The Water Center's
Watershed Review
information on water and watersheds

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Director's message

Welcome to autumn! We hope you had a wonderful summer. We had a productive and exciting one. New research projects are providing our students experience with collaborative and practical research questions, and strengthening our work with on- and off-campus affiliates. We are also excited to announce that our Tuesday Morning seminar series for Winter Quarter (starting January 9th) will focus on global water and health issues. Our Annual Review of Research, scheduled for February 14th, will further our efforts to bring the Center's expertise to the broader community to address water problems. It will be held—as always—in the HUB West Ballroom on the UW campus. And it will be free of charge!

We are proud to feature four outstanding articles in this issue. First, Professor Robert Naiman provides a valuable and compelling perspective on global fresh water, and the major challenges for science and society. Next, we have articles from three Water Center graduate students: Julia Helen Tracy reports on the aquatic ecology of University Slough, David Robert Thurman examines how baffled culverts aid juvenile salmon passage, and Bernadette Visitacion analyzes the costs of stormwater runoff in Puget Sound.

Thank you for your ongoing support for the Water Center. Please see our website for more information on our activities. I hope to see you at the **upcoming Annual Review on February 14, 2007**, if not sooner! ♦ *—Anne C. Steinemann*

In this issue

Save the date!
Annual Review of Research
February 14, 2007

Developing a global perspective on fresh water

About the Author: Robert J. Naiman is a Professor in the School of Aquatic & Fishery Sciences at the University of Washington. He is a founding member of the Executive and Scientific Committees of the Global Water System Program, and chairs the DIVERSITAS Freshwater Committee as well as the UNESCO Ecohydrology Programme. He co-chaired the effort to establish a US program on freshwater systems in the 1990s (Naiman et al. 1995. The Freshwater Imperative: A Research Agenda, Island Press, Washington, D.C.)*

In December 2003, the United Nations General Assembly adopted resolution 58/217 proclaiming 2005 to 2015 as an International Decade for Action with a direct focus on 'Water for Life' (www.unesco.org/water). The resolution called for greater attention to water issues and development efforts, and recommitted countries to achieving the water-related goals of the 2000 Millennium Declaration and of Agenda 21; in particular, to halve by 2015 the proportion of people lacking access to safe drinking water and basic sanitation (Dudgeon et al. 2006). These are vitally important matters, yet their importance should not obscure the fact that the International Decade of 'Water for Life' comes at a time when freshwater resources, including the biodiversity and biological resources contained therein, are facing unprecedented and growing changes from human activities. The general nature of these changes is known, and they are manifest in all regions of the Earth although their relative magnitude varies significantly from place to place. Identifying changes to water regimes and the inherent consequences of those changes to aquatic organisms and human societies has done little, however, to mitigate or alleviate them. The fact remains that, at a global scale, there are grand challenges facing all aspects of fresh waters, from development, governance, and health to biodiversity.

Scientists and policy makers are now beginning to think of fresh waters in terms of a global water system (GWS). They are discussing ways by which the 'system' is being altered, identifying the ecological and policy implications of these changes, and establishing key international programs dedicated to understanding and resolving major social and environmental issues.

The notion of a global water system (GWS)

In the context of water's many roles in the Earth system, the

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concept of a Global Water System provides a useful organizing framework. The GWS has three major interacting components: (1) water in all its forms, as part of the physical hydrologic cycle; (2) biological systems, as integral transformers of water and constituent fluxes that determine biogeochemical cycling and water quality; and (3) human beings and their institutions, as agents of environmental change, and as entities that experience and respond to ongoing transformations of the GWS. Assessing how each of these components and their interactions define the evolving state of the GWS is a fundamental challenge confronting the environmental and human-dimensions science communities.

Fresh water is diminutive by ocean standards, representing but a small fraction of the planet's hydrosphere (< 3% of total volume); nonetheless it serves as an essential building block of the Earth system. Fresh water is intertwined with energy exchange, atmospheric teleconnections, and feedbacks linking major components of the climate system (Vörösmarty et al. 2004). Water movement constitutes the largest flow of any material through the biosphere, and serves as the primary vehicle for physically shaping the continents. The importance of fresh water, which strongly regulates productivity and supports ecosystems and biodiversity, is evident everywhere on Earth.

Fresh water is equally critical to human society. It underpins global food production by providing the fundamental resource upon which irrigation, livestock production, fisheries, and aquaculture depend (Postel 2005). Domestic, industrial, hydropower, and recreational water use is crucial to a growing world population that aspires to long-term improvements in well-being. Providing basic sanitation and clean drinking water remain major public health challenges. More than 1 billion people are without access to clean drinking water, 2.5 billion are without sanitation, and over 5,000 people, mostly children, die each day from water-related diarrheal diseases (World Water Assessment Programme 2003). Key manifestations of variability in the terrestrial water cycle continue to shape human history and are a costly source of vulnerability. In the United States alone, annual drought damage averages $6 billion, with the 1988 drought costing over $60 billion in 2002 dollars. Annual damages from flooding and other extreme weather involving the global water cycle are even more costly. These issues are real, and the consequence is that global water storage capacity will be increased substantially in coming years in an attempt to control variability in water supplies and extreme events.

WATER FOR LIFE
2005–2015

How is the GWS being altered?

The number of ways and the rate by which the GWS is being altered are daunting—but cannot be ignored (Millennium Ecosystem Assessment 2005). Alterations are proceeding without a firm understanding of regional or global scale consequences for both the environment and for human societies. Consider the following abbreviated list of fundamental topics requiring clarity and resolution in the near future:

- International water governance
- Effects of land cover changes
- Consequences of climate change
- Water diversions for agriculture and energy
- Nutrient and sediment transport to coastal zones
- Historic legacies of human and natural interactions
- Water requirements for nature and humans
- The nature of the adaptive capacity of the GWS
- Enhancing institutional and educational capacity

This is always the case when limited natural resources are in demand. One cannot expect complete knowledge, and inaction is not a viable option either. The appropriate response is to act, but with caution matching the uncertainty in the outcomes, and with a firm commitment to monitor the outcome and adapt as needed.

Further, any one topic listed above is a grand challenge for science and policy. However, let's consider a single topic (water diversions) as an example of the complexity. The pandemic alteration of surface and ground water through impoundments, irrigation projects, and other large diversion projects regulated by antiquated governance systems, has lead to fragmentation of river systems, alteration of flow regimes, changed water budgets, declining biodiversity, the loss of traditional goods (e.g., riparian and fisheries), and resulted in major issues related to human health (Postel and Richter 2003). At the same time the development of rivers has provided electricity, flood protection, food, economic well-being, and other "goods and services" to society. Looking forward into a future where water is even scarcer, how will both the needs of the river environment and human societies be met? What could a 'win-win' scenario look like? There is precious time remaining to be proactive; the need for a viable solution is unprecedented.

What are the policy implications of a changing GWS?

While widely recognized that the global water system is an essential aspect of the environment, it also plays a central role in human society. Throughout history, supplies of freshwater have wrought the founding and destruction of civilizations. It can be argued that the concept of a GWS has emerged from the increasingly tight economic, social, technological, and other couplings among society that we term "globalization". As an example, the water policies carried out by large international organizations, such as agribusinesses, have direct impacts on the levels of water abstraction and water diversions worldwide, and hence on the level of wastewater discharges, hydrologic regimes, the biogeochemistry of waters, human health, and the integrity of aquatic ecosystems. Whereas effects of water scarcity have largely been localized in the past, global connections have emerged through the movement of 'virtual water' in the form of agricultural exports and hydropower that buffers the impact of regional water scarcity. In a world where water 'users' span multiple continents, watersheds supply goods and services to distant, increasingly disconnected consumers responding nimbly to market pressures and trends. Will the global market sustain a viable global water system? The answer is not yet clear.

How is the international science community responding?

In the last decade the international science community has initiated a number of innovative programs to better understand all aspects of the GWS and to discover linkages within the GWS having significant implications for the long term vitality of the environment and human society. The initiatives and programs can be categorized into those supported by intergovernmental organizations, by specific countries (but with an international perspective), and by non-profit organizations. Here are three examples of international water programs where faculty and students from the University of Washington are making positive contributions.

An intergovernmental organization

The work of the Division of Water Sciences at UNESCO (www.unesco.org/water), located in Paris, is based on three pillars. First, the International Hydrological Programme (UNESCO-IHP) is an intergovernmental scientific co-operative program in water resources, and a vehicle through which United Nations member countries upgrade their knowledge of the water cycle and thereby increase capacity to better manage and develop their water resources. It aims to improve the scientific and technological basis of methods used for the rational management of water resources, including the protection of the environment (for example, the UNESCO Ecohydrology Programme). Second, the UNESCO-IHE Institute for Water Education, based in Delft (Netherlands), offers training and postgraduate research programs in the fields of water and the environment and is particularly aimed at professionals from developing countries. Finally, the World Water Assessment Programme (WWAP) is a UN-wide program which seeks to develop the tools and skills needed to achieve a better understanding of basic processes, management practices, and policies that will help improve the supply and quality of global freshwater resources. Specifically, WWAP assesses the state of the world's freshwater resources and ecosystems, develops indicators and measures progress toward achieving sustainable use of water resources, helps countries develop their own assessment capacity and documents lessons learned, and publishes the World Water Development Report.

A country-supported international program

The Global Water System Project (www.gwsp.org), based in Bonn and generously supported by the German government, is a science-based activity addressing how humans are changing the global water cycle, the associated biogeochemical cycles, the biological components of the GWS, and identifying the social feedbacks arising from these changes. The GWSP is developing new science concepts and methodologies to promote a better understanding of linkages across traditional disciplinary models. Key research activities include the treatment of spatial and temporal scales, the assessment of uncertainty in coupled models, and methods for collecting and analyzing data specifically targeted at synthesis study. Like other programs, the GWSP's perspective encompasses the global domain but unlike many other programs the overarching GWSP focus is driven by science organized around three broad questions:

- What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?
- What are the main linkages and feedbacks within the Earth system arising from changes in the GWS?
- How resilient and adaptable is the GWS to change, and what are sustainable management strategies?

Each question constitutes a major, unresolved issue in its own right, and requires a comprehensive, interdisciplinary approach. There are also the challenging tasks of assembling core information (data) from around the world, developing cross-disciplinary dialogue, building models, and conducting data analysis. Membership on the science team comes from 16 countries with widely contrasting expertise and philosophies about water.

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A non-profit organization

The international program of biodiversity science, DIVERSITAS (www.diversitas.org), based in Paris, has identified a science agenda for conservation and sustainable use of fresh water to inspire and facilitate a new generation of research (Naiman et al. 2006). This science agenda recognises the importance of freshwater biodiversity as a basic support for life on Earth and for the provision of valuable human-related goods and services. The intention is to advance knowledge on freshwater biodiversity, a topic of international concern that has potentially serious consequences for ecosystems and for humanity. The overarching goal is to establish the scientific basis for effective measures and conservation actions, thereby ensuring sustainable uses of freshwater resources and the ecosystem goods and services provided to human society. Three key research foci integrate the biological and social sciences in this effort:

- Assessing biodiversity in freshwater ecosystems at different scales and the environmental and evolutionary drivers of freshwater biodiversity changes
- Identifying the impacts of freshwater biodiversity changes on ecosystem functioning and connecting the effects to the services provided to society
- Developing objectives and measures to sustainably manage freshwater ecosystems to balance human use and biodiversity protection

This program involves collaboration between ecologists, economists, stakeholders and institutions from over 20 countries with the objective of establishing effective governance and protection of freshwater biodiversity for the long term—thereby benefiting human societies.

What does the future hold?

Clearly, there are many daunting challenges ahead with a rapidly growing world population, economic expansion, regional conflicts, and changing ideologies. Fortunately, there are several additional important research and conservation programs addressing the Earth's freshwater issues: the Freshwater Sustainability Project of The Nature Conservancy (www.tnc.org), the Global River Sustainability Project (www.grsp.org), the Belgian Biodiversity Platform's Freshwater Animal Diversity Assessment (FADA; http://www.biodiversity.be/thematic-forums/freshwater-ecosystems/global-biodiversity-assessment), supported by the European Union, the ministerial-level World Water Forums (www.worldwatercouncil.org), and many others. These programs actively share much of the world's freshwater expertise and data, and will do so more effectively in the coming years if the financial and political support for proactive cooperation is forthcoming. The hope is that these visionary programs and dedicated people, working in concert with interested and cooperating governments, will help resolve the most pressing issues of this UN International Decade of Water for Life.

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Snapshots of current research

Damages and costs of stormwater runoff in the Puget Sound region

Bernadette Visitacion, Civil and Environmental Engineering (MS)

The Puget Sound region, with its rapid population growth and urbanization, is in critical need of more intensive and effective stormwater management. Stormwater runoff has caused a range of impacts, among them greater flooding, landslides, and property damage; a decline in drinking water and surface water quality; and degradation of habitat, both freshwater and marine.

Managing stormwater within the Puget Sound region is not a novel problem—jurisdictions have struggled with this for decades—but they will likely face even greater challenges in the future. Understanding the variety of costs inflicted by stormwater, and the benefits that can be gained by effective stormwater management, can help decision-makers to allocate resources to protect and promote the health of the region.

We investigated the costs of both stormwater damage and stormwater mitigation within the Puget Sound region, and also some quantifiable benefits of properly managing stormwater. The table below summarizes some key findings.

In addition to the reported costs listed here, there are consequences of stormwater runoff that are not easily quantified but are also important to recognize. These costs include social, cultural, and quality-of-life changes; lost recreational opportunities due to degraded water quality; reductions in consumer confidence; decreased tourism; and loss of fish and wildlife. Although jurisdictions are currently spending thousands to millions of dollars annually on stormwater management, their expenditures are still dwarfed by the damage being caused by stormwater runoff. For instance, our study found that unmitigated damage costs nearly ten times more than current expenditures on stormwater management.

Improved information on costs and benefits can help decision-makers and stormwater managers to protect and improve the water quality and biological diversity of Puget Sound. Because stormwater damages are so varied and dispersed in space and time, they commonly occur almost unnoticed. Therefore, understanding the ecological, economic, and societal costs can provide critical information to help allocate resources more effectively to mitigate the impacts of stormwater. ♦

Table 1. Stormwater Costs in the Puget Sound Region

Types of Costs	Reported Costs
Flooding and Property Damage	
Property damage	Flood insurance claim payments have totaled $56 million since 1978; however, this underestimates the total flood losses borne by property owners.
Stormwater facilities	Capital improvement plans indicated annual expenditures of more than $115,333 to $5 million for individual jurisdictions; however, many millions of dollars in shortfalls exceed this reported value.
Stormwater programs	Annual stormwater program budgets range from hundreds of thousands to millions of dollars, with annual costs around $100/person within a stormwater utility district.
Degradation of Water Quality	
Clean-up of polluted water	Reported costs for NPDES Phase I permits average more than $5 million per permittee per year. Water-quality improvement in a single watershed due to a single stormwater-related contaminant cost $1.5 million.
Stormwater treatment	Reported treatment costs for stormwater discharges range from $172,000 to $6.8 million.

Types of Costs	Reported Costs
Loss of Fish and Wildlife Habitat	
Habitat restoration and protection	Individual restoration projects associated with stormwater discharges have cost $100,000 to $100 million, with one project costing $25.8 million in 2005 alone.
Loss of Marine Habitat--Closure of Shellfish Growing Areas	
Shellfish harvest area protection and clean-up	Most urban shoreline areas are permanently closed to harvest. For shellfish harvest areas recently closed or inhibited by contaminants, pollution-prevention and clean-up can cost hundreds of thousands of dollars, with costs of $160,000 to $200,000 annually for one shellfish harvest area alone.
Lost revenues and lost jobs	One harvest area lost over $3 million in shellfish sales due to closed shellfish harvest areas.
Lost recreation opportunities	Fishing and shellfishing generate more than $16.9 million in license sales and over 700,000 customers, indicating the high potential losses from closed areas.

The author thanks Derek B. Booth and Anne C. Steinemann for their contributions to this project, and the Puget Sound Action Team and the Water Center Consortium of regional agencies for their financial support. The Damages and Costs of Stormwater Runoff in the Puget Sound Region report can be found on the Puget Sound Action Team website at http://www.psat.wa.gov/Programs/Stormwater.htm.

Hydrodynamics of sloped-baffled culverts to aid juvenile salmon passage

David Robert Thurman, Civil and Environmental Engineering (MSCE)

The long held belief that juvenile salmon only travel downstream to the ocean is incorrect. More recent evidence suggests that juvenile salmon also travel upstream. Unfortunately, man-made structures such as culverts may be making that very difficult.

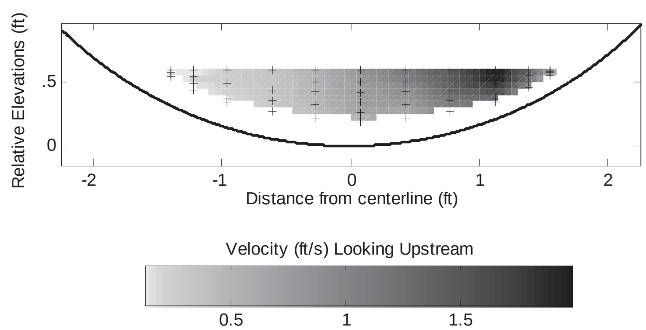
Since 1991, Washington State Department of Transportation (WSDOT) has spent nearly 40 million dollars inventorying stream crossings, conducting habitat studies, and correcting fish passage barriers. There are an estimated 5,853 WSDOT highway crossings. Of the crossings identified as fish bearing, approximately half of those (1,538) are considered fish passage barriers. An additional 1,620 culverts have been identified as fish barriers on Washington Bureau of Reclamation and Forest Service lands.

Many of these culverts are identified as fish barriers because they are required to pass the weakest swimming fish, often juvenile salmon. Juvenile salmon travel upstream in search of lower flows, reduced turbidity, preferred water temperature, predator refuge, food, and available habitat. The ability for juvenile salmon to access the entire drainage will lead to a stronger and healthier population with a reduced mortality rate. Juvenile salmon will also be better prepared for migration and life in the ocean environment.

An economical solution for culverts that are fish passage barriers is to retrofit them with baffles. Baffles improve the flow within culverts by increasing water depths at low water conditions and reducing velocities at higher flowrates. Scientists and engineers studying fish passage often describe the amount of spatial variability in a flow as the diversity of the stream. Baffles increase the flow diversity in culverts by introducing additional flow structures such as eddies, jets, and pools. These structures are important features that break up the symmetry of the flow. By mimicking a river's complex rock and log structures, baffles provide regions for fish to rest and travel. Studies have revealed that fish take advantage of eddies and are able to reduce the amount of energy they expend. We are currently studying the flow in a sloped-baffled culvert to evaluate the structures generated by baffles and to develop a better understanding of juvenile fish passage.

Hydraulic testing was performed at the Washington State Department of Fish and Wildlife Skookumchuck Fish Rearing Facility Culvert Test Bed (CTB) near Tenino, Washington. During the summers of 2005 and 2006, velocity measurements were collected in grid patterns at the full-sized, 6-foot diameter, 40-foot long corrugated culvert. An Acoustic Doppler Velocimeter (ADV) was used to measure all three components of velocity. Flow structures are identified qualitatively and using averaged velocity contour plots. We varied the parameters of culvert slope, baffle spacing, baffle height, and discharge in order to observe trends that may benefit juvenile passage, such as the development of flow structures.

Above: Baffled culvert test bed near Tenino, Washington.



Above: Cross-sectional contour plot of along-culvert velocity showing an asymmetrical flow, described by a jet of water (right) and a region of slower velocity (left).

This project is different from other similar hydraulic studies of baffled culverts, because these tests were completed in conjunction with biological testing of juvenile Coho salmon passage in the same facility and under the same conditions. Biologists from Battelle Pacific Northwest Division randomly chose 100 test fish from the rearing facility and placed fish in the tailwater net pen. The fish were released from the tailwater tank and allowed to ascend the culvert

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to the headwater tank for three hours. Passage rate was defined as the percent of the fish in the headwater tank at the end of the experiment.

The migrating fish seek the path of least resistance (areas of reduced velocity) when traveling up culverts. They have been shown to take advantage of culvert roughness by traveling along the boundary and resting within the corrugations of the culvert. The across-culvert slope of the baffles introduce an asymmetry into the flow, which consists of a jet traveling over the low side of the baffle and a lateral recirculation zone on the high side of the baffle. This asymmetry decreases and the flow becomes more uniform for increasing discharge. The asymmetry appears to be important because the diversity of flow provides paths of reduced velocity for fish to travel. This is consistent with the fish passage results, which show that for higher flow rates the number of paths fish can travel is limited and fewer fish successfully reach the headwater tank. The biological study concluded that baffles do not hinder juvenile salmon passage. However, tests were made comparing the unbaffled culvert as a control against the baffled culvert and it seems that the current baffles do not improve the passage success either.

Our research thus far has indicated that the sloped nature of the baffles is important to creating flow diversity and this effect decreases with increasing discharge. Further data analysis of the different baffle configurations are aimed at improving juvenile passage rates relative to bare culvert rates, as future salmon runs and the ecology of our watersheds begin with and rely on juvenile salmon! ♦

Investigating the aquatic ecology of University Slough before and after the connection of Ravenna Creek

Julia Helen Tracy, College of Forest Resources (MS)

The focus of this study is the aquatic ecology of University Slough and how the ecology may be changed by the connection of nearby Ravenna Creek to the slough. University Slough, a drainage channel excavated in 1971 to take waste surface water from the surrounding area to Lake Washington, is a slow-moving—in some places stagnating—watercourse, yet it provides a rich source of primary production for local avian residents and fish, as well as a good deal of riparian habitat.

Urban hydrology is inarguably impacted by development. Of particular note, urban streams and creeks are routinely polluted, straightened, diverted, channelized, piped, culverted, and otherwise isolated from their natural courses. But attitudes toward streams and creeks in urban areas are changing rapidly and one phenomenon, urban creek daylighting, is becoming increasingly common. Daylighting occurs when a previously covered river, creek, or stream is brought back to the surface. One example is that of Ravenna Creek in northeast Seattle, which has been routed to the sewers since 1948. In 1991, a working group formed of representatives from the University of Washington School of Aquatic and Fisheries Sciences, Department of Landscape Architecture, and local community councils began studying the feasibility of daylighting Ravenna Creek. After many years of negotiations with various stakeholders, a plan was agreed upon by which a portion of Ravenna Creek would be daylighted, routed through a trunk line, connected to the University Slough, and finally returned to Lake Washington.

In 2003, as a master's student looking for a project, I thought some before-and-after comparison of the water quality in the slough could be relevant to studies of both urban water quality and the emerging science of stream daylighting. There were two main study goals, to initiate an overall monitoring plan for the microorganisms living in the slough, particularly the primary producers, and to follow, over time, the periphyton communities at one sample point, tracking changes in species abundance and composition when the higher-quality Ravenna Creek water was added. Periphyton (benthic algae) are primary producers—an important foundation of many stream food webs and useful as biological water quality indicators.

For two field seasons, in 2005 and 2006, periphyton were collected by placing artificial substrata into the slough every two-week interval between mid-February and mid-July, scraping off the accumulated periphyton, and analyzing it for total organic productivity, chlorophyll-*a*, and taxa present. Results from the first field season indicated, as expected, that taxa present were those tolerant of poor water quality, particularly cyanobacteria (blue-green algae), along with grazers, such as ciliated protozoans.

The second field season, mid-February through mid-July of 2006, was intended to be a comparative study following the connection of Ravenna Creek to the slough. The daylighting project was completed and the creek's water ran through University Slough from March 22nd of this year until June 2nd. However, following a 20-year rain event over Memorial Day weekend, University Village flooded

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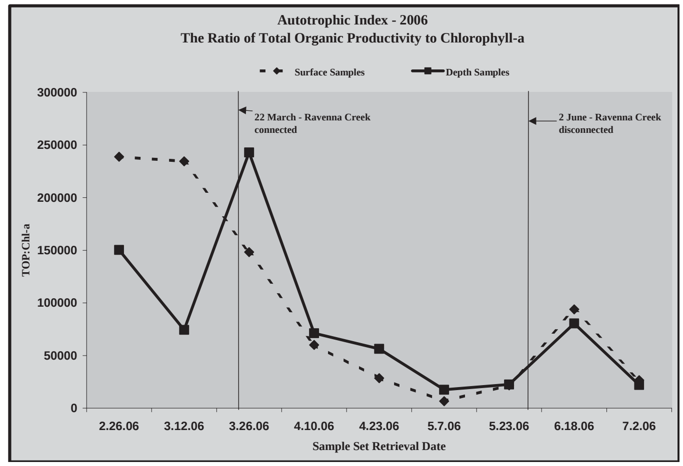
and the owner, convinced that this flooding was caused by the recent creek-to-slough connection, asked Seattle Public Utilities to re-route the creek's water back into the sanitary sewer, effectively ending the comparative study. In addition to the disconnection of the creek, the second field season was plagued by vandalism of the sampling station, so quite a bit of data was simply lost. Ah, the joys of field work...

Nonetheless, preliminary results from this truncated second field season indicate that the water quality of the slough may be significantly improved by the addition of the creek water. During the ten week period the water ran through the slough, some changes were noted. Qualitatively, a higher diversity of diatoms was noted, there appeared to be a greater number of euglenoids (autotrophs) and fewer ciliates (grazers), and turbidity was markedly reduced. Further, the autotrophic index (a measure of water quality based on the ratio of total organic productivity to chlorophyll-*a*) showed a dramatic decrease during the ten week period (see chart, right). Lower values indicated better water quality. While these results are extremely preliminary, they do appear to indicate a trend toward an improvement in water quality for the slough as a result of increased flow.

The city reconnected the creek to the slough on October 6th of this year. If it runs consistently until next year, it is expected that a third field season could reveal significant, positive changes in water quality in University Slough. ♦



*Above: The autotrophic index (a measure of water quality based on the ratio of total organic productivity to chlorophyll-*a*) showed a dramatic decrease during the ten week period that Ravenna Creek was connected to the Slough.*

Coming up!

Jan. 9 - Mar. 6, 2007	The Water Center Seminars: Global Water and Health
Feb. 14, 2007	Annual Review of Research
May 3, 10, 17, 24, 31, 2007	Oceans to Stars Lecture series: Everyday toxic pollutants—health hazards and solutions

For more details, please see: http://depts.washingon.edu/cwws/

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