Imaging the Subsurface: The Effect of Logjams on Groundwater-Surface Water Exchange

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1.Introduction

Initiative: Analyze the effect of logjams on the extent of groundwater-surface water exchange for the first time in a field-setting, using electrical resistivity imaging, a two-dimensional geophysical technique

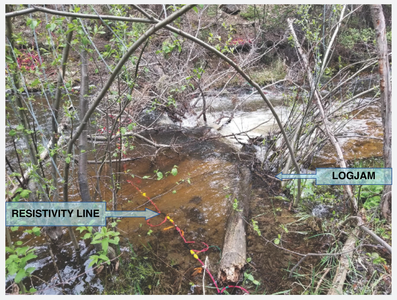

Figure 1. Logjam reach at Little Beaver Creek, the experiment site. ERI set-up displayed, where the resistivity line runs perpendicular to the stream, creating a cross-section.

Traditional methods of measuring exchange are intrusive and incomplete:
-cumbersome borehole installation
-point-measurements sense change in one location (1D), which limits understanding of dynamic exchange[1,5]

1.1. Hyporheic Exchange

Hyporheic exchange (HE): the mixing of groundwater and surface water under and around a stream that contributes to ***water quality*** and ***ecosystem health***[4,6] (Fig.2)

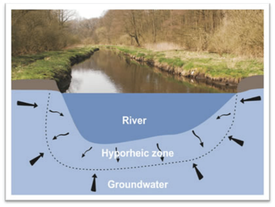

Figure 2. The hyporheic zone, where exchange of surface and groundwater occurs https://cordis.europa.eu/result/rcn/200984_en.html

Natural stream features alter the extent of HE:
- **logjams** increase hydraulic resistance, driving water deeper in subsurface
  - -sudden formation (floods, beavers)—> rapid stream alteration
- **discharge** (flow rate of water) may affect time spent in subsurface or **residence time**, RT)
  - -low-flow may increase RT[3]

Figure 3. Preparing equipment for stream measurements, like discharge. Pictured from left to right: Teodora Mitroi, Jackie Randell, Megan Doughty

Longer residence time allows water to be processed by hyporheic exchange longer, increasing water quality

1.2. Electrical Resistivity Imaging

Electrical Resistivity Imaging (ERI): geophysical surveying method that used to obtain two dimensional (2D) subsurface profile[5]

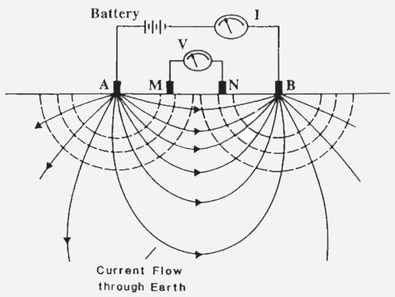

Figure 4. ERI survey of the subsurface: four electrode placed in ground, forming a resistivity array; https://tinyurl.com/y7zhdg39

How it works:
-Electrodes placed across reach—>resistivity-meter sends current through cable (Fig.5)
-Solute is injected in stream as a tracer—> subsurface data collection

Why it works:
- Raw resistivity is collected and used to calculate bulk/apparent resistivity, ρ_a
  - $\rho_a = Rk \quad (\Omega \cdot m)$
  - R=resistivity

Bulk resistivity: average resistivity of soils and rocks influencing current flow
- Electrode spacing accounted for in geometric factor, k
  - A,M,N,B = electrode positions
  - $k = 2\pi\left(\frac{1}{A-M} - \frac{1}{A-N} - \frac{1}{B-M} + \frac{1}{B-N}\right) \quad (m)$

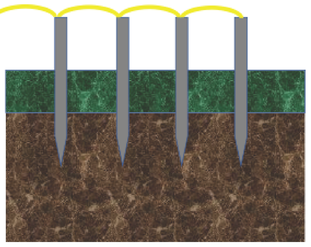

Figure 5. Electrode set-up, with cable attached at the top.

- Bulk vs. Fluid Conductivity: bulk measures heterogeneous subsurface while fluid represents homogeneous surface water[2]

2. Methods

Figure 4. Little Beaver Creek, Arapaho and Roosevelt National Forest, CO

Site Location:
Northern Colorado, Little Beaver Creek

(40.63714017670, -105.52384156100)

Salt used as tracer because it is conservative and conductive, making it easy to detect on a graph.
Equipment:
- -Point-measurement- HOBO logger in stream
- -ERI- Iris Syscal Pro (Fig. 6)
- -Discharge- Velocity Flow Meter

Figure 6. Iris Sal Pro, the resistivity-meter
https://www.geomatrix.co.uk/marine-products/electrical-resistivity/syscal-pro-deep-marine/

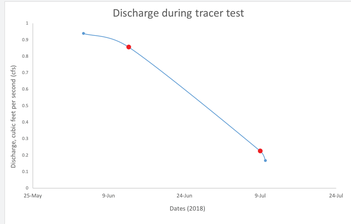

Figure 7. Discharge or flow of the Little Beaver Creek stream during injection June 13, 0.85514 cfs; July 9th, 0.22474 cfs

Measurements taken at two reaches (logjam and control):
- -Fluid Conductivity-point-measurement
- -Raw Resistivity with electrode spacing-ERI data
- -Discharge- flow of June and July test date (Fig.7)

Data processing: MATLAB

3. Results

Fluid vs. Bulk Electrical Conductivity (EC):
-Fluid has minimal tailing (Fig.8A1)
-Bulk has substantial tailing (Fig.8A2)
-Noise from fluid EC measurement

Control vs. Logjam:
-Logjam tailing slower return to background (Fig.8B3)
-Control has slight bump after tracer ends (Fig.8C4)

Flow:
-Low-flow injection slower return to background (Fig.8B3 vs. Fig.8D5)

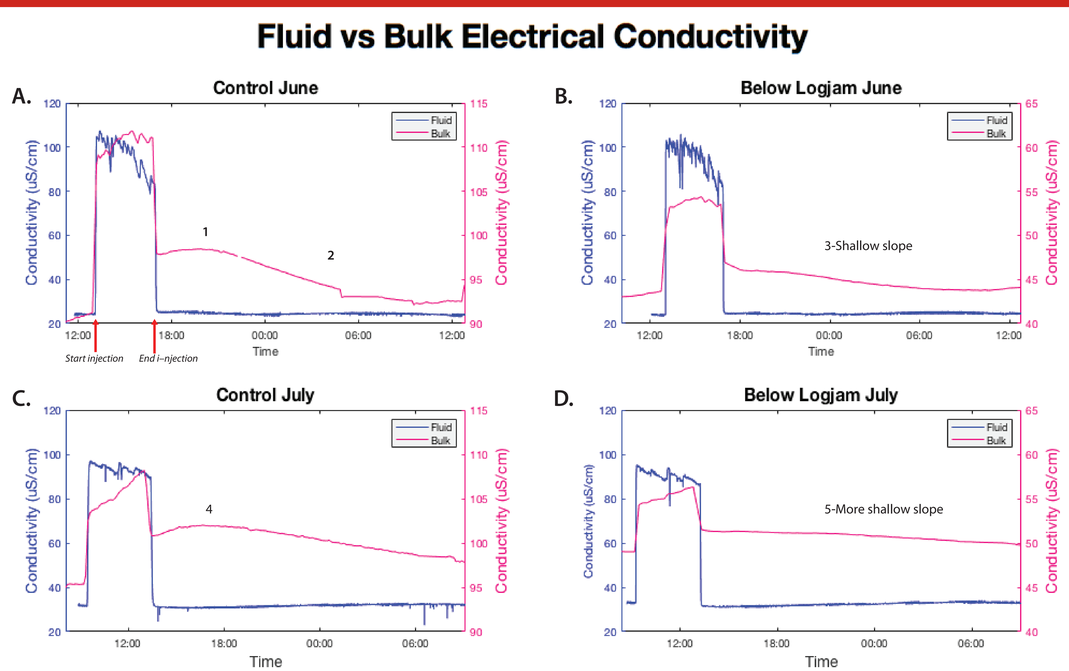

Figure 8 (A,B,C,D). Fluid conductivity versus bulk conductivity during June and July. June has a high-flow discharge rate due to ice-melt (.8551 cfs) while July has a lower discharge rate (.2274 cfs). Data collection occurred at two reaches, control and below logjam.

4. Discussion

June high-flow due to snow-melt

Bulk tailing —> demonstrates subsurface uptake and release

Due to increase in hydraulic resistance, logjam reach implies slower movement in the subsurface.

Results show flow rate influences rate of solute discharge.

Low-flow and logjam: may indicate longer residence time, meaning more filtration.

5. Conclusions

-Logjams increase the extent of hyporheic exchange due to an increase in hydraulic resistance. Longer residence times may occur when flow is low and in the presence of logjams.

-ERI is demonstrated to show a more accurate representation of the subsurface, unlike fluid EC, where noise was abundant.

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