Watershed Review

information on water and watersheds

Center for Water & Watershed Studies

Volume 1 Number 2 | Spring 2003

http://depts.washington.edu/cwws

Message from the directors

Welcome to the second issue of the *Watershed Review*, the quarterly newsletter of the Center for Water and Watershed Studies. We are catching our breath after hosting a successful Annual Review of Research on February 6th. This year, more than 400 attendees heard from 22 speakers and viewed 10 posters. Abstracts of all paper presentations are available on our website. The Center greatly appreciates all of the support (financial and volunteer) that helped make this year's Annual Review possible.

In late December, the University of Washington Press (http://www.washington.edu/uwpress) published the book, *Restoration of Puget Sound Rivers*, a volume of invited papers that address the need for a solid understanding of fluvial processes and aquatic ecology in order to predict both river and salmonid response to restoration projects. The book was edited by Center affiliated faculty and staff. We celebrated the publication with a reception for the authors immediately following the Annual Review, for which we hope many of you were able to attend.

In this issue, findings and implications are presented from the Center's recently completed five-year project, the Wood Compatibility Initiative. Several of the collaborative projects undertaken through this initiative examined the distribution and function of large woody debris, freshwater habitat condition and salmon productivity, historic riparian stand condition, and the relation of geomorphic variability to stream temperature. Key findings and management implications are presented in the article. The entire report is also available at http://depts.washington.edu/cwws/Outreach/Publications/WCIreport.pdf.

The application of a sediment budget in urban stream restoration projects is also included in this issue. Chase Barton summarizes an effort to construct a sediment budget for the Pipers Creek watershed, a small urban stream with modest salmon use and strong community support in northwest Seattle. The project was initiated with the support of Seattle Public Utilities, whose stormwater-piping projects over the past decade have dramatically reduced the rate of water-delivered sediment to the channel network. This reduction, however, has raised the potential concern of insufficient delivery of spawning gravel as an unintended result. The project offers a fine example of applying fundamental principles of hillslope and fluvial geomorphology to answer a real-world management issue.

This longer format of the newsletter, which is being sent to all current subscribers, contains more complete versions of the articles included in the shorter newsletter. The charge for this alternative is to defray our printing and mailing costs and to provide an opportunity for agencies and companies to help support the Center financially. To make an on-line subscription for 2003 see http://www.engr.washington.edu/epp/cwm.htm. ■

Derek Booth (co-director)
Clare Ryan (co-director 2002-2003)
Susan Bolton (co-director, on leave 2002-2003)

In this issue

Research on streamside issues through the Wood Compatibility Initiative 2

Applications of a sediment budget to assist urban stream restoration 8

On-line riparian bibliography 12

Upcoming events 12

Research on streamside issues through the Wood Compatibility Initiative

Susan Bolton and Cara Berman, Center for Water and Watershed Studies
Adapted from Congruent Management of Multiple Resources: Proceedings from the Wood Compatibility Initiative Workshop. U.S.D.A. Forest Service General Technical Report PNW-GTR-563. November 2002.

Introduction

Through the Wood Compatibility Initiative (WCI), the Center for Streamside Studies (CSS) (now the Center for Water and Watershed Studies) at the University of Washington has undertaken a series of research efforts addressing production and protection of forest, fish, wildlife, and other aquatic and riparian resources. These efforts consist of micro-habitat and habitat unit-scale mechanistic studies, trans-scale studies exploring hierarchical linkages of structure and function, as well as the development of a landscape classification model (Berman 2002) linking physical and biological processes across scales and integrating terrestrial and aquatic ecosystem components. Results derived from these efforts provides information to support natural resource management decision-making. Projects focus on the interactive effects of structures and processes across ecosystem elements and scales and at different places within the stream network. It is these synthetic studies that are necessary to respond to today's complex management landscape.

Center for Streamside Studies projects examined the distribution of large woody debris in streams across various ecoregions in Washington, and hydraulic and biologic functions of natural versus engineered wood. Other studies investigated freshwater habitat condition and its relation to salmonid productivity and the role of hyporheic flux in redd selection by salmonids. In collaboration with the Upper Columbia River Timber Growers Association and the U.S. Department of Agriculture, Forest Service district forests and supervisor's offices, historic riparian stand condition, specifically canopy cover related to stream shading, was investigated as well as the role of geomorphic variability in affecting stream temperatures. Wood Compatibility Initiative funded projects have involved collaboration with scientists at the Pacific Northwest Research Station, National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), the City of Seattle, the Weyerhaeuser Foundation, the Lummi Nation, and others. This paper summarizes the results from WCI studies initiated over the past four years.

Findings and management implications

Managers' and regulators' research needs are complex and require a detailed understanding of multi-scalar landscape processes as well as the interactive components of the stream ecosystem. Therefore, it was not unusual for CSS projects to address longitudinal, lateral, and vertical connectivity across multiple spatial and temporal scales. In fact, this approach is required to view the river system holistically and to understand the implications for management decisions.

Conceptual model

The interactive components of a river system form a template on which abiotic and biotic processes unfold. These interactive components exist across spatial and temporal scales and establish a heterogeneous and dynamic system. To conceptualize linkages between stream components, Ward (1989) recognized four dimensions: longitudinal, lateral, vertical, and temporal. Wood Compatibility Initiative funded projects describe these stream linkages and interactions across spatial and temporal scales allowing managers to better predict the consequences of disturbances (natural and human-induced) on aquatic systems. To the four dimensions we add a fifth, a policy-science-management dimension, that assesses and informs attitudes and actions that affect resource protection and recovery.

Longitudinal dimension (elements of the landscape)

The longitudinal dimension reflects upstream-downstream linkages affecting stream processes and patterns. Projects investigating the longitudinal dimension address landscape variability and the distribution and pattern of resources along the longitudinal axis of the stream system.

Large woody debris (LWD) quantity LWD characteristics in unmanaged basins vary according to climatic, geomorphological, and hydrological differences (Fox 2001, Fox et al. 2002.). Instream wood is recognized as an important feature linked to channel processes that benefit salmonids, and various LWD targets exist to help resource managers assess restoration needs. However, existing wood targets do not adequately account for variations in LWD quantity or volume due to longitudinal differences in geomorphology, ecoregion, or disturbance regime. Data analysis suggests that current wood targets are not appropriate for all streams within Washington State. Data indicate that LWD amounts vary by bankfull width (BFW) class and region (Tables 1-3). Project findings provide a baseline for managers interested in assessing existing conditions and establishing recovery targets. This information is useful for modifying existing wood targets established by Washington State's Watershed Analysis as well as other management and recovery programs within the Pacific Northwest.

Eastside forests and stream temperatures Riparian forests also vary along the longitudinal axis according to biophysical factors. However, a paucity of information exists on riparian stands and historical shade levels for eastern Washington forests. Johnston (2002) used air photos, field investigation and General Land Office Surveys to characterize historical riparian forest conditions in eastern Washington, taking into account the historical fire regime and fire suppression. This project also received funding from a coalition of Upper Columbia River Timber Growers Association.

Historical riparian conditions are compared to current conditions to evaluate the effects of various management activities (e.g., fire

Table 1. Large woody debris piece quantity: number of pieces per 100 m of channel length (Fox 2001).

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-6 m	>38	26-38	<26
	>6-30 m	>63	29-63	<29
	>30-100 m	>208	57-208	<57
Alpine	>0-3 m	>28	15-28	<15
	>3-30 m	>56	25-56	<25
	>30-50 m	>63	22-63	<22
[a]DF/PP	0-6 m	>29	5-29	<5
	>6-30 m	>35	5-35	<5

Table 2: Large woody debris volume: cubic meters per 100 m of channel length (Fox 2001).

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-30 m	>99	28-99	<28
	>30-100 m	>317	44-317	<44
Alpine	>0-3 m	>10	3-10	<3
	>3-50 m	>30	11-30	<11
[a]DF/PP	0-30 m	>15	2-15	<2

Table 3. Key piece quantity: number of pieces per 100 m of channel length (Fox 2001).

Region	BFW Class	Good Condition	Fair Condition	Poor Condition
Western WA	0-10 m	>11	4-11	<4
	>10-100 m	>4	1-4	<1
Alpine	>0-15 m	>4	0.5-4	<0.5
	>15-50 m	>1	0.5-1	<0.5
[a]DF/PP	0-30 m	>2	0.5-2	<0.5

[a] Douglas-fir/Ponderosa pine ecoregion

suppression, timber harvest). Findings will allow resource managers and regulators to better understand landscape appropriate strategies for managing eastside riparian forests. Active management within riparian stands raises complex issues, particularly considering the potential reduction of shade along temperature sensitive streams. An understanding of the pre-harvest and pre-fire suppression riparian condition is important for determining appropriate levels of shade and other related riparian forest characteristics.

Longitudinal changes in landform and physical and biological processes also give rise to longitudinal and temporal variation in stream temperature. The natural range of thermal conditions as well as temperature variability at the landscape and watershed scales were examined by Scholz (2001). Findings indicate that temperatures in the Wenatchee National Forest are influenced at the landscape scale by several factors including air temperature, drainage area, elevation, and stream shading. Many of these factors are correlated and affect acute and chronic conditions to different degrees. The physical factors that determine stream temperatures at the landscape scale are not necessarily good predictors of smaller scale temperature regimes. Stream temperatures in several watersheds are perhaps influenced primarily by their high geologic potential for groundwater upwelling, especially in basins with little managed area. This study also received funding from the Wenatchee Supervisor's Office and the U.S. Environmental Protection Agency. Hyporheic studies, discussed more fully under the vertical dimension heading, are also examining the relative role of groundwater on stream temperature compared to other characteristics such as shade, buffer width and composition, and elevation in urban, agricultural and forested landscapes (Reidy In progress, Monohan In progress) and complement these landscape studies on stream temperature and riparian conditions.

Understanding system potential and the mechanisms that establish thermal pattern will also assist those designing restoration measures. The Center for Water and Watershed Studies will continue to interact with Pete Bisson and the U.S. Forest Service on temperature work in eastern Washington.

Fish habitat The interactive components of a river system form a template on which abiotic and biotic processes unfold. The longitudinal dimension is a patchwork of resource availability including habitat for aquatic biota. Physical processes affecting bedload scour, such as flow regime and sediment load, and behavioral processes are examined in the context of bull trout spawning habitat development, disturbance, and selection (Shellberg 2002).

Three primary research questions are addressed. First, what are the general factors influence spawning site selection (substrate, depth, velocity, cover, hyporheic flow), and what are the patterns of scour and fill in these microhabitats? Second, how does the reach scale channel morphology (channel type, sediment transport regime, LWD) affect scour and spawning habitat availability? Finally, what influence does watershed hydrology (runoff timing, frequency, magnitude and duration) have on bedload scour and bull trout distribution? Study results will shed light on the potential influence of physical habitat conditions on bull trout population integrity and distribution and help resource managers identify restoration strategies for this threatened species.

Nutrient dynamics vary longitudinally in river systems as a function of a number of physical and biological processes. In cooperation with NMFS and the City of Seattle, CSS participated in studies in the Cedar River to investigate the effects of salmon carcasses on nutrient dynamics and resident fish populations (Kiffney et al. 2001). Results from this study will provide information on the rate at which anadromous salmon naturally colonize newly available habitat and the means by which they redistribute themselves into fresh water spawning areas—information currently not available for any research. Water quality information is being collected and components of stream food webs are being sampled for nitrogen and carbon isotopes. Findings will elucidate linkages between anadromous and resident population dynamics and stream productivity.

The vertical dimension (reach elements)

The vertical dimension reflects interactions between the channel and contiguous groundwater. Projects investigating vertical connectivity address hyporheic flux across variable landscapes and land uses. Hyporheic zones influence chemical, hydrological, zoological, and metabolic functions at various scales and thereby affect channel physiochemical gradients, nutrient availability, and biotic productivity (Brunke and Gonser 1997). Previously, CSS researchers (e.g., Clinton 2001, Coe 2001) investigated hyporheic flux in large alluvial river systems in forested settings.

Collaborative research between CSS and USFS scientists Rick Edwards and Steve Wondzell and NMFS scientist Peter Kiffney was initiated to study hyporheic processes in urban and agricultural streams across variable landscapes. This research focuses on hyporheic transient storage in urban and agricultural areas in comparison to forested areas and potential effects on stream temperature and nutrient cycling (Reidy In progress, Monohan In progress, Clinton and Weekes In progress). These three studies investigate how transient storage, nutrient retention and invertebrate distribution vary within an array of urban, agricultural, and forested streams. Information derived from this work is important for understanding potential changes in stream temperature and productivity under differing land-use practices.

Temporal and lateral connectivity

In addition to longitudinal and vertical connectivity, the above projects incorporate aspects of temporal variability and lateral connectivity. The temporal and spatial patchiness of resources structure biotic communities. Temporal fluctuation of process dynamics and resource response variables was investigated in projects addressing LWD delivery (Fox 2001), riparian characterization (Johnston 2002), and thermal patchiness (Scholz 2001). The lateral dimension reflects interactions between the channel and the adjacent riparian/floodplain system. Interactive pathways along this dimension facilitate the exchange of matter and energy. Lateral connectivity was investigated in projects addressing LWD input processes (Fox 2001), groundwater recharge/discharge (Scholz 2001, Reidy In progress, Monohan In progress, Clinton and Weekes In progress), and habitat-forming processes (Shellberg 2002) including a literature review of riparian soil studies (Mikkelsen and Vesho 2000).

Policy-science-management dimension

The policy-science-management dimension reflects attitudes, behaviors, and actions related to riparian and aquatic protection and recovery. Projects address policy, information transfer, stream restoration and resource management related topics and are designed to assess attitudes, behaviors, and activities related to riparian and aquatic protection and recovery.

Non-point source (NPS) pollution programs Successful control of NPS pollution depends in large measure on intervention programs that inform participants and create public awareness in communities where the programs operate. One component of this project (Ryan et al. 2001) identifies the motivations of rural landowners to participate in conservation-oriented land management programs that assist landowners in adopting land management practices. Results of the research (Ise 2001) indicate that (1) self-interest, such as the need for technical assistance and the threat of future regulations, is the strongest motivation for participation; (2) land use decisions are often based on factors related to the land's utility for commodity production or personal aesthetics; and (3) attitudes about upholding private property rights are frequently stronger than attitudes about protecting the environment. This research did not indicate that conservation-oriented programs could instill a conservation ethic or significantly influence change to individual conservation attitudes and behaviors. Findings will assist regulators in devising techniques to improve nonpoint source control.

Extent of monitoring In addition to research related to behavior and attitudes, monitoring practices of various stream restoration groups and projects was evaluated. Specifically, the perceived shortcoming in the evaluation of stream restoration and fisheries enhancement projects in Washington State was examined (Bash 1999). While project goals include restoring and improving stream health, it was not known to what extent projects were monitored or evaluated to determine if goals are being met.

Findings revealed that monitoring of stream restoration and fisheries enhancement projects may be occurring at higher rates than resource managers thought. However, the level and quality of monitoring activities was highly variable across the sample. Barriers to monitoring included funding, time, personnel, and lack of cooperation from property owners. Monitoring related topics for managers to consider include: appropriateness of objectives and monitoring measures, need for long-term monitoring, development of funding specifically for monitoring, methods for encouraging or requiring monitoring, and implementation and quality of project monitoring. Information from this study may help those managing and funding projects to better understand the current strengths and limitations of project evaluation, and allow them to adjust their policies accordingly.

Restoration projects Concern for the health of aquatic systems in the

Pacific Northwest encouraged research on new methods to enhance freshwater spawning and rearing habitat and to assess habitat related to salmon productivity. Lack of LWD in streams has reduced the complexity and quality of fish habitat. A project designed to compare the hydraulic and biological performance of native LWD and an organic, engineered alternative to LWD (ELWd™) was undertaken (O'Neal 2000, O'Neal et al. 2000, Savery 2000) and received additional support from the Weyerhaeuser Foundation.

Fish response was not significantly different for the two types of wood. Values of invertebrate metrics were generally higher for samples collected from ELWd™ surfaces than from traditional LWD. Invertebrate samples were also evaluated in terms of the production of available food resources for salmonids. The results showed greater food availability from the ELWd™ structures. In all sampling, benthic samples did not show a clear difference between the wood types. Therefore, innovative sampling methods were created to assess invertebrate production on LWD.

Savery (2000) compared the hydraulic effects of native LWD and an engineered alternative. The physical differences between the native LWD and the ELWd™ had an effect on the ability of the installed structures to maintain channel position. Engineered LWD did not maintain original bank position as well as native LWD. Although some of the differences between pairs was explained by local hydraulics and bank position, the low mass of engineered wood allowed the structure to be moved by the stream. Additionally, engineered roots on the ELWd™ structures improved their stability but were not as stable as native LWD with attached rootwads. The mean scour produced by the two log types was not statistically different. However, the engineered structures created a comparatively large amount of turbulence on the upstream side of the log. Research results related to engineered wood performance provide an evaluation of the effectiveness of an engineered alternative compared to traditional LWD for stream enhancement projects before engineered structures are widely placed.

Management models Current recovery efforts lack a clear understanding of the relationship between freshwater habitat conditions and salmon response. This information is critical to the successful design of salmon recovery plans. To evaluate the distribution of expected salmon production resulting from alternative restoration strategies in Oregon's Willamette River Basin, CWWS, in cooperation with NMFS, is developing a model (Brauner In progress) relating restoration activity to changes in habitat. The resulting model will be linked to a NMFS model relating habitat characteristics to the survival rates of salmon. This project will develop analytical tools to assist resource managers designing or evaluating restoration actions intended to increase salmonid fitness and ultimately productivity.

Riparian forest restoration In January of 1999, Lummi Natural Resources and the Center for Streamside Studies began to analyze the vegetative and environmental data collected in the three years since the inception of the Riparian Zone Restoration Project and to evaluate the project's success. One of the products of this analysis (Wishnie et al. 1999a, Wishnie et al. 1999b) was the establishment of new data collection protocols, field sheets, and comment and damage codes to improve the accuracy and utility of data collection. These materials are an example of an effective approach to data collection: initial and annual survey protocols, data sheets, survey codes, and damage codes.

Conclusion

WCI-funded projects address the following resource management issues and information needs: (1) increase understanding of physical and biological processes across variable landscapes; (2) develop conceptual models allowing inferences within and across regions; (3) explore disturbance processes and implications for management; (4) design multi-scalar monitoring programs; (5) develop linkages between management actions and site-scale alterations; and (6) design and calibrate broad scale monitoring metrics. These projects form the basis for a synthetic approach to understanding and managing complex ecological systems. A recent WCI grant award, to develop a landscape classification model linking physical and biological processes across scales and ecosystem components, allowed us to integrate research findings and meet current resource challenges and data needs (Berman 2002).

To ensure access to CWWS research, efforts are underway to increase the efficiency and effectiveness of our information transfer activities. Efforts undertaken through the WCI program are important to resource managers throughout the Pacific Northwest. We are committed to ensuring broad dissemination of research results as well as fostering dialogue to address issues important to resource managers.

Literature cited

Bash, J.S. 1999. Survey of stream restoration and fisheries enhancement monitoring in Washington State. Seattle, WA: University of Washington, 130 p. M.S. thesis

Berman, C.B. 2002. Assessment of Landscape Characterization and Classification Methods. Report to the U.S.D.A. Forest Service. Available at http://depts.washington.edu/cwws/Outreach/Publications/Landscapeclassification.pdf.

Bruaner, Jody. [N.d] Decision-making under uncertainty: Prioritizing freshwater habitat restoration for salmonid recovery. Ph.D. dissertation in preparation.

Brunke, M. and Gonser, T. 1997. The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology. 37: 1-33.

Clinton, S.M. and Weekes, A. [N.d.] Distribution of hyporheic invertebrates in Puget Sound Lowland streams. Manuscript in preparation.

Clinton, S.M. 2001. Microbial metabolism, enzyme activity, and production in the hyporheic zone of a floodplain river. Seattle, WA: University of Washington, 86 p. Ph.D. thesis.

Coe, H. 2001. Distribution patterns of hyporheic fauna in a floodplain riparian terrace. Seattle, WA: University of Washington, 75 p. M.S. thesis.

Fox, M.J. 2001. A new look at the quantities and volumes of instream wood in forested basins within Washington State. Seattle, WA: University of Washington, 239 p. M.S. thesis.

Fox, M.J.; Bolton, S.; Conquest, L. 2003. Reference conditions for instream wood in western Washington. In: Montgomery, D.R.et al., eds. Restoration of Puget Sound Rivers. Seattle, Washington, University of Washington Press: 361-393.

Ise, J.L. 2001. Motivations of rural landowners to participate in conservation-oriented land management programs. Seattle, WA: University of Washington, 121 p. M.S. thesis.

Johnston, J. G. 2002. Comparison of historic and current stream shade in eastern Washington. Seattle, WA: University of Washington, 130 p. M.S. thesis.

Kiffney, P., Riley, S., Bilby, B., and Inman, C. 2001. Aquatic and terrestrial response to return of anadromous salmonids above Landsburg Dam diversion, Cedar River, Washington. National Marine Fisheries Service working report.

Mikkelsen, K. and Vesho, I. 2000. Riparian soils: A literature review. Center for Streamside Studies Report. http://depts.washington.edu/cwws/Outreach/Publications/soillitreview.html

Monohan, Carrie. [N.d.] Nitrogen retention in riparian buffers along lowland agricultural streams. Ph.D. dissertation in preparation.

O'Neal, J.S. 2000. Biological evaluation of stream enhancement: A comparison of large woody debris and an engineered alternative. Seattle, WA: University of Washington, 103 p. M.S. thesis.

O'Neal, J.S., Watts, A., Bolton, S., and Sibley, T. 2000. A comparison of the hydraulic and biological effects of large woody debris and an engineered alternative. In CD-ROM Proc. ASCE 1999 Int'l Water Resources Engineering Conf. Aug 8-11, 1999. Seattle WA.

Ryan, C.M., Ise, J., and Wolf, K.L. 2001. Nonpoint source pollution programs: Assessing methods and behavioral effectiveness. Center for Streamside Studies Fact Sheet. http://depts.washington.edu/cwws/Outreach/Publications/factsheets.html

Reidy, C. [N.d.] Assessing the variability of hyporheic zones in Puget Sound Lowland streams. M.S. thesis in preparation.

Savery, A.W. 2000. A comparison of the hydraulic effect of large woody debris and an engineered alternative. Seattle, WA: University of Washington, 72 p. M.S. thesis.

Scholz, J.G. 2001. The variability in stream temperatures in the Wenatchee National Forest and their relationship to physical, geological, and land management factors. Seattle, WA: University of Washington, 129 p. M.S. thesis.

Shellberg, Jeffrey. 2002. Hydrologic, geomorphic, and biologic Influences on redd scour in bull char (*Salvelinus confluentus*) spawning streams. Seattle, WA: University of Washington, 206 p. M.S. thesis.

Ward, J.V. 1989. The four-dimensional nature of lotic ecosystems. Journal of the North American Benthological Society. 8(1): 2-8.

Wishnie, M., McClintick, A., Hansen, J., and Bob, F. 1999a. Riparian conversion monitoring data collection protocols. Center for Streamside Studies fact sheet. http://depts.washington.edu/cwws/Outreach/FactSheets/protocolsc.pdf

Wishnie, M., McClintick, A., Hansen, J., and Bob, F. 1999b. Lummi Natural Resources Riparian Zone Restoration Project (RZRP): Proposed Data Collection Protocols Field Sheets Damage Codes. Center for Streamside Studies report. Available at http://depts.washington.edu/cwws/Research/Reports/Lummi/lummi.html ■

Applications of a sediment budget to assist urban stream restoration

Chase Barton, Center for Water and Watershed Studies

Introduction

Changes in land use and hydrology resulting from urbanization alter the processes of sediment production, delivery, and fluvial transport within a watershed. Whereas these changes can sometimes lead to aggradation and decreases in channel volume, a more typical and predictable evolutionary sequence displays degradation and dramatic increases in channel cross-sectional area that can occur following urbanization (Hammer 1972, Booth 1991, Simon 1995). Where channel gradient is moderate to high and local geologic material is susceptible to erosion, channel enlargement can be rapid to catastrophic (Booth 1990, Booth and Henshaw 2001). Such changes in channel dimension can make the process of channel erosion a major source of sediment in an urbanizing watershed (Trimble 1997, Nelson and Booth 2002).

This report presents details of a Masters thesis supported by Seattle Public Utilities in which a sediment budget was constructed for the Pipers Creek watershed to describe how the magnitude and character of sediment production has changed over time, primarily as a result of basin urbanization and subsequent engineering efforts to control channel enlargement and erosion (Barton 2002). In addition, the condition of instream sediment was evaluated to determine if the physical characteristics of the substrate currently constrains the quality of salmonid habitat.

Sediment budget components and results

The sediment budget details the sources and rates of sediment production in the basin, the quantity, quality, and distribution of instream sediment, as well as the character of bedload sediment transport in the mainstem of Pipers Creek.

Sediment production

Sediment production in the Pipers Creek watershed has occurred over four distinct periods: before basin development, following the onset of basin development but prior to significant changes in sediment production, during basin urbanization subsequent to increases in sediment production but prior to channel-stabilization measures, and under the current conditions following channel stabilization and bank armoring throughout much of the channel network. Barton (2002) characterizes sediment production in three of these four periods: prior to basin development, following the onset of increased sediment production resulting from basin urbanization but prior to channel-stabilization measures, and under current conditions. This summary report details the regime of sediment production under the current conditions.

The sediment sources evaluated for the current period in this study include channel enlargement and erosion, landslides, soil creep, and sediment produced off of urban land surfaces. The amount of coarse (>8 mm) and fine (<8 mm) sediment produced by each source was determined through sieve analysis of contributing geologic units and subsequent estimates of the relative contribution of each geologic unit to each sediment production source. The production of fine, coarse, and total sediment from each source is presented in

Table 1. Summary of sediment production by source for the current production period.

Source	**Total sediment production (tonnes year^{-1})**	**Fine sediment production (tonnes year^{-1})**	**% of total fine sediment produced by source**	**Coarse sediment production (tonnes year^{-1})**	**% of total coarse sediment produced by source**
Channel Enlargement	354	319	38	35	65
Urban Sediment	252	252	30	0	0
Landslides	270	253	30	17	31
Soil Creep	12	10	1	2	4
Total	**888**	**834**	**99[1]**	**54**	**100**

[1] The sum of the percentages is less than 100 due to rounding.

Table 1. Channel enlargement, landslides, and sediment produced from urban areas generate 40%, 30%, and 28% of the average annual total.

Sediment storage

Sediment in short-term storage in the active channel was estimated by measuring bar storage, channel storage, and storage behind naturally occurring channel structures such as large woody debris (LWD) and boulder steps. Sediment stored in bars and the active channel are mobile on nearly a yearly basis, and sediment behind LWD and natural boulder weirs becomes mobile when natural structures break apart or readjust. The particle-size distribution of sediment in storage was estimated using pebble counts and bulk-sieve samples. The relative proportions of the total, coarse, and fine sediment stored in short-term storage in the active channel is shown in Figure 1. Though modifications to control the streambed grade and provide bank protection have also created some local structural complexity that encourages bar formation, the prevailing plane-bed morphology, channel entrenchment, and the relative lack of overall complexity does not promote sediment deposition. As such, over 80% of the sediment in short-term storage is located within the channel bed.

Within the mainstem reach, the particle-size distributions of two subsurface-sediment samples indicate levels of fine sediment that have been associated in other field studies with reductions in the survival-to-emergence of coho and chum salmon. Among these studies that assess the effect of fine sediment on salmonid spawning success, different percentages of different size fractions of spawning substrates have been investigated and show strong correlation. As such, no specific parameter of local substrate character has been isolated or identified as “most degrading.” The grain-size distributions of the local subsurface samples, however, are similar to values that have been correlated with degraded spawning conditions (Figure 2). Thus, the physical character of substrate material in the spawning reaches of the Pipers Creek stream network may limit successful coho and chum reproduction.

Sediment transport

Sediment transport was evaluated using one year of hydrologic data (WY 2002) from a stream gauge on the mainstem of Pipers Creek. The precipitation during WY 2002 was approximately 120% of the 30-year normal

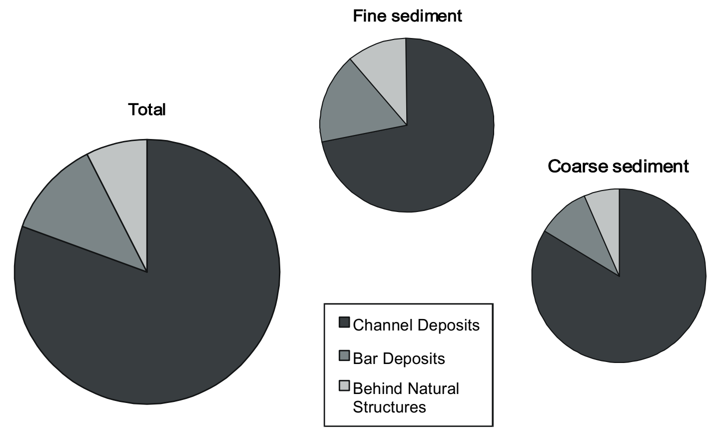

Figure 1. Relative proportions of coarse, fine, and total sediment in each short-term storage element evaluated in the active channel.

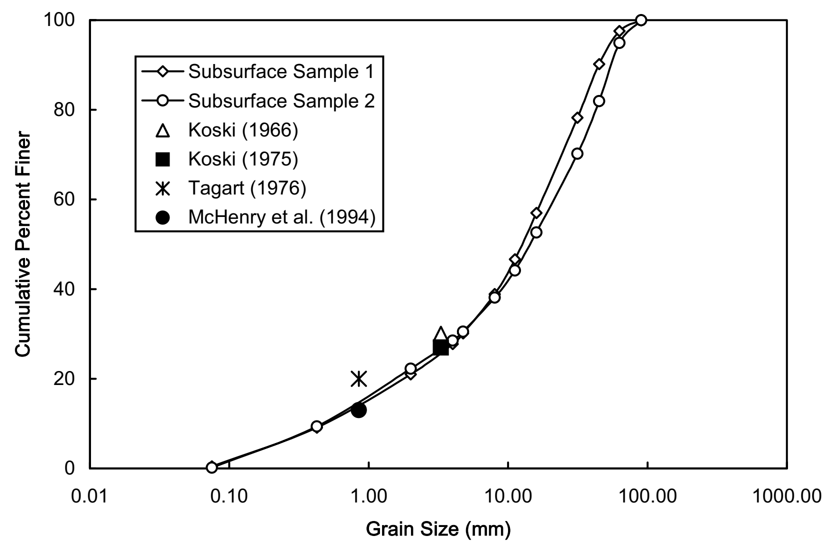

Figure 2. Grain-size distribution curves for subsurface samples from reach PM1. Also shown are substrate qualities that have been correlated in prior field studies with decreased survival to emergence of salmonids.

(National Weather Service 2002). To explore the potential range in sediment transport that would result from variations in precipitation, and therefore discharge, sediment transport was also calculated for potential discharge regimes representing 100% and 80% of normal precipitation by dividing the transport discharge durations from WY 2002 by 1.2 and 1.5 respectively.

Sediment transport was evaluated in two ways. First, the Bagnold (1980) sediment transport equation was used to calculate bedload transport in reach PM1 (Table 2). Secondly, the reach-averaged annual bedload travel distance, or particle transport rate, was calculated using the bedload transport results in con-

Table 2. Results of bedload transport calculations.

Character of Yearly Precipitation on on which Discharge Regime is based	Calculated Bedload Transport Rate (tonnes year^{-1})	Probable Range of Bedload Transport Rates (tonnes year^{-1})
120% of Normal[1]	260	130-520
100% of Normal[2]	220	110-430
80% of Normal[2]	180	90-360

[1] Measured in reach PM1 during WY 2002.

[2] Adjusted from WY 2002 discharge history.

Table 3. Results of particle transport calculations.

Character of Yearly Precipitation on on which Discharge Regime is based	Calculated Particle Transport Rate (m year^{-1})	Probable Range of Particle Transport Rates (m year^{-1})
120% of Normal[1]	220	110-450
100% of Normal[2]	190	95-370
80% of Normal[2]	150	80-310

[1] Measured in reach PM1 during WY 2002.

[2] Calculated based on WY 2002 discharge history.

junction with the estimates for short-term storage (Table 3). In an assessment of bed load sediment transport formulae, Gomez and Church (1989) found the Bagnold equation to be the most reliable means for estimating the magnitude of sediment transport in channels of this general size with limited hydraulic information. Even so, the precision of this equation is limited with anticipated uncertainty of ± 2-fold. This uncertainty is addressed by calculating a probable range for both bedload and particle transport rates.

Conclusion and recommendations

Although sediment production in the Pipers Creek watershed has been reduced from its post-urbanization maximum through efforts at streambed grade control, bank protection, and stormwater diversions over the last 30 years, current sediment production remains six times greater than the estimated historic rate. The magnitude of fine sediment production is seven times the historic rate and may degrade spawning conditions. In addition, stormwater discharges continue to enlarge channels that have not been stabilized or armored, and they also transport more coarse sediment than is currently delivered to the channel network annually.

The most important management issues addressed in this investigation are:

- Continued channel enlargement
- The long-term trend of coarse sediment in the channel network
- The potential consequences of fine-sediment production.

Channel erosion and enlargement is presently the largest sediment source in the basin. This will continue until further channel-stabilization is completed or a new equilibrium is established between transport capacity, sediment supply, and channel form, probably still many years in the future. Further stabilization of 15% of the total channel network could reduce the overall sediment production by about one-quarter of the current rate, and further channel stabilization may be warranted in certain reaches in order to prevent landslides, subsequent to continued channel incision and widening, that could threaten properties adjacent to the Pipers Creek channel network.

As a result of recent projects that have piped top-of-slope culvert outfalls down to the channel, delivery of sediment to the channel network has decreased substantially. In combination with urban-induced increases in discharge, the balance between coarse sediment production and transport has been altered. The entire range of probable bedload transport rates now exceeds the current estimate of coarse sediment production. The response to this imbalance should be a decrease in short-term sediment storage and coarsening of the substrate, occurring over the next one to two decades. A balance between bedload transport and the current rate of coarse-sediment production could be accomplished fully by a modest increase in the D_{50} particle diameter (from 35 mm to 51 mm). Because a reduction in short-term storage should also contribute to compensating for the recent decrease in sediment supply, the magnitude of each response will be muted and not likely to significantly alter the physical character of sediment in the channel network. Thus, the recent reduction of sediment input is not likely to degrade general fluvial processes or habitat quality and no management action is currently necessary to maintain the condition of coarse sediment in Pipers Creek. Continued evaluation of substrate character and channel cross-sections are recommended to monitor the long-term effects of recent and future decreases in sediment supply.

Prior to basin urbanization, sediment production processes generated fine and coarse sediments simultaneously and primarily during large storm events. Now, even small storms wash fine sediment from urban areas and deliver them to the channel network. That sediment increases turbidity and may be deposited in the active channel during relatively low flows to infill gravel pore spaces and potentially reduce the flow of water and delivery of dissolved oxygen to salmonid redds. The fine-sediment content of the substrate in the spawning reaches has been associated with degraded habitat in other studies and may limit the reproductive success of salmonids. Analysis of the rates of survival-to-emergence of salmonids in Pipers Creek is warranted. If fine sediment, currently delivered at seven times its estimated historic rate, is demonstrated to be degrading spawning conditions than a reduction in fine sediment production could be accomplished through further channel stabilization or efforts to reduce the contribution of fine sediment from the urban portion of the basin. Reduction of fine sediment delivered from urban areas would improve water quality, which would also lead to enhanced habitat conditions.

Recommendations resulting from this investigation are as follows:

• Provide additional channel stabilization in specific reaches to reduce sediment production and prevent future landslides that could threaten properties adjacent to the Pipers Creek channel network.

• Take no management action to maintain the condition of coarse sediment in Pipers Creek at the present time. Continued evaluation of substrate character and channel cross-sections are recommended, however, to monitor the long-term effects of the recent decreases in sediment supply.

• Continue erosion control and other preventative sediment-production measures to minimize the amount of fine sediment delivered to the channel network, particularly from urban areas.

• Analyze the rates of survival-to-emergence of salmonids in Pipers Creek, as this factor is likely a limiting condition to spawning success.

References

Barton, C. M. 2002. A sediment budget for the Pipers Creek watershed: Applications for urban stream restoration. Master's thesis. University of Washington.

Bagnold, R. A. 1980. An empirical correlation of bedload transport rates in flumes and natural rivers. Proc. R. Soc. London, Ser. A. 372: 453-473.

Booth, D. B. 1990. Stream-channel incision following drainage-basin urbanization. Water Resources Research. 26: 407-417.

Booth, D. B. 1991. Urbanization and the natural drainage system-impacts, solutions, and prognoses. The Northwest Environmental Journal. 7: 93-118.

Booth, D. B. and P. C. Henshaw. 2001. Rates of channel erosion in small urban streams. In Land Use and Watersheds: Human Influences on Hydrology and Geomorphology in Urban and Forest Areas. American Geophysical Union. Water Science and Application Volume 2: 17-38.

Gomez, B. and M. Church. 1989. An assessment of bed load sediment transport formulae for gravel bed rivers. Water Resources Research. 25: 1161-1186.

Hammer, T. R. 1972. Stream channel enlargement due to urbanization. Water Resources Research. 8: 1530-1540.

National Weather Service. 2002. http://www.wrcc.dri.edu/summary/climsmwa.html.

Nelson, E. J. and D. B. Booth. 2002. Sediment budget of a mixed-land use, urbanizing watershed. Journal of Hydrology. 64:51-68.

Simon, A. 1995. Adjustment and recovery of unstable alluvial channels: identification and approaches for engineering management. Earth Surface Processes and Landforms. 20: 611-628.

Trimble, S. W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science. 278: 1442-1444. ■

On-line riparian bibliography

The joint efforts of the University of Washington, Center for Water and Watershed Studies (formerly Streamside Studies) and the U.S. Forest Service, Stream Systems Technology Center, Rocky Mountain Research Station produced a compilation of over 8,000 riparian references through an extensive search of literature and electronic databases. It is updated annually and is intended for a wide audience including aquatic ecologists, hydrologists, geomorphologists, and policy makers. Sources include journals, government documents, books, monographic series, and conference proceedings. The bibliography can be viewed at http://www.cfr.washington.edu/Riparian/index.html. ■

Upcoming events

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

April 1 – June 3	**Tuesday Morning Seminar Series**, Tuesdays, 8:30 to 9:30 am, 22 Anderson Hall, UW campus
April 3 – June 12	**Monster Seminar Jam**, Thursdays, 11:00 am to 12:00 pm, National Marine Fisheries Service Northwest Science Center, 2725 Montlake Boulevard East
May 28 – 29	Workshop on Instream Flow Science and Management **Instream Flow Science and Management in Western Washington: Developing a Comprehensive, Ecosystem-Based Approach** UW campus. For more information, see http://www.stewardandassociates.com/Instream/.

Professional development programs

For more information on cost, how to register, and other details see http://www.engr.washington.edu/epp

June 4 – 5	**Biological and ecological assessment and habitat monitoring**

Center for Water and Watershed Studies
University of Washington
Box 352100
Seattle Washington 98195-2100
206.543.6920
cwws@u.washington.edu