- The armor layer protects the finer bed subsurface from erosion, but when dislodged during high flow events it can release fine sediment enriched in Phosphorus (P) and Organic Carbon (OC).
- **Hysteresis and seasonal variations** in particulate and soluble reactive phosphorus (PP and SRP) and in Particulate Organic Carbon (POC) could be **controlled by armor layer motion**, which protects finer subsurface sediment from erosion.
- The **critical shear stress (τ_c)** is the stress needed to initiate bedload transport, which varies in time depending on previous flow conditions (magnitude and time)



- The released concentrations of suspended sediment (SS), PP, SRP and POC will depend on the subsurface sediment composition which may partly vary with local hyporheic flux, as it brings water column SS into and out of the streambed.
- Variations in τ_c can also control the timing of armor layer movement.

Methods

1. Capturing Hysteresis:

Turbidity
Collected using a YSI EXO2 Sonde

Water samples (SS, SRP, PP and POC)
Stage-triggered portable ISCO samplers

Flow depth and Discharge
Pressure transducers in stilling wells

Study Site: La Jara Creek, Valles Caldera National Preserve, NM

Channel slope: 8-10% and width: 1 m

2. Armor layer movement:

Tracer particles and Hydrophones

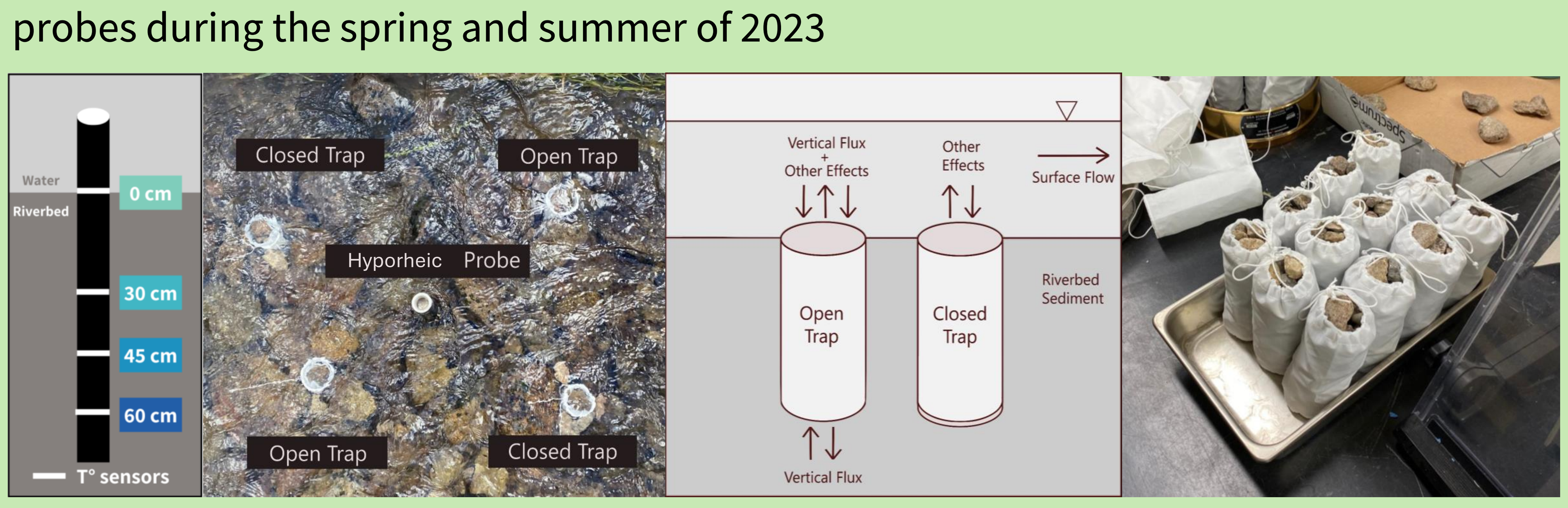
Particle sizes & distances — Particle sizes & timing

Laboratory Procedures
SS – Laser diffraction method (LISST portable XR)
POC – Eurovector elemental analyzer coupled to an Isoprime IRMS
SRP & PP – SpectraMax M2e

- Tracer particle locations were recorded **before** and **after** each high flow event and transported distances were computed through the **triangulation method**
- Hydrophone acoustic signals determine when armor layer moves
- Laboratory flume experiments to quantify how τ_c varies with antecedent flow conditions

3. Hyporheic-induced sediment deposition:

Sediment traps with open and closed bottoms were installed next to hyporheic flux probes during the spring and summer of 2023



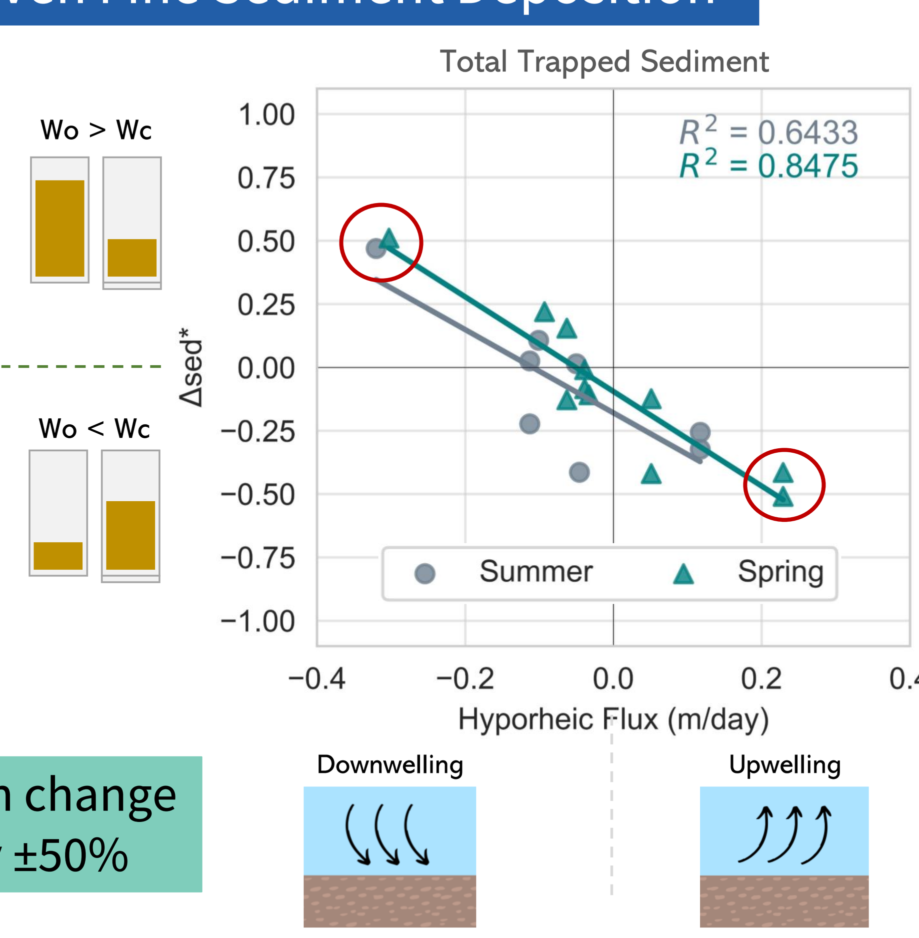
iFLOW (Bertagnoli, et al., 2024) to calculate advective flux using temperature record of the probes

Results — Hyporheic-Driven Fine Sediment Deposition

Percent Difference:

$$\Delta sed^* = \frac{W_o - W_c}{W_c}$$

- Downwelling: more sediment in open traps
- Neutral fluxes: similar amounts
- Upwelling: more sediment in closed traps



Vertical hyporheic flux can change sediment deposition by ±50%

- Longer suspended sediment duration in spring allows for hyporheic flux to influence deposition from the water column for longer, enhancing its effect.
- Hyporheic flux may be able to influence deposition of sand moving as bedload.

Results — Seasonal Constituent Hysteresis

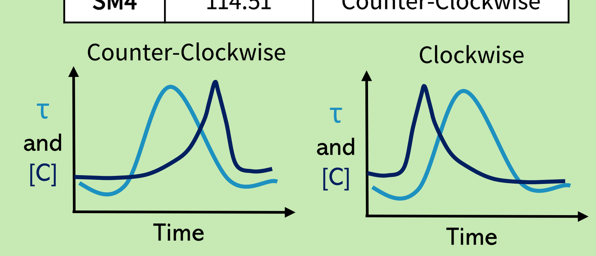
A total of 7 summer storm and 4 snowmelt high flow events were captured for hysteresis.

Peak constituent concentrations

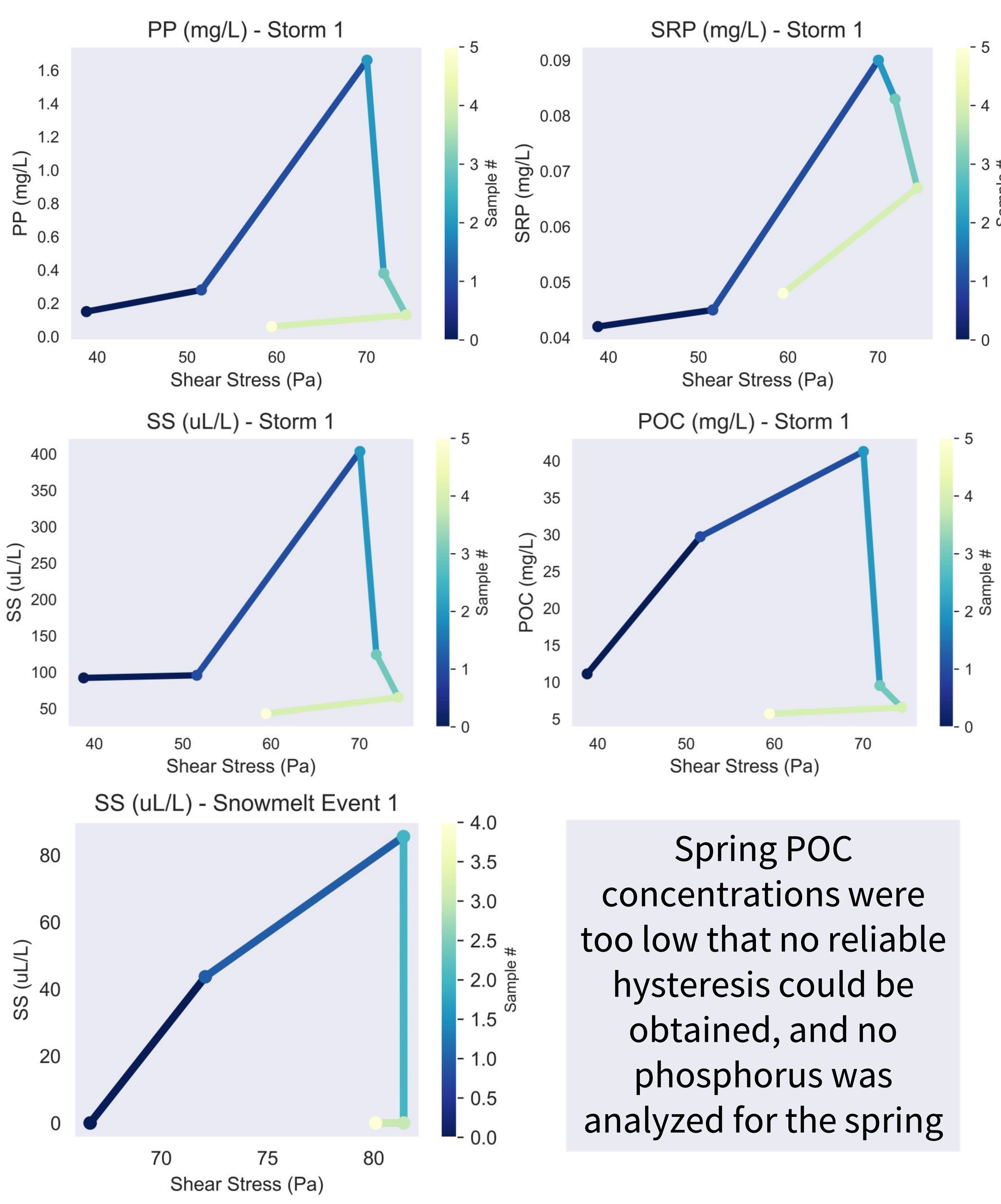
Storm	SS (uL/L)	POC (mg/L)	SRP (mg/L)
ST1	403.52	41.28	0.090
ST2	206.82	6.78	0.071
ST3	204.03	5.37	0.051
ST4	327.45	13.91	0.072
ST5	183.81	5.55	0.082
ST6	232.05	12.67	0.177
ST7	95.96	5.137	-
SM1	85.50	-	-
SM2	64.14	2.29	-
SM3	87.10	3.15	-
SM4	99.54	2.92	-

Peak shear stress and resulting SS hysteresis

Storm	Peak τ (Pa)	SS Hysteresis
ST1	74.39	Clockwise
ST2	23.24	Clockwise
ST3	31.55	Clockwise
ST4	19.49	Clockwise
ST5	2.76	Clockwise
ST6	2.27	Clockwise
ST7	6.69	Clockwise
SM1	81.41	Clockwise
SM2	89.63	Clockwise
SM3	126.94	Clockwise
SM4	114.51	Counter-Clockwise



Example Hysteresis Patterns in Summer and Spring



Spring POC concentrations were too low that no reliable hysteresis could be obtained, and no phosphorus was analyzed for the spring

Particulate constituents (SS, POC and PP) exhibited clockwise hysteresis in the summer. SS behaved similarly in the spring, except for the last high flow event, suggesting depletion of local sediment sources after consecutive high flow events.

Dissolved constituents (SRP) differed in their behavior. Hysteresis for SRP changed for different summer storms. This suggests that SRP might come from different source.

Constituent concentrations were higher in the summer on average, while also experiencing lower peak shear stresses compared to the spring.

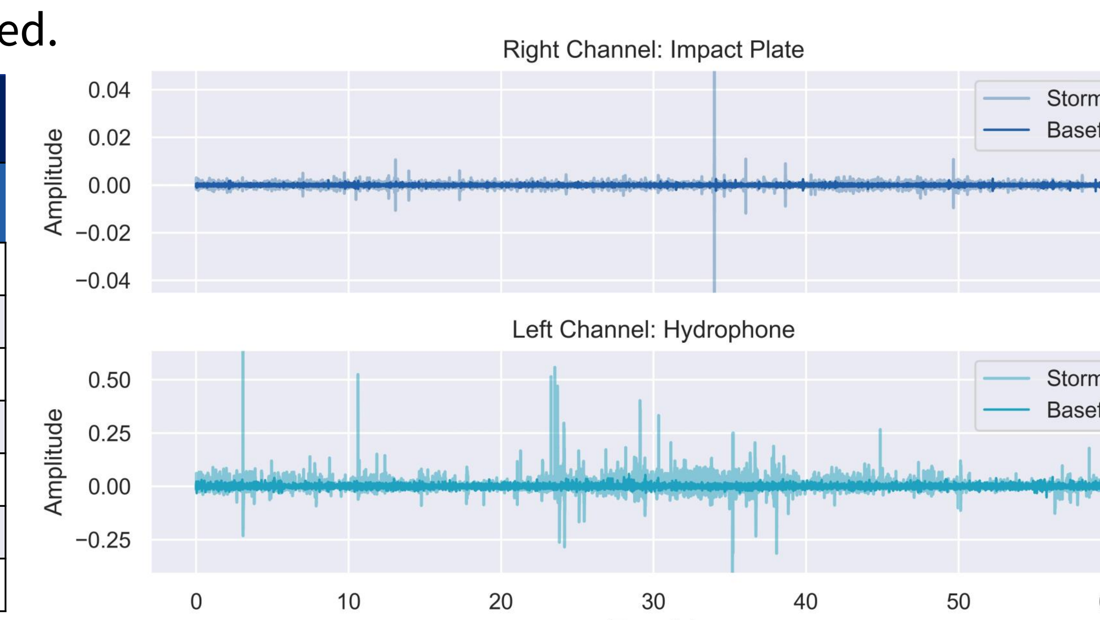
Results — Armor Layer Movement and τ_c

RFID tracer particles: Armor was displaced for each storm. Average traveled distances for each size class and percentage of bed displacement related to peak shear stresses.

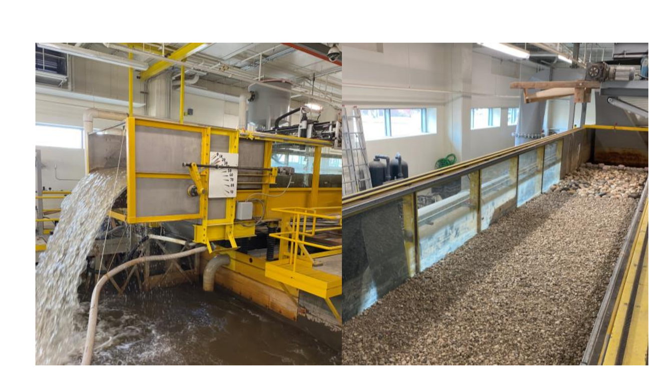
Hydrophones: Preliminarily, all summer storms had **sediment transport occur on the rising limb** of the hydrograph, and specific transported sizes are yet to be determined. Spring recordings have not yet been analyzed.

Timing Between Hydrograph Peak and First Sediment Transport Acoustic Signal

Storm	Date	Hydrograph Peak Time	Transport Signal Time
ST1	07/23/2021	16:30	13:01
ST2	08/03/2022	15:15	14:31
ST3	08/08/2022	15:00	14:16
ST4	07/29/2023	15:30	13:30
ST5	08/13/2023	18:45	18:30
ST6	08/28/2023	12:15	12:15
ST7	09/14/2023	18:00	14:00



Laboratory flume experiments: Critical shear stress varies with both antecedent flow magnitude (flow shear stress) and the duration of antecedent flows, which would be the magnitude and duration in between high flow events in La Jara. This implies hysteresis in fine sediment and nutrients may be partly driven by temporal changes in τ_c



StreamLab at the Center for Ecohydraulics Research, Boise

Current and Future Work

- Our results so far indicate that armor layer motion can be a significant source of fine sediment and organic carbon.
- We are currently looking at better ways to characterize the hysteresis loops by **calculating common hysteresis indexes (HI)** in the literature as well as our own. These can be very useful for determining sediment sources, exhaustion and general transport properties.
- **Hydrophone signal calibration** to physical samples and tracer particles is still necessary to calculate displacement of particle sizes corresponding to the armor.
- Laboratory flume experiments with several different antecedent flow conditions to predict how τ_c varies in time.
- To additionally test fine sediment sources, we are attempting an end member analysis using carbon and nitrogen stable isotopes ($\delta^{13}C$ and $\delta^{15}N$, respectively)

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