The Washington Water RESOURCE

The quarterly report of the Center for Urban Water Resources Management

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Contents

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Message from the Director

This will be a brief message, insofar as the content for this issue of the Newsletter already promises to challenge the layout skills of our indispensable editor, Stephanie Strom of Engineering Professional Programs. Curiously, I had imagined that this issue might provide an opportunity to review recent past publications available through the Center, because the inventory of publications is growing and we have not taken the opportunity in recent months to highlight available reports and titles. Instead, I find myself with too much material, not enough space, and once again the easy opportunity to put off this and other such articles "until next issue."

I suppose this is a good sign. Some projects are actually showing results, and so our newsletter becomes progressively more occupied with actual findings and reports. Others are just beginning, but they hold tremendous promise for greater opportunity, visibility, and utility in the months and years ahead. Our developing connection with other groups on campus, notably the Center for Streamside Studies and the Department of Geological Sciences, continues to show unanticipated benefits in greater access to faculty expertise, students, and operational resources. This summer we have supported ten students, either part time or full time, and this level of activity is likely to continue at nearly the same pace into the fall.

Yet I am not satisfied with our work, because it still falls far short of addressing the full range of topics in "urban water management," and because we are all poorer for that limitation. University research is an inherently narrow activity, and it is the rare project or program that can include a truly broad range of ultimately related, and mutually reinforcing, activities. We have not yet succeeded either, but the effort continues!

On a separate note, the Center is inching fitfully towards joining the modern communication era through the establishment of a web page. Karen Comings, a Ph.D. student here with many more important demands on her time, has nonetheless taken on the task of designing and uploading a web page that includes general information, past newsletters, publications, and summaries of recent and active research projects. Our timing is so close that, as of this writing, I can only tell you to find it though the departmental link at <http://www.weber.u.washington.edu/~cuwrm>, but it should be fully operational by the time of this newsletter's publication. Tell us how to make it more useful!

Also, please come to the Annual Review on October 16. It is one of our few opportunities to meet many of the people who support our efforts and who try to use our results. The more we can all interact, the more likely we are to accomplish something of value. Thanks for your support!

Derek Booth ❖

The Washington Water Resource is the quarterly publication of the Center for Urban Water Resources Management at the Department of Civil Engineering, University of Washington, Box 352700, Seattle, WA 98195.

Annual Review of Center Research

On *October 16th, 1998*, faculty and students affiliated with the Center will summarize our results from this last year's research. The presentations will take place from 9:00 AM until 12:00 noon at the Waterfront Activities Center (WAC) on the University of Washington campus. The WAC is a low building on the shore of Union Bay, southeast of Husky Stadium and northeast of the Montlake Bridge. To get there drive on SR 520 (Evergreen Point Bridge) towards the University from I-5 or I-405 and take the Montlake Boulevard NE exit northbound, cross the Montlake Bridge, continue north a few hundred yards through the major fork in the road at the Pacific Street traffic light and turn right at the next light, 0.1 mile beyond, immediately next to the stadium (a large sign, "West Plaza," will be on your right). Double back to the south to the parking kiosk ($5.00 for the day, pay as you enter). The WAC is at the rear of parking lot "E12" south of the stadium; we will be on the upper (parking-level) floor. Metro buses 43 and 44 also stop nearby.

The schedule of presentations is still being confirmed as this newsletter goes to press, but the following reports are anticipated:

- Center activities relating to Endangered Species Act listings
- Numerical modeling of groundwater in the Duwamish Corridor, City of Seattle
- Puget Lowland urban corridor geology and geologic hazards
- Urban Stream Rehabilitation—status report of the three-year project
- Limitations to vegetation growth in biofiltration swales
- Monitoring protocols for urban streams, and ongoing monitoring work at the Bear Creek/Novelty Hill Urban Planned Developments
- The reestablishment of Boeing Creek and the rates of urban channel change
- Automated land cover classification and watershed impervious-area determinations from LANDSAT imagery
- August snapshot of regional stream temperatures
- A regional database of rehabilitation projects in urban and suburban streams ❖

Groundwater Pathways in the Industrial Duwamish Corridor, Seattle

Background

In 1996, the Center was invited to participate in a project having an unusual combination of technical and public-policy elements, focusing on the redevelopment of industrial land in the Duwamish Valley in the south part of the City of Seattle and adjacent areas of Tukwila and King County. This area has a legacy of extensive industrial activity, some dating back to early in the 20th century, during a period when environmental practices and regulations were much less stringent than today. When property of this kind is sold, refinanced, or redeveloped, lending institutions (and, for certain activities, state law) require that any contamination on the site be assessed and cleaned up to a regulatory standard established and administered by the Washington State Department of Ecology. This requirement is an obligation of the *current* property owner, and so any site with a known or suspected history of past contamination is approached only warily, if at all, by prospective purchasers unless an assessment of site contamination has already been done.

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This consideration, which tends to lessen development and redevelopment in industrial areas, conflicts with the expressed intention of Growth Management legislation to favor redevelopment of industrial areas to accommodate new industry without having to expand the area of land consumed by this form of urban sprawl. Clearly, the most efficient land for industrial development is the same area where *past* industrial activity has already occurred. Yet the cost of required environmental clean-ups can be great, and the uncertainty associated with those ultimate clean-up costs can dampen what would otherwise be appropriate enthusiasm for such actions.

This study of the "Duwamish Industrial Area Hydrogeologic Pathways" was designed to facilitate the redevelopment of these "brownfields" in the Duwamish Corridor by improving the information available for making cleanup-related decisions. Its primary purpose has been to develop an area-wide understanding of the groundwater flow pathways in the Duwamish Valley, so that the groundwater *context* of any individual property can be evaluated quickly and inexpensively. It also should allow regulatory agencies to determine the appropriate standards of decontamination more systematically, based on the ultimate fate of the groundwater.

The City of Seattle and King County jointly funded this project. The study area includes the Duwamish Valley, from the origin of the Duwamish River at the confluence of the Green and Black Rivers in Tukwila, to the river mouth at Elliott Bay. The primary roles of the University of Washington group were to oversee the data collection and analysis, to contribute regional geological expertise in developing the framework for groundwater movement, and to develop a numerical model of groundwater flow in the valley. The University team included Derek Booth and Joel Massmann, professors in the Department of Civil Engineering; Jason Fabritz, a Ph.D. student working directly with Dr. Massmann; and Jeffrey Linn, a Master's student in the Department of Landscape Architecture and who provided the GIS work for an initial pilot study. We worked closely with a consultant team, particularly Lori Herman of Hart Crowser and Kate Snider of Floyd and Snider. Their responsibility included work on the geologic framework and articulation of the conditions relevant to a proposed redesignation of the "highest and best use" for groundwater in the Duwamish Valley, which in turn might change the standards for any future environmental clean-up of previously contaminated sites.

This project has produced two documents. The first is the *Conceptual Model Report*, published in April 1998 and available through the City of Seattle's Office of Economic Development (on compact disc). The *Conceptual Model Report* provided a detailed characterization of the geologic and hydrogeologic conditions, based on comprehensive data collection and analyses, and produced the most complete picture of groundwater pathways currently available for the Duwamish Valley. The second document in this project is the ***Development of a Three-Dimensional, Numerical Groundwater Flow Model for the Duwamish River Basin***, available through either the City or the Center. It summarizes the results of the numerical modeling for the Duwamish Valley, which quantitatively explores those patterns and predictions of groundwater movement through the Duwamish Valley articulated in the *Conceptual Model Report*. In combination, these reports provide an example of how the compilation, evaluation, and analysis of preexisting hydrogeologic data can provide a degree of information that would be completely unavailable were the information considered each in isolation, one piece at a time.

The Computer Model

The computer program used for the Duwamish numerical model was MODFLOW, a publicly available groundwater flow simulation program developed by the U.S. Geological Survey. MODFLOW is a well-documented model used by consultants, government agencies, and researchers, and it is widely accepted in regulatory and legal proceedings.

The three-dimensional numerical model of the Duwamish basin covers approximately 60 square miles. The ***model domain*** of the area for MODFLOW exceeded the ***study area***, originally defined in the *Conceptual Model Report*, so that boundary conditions could be more naturally defined. The boundaries of the numerical model coincide with natural hydrogeologic boundaries to minimize the influence of artificial model boundaries on simulation results.

The hydrostratigraphy used in the Duwamish model is based on the data contained in over 300 boring logs and associated geologic cross sections of the *Conceptual Model Report*. The numerical model used six stratigraphic units discriminated by the *Conceptual Model Report*: 1) bedrock, 2) glacial silt, 3) older alluvium, 4) younger alluvium, 5) Vashon glacial deposits, and 6) coarse-grained deposits of the Highline aquifer, the major source of groundwater for use in the City of Seattle. Interpolation between boring logs and cross sections established the spatial distribution of these six materials in three-dimensional space.

Additionally, the model requires two principal hydraulic parameters as input, the hydraulic conductivity of the various stratigraphic units and the infiltration rate at the ground surface. It assumes the application of a uniform infiltration rate of 10 inches per year, based on recent work by the U.S. Geological Survey. Initial estimates for hydraulic conductivity values were developed using ranges reported in the literature for similar material (Freeze and Cherry, 1979) and from measured values included in the *Conceptual Model Report*.

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Model Results

General Paths of Groundwater Movement

The pattern of water level contours and groundwater flow predicted by the model is qualitatively quite similar to the inferred water levels presented in the *Conceptual Model Report*. Predicted water levels along the western slopes of the study area range between 230 to 330 feet, and the levels in the central part of the study area are 10 to 20 feet above the river level. The horizontal head gradients, which are in the range of 0.001 to 0.01, are also consistent with the head gradients described in the *Conceptual Model Report*.

Estimated Groundwater Budget

The calibrated model produced an estimated groundwater flow budget for the model domain. The flow budget describes how much water leaves the groundwater system through groundwater seeps and through direct discharge to surface water bodies.

Groundwater exits the model domain in one of three ways. About one-third of the groundwater bypasses the Duwamish River altogether and discharges to Lake Washington, Puget Sound, or Elliott Bay through either direct discharge or small shallow seeps and channels. The remainder of the groundwater included in the model domain reaches the Duwamish Waterway first, before moving on to Elliott Bay. The model calculates that about half of this fraction discharges directly from the groundwater system to the waterway, entering along the sides and bottom of the channel. The other half discharges to groundwater seeps that eventually drain into the waterway via surface, piped, or channeled flow.

Groundwater Flow Directions and Locations of Groundwater Seeps

Model results indicate that groundwater flow originating along the ridges of the uplands penetrates relatively deeply into the flow system. Some flow lines penetrate to elevation -150 feet (below sea level) before bending upward and ultimately discharging along the surficial contact between the uplands and the valley floor. Water infiltrated along the flanks of the uplands, and on the valley floor itself, generally follows a much shallower pathway. From the uplands it can discharge to seeps along the lower parts of the same hillslopes; from both areas, it can also discharge directly to the Duwamish Waterway itself. Of considerable interest is the potential for a reversal of groundwater flow, *away* from the Duwamish Valley and potentially contaminating the Highline aquifer with water originating from this source. No credible set of conditions appears to allow this to occur.

Flow directions within the valley sediments are relatively complex and depend on location and depth. At specific locations, the flow may be downward at some depths and upward at other depths. The ultimate discharge location, however, is the Duwamish Waterway or seeps that eventually drain to the waterway. The total discharge to these seeps is approximately 10 cubic feet per second (cfs), or 30% of the infiltration applied to the model domain. This rate makes up no more than about 5 to 10 percent of the river's summertime non-storm discharge.

We have calibrated the model with existing water-level data and have explored the sensitivity of the results to uncertainties in parameter values. Over a range of likely values, the model still shows the same basic behavior: groundwater divides along the upland ridges, downward gradients in the uplands, seeps along the valley edges, and predominately upward gradients in the vicinity of the Duwamish Waterway.

Recommendations

The groundwater model described in this report provides considerable insight in terms of water budgets and groundwater flow directions. However, it is but one resource, which can be improved as additional data and information are collected about the study area. The model can also be used to further identify and prioritize data gaps. Specific topics or areas in which improvements or applications might be particularly important and valuable are summarized below:

1. Additional sensitivity studies

The model could be used to prioritize data collection activities in the Duwamish Basin, by identifying areas that are most critical in terms defining stratigraphy and hydrogeologic parameters. The model could also identify areas in which water level measurements would be most valuable in terms of constraining the stratigraphy and input parameters.

2. Transient modeling to evaluate effects of tidal fluctuations

The existing model is a steady-state model that estimates flow rates under average or mean tidal conditions. It could also be run in a transient mode to consider the extent of tidal fluctuations in the waterway and in Elliott Bay. This would involve specifying storage coefficients for the various stratigraphic units. The results might be useful to evaluate the effects of tidal fluctuations on data collection activities in the vicinity of the waterway.

3. Refining recharge rates based on information regarding land use, vegetation, and topography

The model assumes a uniform infiltration rate of 10 inches per year. Additional data from GIS databases describing land use, vegetation, and topography could be used to estimate spatial distributions for recharge rates. While this will not likely affect the average water budget, it may affect local flow directions and flow rates.

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4. Developing local-scale models in sensitive or high-interest areas

The model described in this report can be used to define boundary conditions for smaller scale models that could provide more detailed pictures of local flow systems. These smaller-scale models might be used in conjunction with contaminant transport models to evaluate presumptive remedies for site remediation activities or to better define the effects of tidal fluctuations on subsurface concentrations. ❖

Environmental Limitations to Vegetation Establishment and Growth in Vegetated Stormwater Biofilters

Runoff from urbanized landscapes is an increasingly common source of surface water degradation. It carries a variety of pollutants including sediments, nutrients, metals, synthetic organic toxins, and pathogens. Where storm sewers transport runoff directly to downstream water bodies, pollutants bypass filtration by vegetation and soils. The result is decreased water quality.

Acknowledging this problem, both federal and local governmental agencies throughout the country have required construction of low cost, in-pipe or end-of-pipe stormwater filtration facilities. One such facility increasingly employed in the Puget Sound region is the biofiltration swale (also called bioswale or biofilter).

Bioswales are open channels possessing a dense cover of grasses and other herbaceous plants through which runoff is directed during storm events. Aboveground plant parts (stems, leaves, and stolons) retard flow and thereby encourage particulates and their associated pollutants to settle. The pollutants are then incorporated into the soil where they may be immobilized and/or decomposed. Despite some experimental evidence to the contrary, herbaceous cover is commonly considered to predict treatment efficiency.

Over 100 bioswales have been constructed in King County over the past ten years to treat runoff associated with residential, commercial and light industrial development. A recent survey by King County Water and Land Resources Division found most swales to be vegetationally depauparate. Water level fluctuation, long-term inundation, erosive flow, excessive shade, poor soils, and improper installation are the most common causes of low vegetation survival. The relative importance of these limiting factors may vary widely from swale to swale. This study was designed to identify those factors that most influence vegetation establishment and growth, so that recommendations can be made to improve future biofiltration swale design and performance. The presumed relation between vegetation abundance and bioswale performance was also investigated.

As his Master's degree research project, now-graduated student Greg Mazer examined environmental conditions for eight biofiltration swales in King County, Washington, to determine the relative importance of the various factors influencing vegetation establishment and growth. Three of these swales were regraded, retrofitted with new soil, and hydroseeded in September 1996. A nested two-factorial greenhouse experiment tested the response of four turfgrass species, commonly seeded in bioswales, to four moisture regimes (three inundation schedules plus a control).

Of the three retrofitted bioswales, only one (SAY7) accrued an abundance of vegetation deemed adequate for effective biofiltration. Vegetation and organic litter biomass there was comparable to that of the three other evaluated swales that also supported high herbaceous cover (at Discovery Elementary School, Pine Lake Park, and the Center for Urban Horticulture), although these swales were seeded 3-9 years ago. Virtually no hydroseeded grasses established at the two other retrofitted swales (SAY8 & SAY9) due to particularly long inundation durations after seeding, a consequence of the local soils and hydrologic regime. However, some volunteer wetland plant species grew in less erosive and shallower areas of these sites.

The proportion of time that each swale was inundated at or above 2.5 cm depth proved to be the variable that was most closely correlated with plant and organic litter biomass ($r^2 = -0.92$). For those plots that experienced summer drought, vegetation biomass was strongly dependent on adequate soil depth ($r^2 = 0.74$). Field monitoring revealed other factors that locally limit bioswale vegetation growth, such as springtime base flow velocity and excessive shading by trees. In contrast, bioswale biomass was *not* well correlated with certain hydraulic variables, such as the rate at which runoff is introduced over the surface of the swale, that *are* important in determining sedimentation potential and thus pollutant removal. As a result, the condition of swale vegetation may not reflect a facility's actual pollutant-removal effectiveness.

In the greenhouse experiment, the "wet" treatment (long-term inundation of seeds) produced equally poor germination amongst all grass species. For each of the other three moisture treatments, *Festuca arundinacea* (Tall Fescue) accrued significantly more biomass, and *Agrostis alba* var. *stolonifera* produced significantly more leaf blades, in comparison to the other species. These greenhouse results were consistent with field observations in retrofitted swale SAY7, where Tall Fescue established more quickly than the other seeded species while

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Agrostis alba var. *stolonifera* achieved nearly equivalent abundance within one year. Both field observations and greenhouse experiments clearly demonstrate that persistent inundation severely limits germination and establishment of those grasses typically seeded in biofiltration swales.

Several shortcomings of current bioswale design and construction are evident from this study. First, the factor that most critically determines vegetation success (inundation during germination) is not acknowledged by present design or construction guidelines. Second, current design guidelines permit flows at overly high rates that can overwhelm the vegetation or circumvent filtration via channeled flow. Finally, factors that contribute to eventual success but that vary widely on a site-by-site basis can only be addressed by careful evaluation and construction, but most bioswales are constructed without incentives to install high-quality stormwater runoff facilities that are suited to the requirements of individual site characteristics.

The results of this study suggest that bioswales design standards should be modified to restrict the permitted inflow discharges to much lower maximum values than at present, and that implementation guidelines should ensure that proper moisture conditions for germination are achieved. Given the multiple challenges to constructing and maintaining functionally satisfactory biofiltration swales, however, construction of alternative stormwater facilities with less critical requirements should be investigated. Carefully designed constructed wetlands, for example, may provide conditions conducive to sediment deposition more readily, offer more effective immobilization and/or greater biological uptake of contaminants, and concurrently create refuge for native flora and fauna.

This report was funded by the Stormwater Technology and Training Consortium of the Center for Urban Water Resources Management, with particular financial contribution from King County Water and Land Resources Division, and additional financial assistance from the Center for Streamside Studies in the College of Forestry at the University of Washington. Assistance was gratefully received from John Koon, Dave Hancock, and Bill Eckel of King County.

Mazer's thesis is Publication G12 of the Center for Urban Water Resources Management. ❖

The Geologic Framework for the City of Seattle and the Seattle-Tacoma Urban Corridor: a New Collaborative Research Project with the U. S. Geological Survey

The Center is beginning a project with tremendous opportunities for both scientific investigation and practical applications. The National Earthquake Hazard Reduction Program (NEHRP) of the U. S. Geological Survey has just awarded us substantial new funding to develop a comprehensive geologic database and set of geologic maps for the City of Seattle. This project will be integrated with our ongoing work on the Puget Sound Lowland's regional geologic framework and conducted in cooperation with ongoing USGS work in earthquake studies and landslide-hazard evaluation (see the Spring 1997 and the Winter 1998 issues of the Newsletter). The primary effort will be led by Kathy Troost, who comes to this project from the consulting firm of Shannon & Wilson with nearly 20 years of experience in the study of recent geologic deposits, particularly in the Puget Sound region and most recently focusing on the Seattle-Tacoma area. She will be working on this project out of the Department of Geological Sciences with other University faculty, in collaboration with a wide range of USGS scientists, and with the primary municipal *user* of such information, the City of Seattle, who will help develop the data and to participate actively in its storage, display, and public access. We anticipate this work continuing for at least the next several years.

The project is particularly exciting because of the wide range of issues that are touched by it. Many engineering applications in urban and urbanizing areas depend on the spatial distribution of geologic materials and the sequence and history of those deposits. These applications include hydrologic modeling and analysis for surface-water and groundwater investigations, geotechnical properties of potential foundation materials, liquefaction and ground-shaking potential, recognition of potential volcanic hazards, location of construction materials, and landslide potential. Other, seemingly "theoretical" questions also depend on our understanding of these deposits and processes, and their investigation can ultimately lead to equally important (and "practical") insights. These include the erosional and depositional processes of ice sheets, the patterns of interglacial deposition, long-term landform stability, unraveling the long-term regional climatic record, modern earthquake recurrences, and the recognition and dating of tectonic deformation and faulting.

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Yet, curiously, Seattle in particular, and the south-central Puget Sound region in general, are served by one of the most incomplete and unorganized sets of geologic information of any major population center in the western United States. The only available geologic mapping of the city itself is over four decades old. None of the active faults in the region, one of which is now known to pass directly under the city and to have produced violent shaking about 1100 years ago, are even recognized on the existing map. The goal of this project is to rectify this shortcoming: to develop a detailed understanding and representation of the three-dimensional distribution of geologic materials beneath Seattle and to embed that information in the context of a coherent, regionally integrated geologic framework for the south-central Puget Sound region.

The project has four components, each designed to address specific objectives:

1. *Regional Stratigraphic Context*—a chronological and lithologic composite section of glacial and nonglacial deposits in the south-central Puget Lowland.

2. *Subsurface Database for the City of Seattle*—a GIS-based compilation of existing geotechnical data, maintained by the City and available to the public in perpetuity. Included in this component will be the creation of a Technical Working Group, assembled to ensure that the database suits current and future needs. Its membership will emphasize senior members of the region's geologic and geotechnical consulting firms, who will be both the major users and the major contributors. Other members will include representatives from the state, city, and local agencies.

3. *Surficial Geologic Maps of the City of Seattle*—new geologic map coverage across the City at 1:12,000 scale, based on field observations and near-surface borehole data.

4. *Three-Dimensional Geologic Framework of the City of Seattle*—integration of the other project components into a graphically supported geologic database and map display.

One of the most important elements of this proposal is the degree of institutional and individual commitment to this collaborative project, which includes not only the primary funding program (NEHRP, U.S. Geological Survey) but also a variety of other related efforts:

1. Pacific Northwest Urban Corridor Mapping project (USGS, Menlo Park, CA)
2. Cascadia Earthquake Loss project (USGS, Golden, CO)
3. Landslide Hazard Assessment project (USGS, Golden, CO)
4. City of Seattle, Department of Construction and Land Use (repository of geotechnical information and a primary user of the database information) and Seattle Public Utilities (home of the city's Geographic Information System and responsibility for drainage and utility infrastructure).

This project represents a unique opportunity to support prior and ongoing investigations in geologic-hazard studies by government agencies. The foundation (and success) of all such applications ultimately rests on the delineation of the underlying geologic framework of the region. The present opportunity to conduct such an investigation is unparalleled, with key agencies and individual investigators having made substantial commitments for the duration of this effort. This project also will allow us to integrate a variety of other local and regional studies being conducted here at the Center—for example, the Duwamish Pathways project (see accompanying article), participation in the City of Seattle's Landslide Policy evaluation, and ongoing geologic investigations relating to watershed assessments—into a broadly based, regional context. Some of these components have been described in earlier issues of the Newsletter, but we can now look forward to a much more comprehensive, and valuable, set of products and outcomes over the next several years. ❖

Urban Stream Rehabilitation—A Progress Report on the Center's 3-Year Project

Urban development in the Puget Lowland has changed the physical and biological conditions of many streams. This region was characterized by extensive conifer forests growing on glacial till and outwash deposits, with many small wetlands and streams. Forested hillslopes and their deep, permeable soils have been replaced by residential and commercial structures, roads, and thin-soil lawns. Constructed drainage networks have been added to the landscape, while streams have been modified to accommodate increased runoff from hillslopes or to protect infrastructure.

In response to these changes, public agencies and private organizations have been engaged in extensive efforts at stream rehabilitation. Techniques for protecting and improving stream conditions can be effective, but only to the extent that they address specific mechanisms of degradation or otherwise compensate for these mechanisms, and only to the degree that they actually result in desired outcomes (such as biologically healthy streams). Understanding the links between urban de-

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PROFESSIONAL ENGINEERING PRACTICE LIAISON (PEPL) Program

The PEPL (PROFESSIONAL ENGINEERING PRACTICE LIAISON) Program, in cooperation with the Center for Urban Water Resources Management, offers a continuing education program in urban water resources management.

As part of the benefits extended to supporters of the Center for Urban Water Resources Management, member organizations submitting five or more registrations for the same course may deduct $30 per registration for a 1-day course, $35 for 1.5-day, $45 for a 2-day course, $50 for a 2.5-day course, and $60 for a 3-day course.

For further information on the *Urban Surface Water Management Continuing Education Program* or on any of the courses on the next page, please contact:

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velopment and stream conditions should be the best guide for selecting appropriate rehabilitation efforts and for establishing feasible objectives for stream conditions, given constraints imposed by the urban landscape.

The goal of our investigation, begun in the spring of 1997, is to identify mechanisms of stream degradation and assess the types of and extent to which rehabilitation efforts can improve stream conditions in an urban landscape. The overall scope of this project was described in the Winter 1998 issue of the Newsletter.

Our investigation thus far has covered nine streams with 18 study sites, listed in Table 1. The watersheds span a range of development from highly urban (*e.g.*, Miller and Thorton creeks) to the rural/suburban (*e.g.*, Rock and Bear creeks). The crudely inverse relationship between urban development and biological condition is shown in Figure 1, which combines data from the first year of this project (1997) with those of an earlier study, "Stream Quality Indices" (see the Winter 1997

1997 B-IBI Sample Site Locations:

Site	Nearby Community	Approx. Location	Appx. Total Impervious Area %	B-BIBI Score
Rock 97.1	Maple Valley	SE 248th St & . Cedar River Pipeline Rd	3.2	48
Big Bear 97.1	Woodinville	Woodinville-Duvall Rd / 210th Ave NE	2	34
Big Bear 97.2	Avondale	NE 164th St & Mink Rd	4	42
Big Bear 97.3	Avondale	NE 148th St & Mink Rd	7	32, 42
Big Bear 97.4	Avondale	NE 148th St & Mink Rd	7	38
Big Bear 97.5	Redmond	NE 133rd St & Bear Creek Rd	9	32
Little Bear 97.1	Mill Creek	180th St SE & 51st Ave SE	4.4	40
Little Bear 97.2	Woodinville	SR 9 & 228th St SE	5.1	34
Little Bear 97.3	Woodinville	SR 9 & 233rd Pl SE	8	22
Little Bear 97.4	Woodinville	63rd Ave SE & 233rd Pl SE	9.9	16
Swamp 97.1	Lynnwood	Larch Way SW & Locust Way	25	30
Swamp 97.2	Lynnwood	Larch Way SW & Locust Way	25	30
Swamp 97.3	Lynnwood	Larch Way SW & Locust Way	25	30
Jenkins 97.1	Kent	164th Pl SE & Covington-Sawyer Rd	13	38
Big Soos 97.1	Kent	Kent-Black-Diamond Rd & SE 290th St	13	36
Thornton 97.1	Seattle	NE 106th St & 14th Ave NE	53	14, 16
May 97.1	Renton	Jones Ave & NE 31st	18	28
Miller 97.1	Normandy Pk	8th Ave SW & 168th Pl SW	50	14

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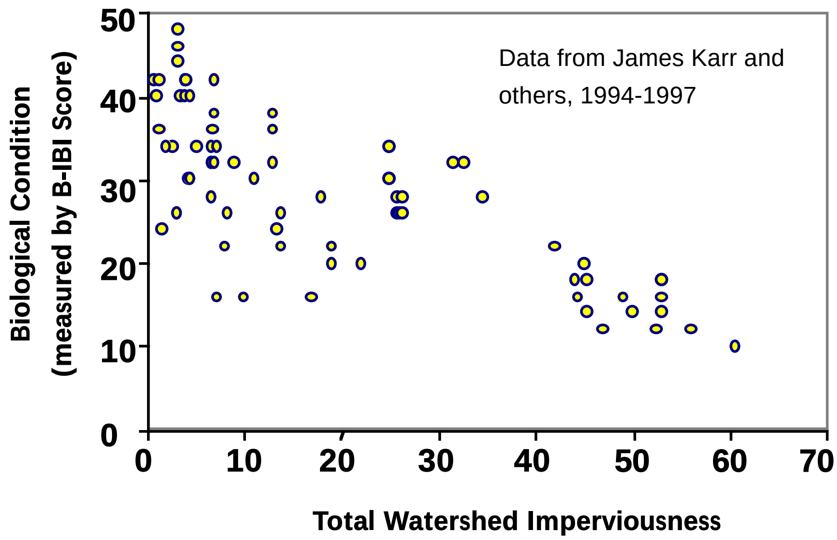
issue of the Newsletter). In this figure, total impervious area is used as an (albeit imperfect) index of urban development (see the Fall 1996 issue of the Newsletter). A city typically has a total impervious area of 60% or greater; a rural area has typically less than 5% impervious area. The Benthic Index of Biological Integrity (B-IBI) is used to represent biological conditions. B-IBI is a multimetric index of the bottom-dwelling insects, worms, and other such invertebrates found at riffles. It incorporates measures of taxonomic diversity, taxa tolerance/intolerance, trophic structure, and population attributes to assess biological conditions of streams. Possible scores range from 10 to 50 points; from the results of other studies, sites that differ by more than 4 points are likely to be biologically different.

Biological Integrity of Puget Lowland Streams



After evaluating the results of our work to date, we are now focusing on six questions:

1. Which of the physical and/or land-use conditions that are observed to be changing along a downstream gradient most closely correlate with, and thus are likely to be influencing, biological conditions?
2. Why are certain B-IBI scores unusually low or high at specific points along a stream, relative to adjacent measurements, where there seem to be no obvious land use/riparian changes between those sites?
3. What physical conditions best account for variation in B-IBI scores at "moderate" levels of development (such as seen in the watersheds of Little Bear, Swamp, Big Soos, Jenkins, and May creeks)?
4. Where B-IBI scores are similar along a downstream gradient or from basin to basin, do physical and/or land-use conditions nonetheless vary? Can we conclude that such variations are biologically *un*important?
5. What is the reason for occasional large measured inter-annual variation in B-IBI scores?
6. Are the apparent upper and lower boundaries on the data in Figure 1 real, or are they simply artifacts of as-yet incomplete data sets?

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Professional Engineering Practice Liaison (PEPL) Courses

October 20-22, 1998
Designing and Implementing Stream Habitat Modifications for Salmon and Trout

November 4 and 5, 1998
Geology and Geomorphology of Stream Channels

November 18, 19, 20, 1998
Hydrologic Modeling and Design of Retention/Detention Facilities

December 2 and 3, 1998
Groundwater Monitoring for Water Purveyors

December 15, 16 and 17, 1998
Wetlands Ecology, Protection and Restoration

January 12 and 13, 1999
Storm and Surface Water Monitoring

February 10 and 11, 1999
New Technology and Concepts in Stormwater Treatment

April 15, 16, and 17, 1999
Quaternary and Engineering Geology of the Central and Southern Puget Sound Lowland

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GEOLOGIC FRAMEWORK (from page 9)

Highlights of 1997 Results

Little Bear Creek, Snohomish County

Intensive work on Little Bear Creek is investigating changes in stream conditions along a systematic downstream gradient of increasing development, occurring in a watershed of relatively uniform topography and geology. B-IBI scores for Little Bear Creek systematically decrease, from a high of 40 points at LB1-97, near its headwaters, to a low of 16 points at LB4-97, located downstream in a commercial area. Benthic macroinvertebrates were sampled at 3 sites in 1994, 5 sites in 1995, and 4 sites in 1997, with some replication of previous years' data. B-IBI scores are generally consistent year-to-year.

Sites in 1997 were located to characterize (1) biological condition near the headwaters, and (2) degradation relative to obvious changes in the riparian corridor or land use. The initial downstream decline in B-IBI, from 40 at site 1-97 to 30 at site 1-94/x-95, occurs in a part of the basin that has progressively more pasture and residential land uses. Overall, B-IBI scores further decline down to the SR 9-SR 522 interchange (e.g., to site 2-97), as land uses shift from low-density residential to commercial and light industrial in close proximity to the channel. Coincident physical changes along this downstream intensification of land use include fewer trees and shrubs in the riparian corridor, channelization, and fining of streambed material.

The biological conditions in several reaches complicate a general pattern of steady downstream degradation. Biological conditions change particularly abruptly in the 500-m reach between sites 2-97 and 3-97, where B-IBI declines from 34 points to 22 points. There is no dramatic change in *watershed* land use between these two sites, but industrial land uses do encroach more closely into the riparian corridor at the downstream site. In addition, the combination of 1994, 1995, and 1997 B-IBI results suggest that biological conditions experience partial, albeit minor, *improvement* downstream of the commercial/light industrial area. The stream here reenters an extensive reach of good riparian corridor, and the apparent improvement in biological conditions here on Little Bear Creek stands in contrast to indiscernible biological effects of more locally varying riparian conditions along Swamp Creek (below).

We are collecting new data this fall to evaluate several hypotheses. These include the expectations that:

1. The initial loss of very good biological conditions results from fragmentation of the riparian corridor by local land uses;
2. The channel form influences biological condition in Little Bear Creek, both (damaging) channelization in the vicinity of 4-97 and recovery of a more natural channel form farther downstream; and
3. Other possible reasons for biological degradation (*e.g.*, water chemistry, temperature, hydrologic regime, fine sediment, and riparian vegetation) are *not* significant factors in the observed changes here.

Swamp Creek, Snohomish County

Three sites on Swamp Creek were selected for 1997 to investigate the effects of local riparian canopy on biological conditions. SW1-97 and SW3-97 have no trees and few shrubs over the channel. Riparian vegetation is predominately grass and blackberry. The channel at these sites is relatively uniform in depth with primarily riffle and glide channel forms. In contrast, SW2-97 has a nearly closed riparian canopy of western red cedar, vine maple, and alder. The channel at SW2 has well-developed pools and riffles. Pieces of large organic debris are in the channel at SW2 and a large side channel parallels the mainstem. Despite these obvious differences, there was little difference in individual metrics and no difference at all in B-IBI scores across these sites (all were "fair," with a score of 30). These results suggest that local corridor conditions or channel morphology are not the dominant control on benthic macroinvertebrate populations, despite the obvious influence of the near-stream environment on biological conditions when those conditions are present over longer distances.

In addition to this last year's data, benthic macroinvertebrates have also been sampled at 1 site in 1994 and 4 sites in 1995. In contrast to Little Bear Creek, strong gradients in B-IBI scores were *not* observed along this stream, perhaps reflecting moderate-density residential and commercial development uniformly distributed throughout the basin. The lowest score was 26 at site a-95 (one of the 1995 samples, the farthest upstream site of all years), in close proximity to the Interstate 5-405 interchange. The sample there had fewer shredders, mayflies, long-lived taxa, and clingers, and also higher relative abundance of pollution-tolerant taxa. Otherwise, there is little variation in B-IBI scores along the creek or year-to-year.

In this upcoming year, we are investigating the possibilities that:

1. Site a-95 has a lower B-IBI than all other Swamp Creek sites due to local and direct influences of I-5/405 interchange, most likely from fine sediment, water chemistry, channel form, and/or local construction, with the effects "diluted" or otherwise are not expressed at downstream sites. Alternatively, biological conditions at site a-95 may be reflective of the nearby upstream wetland, which can have the effect of depressing the "stream-based" B-IBI metrics.
2. Fair biological condition is generally maintained along Swamp Creek because:
    a. Urban development does not increase substantially as a fraction of basin area;

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b. Riparian corridor is only moderately fragmented and fragmentation does not increase downstream; and (or)

c. The stream channel is particularly (and intrinsically) resilient to urban effects, given its low gradient and wide floodplain.

Miller Creek, King County

One site on Miller Creek was selected to investigate the effect of a healthy riparian corridor on the biological condition of a stream in an otherwise highly urban basin (50% total impervious area). MI1 is located in a reach with large alder and big leaf maple trees and dense shrubs along the stream banks. Pieces of large organic debris are located in the channel. B-IBI is an abysmal 12 points, suggesting that a relatively good riparian corridor can be overwhelmed by extensive degradation in the upstream watershed. We are not planning further follow-up here at this time.

Big Bear Creek

Sites in 1997 were located to determine any systematic changes along a downstream gradient and to investigate the biological response to changes in local conditions (in particular, local loss of canopy and horses walking through the stream). We benefited from previous sampling here and had a total of 4 sites in 1994, 1 site in 1995, and 5 sites in 1997. Big Bear Creek has large wetlands upstream of our highest sampling localities, with progressively more residential development and with larger and more frequent openings of the riparian canopy in the downstream direction. There are some subdivisions near the highest site (1-97), although more extensive residential development is found lower, between 4-97 and 5-97.

Biological conditions are generally fair to good in upper Big Bear Creek, with values of B-IBI of 34 at BB1-97 and 42 at BB2-97, but they show a decline to 32 at site BB5-97. The increase in B-IBI between BB1-97 and BB2-97 is a result of more stoneflies and clinger taxa, and higher relative abundance of predators. The decline between BB2-97 and BB5-97 is a result of fewer stoneflies and long-lived taxa, higher relative abundance of pollution-tolerant taxa, and lower relative abundance of predators. B-IBI scores are relatively consistent year-to-year expect at site BB2-97 (equivalent to site 1-94), where B-IBI increased in the intervening three years from 28 to 42.

In this next year, we are investigating whether the observed increase in B-IBI from site 1-97 to site 2-97 results from more wetland influence at 1-97, more intact riparian canopy at 2-97, or less cumulative development at 2-97. We also are exploring whether the abrupt decline between our lowest two sites (4-97 and 5-97) is a demonstrable result of development in the intervening tributary sub-basin.

Big Soos and Jenkins Creeks

Benthic macroinvertebrates were sampled in Big Soos at one site in 1997 (B-IBI was 36) and in Jenkins Creek in two nearby sites in each of two years (1995 and 1997, with B-IBI scores of 40 and 38). In comparison to the highest-scored reference site, Rock Creek, these sites have modestly lower B-IBI due to fewer stoneflies, mayflies (Jenkins), pollution-intolerant taxa, clingers (Jenkins), and long-lived taxa (Big Soos), and lower relative abundance of predators (Big Soos).

In both of these systems, biological condition are better than expected given the estimated impervious areas (compare, for example, with the scores for Little Bear and Big Bear creeks). Indeed, these watersheds show the best biological conditions in our entire data set for their equivalent level of development (expressed as impervious area percentage), suggesting that whatever factors are leading to this outcome should be carefully investigated for their applicability in a more deliberate fashion by watershed managers in other, more degraded systems.

We have hypothesized a variety of (perhaps mutually exclusive) alternatives to explain these results, and we are using this next year to begin a more detailed exploration of them:

1. Development has occurred in a way to have minimal biological effect because development is distant from sampling site, there are large riparian buffers and/or large distances between development and channels, or stormwater quantity/quality controls are effective;
2. Development is so recent that the long-term effects on the biota are not yet obvious; or
3. The watershed is intrinsically resistant to effects of urban development (storm flow, temperature, fine sediment load, low flow) due to the presence of large wetlands, permeable soils/geologic formations, ample subsurface flow, gentle topography, or coarse bed sediment.

Jenkins, Big Bear, Big Soos, and May Creeks, King County

In addition to within-watershed investigations, these sites were also chosen for cross-watershed comparisons, and in particular to consider the hydrologic effects on biological conditions independent of overall levels of urbanization. All of these watersheds have relatively low percentage of total impervious area (7 to 14%), but each displays distinctive stream hydrographs because of their contrasting geologic conditions. B-IBI appears to reflect the character of hydrologic response quite closely: the highest score was seen in Jenkins Creek (JE1 with 38 points), which has extensive permeable deposits across much of its contributing area, the most attenuated runoff response to rainstorms, and the highest unit-area base flow. The lowest score in this group was seen in

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May Creek (MY1 with 28 points), which is by far the flashiest stream of this group. Big Soos (BS1) and Big Bear (BB5) are intermediate in terms of both hydrologic response and B-IBI scores (36 and 32 points respectively). Note, however, that Big Soos Creek actually has a higher B-IBI score than Bear Creek yet nearly 50 percent greater impervious-area percentage. We anticipate that other differences between these streams are also likely to influence biological conditions, but these factors remain to be identified and examined in this ongoing research.

In summary, we are moving closer to an understanding of which physical conditions are likely to be influencing biological conditions, recognizing that these factors may likely vary from watershed to watershed and with different types of land uses. "Watershed" factors, such as aggregate levels of development, are clearly important but the near-stream environment can produce significant effects as well. The role of very localized riparian changes, be they unintentional (small-scale clearing) or intentional (such as a small rehabilitation or revegetation project) are less clear. We are beginning to address this last issue more directly through an inventory of stream rehabilitation projects around the region and a more focused evaluation of their in-stream effects. We presently have a database with more than 300 such projects, and we look forward to giving you an initial report of that work in the next issue of the Newsletter. ❖

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The Regional, Synchronous Stream Temperature Survey of 1998: 600 Sites in 120 Minutes

Cold-water fisheries can be strongly affected by elevated summertime stream temperatures. The determinants of stream temperature are relatively well understood in the abstract, but their quantification in any given watershed is confounded by the vagaries of groundwater and surface-water inflows and the complex interplay of stream orientation and sun angle, canopy cover, and air temperature. Individual temperature measurements can give insight into the specific conditions for a particular stream, but they do not provide the context to evaluate unusual natural or human-induced temperature conditions at any given site.

To rectify this shortcoming, the Center for Urban Water Resources Management, in cooperation with the Center for Streamside Studies, organized an intensive stream-temperature monitoring survey for the afternoon of August 19 of this year. Our intention was to characterize the range, distribution, and determinants of summertime high temperatures in fish-bearing (and tributary to fish-bearing) lowland stream systems in the Puget Sound lowlands. Sites were arrayed to provide system-wide coverage, with watershed areas ranging from 100 km^2 on down to the limits of perennial flow. Reflecting our interest in quantifying human influences, we targeted watersheds with primarily urban and suburban land uses but included some rural and forested basins as controls. About a dozen sites with continuous recording temperature gauges already installed were also covered to provide a temporal context for these “snapshot” data. This effort is one component of our broader assessment of urban stream rehabilitation, described in an accompanying article in this issue of the Newsletter.

Over 100 individuals, representing approximately 20 different agencies and community groups, collected over 600 temperature measurements across the south-central Puget Lowland in a two-hour period. The maximum air temperature that day was exactly the average for the month of August (24 ^oC), and so the results are representative of “normal” but not “extreme” conditions. Data reduction is just beginning as of this newsletter and so conclusions are still pending. Measured water temperatures appear to range from 10 to 20 ^oC, with strong control already evident from local geologic conditions and more erratic influences caused by human modifications to streams and watersheds. As the data are compiled, they will be posted on our web page for reference and downloading.

We owe a special thanks to the individuals and the agencies that actually volunteered their time and resources to accomplish this effort. Whether or not it is repeated next year will depend on the continued willingness of our cooperators to devote their time to this work, the need to augment this year’s data, and the ultimate value of the information collected. ❖

Current Projects at the Center

- **Stream temperature survey** (The Center sponsored a one-day intensive stream-tempurature survey on August 19, 1998. Results will be published in the Fall 1998 issue of the Newsletter.)
- **LANDSAT land cover interpretation** (We have just received funding from the “PRISM” project at the University of Washington to develop an automated land-cover procedure using LANDSAT imagery to quantify impervious-area and forest-cover percentages in urban and urbanizing watersheds. Preliminary results should be available for the Fall 1998 issue of the Newsletter.)
- **Rehabilitation-project database** (We are compiling a database with over 300 stream-rehabilitation projects constructed by local agencies in western Washington. A summary of the included information will appear in the next issue of the Newsletter.)
- **Environmental benchmarks in citizen-based watershed planning** (see description in the Summer 1997 issue of the Newsletter)
- **Boeing Creek reestablishment** (see description in the Spring 1997 issue of the Newsletter; channel was resurveyed in early September and showed almost complete stability since November 1997)
- **Issaquah Creek sediment budget** (see description in the Fall 1997 issue of the Newsletter)
- **UPD monitoring** (see description in the Fall 1997 issue of the Newsletter)
- **Road-ditch and water-quality BMP maintenance** (see Winter 1998 Newsletter)
- **The “Watershed Academy”** (see Winter 1998 Newsletter; first session is September 21-25, 1998 on the University of Washington campus)

The Washington Water

RESOURCE

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