Scaling Of Transient Storage Parameter Estimates with Increasing Reach Length in a Mountain Headwater Stream

M.A. Briggs[1], M.N. Gooseff[1], B. L. McGlynn[2],
1. Colorado School of Mines, Golden CO 2. Montana State University, Bozeman MT

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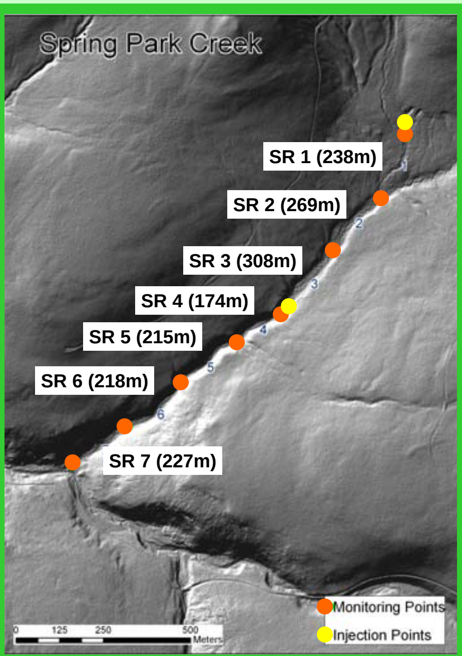
Introduction:

We performed two conservative tracer injections in a mountain stream in order to access the relationship between storage parameters on the short sub-reach scale to the longer reach which they comprise.

Site Description:

Data was collected at Spring Park Creek (SPC), which is located in the Tenderfoot Creek Experimental Forest in the Little Belt Mountain Range, Montana. SPC is one of the four first order flumed tributaries to Tenderfoot Creek which join the main stem above the Lower Tenderfoot flume. For our investigation SPC was delineated into seven sub-reaches (SR), numbered from upstream (North) down to the confluence. These sub-reaches were then grouped to form six combination reaches (C) of increasing length.



Methods:

Conservative NaCl was injected over two six-hour periods during consecutive days (8/16/06, 8/17/06) and empirical EC data was collected for all sub and combination reaches. For every conductivity probe standards of known concentration were used to convert the stream EC records to stream NaCl concentration (Gooseff and Mcglynn, 2005). The fallowing TSM OTIS was used to simulate this observed data:

$$\frac{\partial C}{\partial t} = -\frac{Q}{A}\frac{\partial C}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(AD\frac{dC}{dx}\right) + \alpha\left(C_S - C\right) + \frac{q_L}{A}\left(C_L - C\right) \qquad (1)$$

$$\frac{dC_S}{dt} = \alpha\frac{A}{A_S}\left(C_S - C\right) \qquad (2)$$

Where, C is the solute concentration in the stream (mol L^{-1}), Q is the volumetric flow rate ($m^3\ s^{-1}$), A is the cross-sectional area of the main channel (m^2), D is the dispersion coefficient ($m^2\ s^{-1}$), C_S is the solute concentration in the storage zone (mol L^{-1}), A_S is the cross-sectional area of the storage zone (m^2), α is the stream storage exchange coefficient (s^{-1}), q_L is the lateral inflow rate ($m^3\ s^{-1}\ m^{-1}$ length of stream, or $m^2\ s^{-1}$), C_L is the lateral inflow solute concentration, t is time (s), x is distance downstream (m).

After a reasonable fit was determined using OTIS, OTIS-P was used to calculate parameters that minimize the squared differences from observed data. This technique allowed us to specify a 95% confidence interval for most values, and an overall residual sum of squares (RSS) for each reach.

Once solute transport parameters were estimated for each SR and C reach the Damkohler Number (*DaI*) and the New Metric (F_{med}) were determined. The *DaI* is a method of accessing the reliability of parameters, and should fall within one order of magnitude of 1×10^0. The F_{med}^{200} describes the fraction of median travel time which is due to storage normalized to a 200 m reach.

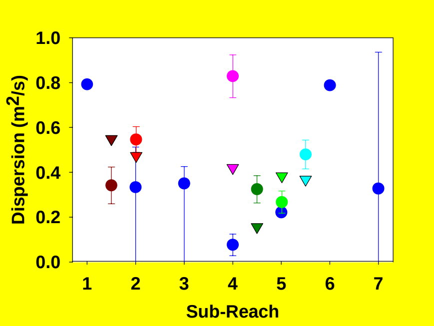
$$DaI = \alpha\frac{(1 + A/A_S)L}{u} \qquad (3)$$

$$F_{med}^{200} = (1 - e^{-L(\alpha/u)})\frac{A_S}{A + A_S} \qquad (4)$$

Results:

The RSS of the TSM fits for the C reaches was 65 less on average in comparison with the SR reaches. The parameters of *D* (dispersion) and *A* (channel x-sect. area) are positively correlated with increasing reach length, while A_s (x-sect. area of storage zone) and α (storage exchange coefficient) are not . The DaI (Damkohler #) was very low for the SR reaches, but more optimal for longer stream lengths.

Fig. 1



- ● SR VALUE WITH 95% CONFIDENCE INTERVAL
- ● C1-2 VALUE WITH 95% CONFIDENCE INTERVAL
- ● C1-3 VALUE WITH 95% CONFIDENCE INTERVAL
- ● C1-7 VALUE WITH 95% CONFIDENCE INTERVAL
- ● C4-5 VALUE WITH 95% CONFIDENCE INTERVAL
- ● C4-6 VALUE WITH 95% CONFIDENCE INTERVAL
- ● C4-7 VALUE WITH 95% CONFIDENCE INTERVAL
- ▽ WEIGHTED AVG. OF C REACH COMPONENTS

Fig. 2

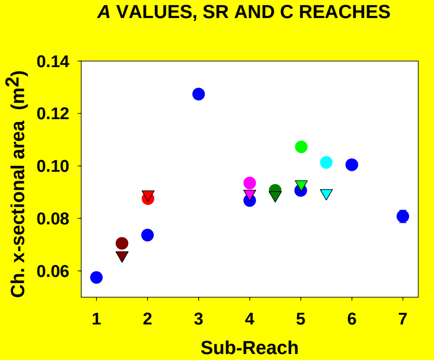


Fig. 3

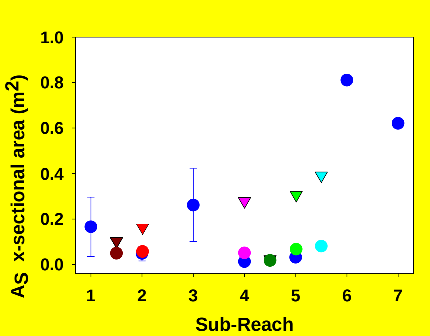


Fig. 4

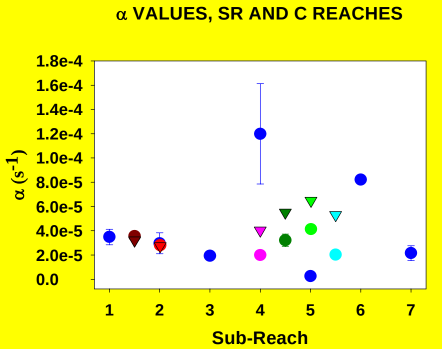


Fig. 1-2: Both *D* and *A* rise with increasing C reach length, and C reach values are generally greater than SR values. The average 95% confidence interval for *D* was largest proportionally to all other parameters.

Fig. 3-4: The weighted avg. of A_s and α over estimates the C reach values in almost every case, perhaps inflated by SR values for which we have lower confidence.

Fig. 5

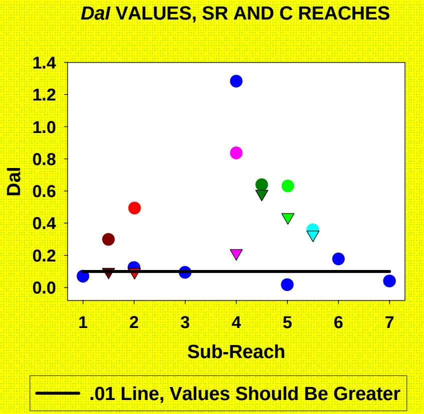
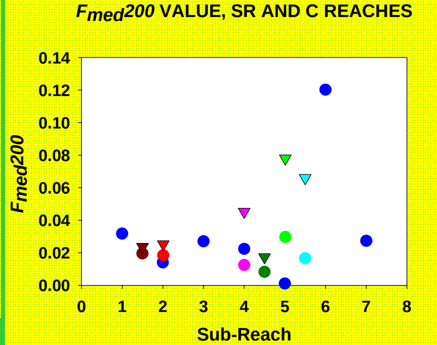


Fig. 5-6: The DaI evaluations suggest that there is a greater interaction between the tracer the storage zone over longer reach lengths, yet the F_{med}^{200} metric does not trend up.

Fig. 6



Discharge Over Injections

Fig. 8

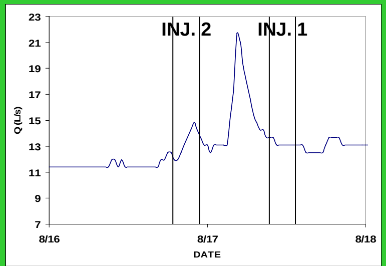


Fig. 8: Several small storms passed through the watershed over the injection period. The changing discharge may have effected our ability to estimate solute transport parameters, especially during the first injection.

Discussion & Conclusions:

•The weighted average of a combination reach's components was not a consistent predictor of that C reach value for any parameter.

•*D* and *A* increase with reach length, which is to be expected.

•According to *DaI* calculations, the majority of our sub-reach lengths may have been too short to facilitate enough interaction between the tracer and the storage zone to provide reliable parameter estimates.

•The F_{med}^{200} metric suggests that storage does not play a major role in median mass transport times in this stream, even over the longer reach lengths.

•A logical next step would be to use UCODE to perform a parameter sensitivity analysis.

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Briggs, M (mabriggs@mines.edu), MN Gooseff, and B. McGlynn

Abstract. Numerous studies have used the methods of stream tracer experiments and subsequent solute transport modeling to determine transient storage characteristics of streams. Experimental reach length is often determined by site logistics, morphology, specific study goals, etc. Harvey et al. [1996] provided guidance for optimal study reach lengths, based on the Dahmkoler number, as a balance between timescales of advective transport and transient storage. In this study, we investigate the scaling of parameters in a solute transport model (OTIS) with increasing spatial scale of investigation. We conducted 2 6-hour constant rate injections of dissolved NaCl in Spring Park Creek, a headwater stream in the Tenderfoot Creek Experimental Forest, Montana. Below the first injection we sampled 4 reaches ~200m in length, we then moved upstream 640m for the second injection and sampled 3 more ~200 m reaches. Solute transport simulations were conducted for each of these sub-reaches and for combinations of these sub-reaches, from which we assessed estimates of solute velocity, dispersion, transient storage exchange, storage zone size, and Fmed (proportion of median transport time due to storage). Dahmkoler values calculated for each simulation (sub-reaches as well as longer combined reach) were within an order of magnitude of 1, suggesting that our study reach lengths were appropriate. Length-weighted average solute transport and transient storage parameters for the sub-reaches were found to be comparable to their counterparts in the longer reach simulation. In particular the average dispersion found for the sub-reaches (0.43 m^2/s) compared very favorably with the value for dispersion calculated for the larger reach (0.40 m^2/s). In contrast the weighted average of storage zone size for the sub-reaches was much greater (1.17 m^2) than those calculated for the injection reach as a whole (0.09 m^2) by a factor of ~13. Weighted average values for transient storage exchange and size for the sub-reaches were both found to be higher than that of the reach as a whole, but only by factors of ~2.5 and 3 respectively. This study indicates that some values of solute transport and transient storage for a particular reach can be reasonably extrapolated from its corresponding component reach values.

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Additional information at:
http://www.mines.edu/~mgooseff/web_research/hydroscapes.html