Quantifying Surface Water-Groundwater Exchange Using Temperature Profile Inverse modeling in a Riparian Wetland

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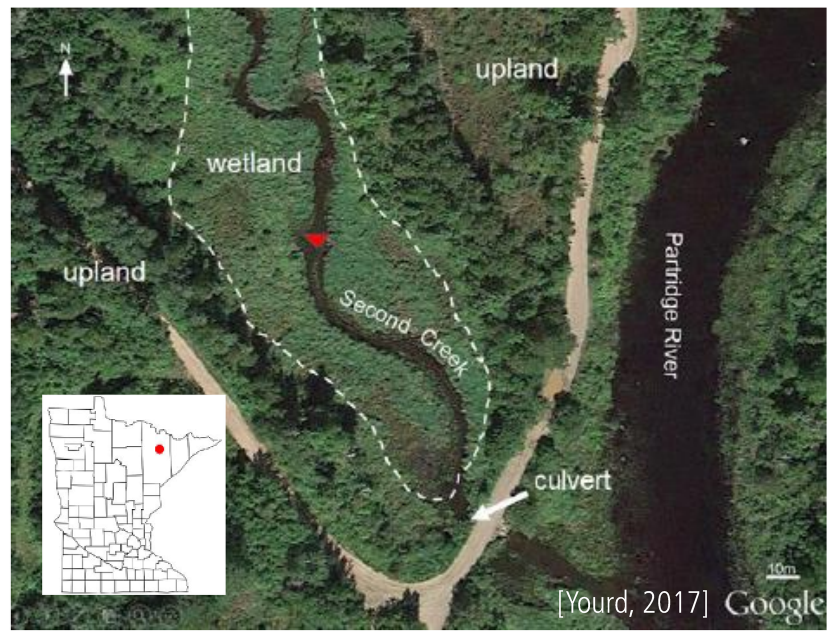
Introduction



- **Motivation**: understand how mining derived sulfate affects biogeochemical cycling in first order streams on Minnesota's iron range. The geochemical gradient is controlled by surface water-groundwater exchange (hyporheic flux) [Hayashi & Rosenberry 2002; Kurtz et al. 2007]
- **Goal:** quantify hyporheic flux at a mining impacted stream using inverse temperature profile modeling
- **Site**: Second Creek is a riparian wetland located in Minnesota's Iron Range

Methods

- Hydraulic conductivity is estimated by reducing the residual between an observed temperature profile and a modeled profile

Forward model governing equation

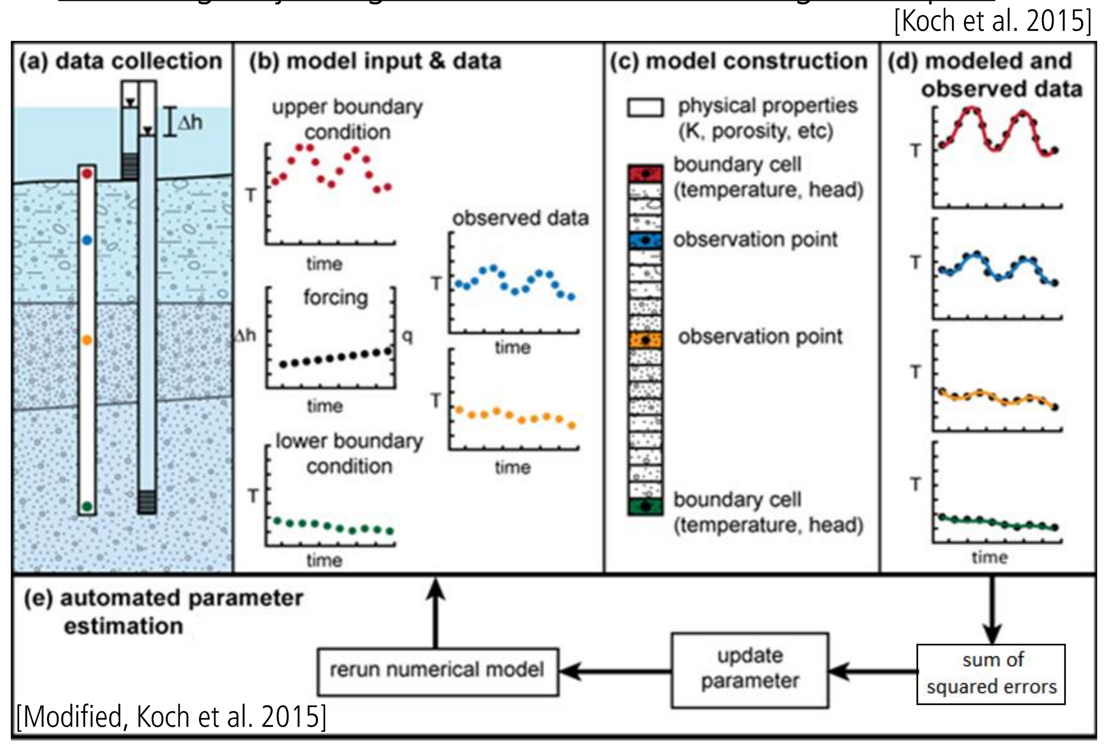
$$(\lambda_s + q_z \alpha C_w)\frac{\partial^2 T}{\partial t^2} - q_z C_w \frac{\partial T}{\partial z} = \frac{\partial T}{\partial t}(\phi C_w + (1-\phi) C_s)$$

$$q_z = -K\frac{dh}{dz}$$

[Healy, R.W., and A.D. Ronan. 1996]

Estimating K by fitting model to observations using 1DTempPro

[Koch et al. 2015]



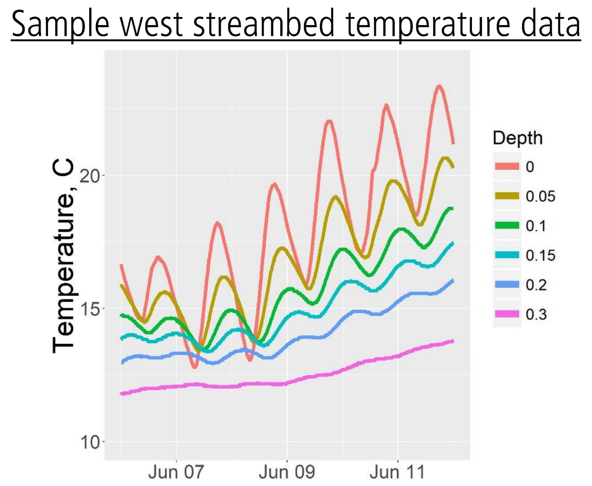
[Modified, Koch et al. 2015]

Parameter	Symbol
Hydraulic conductivity	K
Porosity	ϕ
Saturated thermal conductivity	λ_s
Sediment heat capacity	C
Water heat capacity	C_w
head	h
Dispersivity	α
Hyporheic flux	q_z
Temperature	T

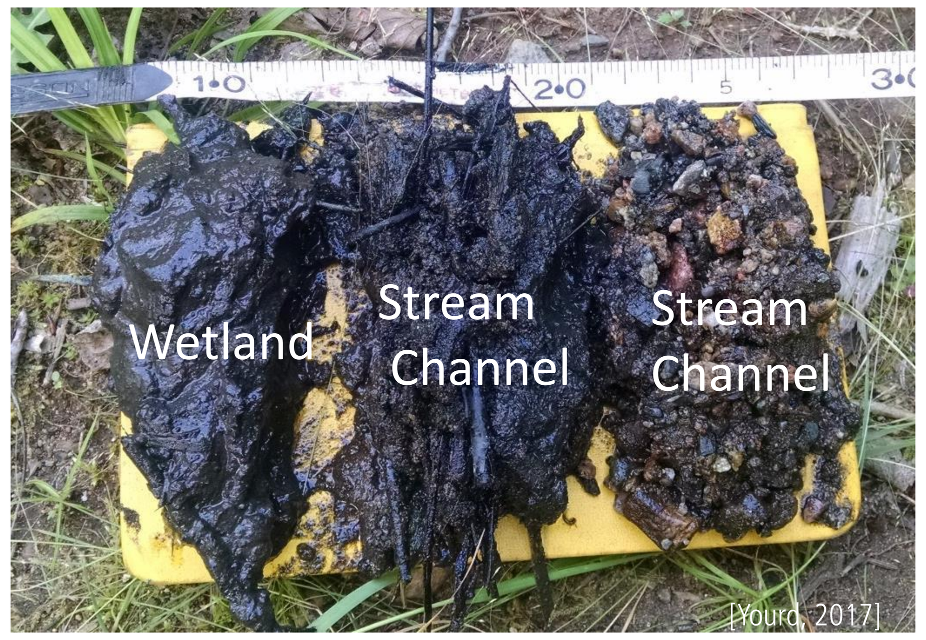
Data collection

- Three temperature probes were collocated with piezometers across the site
- Pressure and temperature were measured at 15 minute intervals to capture diurnal variability over the summer
- Data was collected using low cost, open source data loggers developed in house [Wickert, 2014]

Sample west streambed temperature data



Sediment characterization



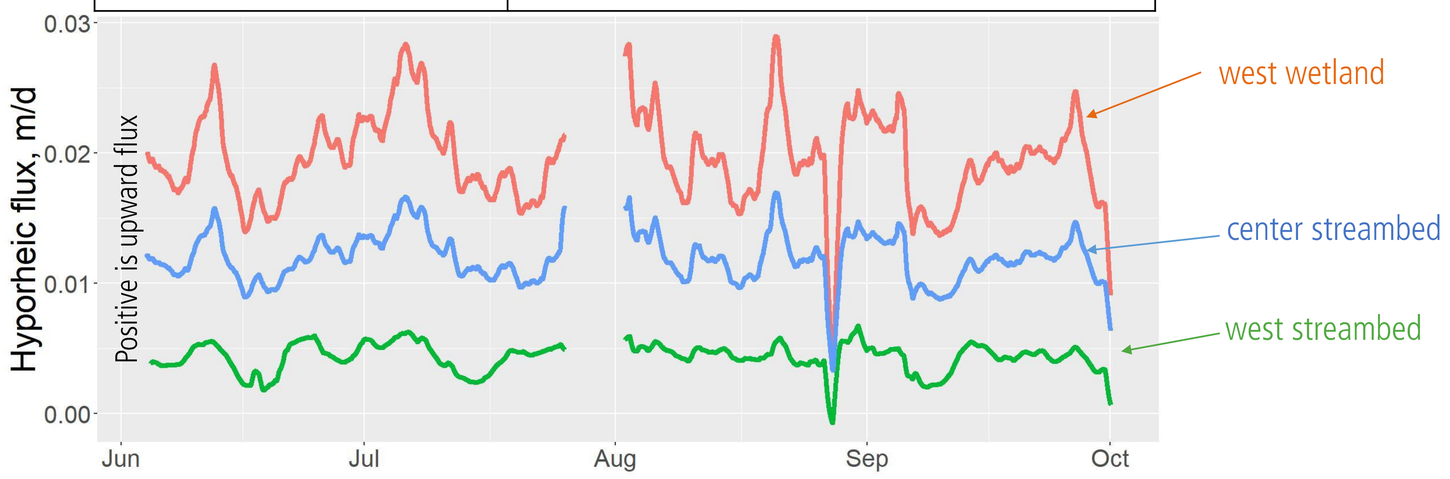
- Thermal properties of the streambed and wetland sediment are required for modeling the temperature profile
- Site sediment is characterized by high organic content, low dry bulk density, high porosity [Mybro, 2013]
- Measured dry bulk density from [Mybro, 2013] used to estimate the fraction of silicate and soil organic matter
- 80-90% SOM, 10-20% silicate
- Thermal conductivity and sediment heat capacity constrained by computing upper and lower bounds based on [Farouki,1961]

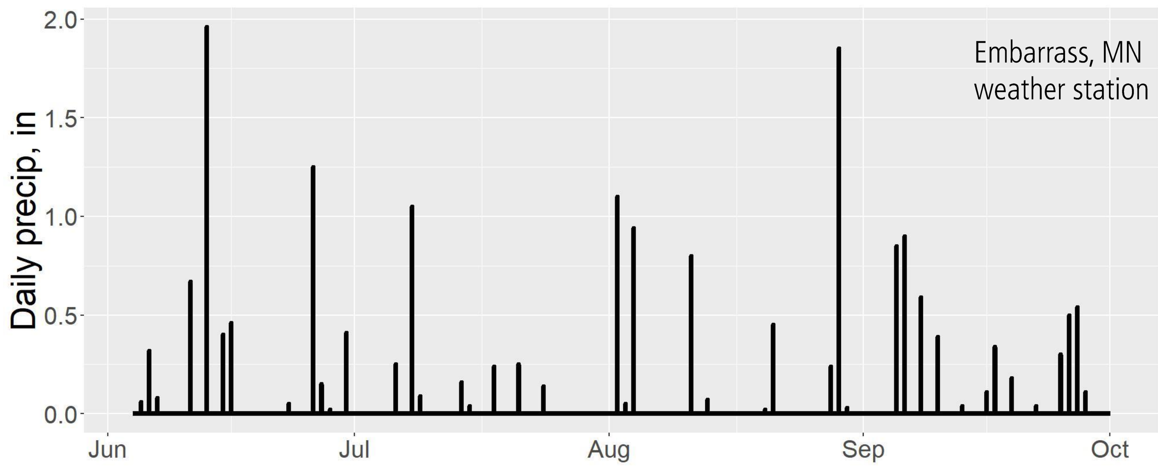
$$\lambda_{min} = \frac{x_{Si}}{\lambda_{Si}} + \frac{x_{Som}}{\lambda_{Som}} \qquad \lambda_{max} = x_{Si}\lambda_{Si} + x_{Som}\lambda_{Som}$$

- Dispersivity estimated from the range provided in [Zheng & Bennet, 1995]

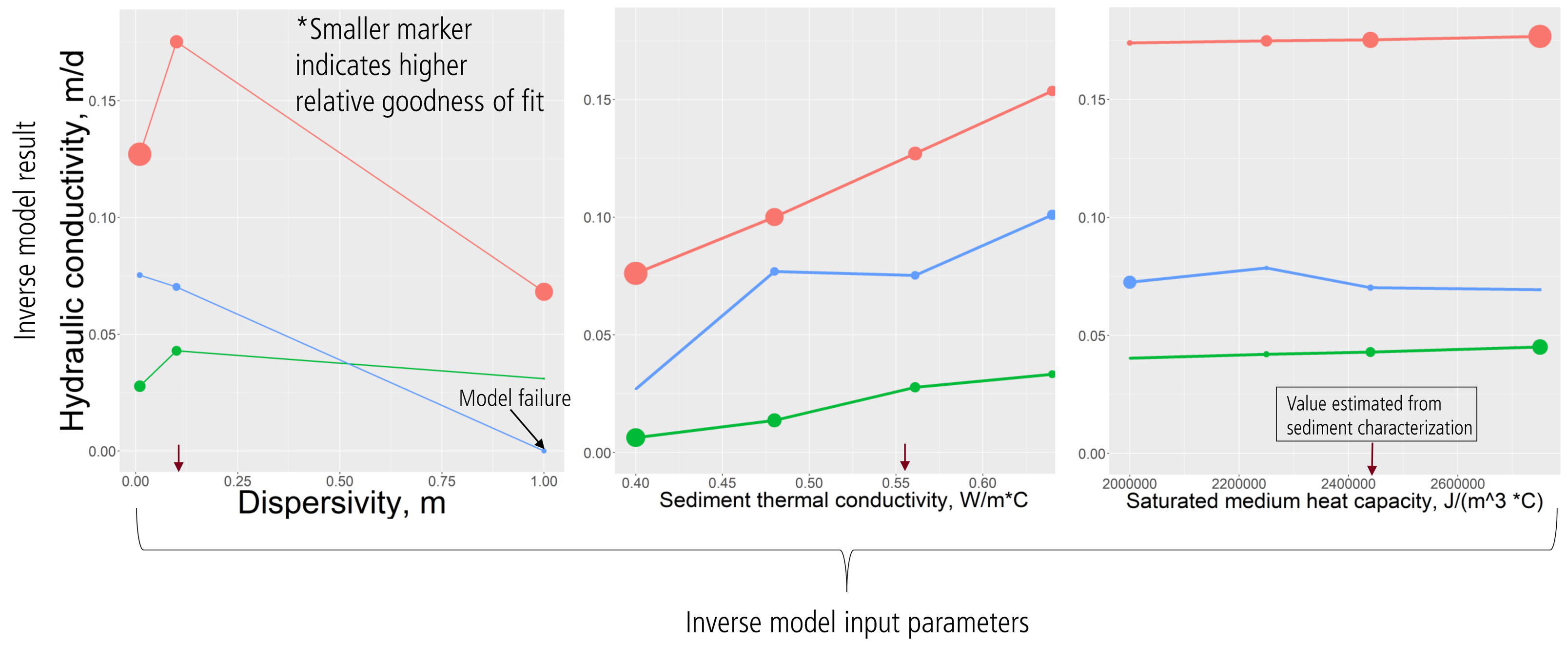
Results

Location	Hydraulic conductivity, m/d
West wetland	0.07
Stream west	0.04
Stream center	0.18





Model fit and sensitivity analysis



- Models fit the observed profiles well with average error between 0.09 and 0.17 degrees C.
- Input parameter values were chosen to minimize model misfit.
- Sensitivity testing matched intuition for dispersivity and thermal conductivity:
  - At high dispersivity, low upward flux is required and dispersity is the dominant mode of heat transport.
  - As thermal conductivity increases, larger upward flux Is required to counteract downward heat diffusion
- Saturated heat capacity is relatively insensitive compared to site variability

Conclusions

- Flux in the hyporheic zone is consistently upward throughout the summer so groundwater influences geochemistry in the streambed
- Flux is spatially variable due to sediment heterogeneity
- The lowest magnitude of flux occurs in the stream channel rather than the wetland.
- The influence of precipitation on hyporheic flux is seasonally dependent

Future work

- Similar data with higher spatial resolution, and longer collection time (May–October) was collected in 2017
- 2017 data includes a long term flux reversal and could improve heterogeneity resolution
- 2018 field campaign potential: unique parameterization based on sediment collected at each probe location

References

Farouki, O., 1961. *Thermal properties of soils*. United States Army Corps of Engineers Cold Regions Research and Engineering Laboratory.; **Hayashi, M. & Rosenberry, D.O., 2002.** Effects of Groundwater Exchange on the Hydrology and Ecology on Surface Water. *Groundwater.*; **Healy, R.W., and A.D. Ronan. 1996.** Documentation of computer program VS2DH for simulation of energy transport in variably saturated porous media – modification of the U.S. Geological Survey's computer program VS2DT. *U.S. Geological Survey Water-Resources Investigations Report.*; **Koch et al. 2015.**, 1DTempPro V2: New Features for Inferring Groundwater/Surface-Water Exchange, *Groundwater.*; **Kurtz, A.M. et al., 2007.** The importance of subsurface geology for water source and vegetation communities in Cherokee Marsh, Wisconsin. *Wetlands.*; **Mybro, A., 2013.** Wild Rice Sulfate Standard Field Surveys 2011, 2012, 2013: Final Report. *University of Minnesota.*; **Yourd, A., 2017.** *Using reactive transport modeling to link hydrologic flux and root zone geochemistry at Second Creek, a sulfate enriched wild rice stream in northeastern Minnesota, Masters Thesis, University of Minnesota.*; **Wickert, A 2014.** The Alog: inexpensive, Open Source, Automated Data Collection In the Field. *The Bulletin of the Ecological Society of America* **Zheng, C. & Bennett, G., 1995.** *Applied Contaminant Transport Modeling* . John Wiley & Sons.