The Washington Water

RESOURCE

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Message from the Director

Although I have been the director of the Center for Urban Water Resources Management for little more than a year, a second end-of-the-calendar-year is upon us and so the impulse for review and long-range planning is high. The Center has had its fourth Advisory Board meeting under my tenure earlier this month, and from that discussion I have several observations, conclusions, and plans for the future of the Center.

Sources of Projects. Over the 6-year life of the Center, we have seen a remarkable shift in the sources of research funds. The Center was begun with a two-year grant from the State Department of Ecology's Centennial Fund program that supported a full-time director, half-time staff support, several graduate students, and a variety of training and research projects. This program was anticipated to be the major source of ongoing funds for the Center, and in fact two additional projects were supported from subsequent Centennial Fund cycles ("Improved On-Site Stormwater Management" and "Development of Stream Quality Indices"). As I described in the newsletter one year ago, however, the Department of Ecology and the University of Washington realized shortly after the Center was established that the two agencies have contradictory and incompatible policies regarding "acceptable" overhead rates for research grants. This problem has never been resolved, and so State funding of the Center has almost entirely disappeared.

Following this impasse, local jurisdictions (notably King County, Bellevue, Snohomish County, Olympia, and the then-independent Metro) stepped forward to support the Center in both cooperative activities and specific research projects. Until recently this has been the primary source of funds, and it has demonstrated the willingness of local agencies to pool resources in support of common goals. The budgetary and policy constraints of local agencies, however, have made this source of support difficult to predict from year to year despite the participation and enthusiasm of agency staff and management.

The Center's recent success with obtaining Federal grants and contracts has introduced yet a third emphasis in funding sources (these grants include Watershed Restoration Training [EPA], the Puget Lowland Urban Corridor Geology and Geologic Hazards [USGS], Clackamas County Watershed Assessment and Environmental Indicators [NRCS], and Rehabilitation of Ur

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MESSAGE (from page 1)

ban Streams [NSF-EPA]). That success is welcome, in that larger and more long-term projects are being initiated here. Yet it is also worrisome, because the original needs that led to the creation of the Center in 1990 do not necessarily hold equal importance for the various Federal agencies now involved in our research. If strong local or state support is not reestablished, those original needs may never retain prominence in the Center's suite of research activities.

Cooperative Functions. This set of activities has always been, in my mind, the underlying rationale for the Center's presence. A year ago I suggested that these activities fall into four categories: technology transfer, collaboration on research, professional education, and outreach. Our success in these efforts has been mixed. The Center's publication distribution service has been active, with nearly double the orders during this year compared to last; newsletter subscriptions are slowly increasing as well. The "Urban Surface Water Management Continuing Education Program," administered through the Professional Engineering Practice Liaison Program, has a full curriculum and well-attended classes; we are also accepting and supporting a new group of highly qualified graduate students that are beginning to contribute to the broader professional community as well. Work at the Center has been featured in several national publications, most recently the November issue of *Landscape Architecture*, and the phone and mail responses to these exposures have been surprisingly high.

Yet some of these functions are also struggling. We are having very little success in fielding cooperative research projects (see below), one of the primary benefits of a cooperative "research" center. We also see tremendous disparity between individual member agencies in their ability and willingness to support this work financially; the lack of a stable source of funds to maintain this effort makes its continuation beyond 1997 uncertain.

Cooperative Research Projects. Few of the research projects at the Center are truly multi-jurisdictional. Of those that are currently supported by local agencies, they almost exclusively represent the desire by a particular organization to solve a problem of particular interest, with their own funds made available to cover fully the anticipated work. I have not been successful in attracting other participants to join in planned or ongoing projects ("Cooperative Research Opportunities"), and despite the several regional confederations based on water-related issues (*e.g.*, NPDES permitees) the Center has yet to participate in answering any of the questions arising out of these groups that need answers. I see this arena as the one in greatest need of improvement over the next year if the Center is to achieve its greatest potential benefit to the region's water-resources managers.

Derek Booth ❖

Characterizing the Magnitude of Urban Development

There is great appeal to identifying a single "index" variable that characterizes the magnitude of urban development in a watershed. Patterns can be readily displayed, correlations are simplified, and communication between scientists and planners is enhanced. Yet urban development comes in many styles, occurs on many different types of landscapes, and is accompanied by a variety of mitigation measures designed to reduce its negative consequences on downstream watercourses. So any simple correlation between urbanization and aquatic-system condition appears unlikely.

Past and even current efforts to quantify the degree of urban development have not been consistent. The most widely accepted parameter is "the percent impervious area in the contributing watershed" (see the recent review article of Schueler, 1995) but even the use of such a seemingly clear term has been inconsistent and ambiguous.

The most important clarification lies in the distinction between ***total*** impervious area (TIA) and ***effective*** impervious area (EIA). TIA is the "intuitive" definition of imperviousness: that fraction of the watershed that is covered by constructed, non-infiltrating surfaces such as concrete, asphalt, and buildings. Hydrologically this definition is incomplete for two reasons. First, it ignores nominally "pervious" surfaces that are sufficiently compacted or otherwise so low in permeability that the rate of runoff from them is similar or indistinguishable from pavement. For example, Wigmosta and others (1994) found that the pervious area of a residential subdivision in western Washington, primarily thin sodded lawns installed over glacial till, occupied 71 percent of the watershed area and produced over 60 percent of the runoff on both a single-storm and seasonal basis. Clearly, this hydrologic contribution cannot be ignored entirely.

The second limitation of TIA is that it includes some paved surfaces that may contribute nothing to the storm-runoff response of the downstream channel. A gazebo in the middle of parkland, for example, probably will impose no hydrologic changes into the catchment except a very localized elevation of soil moisture at the edge of its roof. Less obvious, but still relevant, will be the different downstream consequences of rooftops that drain alternatively into a piped storm-drain system with direct discharge into a natural stream or onto splashblocks that disperse the runoff onto the garden or lawn at each corner of the building.

The first of these TIA limitations, the production of significant runoff from nominally pervious surfaces, is typically ignored in the characterization of urban development. The reason for such an approach lies in the difficulty in identifying such areas and estimating their contribution, although site-specific studies demonstrate that these tasks can be accomplished with simple field methods and the resulting hydrologic insights are often valuable (*e.g.*, Burges and others, 1989). Furthermore, the degree to which pervious areas shed water as overland flow should be related, albeit imperfectly, with the amount of *impervious* area: where construction and development is more intense and covers progressively greater fractions of the watershed, the more

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Center Projects

Current and Recently Completed Projects at the Center

- Maintenance Of Filter Berms In Detention Ponds (Fall 1995-Summer 1996): Described in detail in the Spring 1996 newsletter, the final report on this project is completed and is available from the Center (Publication K13).
- Maintenance of Failed Biofiltration Swales (see Summer 1996 Newsletter): Three swales in north-central King County were reconstructed this fall to revised design standards and replanted with a specially developed mixture of grass seeds. Field measurements on these swales, other control swales, and parallel greenhouse experiments are continuing through this next winter and spring.

Other active projects at the Center include:

- Development of Stream Quality Indices (see Winter 1996 Newsletter). A preliminary discussion of some of the results of this three-year project (and the previous Wetlands Research Project) is now available as Publication K12; more substantive reports of this work are planned over the next several months.
- Environmental Benchmarks in Citizen-Based Watershed Planning (see Summer 1996 Newsletter)

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Center Projects

Other active projects (continued)

- Soil Amendments to Improve Infiltration (see Summer 1995 Newsletter). A full-scale field test of the hydrologic, economic, and aesthetic effects of soil amendments is being planned for a new development in the city of Redmond for 1997; more information will be forthcoming in the next issue of the Newsletter.
- Lakemont Boulevard Construction Oversight (see Fall 1995 Newsletter)
- Improvement of Runoff Quality and Quantity from Road Shoulders (see Winter 1996 Newsletter)
- Infiltrative Parking Lot Surfaces (see page 8)
- Eastgate Water-Quality Pond Performance (see Summer 1996 Newsletter)

Upcoming Projects at the Center

- Urban Stream Rehabilitation in the Pacific Northwest (Spring 1997-Spring 2000): (see Summer 1996 Newsletter)
- Hydrogeologic Pathways, Duwamish Corridor (Winter-Fall 1997): The City of Seattle and King County are establishing a consultant contract for 1997 to collect hydrogeologic, contaminant, and historic land-use data along the Duwamish Corridor. The Center will be a partner with the City and County in overseeing the data collection and analysis for this project in order to

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CHARACTERIZING THE MAGNITUDE *(from page 3)*

likely that the intervening green spaces have been stripped and compacted during construction and only imperfectly rehabilitated for their hydrologic functions during subsequent "landscaping."

The second of these TIA limitations, inclusion of non-contributing impervious areas, is formally addressed through the concept of effective impervious areas, defined as the impervious surfaces with direct hydraulic connection to the downstream drainage (or stream) system. Thus any part of the TIA that drains onto pervious (*i.e.* "green") ground is excluded from the measurement of EIA. This parameter, at least conceptually, captures the hydrologic significance of imperviousness. EIA is the parameter normally used to characterize urban development in hydrologic models.

Yet the measurement of EIA is complicated. Studies designed specifically to quantify this parameter (*e.g.*, Alley and Veenhuis, 1983; Laenen, 1983; Prysch and Ebbert, 1986) must make direct, independent measurements of both TIA and EIA. The results can then be generalized as either a correlation between the two parameters (for example, Alley and Veenhuis found that $[EIA] = 0.15\,[TIA]^{1.41}$ in their highly urbanized watersheds in Denver, Colorado) or as a "typical" value for a given land use. Dinicola (1989) used earlier studies such as these to recommend a set of values for use in studies of western Washington watersheds. These values are the basis for impervious-area percentages in recent King County basin plans, and they probably should be used consistently throughout the region until a more careful and local analysis has occurred here.

Presumed Relationship between Imperviousness and Land Use (from Dinicola, 1989)

LAND USE	TIA (%)	EIA (%)
Low density residential (1 unit per 2-5 acres)	10	4
Medium density residential (1 unit per acre)	20	10
"Suburban" density (4 units per acre)	35	24
High density (multi-family or 8+ units per acre)	60	48
Commercial and industrial	90	86

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CHARACTERIZING THE MAGNITUDE (from page 4)

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Preventing the Problems of Urban Runoff

by Bruce K. Ferguson, School of Environmental Design, University of Georgia; excerpts from an article in the winter 1995-1996 issue of *Renewable Resources Journal*.

Water belongs in the soil. This principle is supported by the fundamental way landscapes maintain themselves, and by decades of experience in thousands of documented field installations. But it is astonishingly unrecognized in stormwater management conventions in large areas of the country.

The Importance of Infiltration

Since before human beings walked on the earth on two feet, nature has been infiltrating water. This is not a matter of preference or professional convention. Infiltration happens in nature. As an ecosystem develops with succession, the soil evolves. Roots of grasses and trees reach into the soil; root hairs separate particles of clay; ants and beetles excavate voids in the soil mass; roots decompose, leaving networks of macropores; leaves fall from the trees each year to form a mulch over the soil; earthworms pull the leaves into their burrows, where they ingest them and add their organic matter to the soil structure; the boles fall to the earth and feed mosses as they decompose. Mineral soil is made open and porous. Clay takes on the permeability of gravel. This is a system that accepts and absorbs rain.

By infiltrating, the environment maintains its equilibrium and its health. In the soil, moisture is held like water in a kitchen sponge. Further below, it forms sheets and pools of ground water. All the world is a lake. Over all the area of every watershed, in the pores of the soil, there is more storage than the Corps of Engineers could build with dams. Storage in the soil turns intermittent pulses of rainfall into a perennial moisture supply to the roots of plants. The grasses and trees give their organic matter to the soil, where it supports the soil's water-holding capacity to which native plants are adapted. From the soil and groundwater the water discharges slowly, months after the rain falls, to the streams and wetlands where, during base flow periods, the volume of water remaining in the pools is the last remaining resource that aquatic organisms possess for survival. Soil and water and trees and fish, sharing the same functioning landscape, all evolve together.

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Center Projects

Upcoming Projects at the Center (continued)

yield a product of the highest possible quality and utility. We will focus on several specific tasks. The first will be that of oversight and quality control for the data being collected by the consultants, and preparing an independent analysis of the unavoidable errors and uncertainty in the data so collected. The second will be to develop a groundwater model that uses the hydrogeologic stratigraphy and known contaminant sources as model inputs, and the water-level data and measured areas of contamination for model validation. Third, we will help develop a prototype Internet web site, through either the University's or the City's computer network, to allow public access of at least a subset of the data and to assess the value and feasibility of more complete web posting of the project's results. Finally, we look to assess the appropriate range and types of decisions that can be made using the kinds of comprehensive yet imperfect data so characteristic of groundwater studies. Our participation should ensure that the findings and recommendations of this study will be broadly recognized as *credible* and *unbiased*, outcomes that might otherwise be questioned by the large number of privately funded and privately conducted contamination studies that have occurred in this area in the last decade.

Center Projects

Cooperative Project Opportunities

As described previously, the Center continues to seek opportunities to execute research projects most efficiently through multiple sponsors. In many cases, the study being supported by one agency will yield results of benefit to other agencies as well with little additional cost. Subsequent participants thus may be able to join these projects for substantially less than full cost, benefiting from their own staff's involvement and (in the case of field-oriented studies) the inclusion of additional sites of particular interest. Please contact the Center for more information on the following projects:

- Maintenance of failed biofiltration swales
- Runoff reduction using soil amendments
- Modular pavement systems for parking areas: water quantity and water quality performance.

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PREVENTING (from page 5)

Options in Development

But upon the soil we build cities. Our roofs and pavements seal over the organic mulch and the soil pores, depriving the soil of water and air. They deprive native plants of the soil moisture to which they are adapted. They deprive ground water reservoirs of replenishment. They deprive the streams and wetlands of their sustenance. By deflecting water across the surface, they make floods bigger downstream, eroding as they go.

Knowing that vegetated soils absorb rainfall readily, we can preserve them to a degree by reducing the area of pavements. We can concentrate and cluster development to reduce the overhead in connecting roads; we can double-load parking lots to share traveling and turning lanes. In the areas that we leave unpaved, vegetation can maintain soil pores and return a corresponding portion of the site's water to its natural path.

But for any given land use program there is a limit to how much we can make pavements disappear with mere cleverness, so we must attack the impervious materials themselves. For 25 years we have known how to make permeable pavements.

Permeable Pavements

Porous asphalt was developed in 1970. There are now hundreds or thousands of installations of it, mostly in the mid-Atlantic area but also in the Carolinas, Texas and other areas. The distinctive open-graded surface layer has been used in every type of pavement from residential driveways and parking lots to interstate highways. The permeability of the distinctive porous surface layer is several times greater than the rainfall rate during the most intense five minutes of the 10-year storm anywhere in the United States. Under the surface, an open-graded stone base holds water until it infiltrates the underlying soil, and forms a structural "drainage blanket" between standing water and the wearing course.

The surface of porous asphalt clogs from inadvertent sedimentation and smearing of the asphalt cement by turning vehicles. It is easy to accept the degree to which it does so. Typically about five percent of the surface becomes clogged. Individual clogged spots tend to be a few square feet in area. Rain water that falls on a clogged spot moves a foot or two to reach the unclogged pavement, where it infiltrates.

Porous asphalt costs about 10 percent more than an equivalent amount of non-porous asphalt. But porous asphalt is not just a pavement structure; it is also part of the drainage system. When the total cost of site development is added up, porous pavement can save more than 30 percent of favorable sites.

Every time we build an impermeable pavement we must ask ourselves why did we not give rain water the chance to come into contact with soil. Impervious pavements should be built only as special cases, responding to particular site-specific needs such as swelling soils, highly plastic soils, and steep slopes where moving water in the base course could erode the subgrade. That leaves perhaps ninety percent of the pavement area we build which ought, by rights, to be porous and permeable.

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PREVENTING (from page 6)

Infiltration Basins

But there will always be some runoff left, from the roofs and from the portion of the pavements that we could not make permeable. So the third and final stage of hydrologic restoration is infiltration basins—depressions in the earth that capture and hold concentrated runoff while it infiltrates through the basin bottom. Infiltration basins have been used for urban stormwater since the 1930s, so we now have six decades of field experience. There are more than 10,000 of them in North America, from the Caribbean to Canada and from coast to coast.

Infiltrating only a small volume of water from each runoff event can largely restore environmental function. Small, frequent urban floods are, cumulatively, as damaging in the long run as great rare ones. Controlling them by eliminating some of the runoff volume is a major contribution to erosion control and property protection. In most of the United States the "first flush" of runoff carries most of the urban pollution. Debris and oil accumulate on pavements in the dry periods between storms; they tend to be concentrated in the small volume of runoff from small, frequent storms and in the first runoff from large storms. For ground water replenishment, most of the water that is available over a year is in small, frequent storms. A great 25-year storm does little for ground water in the long run, because it brings only a minute part of the amount that needs to be replenished in a quarter of a century. Infiltration of small, frequent runoff amounts does not prevent or mitigate great, rare disasters, but it restores the day-to-day functioning of a watershed's environmental balance.

Proof in Practice

Infiltration itself is not a mystery. In today's world the choice of whether to use infiltration need not be based on convention, supposition, rumor or fear of the unknown. Too many designers still refer to infiltration as an "innovation" or "cutting-edge" practice. With 60 years and 10,000 case studies behind it, it is time for infiltration to join the realm of techniques that all of us can draw on selectively and knowledgeably in our every day work. It is time for the design and environmental community to bring the state of the practice up to the state of the science.

The goal is to solve environmental problems, by whatever method is supported by the evidence. To restore bio-physical integrity and reintroduce the mechanisms of natural equilibrium, we must seek new and better ways with an open mind, a humble heart, and a will of iron. ❖

Subscription Renewals

Center subscription renewals for 1997 will be sent out in January. Should you continue to participate? We would hope so, but only if you are finding some direct or indirect benefit from our work here—an expanded newsletter, ready access to a growing list of recent publications, training discounts, and broadened access to research opportunities and research results. Subscriptions cover the cost of the newsletter and help support many of the ongoing, cooperative functions of the Center as well.

The best features of Center cooperation and communication are obviously meaningless without someone to cooperate with and communicate to! To that end we will repeat the invitation for you to add additional recipients of the newsletter to your subscription, and we have reduced the subscription rates for private consulting firms from earlier years in acknowledgment of the inequity and hardship in the rate structure that many of you have felt previously. All other rates will remain unchanged.

Thank you for your support, be it new or long-standing. Please feel free to contact the Center Director (Derek Booth at the University of Washington) or the Chair of the Center's Advisory Board (Joan Lee at Snohomish County Surface Water Management) with your questions, comments, or concerns. ❖

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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Evaluation of Infiltrative Pavement Systems for Parking Areas: Water Quantity and Water Quality Performance

In a notable exception to the general absence of multijurisdictional research projects, the Center has coordinated a joint effort to evaluate the long-term performance of infiltrative pavement systems for parking lots. Major cooperators in the first phase of this project have been King County, the City of Olympia, Washington State Department of Ecology, and the City of Renton. Nine parking stalls using five different surface materials were constructed as part of a new employee parking lot at the King County Roads Maintenance shops in Renton, Washington, during the winter of 1996. Surface and subsurface water samples are being collected and measured by specially designed and installed gauging equipment. This study is designed to evaluate not only the short-term, qualitative performance of infiltrative surfaces ("Does water soak in?") but also the long-term water-quality and water-quantity benefits of these systems under real-world usage ("How well do they really work? How clean is the infiltrating water? Do different pavement systems yield different results?"). Final conclusions are not expected until the parking lot has seen several years' worth of usage, but this study should eventually demonstrate how well these systems address key runoff-management issues in the Pacific Northwest, particularly reducing surface runoff and preserving groundwater quality.

Out of the large variety of infiltration pavement systems currently available, four were selected for evaluation because they span the full range of impervious-surface coverage over the ground and include both grass-filled and gravel-filled systems. Two adjacent parking stalls are constructed in each of the following systems, for a total of eight stalls:

1. UNI Eco-stone, with about 75 percent coverage by impervious blocks with gravel infilling.
2. Turfstone, with about 50 percent coverage by impervious blocks, infilled with soil and planted with grass.
3. Grasspave2, with virtually no impervious-area coverage by a plastic network, infilled with gravel.
4. Grasspave2, infilled with sand and planted with grass.

A ninth stall is paved with asphalt as a control.

The instrumentation allows us to measure and record rainfall, runoff, and infiltration for each surface. Any surface runoff is collected at the head of each pair of stalls and measured in a tipping-bucket gage attached to a continuous recorder. A fraction of the subsurface runoff is collected by a subsurface drain running down the middle of each stall and similarly measured. A portion of this subsurface runoff can also be collected in treatment-specific composite samples for water-quality testing; a preliminary sampling program is occurring this fall. The same collection and instrumentation is installed for the ninth control stall, covered in asphalt (but without the subsurface drain, from which no runoff would be expected).

We hope to answer the following questions through this research:

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EVALUATION (from page 8)

1. What are the relative installation costs of different infiltration systems?
2. How well do each of the systems infiltrate surface runoff in a site with intrinsically favorable soil conditions, both qualitatively and quantitatively?
3. What is the long-term performance of each system under normal, daily parking-lot usage, for both durability and infiltratibility?
4. What special benefits and/or requirements are imposed by grass, as opposed to gravel, filling of the individual cells?
5. What are the maintenance costs, if any, of each of the systems?
6. What are the water-quality benefits of each of the systems?

Although several of these issues will require two or three years of operation, we believe that we can already provide information on several of these issues. A preliminary report will be available through the Center's publications distribution service in early 1997 and will be highlighted in the next issue of this newsletter. ❖

New Publications Available Through the Center

To order these or any other publications, or to receive a complete listing of available titles, contact the Center's publication distribution service using the order form on page 11.

• Water Quality Monitoring: Where's the Beef?: by Robert C. Ward, 1996, 8 p. (originally published in Water Resources Bulletin, v. 32 no. 4).

From the abstract:

Water quality monitoring, as a function of society's efforts to manage the environment, is the contact mechanism that management and the public have with the actual water quality in the environment. Water quality monitoring has been studied extensively for many years to ensure that it produces information about water quality conditions. Current efforts to reduce government spending will have negative impacts on those government functions deemed to be non-responsive to the needs of the public. How well does water quality monitoring inform taxpayers about the status and trends in water quality conditions in the United States? This paper reviews a number of past efforts to "improve" water quality monitoring, discusses barriers to such improvement, and suggests ways that monitoring can be made more accountable for the information it should be producing for public understanding of water quality conditions. In particular, the need for standardization in data analysis and reporting of information to the public, is highlighted.

(Robert Ward first coined the all-too-apt description of water-quality monitoring, "Data-rich but information-poor," in 1986.)

Price = $2.50 (I3)

• Storm Water Sampling from Storm Drains Influenced by Tides: by Matthew Brennan, 1996, M.S. Thesis, University of Washington, 90 p.

This report documents the results of and problems with conducting a stormwater sampling study in three drainage basins emptying into the Elliot Bay/

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1997 Professional Engineering Practice Liaison (PEPL) Courses

January 15 and 16
Geology and Geomorphology of Stream Channels

February 2, 3, 4
Designing and Implementing Habitat Modifications for Salmon and Trout

February 25, 27, March 4, 6, 11
Effective Writing for Technical Professionals

March 11
Successful Negotiation Skills in Construction Projects

March 25 and 26
Hydrologic Modeling and Design of Retention/Detention Facilities

March 27 and 28
Introduction to MODFLOW and MODPATH Models: Applications for Groundwater and Subsurface Vapor Extraction and Control

April 16 and 17
Storm and Surface Water Monitoring

May 6 and 7
Achieving *Real* Success as a Project Manager

June 10 and 11
Use of Constructed Wetlands for Improving Stormwater Quality

June 17 and 18
Innovations in Municipal Anaerobic Sludge Digestion: Design Operations, Meeting 503 Regulations

PUBLICATIONS (from page 9)

Duwamish River estuary in Seattle, Washington. The sampling locations were chosen to maximize the contributing drainage area, but as a result tide water inundated each of the sampling locations at high tides, limiting the timing and duration of storm water sampling. Many technical obstacles to collecting data were identified and overcome in the first year of the study, and samples were collected at each of the three sampling locations. Because the samples were taken from a fraction of the total duration of the storms, however, uncertainty was introduced to the estimation of pollutant event mean concentrations. Recommendations are made to improve the effectiveness of data gathering in locations such as those studied. Several spreadsheet storm water quality models were applied to the Duwamish Study drainage basins to determine their usefulness in pollutant load estimation. Constant concentration and unit load models had the most accurate results, and have the potential to estimate loads with an accuracy of within a factor of two.

Price = $13.50 (I4)

- Watershed Determinants of Ecosystem Functioning: by Richard R. Horner, Derek B. Booth, Amanda Azous, and Christopher W. May, 1996 (originally published in the conference proceedings of the Engineering Foundation Conference, "Effects of Watershed Development and Management on Aquatic Ecosystems," August 4-9, 1996).

By the mid-1980s it was clear that urban stormwater runoff was strongly implicated in the ecological degradation of streams and freshwater wetlands. It was also apparent that the causes of these modifications were rooted in watershed hydrology and sediment transport as well as in reduced water quality.

Recognition of these connections, and the rapid pace of development in the region, stimulated research to define the linkages among stream and wetland habitat structure, conditions in the surrounding landscapes, and the associated biological responses. One such project ("Stream Indices") monitored watershed and riparian zone conditions, flow, physical habitat characteristics, water quality, benthic macroinvertebrates, and fish in 31 reaches on 19 low-order streams, representing a gradient of urbanization over a three-year period. A second project ("Puget Sound Wertlands Research"; see also Publication CK9 below) followed 19 palustrine wetlands during an eight-year period when urbanization began or increased in the watersheds of about half, while the remainder were essentially unchanged.

Overall, the findings of these projects agree that the effects of modified hydrology accompanying urbanization exert the earliest and, at least initially, the strongest deleterious influences on the freshwater ecosystems studied. Furthermore, the results agree that the steepest rates of decline in biological functioning of both the streams and wetlands, and the conditions necessary to support that functioning, occur as urbanization increases total impervious land cover from 0 to about 6 percent, unless mitigated by extensive riparian protection, management efforts, or both. Thereafter, the decline proceeds at a slower rate as impervious cover increases further. The results suggest that management efforts should concentrate on *preservation* through land-use controls where resource values are high, and concentrate on *prevention* (of further degradation) and *enhancement* (of what remains), especially directed at riparian zones, where functioning is impaired but not lost entirely.

Price = $5.00 (K12)

- Evaluation of Filter Berms in Double-Cell Dry Detention Ponds, King County, Washington: by Karen Billica and Derek Booth, Center for Urban Water Resources Management, University of Washington, October 1996.

In 1990, King County began requiring double-cell dry detention ponds for the temporary storage of surface water runoff, with the intention of adding water *quality* benefits to the primary function of controlling runoff *quantity*. However, County personnel have found that many of the berms impound water in the first cell for many days or even weeks, presumably from clogging of the filter window by fine-grained sediment. The primary objective of this study was to determine how to identify rapidly and to maintain most efficiently these clogged berms. A secondary objective of this study was to determine a set of design recommendations to minimize or to avoid altogether any future problems with berms that have not yet been constructed.

Based on observations of water levels, inflow and outflow turbidity, and berm materials in 21 detention ponds conducted during the winter and spring of 1996, the report concludes that clogging occurs primarily because filter windows are almost never constructed in accord with design specifications, exacerbated in many cases with high incoming sediment loads during construction of the surrounding watershed. Monitoring existing filter windows for failure can be done without special equipment

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simply by observing differences in water levels across the two cells within 2 to 5 days of the last significant rainfall. A simplified filter window design would achieve more robust results in the field. However, double-cell dry detention ponds probably will never be effective enough at removing pollutants to make a major contribution to a watershed's water quality.

Price = $5.00 (K13)

- Watershed Urbanization Effects on Palustrine Wetlands: A Study of the Hydrologic, Vegetative, and Amphibian Community Response Over Eight Years: by Nancy T. Chin, 1996, M.S. Thesis, University of Washington.

This thesis reviewed the eight-year data set of the Puget Sound Wetlands and Stormwater Management Research Program for trends in water-level fluctuation, water quality, vegetation, and amphibian populations as functions of watershed development. The strongest trends associated with urbanization were expressed by hydrologic measures of wetland function; other changes, such as a decline in amphibian populations, were noted but without a strong correlation with the magnitude of surrounding development. Nineteen wetlands are represented in this study, with eight experiencing significant surrounding land-use change and the other eleven serving as controls.

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