MA Water Resources Research Center

Annual Report
FY 2008

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Front cover photograph by Marie-Françoise Walk – Fall River, Gill, MA

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Introduction

This report covers the period March 1, 2008 to June 30, 2009[1], the 43rd year of the Massachusetts Water Resources Research Center (WRRC). The Center is under the direction of Dr. Paula Rees, who holds a joint appointment as Director of the WRRC and as Director of Education and Outreach of the Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere at the University of Massachusetts Amherst.

Dr. Stephen Mabee of the UMass Amherst Department of Geosciences completed the three-year 104G USGS grant to look at *A Regional Approach to Conceptualizing Fractured-Rock Aquifer Systems for Groundwater Management*.

At the University of Massachusetts Amherst, Dr. Baoshan Xing of the UMass Plant, Soil, and Insect Science Dept. continued work on the second year of a two-year project on the *Environmental Behaviors of Engineered Nanoparticles in Water*. His project was granted a no-cost extension until May 31, 2010.

Four $5,000 projects to support graduate student projects were granted to study:

- *Quantifying Sediment Transport in Red Brook, Wareham, MA: Impacts of Dam Removal* by Steven Kichefski and Dr. Ellen Douglas, Dr. Allen Gontz, Dept. of Environmental, Earth & Ocean Sciences, UMass Boston;
- *Estimation of Climatic and Anthropogenic Influences on Freshwater Availability* by Yushiou Tsai and Dr. Richard Vogel, Dept. of Civil & Environmental Engineering, Tufts University;
- *Toxicity of Carbon Nanotubes to the Activated Sludge Process: Protective Ability of Extracellular Polymeric Substances* by Lauren Luongo and Dr. Xiaoqi (Jackie) Zhang, Dept. of Civil and Environmental Engineering, UMass Lowell;
- *Characterization of Wastewater Effluent from Western Massachusetts Publicly Owned Treatment Works Using Metaproteomic Analysis* by Pamela Westgate and Dr. Chul Park, Dept. of Civil & Environmental Engineering, UMass Amherst.

Other projects conducted at WRRC include the *Acid Rain Monitoring Project*, the *Tri-State Connecticut River Targeted Watershed Initiative*, and continued collaboration with UMass Extension on a stream continuity project. The Center is also working on a stormwater clearinghouse project that enables users to search the web for stormwater Best Management Practices and to find innovative technologies available to treat stormwater.

WRRC was involved in three projects incorporating modern information technology into environmental research, teaching at the middle school and University levels, and public outreach in the Connecticut River watershed. All three use location-aware hardware and software technologies and handheld computers to enhance understanding of complex, place-based environmental issues.

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[1] The USGS reporting year covers March 1 to February 28, while the University of Massachusetts and the Commonwealth of Massachusetts fiscal years run from July 1 to June 30. Projects funded by the State are reported for the period July 1 2008 - June 30, 2009.

The sixth annual water resources research conference, *Water Dependencies in New England: Systems, Stresses, and Responses*, was held at UMass on April 7, 2009.

Research Program

Six research projects were conducted this fiscal year: one research project was funded through the USGS 104B program and continued for its last year, and received a no-cost extension through May 2010. Four new projects were funded through the 104B program and were completed this year. Progress reports for all six projects follow:

1. A Regional Approach to Conceptualizing Fractured-Rock Aquifer Systems for Groundwater Management (USGS 2003MA19G)

Principal Investigators: Stephen B. Mabee, State Geologist, UMass Amherst and Michele Cooke, Professor, UMass Amherst Geosciences
Start Date: 9/30/2003
End Date: 12/27/2008
Reporting period: March 1 2008 – February 28 2009
Research Category: Groundwater Flow and Transport
Focus Category: Water Supply, Groundwater, Water Quantity
Keywords: Fracture Characterization, Domain Analysis, Well Yield, Fractured Rock Aquifers, Groundwater Availability, Groundwater Mapping, Borehole Geophysics

Problem Statement and Research Objectives

The use of fractured-bedrock aquifers to meet private, public and commercial water supply needs is increasing in the New England region. Municipalities and water suppliers are finding it increasingly difficult to locate and develop water supplies in overburden aquifers because of contamination and a lack of suitable sites. In addition, recent droughts in the northeast have forced many communities and homeowners to drill new wells. As a result, water suppliers are going deeper into bedrock aquifers. Yet information on the factors that influence the availability and recharge characteristics of fractured bedrock aquifers in highly deformed crystalline metamorphic rocks is limited.

The availability of water in fractured rock aquifers is particularly critical in New England because growth and development along the coast, major transportation corridors and in rural communities adjacent to large metropolitan areas is rampant. For example, the I-495 corridor in Massachusetts, a circumferential highway 30 miles west of Boston, has become the focus of recent growth. Professional office buildings, research and development parks associated with the computer industry, warehouses and light industry are springing up along this corridor, as are housing and condominium developments. Municipalities and water suppliers are simply unprepared for the onslaught of development and need help in understanding the complex dynamics of the ground water system.

Sustaining and managing ground water resources in fractured bedrock requires an evaluation of 1) the availability of water, 2) the source and vulnerability of recharge to water supply wells and 3) the impact of water withdrawals from the bedrock on streams, wetlands and unconsolidated aquifer systems that overlie the bedrock.

These evaluations all require basic information on the physical characteristics of the ground water system.

The objectives of this project are to gather regional bedrock characteristics that relate to the occurrence and movement of ground water in bedrock and use this information to begin constructing regional conceptual models of the fractured-rock aquifers in the Nashoba terrain in Massachusetts. The approach utilizes existing information augmented by the collection of low-cost field data to develop regional conceptual models of the ground water flow system. Water managers can then use these conceptual models as an initial framework for formulating an understanding of bedrock flow behavior and recharge characteristics.

Methodology

Specific tasks of this project involve: 1) Fracture Characterization and Domain Analysis - collection and synthesis of fracture characterization data over the region and mapping of the spatial distribution (domain analysis) of fracture sets and their characteristics, 2) Compilation and Analysis of Existing Well Data - compilation and statistical analysis, including variography, of available well data to link spatial continuity of well yields to characteristics of the fractured rock system, 3) Borehole Geophysics - collection of optical and acoustic televiewer data from selected boreholes to verify sheeting joints, 4) Compilation of Regional Litho-Group Map - development of a mapping classification system that uses the notion of "litho groups" to characterize bedrock units in terms of their fracture characteristics, physical properties and geologic setting (e.g., overburden type and thickness) and 5) Conceptual Model - preparation of a qualitative conceptual model of ground water flow behavior in each litho group category.

Principal Findings and Significance

A new method has been developed to quantitatively assess the hydraulic properties of fractured rocks that is independent of geology. This approach uses easily obtained fracture data to prescribe hydraulic properties of discrete fracture networks (DFNs) to rocks with negligible matrix porosity. The properties that are required to provide a hydraulic property estimate are fracture intensity, size, intersection angle of fractures, and number of fracture sets in a fracture network. The ratio (R) of the permeability of a fracture network to the permeability of a single fracture within an identical model domain is used to quantify the hydraulic character of DFNs with fracture sets that comprise persistently parallel fractures. Results reveal that R is consistently most sensitive to the angle of intersection of fractures in a network and least sensitive to the fracture intensity. The analyses also show that there is a predictable relation between R and the above mentioned parameters. Thus, a methodology for developing type curves through numerical simulations is also provided. These type curves are a series of graphs, which provide R estimates that are based on unique combinations of fracture properties and configurations collected in the field. Estimates of R from the type curves can then be used to compute the first-order approximations of fracture network permeability or hydraulic aperture at a cost far less than that associated with performing aquifer tests.

Publications and Conference Presentations

Articles in Refereed Scientific Journals

Manda, Alex K., Stephen B. Mabee, Donald U. Wise. 2008. Influence of rock fabric on fracture attribute distribution and implications for groundwater flow in the Nashoba Terrane, eastern Massachusetts. Journal of Structural Geology, v.30, pp.464-477.

Manda, Alex K., Stephen B. Mabee, David F. Boutt. (In Review). Effects of fracture configurations and properties on the hydraulic properties of three-dimensional networks. Submitted to Water Resources Research.

Manda, Alex K., Stephen B. Mabee (In Review). Comparison of three fracture sampling methods in layered rocks. Submitted to International Journal of Rock Mechanics and Mining Science.

Dissertations

Manda, Alex K. 2009. Development and validation of conceptual models to characterize the fractured bedrock aquifer of the Nashoba Terrane, Massachusetts. Ph.D. Dissertation, Geosciences Department, University of Massachusetts, Amherst, Massachusetts, 159p.

Conference Proceedings

Manda, Alex K., Stephen B. Mabee, David F. Boutt. 2007. Discrete Fracture Network Modeling of Hydrostructural Domains: An Example from Eastern Massachusetts, in U.S. EPA/NGWA Fractured Rock Conference: State of the Science and Measuring Success in Remediation, September 24-26, 2007. Portland, Maine, pp.480-488.

Published Abstracts

Manda, Alex K, Stephen B. Mabee, David F. Boutt. 2006. Characterizing fractured crystalline bedrock aquifers using hydrostructural domains in the Nashoba terrane, eastern Massachusetts. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.25.

Diggins, John P., David F. Boutt, Alex K. Manda, Stephen B. Mabee. 2006. Estimating bulk permeability of fractured rock aquifers using detailed outcrop data and discrete fracture network modeling. Geological Society of America Annual Meeting, Philadelphia, Abstracts with Programs, v.38, no.7, p.223.

Manda, Alex K., Stephen B. Mabee, Steven A. Hubbs. 2005. Field mapping and fracture characterization techniques predict groundwater preferential flow paths in fractured bedrock aquifers, Nashoba terrane, MA. EOS Transactions, American Geophysical Union, v.86, no. 52, Fall Meeting Supplement, Abstract H23E-1477.

2. Environmental Behaviors of Engineered Nanoparticles in Water (USGS 2007MA73B)

Principal Investigator: Baoshan Xing
Start Date: 3/1/2007
End Date: 5/31/2010
Reporting period: March 1 2008 – February 28 2009
Keywords: Nanoparticle; sorption, suspension; toxicity, environment

Problem Statement and Research Objectives

Knowledge of engineered nanoparticles in water is critical for evaluating their environmental fate, exposure, toxicity and risk. The research objectives this year were:

1. To characterize colloidal and aggregation behavior of nanoparticles as affected by pH and organic matter;

2. To examine the adsorption and desorption of organic chemicals by nanoparticles;
3. To evaluate the uptake and phytotoxicity of nanoparticles.

Methodology

Batch sorption techniques, DSL, liquid scintillation counting, HPLC detection, TEM and SEM examinations, and monitoring of plant growth in a greenhouse.

Principal Findings and Significance

Our preliminary data show that ZnO nanoparticles were toxic to plants and present inside the root cells via uptake; the latter is significant in terms of possible accumulation along the food chain. Al_2O_3 nanoparticles in aqueous suspension could be stable in the presence of certain dissolved organic matter, and at pH being away from the zero point of charges. Natural Organic Matter (NOM)-facilitated suspension could promote the mobility and exposure of nanoparticles (oxides and carbon nanotubes). Coating of NOM on metal oxide nanoparticles greatly increased their sorption of polyaromatic hydrocarbons (PAH). Bisphenol A and 17α-ethinyl estradiol were strongly adsorbed carbon nanotubes (CNTs) with hysteresis. Therefore, CNTs, particularly single-walled CNTs, may be potentially used for water treatment. We also observed that π-π interaction is an important contribution for adsorption of aromatic-ring containing compounds by CNTs, such as bisphenol A and phenolic chemicals. These results are useful to understanding the interactions between CNTs and organic contaminants and environmental behavior of CNTs.

Publications and Conference Presentations

Several Platform and poster presentations will be given at the International Conference of Environmental Application and Implication of Nanotechnology, June 9-11, 2009, Amherst, MA.

Articles in Refereed Scientific Journals

Ghosh, S., H. Mashayekhi, B. Pan, P. Bhowmik and B. Xing. 2008. Colloidal behavior of aluminum oxide nanoparticles as affected by pH and natural organic matter. Langmuir, 24(21): 12385-12391.

Wang, X.L., J.L. Lu, M. Xu and B. Xing. 2008. Sorption of pyrene by regular and nanoscaled metal oxide particles: Influence of adsorbed organic matter. Environ. Sci. Technol. 42(19); 7267-7272.

Pan, B., D.H. Lin, H. Mashayekhi and B. Xing. 2008. Adsorption and hysteresis of bisphenol A and 17α-ethinyl estradiol on carbon nanomaterials. Environ. Sci. Technol. 42(15): 5480-5485.

Lin, D.H. and B. Xing. 2008. Tannic acid adsorption and its role for stabilizing carbon nanotube suspensions. Environ. Sci. Technol. 42(15): 5917-5923.

Lin, D.H. and B. Xing. 2008. Root uptake and phytotoxicity of ZnO nanoparticles. Environ. Sci. Technol. 42(15): 5580-5585.

Lin, D.H. and B. Xing. 2008. Adsorption of phenolic compounds by carbon nanotubes: Role of aromaticity and substitution of hydroxyl groups. Environ. Sci. Technol. 42(19); 7254-7259.

Conference Proceedings

Ghosh, S. and B. Xing. "Influence of structurally different humic acids on the colloidal chemistry of aluminum oxide nanoparticles." Humic Science & Technology Conference Twelve, Boston,MA, March 18-19, 2009. P. 51.2

Pan, B. and B. Xing. "Competitive adsorption of endocrine disrupting chemicals on carbon nanotubes." The 24th Annual International Conference on Soils, Sediments, and Water. Amherst, MA, October 20-23, 2008. p.90 in the abstract book.

Bai, Y.C., D.H. Lin and B. Xing. "Influence of sonochemical oxidation on the dispersion of multiwalled carbon nanotubes." The 24th Annual International Conference on Soils, Sediments, and Water. Amherst, MA, October 20-23, 2008. p.92 in the abstract book.

Ghosh, S., B. Pan, H. Mashayekhi, P.C. Bhowmik and B. Xing. "Colloidal behavior of aluminum oxide nanoparticles as affected by pH and humic acid (HA)." The 24th Annual International Conference on Soils, Sediments, and Water. Amherst, MA, October 20-23, 2008. p.91 in the abstract book.

Pan, B. and B. Xing. "Adsorption of hydrophobic organic contaminants on carbon nanotubes in different organic solvents." 2008 ASA-CSSA-SSSA International meetings, Houston, Oct. 5-9, 2008. Abstract #: 61-7.

Student Support

Mr. Hamid Mashayekhi and Miss Wei Jiang, Ph.D. students in the Department of Plant, Soil & Insect Sciences at the University of Massachusetts Amherst.

Notable Achievements and Awards

One of my graduate students, Wei Jiang, won a first place for her poster presentation at the **Water Dependencies in New England 6th Annual Conference**: http://www.umass.edu/psis/news/ne_water_conf.html

3. Quantifying Sediment Transport in Red Brook, Wareham, Massachusetts: Impacts of Dam Removal on Hydrogeomorphology and Aquatic Habitat (USGS 06HQGR0091 2008 MA 133B)

Primary Principal Investigator: Ellen M. Douglas, PE, PG, PhD, Assistant Professor, Hydrology, Environmental, Earth and Ocean Sciences, University of Massachusetts Boston
Other Principal Investigator: Allen M. Gontz, Assistant Professor, Environmental, Earth and Ocean Sciences, University of Massachusetts Boston
Start Date: March 1, 2008
End Date: Feb 28, 2009
Keywords: stream barrier, dam removal, sediment transport, fluvial processes

Problem and Research Objectives

The U.S. Environmental Protection Agency identified sediment as the most widespread pollutant in the Nation's rivers and streams, affecting aquatic habitat, drinking water treatment processes, and recreational uses of rivers, lakes, and estuaries. (Bent et al., 2001). Confounding these impacts is the fact that dams, dikes and water control structures impound sediment and impede the natural flow and transport processes within a river. In addition, the effects of the removal of such flow impoundments on sediment processes are largely unknown. Since 2000, the Massachusetts Riverways Program and partners have overseen the removal of six dams and have seven more priority projects in various stages of the dam removal process[2]. Despite the importance of sediment concentrations in water quality, little has been done in Massachusetts to document the long term impacts of dam removal on sediment transport and its ultimate impact on the local watershed. With this in mind, our research has quantified the pre- and post- dam removal sediment

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[2] http://www.mass.gov/dfwele/river/programs/stream/index.htm

dynamics within the Red Brook, a 4.5 mile small, spring-fed, coastal stream near the town of Wareham in southeastern Massachusetts. Red Brook is currently on the priority projects list of the Massachusetts Riverways Program[3]. The long-term goal of the Red Brook Restoration project is to naturalize the stream and restore its function by removing man-made structures, eliminating sources of unnatural sedimentation, and enhancing habitat for anadromous fishes, specifically Salter brook trout[4]. This sea-run brook trout is found in very few places in Massachusetts, making this a critical habitat for restoration. The Red Brook Restoration project is innovative in that the sediment mitigation plan will not include dredging, but rather, will rely on the natural re-suspension and transport of accumulated sediment (Tim Purinton, Massachusetts Riverways Program, personal communication, Nov 14, 2006). Critical needs for this project include understanding sediment dynamics, determining sediment sources and developing a sediment management plan. In support of these critical needs, the objectives of our research are to:

- Characterize the hydrogeomorphic characteristics of the lower Red Brook;
- Quantify cross-section geometry and sediment transport before and after removal of the Upper Flume, which occurred in September 2008..
- Test and compare methods outlined in the newly published guidelines for stream barrier removal.

Methodology

Monitoring began in April 2008 with a combination of in-situ measurements (for channel geometry and bedload sampling), geophysical techniques (ground penetrating radar) and a remotely-accessed environmental sensor network to monitor flow in the Brook before and after the flume removal. We have based our monitoring approach on four methodologies recommended in the *Stream Barrier Removal Monitoring Guide* (Collins *et al*., 2007). These include detailed cross-section surveys, grain-size analysis, longitudinal profiles and photostations. Prior to Upper Flume removal in September 2008, we established 14 permanent cross-sections throughout the study area with two of these several hundred feet upstream of the Upper Flume as reference cross-sections. When surveying each cross-section we also probed the channel bottom to refusal to determine the depth of unconsolidated sand deposits overlaying the natural gravel bed. The natural gravel bed is the preferred habitat for salter trout. In June 2008, we conducted a Ground Penetrating Radar survey of the project reach. This provided another means of defining the longitudinal profile of the reach and to estimate the depth of sand deposits. Also in June 2008, thanks to the funds made available through this WRRC grant, we installed a remotely monitored acoustic depth sensor for continuous monitoring of changes in the water surface elevation of the Brook (see Figure 1). Distance to the water surface is measured continuously; data is telemetrically transmitted to a website: https://www.hobolink.com/p/0c1219967f03a7a652064389eeb98356. A rating curve for this cross-section is being established using periodic streamflow measurements. An electromagnetic current sensor will be added to this station in early summer 2009. This will enable us to continuously measure changes in both depth and velocity, and thereby remotely monitor streamflow. In July 2008, we surveyed a longitudinal profile and valley-wide cross-sections using a Real Time Kinetic GPS system. We are periodically collecting bedload transport and streamflow measurements from the upstream and downstream ends of the study reach in order

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[3] http://www.mass.gov/dfwele/river/programs/priorityprojects/redbrook.htm

[4] http://www.americanrivers.org/site/News2?JServSessionIdr006=fo8tyzfmr1.app6b&page=NewsArticle&id=9111&news_iv_ctrl=-1

Figure 1: Remotely accessed water depth sensor installed at Red Brook with funding from this grant.

to estimate sediment flux through the system. All 14 cross-sections were resurveyed in Winter 2009 to establish sub-annual, post-flume removal changes in channel geometry. Another round of cross-section surveys is scheduled for Summer 2009.

Principal Findings and Significance

Continuous WSE data collected from the sensor indicate a significant tidal influence, which needs to be accounted for in our rating curve (see Figure 2). Data reduction and analysis is currently underway. Statistical analysis of the difference between Winter 2009 and Summer 2008 geometry at the 14 cross-sections indicated significant changes only in the cross-sections closest to the former Upper Flume site (see Figure 3a and 3b). This is one of the major challenges of this project. A streamflow hydrograph estimated from the sensor data combined with the established rating curve is being used to calibrate a HEC-RAS model of the Brook. This model will be used to estimate the time for transport of sand deposits within the reach and project the possible effects of future restoration activities at the Brook.

References

Bent, G. C., J. R. Gray, K. P. Smith and G. D. Glysson, 2001. A synopsis of technical issues for monitoring sediment in highway and urban runoff, U. S. Geological Survey Open File Report 00-497, Northborough, Massachusetts.

Collins, M, K. Lucey, B. Lambert, J. Kachmar, J. Turek, E. Hutchins, T. Purinton and D. Neils. 2007. Stream Barrier Removal Monitoring Guide, Gulf of Maine Council on the Marine Environment. Available on-line at www.gulfofmaine.org /streambarrierremoval.

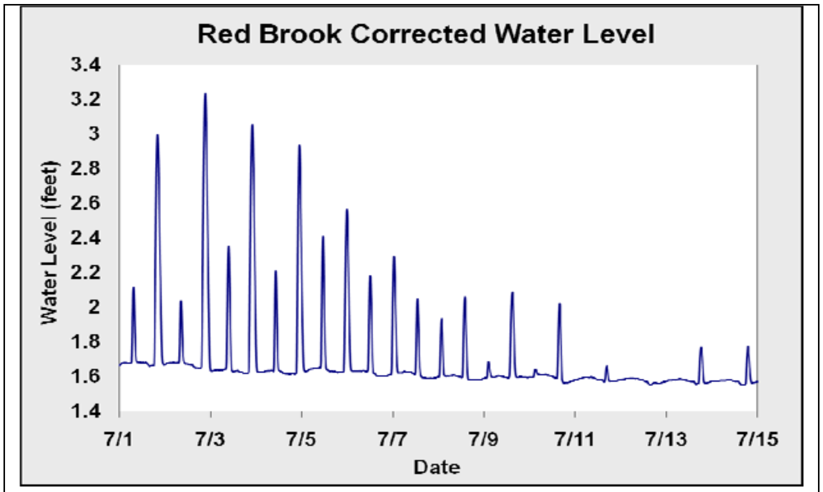

Figure 2: Segment of continuously monitored water levels from acoustic sensor installed with funding from this grant.

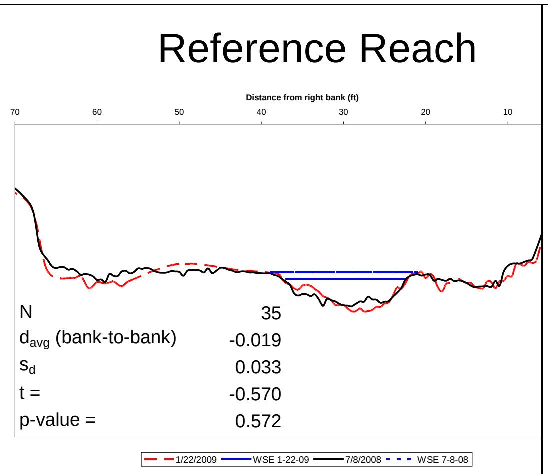

Figure 3a: Difference between Summer 2008 (black) and Winter 2009 (red) channel elevations at the reference reach. Average difference is not statistically significant at 95%.

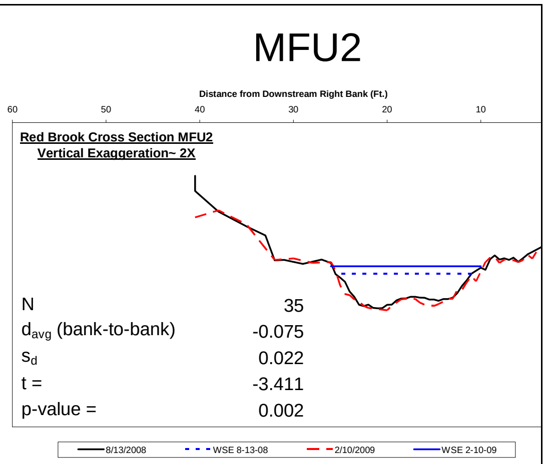

Figure 3b: Difference between Summer 2008 (black) and Winter 2009 (red) channel elevations at cross-section just downstream of former Upper Flume location. Average difference is statistically significant at 95%.

Publications and Conference Presentations

Articles in Refereed Scientific Journals

Kichefski, S. and E. M. Douglas, Monitoring changes in flow and sediment transport in Red Brook, a small coastal stream in southeastern, Massachusetts, in preparation.

Fradkin, B. and E. M. Douglas, Modeling the impacts of river restoration on fluvial hydrology in Red Brook, in preparation.

Conference Presentations

Monitoring and Modeling the Hydrological Impacts of Stream Restoration in Red Brook, a small coastal stream in southeastern Massachusetts, Water Resources Research Conference, April 2009, Amherst, MA.

Monitoring the restoration of Red Brook, a small coastal stream in southeastern Massachusetts, Geological Society of America, Northeast Chapter, March 2009, Portland ME.

Modeling the Hydrological Impacts of Stream Restoration in Red Brook, a small coastal stream in southeastern Massachusetts, Geological Society of America, Northeast Chapter, March 2009, Portland ME.

Monitoring the restoration of Red Brook, a small coastal stream in southeastern Massachusetts, AGU Fall 2008, San Francisco, CA.

Graduate Theses

Kichefski, Steven, Monitoring changes in flow and sediment transport in Red Brook, a small coastal stream in southeastern, Massachusetts, MS thesis, Environmental Science, University of Massachusetts Boston, August 2009.

Fradkin, Barry, Modeling the impacts of river restoration on fluvial hydrology in Red Brook, MS thesis, Environmental Science, University of Massachusetts Boston, August 2009.

Graduate Student Support

Matching funds for this project supported Steven F. Kichefski during the 2008-2009 academic year towards completion of an MS in Environmental Sciences at the University of Massachusetts, Boston.

4. Estimation of Climatic and Anthropogenic Influences on Freshwater Availability

Principal Investigators: Richard M. Vogel, Yushiou Tsai
Start Date: 4/7/2008
End Date: 7/25/2008
Reporting period: March 1 2008 – February 28 2009
Research Category: Climate and Hydrological Processes
Focus Category: Water Supply, Water Use, Water Drought

Problem and Research Objectives

Of the previous research which attempt to evaluate sensitivity of streamflow to various factors, most such studies have taken changes in climate into account, but fewer studies have considered both the changes in climate and land use. Generally it is agreed among researchers that land cover is a significant factor influencing watershed hydrology (Oudin et al., 2007; Andreassian 2004). In many watersheds around the globe, drastic landscape changes have occurred due to urbanization over decades. Numerous studies have found that impacts due to changes in land cover are important when considering their hydrologic impacts on urbanized watersheds (Beighley and Moglen, 2003; DeWalle et al., 2000, Zhang et al, 2001). Some of these urbanized watersheds, both in the U.S. (Canfield et al., 1999; Zarriello and Ries, 2000; Changnon 2002) and elsewhere (Schot and Vanderwal, 1992; Zarghami et al, 2008), have experienced surface and/or groundwater depletion due to increasing water demand that is largely driven by increases in human population density. Although many previous urban water demand studies have found that climate factors are important to urban water demand (Renwick and Green, 2000; Lyman, 1992; Foster et al., 1979; Billings and Day, 1989), few studies have addressed factors which impact both water supply and demand in a systematic fashion. One example is the study by Schulze (2000) which estimated precipitation elasticity of annual streamflow and precipitation elasticity of water demand by calibrating a water balance model across some watersheds in South Africa. A comprehensive analysis of all three essential influences: climate, land-use, and human water-withdrawal combined is needed to understand the relative importance of the interactions among those factors on water scarcity.

To achieve our objective, we proposed to evaluate the regional sensitivity of streamflow by first postulating

$$Q = f(P, T, L_a, L_g, L_f, L_u, W) \tag{1}$$

where Q, P, T, L_a, L_g, L_f, L_u, W represent streamflow, precipitation, temperature, agriculture land, grass land, forested land, urban land, and water withdrawals respectively. Then we proceeded on estimation of a specific measurement of sensitivity: elasticity based on equation (1).

Methodology

Estimation of Elasticity

Schaake (1990) borrowed the concept of elasticity from the field of economics and introduced the concept of elasticity of streamflow into the field of hydrology. In general, for variables Y and X_i which are associated by a continuous and differentiable function $y = f(x_1, \dots, x_i)$, the X_i elasticity of Y, which measures the proportional change in Y in response to proportional change in X_i, is defined as

$$\varepsilon_{y,x_i}(x_i) = \frac{\partial y}{\partial x_i}\frac{x_i}{y} \tag{2}$$

The point estimate of X_i elasticity of Y, which we term $\varepsilon_{y,x_i}(x_i)$, is a function of x_i and is critically dependent on the functional form $y = f(x_1, \dots, x_i)$ and its first order derivative $f'(x_1, \dots, x_i)$. The "factor" elasticity of streamflow denotes a proportional change in streamflow in response to a proportional change in a certain "factor", for example, the precipitation elasticity of streamflow represents a percentage change in streamflow in response to a percentage change in precipitation. Another commonly adopted measure of elasticity is defined about the mean values of the function so that the sensitivity of a variable Y to changes in variable X_i can be termed the X_i elasticity of Y about their mean values, which we denote as $\varepsilon_{\bar{y},\bar{x}_i}$, and define as:

$$\varepsilon_{\bar{y},\bar{x}_i} = \frac{\partial y}{\partial x_i}\frac{\bar{x}_i}{\bar{y}} \tag{3}$$

Standardized departures about mean-ordinary least squares (SDM-OLS) elasticity estimator:

According to equation (1), we suppose that the absolute change in Q is a linear combination of the absolute changes in P, T, L_a, L_g, L_f, L_u, and W:

$$dQ = \frac{\partial Q}{\partial P}dP + \frac{\partial Q}{\partial T}dT + \frac{\partial Q}{\partial L_a}dL_a + \frac{\partial Q}{\partial L_g}dL_g + \frac{\partial Q}{\partial L_f}dL_f + \frac{\partial Q}{\partial L_u}dL_u + \frac{\partial Q}{\partial W}dW$$

(4)

Substituting the absolute change in each term in (4) for the departure from the mean, we obtain:

$$Q - \overline{Q} = \frac{\partial Q}{\partial P}(P - \overline{P}) + \frac{\partial Q}{\partial T}(T - \overline{T}) + \frac{\partial Q}{\partial L_a}(L_a - \overline{L}_a) +$$

$$\frac{\partial Q}{\partial L_g}(L_g - \overline{L}_g) + \frac{\partial Q}{\partial L_f}(L_f - \overline{L}_f) + \frac{\partial Q}{\partial L_u}(L_u - \overline{L}_u) + \frac{\partial Q}{\partial W}(W - \overline{W})$$

(5)

and equation (5) is equivalent to

$$\frac{Q - \overline{Q}}{\overline{Q}} = \frac{\partial Q}{\partial P}\frac{\overline{P}}{\overline{Q}}(\frac{P - \overline{P}}{\overline{P}}) + \frac{\partial Q}{\partial T}\frac{\overline{T}}{\overline{Q}}(\frac{T - \overline{T}}{\overline{T}}) + \frac{\partial Q}{\partial L_a}\frac{\overline{L}_a}{\overline{Q}}(\frac{L_a - \overline{L}_a}{\overline{L}_a}) +$$

$$\frac{\partial Q}{\partial L_g}\frac{\overline{L}_g}{\overline{Q}}(\frac{L_g - \overline{L}_g}{\overline{L}_g}) + \frac{\partial Q}{\partial L_f}\frac{\overline{L}_f}{\overline{Q}}(\frac{L_f - \overline{L}_f}{\overline{L}_f}) + \frac{\partial Q}{\partial L_u}\frac{\overline{L}_u}{\overline{Q}}(\frac{L_u - \overline{L}_u}{\overline{L}_u}) + \frac{\partial Q}{\partial W}\frac{\overline{W}}{\overline{Q}}(\frac{W - \overline{W}}{\overline{W}})$$

(6)

According to equation (3), equation (6) can be expressed in terms of elasticities about the mean:

$$\frac{Q - \overline{Q}}{\overline{Q}} = \varepsilon_{\overline{Q},\overline{P}}(\frac{P - \overline{P}}{\overline{P}}) + \varepsilon_{\overline{Q},\overline{T}}(\frac{T - \overline{T}}{\overline{T}}) + \varepsilon_{\overline{Q},\overline{L}a}(\frac{L_a - \overline{L}_a}{\overline{L}_a}) +$$

$$\varepsilon_{\overline{Q},\overline{L}g}(\frac{L_g - \overline{L}_g}{\overline{L}_g}) + \varepsilon_{\overline{Q},\overline{L}f}(\frac{L_f - \overline{L}_f}{\overline{L}_f}) + \varepsilon_{\overline{Q},\overline{L}u}(\frac{L_u - \overline{L}_u}{\overline{L}_u}) + \varepsilon_{\overline{Q},\overline{W}}(\frac{W - \overline{W}}{\overline{W}})$$

(7)

where $\varepsilon_{\overline{Q},\overline{P}}$, $\varepsilon_{\overline{Q},\overline{T}}$, $\varepsilon_{\overline{Q},\overline{L}a}$, $\varepsilon_{\overline{Q},\overline{L}g}$, $\varepsilon_{\overline{Q},\overline{L}f}$, $\varepsilon_{\overline{Q},\overline{L}u}$, $\varepsilon_{\overline{Q},\overline{W}}$ represent the precipitation, temperature, agriculture-land, grass-land, forested-land, urban-land, and water-withdrawal elasticities of streamflow, respectively. A natural estimator of the elasticities in equation (7) would be an ordinary least squares (OLS) regression estimator without fitting intercept if the residuals in (7) are approximated by a normal distribution. It will be necessary to check this assumption in practice.

Data

All watersheds across the eastern United States, consisting of water resources regions 01, 02, and 03 (Figure 1), are included in the analysis and they are delineated at the 8-digit hydrologic unit code (HUC) scale. For each HUC, we compiled a set of data which contains observations of streamflow, precipitation, temperature, size of forested land, size of agriculture land, size of grass land, size of urban land, and freshwater withdrawals for year 1995. All values in this set of data, except the land-use and freshwater withdrawals, were smoothed temporally from water years 1993 to 1997 to represent the observations for 1995.

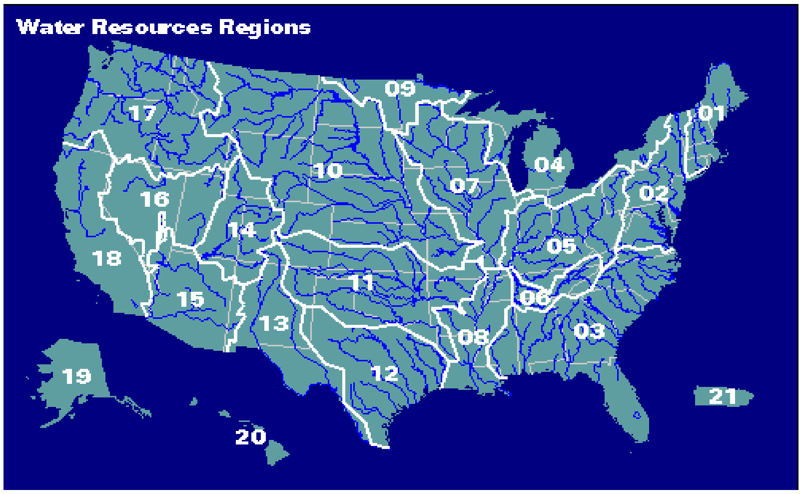

Figure 1. The map of the U.S. water resources regions.

Streamflow Data: Monthly streamflow observations accounting for human water withdrawals and return flows for all watersheds were compiled by the U.S. Geological Survey (USGS). The annual mean streamflow (cubic kilometers) for water year 1995 was estimated by arithmetic mean. The annual minimum flow (cubic kilometers) for water year 1995 was represented by the minimum of the monthly flows from water years 1993 to 1997.

Climate Data: Monthly precipitation observations at water year 1995 are estimated from a spatial interpolation model: PRISM (parameter-elevation regressions on independent slopes model) for each watershed (Daly et al., 1994). PRISM is considered a better approach than other interpolation methods such as inverse distance or kriging for it employs a spatial regression procedure that accounts for topography affecting precipitation or temperature. The annual mean precipitation (millimeters) was estimated by arithmetic mean. The annual mean temperature in $^{0}\mathrm{C}\times 10$ are used in this study.

Land Use Data: The sizes of the forested, agriculture, grass and urban lands (in square kilometers) of all watersheds across the eastern U.S. at year 1997 were compiled by using the Enhanced National Land-Coverage Datasets (NLCDE) that was developed based on the National Land Coverage Dataset (NLCD).

Water Withdrawal Data: The total fresh water withdrawals (million gallons/day) of each watershed in 1995 were obtained from the water use data published by the USGS, in which estimates of withdrawals categorized by area, use, and source are compiled at a five-year interval. The total fresh water withdrawals, which were the sum of the total fresh ground and surface water withdrawals, consist of water use for public supply, commercial, domestic, industrial, thermoelectric power, mining, livestock, and irrigation.

Principal Findings and Significance

Results

The estimates of the elasticities of the annual mean streamflow (1) across the eastern United States were obtained for water resources regions 01, 02, and 03 and are given in Table 1 and Figure 2. The p-values associated with all estimates are fairly small, except these associated with temperature elasticity (p-value = 0.444), agriculture-land elasticity (p-value = 0.813), grass-land elasticity (p-value = 0.747), and water-withdrawal elasticity (p-value = 0.322) across region 01. Small p-values indicate model coefficients with a high degree of precision. In general, as long as the p-value is less than 0.05, the coefficients can be considered to be statistically significant. The estimates of temperature elasticity are negative as expected and indicate that the increase in temperature leads to decrease in streamflow. Generally, the water withdrawal elasticities had either high p-values (regions 1 and 2) or were positive (region 3) which makes little sense. We conclude that water withdrawal elasticity can only be computed at much smaller spatial and temporal scales than considered here.

A comparison of estimates of precipitation elasticity from this research against those of Vogel et al. (1999) and Limbrunner (1998) is shown in Table 2. There is fairly close agreement between the three studies.

The estimates of the elasticities of the annual minimum flow are given in Table 3 and Figure 3. A comparison of Tables 1 and 3 indicates that the relative sensitivity or elasticity corresponding to changes in urban land and human water are much greater for the low flows than for the annual mean streamflows. Further work is needed at a much finer spatial and temporal scale to obtain more meaningful elasticities. Still, the results given here do quantify the impacts of changes in climate and land use on streamflows.

Table 1. The estimates of the elasticities of the annual mean streamflow and their p-values enclosed in brackets below the elasticity estimates.

Region(s)	**Elasticities of the Annual Mean Streamflow**						
	Precipi-tation $\varepsilon_{\overline{Q},\overline{P}}$	**Tempera-ture** $\varepsilon_{\overline{Q},\overline{T}}$	**Agricul-ture land** $\varepsilon_{\overline{Q},\overline{L}a}$	**Grass Land** $\varepsilon_{\overline{Q},\overline{L}g}$	**Forested Land** $\varepsilon_{\overline{Q},\overline{L}f}$	**Urban Land** $\varepsilon_{\overline{Q},\overline{L}u}$	**Water With-drawal** $\varepsilon_{\overline{Q},\overline{W}}$
01, 02, 03	1.443 (0.000)	-0.653 (0.000)	0.094 (0.000)	0.094 (0.000)	0.709 (0.000)	0.135 (0.000)	0.012 (0.071)
01	1.259 (0.00)	-0.065 (0.444)	0.006 (0.813)	0.007 (0.747)	0.883 (0.000)	0.160 (0.000)	-0.015 (0.322)
02	1.281 (0.001)	-0.450 (0.000)	0.186 (0.000)	0.115 (0.000)	0.609 (0.000)	0.140 (0.000)	-0.023 (0.094)
03	2.054 (0.000)	-0.710 (0.000)	0.136 (0.000)	0.128 (0.000)	0.609 (0.000)	0.147 (0.000)	0.024 (0.001)

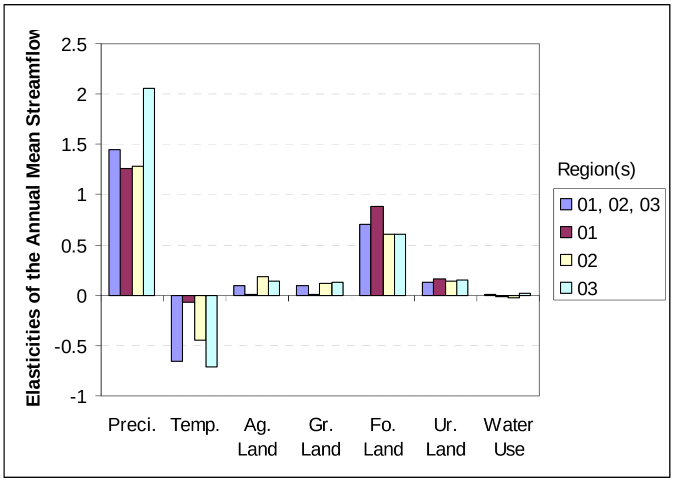

Figure 2. Estimates of all types of elasticities of the annual mean streamflow across (1) regions 01, 02, 03, (2) region 01, (3) region 02, and (4) region 03. The p-values associated with all estimates are fairly small, except these associated with temperature elasticity (p-value = 0.444), agriculture-land elasticity (p-value = 0.813), grass-land elasticity (p-value = 0.747), and water-withdrawal elasticity (p-value = 0.322) across region 01.

Table 2. Comparison of precipitation elasticity estimates obtained from this research, Vogel et al (1999), and Limbrunner (1998)

	Precipitation Elasticity		
Region	Elasticity obtained using SDM-OLS estimator (this research)	Mean at site elasticity (Limbrunner)	Elasticity by regional nonlinear regression (Vogel)
01	1.26	1.53	1.21
02	1.28	1.51	1.63
03	2.05	1.97	2.26

Table 3. The estimates of the elasticities of the annual low flow (the lowest monthly flows from water years 1993 to 1997) and their p-values enclosed in brackets below the elasticity estimates.

Region(s)	**Elasticities of the Annual Mean Streamflow**						
	Precipitation $\varepsilon_{\overline{Q},\overline{P}}$	**Temperature** $\varepsilon_{\overline{Q},\overline{T}}$	**Agriculture land** $\varepsilon_{\overline{Q},\overline{L}a}$	**Grass Land** $\varepsilon_{\overline{Q},\overline{L}g}$	**Forested Land** $\varepsilon_{\overline{Q},\overline{L}f}$	**Urban Land** $\varepsilon_{\overline{Q},\overline{L}u}$	**Water With-drawal** $\varepsilon_{\overline{Q},\overline{W}}$
01, 02, 03	2.656 (0.00)	-0.805 (0.00)	0.066 (0.237)	0.151 (0.020)	0.582 (0.000)	0.305 (0.000)	0.031 (0.250)
01	2.463 (0.213)	-1.445 (0.015)	-0.409 (0.020)	-0.196 (0.208)	0.868 (0.000)	0.226 (0.200)	0.214 (0.045)
02	2.367 (0.101)	-0.874 (0.019)	0.251 (0.004)	0.081 (0.430)	0.431 (0.016)	0.375 (0.000)	-0.094 (0.074)
03	2.409 (0.003)	-1.323 (0.162)	0.094 (0.341)	0.374 (0.007)	0.091 (0.677)	0.410 (0.000)	0.063 (0.065)

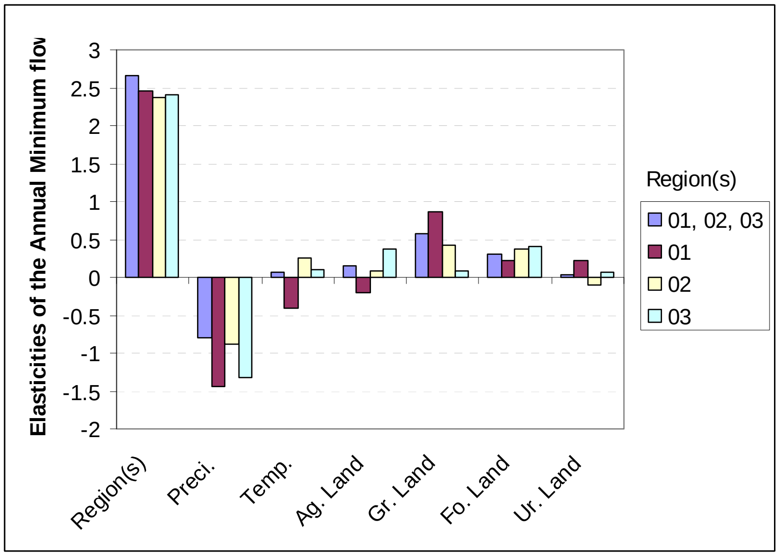

Figure 3. Estimates of all types of elasticities of the annual minimum flow across (1) regions 01, 02, 03, (2) region 01, (3) region 02, and (4) region 03.

Conclusions and Discussions

Our results indicate that across broad regions of the eastern United States the annual mean streamflow is most sensitive to the changes in annual mean precipitation, followed by changes in mean temperature, forested land, urban land and/or agriculture lands, grass land, and the human water withdrawals (p-value = 0.071 and 0.001 for regions 02 and 03 respectively). Over the spatial and temporal scales considered, changes in water use behavior do not seem to have a very large impact on streamflow levels. We expect that if the analysis was done at much finer spatial and temporal scales, that much greater water withdrawal elasticities would be seen. Generally, the impacts of changes in urban, agriculture, and grass lands to the annual mean streamflow are approximately the same throughout the eastern U.S. We also found similar precipitation elasticities of annual streamflow as did recent national analyses by Limbrunner (1998) and Vogel et al. (1999).

Generally this initial research documents the impacts of changes in land use, climate and to some extent water withdrawals on annual average and annual minimum streamflows across broad regions of the eastern United States. The sensitivity of streamflows to changes in urban and forested land uses are quite dramatic and together are on par with the sensitivity of streamflows to changes in climate. Thus our work highlights the importance of land-use management for controlling future changes in streamflow.

Publications and Conference Presentations

Articles in Refereed Scientific Journals

Tsai, Y. and R.M. Vogel, 2009, Impact of Climatic and Human Influences on Freshwater Availability, *Advances in Water Resources*, manuscript in preparation.

Dissertations

Tsai, Y., 2009, The Sensitivity of Streamflow to Changes in Climate, Land Use and Water Infrastructure, Tufts University, dissertation in progress, expected completion, 2010.

Student Support

Yushiou Tasi, Ph.D. student in the Department of Civil and Environmental Engineering at Tufts University

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5. Toxicity of Carbon Nanotubes to the Activated Sludge Process: Protective Ability of Extracellular Polymeric Substances (2008MA135B)

Primary Principal Investigator: Xiaoqi (Jackie) Zhang
Other Principal Investigator: Lauren Luongo
Start Date: April 1, 2008
End Date: March 31, 2009
Keywords: Activated sludge, Carbon nanotubes, Extracellular polymeric substances (EPS), Respiration inhibition test.

Problem and Research Objectives

The discharge of carbon nanotubes (CNTs) from industrial waste or disposal of such materials from commercial and/or domestic use will inevitably occur with increasing production and enter into wastewater treatment facilities with unknown consequences. The objective of this study was to evaluate the possible toxicity that multi-walled carbon nanotubes (MWCNTs) incur on the microbial communities present in the activated sludge by using a respiration inhibition test and the role of EPS when the activated sludge is exposed to MWCNTs.

Methodology

(1) MWCNTs

MWCNTs with purity greater than 90% (Sigma-Aldrich) were used. The outer diameter, inner diameter, and length were reported by the manufacturer to be 10-15 nm, 2-6 nm, and 0.1-10 µm. The impurities include 2.3% Al and 1.9% Fe trace metal with no amorphous carbon present.

Four concentrations of MWCNTs in distilled water were prepared, 0.64, 1.44, 2.16, and 3.24 g/L. Selection of these concentrations was based on preliminary tests performed in the laboratory in order to achieve a dose-response of the impact of MWCNTs on the respiratory inhibition to the microbial communities in the activated sludge. The MWCNTs were sonicated to achieve better dispersion by using an ultrasonic cup horn (Sonicator 3000 Ultrasonic Liquid Processor, Misonix Incorporated).

(2) Field sampling and sample preparation

Fresh activated sludge was obtained from the aeration tank of the Lowell Wastewater Treatment Facility (Lowell, MA) every morning before each experiment and transported immediately to the laboratory. In the laboratory, the mixed liquor was mixed, aerated and its mixed liquor suspended solids (MLSS) was measured according to standard methods (American Public Health Association, 1998). As part of the requirements for the respiration inhibition test conducted later, the mixed liquor was concentrated to a MLSS of 2000 mg/L based on the initial MLSS information (EPA, 1996). Half of the concentrated mixed liquor was sheared to release the EPS from the activated sludge flocs and the other half was left as unsheared. A commercial Waring blender (model 5011) was used to successfully shear the mixed liquor for 5 minutes on high (22,000 rpm) (Henriques and Love, 2007). The blender was wrapped with ice packs to prevent temperature increases during the shearing process.

(3) EPS content quantification

Both the sheared and unsheared samples were filtered through a 1.0 µm glass fiber filter by using a 25 mL syringe (and stored at -20°C if not analyzed immediately).

The EPS content was quantified through soluble protein and carbohydrate analyses to determine the release of EPS as a result of mechanical shearing. A Total Protein Kit (Micro-Lowry Peterson's Modification) was obtained from Sigma-Aldrich (Lowry et al., 1951), BSA was used as standard. The Dubois method was used for carbohydrate analysis (Dubois et al., 1956), dextrose was used as standard. A UV-visible spectrophotometer (Agilent 8453) was used to measure the absorbance. DNA concentrations were also measured using a fluorometer (Hoefer DyNA Quant 200, Amersham Biosciences) and calf thymus as a standard solution of known DNA concentration (Labarca et al., 1980). DNA concentrations were measured to test for any disruption in cell viability during the shearing process.

(4) Respiration inhibition test

A respiration inhibition test was used to measure biological activity. It was performed on both sheared mixed liquor and unsheared mixed liquor to demonstrate the potential toxicity posed by MWCNTs and to better understand the extent of EPS in protecting the microorganisms from the toxicity of CNTs.

Principal Findings and Significance

The main conclusions that can be drawn from this study are summarized as the following:

- Shearing didn't affect respiration rates.
- Greater respiration inhibition was seen in the sheared activated sludge (Figure 1), suggesting the importance of EPS
    - By binding MWCNTs
    - Reduce their toxicity
- Mechanical shearing of mixed liquor (and the subsequent release of EPS into the bulk liquid) allowed the microbial communities to be more readily exposed to the MWCNTs, which subsequently resulted in more respiration inhibition for the sheared mixed liquor compared to the unsheared mixed liquor.

This work illustrates that MWCNTs could pose toxicity in a biological wastewater treatment process. Further research is needed to exam the mechanisms of the toxicity induced by MWCNTs and the factors that have contributed to the toxicity seen.

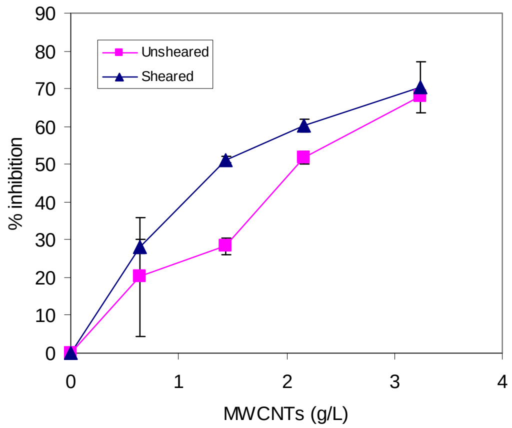

Figure 1. Respiration inhibition for both sheared and unsheared activated sludge.

Publications and Conference Presentations

Dissertation

Luongo, Lauren, 2008, Toxicity of carbon nanotubes to the activated sludge process: Protective ability of extracellular polymeric substances, MS thesis, Department of Civil & Environmental Engineering, University of Massachusetts Lowell, Lowell, MA, ~180 pages.

Conference Proceedings

Luongo, Lauren and Xiaoqi Zhang, 2009, Toxicity of carbon nanotubes to the activated sludge process: Protective ability of extracellular polymeric substances. *International Conference on the Environmental Implications and Applications of Nanotechnology.* June, 2009, Amherst, MA. (Accepted)

Student Support

Lauren Luongo, (2008) MS in Environmental Studies, Department of Civil & Environmental Engineering, UML

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6. Characterization of Wastewater Effluent from Western Massachusetts Publicly Owned Treatment Works Using Metaproteomic Analysis

Principal Investigator: Dr. Chul Park
Start Date 5/18/2008
End Date 8/31/2008
Keywords: Connecticut River, effluent, protein, proteomics, wastewater treatment plant

Problem and Research Objectives

Current effluent standards for publicly owned treatment works (POTWs) require 5-day biological oxygen demand (BOD_5) and total suspended solids (TSS) to be less than 30 mg/L on a monthly average basis. While the implementation of these regulatory standards has contributed to significant improvements in the health of receiving waters in the United States, they still allow a considerable amount of organic matter to enter into natural waters via the discharge of treated wastewater. For example, it was reported by the EPA (2000) that POTW effluents account for 42% of the total BOD_5 load into the Connecticut River, which is greater than that from urban and rural run offs and other types of point-source discharges into the same water body.

While pathogenic organisms and trace organics in the wastewater effluent have been extensively studied, organic matter contributing to the allowable limit of 30 mg/L BOD_5 and TSS remains largely uncharacterized. It is expected that POTW effluent would contain any form of organic matter, from unprocessed or partially degraded influent sewage organics to the constituents of biological sludges that escape settling or membrane processes due to ineffective solid/liquid separation. Given the wide array of inputs into a wastewater treatment plant and the biological processes that occur in wastewater treatment facilities, there are many possible sources of organic pollutants that could be commonly released from POTWs under current environmental regulations.

It was previously reported that wastewater effluent organic matter mainly consists of proteins, polysaccharides, and humic substances, with proteins being the most quantitative organic constituent (Confer et al., 1998; Park, 2002). Although proteins constitute a significant portion of POTW effluent organic matter, their identity and nature remain largely unrevealed (Holbrook *et al*., 2005; Jarusutthirak *et al.*, 2002). Consequently, their ecological and environmental impact on receiving waters has been rarely characterized.

The objective of this research was to apply molecular biological techniques in protein research (proteomics) to wastewater effluents to characterize proteins present in effluents that are continuously discharged to the Connecticut River.

Methodology

The proposed research work was composed of two main research tasks: 1) development of methodology, especially a protein concentrating procedure and 2) characterization of effluent proteins from two local wastewater treatment plants that discharge effluents to the Connecticut River. The treatment plants included in this study were the Amherst and Northampton, MA wastewater treatment plants.

The development of an efficient concentrating method is necessary to apply proteomics to wastewater effluent analysis. Various sample preparation processes including ammonium sulfate precipitation, freeze drying, and ultrafiltration have been conducted to find the best method for concentrating proteins in effluents. We determined that ammonium sulfate method was the most suitable for concentrating the proteins and preparing the samples for downstream proteomic analysis: some of these results are shown in the following section. Following the concentrating stage, proteins were separated by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). We have tried several gel staining methods including Coomassie blue staining, silver staining, and zinc staining and we have chosen the first two staining procedures for our routine analysis. We have also conducted zymogramic electrophoresis to detect and isolate active proteolytic enzymes from various effluent samples. Some effluent concentrate samples were sent to another laboratory for liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis to identify isolated proteins. In addition, various effluent parameters such as

TSS, chemical oxygen demand (COD), cations, anions, and inorganic nitrogen species were measured.

Principal Findings and Significance

The SDS-PAGE results first showed that the protein profiles between primary effluent (partially treated raw sewage) and secondary effluent (final effluent) are consistently different. Figure 1 shows the protein profile in primary and secondary effluents from the Northampton wastewater treatment plant (WWTP). As the figure shows, some heavier proteins only appear in the secondary effluent but not in the primary effluent, indicating that they are soluble microbial products produced during the biological process in wastewater treatment. On the other hand, some protein bands show in both primary and secondary effluents signifying that these influent proteins persist in the treatment system. Figure 1 also shows that samples that were freeze dried were not as well resolved on the gel as the ammonium sulfate concentrated samples. This is also important information obtained in this study because selecting a right concentration method is critical in performing gel electrophoresis and subsequent mass spectrometry. Most interestingly, 0.45μm filtered secondary effluent (Lane 3) shares high similarity with the crude effluent (Lane 2), indicating that the cell/particle-free fraction of effluent still contains a significant number of protein molecules. This data implies that although some additional filtration steps such as microfiltration will be implemented in the facility, these materials will still be continuously lost to the receiving water. That is, different types of unit operation need to be considered if these protein materials are to be removed from the final discharge.

Figure 2 shows that effluent proteins in Amherst WWTP are substantially different from those from the Northampton wastewater treatment facility (Figure 1), strongly suggesting that two facilities result in different microbial products. This data further suggest that our proteomic approach on effluent could also be used for studying upstream processes.

Figure 3 demonstrates that all effluent samples revealed distinct proteolytic activity against casein proteins. The detection of proteolytic enzymes from the secondary effluent (even from 0.45μm filtered sample) itself is meaningful, but more importantly the data implies that effluent-derived enzymes can degrade aquatic organic matter and, therefore, possibly modulate nutrient cycling in receiving waters.

The current research has allowed us to establish the proteomics method that will be used for future research. The research will be expanded to obtain protein profiles from different facilities including the facilities with biological nutrient removal processes. In the long term, protein bands will be analyzed using tandem mass spectrometry (MALDI-TOF/TOF and LC-MS/MS) until a mass map of proteins from a given facility is constructed. We expect that the established proteomic datasets will permit monitoring the fate of proteins directly in the receiving water or modified laboratory bioassays to evaluate the bioavailability of effluent proteins in receiving waters.

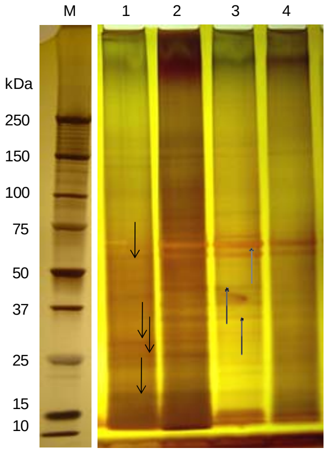

Figure 1. SDS-PAGE of primary effluent (Lane 1), secondary crude effluent (Lane 2), secondary 0.45µm filtered effluent (Lane 3) following ammonium sulfate precipitation, and secondary 0.45µm filtered effluent following freeze drying (Lane 4) from activated sludge facility in Northampton, MA. Up arrows are examples of protein bands that are only found in secondary effluent but not in primary effluent, i.e., soluble microbial products. Down arrows are examples of proteins that are found both in primary and secondary effluents, indicating their persistence in the treatment process. Lane M: molecular weight markers.

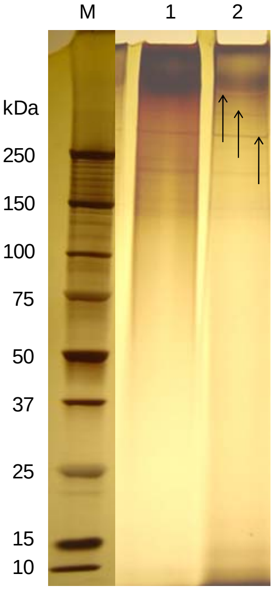

Figure 2. SDS-PAGE of secondary crude effluent (Lane 1) and secondary 0.45µm filtered effluent (Lane 2) following ammonium sulfate precipitation from activated sludge facility in Amherst, MA. Arrows are examples of proteins that are found in the current facility but not in Northampton facility. Lane M: molecular weight markers.

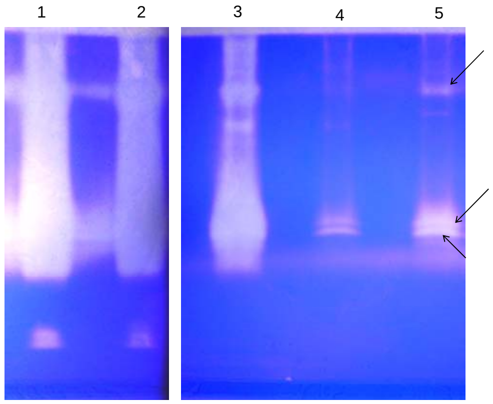

Figure 3. Zymmogramic electrophoresis of Northampton WWTP's primary effluent (Lane 1), Amherst WWTP's primary effluent (Lane 2), Northampton WWTP's secondary crude effluent (Lane 3), secondary 0.45µm filtered effluent (Lane 4), and Amherst WWTP's secondary crude effluent (Lane 5). Proteolytic activity is evidenced by clear streaks and bands where the enzymes have digested the casein protein. Areas of undigested casein are blue. Enzyme bands indicated with arrows are presumably the same proteolytic enzymes found from two different facilities' effluents.

Publications and Conference Presentations

Conference Platform Presentation:

Pamela Westgate and Chul Park (2009) Characterizing the proteins in domestic wastewater effluent discharged to the Connecticut River using proteomic analysis, MAWRRC Conference, University of Massachusetts Amherst.

Poster Presentation and Conference Proceeding

Pamela Westgate and Chul Park (2009) Evaluation of Effluent Proteins: Towards Characterization of Effluent Organic Nitrogen, Water Environment Federation 82nd Annual Technical Exhibition and Conference (WEFTEC 2009), Orlando, FL.

Student Support

Pamela Westgate, Master Candidate, Department of Civil & Environmental Engineering, UMass Amherst

Notable Achievements and Awards

The PI's startup funds at UMass Amherst were also used to conduct the current research and to support Ms. Westgate. The data from this research was very useful for preparing a new proposal to MAWRRC funds in 2009. Our proposal "*Assessing the Transport and Fate of Effluent Organic Nitrogen in the Connecticut River and Long Island Sound Using Mass Mapping Proteomics Technology*" was selected for funding ($30,000) in 2009. This project also brought up the matching funds ($30,000) from Springfield Water and Sewer Commission.

References

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Holbrook, R. D., Breidenich, J., Derose, P.C. (2005) Impact of Reclaimed Water on Select Organic Matter Properties of a Receiving Stream-Fluorescence and Perylene Sorption Behavior. *Environmental Science and Technology*, 39, 6453-6460.

Jarusutthirak, C., Amy, G., Croué, J.-C. (2002) Fouling Characteristics of Wastewater

Effluent Organic Matter (EfOM) isolates on NF and UF Membranes.

US EPA (2000) Progress in Water Quality-An Evaluation of the National Investment in Municipal Wastewater Treatment. EPA-832-R-00-008, June, 2000.

7. Acid Rain Monitoring Project (MADEP)

Principal Investigator: Marie-Françoise Walk, MA Water Resources Research Center, UMass Amherst
Start Date: July 1, 2008
End Date: June 30, 2009
Reporting period: July 1 2008 – June 30 2009
Keywords: Acid Deposition, Surface Water Quality, Volunteer Monitoring

The Acid Rain Monitoring project continued for the 7th consecutive year after an 8 year hiatus preceded by 10 years of consecutive sampling. About 150 sites (mostly streams) were sampled by volunteer collectors and tested for pH and alkalinity by volunteer labs. Of those, 23 long-term sites were analyzed for the full suite of major cations and anions. The data from 1983 to 1993 were previously analyzed for trends relevant to acid rain control. With sufficient new data on lakes and streams collected over the past 7 years, changes resulting from passage of state and federal clean air act revisions can be evaluated. These analyses are in process and should provide important evidence in the ongoing debate about clean air standards.

The more than 43,000 records of water chemistry for Massachusetts' lakes and streams, now covering 1983-2009, are posted on a web site in a searchable and downloadable form so that additional data analyses specific to the user may be conducted (http://umatei.resuo.ads.umass.edu/armproject1/).

Students Supported

1 BS student in Economics at UMass Amherst.
1 PhD student in Chemistry at UMass Amherst.

8. Tri-State Connecticut River Targeted Watershed Initiative (US EPA)

Principal Investigator: Jerry Schoen, MA Water Resources Research Center, UMass Amherst
Start Date: December 1, 2007
End Date: December 31, 2010

Reporting period: July 1 2008 – June 30 2009
Keywords: Connecticut River, Water Quality, Volunteer Monitoring, Information Technology

Problem and Research Objectives

The Connecticut River has been described as "our Boston Harbor" because the river still has significant water quality problems; particularly combined sewer overflows (CSOs) which prevent the river from achieving federal Class B fishable/swimmable water quality standards. Similar to Boston Harbor, clean-up costs are very high, estimated at $325 million for CSOs in Springfield, Chicopee, and Holyoke alone, but the benefits of cleaner water will be also be enormous due to the popularity of the river for recreation and riverfront economic development. According to the USGS, bacteria levels in the Connecticut River, which can measure as high as 10,000 fc/100ml, are among the highest found in southern New England rivers. From the Holyoke Dam south to Connecticut, water quality standards are not supported (for primary contact), due to pathogens and suspended solids, primarily from urban runoff and combined sewer overflows. This is an environmental justice issue, as many low-income residents in the Holyoke-Springfield reach use the river for fishing and swimming. The Connecticut Department of Environmental Protection concluded that nitrogen loads from the Connecticut River to Long Island Sound must be reduced by 58% in order to reverse eutrophication. In New Hampshire and Vermont, water quality is impaired due to erosion, sedimentation, and combined sewer overflows, and mercury and PCBs render fish consumption unsafe.

The Tri-State Connecticut River Targeted Watershed Initiative addresses the most significant water quality problems of the Connecticut River watershed: major bacterial pollution from combined sewer overflows and urban stormwater; extensive streambank erosion; threats to public water supplies; and nutrient loading from agricultural runoff. It is funded under a $953,000 Targeted Watershed Initiative grant from the U.S. Environmental Protection Agency, matched by $458,000 in local funding commitments.

WRRC involvement in this project, carried out in collaboration with the UMass Center for Educational Software Development (CESD), is aimed at improving main stem water quality and public use, and conducting innovative public outreach and participation. University activities include "rapid response" water quality monitoring and an innovative IT-based public outreach campaign that includes a web-based virtual watershed tour highlighting water quality problems and project sites, and mobile story tours for each task in the EPA grant.

Water Quality Monitoring

Until now only limited water quality information has been available for the Connecticut River. This information has indicated that in many urbanized areas the river's bacterial contamination is so high during wet weather events—due to combined sewer overflow discharges and to urban stormwater flows—that it does not meet standards for recreational uses.

This bacteria monitoring project examines water temperature and bacteria at 26 sites along the river, on river stretches between Turners Fall and Greenfield, Massachusetts, between White River Junction, New Hampshire, and Hartford, Vermont, and between Chicopee and Holyoke, Massachusetts (starting soon). Data will provide a more complete picture of the river's health and understanding about sources of contamination. This will be useful not only to recreational users who have direct contact with the waters, but to local, state, and federal officials in addressing combined sewer overflow discharges and stormwater flows.

The nutrient monitoring project involves two demonstration best management projects (BMPs) undertaken at a dairy farm and UMASS farm in Hadley, MA to fence livestock out of rivers and install native plantings to restore riparian corridors. The samples are collected in wet weather as well as in dry weather events.

During the first year of the two year project, there were 33 sampling days in which a total of 362 bacteria samples were collected. One dry weather and two wet weather samples were collected for the nutrient monitoring. Additional samples will be taken in summer of 2009, and again when installation of BMPs is complete.

Information Technology

Project Website with Virtual Watershed Tour

WRRC and CESD have developed a project web site: http://www.cesd.umass.edu/twi/. The web site includes a multimedia *virtual tour* of the watershed. Maps, photographs, graphs, audio and text illustrate valuable recreational, economic, and public health resources provided by the river along its length from source to sea. Site users will be able to virtually fly over the watershed and zoom in to selected locations to learn of popular boating, fishing, swimming areas, water supply, agricultural lands, etc. Site will contain links to other sites about natural and cultural history of the Connecticut River.

Mobile story tours

WRRC and CESD are developing mobile tours for each of the project components. Users will be able to learn of events and activities occurring at project site areas by playing back information about the project on mobile devices, while walking through the sites.

Electronic Field Guide

WRRC is using software available from UMass Boston's Electronic Field Guide (EFG) project http://efg.cs.umb.edu/efg/ to produce an electronic field guide to observational water quality indicators (e.g. pictures and narrative description of pollution or sediment plumes, degraded stream banks, when foam is or is not likely to be a sign of pollution). This is being created for the web site and for handheld versions. The guide will advise users how to document suspected pollution problems with photos, description and location information, how to submit observations to project staff. Project staff will follow up to validate observations and contact local authorities as appropriate.

9. Blackstone River Water Quality Study

In 2004, UBWPAD initiated the Blackstone River Water Quality Study in order to develop a watershed management tool for the Blackstone River basin that could be used to evaluate the impacts of the plant effluent, the effectiveness of point source control versus non-point source management, and the effectiveness of alternative management strategies on downstream river quality. To support this effort, the

Blackstone River HSPF Water Quality Model was developed by the University of Massachusetts Amherst and CDM. A description of the model development and calibration is presented in the Blackstone River HSPF Water Quality Model Calibration Report (UMass and CDM, 2008).

In the fall of 2008, the HSPF water quality model was used to simulate different UBWPAD effluent characteristics in order to evaluate potential improvements in water quality resulting from treatment plant upgrades at both UBWPAD and the Woonsocket WWTF. The results of these simulations were presented in the Blackstone River HSPF Model Scenario Report (MAWRRC, 2008).

In 2009, CDM and UMass reviewed simulated hourly dissolved oxygen (DO) concentrations at selected locations along the main stem of the Blackstone River. Instantaneous and hourly DO measurements collected in 2006 as part UBWPAD's field program were used as calibration targets. Model mainstem slope, and DO and temperature parameters were revised to improve the match between simulated and observed diurnal DO variations and concentrations. The model revisions did not significantly change nutrient simulation results from the earlier modeling effort.

A revised scenario study was also conducted in 2009. Ten scenarios were developed to assess the effectiveness of three alternative management strategies on downstream water quality under actual flow conditions (as opposed to design flow conditions), including: (1) point source reductions at UBWPAD, (2) nonpoint source pollution reduction, and (3) dam management to reduce or eliminate the additional travel time created by the impoundments behind the dams. Water quality metrics for Chlorophyll a, phosphorous and dissolved oxygen, derived from the draft Total Maximum Daily Load For Nutrients in the Upper/Middle Charles River, Massachusetts (CRWA and Numeric Environmental Services, 2009) were used to compare scenarios. As noted previously, while these metrics offer a useful point of reference, natural variability in base-line conditions warrants the development, in coordination with regional regulatory agencies, of metrics specific to the unique characteristics of the Blackstone. Graphs and tables of simulated summer low flow (7Q10 conditions) instream concentrations summarize the scenario comparison in terms of the selected metrics. Hydrologic conditions for this year are representative of summer low flow (7Q10) conditions. However, because the model was run dynamically from 1997 to 2007, the results presented for 2002 represent river response to the full range of hydrologic and loading conditions that occurred during the recreational season, including but not limited to summer low flow.

Simulation results indicate that several factors limit or influence instream responses to nutrient reduction including phosphorus abundance, travel and residence time, and sedimentation processes. Limiting factors and their inter-linkages are discussed further below.

Removal of dams along the river has a significant impact on travel time. Longer travel times result in a longer residence time in impoundments along the river and shorter travel times result in a shorter residence time. Simulation results indicate that travel time, or more specifically the increased residence time of phosphorus in impoundments, is one of the important factors controlling algal growth along the river. When impoundments are present to retard the downstream transport of phosphorus, even slightly elevated levels of phosphorus can result in higher Chlorophyll a concentrations along the river. However, if no impoundments are present, there is insufficient time for algae to take advantage of increased phosphorus levels. For example, dam management combined with the 2001 NPDES design at UBWPAD may be sufficient to manage Chlorophyll a concentrations along the Massachusetts portions of the river. However, reduced opportunities for algal uptake and sedimentation of phosphorus in Massachusetts segments of the river result in higher phosphorus availability along the Rhode Island segments of the river in comparison to UP1 load reductions only (e.g., UP1 vs. UP1_FERC and UP1_NoDams). This results in higher Chlorophyll a concentrations, but only in the presence of impoundments (e.g., FERC versus no dam scenarios).

Simulated Chlorophyll a concentrations in Rhode Island are fairly insensitive to changes in phosphorus load alone. This is likely due to the high availability of phosphorus in comparison to ambient background conditions for forested land use where phosphorus concentrations are low enough that algal growth is limited independent of travel time. However, while load reductions paired with dam management have the combined potential to result in Chlorophyll a values below the target values, the resulting TP concentrations along the river remain above the target values. If phosphorus levels in the river are only of concern due to their influence on algal growth, higher target values may be acceptable if the hydrodynamics of the river are also managed.

The following is a list of the key findings from this study:

- The simulated scenarios that resulted in the reduction of peak Chlorophyll a concentrations in the Massachusetts portions of the river to achieve study metrics, include UP1_NPS60, UP2, UP1_FERC, and UP1_NoDams, UP1_NPS60FERC, UP2_NPS60_FERC. These are all combination scenarios that include not only point source reductions, but also non-point source reductions and/or impoundment management.
- Simulation results suggest that only in the scenario where all the dams are removed (UP1_NoDams) do simulated Chlorophyll a concentrations in both the Massachusetts and Rhode Island portions of the river meet the Chlorophyll a water quality metric.
- Travel time appears to be an important factor influencing algal growth, and thus peak Chlorophyll a concentration, in the river.
- Simulated Chlorophyll a values in Rhode Island are fairly insensitive to changes in phosphorus load alone.
- Simulation results suggest that peak TP water quality metrics for both the Massachusetts and Rhode Island portions of the river are not achieved by any of the river management scenarios included in the study.
- Simulation results suggest that summer peak and mean TN water quality metrics for both the Massachusetts and Rhode Island portions of the river are not achieved by any of the river management scenarios included in the study.
- TN flux out of the basin is less responsive than TP to changes in external loads. For example, under UP1_NPS60, which results in the largest reduction, TN flux from the Blackstone is 63% of that under historical conditions while TP flux is 36%. This is likely mainly due to the larger percent reductions in TP (2008 limit is 13% of the 2001 limit at UBWPAD) than TN (2008 limit is 63% of the 2001 limit at UBWPAD).
- Simulated instream TP concentrations along the Massachusetts portion of the river are higher than in Rhode Island, with observable increases occurring downstream of most WWTFs.
- When impoundments are present to retard the downstream transport of phosphorus, even slightly elevated levels of phosphorus can result in higher

Chlorophyll a concentrations along the river. However, if no impoundments are present, there is insufficient time for algae to take advantage of increased phosphorus levels.

- As dams are removed, residence time in the river decreases and there is less opportunity for algal growth and, in the case of phosphorus, less settling. As a result, more phosphorus "flows through" the river to Narragansett Bay rather than being utilized by algal or deposited in the streambed.
- TN attenuation is minimally impacted by dam removal. This suggests that the river is phosphorus limited and also points to the importance of sediment processes in terms of TP fate and transport.
- Less nutrient load reduction may be necessary to achieve Chlorophyll a targets if the hydrodynamics of the river are managed, here explored through dam removal.
- Model simulations suggest that plausible load reduction alone will not achieve TN, TP and Chlorophyll a metrics.
- If phosphorus levels in the river are only of concern due to their influence on algal growth, higher TP target values may be acceptable if the hydrodynamics of the river are also managed.
- Decreases in nutrient inputs to the watershed do not necessarily translate into equivalent decreases in fluxes out of the basin due to internal processes such as sedimentation, algal growth, and other water column – bed dynamics.

The 2009 scenario results are only presented for actual flow conditions. However, design flow simulations, which are typically used as the basis for Total Maximum Daily Load (TMDL) development, were evaluated in the 2008 scenarios analysis. Simulation results presented in the 2008 Blackstone River HSPF Model Scenario Report (MAWRRC, 2008) illustrate that instream concentrations under design flow conditions are consistently higher than those simulated under actual flow conditions. Design flow scenario simulations were deferred in the 2009 analyses because the target metrics were not first met under actual flow conditions. In addition, further work is necessary to finalize design flow simulation details and to develop comparison metrics specific to the Blackstone River. It is anticipated that design flow simulations will be evaluated subsequent to model validation based on 2008 data collected by USGS and MADEP.

Information Transfer Program

1. Water Resources Conference 2009

Principal Investigators: Paula Rees, Director, and Marie-Françoise Walk, MA Water Resources Research Center, UMass Amherst
Start Date: 3/1/2008
End Date: 2/29/2009
Reporting period: March 1 2008 – February 28 2009
Descriptors: Conference, Water Resources, New England

The Water Resources Research Center organized the sixth annual Water Resources Research Conference: Water Dependencies in New England. While the conference took place in April, most of the work for this conference was accomplished in the reporting period. The Cooperative State Research, Education, and Extension Service New England Regional Program again cooperated in planning the conference. Six co-sponsors helped underwrite the cost of the conference. Attendance increased from last year, to 144. Thanks to an increased sponsorship from the Massachusetts Department of Environmental Protection, attendance and presentations by DEP personnel were greatly increased this year. The Steering Committee was expanded to include many non-UMass professionals. Thirty posters were presented and there were 36 paper platform presentations in three concurrent sessions. The presentations were grouped into four tracks subdivided into three sessions each:

Water Resources Management and Planning

Water Quality and Enforcement
Effective Water Management Regulations
Water Resources Planning

Water Issues in the Field, Lab, and Classroom

Fish: Water Resources Management Indicator
Water Research and Climate Change
Case Studies in Water Resources Education

Stormwater Challenges

Low Impact Development
Stormwater Best Management Practices
Stormwater Monitoring and Management

Identification, Assessment, and Remediation

Surface / Ground Water Interactions
Contaminants in Water
Wastewater Issues

The Keynote Address was given by Konstantine P. Georgakakos, Sc.D, Director, Hydrologic Research Center and Adjunct Professor, Scripps Oceanographic Institute.

2. Innovative Stormwater Technology Transfer and Evaluation Project (MADEP)

Principal Investigator: Jerry Schoen, MA Water Resources Research Center
Start Date: 1/1/2008
End Date: 6/30/10
Reporting period: July 1 2008 – June 30 2009
Descriptors: Stormwater, Water Quality, Non-point Source Pollution

The Massachusetts Dept of Environmental Protection (MADEP) awarded WRRC a two and a half year grant to continue a previous project WRRC staff had contributed to in FY’05 and FY’06. The goal of this project is to provide technology transfer information about innovative stormwater Best Management Practices (BMP) to MADEP, conservation commissions, local officials, and other BMP Users. The project maintains and updates the database already in place (www.mastep.net) and will continue to expand the database by adding information pertaining to at least twenty new proprietary BMPs and at least ten conventional and ten Low Impact Development BMPs. In the first six months of this project, WRRC staff met with the

Massachusetts Stormwater BMP working group to get input on revision of BMP category rating system and redesigned the rating system.

Timeline priorities for year 1 of the project were also identified with the help of DEP, EOEA staff and external advisors (e.g. Mass Highways staff, vendors).

3. Stream Continuity Project

Under a memorandum of understanding with UMass extension, WRRC staff worked to coordinate volunteers and manage the database for the Stream Continuity Project, a study looking at stream crossings and their status at creating barriers for fish and wildlife passage.

4. Other Information Transfer/Outreach

WRRC maintains a web site at www.umass.edu/tei/wrrc and a listserv of 1044 members to inform the public of latest water resources research news.

Information Technology

WRRC is involved in three projects using information technology for environmental research, teaching and outreach. In all three projects, WRRC is partnering with the UMass Center for Educational Software Development.

1) An eQuest program, funded by the Department of Elementary and Secondary Education, engages Athol middle-school students in learning phenology and biodiversity concepts by exploring natural and built areas of the North Quabbin region, aided by location-aware handheld computers and web-based mapping programs such as Google Earth. This project is a collaboration among WRRC, the Athol-Royalston Regional School District, Harvard Forest, and the Millers River Environmental Center.
2) A UMass Academic Technology grant is being used to redesign three plant identification courses to incorporate handheld computers and electronic field guides. Collaborators include John Ahern (Landscape Architecture & Regional Planning), Karen Searcy (Biology), and Robert Stevenson (Biology, UM Boston).
3) For the EPA-funded Tri-State Watershed Initiative in the Connecticut River watershed, the Center is developing a Google-Earth-based virtual tour of the watershed and handheld-computer mobile tours of selected areas where environmental restoration work is occurring in the watershed.

Other Activities

1. Environmental Analysis Laboratory

Reporting period: July 1 2008 – June 30, 2009

The Environmental Analysis Laboratory (EAL) was created in 1984 by WRRC to assist the Acid Rain Monitoring Project (ARM) by analyzing more than 40,000 samples for a suite of 21 parameters. Since 1988, the Lab has provided services to a wide range of off-campus and on-campus researchers. EAL provides chemical analysis of water, soils, tissue, and other environmental media for University researchers, public agencies, and other publicly-supported clients. The EAL conducts a wide variety of analyses to support environmental research, management, and monitoring activities. EAL provides high quality analytical services for inorganic substances in water including nutrients, inorganic anions, and metals and has especially distinguished itself in the analysis of trace levels of phosphorus.

In this past year, EAL continued to provide laboratory support for the Acid Rain Monitoring Project, including a quality-control program for pH and alkalinity and analytical determinations for a suite of 15 parameters. The quality-control program for volunteer-monitoring groups continued for pH, alkalinity and dissolved oxygen. Analytical services were provided for ten Massachusetts and Connecticut volunteer groups, the town of Barnstable, three university researchers, the Department of Environmental Health and Safety and Lycott Environmental, Inc. A new collaboration with the Chemistry Department was initiated, with Dr. Julian Tyson and his lab now responsible for sample analyses and new methods development.

The new management structure of the lab provides a unique opportunity to provide both the campus community and others with specialized methods development as well as basic analytical services. This includes an ability to analyze media other than water and soil, and is a significant expansion of capabilities in comparison to the original lab. There is the potential for unique graduate thesis components to result from method development requests. It establishes a set fee schedule and central contact point for inquiries, and avoids PI to PI requests for “favors” in terms of running analyses. In so doing, it strives to establish a higher degree of analytic quality for methods development and special requests. In summary, potential opportunities include:

- Methods development
- Potential for graduate thesis components
- Centralized point of inquiry for campus
- Better control of quality control for across campus analytical requests.
- Undergraduate research opportunities.

2. Working Groups

Reporting period: July 1 2008 – June 30, 2009

The WRRC has been participating in the coordination of interdisciplinary working groups on themes such as “Water” and “Environmental Contaminants.” Each year the working groups help identify several seminar speakers and host their visit as part of The Environmental Institute (TEI) sponsored seminar series.

The Fall 2008 TEI Lecture series theme was “Water Sustainability” and featured several topics of interest to the Water Working Group:

- Shane Snyder, Research Development Project Manager, Southern Nevada Water Authority. Emerging Contaminants and Water Quality: Endocrine Disruptors and Pharmaceuticals in the Environment.
- Ken Conca, Professor of Government and Politics, University of Maryland. Governing Water: Understanding the Global Water Crisis.
- Charles Vorosmarty, Research Professor, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire. Global Hydrology: Lessons from the U.S. Northeast Corridor.
- Mark Person, Professor of Hydrology, New Mexico Institute of Mining and Technology. Offshore Freshwater: A Potential Resource for Coastal Areas. Pleistocene Hydrogeology of the Atlantic Continental Shelf in New England.

The Spring 2009 TEI Lecture Series theme was "Emerging Technologies and the Environment" and featured three speakers:

- Richard B. Primack, Professor of Biology, Boston University. Climate Change Comes to Thoreau's Concord
- Konstantine P. Georgakakos, Managing Director, Hydrologic Research Center and Adjunct Professor, Scripps Institution of Oceanography. Science Based Water Management: Prediction and Decision Support Under Climate Change
- Erika S. Weinthal, Associate Professor, Division of Environmental Sciences and Policy, Nicholas School of the Environment, Duke University. Shoring Up Peace: Water Management in Post-Conflict Societies.

During each visit, Water Working group members had opportunities to interact with the speaker to discuss emerging issues and trends in research and education. These interactions have assisted in proposal development and will hopefully lead to future collaborations.

In addition, members of the working groups worked on two IGERT proposals during the reporting period:

- **IGERT: Understanding Manufactured Nanomaterials in the Environment through Research and Science Education**.
- **IGERT: Sensing, Modeling and Policy for Water Sustainability.** The water sensing IGERT was invited to the full proposal stage. In addition, working group faculty collaborated on proposals to the NSF Cyber-Enabled Discovery and Innovation (CDI) program. Further, several faculty contributed summer workshop ideas for a feasibility study evaluating the viability of the University hosting summer workshops for high school students interested in water and the environment.

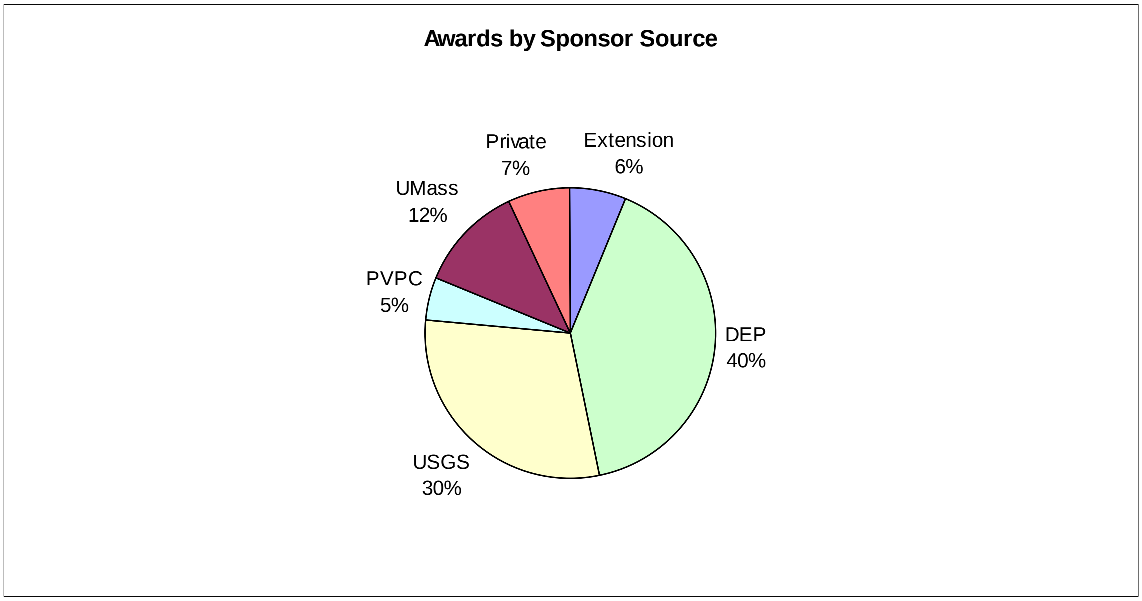
Financial Overview

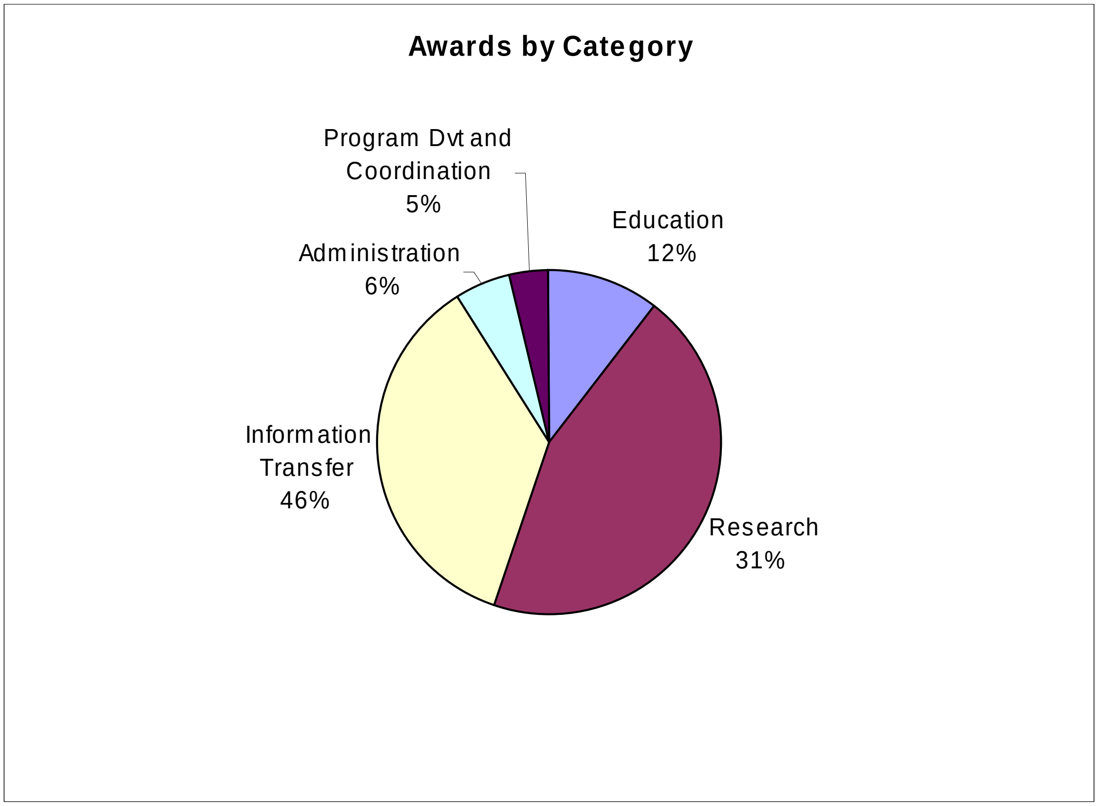
Center revenues come strictly from grants and contracts. The University of Massachusetts contributes 40% of the salary for a half-time Director and also provides physical facilities for the WRRC.

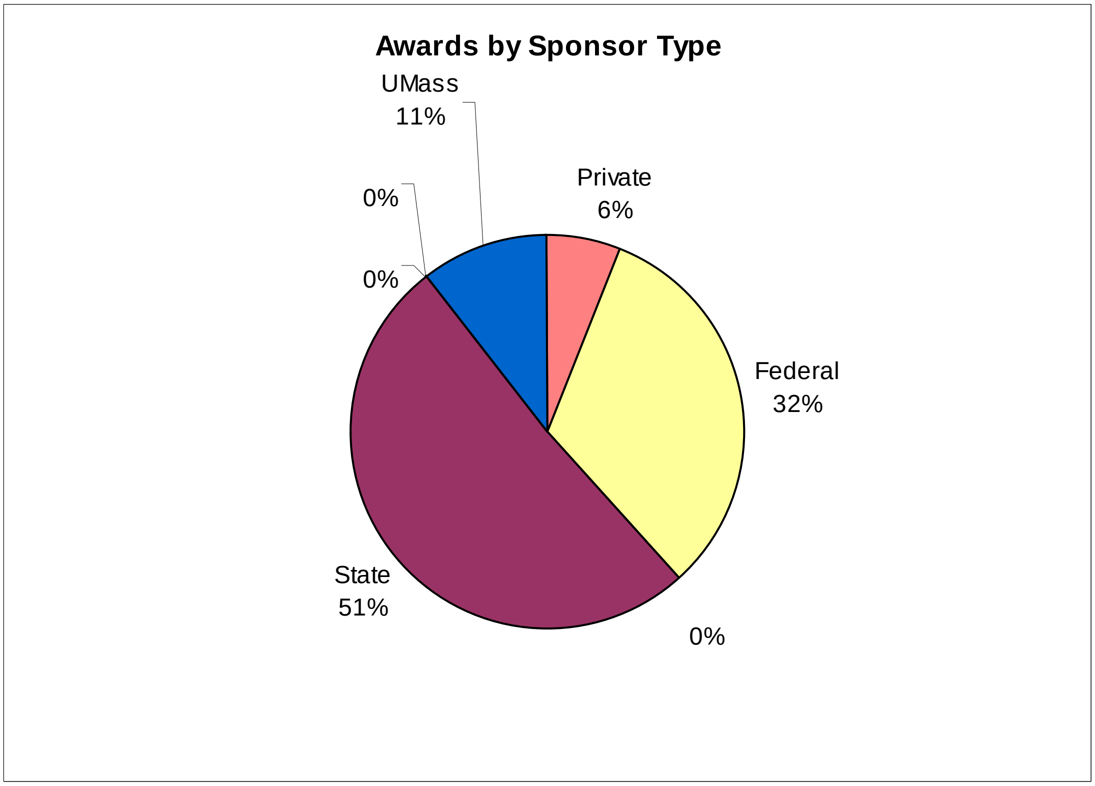
Total revenues amounted to $338,668:

USGS 104B:	$92,336 broken down as follows:
	$25,000 Xing research project
	$5,000 Zhang research project
	$5,000 Douglas research project
	$4,979 Park research project
	$5,000 Vogel research project
	$6,000 EAL
	$17,693 Administration
	$23,664 Conference

Extension (MassWWP)	$20,000 Extension-WRRC MOU
DEP (Stormwater Project)	$58,235
DEP (Acid Rain Project)	$50,000
Acad Tech	$11.500
PCSWMM	$15,450
CT River Tri-State Initiative	$13,981
Blackstone River	$40,171
UMass (Director)	$25,340
Conference Revenues	$11,620
Lab	$10,000




Awards by Category
Program Dvt and Coordination 5%
Education 12%
Administration 6%
Information Transfer 46%
Research 31%


Awards by Sponsor Type
UMass 11%
Private 6%
0%
0%
Federal 32%
State 51%
0%