The Washington Water RESOURCE

The quarterly report of the Center for Urban Water Resources Management

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Message from the Director

This issue of the *Newsletter* provides the opportunity to highlight the research results of one element of our three-year project on urban stream rehabilitation, which is drawing to a close at the end of this year. Forthcoming issues will continue to explore the many facets of this project, which has helped to support such diverse studies as our intensive temperature survey, three years of biological monitoring across a gradient of urban streams, sediment-stability assessments, remotely sensed land-cover classification, hydrologic characterization of disturbed watersheds, evaluation of the relative roles of riparian-corridor and whole-watershed conditions, and stream-monitoring strategies. The challenges of integrating, and of articulating, these diverse yet interrelated facets has proven to be more daunting and time-consuming than I ever anticipated, but the results and recommendations that emerge from this body of work should be of long-lasting value to the region as a whole.

In the interim, the Center is co-organizing a session at the upcoming American Geophysical Union's annual meeting focusing on "The Scientific Basis for Stream Restoration." The meeting will be held May 30-June 3 in Washington DC, a delightful time of year in the nation's capital; and although such a trip might normally be difficult to justify, the scope of papers that will be presented should have widespread relevance. The web site for the meeting is at http://www.agu.org/meetings/sm00top.html.

Although progress is always slow in the formal dissemination of research results, I am very happy to report that two articles are "in press" in archival journals and likely to appear in print within several months. They are:

- K. J. Comings, D. B. Booth, and R. R. Horner, "2000, Pollutant Removals by Two Wet Ponds in Bellevue, Washington." *ASCE Journal of Environmental Engineering* (in press; full report available from the Center as publication G13).
- J. Scholz and D. B. Booth, "2000, Monitoring Small Urban Streams: Strategies and Protocols for Humid-Region Lowland Systems." *Environmental Monitoring and Assessment* (in press; preprint version is publication E17 and available to download from the Center's web site).

We have made a number of additions to our web site, and I hope to expand our use of it to improve the visibility and applications of our various research efforts. Its maintenance has been the sometimes-thankless and always-unpaid labor for Karen Comings, one of our Ph.D. students here. Thanks to her efforts, we have a large number of research reports and abstracts that can be directly downloaded, all but one of our past newsletter issues from 1996 through 1999, and subscription and publication-order forms. We also host several multi-agency documents and compilations, notably the "Urban Issues" Endangered Species Act Library and Database (described in the last issue of the *Newsletter*), abstracts from the Salmon in the City conference in

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1998, and a new publication arising from the "Soils for Salmon" workshop in 1999. Occasionally we are inspired to rearrange the location of specific documents, so if your bookmarked links don't work right, begin at our home page (http://depts.washington.edu/cuwrm/) and start again!

Lastly, we can see two long-range items on the schedule. First, the Center has co-produced (together with the Center for Streamside Studies) a popular week-long course in the U. S. Environmental Protection Agency's "Watershed Academy" series. Its popularity no doubt stemmed, in part, from EPA's generous subsidy of the instructional costs; but after two years they have seen major cutbacks across all of their training efforts, and as we go to press I anticipate that the course will not be offered again this year. We do still offer a somewhat shorter (and slightly more expensive) course in the fundamentals of urban watersheds through Engineering Professional Program's PEPL program. This course is next scheduled for early 2001; check the PEPL web site at http://www.engr.washington.edu/epp/Pepl/pepl.html for details and a great deal of additional information on other, related, course offerings.

The second scheduling item is the date of our annual review and presentation of the Center's research. It will be the morning of Friday, October 20, and as promised we are moving to larger quarters (and free parking) at the Center for Urban Horticulture, across from University Village. More information will be forthcoming in the late-summer issue of the *Newsletter*, but do mark your calendar now!

❖ *Derek Booth*

Effectiveness of Large Woody Debris in Urban Stream Rehabilitation

By Marit G. Larson, Graduate Research Assistant, Center for Urban Water Resources Management

INTRODUCTION

In-stream rehabilitation projects are commonly built in response to problems that result from both local sources and diffuse watershed degradation. Local problems, such as an improperly sized culvert, are relatively easily identified and corrected. Reversing the consequences of watershed degradation, such as channel widening and incision, is much more difficult if conditions that led to stream degradation remain unchecked. Despite this challenge, large amounts of money are being spent on in-stream projects in urban or urbanizing basins, because of numerous recognized problems on these streams, the interest of local communities in restoring the amenities these streams provide, and the relative ease and economy of site-specific in-stream work.

This study investigates the effectiveness of one common technique, placement of in-stream large woody debris (LWD), to reverse local effects of watershed degradation in the absence of any systematic watershed-scale rehabilitation measures. To accomplish this, six stream rehabilitation projects in western Washington State that employ LWD were examined with the objective of answering the following questions:

- Does in-stream placement of LWD produce physical channel characteristics typical of streams in less-disturbed watersheds?
- Does biological integrity improve after LWD is added?
- How can LWD project designs be improved?
- Does watershed-scale disturbance, generally unaffected by LWD projects, exert an equivalent or greater effect on the physical and biological recovery of the channel than the local in-channel conditions that are addressed by the LWD?

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THE USE OF LWD IN CHANNEL ENHANCEMENT

LWD plays prominent roles in regulating channel morphology and habitat in the Pacific Northwest, from steep and narrow headwater streams to wide low-gradient rivers. These functions make it a critical component of current stream and river restoration and enhancement efforts. The effects of LWD on moderate-gradient streams (0.5-4% slope) with bankfull widths of about 4-40 m have been studied in greatest detail. The steeper of these channels, dominated by riffle and glide features, are classified as "plane-bed." Lower-gradient streams commonly display regularly alternating riffles and pools in a meandering planiform. The transition from "plane-bed" to these flatter "pool-riffle" channels, under a particular sediment-supply and flow regime, can be controlled by the presence of LWD or other obstructions that form scour pools, bars, sediment storage sites, and steps in channels that would otherwise maintain a relatively uniform, planar bed. In these channels, LWD can influence bank stability, pool and bar formation, sediment retention, and grade.

Several constraints increase the difficulty of returning LWD to streams in urban systems. In most urban basins there is little possibility of restoring natural LWD recruitment. Opportunities for allowing LWD to influence channel morphology are also limited by channel confinement and constrictions. The proximity of structures and property to the channel also limits any tolerance for the random development of log jams, intermittent channel widening, debris entrapment, backwater, or LWD movement. The integration of LWD into urban systems also requires gaining acceptance and educating the community at a level not necessary when working in remote areas.

APPROACH AND METHODS

Study Sites

To investigate whether in-stream structures can mitigate the impacts of watershed urbanization, six in-stream rehabilitation projects were examined in watersheds that span a range of watershed development intensities (Table 1), and that generally identified "habitat enhancement" as a primary or secondary goal. Development intensity in the watershed area contributing to each project was determined from GIS land cover data layers based on 1995 Landsat satellite imagery classified by King County Land and Water Resources Division (Jeff Burke writ. comm., 1998) at 30-m resolution. For this analysis, land cover was considered developed if classified as "high," "medium," or "low-intensity" development; "bare rock/concrete," "bare ground/asphalt," and "recently cleared" land (Table 2).

Table 2. Watershed and stream characteristics

	Forbes	Thornton	Swamp	H. Hills	L. Jacob's	Soosette
Stream characteristics						
Avg. bankfull width (m)	3.5	5.4	10.4	4.1	6.4	8.7
Bed slope	0.037	0.006	0.005	0.046	0.028	0.019
D_{50} (mm)	14 (26)	18	14	11	39	51
Upstream drainage (km^2)	3.5	25.4	53.6	2.2	11.1	13
Percent upstream development						
Watershed	82%	93%	72%	62%	52%	58%
Riparian buffer (100 m)	70%	75%	47%	44%	43%	34% (45%)*
Basin relief (m)	45	45	150	45	45	45
Basin gradient (relief / basin length)	0.009	0.0045	0.003	0.0022	0.0075	0.0075

*Percent development in riparian buffer beginning at upstream end of the project.

Installed LWD frequency, size, and position

A section of stream, at least 20 times the bankfull width, was surveyed in the project reach and just upstream of the project. All pieces of wood greater than 10-cm diameter and longer than 1m in any portion of the bankfull channel were counted. Root wads greater than 0.02 m^3 in volume were also included. The diameter and length of every piece was estimated; every 5-10 pieces the lengths and widths were measured with a tape to calibrate the visual estimate. "Key pieces" were also identified; they are those pieces of LWD defined as being independently stable within the bankfull channel (i.e., not held or trapped by other material) and retaining or having the ability to retain other LWD.

Pools

Residual pool depths (RPDs) were measured in the field and calculated from longitudinal thalweg surveys. RPD is the difference between depth of water in the pool and at the top of the downstream riffle. Only pools with a RPD at least 25% of the bankfull depth and minimum pool length at least 10% of the bankfull width were included. Pre-project information on pool numbers was taken from the Fish Habitat Relation (FHR) surveys conducted by the King County Water and Land Resources Division. The influence of LWD on the formation of pools was determined by field observation, with two categories identified: pools formed by wood and pools formed by some other mechanism (such as scour around a boulder or lateral scour against an armored bank.

Biology

Benthic invertebrate samples were collected at five of the six rehabilitation projects in a companion study by Sarah Morley in the UW School of Fisheries and analyzed according to the Benthic Index of Biological Integrity (B-IBI). Sample sites were located on riffles just upstream and downstream of the project reaches. The B-IBI is a multimetric index that uses 5 different categories of measures of macro-invertebrate samples (taxa richness, community composition, feeding groups, tolerance/intolerance, dominance) to assign a score that ranges from 10 (very poor) to 50 (excellent).

Table 1. Project Characteristics

	Forbes	Thornton	Swamp	H. Hills	L. Jacob's	Soosette
Project Characteristics	*ANCHORED LWD*			*UNANCHORED LWD*		
Year constructed	1988	1997	1997	1996	1995	1994
Project length (m)	210	280	370	240	430	1430
LWD placement	cabled and in weirs	cabled and in weirs	anchored as deflectors	unanchored, by crane	unanchored, by crane	unanchored, by helicopter
No. pieces LWD added	18	25	48	300	80	280
Approx. cost ($/m)*	$350(1)	NA	$160(2)	$580(2)	$120(2)	$280(2)
Project Objectives						
Flood control	X	X	X	X	X	
Sediment and erosion control	X	X		X	X	X
Habitat enhancement	X	X	X		X	X

*Costs based on preliminary estimates of construction costs divided by project length: (1) from Parametrix Inc. (2) from King County Department of Natural Resources

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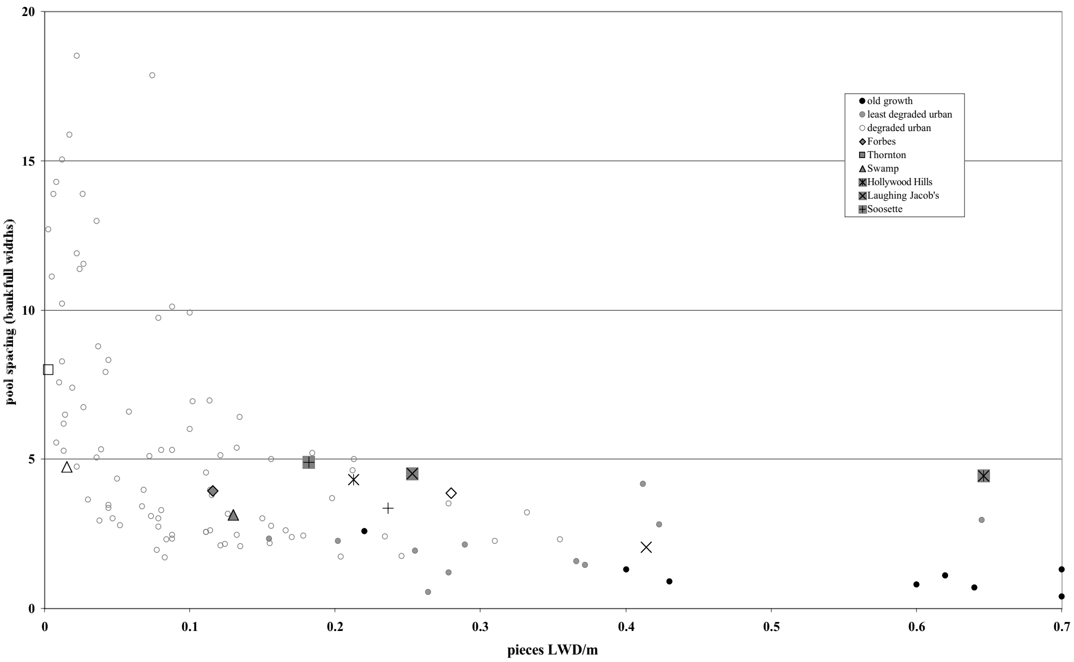

Figure 1. Pool spacing vs. LWD loading — comparison with reference sites, and between "project" and "upstream" sites.

RESULTS

Installed LWD Frequency, Size, and Position

LWD frequency was used to compare project-reach and upstream conditions to those of reference streams. In the study reaches, LWD loadings were highest — in the range of the "least degraded urban streams" — in the projects using unanchored LWD (Figure 1). Only one of the streams (Hollywood Hills) had an LWD frequency considered "ideal" for a natural stream. At the projects where the wood was anchored, LWD loadings were still typical of degraded urban streams and clear-cut. No logs of sufficient size to be "key" pieces were added to the widest stream (Soosette), where LWD was not anchored.

LWD Mobility

Where the post-construction interval had experienced one or more 2-year to 10-year discharges, no anchored LWD moved at any of the project reaches. At the one unanchored LWD project where over 50% of the LWD were considered key pieces (Hollywood Hills), there was no significant LWD movement.

In the two unanchored LWD projects with few or no key pieces, however, LWD movement was documented. Two unanchored logs at Swamp Creek were transported over 300 m and out of the project reach. After a 10-yr flow event in Laughing Jacob's Creek, numerous pieces of LWD were either transported downstream (most 20-30 m), moved across the channel, or abandoned on adjacent banks by high flows. Small-diameter logs with roots attached and placed entirely in the channel appeared to move further than larger-diameter smooth logs placed perpendicular to the channel and partly resting on the banks. At Soosette Creek, dozens of smooth logs (as well as logs with branches drilled into them, ostensibly to mimic the form of "real" trees), moved several 10's of meters. Most logs were found in piles where they had been carried.

Pool Spacing, Formation, and Depth

In the project reaches, pool spacing was insensitive to LWD loading (Figure 1). At three sites (Hollywood Hills and Laughing Jacob's and Soosette creeks), pool spacing was wide compared to least-degraded urban streams with the same amount of LWD. Forbes and Swamp creeks, where the LWD was anchored, had pool spacings most similar to those found in forested and least-degraded urban streams despite low LWD frequencies. Wherever pre-project data were available, pool spacing was reduced in all projects (Figure 2). At Soosette and Swamp creeks, however, pool spacing narrowed only slightly.

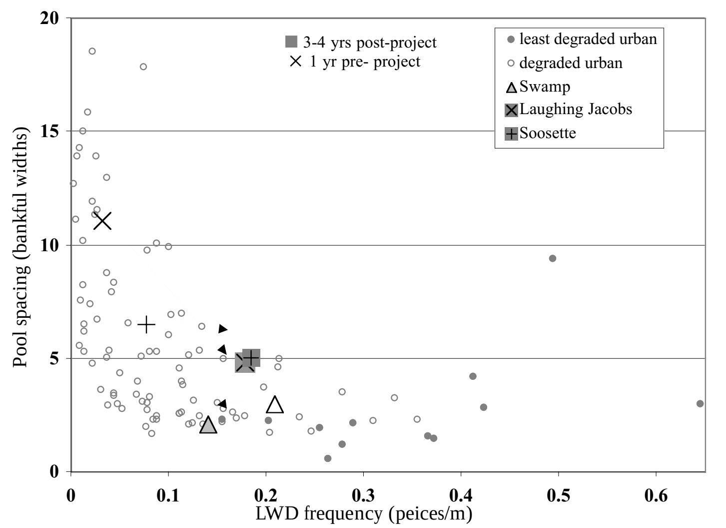

Figure 2. Pool spacing vs. LWD Frequency over time at Laughing Jacob's and Soosette creeks (King County's FHR survey data).

Sediment Storage and Grade Control

Although the indirect influence of LWD on sediment retention was not measured precisely, about one-third of the channel sediment storage appeared to be associated with LWD at most sites. Sediment storage usually increased with an increase in LWD frequency in a given stream. There were few locations in each stream where LWD retained sediment in the form of a discrete wedge. Added LWD contributed most to grade control (11-23%) on the highest gradient streams (Forbes Creek, Holly-

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wood Hills and Laughing Jacob's Creek; slopes = 0.026-0.046) where the wood was spanning the full width of the channel. On the low-gradient streams (Thornton and Swamp creeks; slopes = 0.005-0.008), LWD contributed little to grade control (0-6% of total elevation loss).

Biological Conditions

Almost uniformly, the sites showed no significant improvement in B-IBI score (i.e. at least 4 point difference) between upstream and downstream of the project (Table 3). One partial exception was at Soosette Creek, where scores improved at the downstream site. Yet the upstream site was over 1.5 km upstream of the downstream site, and the pre-project score at this same upstream site was also significantly worse than the pre-project score was at the downstream end of the project.

Table 3. B-IBI scores at project sites; 1998 data from S. Morley (UW)

	Forbes	Thornton	Swamp	Hollywood Hills	Laughing Jacob's	Soosette
Project reach	16	12	26	NA	22 (32)[1]	45 (36, 34)[2]
Upstream reach	16	10	24	NA	(32)[3]	36
Pre-project						(18)[4]

1 Sampled by Morley in 1999 at a more remote riffle 40 m upstream of the 1998 site.
2 Sampled by King County in 1995 and 1998 approximately 440 m upstream of Morley's site.
3 Sampled by Morley in 1999.
4 Sampled in 1993 by Emily Greenberg (UW) approximately 180 m upstream of Morley's site.

Local physical channel characteristics, such as LWD frequency or pool spacing, generally had *no* relation to the B-IBI score. There appeared to be only a very weak positive relationship between B-IBI score and indicators of bank and bed stability or median grain size. In contrast, B-IBI scores showed a strong correlation to the percentage of urban development in the basin. The scores for all but one of the projects fall in the middle of the range of that found by Sarah Morley (UW) on streams with similar levels of development. Only Soosette Creek shows an unexpectedly high score for the level of development in the watershed that might be attributable, in part, to the influence of the LWD project.

DISCUSSION

Best Streams for Effective LWD Placement

In general, LWD has the greatest influence and range of functions on moderate-slope (0.01-0.03) alluvial channels classified morphologically as pool-riffle or plane-bed. Particularly in PSL streams, which tend to lack boulder or bedrock obstructions, and in urban streams, lacking deep-rooted woody bank vegetation, LWD is the primary pool-forming mechanism. In wide low-slope channels, LWD addition may have less influence, particularly if resistant banks allow lateral scour to create free-formed pools. Where the riparian zone has been disturbed, however, critical bank cohesion provided by deep-rooted woody vegetation may be absent and added LWD can provide hard points needed to scour pools as well as helping to maintain channel form and position.

Evaluation of Project Design

Limited project effectiveness may result from either of two causes: projects were built with an inadequate design, or "appropriate" designs nonetheless yield inadequate results. Some criteria for the design of in-stream structures using LWD can be extracted from the research on the function of LWD in forested streams. Such "design criteria" can be compared with conditions at the six rehabilitation projects to evaluate the success of each project in meeting them (Table 4). So, for example, anchored LWD used in projects rarely met the size criteria for "key pieces." Yet where anchored, a higher percentage of the LWD significantly obstructed the flow, was in contact with the bed, and was adequately spaced (F, T, Sw) than where unanchored (HH, LJ, So).

Meeting design criteria is critical only if these criteria are relevant to attaining actual project objectives. Table 5 shows the extent to which a specific criterion (Table 4) was met, and whether the associated objective was generally achieved. For example, "obstruction width" was an important factor in forming pools at most sites, because when these suggested criteria were met (shaded box) these objectives were usually met (✔). Conversely, "key piece frequency" is probably also impor-

Table 4. Design criteria inferred from reported stable LWD in natural channels.

Inferred LWD Design Criteria		
Description	**Value**	**Reference**
Key piece sizes & frequency		
W_{bk} = 3-5m[(1)]	0.4 m^3	Bisson et al., 1987
W_{bk} = 6-10m[(1)]	0.8 m^3	Bisson et al., 1987
Min. # key pieces per meter[(1)]	0.13 LWD/m	Bisson et al., 1987
W_{bk} = 0-5m[(2)]	1 m^3	WFPB, 1997
W_{bk} = 6-10 m[(2)]	2.4 m^3	WFPB, 1997
Min. # key pieces per W_{bk}[(2)]	0.3 LWD/W_{bk}	WFPB, 1997
Obstruction angle or width		
Angled to flow; partially elevated[(3)]	90°	Cherry and Beschta, 1989
obstructing flow or W_{bk}[(4)]	>30%	Lisle, 1986
obstructing flow[(5)]	>10%	Cherry and Beschta, 1989
Burial and angle		
Angled to flow; mostly buried[(1)]	<30°	Bisson et al., 1987
Cross-bed position		
Angled to flow; on bed[(5)]	90°	Gippel et al., 1996
Log spacing		
Spacing in any direction[(5)]	>10 log dia.	Gippel et al., 1996
downstream distance[(4)]	>3 W_{bk}	Lisle, 1986
Log loading		
Volume per channel area[(4)]	0.01 m^3/m^2	Lisle, 1986
pieces per channel area[(6)]	0.035 #/m^2	Montgomery et al., 1995

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tant, because at most sites the criterion were not met (white box) and neither were the associated objectives (-).

Most criteria were *not* sufficient to ensure that specific project objectives can be met. For example, the implied criteria for cross-bed position and burial of LWD were achieved at several projects (shaded box) but the project objectives were still not attained (-). The same was true of log loading—even adequate amounts of LWD did not ensure that all projects objectives would be met.

Table 5. Objectives and LWD design criteria met and not met at project sites*

LWD Design Criteria and Objectives	Objectives and criteria met or not						Suitability of design criteria for meeting project objectives
	F	T	Sw	HH	LJ	So	
Obstruction width for pool formation	?	?	√	√	√	√	Important for pool formation, whether as a result of size or position.
Log spacing for hydraulically independent effect	√	√	–	–	–	√	Important in maximizing effect of added LWD.
Key piece frequency for stability for *influencing flow*	–	–	?	√	–	–	Important for stability of unanchored LWD, and for flow influence and debris trapping of anchored LWD.
Log loading for project objectives	–	–	–	–	–	–	Probably important, but depends on LWD position and size.
Cross-bed position for sediment retention	–	–	–	–	–	–	Probably important for sediment retention, but not sufficient.
Burial and angle for stability	NA	NA	√	√	–	–	LWD burial and position important for stabilizing smaller pieces.
Obstruction angle for pool formation	?	?	√	?	√	√	Irrelevant for pool formation, particularly if LWD is too small.

Key:

√ objective usually met	_objectives usually not met	criteria met	less strict criteria met	Criteria not met	? not determined

* Forbes (F), Thornton (T), Swamp (Sw), Hollywood Hills (HH), Laughing Jacob's (LJ), Soosette (So).

Watershed Controls on the Effectiveness of In-stream Structures

At the projects in the least degraded watersheds (52-58% development), there was little evidence that the urban-modified flow pattern were undermining in-stream efforts to enhance the channel. Some LWD was mobilized in these project reaches, but most of these unstable pieces were either smooth poles or clearly too small. Local incision was occurring in these reaches as well, but mostly by entrenchment through recently deposited sediment. Any downstream deposition primarily resulted from remobilization of materials deposited within the upper project, not as a result of high sediment loads from upstream in the watershed. An undeveloped riparian corridor, ubiquitous along the project reaches in the least developed basins, also aided the channel enhancement effort.

CONCLUSIONS

This work evaluates the effectiveness of in-stream projects using LWD in urban streams where no systematic effort had been made to reduce degradation at the watershed scale. These types of projects are increasingly popular, particularly in the Pacific Northwest, where LWD is recognized as an important element in physical habitat important for salmonids. Yet there is little evidence that these in-stream projects can reverse even the local expressions of watershed degradation in urban channels.

Six urban stream rehabilitation projects using LWD were investigated here, and four questions were posed:

- Does in-stream placement of LWD produce physical channel characteristics typical of streams in less disturbed watersheds?
- Does biological integrity improve after LWD is added?
- Does watershed disturbance exert an equivalent or greater effect on the physical and biological recovery of the channel than the local in-channel conditions addressed by the LWD?
- How can LWD project designs be improved?

Adding LWD to urban streams produces physical characteristics more like those in forested and "least-disturbed urban" streams. Comparing pre- with post-project data, distances between pools decreased after LWD was added. Where pre-project data are not available, the high proportion of pools formed by added LWD also suggests that the projects reduced the pool spacing. Artificially added LWD is apparently not always as efficient in forming pools as the natural wood, however.

Some specific objectives were achieved by in-stream LWD additions, while others were not. Increased pool habitat and increased channel complexity were achieved in most of the projects. Stabilizing or retaining sediment to reduce downstream sedimentation and flooding, in contrast, was not possible by adding LWD to the channel. The influence of watershed disturbance on the physical channel response was particularly evident, and in several instances it simply overwhelmed any potential benefits of LWD. High sediment loads buried some LWD, high flows transported seemingly appropriately sized LWD out of the channel, and high flows caused incision beneath the influence of LWD formerly within the bankfull channel.

Biological integrity, as measured by the Benthic Index of Biological Integrity (B-IBI), did not change in response to added LWD. In the one stream where the upstream had a significantly lower score than the downstream site (Soosette Creek), the setting of the upstream site was not comparable to the project site with regard to roads, stormwater discharges, recent construction, and other development. At the only other project where upstream and downstream B-IBI scores were significantly different they *worsened* downstream, in consort with the physical conditions. These scores indicate that although projects several hundred of meters long may improve physical habitat in a stream reach over the evaluated time scales of 2-10 years, they do not contribute to improvement in biologic conditions of the benthos.

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Management Implications

Adding LWD to a degraded stream in an urban setting will not guarantee that it will perform the functions provided in undisturbed stream systems. Whereas adding LWD is likely to achieve a number of specific objectives, a proliferation of instream LWD projects will not ensure habitat protection or biological recovery. Therefore, it is critical to identify the primary factors causing degradation in a reach; evaluate existing channel conditions; and determine which, if any, objectives can be met with in-stream enhancement projects. Not all placement techniques and types of LWD are equally suited to meet specific design objectives. The trade-offs between costs of anchoring smaller LWD or placing unanchored larger LWD should be considered against the importance of each objective. Finally, recognize that adding LWD to urban streams may not be physically detrimental, but resources should not be allocated to stream projects in the name of stream ecosystem enhancement while overlooking the control of source problems in the watershed.

The full M.S. thesis of this research is available from the Center as Publication K25.

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UPCOMING RESEARCH (1)

Application of Remotely Sensed Data to Regional Analysis and Assessment of Stream Temperature in the Pacific Northwest

Under the direction of Professor Stephen Burges, along with professors Alan Gillespie and Derek Booth, the Center is about to participate in a new 3-year projected funded by the U.S. Environmental Protection Agency focused on a key water-quality parameter, stream temperature. It arises in part from the Center's past efforts at intensive field-based measurements, greatly augmented by new technology, collaboration with investigators elsewhere on campus, and a much broadened scope over our previous efforts.

The principal goals of the proposed work are to develop efficient methods for regional assessments of stream temperature and to demonstrate how the methods can be applied to assess effects of land use on stream temperature. We will evaluate the utility of remotely sensed thermal infrared (TIR) and visible images of streams and stream corridors for increasing the data coverage for regional stream temperature analysis and assessment. We have selected water temperature to illustrate and explore methods for regional water quality assessments because water temperature is biologically important; it is affected by anthropogenic activities; and surface (skin) temperature can be measured from remote instruments that detect TIR signals.

The ecological integrity of many rivers and streams in Washington State are threatened by elevated temperature. According to the state Department of Ecology, "By far, temperature is the most prominent water quality problem for the water bodies listed" as water quality impaired in the state. Stream temperature is a vital concern in the Pacific Northwest where cold-water refugia are essential for the survival of threatened and endangered salmon and warm water can be lethal. Regional-scale assessments are needed for: 1) monitoring water temperature because it is a spatially distributed condition; and 2) analyzing water temperature because it is influenced by spatially distributed conditions including anthropogenic activities near to and distant from stream channels.

The National Water Quality Assessment Program (NAWQA) has selected summer stream temperature as a focal point for regional water quality assessment in the Puget Sound Basin. Regional temperature assessments, however, are limited by sparse sampling in both space and time, given the area (or length of stream) of concern. In the Puget Sound ecoregion for example, the State of Washington relied on periodic data collected at 76 stations to assess water quality conditions of 12,721 km of streams and rivers (i.e., one station for 167 km of stream).

NEED FOR EXPANDING SPATIAL COVERAGE OF STREAM TEMPERATURE MONITORING

The physical, chemical, and biological integrity of river ecosystems depend on the water quality in all reaches from head-

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waters to receiving waters. Regional temperature monitoring programs, however, are often focused on larger rivers. For example, all of the USGS Water Quality Network stations in the Puget Sound ecoregion are on the mainstem of large rivers. This point can be further illustrated with middle Green River basin, which has a number of segment that are water quality impaired for temperature. Yet Washington State has only two temperature stations in the middle basin, one on the Green River above its confluence with Soos Creek and one on Soos Creek above its confluence with the Green River though other agencies and organizations monitor water quality in the basin. Monitoring results indicate that temperature exceeds water quality standards in a number of locations periodically during summer months.

Regional relationships can be derived for estimating stream temperature in terms of basin characteristics and some hydrological and climatological variables. The approach would be along similar lines to those that have long been used by hydrologists to estimate low flow rates. Development of such relationships requires long records from many monitoring locations with concurrent data records. In general, appropriate data records are not readily at hand, and it is unlikely that derived relationships would be adequate to map low flow temperatures throughout the channel network of a basin. Consequently, this approach may be limited for estimating, with any confidence, temperatures in other streams, particularly numerous smaller feeder streams throughout a basin. An objective of our investigation is to develop and evaluate methods for extending spatial coverage of regional stream temperature assessments.

Three *applications* of remotely sensed, thermal and visible, images to regional stream temperature assessments will be considered:

1) *Locating ground stations in a temperature monitoring network*. The objective is to evaluate whether remote imagery can be used to identify stream reaches that have strong temperature gradients. This information will be used to determine the length of stream that can be represented by a monitoring station, to evaluate whether temperature monitoring stations are representative of streams in the basin, and to identify reaches in a stream network that may not require monitoring because temperature is likely to be uniform and cool.
2) *Remote measurement of stream temperature*. There are three objectives for this application: i) to develop empirical relationships between surface (top 100 mm) and kinetic (moving and mixed) temperature in relatively shallow water (<1 m); ii) to identify the information (data quality) lost when using remote platforms (i.e., aircraft and satellite) to determine temperature; and iii) to characterize the types of stream that are amenable to remote temperature monitoring. If stream temperatures can be estimated from images with known and acceptable levels of confidence, then regional temperature assessments will be less sensitive to the uncertainty associated with sampling temperature at a relatively small number of ground stations.
3) *Remote collection of local, spatially distributed data for stream temperature analysis*. While remote measurement of stream temperature may not be feasible for smaller streams, temperature in these streams may be strongly influenced by near-stream ground temperatures. The objective is to estimate ground (and shallow ground water) temperatures using remote imagery and incorporate this information in a stream temperature model. This application will improve representation and analysis of stream temperature dynamics.

APPROACH

We will analyze and assess summer water temperatures throughout a moderate size (<100 km^2) stream basin in the Puget Sound Lowland ecoregion of Washington State. The stream basin has land use and physical conditions representative of many basins in the region. Data will be collected from three platforms: ground, aircraft, and satellite. Ground-based measurements of hydro-meteorological conditions will

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be made continuously at ground stations and, synoptically, using field surveys. Thermal infrared data will be collected using a hand-held, forward-looking infrared (FLIR) radiometer at ground stations. The radiometer will be mounted on an aircraft to collect TIR and visible images of streams and stream corridors. Thermal infrared (TIR) and visible images of the basin will also be obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) which will be mounted on the Earth Observing System (EOS) satellite AM-1. Additional ground-based instruments will be deployed for contemporaneous, detailed characterization of temperature.

Application 1, *Locating ground stations*, will be evaluated using aircraft-based FLIR images and a ground-based survey of stream temperature in the selected basin. Application 2, *Remote measurement of stream temperature*, will be evaluated using TIR images collected on the ground and from aircraft and satellite, as well as detailed temperature measurements at ground stations. Application 3, *Remote collection of data for stream temperature analysis,* will be evaluated using an existing hydrologic simulation model that accounts for hillslope, groundwater, and open channel processes under low-flow conditions. The EPA model, Hydrologic Simulation Program Fortran, is suitable and will be our first choice. Stream temperature will be simulated using existing algorithms, though some modification may be necessary to incorporate spatially distributed data provided by remote imagery.

Expected Results

Remotely collected data offer potentially significant opportunities for regional water quality assessments. The conditions where and when remote images can be used to estimate stream temperature, and the accuracy, precision, and resolution of remotely sensed temperatures will be a key finding. We expect to identify the number and location of monitoring stations, combined with remote sensing data, needed to represent the spatial distribution of water temperature in the form of maps of channel network temperatures in a stream basin during summer low flow conditions.

We anticipate demonstrating use of remotely sensed data to estimate the spatial distribution of shallow, near-stream (hillslope), groundwater temperature. These data will help in the analysis of temperature in small streams where remotely sensed images cannot resolve the stream surface temperature directly. Our findings will identify and evaluate methods for extending stream temperature monitoring over larger geographic areas. In the Puget Sound region, cold-water reaches provide refugia for salmon while warm-water reaches may not be suitable as habitat because of elevated temperature. As a result, our findings will identify appropriate methods for analyzing temperature as part of ecological risk assessment in the region. Our findings will also provide methods to improve assessment and management of potential or existing adverse stream temperatures associated with land use, particularly close to streams. ❖

UPCOMING RESEARCH (2)

Performance Evaluation for Ultra-Urban Storm Water Technologies

The University of Washington has teamed with the Washington State Department of Transportation (WSDOT) and the Environmental Technology Evaluation Center (EvTEC) to conduct a performance evaluation of "ultra-urban" storm water treatment technologies. Ultra-urban technologies are designed to remove pollutants from wet weather runoff in highly developed areas where land values are high and available space is limited. These technologies differ from traditional storm water treatment methods (e.g., water quality ponds and grass swales) in that they are extremely compact and can be retrofitted into existing storm water collection systems.

The primary objective of the performance evaluation is to provide baseline data on the effectiveness and pollutant removal efficiency of several ultra-urban technologies. Results of the evaluation will be summarized and distributed to federal, state, and local environmental agencies for use in developing storm water Best Management Practices (BMPs). Examples of the treatment processes used in ultra-urban technologies include:

- Enhanced settling through a compartmentalized treatment unit
- Filtration through various media, including shale, perlite, zeolite, and leaves
- Solids deflection by a perforated separation screen
- Solids concentration by centripetal forces in a swirling treatment unit

At the current time, four ultra-urban technology manufacturers have agreed to participate in the evaluation by installing treatment units at a site owned by WSDOT. The evaluation site is located under the Interstate Highway 5 (I-5) Ship Canal Bridge, just north of the Burke-Gilman Trail. Highway runoff from I-5 will be diverted into four testing bays at the site, where treatment units will be installed and operated under variable flow conditions. Comprehensive laboratory analysis of influent and effluent samples will be conducted to determine removal efficiencies for solids, metals, nutrients, and organic constituents. In addition, field data on hydraulic performance, operational considerations, and maintenance requirements will be collected.

Construction of the evaluation facility will be completed during the summer of 2000, and full-scale testing will begin during the winter of 2000/2001. Through an initial contact through the Center for Urban Water Resources Management, the University has already begun preliminary work at the site to document baseline storm water characteristics. Dr. David Stensel is the principal investigator for UW in the Department of Civil and Environmental Engineering; working with him is Christopher Brueske, Graduate Research Assistant. It is anticipated that the evaluation site will provide research opportunities for UW faculty and students for several years to come. ❖

Scour of Salmonid Spawning Beds in Low Gradient Gravel Bed Rivers

By Paul DeVries, Graduate Research Assistant, Department of Civil and Environmental Engineering

INTRODUCTION

Salmon, trout, and charr select specific spawning sites in gravel bed rivers and bury their fertilized eggs within the gravel matrix. The location of the egg nest, or redd, reflects streambed characteristics that provide a suitable incubation environment for the developing embryos. In addition to several other factors, the selected spawning location may reflect the stability of the bed with respect to scouring during floods, where substrate and channel characteristics at the redd site influence whether mechanical disturbance of the bed extends down to the elevation of the buried embryos during their incubation period. It has been inferred that scouring of salmonid redds could control salmonid distributions and population abundance in gravel bed rivers under specific circumstances.

Land use and water management activities can cause significant changes in sediment delivery and flood characteristics. Increased delivery of finer sediment particle sizes and increased frequency of larger flood magnitudes have been hypothesized to be linked to increased scour depths in the stream channel, with subsequent negative effects on salmonid populations. Salmonids serve as an important source of food and income, and provide for significant recreational and cultural needs. They also are critical indicators of good water quality and proper ecosystem and watershed management. Large-scale loss of distinct salmonid populations and genetic diversity has already occurred because of extensive destruction and adverse modification of their habitat, dam construction, overfishing, and long term climatic variation. If scour has a direct effect on population levels, the ability to predict scour depth is a fundamental component of strategies for protection and recovery of stressed salmonid populations.

However, relatively little is known regarding scour processes in salmonid spawning beds, and the absence of relevant data has precluded accepting or rejecting the hypotheses above. These observations motivated the present research, for which there were four principal goals:

(I) To provide fundamental insight into scour mechanisms and the corresponding linkages with bedload transport and hydrology;
(II) To develop practical methods for predicting scour depth magnitudes;
(III) To evaluate linkages between scour, salmonid spawning behavior, and reproductive success; and
(IV) To guide future investigations of scour and its relation to salmonid populations, land use, and water management.

FIELD STUDIES

A field investigation was conducted in eleven gravel bed river reaches between approximately 100 and 300 m long, with slopes between 0.001 and 0.01, in Western Washington. Study sites were located in the North Fork Stillaguamish River, the Snoqualmie River, Issaquah Creek, and the Willapa River basins. The streams were selected to represent a wide range of hydraulic and geomorphic characteristics, including channel size and shape, channel slope, bed substrate size, and flood flow depth. Scour monitors were installed and bed elevations surveyed before and after floods. Streambed substrate grain sizes were characterized in the vicinity of each scour monitor, and local bed shear stresses were estimated.

RESULTS

Measured scour depths at specific locations of the streambed reflected two characteristically different processes that operate concurrently. Substrate disturbance is caused by (i) bedload layer motion, and (ii) spatial and temporal variations in sediment transport rate. The first involves disturbance over a short time scale (e.g. seconds to minutes) by entrained and moving particles. The second occurs over the course of the flood and is manifest by a change in bed surface elevation. In the case of equilibrium sediment transport, the bed surface neither rises nor falls and the disturbance depth is a function only of the bedload layer thickness.

The data indicated that the moving bedload layer was relatively thin in the study rivers. Estimates of the maximum depth of substrate disturbed by a moving bedload layer ranged between approximately 1.5 times the 50th (D_{50}) and twice the 90th (D_{90}) percentile particle sizes of the streambed surface grain size distribution. The upper bound was also found to be proportional to the size of the largest stone that the flow was capable of moving. The maximum bedload disturbance depth became independent of flood flow magnitude once the largest particles present were mobilized, and was suggested by granular flow research to increase only when the flow magnitude in each study river exceeded that of the 500-year flood. Bedload disturbance depth did not increase with estimated bedload transport rates because of large stresses needed to mobilize two or more layers of the bed. Increases in transport rate appear to be affected by the surface particles moving faster instead. The data indicate that reach-average measurements of disturbance depth may increase with shear stress primarily because a greater bed area and larger particles become active, rather than a significantly deeper layer. There was also stratigraphic evidence of the existence of thin subsurface layers of the streambed (below the surface armor layer) that extended in the upstream-downstream direction of gravel motion, and across a certain width of the active bed.

Considering this apparent limitation to the depth of disturbance by moving gravel and cobble bedload layers, large magnitude scour depths in spawning beds must instead be associated with spatial and temporal variation in sediment transport rates. These transport rate imbalances occurred in three forms in the study rivers. They were, in order of increasing spatial scale: (i) scour and fill of transient, finer grained bedforms located downstream of partial flow obstructions causing differen-

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tial mobility during a flood (salmonids generally do not spawn in such deposits, however); (ii) at the pool-riffle scale, where scour depth depends on inter-riffle distances and riffle deposit size and morphology; and (iii) at the reach scale in response to temporal and spatial variability in sediment supply to the channel. With respect to the second form, greatest scour occurred at the upstream end of the riffle deposit, in the “pool edge” region, in large part because the rate at which material was transported downstream from that location exceeded the rate arriving from upstream for a certain period of time. Scour depths in the downstream portion of the “pool tail” region and the rest of the riffle were generally much shallower, and reflected a combination of bedload disturbance depth and relatively small drops in bed elevation that likely occurred in response to the third form of sediment transport imbalance. The results suggested that many previous measurements of “scour and fill” were more likely to have been of maximum bedload disturbance depth occurring near the flood peak, than of a lowering and subsequent raising of the bed elevation.

IMPLICATIONS TO SALMONID INTRAGRAVEL SURVIVAL

Salmonids appear to have adapted to these processes by burying eggs deeper than the characteristic bound of bedload disturbance depth determined in this study. A review of published egg burial depth data and associated streambed substrate sizes indicated that most if not all species of salmonids bury the majority of their eggs below the maximum bedload disturbance depth, and below the characteristic range of total scour depths measured at representative spawning locations in the study rivers. This included streams that have experienced significant changes in sediment supply (e.g., the North Fork Stillaguamish River, which has received significant amounts of landslide-generated material in the past). It remains to be determined whether the magnitudes of bed elevation change measured at spawning locations in this study are representative of spawning habitat in other streams. The wide range of physical parameters sampled suggest that they may be, but more work is needed.

Salmonids also appear to have adapted by constructing redds in locations of the channel least likely to experience significant sediment transport rate imbalances. They bury their eggs in reaches where there is an abundant supply of gravel and cobble, and at locations along the riffle deposit that receive coarse bedload from immediately upstream in the same deposit. In both cases, the redd location is downstream of a supply of gravel and cobble that is sufficient to offset significant sediment transport rate imbalances. ❖

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Evaluation of Wet Ponds for Phosphorus Reduction

By Karen Comings, Graduate Research Assistant, Center for Urban Water Resources Management

This study investigated the magnitude of phosphorous removal from urban stormwater runoff occurring through two detention/retention ponds of alternative designs, located in southeastern Bellevue and draining into Lake Sammamish. Removal of pollutants from stormwater runoff by the ponds generally ranged from one-quarter to three-quarters of the measured constituents. Of those measured, total suspended solids (TSS) exhibited the greatest removal efficiency, with removal of phosphorus ranging from 29% (retrofitted pond) to 49% (originally designed water-quality pond). A summary of this study appeared in Volume 8, number 3 of the *CUWRM Newlsetter*.

Publication G13; cost = $15.00

"Soils for Salmon"— How Soil Amendments and Compost Can Aid in Salmon Recovery

In the wake of the National Marine Fisheries Endangered Species Act listing of Chinook salmon, more than 200 professionals gathered at the Center for Urban Horticulture at the University of Washington for the first *Soils for Salmon, The Urban Environment* seminar in March 1999. Led by the Washington Organic Recycling Council (WORC), the seminar addressed the relationship between urban soils, hydrology and salmon habitat.

Soils for Salmon is a project of the Washington Organic Recycling Council (WORC) designed to increase awareness of soil improvement as a means to support salmon and other species recovery. A goal of *Soils for Salmon* is for local governments to develop Best Management Practices that conserve native soils and improve disturbed soils. Soil degradation and water pollution are widely recognized as major environmental problem, and so:

- Healthy soils directly contribute to healthier water resources and thus indirectly support salmon;
- Steps taken to improve soils lead to improved water quality and quantity that will result in healthier fish habitat;
- Increased use for compost helps close the recycling loop through beneficial use of organic materials.

A healthy soil provides a number of vital functions including the ability to store water and nutrients, regulate the flow of water, and immobilize and degrade pollutants. Compost is the product resulting from the controlled biological decomposition of organic waste (such as yard debris, food waste, soiled paper, wood waste, biosolids and manures). Compost has the ability to bring back many critical functions to urban soils, which have lost their ability to hold and retain water, and bind pollutants. Just as the retention of forest cover has been recognized as a land use tool for managing water quality and water volume, it is critical that soil structure retention be considered as a tool in the regulatory and land use tool box. Because salmon and other fish species rely on clean, fresh water to survive, they equally need healthy soil in the watershed above them. The *Soils for Salmon* challenge is to implement a strategy designed to improve soil health. The goal is to improve the characteristics of urban soil to perform more like a native soil so that a more vibrant diversity of organisms will thrive, healthier plant growth will be sustained, and air and water will be held and retained longer. Implementation of *Soils for Salmon* supports salmon and other species recovery efforts at the same time helping support agricultural viability and recycling organic waste into beneficial uses. Each of these helps to move the Pacific Northwest in the direction of a more sustainable future through healthier soil and water.

From this workshop, a paper has been written that discusses the function of soils, their relationship to water, the human impact on soils, and how disturbed soils can be improved. It takes a preliminary look into actions local and state governments can begin to make to protect soil health and salmon habitat. Now is the opportunity to focus on improved soil as an additional management tool, given the current attention to endangered species in the Pacific Northwest.

The document can be viewed or downloaded from the "PUBLICATIONS" page of the CUWRM web site (http://depts.washington.edu/cuwrm/, look for document #7 under "Available Online").

Effectiveness of Large Woody Debris in Urban Stream Rehabilitation

by Marit G. Larson, Graduate Research Assistant, Center for Urban Water Resources Management, 1999, 156 p.

See accompanying article -- Publication K25; cost = $23.00

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