

Estimating Intermediate-Scale Groundwater Net Exchange Using Synoptic Environmental Tracer Sampling

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Traditional Tracer Meth

K.R. Beisner et al.

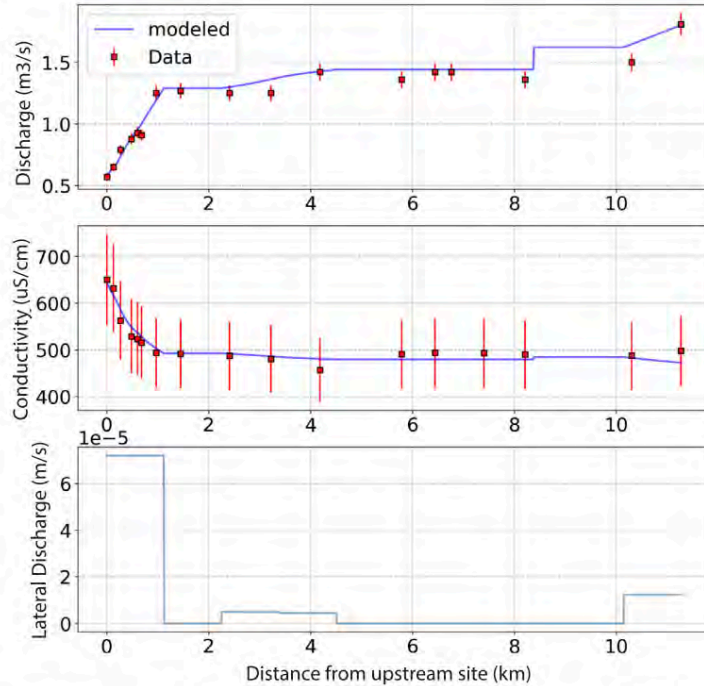


Fig. 14. Measured and modeled discharge (top), conductivity (middle), and best fit groundwater flux (bottom) along the study reach.

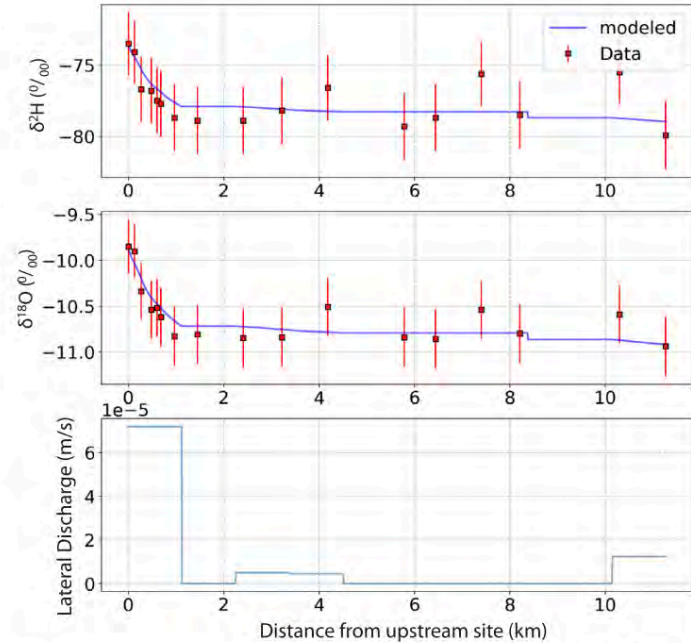


Fig. 16. Measured and modeled $\delta^2\text{H}$ (top), $\delta^{18}\text{O}$ (middle), and best fit groundwater flux (bottom) along the study reach.

ELSEVIER

High
groundwater
helium
concentration
Kelli

WILEY

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010276, 2011

water

.2

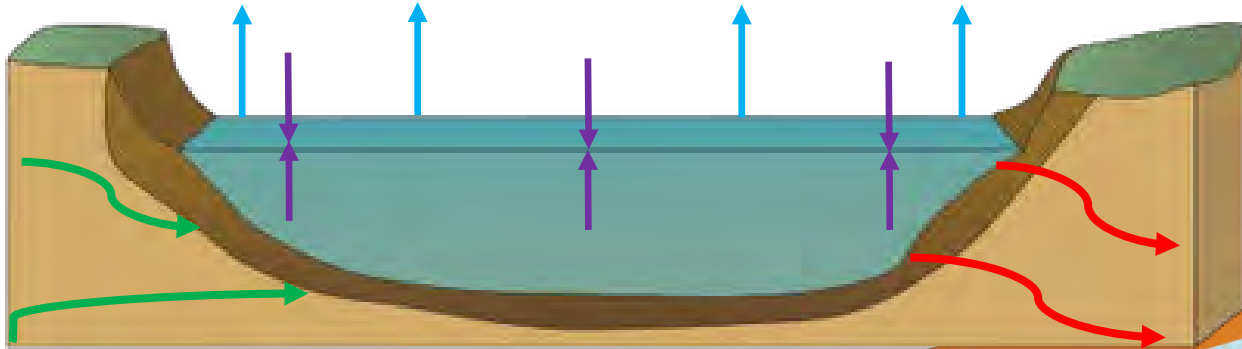
Stream Modeling

Tracer Mass balance Equation

$$\frac{dQC}{dx} \frac{1}{A} = \frac{k(C - C_{ATM})}{d} - \lambda C + \frac{Q_T C_T}{A} \delta(x - x_t) - \frac{Q_{div} C}{A} \delta(x - x_{div}) + \frac{q_{gi} C_{GW}}{d} - \frac{q_{go} C}{d}$$

Water Mass balance Equation

$$\frac{dQ}{dx} = P_w - E_w + Q_{trib} \delta(x - x_{trib}) - Q_{div} \delta(x - x_{div}) + q_{in} - q_{out}$$



Stream Transport Modeling

Chain rule!

$$\frac{dQC}{dx} = C \frac{dQ}{dx} + Q \frac{dC}{dx}$$

$$\frac{dQ}{dx} = Pw - Ew + Q_{trib}\delta(x - x_{trib}) - Q_{div}\delta(x - x_{div}) + q_{in} - q_{out}$$

Solving for $Q \frac{dC}{dx}$ - term

$$Q \frac{dC}{dx} = I(C_{GW} - C) + wEC - kw(C - C_{atm}) - dw\lambda C$$

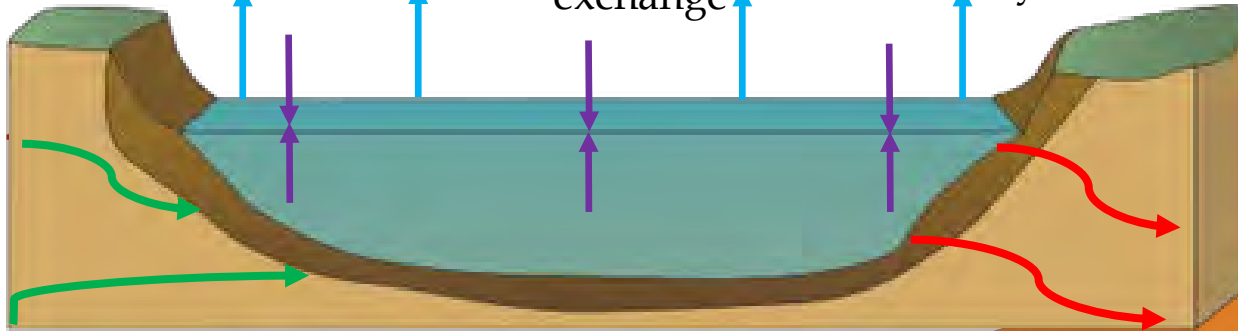
Groundwater loss

Groundwater inflow

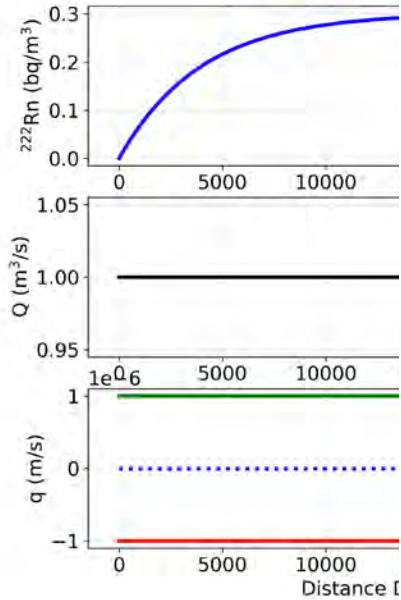
Evaporation

Gas exchange

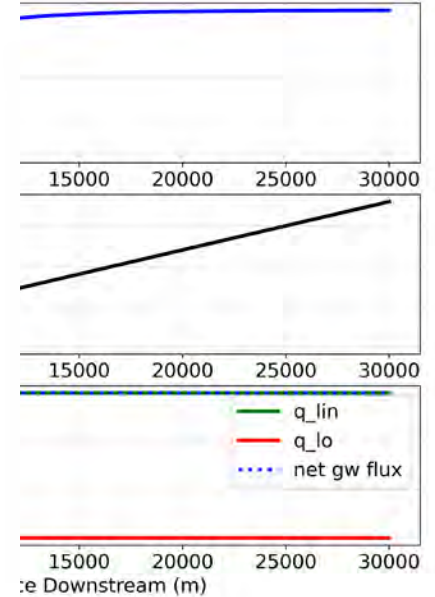
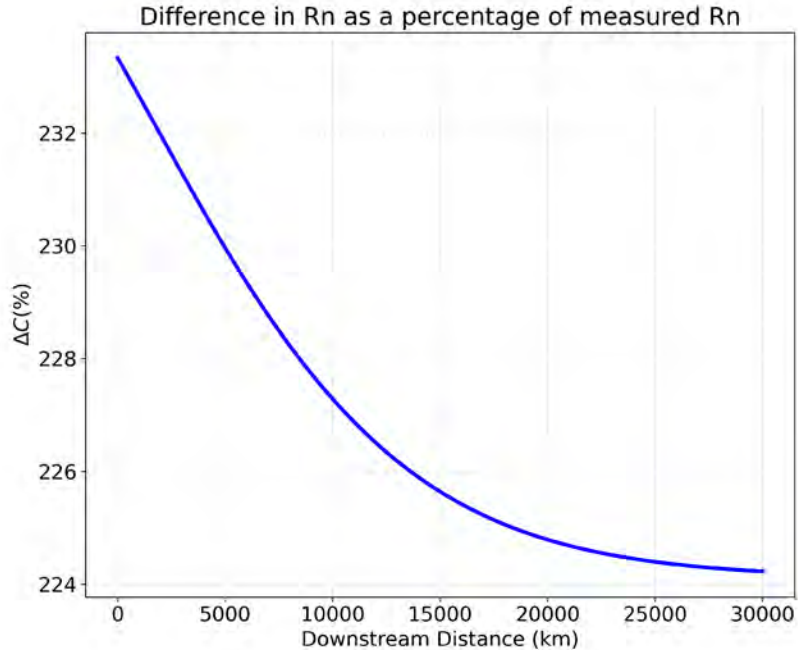
Radioactive decay



Exploring Toy Model – Constant Fluxes

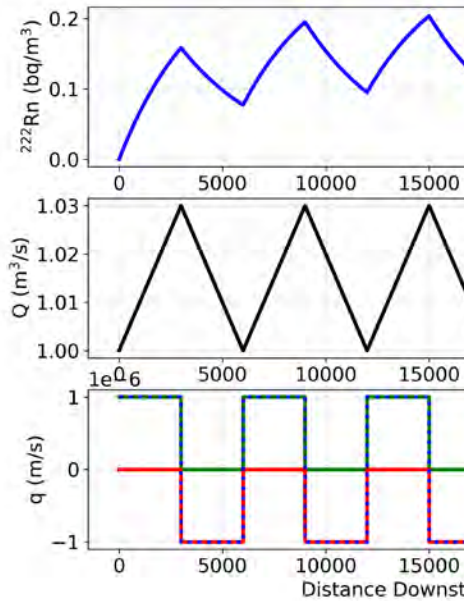


Net exchange is
no change in discharge.

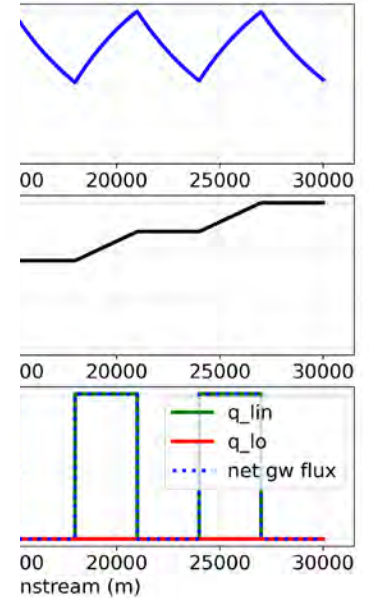
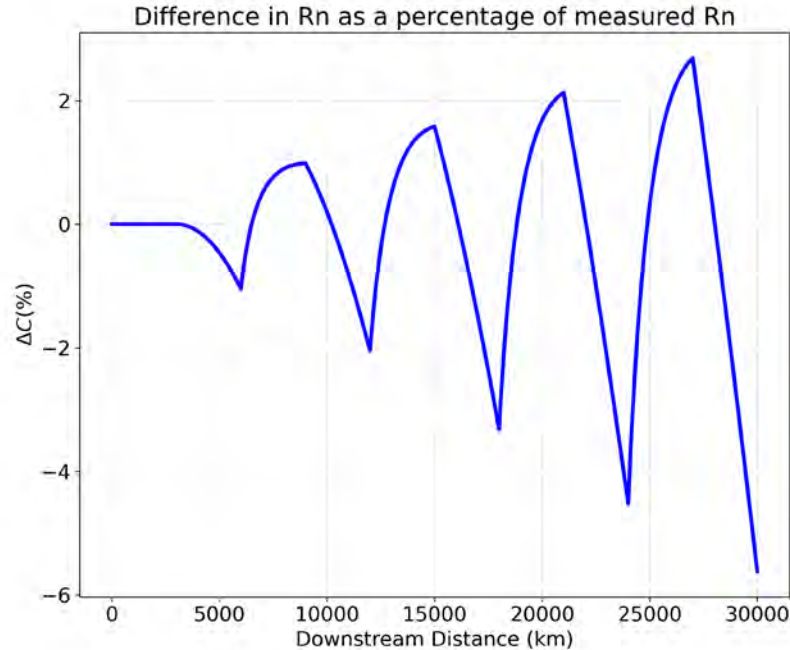


change is not zero,
change in discharge hard to
distinguish by gaging.

Exploring Toy Model – Stepped functions

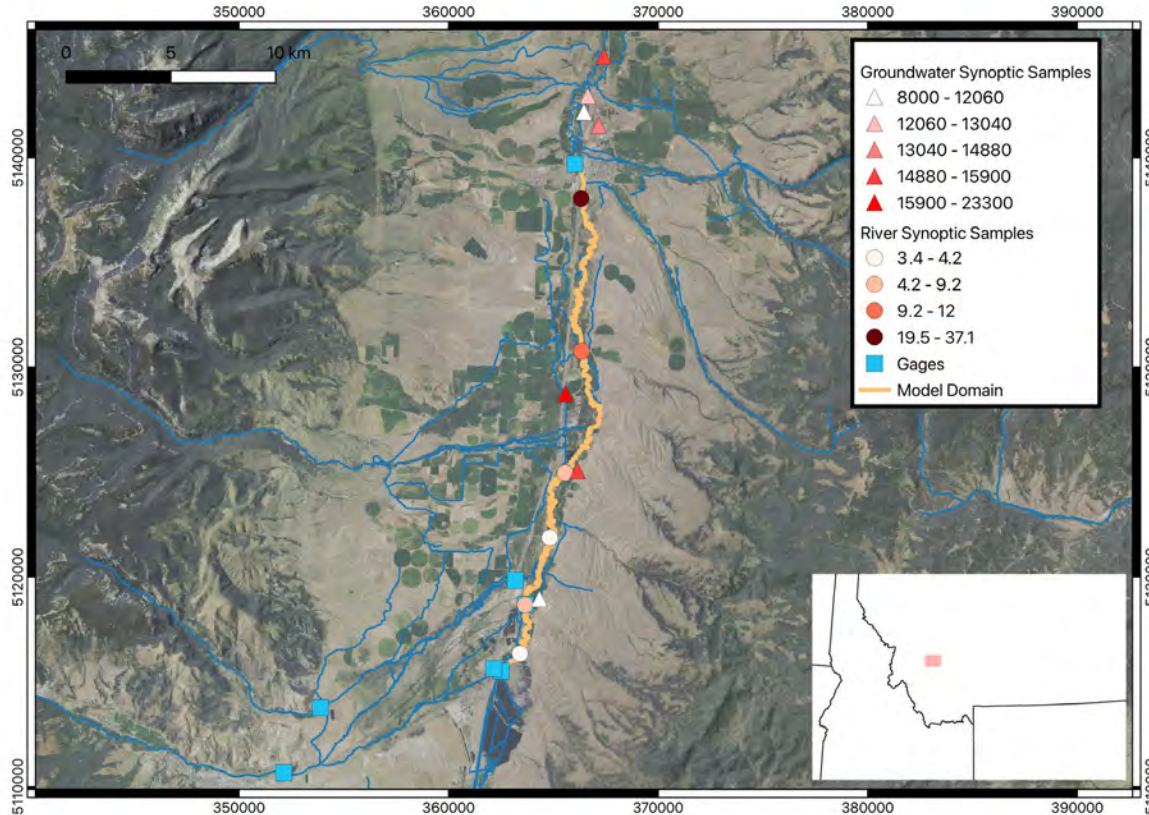


Net exchange is zero,
no change in discharge.



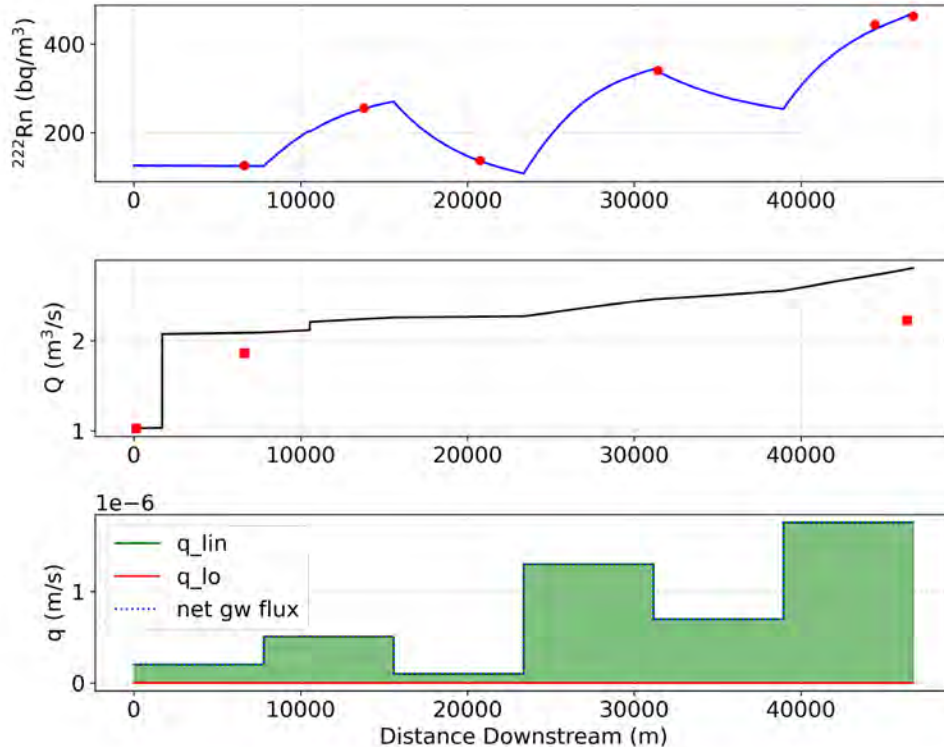
Net exchange is not zero,
change in discharge hard to
distinguish by gaging.

Real World Trial



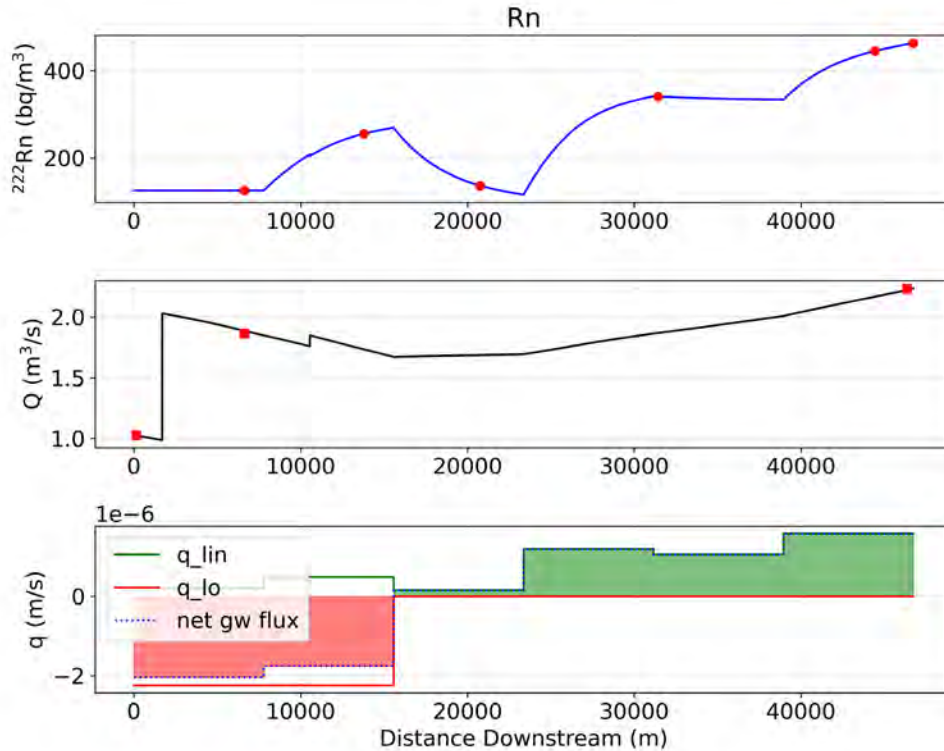
- Study reach in western Montana on the Upper Clark Fork River between Warm Springs and Deer Lodge MT.
- Reach is around 47 km long, in a mountain block bounded alluvial basin.
- Lots of agriculture and a “rich” mining history.
- Despite many years of reclamation and stream sampling, little known about the groundwater and stream water interaction.
- We did an initial stream and groundwater synoptic survey to explore groundwater stream water interactions.

Upper Clark Fork – No Loss Results



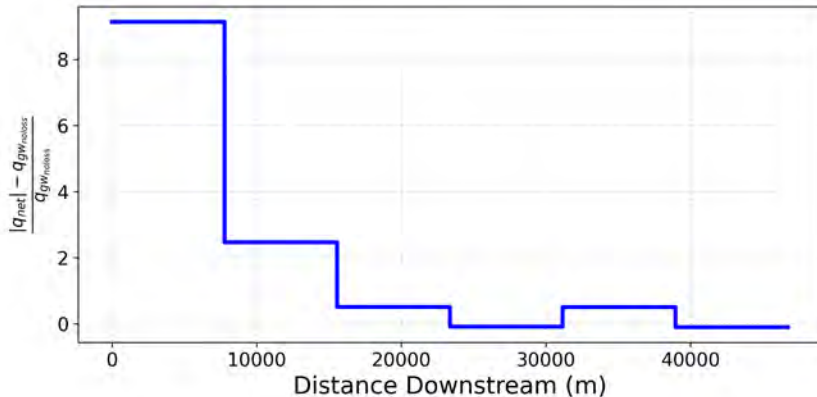
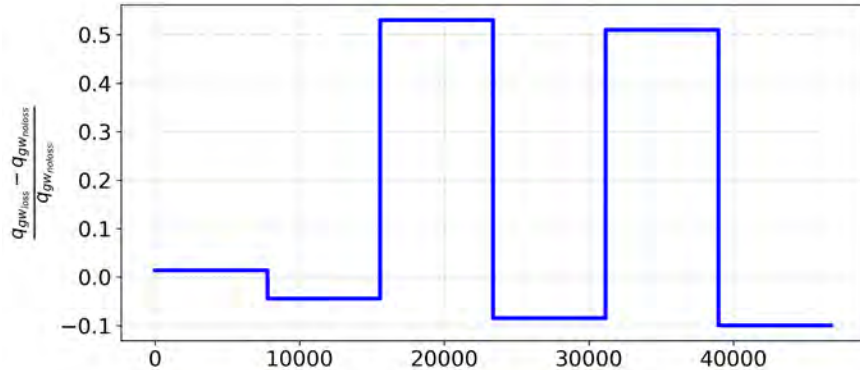
- Classic method - estimates only gain along the reach
- Can fit the observed Radon quite well
- Can't fit the discharge data as well
 - It is trying to fit discharge
- Lower discharge in first 20 km
- Higher discharge in second 20 km

Upper Clark Fork – Full Fit for Net Exchange



- Optimize for net exchange along the reach
 - Both q_{in} and q_{out}
 - 6 steps for q_{in}
 - 3 steps for q_{out}
- Fits the observed Radon quite well
- Fits the discharge very well
 - Seems even more promising!
- Net losing over first 15 km
- Net gaining over last 20 km
- Neutral in the middle 5 km

Comparing Estimated Groundwater Fluxes



- The total groundwater inflow is underestimated when no loss is considered.
 - Up to 50% more inflow when loss is considered
- Net exchange is much higher than groundwater inflow when loss is considered
 - Up to 8 times more exchange when we consider loss

Conclusions

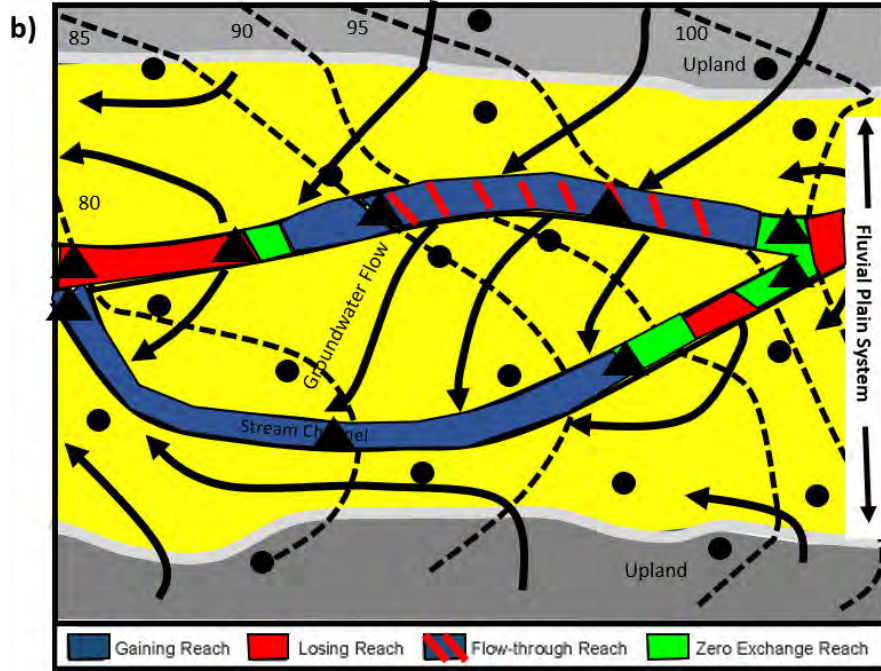


Image From: Woessner, William W. 2020,
Groundwater-Surface Water Exchange, The Groundwater Project
– Guelph, Ontario, Canada.

- It is likely that even over short distances, a stream has a variety of different interactions with the local groundwater system.
 - Net exchange is probably a better way to think about these interactions rather than just gain or loss alone.
- Stream tracer-based methods are sensitive to loss!
 - This is, at least, not what I thought previously
- The relative sensitivity depends on the interaction type but can have very large tracer signals of loss.
- Synoptic stream gauging and tracer sampling datasets can be used to estimate ground water inflow and out flow.
 - Probably fits data better in many cases
- Groundwater discharge is probably a higher than estimates made without considering loss.
- Net exchange is likely much higher when loss is considered.

Prost