Functional Measures of Stream Ecosystem Health in Urban Streams of Puget Sound, Washington

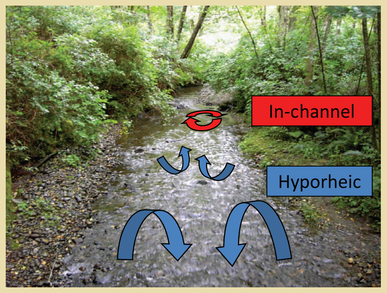
Andrew S. Gendaszek, Robert W. Black, and Chris Konrad - U.S. Geological Survey - Washington Water Science Center

Abstract

Urbanization affects stream habitats directly through structural modification (e.g. bank protection, channelization and bridges) and indirectly through riparian deforestation, hydrologic alteration, and changes in sediment delivery to the channel. The relation between land-use changes accompanying urbanization and changes in streamflow patterns and their impact on in-stream habitat are often difficult to address based on direct, physical habitat collected measures at varying scales. To address these limitations, we quantified the importance of transient storage as a functional measure of in-stream habitat complexity by modeling the passage of a dye tracer injected into 21 urban and rural streams with the USGS solute transport model OTIS (One-Dimensional Transport with Inflow and Storage). The OTIS model was used to generate transient storage metrics for 18 of the 21 streams where a good fit was achieved between measured and modeled tracer data. The importance of transient storage decreased with increasing urban development and was significantly related to the number and location of road crossings upstream of the study sites as well as with macroinvertebrate metrics and a biotic index developed for the study area. The preliminary results of this study demonstrate how a transient storage model (OTIS) can be used to characterize ecologically relevant in-stream habitat conditions and how these results can be used to identify potential watershed scale perturbations that affect in-stream habitat.

What is Transient Storage?

- Transient storage refers to any process that will slow down the bulk flow of the stream and can result from:
- In-channel dead zones such as pools, eddies, large woody debris, and side channels
- Hyporheic (subsurface) exchange flow caused by bedforms, pool-riffle sequences, alluvium, and ground water-surface water mixing



Questions, Hypothesis, and Approach

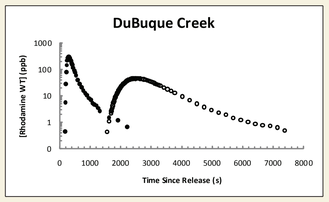
- How can quantifying transient storage augment physical habitat surveys in characterizing in-stream habitat within urbanizing areas in Puget Sound?
- Do transient storage metrics relate to urbanization measures and biological metrics?
- We hypothesize that transient storage (both in-channel and hyporheic) will decrease in urban streams because of reduced habitat complexity.
- To address these questions, a short-term tracer injection was conducted at each of the 21 study sites.

Methods: Dye Tracer Injections and Solute Transport Modeling

1) Tracer Injection

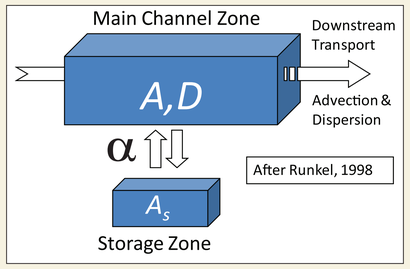
Rhodamine WT was instantaneously injected upstream of each study reach across a turbulent riffle to facilitate vertical and horizontal mixing with stream water.

2) Measurement of Tracer Breakthrough Curve



Water samples were collected at 10-second to 5-minute intervals from the thalweg at the upstream (filled circles) and downstream (open circles) ends of the study reach. Rhodamine WT concentration of each sample was determined by fluorometric analysis.

3) Solute Transport Simulation



Rhodamine WT concentrations measured at downstream end of the reach are simulated with OTIS (One-Dimension Transport with Inflow and Storage), which incorporates advection and dispersion of solute in the main channel and exchange into a transient storage zone where solute is temporarily retained. Discharge, upstream solute concentrations, and stream length are specified for each stream prior to simulation. Main channel cross-sectional area (A), dispersion (D), storage-zone cross-sectional area (A_s), and exchange rate between the main-channel and storage zones (α) are estimated by a nonlinear least squares fit to the experimental data.

4) Transient Storage Metrics

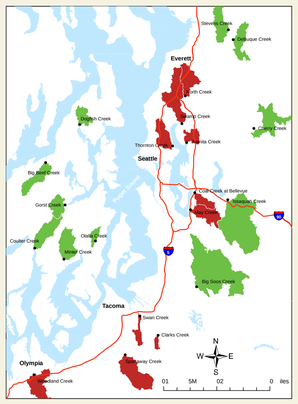
$$\frac{A_s}{A}$$ **Spatial Scale of Transient Storage**

$$T_s = \frac{A_s}{A\alpha}$$ **Temporal Scale of Transient Storage**

$$F_{med}^{200} = \frac{t_{median} - t_{median}^{main}}{t_{median}}$$ **Integrative Measure of Transient Storage**

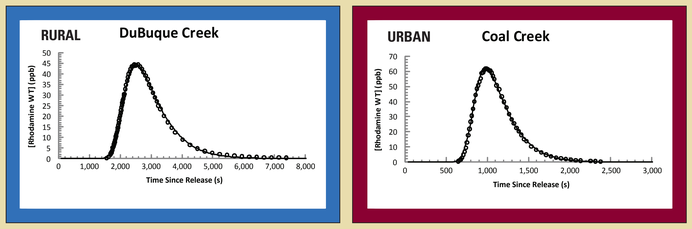
Transient storage metrics are calculated from optimized solute transport simulations and parameters and indicate: a) Relative size of the storage zone (A_s/A), b) Average time spent in transient storage (T_s), and c) The fraction of median travel time due to transient storage normalized to a 200-m long reach (F_{med}^{200}; Runkel, 2002).

NAWQA Study Sites

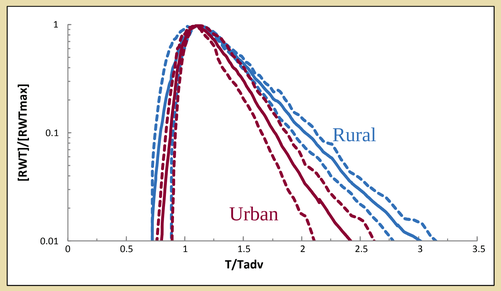


21 USGS National Water Quality Assessment (NAWQA) study sites: 10 sites within highly urbanized watersheds centered around Seattle, Tacoma, and Everett (red) and 11 sites within un-urbanized watersheds (green). Selected sites have similar climate geology and topography.

Results



Measured downstream Rhodamine WT breakthrough curves (open circles) and best-fit transient storage simulations (solid lines) for representative rural (Dubuque Creek) and urban (Coal Creek) streams.

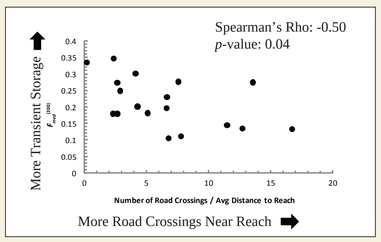


Average Rhodamine WT breakthrough curves (solid lines) for five most urbanized sites (red) and five least urbanized sites (blue) normalized by advection time (time from release to peak concentration) and maximum Rhodamine WT concentration. Dashed lines indicate average ± 1 standard deviation of mean normalized Rhodamine WT concentrations; this shows that in past ~ 1.5 advective timescales, less dye was retained by the five most urbanized streams relative to the five least urbanized streams.

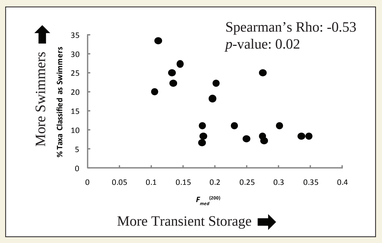
Stream	L (m)	Q (l s^{-1})	v (m s^{-1})	A_s/A	T_s (s)	F_{med}^{200}
Big Beef	190	113	0.18	0.52	211	0.33
Big Soos	200	738	0.41	0.43	107	0.27
Catherine	122	13	0.02	0.31	756	0.19
Cherry	136	151	0.19	0.28	130	0.2
Clarks	150	244	0.66	0.54	58	0.34
Coal	150	64	0.19	0.19	133	0.13
Coulter	150	398	0.25	0.29	173	0.17
Dogfish	207	120	0.19	0.14	91	0.1
Dubuque	130	16	0.05	0.25	369	0.18
Gorst	126	377	0.31	0.38	92	0.27
Issaquah	225	706	0.35	0.28	153	0.14
Juanita	122	19	0.2	0.39	118	0.27
May	122	154	0.22	0.33	63	0.24
North	150	135	0.19	0.45	167	0.3
Olalla	76	178	0.21	0.22	67	0.17
Spanaway	59	165	0.18	0.15	56	0.11
Thornton	61	109	0.16	0.21	101	0.13
Woodland	122	370	0.36	0.33	115	0.23

Results of Dye Tracer Experiments: Length of study reach (L), discharge during tracer experiments (Q), advective velocity (v) measured as the time to peak Rhodamine WT concentration divided by reach length, and transient storage metrics: A_s/A, Ts, and F_{med}^{200}.

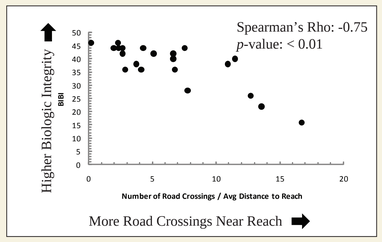
Urbanization, Transient Storage & Biologic Indices



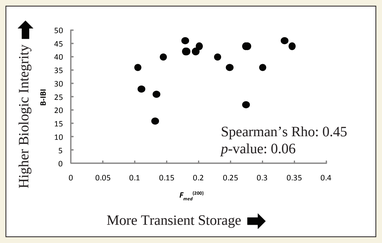
As number and proximity of road crossings increase (more urban) transient storage as measured by F_{med}^{200} decreases (reduced hydrologic complexity). This tends to support the hypothesis that urbanization decreases stream habitat complexity.



The percentage of invertebrate taxa characterized as swimmers in each sample decreases as the hydrologic complexity (as measured by F_{med}^{200}) increases. An increase of hydrologic complexity provides additional micro-habitats for invertebrates with additional behavioral characteristics which dilute the percentage of swimmers at a site.



The Benthic Index of Biological Integrity (BIBI) decreases with increasing number and proximity of road crossings. It is hypothesized that road crossings alter stream hydrology as well as stream chemistry, which reduces the multi-metric BIBI score.



BIBI scores weakly increase with F_{med}^{200}. Because F_{med}^{200} is a hydrologic measure and represents only part of the anthropogenic "drivers" that are addressed by the BIBI scores, it is understandable that these two variables are weakly correlated.

Summary of Findings

- Dye tracer took longer to move through the five most rural streams than the five least urbanized streams relative to timescales of advection. This suggests that the five most urban streams have less habitat complexity.
- Transient storage metrics did not have a simple relationship to physically measured habitat metrics.
- Transient storage and biologic integrity are related to the proximity of road crossings.
- Indirect and direct relation between biologic measures and transient storage are apparent from our data.
- Transient storage metrics may represent a valuable additional measure suitable for characterizing habitat conditions in urban streams as well as assessing potential hydrologic impacts to streams in urbanizing watersheds.

Acknowledgments

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References

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Andrew Gendaszek
USGS Washington Water Science Center
934 Broadway Ave. Suite 300, Tacoma, WA 98402
Telephone (253)-552-1612 Fax (253)-552-1582
agendasz@usgs.gov *http://wa.water.usgs.gov/*