Moving beyond a snapshot: towards a time-continuous understanding of hyporheic exchange

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Hi All! Recently, I received a 2015 AGU Horton Research Grant. I am very grateful and honored to accept this grant. I'd like to use this post to share my proposed research questions and methods with the YHS community.

What is a Hyporheic Zone and Why Should We Care?

Flowing stream waters are hydrologically connected to adjacent groundwaters. These connections help maintain the physical and chemical integrity of streams. In a uni-directional sense, streams lose and gain water to/from groundwater aquifers. In a bi-directional sense, streams are connected to groundwaters via hyporheic exchange (HE) flowpaths. HE moves water, nutrients, dissolved oxygen, and carbon into and out of hyporheic zones (HZs) - saturated subsurface regions beneath and adjacent to a stream channel, where streamwaters and groundwaters mix. In the HZ, sufficiently long residence times and contact with microbes facilitates nutrient transformations vital to the health of stream ecosystems (Boulton et al., 1998).

Given the ecological significance of HZs, it is necessary to understand the physical functionality of HZs over a broad spectrum of timescales (seconds to years). Our current understanding of HE is largely based on experimental tracer evidence. During a tracer experiment, solutes are injected into flowing steamwaters and move downstream. Samples are taken several hundred meters downstream of an injection sire to measure the temporal "breakthrough" of the added solutes. The analysis of solute "breakthrough curves", reveals useful information about the physical and chemical function of HZs. However, the duration of tracer experiments are short (hours to days), and are often carried out during near steady discharge conditions. Understanding long timescale behavior of HZs, on the order of months to years, when unsteady flows dominate, remains an elusive goal for stream ecologists and hydrologists. A broader temporal perspective of HE is necessary to understand how HZ function will change as hydrologic regimes are altered by human activity and global climate change (Wagener et al., 2010).

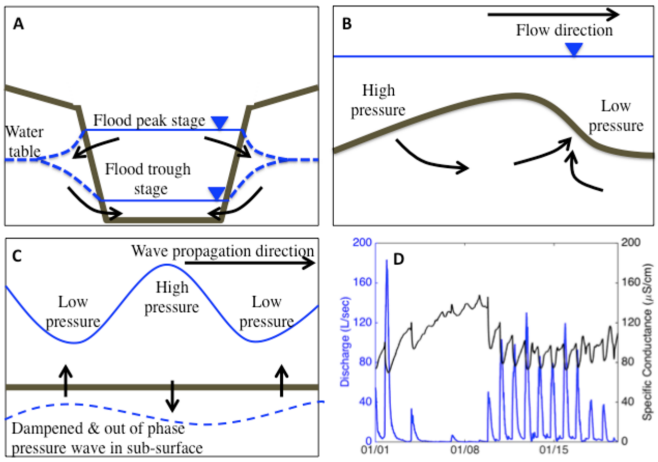

Figure 1: *Bank storage (A), bedform induced pumping (B), and wave pumping (C) are unsteady flow-driven processes controlling HE in the MDVs. Seasonal variations in stream solute loads on a MDV stream (D) are a manifestation of the co-occurrence of these processes (A-C). Schematics A-C were modified from Precht & Huttel (2003)*

The investigation of long timescale behavior of HZs, motivated my application for the 2015 AGU Horton Research Grant. My proposed research is focused on two specific goals: (1) quantifying how unsteady stream flow controls HE, and (2) developing a predictive understanding of how HZ function will

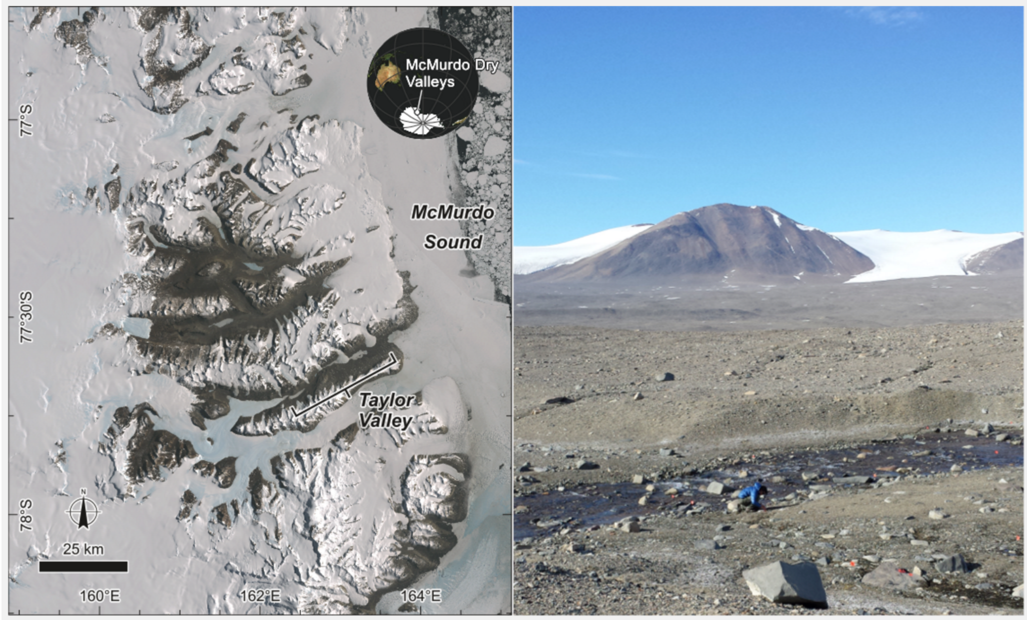

Figure 2: *A map of the greater MDV region highlighting the location of Taylor Valley. A field technician collects samples from the riparian zone of a stream in Taylor Valley, Green Creek (right). Cartographic credit: Brad Herried, Polar Geospatial Center, University of Minnesota.*

respond to climate change. To address these goals, I will monitor and model surface water - groundwater interactions along streams in the McMurdo Dry Valleys (MDVs) of Antarctica. The MDVs hydrologic system is simplified by a complete lack of vascular vegetation (i.e., transpiration), and no deep groundwater interactions Hence the MDVs provide something of an outdoor laboratory field setting.

Hyporheic Exchange and Unsteady Flows

The hydraulic behavior of HZs in temperate rainfall-runoff dominated catchments is controlled by two variable head boundary conditions: stream stage and hillslope groundwater level. Dynamic hillslope groundwater levels alter riparian hydraulic gradients and exert boundary condition controls on HE (Voltz et al., 2013, Ward et al., 2012, White, 1993). Unsteady stream flows control HE through bank storage (Chen Chen, 2003) (Figure 1, A), bedform induced pumping (Boano et al., 2007) (Figure 1, B), and wave pumping (Precht Huettel, 2003) (Figure 1, C). It becomes difficult to understand how unsteady stream flow controls HE in temperate catchments, because we must first accurately characterize spatial and temporal dynamics of hillslope storage. However, in the natural hydrologic laboratory of the MDVs, unsteady stream flow is the only forcing on HE and time-continuous stream solute loads are a manifestation of stream flow-driven HE (Figure 1, D).

The McMurdo Dry Valleys

The McMurdo Dry Valleys (Figure 2) are characterized by an extremely cold and dry climate. The long-term mean annual temperature and relative humidity as measured at Lake Hoare in Taylor Valley are -17.7 ^{o}C and 66%, respectively (Doran et al., 2002). Precipitation falls only as snow, and total annual snowfall rarely exceeds 100 mm snow-water equivalent). Streamflow is almost entirely generated by daily pulses of glacial melt and inter-annual variability in streamflow is directly related to inter-annual variability in glacier surface energy budgets. In this unique system, HZs provide a valuable nexus between aquatic and riparian hydro-ecological systems (Gooseff et al., 2011, McKnight et al., 1999).

Planned field work

Between January 1 and February 15, 2016 our field campaign will continuously monitor the hydraulic and particle response of HZs to unsteady flow variations. We will deploy a network of instrumented riparian wells to quantify how hydraulic head gradients in the HZ respond to consecutive daily floods. We will also to sample aging hyporheic waters for Rn-222 activity, which can be used to estimate hyporheic residence times. Our measurements will be used to constrain unsteady groundwater flow models, which will provide a useful tool for predicting how HZ functionality might change under future climate and runoff scenarios expected in the MDVs.

What's next?

As of now, we've shipped our field equipment to McMurdo Station, our flights are booked for a December 26 departure, and field camps in the Dry Valleys are expecting our arrival. Between now and January 1 we can only hope for a warm (and wet) season and get excited to make measurements. Believe me, there is no shortage of excitement!

Let's chat!

Do you have questions or suggestions about my proposed research? Would you like to know more about the physical hydrology of the McMurdo Dry Valleys? Stop by my poster at the 2015 AGU Fall Meeting in San Francisco!

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About the author

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