Volume Control – Selected Research Underpinnings

Volume-Based Hydrology – Examining the shift in focus from peak flows and pollution treatment to mimicking pre-development volumes (Reese 2009)

Volume-Based Hydrology starts with the premise that it is the increased volume of runoff due to urban development that is causing a set of problems, and that any other focus-variable (velocity, peak flow, impervious percent, event mean concentration reduction, etc.) is mostly one step off from the real problem: increased volume. If we focus first on volume, then the other variables will fall more readily into line.

Lessons learned from around the country focus on keeping gallons of runoff out of the storm sewer system. So maybe Volume-Based Hydrology is really a runoff *volume reduction* phenomenon or strategy for reducing flood damages. Second, there is a growing body of knowledge that the *treatment* of runoff is not as effective as the *removal* of runoff (and the mass of pollutants it carries) needing treatment. So, Volume-Based Hydrology is really a stormwater *pollution reduction* phenomenon or strategy for protecting water quality. It is also now becoming apparent, at least in humid climates, that volume of flow over time, and not simple peak flow, is the right variable when considering erosion in many open-channel systems. In fact, peak flow controls may exacerbate the erosion problem, forcing larger volumes of flow into the channel cross section. So it seems Volume-Based Hydrology is a channel erosion phenomenon or strategy for protecting aquatic habitat and sensitive biological communities.

The article is offered in the hopes of stimulating some new thinking on the subject (and renewing some old), as well as giving some technological insight along the way.

Fundamentals of Urban Runoff Management – Technical and Institutional Issues (Shaver, E. et al., 2007)

The Clean Water Act describes water quality as the combination of chemical, physical, and biological attributes of a water body. Although water resource degradation from urban NPS pollution has been considered the leading cause of ecological damage, this is not always the primary cause of water quality problems. In fact, by the time the water quality impacts become evident the damage has already largely been done by water *quantity* impacts (Lyons 2004). The shift in the natural hydrologic regime from a groundwater-dominated system to one dominated by surface runoff resulting from watershed urbanization can have significant ramifications on river and stream hydrology.

Urban land use changes can increase impervious land cover, decrease soil permeability and vegetated cover, reduce initial abstractions, and shorten runoff response times. Such changes can result in increased volumes, rates, durations, and frequencies of surface runoff and waterway flows. Such increases can adversely impact waterways through channel enlargement, bank undercutting, aquatic habitat destruction, increased sediment loadings, and increased water temperatures. Such impacts have been extensively documented through research.

All of these characteristics represent alterations in the natural hydrologic regime to which aquatic biota have adapted over the long term. These are significant hydrologic changes that can negatively impact aquatic biota directly or indirectly. The biological effects include altered biotic interactions, food web (trophic) changes, chronic (sublethal) and acute (lethal) toxicity. How the many urban stressors might affect the biota in a receiving water is very complex, imperfectly understood, and hard to forecast with assurance. The multiple stressors that often accompany urbanization can interact synergistically or antagonistically. In addition, the organisms under stress can interact with one another. The sum total of these interactions within an aquatic ecosystem represents the cumulative impacts of urbanization.

Urban Stormwater Management in the United States (National Research Council 2009)

Urbanization causes change to natural systems that tends to occur in the following sequence. First, land use and land cover are altered as vegetation and topsoil are removed to make way for agriculture, or subsequently buildings, roads, and other urban infrastructure. These changes, and the introduction of a constructed drainage network, alter the hydrology of the local area, such that receiving waters in the affected watershed experience radically different flow regimes than prior to urbanization. Nearly all of the associated problems result from one underlying cause: loss of the water-retaining and evapotranspirating functions of the soil and vegetation in the urban landscape. In an undeveloped area, rainfall typically infiltrates into the ground surface or is evapotranspirated by vegetation. In the urban landscape, these processes of evapotranspiration and water retention in the soil are diminished, such that stormwater flows rapidly across the land surface and arrives at the stream channel in short, concentrated bursts of high discharge. This transformation of the hydrologic regime is a wholesale reorganization of the processes of runoff generation, and it occurs throughout the developed landscape. When combined with the introduction of pollutant sources that accompany urbanization (such as lawns, motor vehicles, domesticated animals, and industries), these changes in hydrology have led to water quality and habitat degradation in virtually all urban streams.

The current state of the science has documented the characteristics of stormwater runoff, including its quantity and quality from many different land covers, as well as the characteristics of dry weather runoff. In addition, many correlative studies show how parameters co-vary in important but complex and poorly understood ways (e.g., changes in macroinvertebrate or fish communities associated with watershed road density or the percentage of impervious cover). Nonetheless, efforts to create mechanistic links between population growth, land-use change, hydrologic alteration, geomorphic adjustments, chemical contamination in stormwater, disrupted energy flows and biotic interactions, and changes in ecological communities are still in development. Despite this assessment, there are a number of overarching truths that remain poorly integrated into stormwater management decision-making, although they have been robustly characterized for more than a decade and have a strong scientific basis that reaches even farther back through the history of published investigations, namely:

- There is a direct relationship between land cover and the biological condition of downstream receiving waters
- The protection of aquatic life in urban streams requires an approach that incorporates all stressors.
- The full distribution and sequence of flows (i.e., the flow regime) should be taken into consideration when assessing the impacts of stormwater on streams.
- Roads and parking lots can be the most significant type of land cover with respect to stormwater.

Relationship of stream ecological conditions to simulated hydraulic metrics across a gradient of basin urbanization (Steuer, J., et al. 2009).

The relationships among urbanization, stream hydraulics, and aquatic biology were investigated across a gradient of urbanization in 30 small basins in eastern Wisconsin. Simulation of hydraulic metrics with 1-dimensional unsteady flow models was an effective means for mechanistically coupling the effects of urbanization with stream ecological conditions (i.e., algae, invertebrates, and fish). Our approach required construction of a 1-dimensional hydraulic model for each stream reach. Once the hydraulic models are developed, relative effects of changes in channel form on hydraulic metrics can be readily simulated. Changes, such as channel restoration, stone weirs, artificial meanders, and obstacle construction, all increase hydraulic heterogeneity, which in turn affects factors, such as stream depth, velocity, and shear stress. Modifications within watersheds change stream hydraulic variables as a function of physiographic setting. Watershed detention or infiltration practices can decrease peak streamflow or volume, which will in turn affect stream depth and velocity, values which determine Froude and Reynolds numbers. Changes in these hydraulic variables were strongly correlated with changes in biological metrics in our study. Our study demonstrated the value of temporally and spatially explicit hydraulic models for providing mechanistic insight into the relationships between hydraulic variables and biological responses. Thus, our modeling approach might have advantages over use of traditional hydrologic variables, particularly for predicting effects of reach- and watershed-scale management actions on biological communities.

Determination of biologically significant hydrologic condition metrics in urbanizing watersheds: An empirical analysis over a range of environmental settings (Steuer, J., et al. 2009. Under review)

Abstract

We investigated the relations among 83 Hydrologic Condition Metrics (HCM) and changes in algal, invertebrate, and fish communities in five metropolitan areas across the continental United States. We used a statistical approach that employed spearman correlation analysis, regression tree analysis, and multiple linear-regression modeling to identify five HCM that were strongly associated with observed ecological changes. Average flow magnitude, high-flow magnitude, high-flow event frequency, high-flow duration and rate of change of stream cross-sectional area were the HCMs most consistently associated with changes in aquatic communities. Although our investigation used an urban gradient design with short hydrologic periods of records (<= 1year) of hourly cross-sectional area time series, these

five HCM were consistent with previous investigations using long-term daily flow records. The ecological sample day was often included within the hydrologic period. Regression models explained up to 67%, 85%, and 81% of variance for specific algae, invertebrate, and fish community metrics, respectively. National models were generally not as statistically significant as models for individual metropolitan areas. High-flow event frequency, a hydrologic index found to be transferable across stream type and useful for classifying habitat by previous research, was also found to be the most ecologically-relevant HCM; transformation by precipitation increased national scale applicability. We also investigated the relation between measures of stream flashiness and land-cover indicators of urbanization and found that several land-cover characteristic and pattern variables were strongly related to these HCM and therefore may be effective land-use management options in addition to wholesale impervious area reduction.

Impacts of Impervious cover on Aquatic Systems – Watershed Protection Research Monograph No. 1. (Center for Watershed Protection. 2003)
This research monograph comprehensively reviews the available scientific data on the impacts of urbanization on small streams and receiving waters. These impacts are generally classified according to one of four broad categories: changes in hydrologic, physical, water quality, or biological indicators. More than 225 research studies have documented the adverse impact of urbanization on one or more of these key indicators. In general, most research has focused on smaller watersheds, with drainage areas ranging from a few hundred acres up to ten square miles.

The report points out that a strong relationship between impervious cover (IC) and declining stream quality indicators does not always mean that the IC is directly responsible for the decline. In some cases, however, causality can be demonstrated. For example, increased stormwater runoff volumes are directly caused by the percentage of IC in a subwatershed, although other factors such as conveyance, slope and soils may play a role

In other cases, the link is much more indirect. For these indicators, IC is merely an index of the cumulative amount of watershed development, and that more IC simply means that a great number of known or unknown pollutant sources or stressors are present. In yet other cases, a causal link appears likely but has not yet been scientifically demonstrated. A good example is the more than 50 studies that have explored how fish or aquatic insect diversity changes in response to IC. While the majority of these studies consistently shows a very strong negative association between IC and biodiversity, they do not really establish which stressor or combination of stressors contributes most to the decline. The widely accepted theory is that IC changes stream hydrology, which degrades stream habitat, and in turn leads to reduced stream biodiversity. The natural hydrology of streams is fundamentally changed by increased watershed development including: increased volume, increased peak discharge rates, increased bankfull flow, and decreased baseflow – which can be controlled.

Impacts of Urban Land Cover in Trout Streams in Wisconsin and Minnesota (Wang, et al. 2003)
The amount of connected impervious surface area in the watershed was negatively correlated with a fish-based coldwater index of biotic integrity (IBI), catches of all coldwater and coolwater fishes and trout, and percentage of intolerant fish; it was positively correlated with fish species richness and the percentage of tolerant fish. Nonlinear models were developed by means of a 90% quantile regression analysis to predict the maximum possible IBI score (potential), abundance of trout, and percentage of intolerant fish at a given level of imperviousness. At a connected imperviousness of less than about 6% for a watershed, all three variables could have high values, whereas at a connected imperviousness above 11% values were inevitably low. Between 6% and 11%, minor changes in urbanization could result in major changes in stream fishes. Canonical correspondence analysis identifies water temperature and base flow as the key instream habitat factors explaining stream fish assemblage patterns.

Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales (Wang, et al. 2001)
The amount of connected impervious surface in the watershed was the best measure of urbanization for predicting fish density, species richness, diversity, and index of biotic integrity (IBI) score; bank erosion; and base flow. Nonlinear models were developed using quantile regression to predict the maximum possible number of fish species, IBI score, and base flow for a given level of imperviousness. At watershed connected imperviousness levels less than about 8%, all three variables could have high values, whereas at connected imperviousness levels greater than 12% their values were inevitably low (for warmwater streams).

Watershed Urbanization and Changes in Fish Communities in Southeastern Wisconsin (Wang, et al. 2000)

Abstract
Our findings are consistent with previous studies that have found strong negative effects of urban land uses on stream ecosystems and a threshold of environmental damage at about 10 percent imperviousness. We conclude that although agricultural land uses often degrade stream fish communities, agricultural land impacts are generally less severe than those from urbanization on a per-unit basis.

The study suggests that declining water quality was not the primary cause of the fish community shifts that were observed. The researchers speculate that urbanization-induced hydrological changes, particularly more frequent and larger floods during wet periods and reduced base flows in dry periods, caused declines in fish species richness.