Flux-Driven Deposition: The Influence of Vertical Hyporheic Flux Direction and Magnitude on Fine Particle Deposition

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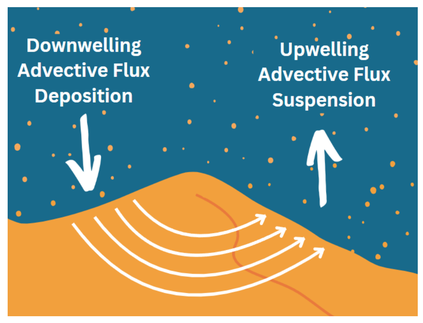
Background and Motivation



- Hyporheic flow - the movement of water through subsurface fluvial sediments - is vital for aquatic ecosystems by supporting nutrient cycling and solute transport.
- Fine sediment (sand, silt and clay) deposit onto the riverbed after high flow events due to gravitational settling and turbulence.
- Deposition can also be influenced by vertical hyporheic flux (VHF) but has mostly been studied for silt in clay and in sand-bedded channels and less is known about how VHF influences sand in steep, coarse mountain streams.

Research Questions:

- What role does vertical hyporheic flux play in fine sediment deposition compared to other processes?
- How do downwelling and upwelling fluxes influence the transport and storage of different grain sizes in mountain streams?

Methods

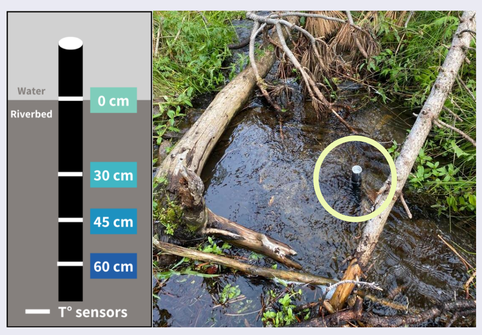
Field campaigns during 2023 spring snowmelt high flows and summer monsoon storms were conducted to capture sediment transport, deposition, and local hyporheic fluxes.

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

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

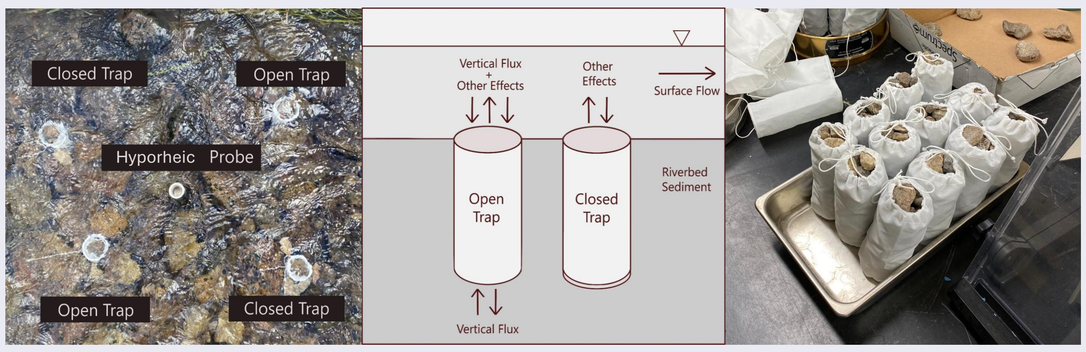
1. Measuring Vertical Hyporheic Flux:

- Installed seven temperature-based flux probes along the channel to record data every 15 minutes. Probes measure temperature at multiple depths to estimate vertical exchange between surface water and the riverbed.
- iFLOW (Bertagnoli, et al., 2024) to calculate advective flux using temperature record of the probes, focusing on the **top 30 cm**.
- Lastly, we calculated **seasonal average flux** magnitude during active sediment transport to represent VHF at each probe.



2. Measuring Sediment Deposition:

- Deployed **paired sediment traps** (open-bottom and closed-bottom) at each flux probe location. Open-bottom traps allowed hyporheic exchange; closed-bottom traps blocked it to isolate deposition from other processes.
- Traps collected sediment in fine-mesh bags and coarse gravel matrix over the full season, representing the seasonal average deposition at each site.



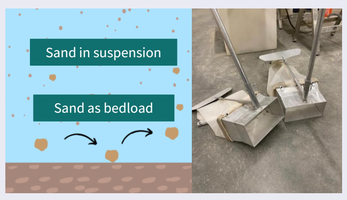
$$\Delta sed^* = \frac{W_o - W_c}{W_c}$$

W_o: Sediment weight in open traps
W_c : Sediment weight in closed traps

- Calculated the **normalized difference in sediment mass (Δsed*)** between open and closed traps to isolate the contribution of vertical hyporheic flux to deposition.

3. Water Column Sediment and Bedload Transport:

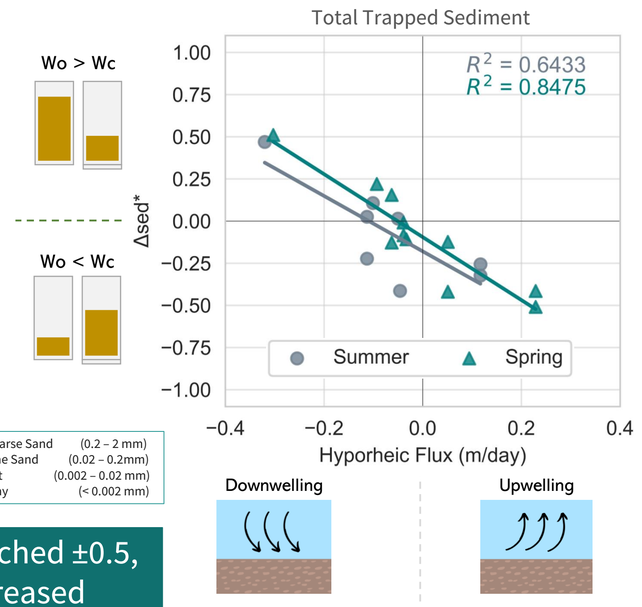
- Deployed a **turbidity sensor** and **ISCO samplers** to collect water samples and monitor suspended sediment. Grain size distributions were obtained using a **LISST portable XR** laser diffraction instrument.



- Bedload samples were obtained during spring high flow events and bedload transport was estimated through critical shear stress (τ_c) analysis from Wilcock and Kenworthy, 2002

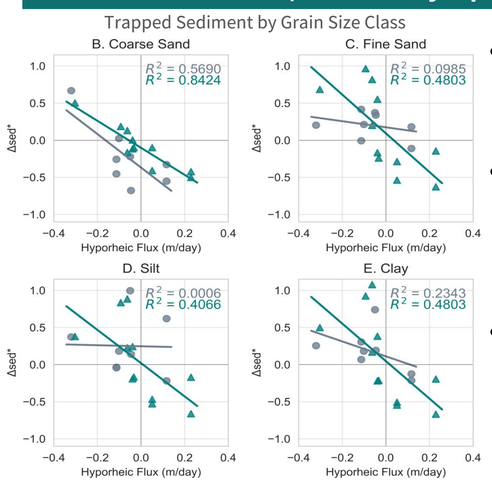
Results

- **Downwelling** (negative VHF) increases deposition in open traps — Δsed* is positive, as water carries sediment into the bed.
- **Near-zero exchange** (neutral VHF) results in similar deposition between open and closed traps — Δsed* is close to zero.
- **Upwelling** (positive VHF) reduces deposition in open traps — Δsed* becomes negative, as water moves sediment out of the bed.



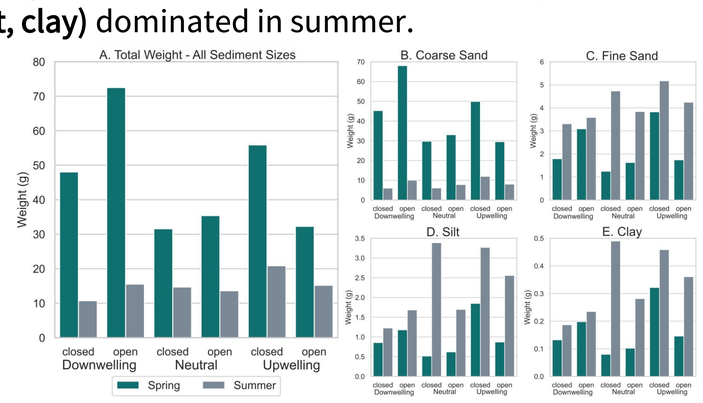
Coarse Sand	(0.2 – 2 mm)
Fine Sand	(0.02 – 0.2mm)
Silt	(0.002 – 0.02 mm)
Clay	(< 0.002 mm)

In extreme cases, Δsed* values reached ±0.5, meaning VHF increased or decreased sediment deposition by up to 50%.



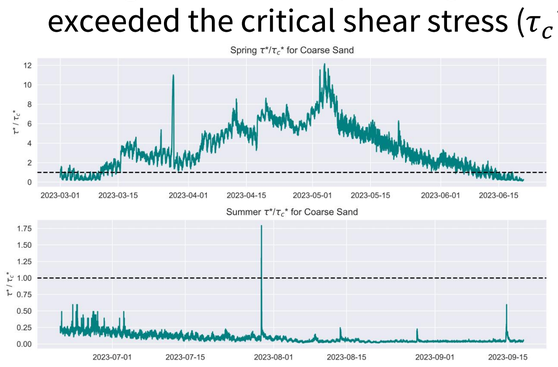
- **Coarse sand showed the strongest relationship** with VHF, out of all grain sizes for both spring (R^2 = 0.85) and summer (R^2 = 0.64).
- **Spring had significant relationships** between Δsed* and VHF for all grain sizes, while summer showed no significant patterns for fine sand, silt and clay.
- These sediment relationships may result from overall differences in **total sediment deposition** between spring and summer, independent of hyporheic flux.

- **Spring traps collected more total sediment** than summer traps.
- This difference was driven by **higher coarse sand deposition** in spring, while **finer sediments (fine sand, silt, clay)** dominated in summer.
- On average, spring traps had **180% more coarse sand** and **56% less fine sediment** by weight compared to summer.
- This matched water column grain size distributions, where lower concentrations of fines were available in spring compared to summer.



Higher coarse sand deposition in spring and better coarse sand Δsed* and VHF relationship: Bedload transport

- **Spring flows** were high enough to mobilize coarse sand as bedload and regularly exceeded the critical shear stress (τ_c*=0.867), while summer flows rarely did.



- Bedload support this, with spring samples being ~49% coarse sand and 21% gravel
- Stronger coarse sand–VHF correlations suggest **bedload is responsive to VHF due to sustained riverbed contact.**

Overall better relationships in spring than in summer: Time in Suspension

- Spring sediment stayed suspended ~9x longer, increasing chances of VHF interaction with the water column and driving sediment deposition of all sizes.
- Summer short storm durations limited VHF influence, causing worse relationships.
- Lower shear-to-settling ratios for summer concentrated fine sediment near the bed, enhancing deposition amounts independent of VHF.

Main Findings and Conclusions

- Vertical hyporheic flux (VHF) alters sediment deposition by up to 50%. Downwelling enhances deposition while upwelling reduces it.
- Longer sediment suspension times will allow longer water column and VHF interaction, enhancing the relationship between Δsed* and VHF.
- Coarse sand being transported as bedload can be affected by VHF as it is closer to the riverbed interface and is readily exposed to VHF.
- Our findings are one of the first demonstrations of the relative contribution of VHF to sediment deposition compared to other effects in mountain streams.