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Message from the director

As many recipients of the Center's newsletter are aware, we have been actively searching for a new Director to take my place when I step down from this position as of September 16th of this year. I am delighted to report that we have been successful beyond our greatest expectations, and that Anne Steinemann will become the new Director at the end of the summer. Anne comes to us most recently from Georgia Institute of Technology and Scripps Institution of Oceanography, after completing graduate and post-graduate work at Stanford University. Her focus is in water resources management and hydrology, with strong interdisciplinary expertise in environmental planning, public policy, economics, climate and societal impacts, and public health. In the last five years, she has published widely on drought planning, human health impacts of environmental pollutants, and sustainable development; she has also received several million dollars in grant funding for studies of climate, drought, and community values towards environmental issues. Her decision to come here reflects the strong effort by several colleges within the University of Washington to assemble an attractive offer, and it reflects very well on the Center's role in such interdisciplinary cooperation.

Anne will have ample opportunity to develop and share her view of the Center's future in

the coming months, but I still wanted to take this opportunity to provide a glimpse of that future. She has repeatedly articulated the intention to pursue substantial, multi-year funding for the Center from federal sources; she wants to use those resources not only to strengthen our national and international reputation, but also to support the application of scientific research to our regional water-resource problems and issues. Her portfolio displays substantial service to national, state, and local governments, and I have no doubt but that she will be equally active in her work here as well. For a little while longer yet, her website is located at <http://www.coa.gatech.edu/crp/facstaff/steinemann.htm>; feel free to visit her there, and look forward to her arrival on campus this fall. ♦

Derek Booth

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Moving beyond the river continuum concept: The importance of discontinuity in stream networks

Cara Berman was the research scientist at the Center for Water and Watershed Studies for three years.

This article was the result of an effort completed for the USDA Forest Service, Pacific Northwest Research Station entitled, "Assessment of Landscape Characterization and Classification Methods" (<http://depts.washington.edu/cwws/Research/Indicators/physical.html>). One might wonder how a report on landscape classification led to a discussion of stream networks as discontinuous resource patches, rather than as a continuum of biotic communities and habitats. This is because classification is ultimately about predicting the variable distribution and pattern of biotic and abiotic resources within a stream network. In reviewing existing landscape classification systems, however, it

quickly became apparent that the majority of classification approaches are based on a "river continuum" perspective of stream networks. It is the inability to predict discontinuities that undermines classification. This article focuses on the importance of discontinuities in the stream network to the structure of aquatic communities, and to land-management efforts addressing aquatic protection and enhancement, by considering the following topics:

1. The progression from the River Continuum Concept (Vannote et al. 1980) to alternative theories embracing the discontinuity of lotic systems;
2. The mechanisms driving stream network discontinuity;
3. The ecological importance of stream network discontinuity, using discontinuous thermal profiles on salmonid distribution and bioenergetics as a case study; and
4. The ecological importance of stream network discontinuities in developing effective conservation and protection strategies for aquatic systems.

In 1975, Hynes described the importance of stream context and observed that "in every aspect, the valley rules the stream." This tight coupling of water and land led stream ecologists to a holistic, systems-based view of riverine ecosystems. In 1980, The River Continuum Concept (RCC) of Vannote et al. described the longitudinal structure of river systems. By distinguishing a continuum of habitats arranged from headwaters to mouth, the RCC described productivity and species distribution as a function of stream network position and catchment context. Deviations from the predicted

progression of habitat attributes were considered noise, and stream system heterogeneity went unrecognized or under-appreciated.

Since the 1980s researchers have documented the limitations of the RCC. Exceptions to the RCC have driven development of alternative theories to explain the distribution of habitats and biota within stream networks. Examples include the "Serial Discontinuity Concept," developed by Ward and Stanford (1983, 1995), which identified "discontinuities" arising from dams and geomorphically discontinuous stream reaches; the "Flood Pulse Concept" developed by Junk et al. (1989) and Tockner et al. (2000), which recognized the importance of strong lateral connectivity between some rivers and their floodplains in altering the continuum of habitats outlined by Vannote et al. (1980); and the "Hyporheic Corridor Concept," developed by Stanford and Ward (1993), which recognized the importance of lateral and vertical connectivity, respectively, to the progression of lotic habitats. These alternative concepts, while not providing a unifying theory of stream discontinuity and heterogeneity in lotic systems, were important in loosening the grip of the RCC on ecological theory and pointing to the ecological importance and underlying mechanisms driving heterogeneity.

Like the RCC, the serial discontinuity, flood pulse, and hyporheic corridor concepts were based on stream network position, but these concepts expanded on the RCC to include the direction and magnitude of stream network connections to the landscape (i.e., longitudinal, lateral, and vertical connections). As the strength of these connections varies along the longitudinal

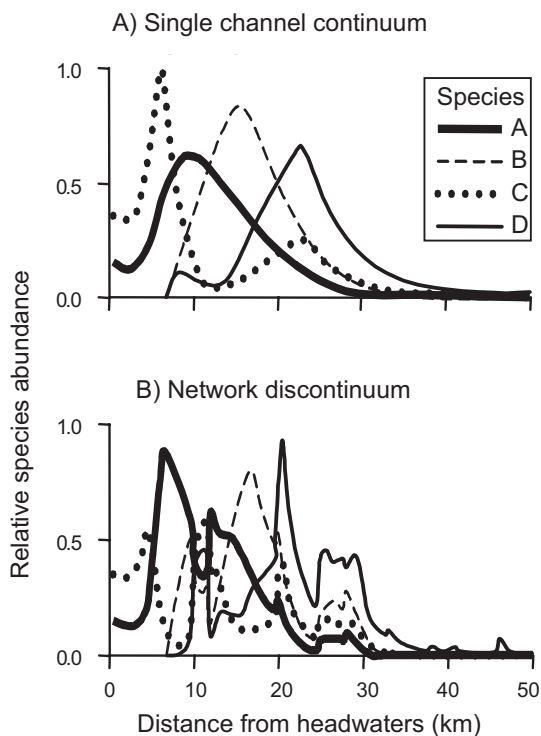


Figure 1. Relative abundance of 4 species of aquatic organisms from headwaters to mouth predicted by a simple heuristic model of a simple linear continuum (A) vs. a patchy, networked discontinuum (B) (From Poole 2002).

stream profile, exceptions to the RCC appear. These exceptions to the predicted progression of habitats and communities are termed discontinuities.

Rather than a longitudinal progression of habitat attributes and biotic communities, a zonal or patchy pattern is the norm for most stream ecosystems (see Figure 1). Discontinuities reflect the downstream variation in stream segment structure (Benda et al. 2004). As stream segment structure changes, the magnitude and direction of stream connections vary, creating discontinuous resource patches along the river network. The spatial distribution of these discontinuous resource patches is ecologically important, driving abiotic and biotic resource distribution, biotic diversity, and influencing the ability of organisms to complete life histories and survive disturbances.

Rice et al. (2001) described abrupt shifts in longitudinal trends associated with geomorphological and hydrological attributes wherever water and sediment fluxes were modified, such as at tributary confluences and lateral sediment sources (see Figure 2). In other words, tributaries and lateral sediment sources may reset longitudinal trends for biotic communities and abiotic resources. In these instances, basin geometry drive discontinuities with repeated adjustment along the stream profile (Benda et al. 2004).

Ward et al. (1999) described the importance of lateral connectivity between alluvial channels and their floodplains in creating discontinuous patches of high biodiversity. Lateral flooding produces a diverse array of floodplain habitats differing in water chemistry, physical structure, and temperature critical to meeting life history requirements of a diverse array of biota. This spatial heterogeneity expands the

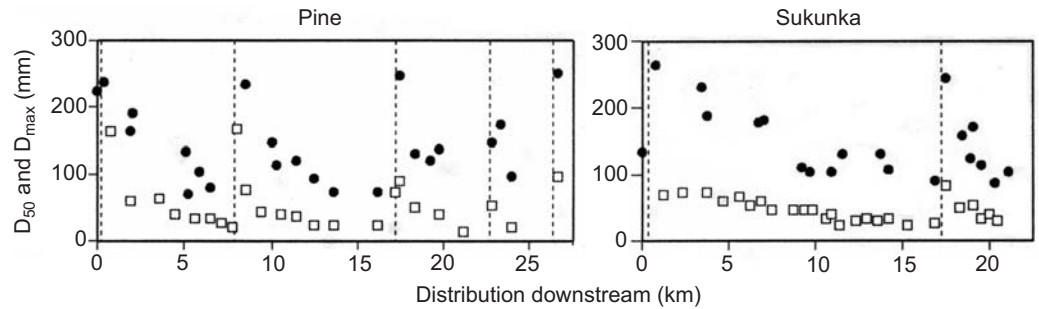


Figure 2. Physical habitat variables of two study reaches, Pine and Sukunka. Dashed lines indicate positions of lateral sediment sources. D_{50} is median grain size (squares) and D_{max} is maximum grain size (circles) for bed surface particle size distribution (Rice et al. 2001).

resource gradient and in turn provides the template for increased biological diversity.

During the spring flood pulse, the Danube River maintains a variety of habitat zones differing in temperature, physical structure, and chemistry depending on stream network position and stream segment structure and pattern (Schmutz and Jungwirth 1999). Water temperature varies within and between stream segments creating a mosaic of thermal habitats for rearing and spawning fishes and other biota (Figure 3).

Vertical connectivity between surface flows and the alluvial aquifer are also driven by stream segment structure. The magnitude of hyporheic flux in a stream is a function of stream channel pattern, streambed heterogeneity, alluvial aquifer structure, and streamflow variability. Additionally, hyporheic flux has a lateral component that connects riparian zones, various multi-channel forms, paleochannels, and floodplain aquifers. Where strong vertical and lateral connections occur, discontinuities reflecting changes in nutrient, community, and thermal gradients appear (Poole and Berman 2001).

Baxter and Hauer (2000) found that bull trout redds in the Swan River Basin, Montana were primarily located in bounded alluvial valley segments (i.e., unconfined stream sections with a downstream geomorphic knickpoint). These

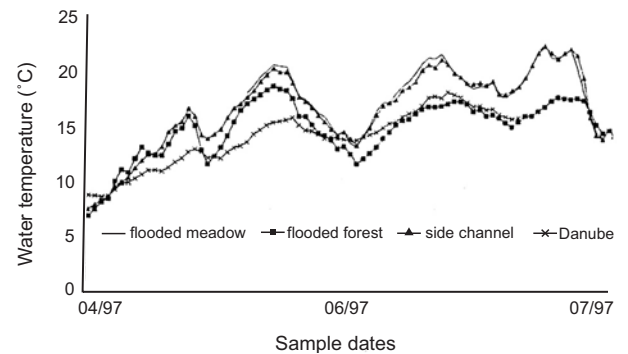


Figure 3. A mosaic of thermal habitats created by the spring flood pulse on the Danube River (Schmutz and Jungwirth 1999).

segments provided complex patterns of hyporheic exchange and extensive upwelling. Bull trout used stream reaches that were strongly upwelling. Within spawning reaches, bull trout selected transitional bed forms that provided strong down-welling environments. At multiple scales, including the stream segment, stream reach, and habitat unit scales, discontinuous hydrological patches were found to be ecologically important to spawning bull trout.

The RCC hypothesized predictable downstream changes in temperature regimes, with a maximum daily temperature pulse greatest in fourth or fifth-order river segments. Although measured stream temperatures typically trend toward atmospheric temperatures in a downstream direction, downstream temperature profiles are often discontinuous, showing abrupt changes from

one reach to another. Where insulating and buffering influences are strong, downstream temperature trends are reduced or eliminated (Figure 4).

Conditions external to the channel are responsible for determining the rate of heat and water delivery to the stream system and are thus a component of the stream's physical setting. Stream segment structure in turn exerts internal control over water temperature by influencing insulating and buffering capacity. Insulating processes are those stream characteristics that influence the rate of heat flux into and out of a stream. For instance, channel width and the riparian vegetation height, density, and proximity to the channel affect insulating efficiency. Land-use actions that increase channel width, decrease channel depth, remove riparian vegetation, or reduce channel complex-

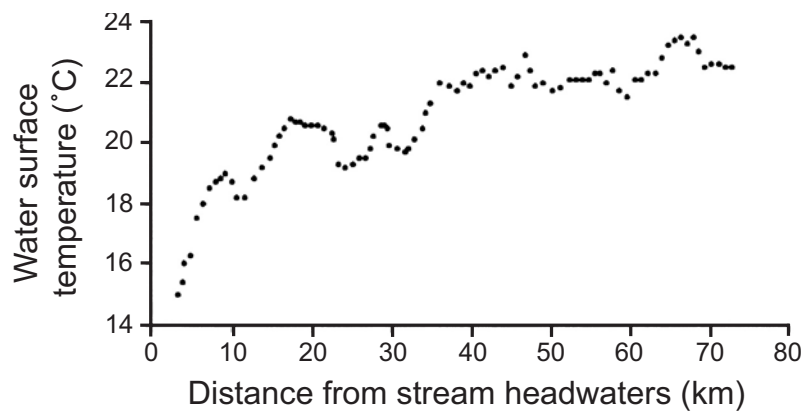


Figure 4. Downstream profile of water surface temperature in the North Fork John Day River (Poole and Berman 2001).

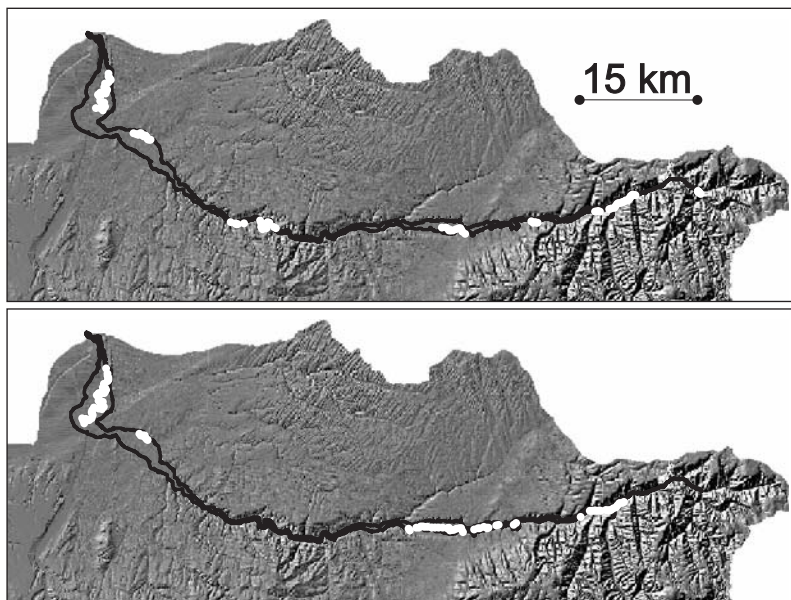


Figure 5. Observed cool water zones (top) vs. predicted zones with high potential for hyporheic flow derived from geomorphic assessment (bottom) (Umatilla River, OR; O'Daniel and Poole In Prep.).

ity decrease insulating capacity. Buffering processes, on the other hand, may either heat or cool a stream channel. Buffers operate by storing heat already in the stream system rather than adding or removing heat, and by integrating variation in discharge and temperature over time (Poole and Berman 2001). If water and heat flow regimes are constant, buffers have no effect on channel water temperature. Hyporheic flux is perhaps the most important stream temperature buffer, with importance across spatial scales of the streambed, meander bend, and floodplain (Baxter and Hauer 2000). Thus stream segment structure determines the magnitude of hyporheic flux, and so land use that decouples vertical and lateral connections and affects stream morphology can severely curtail hyporheic buffering capacity (Figure 5).

Discontinuities in the thermal profile are ecologically important. Summertime thermal discontinuities and their relation to salmonid bioenergetics provide an illustrative example. Refugia are thermal patches or discontinuities that are cooler than ambient river conditions. These thermal patches may occur at various scales. Radio telemetry data suggest that salmonids develop habitat usage patterns that control internal temperatures to best conserve their energy. As river temperature increases, fish metabolic rate increases and therefore less energy may be available for necessary behavioral and physiological functions. For instance, Berman and Quinn (1991) found that a 2.5°C decrease in internal temperature of adult spring chinook salmon produced an approximately 3 to 20% reduction in total daily energy expenditure, depending on fish size and activity level. Kinnison et al. (2001) demonstrated that increased energy expenditure during adult migration of chinook salmon resulted in a reduction of female egg size. Egg size is strongly correlated with initial offspring size in salmonids and offspring size is correlated with survival. Therefore, excess energy expenditure prior to spawning may reduce adult salmonid spawning success. An ability to locate even small temperature variations may produce meaningful reductions in basal metabolic rate. Benefits derived from residing within thermal patches may accrue in winter, spring, and summer and across life history stages.

Although research examples point to the importance of stream network discontinuities in general, and thermal discontinuities in particular, few studies or management efforts are informed by this knowledge. This raises two questions: (1) How might land use affect thermal discontinuities and patterns? (2) How might land management actions including protection and recovery strategies be informed by the concept of stream network discontinuities? Research has shown that land-use activities may both increase

and decrease thermal patch heterogeneity. Torgersen et al. (1999) provided evidence that land-use patterns may fragment cold-water thermal patches at the stream segment scale. Conversely, discontinuous thermal patches may be lost at the reach scale. It is important to note the scale-dependent nature of thermal discontinuities, which includes scale-dependent responses to land use.

Where hyporheic flux is important to the development of discontinuous thermal profiles, elimination of stream buffering capacity may have numerous ramifications. We might expect a loss of thermal heterogeneity at smaller scales (i.e., habitat and reach) and an increase in thermal heterogeneity at larger scales (i.e., stream segment) (Torgersen et al. 1999). Actions affecting stream buffering and insulating efficiency may also lead to a cumulative increase per stream kilometer in the rate at which water approaches an equilibrium temperature, resulting in potentially "good" habitat changing to marginal habitat and marginal habitat to unusable habitat (Figure 6; Poole and Berman 2001). Additionally, as buffering efficiency decreases or is lost from the system, larger daily temperature fluctuations may occur, increasing the importance of thermal discontinuities to biota. At stream reach and segment scales, loss of buffering efficiency leads to decreases in thermal variability along the downstream temperature profile, affecting the spatial variability and distribution of organisms along the stream profile.

The loss of a thermally discontinuous stream profile has several repercussions, of which the first is a loss of energy conservation and bioenergetic efficiency in biota. Thermal inertia (i.e., the resistance to internal temperature fluctuation) facilitates energy conservation in salmonids. Resistance to internal temperature fluctuation may allow salmonids to maintain energy benefits derived from cold-water patches for an extended period of time, the length of which is size-dependent. If disruption of buffering processes occurs and thermal discontinuities are reduced, the distribution, availability, and connectivity between cold-water patches will be altered. As a result, increased isolation of thermally suitable patches from other thermally suitable patches within the stream network may reduce salmonid community diversity within patches. For bull trout, Dunham and Rieman (1999) found that as habitat patch size decreases and those patches become more isolated, the occurrence of fish generally decreases. Owing to bioenergetic efficiency and thermal inertia, large fish of the same species may move between isolated thermal patches more effectively than small fish, differentially altering migration pattern between patches across fish-age classes, and therefore altering the community structure of fish in isolated thermal patches. Overall, river-

ine systems with fragmented and simplified thermal patch structures contain fewer and a less diverse array of salmonids.

A second ecological repercussion is the restricted distribution of aquatic biota (Figure 7). The distribution of salmonids is influenced by the pattern of thermal patches at the stream segment, reach, and habitat-unit scales. Loss of coarse or fine-scale thermal patches may lead to alterations of community structure as well as reduced species distributions with populations becoming largely fragmented and isolated.

Finally, the loss of insulating and buffering processes can reduce the distance that ground water temperature dominance extends downstream, particularly in middle reaches where the stream's temperature regime transitions from being dominated by groundwater temperature to being dominated by atmospheric conditions. This can result in an overall reduction in the length of stream containing suitable habitat for salmonids (Poole and Berman 2001).

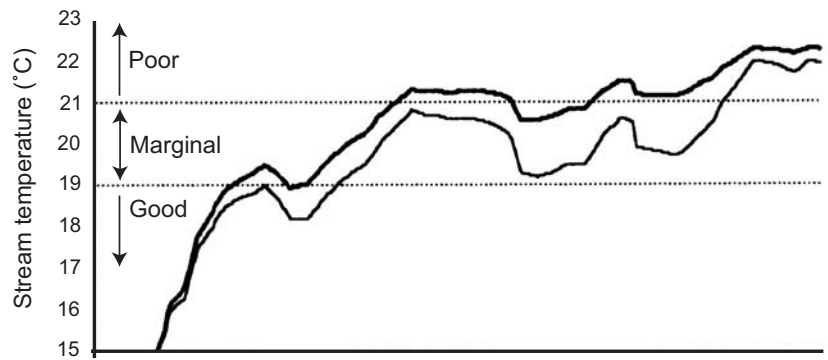


Figure 6. Thinner pre-disturbance line derived from data presented by Torgersen and others (1999); thicker post-disturbance line represents the effects of a hypothetical change in stream structure that results in a cumulative 2.5% increase per stream kilometer in the rate at which water approaches an assumed equilibrium temperature of 22.5° (Berman and Poole 2001).

Fish distribution in the Wenaha River 4-9 August 1998

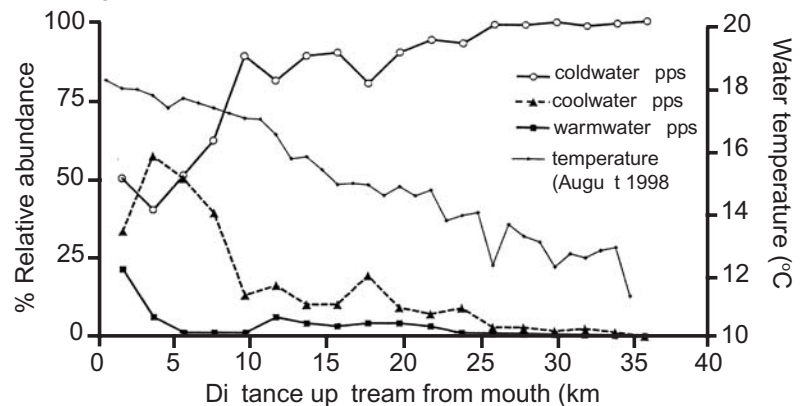


Figure 7. The relationship of fish assemblage pattern to downstream temperature profile. At temperatures of 17° and higher, the relative abundance of cool and warmwater species increases; below 17°, coldwater species abundance is greatest (Li et al. 1999).

These anticipated changes in the thermal profile may lead to the expansion of cool and warm-water species, including non-natives and native opportunists (Scott and Helfman 2001).

So, how might land management be informed by the concept of stream network discontinuities? The RCC hypothesized predictable downstream changes in temperature regimes. I would argue that this perspective continues to cloud our view in management applications, including protection, restoration, and monitoring. Protective strategies, such as temperature criteria, often incorporate a continuous downstream increase in temperatures, smoothing out trend reversals important to biota. Additionally, predictive tools are available that allow users to extrapolate stream temperatures from related variables such as elevation and distance from the headwaters, but they are based on a model of progressively increasing stream temperatures. Evaluative studies investigating effects of land management activities on site-specific conditions often assume downstream trends in temperature, leading to potentially erroneous conclusions regarding management practices. Classification systems in general and the RCC in particular have led to the study of streams and biota based on sampling discrete points along the stream continuum and extrapolating between them.

In conclusion, fundamental to increasing the effectiveness of protection and restoration strategies is the addition of two key concepts: (1) the importance of discontinuities and the physical structures and processes driving important patterns; and (2) the spatial scale and the scale-dependent nature of patches and species response. "A continuous view of the river rather than just viewing disjunct reaches is necessary for effective protection and restoration of salmonids and other aquatic biota (Fausch et al. 2002)."

To restore stream temperature patterns and dynamics, a full understanding of historically dominant external drivers and internal structural modifiers of stream temperatures across an entire basin is needed. In this way, a spatially and temporally explicit view of basin-wide thermal patterns may be developed. We must recognize the importance of the spatial arrangement of habitats for spawning, feeding, and rearing, refugia for different life stages, and the connectivity between habitats to allow completion of the organism's life history. Thermal patterns at multiple scales are indicative of functional landscape linkages and catchment context. These patterns are ecologically important and should serve as a template for restoring river structure, processes, and connectivity.

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Urban stormwater characterization in a Seattle neighborhood

Amy M. Engstrom just completed her M.S.C.E. degree in Civil and Environmental Engineering

Increasing urbanization has led to significant changes in the natural systems of the Puget Sound. These changes include alterations in the hydrologic flow regime and shifts in the chemical and biological makeup of stormwater runoff from these developing areas. In particular, anthropogenic activity introduces chemical and biological constituents to the catchment. Trace metals, suspended solids, nutrients, pesticides, petroleum products, and *E. coli* and fecal coliform bacteria are generally found in higher concentrations in urbanized and urbanizing areas than in natural systems, due to more people, vehicles, roads, and building materials.

Implementing stormwater management strategies, such as Best Management Practices (BMPs), can mitigate the consequences of increased urbanization. The City of Seattle has engaged in a variety of such stormwater management efforts in "ultra-urban" settings, collectively termed Natural Drainage Systems (NDSs) projects. These include the Street Edge Alternative (SEA Street) Millenium Project and the Broadview Green Grid, both located in the Pipers Creek watershed in North Seattle. Design elements such as native vegetation, vegetated swales, and infiltration basins have been incorporated into these projects. Future NDSs will be designed and implemented based on the relative successes of the various design elements of these initial projects.

As these future NDS projects reach their design phase, it is vital to have an accurate quantification of the successes of already-constructed projects using both hydrologic and water quality metrics. Initially, mitigating hydrologic impacts had been the primary focus of these projects. However, as additional projects have been planned and constructed using a variety of techniques and design elements, the need was recognized to implement a monitoring program that included both hydrologic and water-quality parameters. Monitoring plans were set in place to quantify the existing pre-construction conditions in catchments slated for future NDS projects.

Hydrologic monitoring and water-quality sampling were performed during storm events from fall 2002 through spring 2004 in two separate catchments in which future NDS projects were planned. Storm samples were analyzed for numerous water quality parameters, including total and dissolved metals, total suspended solids (TSS), hardness, nutrients, total petroleum hydrocarbons, pesticides, herbicides, particle size distribution (PSD), pH, temperature, and *E. coli* and fecal coliform bacteria. Of these measurements, TSS, PSD, and total and dissolved metals were analyzed in this study.

Heavy metals, especially copper, lead, and zinc, are by far the most ubiquitous priority pollutants found in urban runoff, according to the U.S. EPA's Nationwide Urban Runoff Program (US EPA 1983). The met-



An example of Street Edge Alternative (SEA Street) Project.

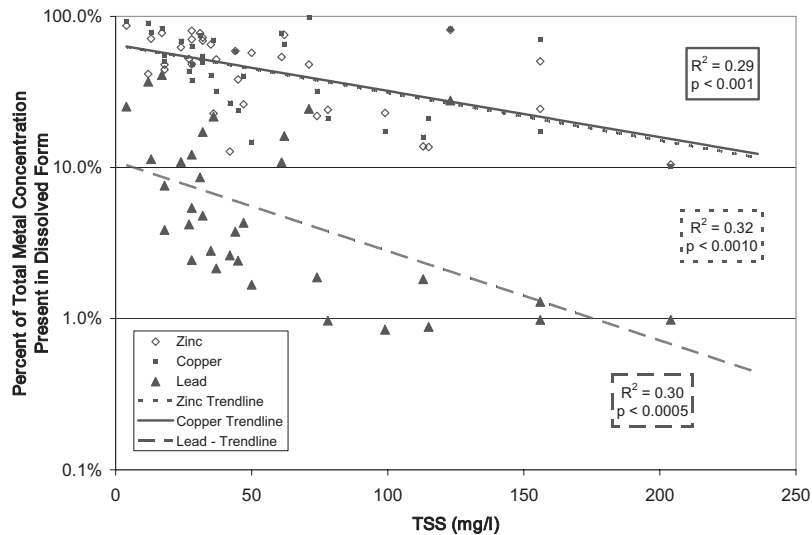


Figure 1. TSS and metals partitioning relationships.

als are introduced into catchments through anthropogenic activities. These metals are a cause for concern due to the potential for toxicity. Once present, they cannot be chemically transformed or destroyed like other constituents such as organic matter (Davis et al. 2001).

Metals in stormwater runoff are typically expressed as the concentration of either the dissolved metal or the total metal (a sum of the dissolved and particulate-bound phases). The dissolved phase is considered to be the most detrimental to ecosystem health because it is more biologically available, whereas the particulate-bound fraction is stable and therefore less toxic. Various factors influence the relative concentrations of particulate-bound and dissolved forms of metals in urban runoff. These factors include TSS, pH, dissolved oxygen concentration, ionic strength, hardness, and amount of organic material present (Morrison et al. 1990). The partitioning of metals into dissolved and particulate phases is a dynamic process. Depending on conditions, metals can dissociate from particles and become dissolved and bioavailable, or dissolved metals can sorb onto particles (Charlesworth and Lees 1999).

Constituents such as heavy metals are strongly associated with solids in urban runoff (as measured by TSS; Minton 2002; Sansalone et al. 1998), with solids acting as vectors for these pollutants. Lower TSS concentrations mean less surface area onto which metals can bind. Although greater TSS concentrations are linked with greater percentage of total metal present, those associated metals are in particulate form and, therefore, of lower mobility and lower bioavailability. Smaller particles have a larger surface area to volume ratio than do larger particles—surface area as a function of particle volume increases drastically with

decreasing particle size. This physical characteristic is enhanced by the fact that actual particles are pitted and porous, increasing surface area over the estimate for surface area based on a completely spherical particle (Sansalone et al. 1998; Minton 2002). The relatively large surface areas of smaller particles thus act as reservoirs for reactive constituents, including metals (Sansalone et al. 1998).

This research has concentrated on the relationships between solids and metals in urban runoff, specifically focusing on the dependence of metals partitioning on TSS and on the dependence of metals partitioning on concentrations of solids in the smallest size fractions. Figure 1 shows linear regressions for TSS and metals partitioning for the metals copper, lead, and zinc. Each of the three data sets show significant downward trends, indicating that as TSS concentration increases, a smaller fraction of total metal is present in dissolved form.

Results of the PSD analysis consisted of concentrations of particles ($\mu\text{L/L}$) in each of 32 size classes ranging from <1.36 microns through 250 microns. These data were compared with metals data from each storm event. Linear regressions were performed to quantify the dependence of the metals on concentrations of solids in each of the size bins. The highest coefficients of determination (R^2) values were from the linear regressions with the smallest size classes and total and dissolved metal concentrations. These R^2 values then decreased over increasing particle size.

Quantifying relationships between metals and solids parameters should aid in the understanding of complex chemical and physical interactions in an aqueous environment. These relationships may provide insight on the removal capacities of existing BMPs, which generally utilize sedimentation as a primary means of constituent removal. Sedimentation is a common method of urban stormwater mitigation that relies on the settling of particles out of the water column before discharge into a downstream water body. However, if constituents such as metals are associated with the smallest particles, then sedimentation will not effectively remove pollutants due to the very slow settling velocities of very small particles.

As additional NDS projects are implemented in the coming years, results from this research will allow for a comparison of pre- and post-improvement stormwater runoff conditions using the suite of mitigation techniques common to these projects. This should document the relative effectiveness of various stormwater management techniques on alleviating the effects of urbanization, both in the catchments themselves and on downstream natural systems.

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Abstracts of theses and dissertations

Below is an abstract from a recently completed dissertation of an affiliated graduate student. The web site has a list of all affiliated students who have graduated, many of their abstracts, and some entire theses or dissertations (<http://depts.washington.edu/cwws/Theses/abstracts.html>).

Measurements and mechanisms of microbial PAH bioremediation in undisturbed marine sediments

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This research examined mechanisms of polyaromatic hydrocarbon (PAH) microbial remediation in superfund marine sediments (Eagle Harbor, Puget Sound) by studying a single representative compound phenanthrene, a three-ring PAH, to frame the research questions and hypotheses. First, the studies determined estimates of the relative effects that environmental conditions and experimental methods had on the apparent, measured PAH biodegradation rate and extent in realistic settings including undisturbed marine sediment. Statistical analysis of published data led to a categorical model that quantified the influences of biodegradation 'ability' and PAH 'bioavailability' on the PAH biodegradation rates (accuracy within one order of magnitude). Second, analysis of the realistic phenanthrene biodegradation rate data in undisturbed marine sediments as a function of depth (0–10 cm) established that the average first-order rate coefficients in Eagle Harbor sites were up to 0.0086 day⁻¹ and surface sediments (0–1) often showed the highest biodegradation activities. Third, targeted controlled release materials were designed to support anaerobic biodegradation by sulfate and nitrate acting as electron acceptors. Two types of materials, nitrocellulose and calcium sulfate, were found to significantly enhance (factor of 2–3) PAH biodegradation rates in anaerobic marine sediments when measured by the whole core injection method. Fourth, two-dimensional models incorporating diffusion, sorption and Monod biodegradation were developed to analyze the measurement method, "whole core injection." The models quantified the influence of contaminant aging, indicators' maldistribution, and smearing on the accuracy of measurement. Finally, by coupling both contaminant biodegradation and electron acceptor consumption processes, the models investigated the key factors (sorption, biodegradation rate, electron acceptor's concentration, inhibition effect, biodegradation stoichiometry, and spacing of added electron acceptor) that control PAH biodegradation in undisturbed anaerobic sediments using dimensionless groups. By simulations, addition of controlled release nitrate (nitrocellulose) was illustrated as the most efficient way to accelerate in situ bioremediation of PAHs in heavily polluted Eagle Harbor sediment sites. Up to 35% of total PAH contaminant (300mg/L) was predicted to be removed within 5 years. ♦

Quantifying headwater streams and the connection to the soil

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Headwater streams (first order) are the initiation points and primary sources of water feeding a drainage network (Stanford 1996). Headwater streams are generally fed by spring water or snow melt and act as a vital link between terrestrial and aquatic systems, transporting nutrients through the drainage network to the sea. In western Washington more than 50% of the stream mileage is made up of these first order reaches, and yet there is little knowledge of basic quantitative parameters like stream discharge, nutrient concentrations, and potential nutrient export. As human activities such as timber harvest occur across a landscape, some disturbance to streams and upland soil invariably occurs. Impacting this link between terrestrial and aquatic cycles yields further changes to water and nutrient fluxes. The current concern with salmon population recovery and habitat has focused attention on downstream fish-bearing reaches with few studies directed at the source—headwater streams.

Experimental watershed design

Research to address the basic physical and chemical properties of low-elevation western Washington headwater streams is underway at Capitol State Forest, outside Olympia. Waddell Creek, which drains the northeastern portion of the forest, is being developed as an experimental watershed to assess conditions of streams at relatively undisturbed (under approximately 70 year-old Douglas Fir/Western Hemlock) and harvested conditions. This watershed is building on the small-watershed approach (Likens and Bormann 1995), where discrete sampling points act as the cornerstone from which all upstream research efforts and ecological comparisons are placed. Within the Waddell Creek drainage 14 headwater streams instrumented with V-notch weirs and pressure transducers will be used to define stage-discharge relationships (Herschy 1995) where stream hydrographs can be produced. Hydrographs coupled with stream water chemical analysis (see Table 1 for experimental treatments, nutrients sampled, and sampling rates) will generate nutrient export budgets. Waddell Creek will be sampled to compare total basin nutrient export to the 14 individual streams.

Large-scale disturbance, like timber harvest, can change stream physical and chemical conditions from pre-disturbance levels with recovery presumed to be intimately linked to upland terrestrial system recovery (Meyer and Tate 1983). This terrestrial-aquatic recovery link will be tested through a chronological sequence. Replicate streams, within about 5

year old plantations, approximately 15 year old plantations, and controls (traditionally harvested with no riparian buffer), will be studied to understand how small streams react over the long term. Streams harvested this year (2004) or next year (2005) will also be studied to better understand impacts over the short term.

Baseline information from streams at undisturbed and disturbed states lead to the next question: Do riparian buffers mitigate changes to stream properties associated with harvest? Buffered stream replicates in freshly harvested and 5-year-old stands will allow comparison of traditional and buffered streams at these similar stand ages.

Investigation of first order streams is not common and is of great interest to the scientific community, land managers, and regulators alike. This research will provide data and contribute to the Washington State Department of Natural Resources habitat conservation plan. With increasing levels of timber harvest slated for state owned lands, better understanding of these systems will lead to improved balance between production and ecological needs.

Connecting land to streams

Understanding the connectivity between terrestrial and aquatic systems is important when attempting to address current and future environmental problems (Grimm et al. 2003), because the near-stream/saturated zone, where hillslope hydrologic flow paths and saturated soil meet, produces intense biogeochemical N transformations (Cirmo and McDonnell 1997). Transport of N to the saturated zone is the focus



Weir and stilling well (pressure transducer inside) installed at Capitol Forest.

of my terrestrial research questions:

- Is there a difference in soil N availability between the upland and near stream non-saturated areas that feed the saturated zone?
- Will soil N status correlate to stream water chemistry?

Near-stream groundwater monitoring wells and ion exchange resins (IER) will be utilized to assess availability of NH_4^+ and NO_3^- . Four transects per stream, on five total streams, will be anchored at these wells. Installed upslope from the saturated zone to capture subsurface water entering the saturated zone, these wells are generally 5 m from the stream. Separate cation and anion IER bags will be buried at two depths (10 cm and 30 cm) next to the wells and at up slope to points approximately 10 m and 20 m on each transect. The IER bags will attempt to observe N availability and movement from upland slope to the near-stream saturated zone in two separate two-month periods: October–November and March–April. IER bags will also be placed in the wells to capture NH_4^+ and NO_3^- in subsurface waters. Soil analysis for C/N ratio, cation exchanger capacity (CEC), texture, and soil water relation parameters within each stream basin will help frame these research questions and substantiate modeling efforts.

Modeling, teamwork, and PRISM

The Waddell Creek basin is rapidly becoming a site where students and agencies are coming together to address headwater stream process and down stream implications. Utilizing generated data, graduate student Poranee Rattanaviwatpong from the Department of Chemical Engineering is constructing a coupled hydrological/geochemical model (DHSVM/

RHOMBUS) to predict water and nutrient export from this basin. However, models are only as good as the parameters that feed them. The basin's small size, numerous sampled streams, and parameters provide data that will represent resolution not associated with many models currently in operation. This model will also be fed into Prism (Puget Sound Regional Synthesis Model) to add more layers to the evolving database/modeling effort. The arrival of new graduate students, who will begin research in this region this fall (2004), will increase knowledge of the connections between land and stream.

References

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Table 1. Waddell Creek experimental design and sampling protocol.

Stream treatment	# of streams	Chemical analysis	Species	Sampling frequency	Samples per treatment
Control	3	Total N, C, P, ions ** pH & Alkalinity	• Total N, Dissolved organic N, NO_3^- and NH_4^+ • Total Organic C, Dissolved Organic C, pCO_2 , and Alkalinity • Total P, pH **ICP analysis (Al, As, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Zn)	1 x month (Dec–Sept)	48
~5 year old traditional	3				48
~15 year old traditional	3				48
Freshly harvested	1 - traditional 2 - buffered				48
~ 5 year old buffered	2			26	
Total catchment	1			16	
Totals	15		2–3 x month (Oct–Nov)	234	

CWWS email lists

The Center maintains two email lists relating to the water resources and watershed science fields. The employment email list has job announcements from tribes, agencies, non-profit organizations, and industry. The other email list is a bulletin of upcoming events in and around the PNW (usually), sent weekly during fall, winter, and spring quarters. If you would like to be on either list, please send an email to cwws@u.washington.edu, indicating to which list you would like to be added. ♦

Upcoming events

Details for these events can be found at <http://depts.washington.edu/cwws/Outreach/Events/seminars.html>

October 5 – Tuesday Morning Seminar Series, 8:30 to 9:30 am, 22
December 7 Anderson Hall, UW Campus (schedule will be posted on the website in September)

Professional development programs

For more informatin on cost, registration, and other details, see <http://www.engr.washington.edu>. Specific dates will be available on Engineering Professional Programs site soon.

October	Improving Stormwater Management Using Low Impact Development Practices
	Biofiltration and Bioretention for Stormwater Runoff Quality Enhancement
November	Wetland and Upland Habitat Restoration Design

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