Water Resources Center
Annual Technical Report
FY 2012

Introduction

Delaware Water Resources Center

June 1, 2013

The Delaware Water Resources Center receives an annual Federal matching grant as authorized by section 104 of the Water Resources Research Act of 1984 (Public Law 98-242) as amended by Public Law 101-397, Public Law 104-147, and Public Law 106-374. The U.S. Geological Survey (USGS), Department of the Interior, administers the provisions of the Act. This annual evaluation report describes, in the format prescribed by the USGS, the research, training, and information transfer activities supported by the section 104 grants and required matching funds during fiscal year 2012.

Understanding the nature of the water quality and water supply problems faced in Delaware, historically and today, requires knowledge of the physiographic nature of the state, its climate, and major land uses. Geologically, Delaware is comprised of the Piedmont and Atlantic Coastal Plain Provinces. Only the northernmost 6% of the state is within the Piedmont, a region created of very old igneous and metamorphic rock. Soils range from well-drained, highly productive silt loams in the Piedmont to well– and excessively well-drained sandy loams and loamy sands in the Coastal Plain. Significant areas of poorly drained soils are also present, particularly in southeastern Delaware. Erosion and surface runoff are the main concerns in the Piedmont, while leaching of contaminants to shallow ground waters is the main water quality problem in the Coastal Plain. Average annual rainfall is plentiful (45 inches/year) and rather constant, averaging 3 to 4 inches/month in winter and spring and 4 to 5 inches/month in summer. Precipitation typically exceeds evapotranspiration by 12 to 18 inches/year, providing 10 to 12 inches/year of ground water infiltration.

Surface water is the main water supply source in the Piedmont, although the Cockeysville Formation is an important local aquifer of fractured marble and dolomite. This province is dominated by the Christina River Basin, fed by rivers that first flow extensively through Pennsylvania and Maryland. Water quality of the White Clay and Red Clay Creeks and Brandywine River is strongly affected by land use and point sources of pollution in neighboring states. Those rivers flow into the Christina River which, in turn, flows into the Delaware River.

Ground water is the major water supply source for the Atlantic Coastal Plain, a province of southeastwardly thickening unconsolidated and semi-consolidated sediments over crystalline basement rock. A primary aquifer in this province for water supply, stream base flow, and confined aquifer recharge is the unconfined Columbia aquifer. In a southwardly expanding wedge, the western portion of this area flows to the Chesapeake Bay through headwaters of the rivers and creeks of the Delmarva Peninsula's eastern shore. The mideast section of the province flows to the Delaware Estuary, fed by the watersheds of 15 creek and river systems. The southwest portion of the state flows into the Inland Bays of Delaware and Maryland and the Atlantic Ocean.

According to the Delaware Office of State Planning Coordination's 2007 Land Use/Land Cover data set, the major land use in Delaware is agriculture (526,070 acres; 41% of the 1.28 million acres in the state), which is dominated by a large, geographically concentrated poultry industry. Other main land uses are urban (19%), wetlands (19%), forests (15%), open water (4%), and barren land (1%). Delaware has 2509 miles of streams and rivers, 2954 acres of lakes/reservoirs/ponds, 841 square miles of estuarine waters, and 25 miles of ocean coastline. Approximately three-quarters of the state's wetlands are freshwater, and one-fourth is tidal.

Protection of the quality and quantity of the state's surface waters and aquifers is a major concern to all agencies and individuals responsible for water resource management in Delaware. Ground water protection is particularly important given the increasing reliance on this resource for drinking water. In general, the key priority water resource issues today are (not prioritized): (1) enhanced management and control of stormwater runoff, erosion and sediment; (2) improved understanding of sources, transport, fate, and remediation of toxic organics and trace elements; (3) comprehensive management of agricultural nutrients and sediment; (4) identifying sources of pathogenic organisms and preventing human health impacts; (5) increased understanding of the response of aquatic systems to pollutants; (6) identification and protection of wellheads and aquifer recharge areas; (7) better management of water supply and demand and development of a systematic means to deal with droughts and floods; (8) treatment and disposal of on-site sewage; (9) protection and restoration of wetlands; (10) prevention of saltwater intrusion to potable water supplies; and (11) protection of functioning riparian areas.

The Water Resource Problems of Delaware

Surface Water Quality

Point Sources: Delaware has a number of serious, documented surface water quality problems. Many can be traced back to point source pollution problems in past decades; others reflect ongoing anthropogenic activities that degrade surface water quality. Water quality is a major state environmental priority and improvements have occurred, particularly since the 1970s, due to the use of state and federal regulatory and funding means to address "end-of-pipe" point sources of surface water pollution. Much of this improvement was due to aggressive use of federal funding, available in the late 1970s and early 1980s under the Clean Water Act, combined with local funding, to expand and improve municipal wastewater treatment systems.

The National Pollution Discharge and Elimination System (NPDES) Program in Delaware has reduced the number of individual "point source" permits to discharge wastewater from over 200 in the 1970s to 65 as of 2012. Of those, seven are all or almost all stormwater. NPDES permitting programs have been expanded to address pollution in stormwater runoff from concentrated animal feeding operations ("CAFOs," 350 permittees), construction (2250 permittees as of May 2013), and ongoing industrial activities (378 permittees). Current initiatives include implementation of "Total Maximum Daily Load" (TMDL) requirements, in a long term multi-state effort to reduce PCBs in the Delaware River, and implementation of "Best Available Technology" for cooling water intake structures which draw in tens and hundreds of millions of gallons per day of water from Delaware waters. Major reductions in oxygen demanding materials and toxics in surface waters have been achieved. Future investments in water quality will likely weigh the cost-effectiveness of further reducing point source pollution, versus non-point sources of water quality problems. Currently, the Federal American Recovery and Reinvestment Act and the State Clean Water Revolving Fund are providing funds for infrastructure to reduce point source pollution and other pollution sources.

The major surface water quality problems in Delaware include:

Urbanization: A rapidly expanding urban population is increasing pressures on Delaware's surface waters. Rivers and streams are being affected by elevated temperature and low dissolved oxygen levels that can result from degradation of streambanks and stream channels. In residential and urban areas, increases in impervious surface have resulted in greater and flashier stormwater runoff, leading, in turn, to erosion, sedimentation, shallower water levels and destabilization of stream channels. Biological and habitat quality are also being affected by removal of stream buffers and stream bank "hardening" through use of riprap and concrete.

Drainage: Extensive drainage systems have been installed throughout the state, especially in coastal plain areas. Most were constructed in the 1930s and 1940s by the Civilian Conservation Corps and the Works Progress Administration. At that time, building a drainage ditch system involved channelizing and straightening headwaters of existing natural streams, then constructing ditches out and back from the channelized stream. Upland wetlands were often drained to reduce mosquito populations. A state "tax ditch program" is re-constructing ditches and in doing so wetlands are protected or augmented and management practices are used to minimize impacts to habitat. The effects on the biological and habitat quality of the waterway once it is stabilized are just starting to be known. Another trend today is the proliferation of public ditch projects instead of tax ditches. Public funding makes the choice by landowners to tax themselves for reconstruction and maintenance of ditches less compelling. Public ditch projects are typically smaller (a few hundred feet) in scope and take place in the upper reaches of streams (typical bottom width is 3 feet) to augment mostly residential and some agricultural drainage. These projects are often carried out by the Conservation Districts. Little is currently known about the impacts to water quality or ecology from such projects. This lack of information may be important since protection of small headwater streams is critical to watershed health. Few streams in Delaware are unaffected by current or historic drainage projects that modify watershed drainage, natural stream channel configuration, buffers, and nutrient transport.

Nutrients: Nutrients are a leading cause of water quality degradation in Delaware. Nutrient effects can be seen especially in lakes, ponds, bays, and estuaries that receive nutrients conveyed by rivers, streams, and ground water. According to the State of Delaware’s April 1, 2010 combined 305(b) and 303(d) report, Delaware waters are generally considered to suffer from eutrophication and low dissolved oxygen related to nutrient enrichment. Primary land-based sources of nutrients in Delaware are agricultural practices, septic systems, and urban runoff. About 41% of Delaware’s land area is devoted to agricultural activities and 19% to urbanized uses. Delaware’s agricultural industry has a strong broiler industry component that heavily influences the state’s overall agricultural nutrient balance and has long created nutrient management problems because of the large amount of manure that must be land applied; commercial inorganic fertilizers used by farmers, other land managers and homeowners also contribute nutrients to ground and surface waters. About 70% of Delaware’s cash farm income comes from broilers, with annual production ranging from 260 to 280 million broilers, primarily in Sussex County, the largest broiler producing county in the U.S.

Other Problems: Toxics have affected Delaware waters resulting in fish consumption advisories for the Delaware River and Bay, Atlantic coastal waters including the Inland Bays, and twenty smaller waterbodies in 2009. The primary pollutant is polychlorinated biphenyl (PCB). Chlorinated pesticides, dioxins, and mercury have also been identified. Though PCBs have long been banned, they are persistent in the environment and are transported from land to waters through runoff. Once in runoff, PCBs settle in waterbody sediments where they enter the aquatic food chain. Another problem is pathogenic organisms. New designated uses and surface water quality standards as amended on July 11, 2004 indicate that pathogenic organisms in surface waters have negatively affected shellfish harvesting and caused 86% of Delaware’s rivers and streams to not fully support the swimming use; 98% do not fully support the fish and wildlife use. Most waters do not meet standards because of nonpoint source pollution impacts.

Ground Water Quality

The domestic needs of approximately two-thirds of the State’s population are met with ground water provided by both public and private wells. Most of the water used for agriculture, Delaware’s largest industry, and self-supplied industrial use, is also derived from ground water sources. A shallow water table and highly permeable soils make Delaware’s ground water vulnerable to pollution. Shallow unconfined aquifers are especially vulnerable, though deeper confined aquifers are susceptible as well because they subcrop beneath and are recharged by unconfined aquifers.

Major ground water quality problems in Delaware today are:

Nutrients: Nitrates from agriculture and septic systems are, by far, the major contaminant in Delaware’s ground water. There are also some concerns about dissolved phosphorus transport to surface waters by shallow ground water flow in parts of the state where shallow water tables are interconnected with surface waters by ditches and/or tiles.

Organics: Hydrocarbons have also been found as have pesticides, though not at levels which cause alarm. A major source of hydrocarbons, such as MBTE, is leaking underground storage tanks (USTs) while agricultural activities are the source of pesticides. There are 12,050 regulated underground storage tanks in the State; 9651 have been properly abandoned and 2399 are still in use. Since the 1980s 314,040 releases to ground water have been confirmed and 2800 of those (USTs) have been closed. Over the period 2002-2003, 142 sites had confirmed releases with 30 confirmed ground water releases.

Saltwater Intrusion: Problems with private wells occur sporadically from seasonal saltwater intrusion along the Delaware River and the Inland Bays/Atlantic Ocean coastal areas. No major problems have occurred and only one public well in Lewes required abandonment. Saltwater intrusion will become a recurring issue as sea level rises.

Trace Elements: Though not considered a health threat, iron concentrations are a widespread problem in Delaware for cosmetic reasons. Many public water supplies have treatment systems to remove iron. Thirty-four percent of 561 raw ground water samples analyzed by Delaware's Office of Drinking Water in 2002 exceeded the secondary contaminant level standard of 0.3 mg/L. Concerns exist about arsenic in ground waters because of the long-term application of this element in poultry manure to soils overlying shallow drinking water aquifers, the presence of brownfield soils in urban areas that had been used as tanneries or other industries, and the lowered drinking water standard for arsenic.

Wetlands Quality: Studies of nontidal wetlands in the St. Jones and Murderkill watersheds have recently been conducted. Beyond assessment of trends, primarily rate of loss, overall condition of wetlands and identification of major stressors affecting wetland function were recorded. These reports are found at: http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/Wetland-Monitoring-and-Assessment.aspx.

Water Supply: Half of Delaware's population is located in the Piedmont (6% of land area) and uses surface water for drinking water. The other 50% of the population relies on ground water and is spread throughout the remaining 94% of the State. With regard to the amount of water used, ground and surface water are of equal importance; with regard to area served, ground water is overwhelmingly dominant. Capacity concerns are important north of the Christina River due to population concentration and the reliance on surface water. For the rest of the state, the reliance on abundant ground water and a diffuse pattern of development suggest that the supply of potable water is not currently a problem. Recent drought emergencies have brought water supply demand in northern Delaware into conflict with the need to maintain minimum pass-through flows in streams for protection of aquatic resources. Benthic organisms, the foundation of the aquatic food chain, cannot move to avoid dry stream bed conditions. This suggests that not maintaining pass-through flows at all times would be detrimental to stream aquatic life. Required pass-through flows can be high; the need to ensure those flows can result in practices or structures such as reservoirs that are economically inhibitory or may cause as much or greater environmental degradation as occasional dry stream bed periods.

Recent Initiatives Promoting Delaware Water Quality

Water quality standards for surface waters in Delaware, revised and adopted effective July 11, 2004 by the Delaware Department of Natural Resources and Environmental Control (DNREC), include amendments to protect swimmers by making bacteria standards consistent with U.S. Environmental Protection Agency guidance and 2000 federal Beaches Environmental Assessment and Coastal Health (BEACH) Act requirements.

To ensure that Delaware waters meet state, regional, and national water quality requirements and goals, the State has one of the most extensive water quality monitoring networks in the nation. Our water resources in this State are regularly tested for biological and chemical parameters. The results are reported in even years in the State's Watershed Assessment Report (305(b) report). Waters that do not meet water quality standards are listed in the State's 303(d) list. Both of these reports are available at: http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessment305band303dReports.aspx. The extensive water quality data have allowed tracking of long term progress made towards improving Delaware's water resources.

Delaware's non-attainment of Clean Water Act standards as described in the 1996 303(d) list was addressed by a federal court order requiring the development of total maximum daily load (TMDL) regulations for nearly the entire state, according to a schedule that concluded in 2010 for nutrients and bacteria. TMDLs establish the maximum amount of pollutants a water body can receive daily without violating water quality standards, allowing the use of these waters for swimming, fishing, and drinking water supplies. TMDLs have been established for nutrients, bacteria, PCBs, and toxics. TMDL analysis documents and regulations can be found at: http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedAssessmentTMDLs.aspx.

Additional programs are in place to ensure continued compliance with the court order and to achieve water quality standards. Now that TMDLs are in place, Pollution Control Strategies (PCSs) are being developed to address how, where and when pollutant loads will be reduced to achieve TMDL levels. The PCSs generally offer voluntary and regulatory strategies for urban, suburban and agricultural land uses and are developed through a public process where recommendations are made by Tributary Action Teams (TATs), groups of stakeholders formed with the purpose of addressing water quality concerns.

The PCSs for the Appoquinimink, Broadkill, Christina, Murderkill, Nanticoke, St. Jones, and Upper Chesapeake (Chester and Choptank) watersheds have been drafted. In the Inland Bays, Nanticoke, Murderkill, and Appoquinimink watersheds, the TAT process and the development of a draft PCS took many years. An expedited process was developed to shorten the PCS development process, which was used in the Christina, St. Jones, Broadkill, and Chester and Choptank watersheds. Drafts of the PCSs for the Mispillion and Cedar Creek watersheds are being circulated within DNREC and are awaiting final approval. To follow progress of the TATs or get more information about them, go to: http://www.dnrec.delaware.gov/swc/wa/Pages/WatershedManagementPlans.aspx

Other DNREC Water Quality Initiatives Include:

Sediment and Stormwater Management Program: The current Delaware Sediment and Stormwater regulations require management of both stormwater quantity and quality of runoff. The first preference in management of runoff water quality is best management practices that promote recharge of stormwater such as Green Technology BMPs. These include filtering practices, and practices that allow for recharge such as filter strips, biofiltration swales, bioretention, and infiltration facilities. The regulations are currently undergoing revisions to address management of stormwater volume, provide for a watershed approach to stormwater management, and strengthen construction site stormwater management requirements. More information on the Delaware Sediment and Stormwater program is available at: http://www.swc.dnrec.delaware.gov/Pages/SedimentStormwater.aspx. More information specifically related to the proposed regulation revisions is found at: http://www.swc.dnrec.delaware.gov/Drainage/Pages/RegRevisions.aspx.

Non-point Source (NPS) Pollution: DNREC continues to reduce non-point source pollution through enhanced coordination of the Division of Watershed Stewardship's Cost Share Programs through the USEPA's NPS Management 319 Program and the National Oceanic and Atmospheric Association's (NOAA) Coastal NPS Management 6217 program along with the Delaware Nutrient Management Commission's (DNMC) program through the Delaware Department of Agriculture (DDA) and other programs. The effort allows DNREC to direct millions of dollars every year toward a comprehensive NPS program to reduce pollutant loads, restore streams and buffers, and install best management practices (BMPs) such as cover crops, nutrient management plans, manure storage structures, manure relocation, and urban best management practices within impaired watersheds. More information on the NPS 319 program is available at: http://www.dnrec.delaware.gov/swc/district/Pages/NPS.aspx and information on Delaware's Coastal Management Program is available at: http://www.dnrec.delaware.gov/coastal/Pages/CoastalMgt.aspx.

Stream and Wetland Restoration: Rehabilitating stream corridors by reestablishing natural floodplains and sinuous low-flow channels, stabilizing stream banks, decreasing erosion, improving biological water quality, increasing wildlife habitat, providing buffers along the streams, establishing wetlands, promoting ground water recharge and water storage, controlling invasive plant species and reintroducing native species, trapping and uptake of nutrients are examples of the benefits that result from projects DNREC has implemented to improve the ecological quality and biological diversity in the State's watersheds. Several stream restoration projects completed in northern New Castle County within the past several years along Pike Creek include the Independence School (stream and wetlands), Meadowdale, Three Little Bakers Golf Course (stream and wetlands) as well as Delaware Park along Mill Creek. Wetland restoration projects that feature stormwater being filtered through a wetland before entering a stormwater basin were implemented at Christ the Teacher Catholic School, and the Hindu Temple.

Onsite Wastewater Treatment Systems (Septics): Delaware's "Regulations Governing the Design, Installation and Operation of On-Site Wastewater Treatment and Disposal Systems" were amended in 2002 and 2005 and are currently being revised again; the promulgation of the revised regulations will likely be in the third quarter of 2013. Legislation was also passed creating a Class H Licensed System Inspector Program which was part of the amended 2005 regulations. Other highlights of the amendments included advance treatment for systems greater than 20,000 gpd, use of effluent filters on all septic tanks, risers on all septic tanks, requirements for all licensees to take 10 hours of continuing education training annually, and for all subdivisions greater than 100 lots to use a community/cluster system with advance treatment. Grant funds have been used in the past few years to implement a septic system pumpout and inspection program, and a holding tank inspection and pumpout program in Sussex County. Both programs have been very successful in identifying failing systems and allowing DNREC to provide assistance to system owners in making repairs or replacements as needed. Resources for the septic inspection and pumpout program only lasted two years as it was a pilot program. However, the holding tank inspection and pumpout program is still operating and has moved statewide with an annual 98% compliance rate. DNREC has also worked with the wastewater community to develop performance standards for nitrogen and phosphorus of onsite wastewater systems which should be incorporated in the revisions to the statewide regulations in the near future. In 2008 the "Regulations Governing the Pollution Control Strategy for the Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay Watershed" were adopted and in these regulations the performance standards for nitrogen and phosphorus of on-site wastewater systems were adopted as well as the requirement for inspection of septic systems prior to the sale of properties that utilizes septic systems. To view these regulations, go to: http://www.wr.dnrec.delaware.gov/Services/Pages/GroundWaterDischarges.aspx.

Source Water Assessment and Protection: The DNREC Source Water Assessment and Protection Program (SWAPP) provides for the assessment and protection of sources of public drinking water, both surface and ground water. The assessment consists of three critical steps: first, delineation of source water areas; second, identification of existing and potential sources of contamination; and finally, assessment of the susceptibility of the source water area to contamination. The Site Index Database identifies the location and status of both existing and potential sources of contamination within the State. Most potential point sources have been mapped and rated. In 2004, the Source Water Protection Program developed a guidance manual for local governments. This document was updated in 2005. For more information on source water protection, go to: http://www.wr.udel.edu/swaphome/index.html. Delaware SWAPP is a cooperative effort between DNREC, Delaware Division of Public Health, and the University of Delaware's Water Resources Agency. A citizen's advisory group (CTAC) was formed to assist DNREC in the development and implementation of the program and to ensure public involvement. SWAPP is a multi-phase program that is expected to be completed in the next few years.

Cooperative Efforts: Cooperation among DNREC, residents, other agencies-state and federal, universities, county and municipal governments, conservation districts, and non-governmental organizations (NGOs) helps bring Delaware water goals to fruition. Pollution Control Strategy development and implementation of TMDL regulations is driven by Tributary Action Teams (TATs). The Center for the Inland Bays, University of Delaware Cooperative Extension, the Sea Grant Program at the University of Delaware College of Earth, Ocean, and Environment, University of Delaware Water Resources Agency, Delaware State Cooperative Extension, the Camden-Wyoming Rotary Club, the State of Delaware's Nutrient Management Commission, New Castle, Kent and Sussex County governments, Sierra Club, the county conservation districts, USDA, other DNREC divisions and many others have been vital contributors in the development of PCSs and TATs.

All of the projects implemented in TMDL watersheds to address water quality concerns require a cooperative effort and partnerships to be formed, not just in government interactions, but between members of TATs and the public as well. Finding a solution for cleaner water will require more innovative solutions, greater regulatory control, additional financial resources, and a willingness to make a change by everyone affecting Delaware's watersheds, as we are all part of the problem and we must work together to find a reasonable solution for everyone.

Delaware Water Resources Center: An Overview

The Delaware Water Resources Center (DWRC) has been a part of the University of Delaware since 1965. From 1965 until 1993 the DWRC was located in the University of Delaware's Research Office. In 1993, the DWRC was formally moved to the College of Agriculture and Natural Resources (CANR) where, since 1997, Dr. Tom Sims, Deputy Dean for Academic Programs and Research, has served as DWRC Director. The DWRC works with all organizations and agencies in Delaware with an interest or responsibility in water resources. We have a 12- to 15-member Advisory Panel representing a wide variety of water resource backgrounds. We regularly cooperate with the Delaware Water Resources Agency, Delaware Geological Survey, Delaware Department of Natural Resources and Environmental Control, the Center for the Inland Bays, the Delaware Nutrient Management Commission, Delaware State University, USDA Natural Resources Conservation Service, Delaware Nature Society, and The Nature Conservancy, to name but a few. The DWRC has always supported a wide range of water resource related research, education, and information transfer programs. We cooperate with many academic departments and units that conduct water-related research at Delaware State University's Department of Agriculture and Natural Resources and the University of Delaware (UD), including the UD Water Resources Agency in the Institute for Public Administration, the UD Departments of Biological Sciences, Chemistry, Civil and Environmental Engineering, Geography, Geological Sciences, and Plant and Soil Sciences, as well as the UD Colleges of Agriculture and Natural Resources; Arts and Sciences; Engineering; and Earth, Ocean, and Environment. Close communication is maintained between the DWRC and state natural resource agency representatives and water officials to address priority water quality and water quantity concerns in the state. Through efforts such as these, the DWRC has provided key stakeholders a forum for discussion and an opportunity for education regarding water resources.

Section 104 Objectives

The DWRC has defined a three-fold mission to meet the goals of the Water Resources Research Act:

(1) To support research that will provide solutions to Delaware's priority water problems;

(2) To promote the training and education of future water scientists, engineers, and policymakers; and

(3) To disseminate research results to water managers and the public.

To meet these goals we have focused our efforts into three major areas:

(1) Graduate Fellowship Program: A competitive graduate fellowship program supports graduate fellows on a three-year cycle. Of the graduate fellows supported during the period of this report, one who achieved his M.S. was in the UD College of Agriculture and Natural Resources (CANR), followed by a fellow CANR student starting her Ph.D. and the third is pursuing his Ph.D. in the UD College of Arts and Sciences. Their research focuses on quantifying carbon amount and quality for transport of contaminants in landscapes and microbiome of the eastern oyster.

(2) Undergraduate Internship Program: We initiated a highly successful undergraduate internship program in 2000. In thirteen years, over 107 undergraduate internships were made possible via funding from DWRC/USGS, four Colleges within the University of Delaware (UD), UD's Institute of Soil and Environmental Quality, Delaware Geological Survey, DNREC, and the Department of Agriculture and Natural Resources at Delaware State University. DWRC interns work with faculty to conduct research, prepare a written project report, and present their findings at an annual poster conference.

(3) Information Transfer: The DWRC website and newsletters are sources of up-to-date information on DWRC activities and water-related issues of importance to Delaware and the region. Our website provides information on water resources problems, links to water-related organizations, internship and job opportunities in water resources, a calendar of upcoming events, and a Kids Zone for teachers and parents. We also co-sponsor state-wide conferences on water resource topics of current interest.

Delaware Water Resources Center Program Goals and Priorities

1. Institute Director: Dr. J. Thomas Sims, T.A. Baker Professor of Soil and Environmental Chemistry, Deputy Dean, College of Agriculture and Natural Resources, Director, Delaware Water Resources Center, 113 Townsend Hall, University of Delaware Newark, DE 19716-2103, Phone: 302-831-2698, FAX: 302-831-6758, email: jtsims@udel.edu

2. Administrative Personnel: Maria Pautler, Program Coordinator, Phone: 302-831-0847, FAX: 302-831-0605, email: mpautler@udel.edu

3. Abstract of Program and Management Overview: The Delaware Water Resources Center (DWRC) research, education and information transfer programs focus on issues of state and regional importance to both water quality and water quantity. Long-term priority areas of the DWRC have included nonpoint source pollution of ground and surface waters, development of ground water supplies, the impact of hydrologic extremes on water supply, and socio-economic factors affecting water supply and water quality. In 2000, the DWRC Advisory Panel identified five specific areas for near-term DWRC research efforts: (1) Agricultural nutrient management and water quality; (2) Basic and applied research on sources, fate, and transport of water pollutants; (3) Quantifying response of aquatic ecosystems to pollutant inputs; (4) Water supply, demand, and conservation, as affected by changing land uses in Delaware and the mid-Atlantic states; and (5) Management and control of stormwater runoff. The FY12 DWRC public water conservation/educational outreach program addressed these issues. DWRC’s research program during the same period addressed these concerns by supporting graduate fellowships in water quality, an undergraduate student internship program, and public information forums including an intern research poster session.

2012-2013 DWRC Fellowship and Internship Research Program

Two fellowships were funded for the second year in 2012-2013 based on satisfactory progress reporting to the DWRC Advisory Panel:

a) Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed Scale Model

Graduate Fellow: Gurbir Dhillon followed by Zhixuan Qin; Advisor: Shreeram Inamdar, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

b) Microbiome of the Eastern Oyster, *Crassostrea virginica*

Graduate Fellow: Eric Sakowski; Advisor: K. Eric Wommack, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

Seven internships were awarded for 2012-2013 based on a review of proposals submitted by potential undergraduate interns and their advisors to the DWRC Advisory Panel:

a) Developing Scientifically-Based Food Safety Metrics for Water Management and Irrigation Methods

Undergraduate Intern: Lindsey Cook; Advisor: Kalmia Kniel, Department of Animal and Food Sciences, College of Agriculture and Natural Resources, University of Delaware.

b) Characterization of Viral Diversity within the Mantel Fluid of the Eastern Oyster, *Crassostrea virginica*

Undergraduate Intern: Julia Hagemeyer; Advisor: K. Eric Wommack, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

c) Water Quality Impacts of Landscape Best Management Practices That Enhance Vegetation

Undergraduate Intern: Kayla Iuliano; Advisor: Shreeram Inamdar, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

d) Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip Irrigation

Undergraduate Intern: Daniel Kardashian; Advisors: J. Thomas Sims, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware and James Adkins, Carvel Research and Education Center, University of Delaware.

e) The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed

Undergraduate Intern: Tyler Monteith; Advisor: Joshua Duke, Department of Applied Economics and Statistics, College of Agriculture and Natural Resources, University of Delaware.

f) Water Quality Management in Urban Ecosystems

Undergraduate Intern: Timothy Schofield; Advisors: Susan Barton and Jules Bruck, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

g) Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron

Undergraduate Intern: Wendi Xu; Advisor: Pei Chiu, Department of Civil and Environmental Engineering, College of Engineering, University of Delaware.

Research Program Introduction

None.

Microbiome of the Eastern Oyster, Crassastrea virginica

Basic Information

Title:	Microbiome of the Eastern Oyster, Crassastrea virginica
Project Number:	2010DE171B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Not Applicable
Focus Category:	Ecology, Non Point Pollution, Conservation
Descriptors:	None
Principal Investigators:	Eric Wommack

Publications

1. Sakowski, E. and E. Wommack, 2011, Exploring the Commercial Microbial Communities of the Eastern Oyster, <i>Crassostrea virginica<i> Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 16 pages.
2. Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 7.
3. Sakowski, E. and E. Wommack, 2012, Exploring the Commensal Microbial Communities of the Eastern Oyster, Crassostrea virginica. Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 16 pages.
4. Sakowski, E. and K.E. Wommack, 2013, Exploring the Commercial Microbial Communities of the Eastern Oyster, Crassostrea virginica. Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 16 pages.
5. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 5.

Project Title: Exploring the commensal microbial communities of the Eastern Oyster, *Crassostrea virginica*

Investigators: Eric Sakowski, Dr. K. Eric Wommack

<u>Background/ Justification</u>

The American Eastern oyster, *Crassostrea virginica*, plays a vital ecological and economic role throughout its home range. Naturally occurring from the Gulf of St. Lawrence in Canada to the coast of Brazil (Comeau, Pernet et al. 2008), *C. virginica* forms oyster reefs that act as erosional breaks within estuaries and provide protection from predators for many invertebrates and small fish. In addition, *C. virginica* reduces turbidity and improves water quality as it filters water to feed. These oysters are capable of filtering water at a high rate – up to 6.8L h^{-1} (Riisgard 1988) – for a few hours at a time. It is estimated that in colonial times, oysters filtered the entire volume of the Chesapeake Bay (68 trillion liters) in as little as three days. Today, the process takes over a year as the population of oysters in the region has dropped to one percent of historical values.

The decimation of *C. virginica* populations began in the late 19th century as a result of over-harvesting and habitat degradation (Rotschild, Ault et al. 1994). Since the 1950s, two protozoan diseases introduced to the area, *Haplosporidium nelsoni* (the causative agent of the disease MSX) and *Perkinsus marinus* (which causes Dermo), have resulted in oyster mortality and further population decline (Ewart and Ford 1993). Despite these difficulties, the oyster industry remains an important fishery, with an estimated value of over $100 million annually (NOAA NMFS, 2004).

Thus, the study of oyster health and susceptibility to disease is of ecological and economic concern. Understandably, the majority of research regarding oyster microbiology has focused on MSX and Dermo (reviewed in Lafferty, Porter et al. 2004), as well as human pathogens associated with raw shellfish consumption. One area of interest that remains largely unexplored, however, is the impact of commensal microbial communities on oyster ecology and health. Studies of microbial-metazoan relationships in other organisms have demonstrated that commensal microbial communities can influence efficiency of energy extraction from food and may help regulate body weight (Turnbaugh, Ley et al. 2006). Commensal microbial diversity has also been inversely correlated with pathogen colonization in both chickens (Nisbet 2002) and humans (Klepac-Ceraj, Lemon et al. 2010).

Studies of sessile marine invertebrates have shown commensal microbial composition to be host specific, differ from surrounding water and play a role in regulating various metabolic and biogeochemical processes (Raina, Tapiolas et al. 2009; Pfister, Meyer et al. 2010). However, many oyster-related microbial studies have examined the presence/absence of pathogenic bacteria (Lee, Panicker et al. 2003) or phages infecting those bacteria (DePaola, Motes et al. 1998), while knowledge of microbial community structure, dynamics, and impacts on oyster health remain limited. One of the major hurdles to such investigations has been the inability to cultivate >99% of environmental bacteria and viruses (Kennedy, Flemer et al. 2010). The decreasing cost of high-throughput sequencing has now made it feasible to examine microbial communities at a high resolution across many samples. This project seeks to utilize next-generation sequencing technology to examine oyster-associated commensal microbial community structure and dynamics over time and between healthy and diseased individuals.

Objectives

This project seeks to:

1.) Determine the abundance of bacteria and viruses in oyster extrapallial fluid and water over time
2.) Identify commensal bacterial diversity within extrapallial fluid and surrounding water using molecular-based approaches
3.) Identify viral diversity within extrapallial fluid and surrounding water using molecular-based approaches
4.) Examine the influence of local geography on variation in microbial communities
5.) Observe differences in the commensal microbial communities of healthy and MSX or Dermo-infected oysters

Methodology

Annual survey sample collection. Five oysters were harvested each month beginning in October 2010 from the Smithsonian Environmental Research Center (SERC) in Edgewater, MD and transported 20 minutes to Annapolis, MD for processing. Each oyster was rinsed with DI and scrubbed with 70 percent ethanol prior to mantle fluid extraction. A hole was drilled into the posterior end of the oyster at the interface between valves. Mantle fluid was extracted using a 5mL syringe. Samples were placed on ice and transported back to Newark, DE for further processing. A 10L water sample was collected at the same site and time as the oysters. The sample was placed in a cooler filled with water from the site to maintain temperature for transport back to Newark, DE.

Local geography variation collection. Ten oysters and two 10L water samples were collected at four oyster bars located within 3 miles of one another on the Choptank River, a tributary of the Chesapeake Bay (Figure 6). Oyster samples were obtained by dredging. Water samples were obtained by deploying a niskin bottle ~1m above the reef. Oysters were kept on ice prior to processing. Water samples were processed on site.

Disease survey. Ten oysters and a 10L water sample were collected from 4 Maryland Department of Natural Resources disease-monitoring stations in the Chesapeake Bay during October 2011 and 2012 (Figure 8). Two of the chosen sites have historically high levels of Dermo infection, while two have low levels. Oyster and water samples were processed on site. Oyster tissues were tested for the presence of MSX and Dermo by histologist Carol McCollough of MD DNR.

Bacterial and viral counts. A 200μL aliquot of each oyster sample was combined with 37% formalin to a final concentration of 1%, snap-frozen in liquid nitrogen, and stored at -80°C to be used for bacterial and viral counts. Likewise, 4.5mL of the sample water was combined with 37% formalin and frozen for counts. Samples were thawed on ice and combined with 0.22μm-filtered 1x PBS in the following ratios: 10µL extrapallial fluid in 990µL PBS for oyster samples; 70µL water in 930µL PBS for water samples. The solutions were rocked at 30°C for twenty minutes and then vacuum filtered onto a Whatman 0.02µm, 13mm Anodisc filter. Filters were stained with 400µL of 2.5x SYBR Gold in the dark for fifteen minutes prior to being mounted onto slides. Slides were placed at -20°C until viewing.

Bacteria and viruses were visualized using epifluorescence microscopy with a 40X oil-immersion objective. Pictures were taken at 15 randomly-selected sites on each filter. Viruses were counted using the iVision software. Bacteria were counted manually. Bacterial and viral abundances were calculated based on the following equation: $Vt = Vc \div Fc \times At \div Af \div S$, where Vt = viral abundance mL^{-1}, Vc = total number of viruses counted, Fc = total number of fields counted, At = surface area of the filter (μm^2), Af = area of each field (μm^2), and S = volume of sample filtered (mL) (Suttle and Fuhrman 2010).

Bacterial DNA isolation. Oyster samples were combined with 1x PBS buffer at a 1:25 ratio and rocked for 1 hour at 30°C. Samples were then filtered through a Millipore Sterivex 0.22µm filter unit. Approximately 500mL of water was pumped through a Millipore Sterivex 0.22µm filter.

DNA was extracted from each of the filters as follows: 10µL of proteinase-K (20mg/mL) and 20µL of lysozyme (100mg/mL) were combined with 1mL of DNA Extraction Buffer (DEB; 100 mM Tris buffer (pH 8), 100 mM NaEDTA (pH 8), 100mM phosphate buffer (pH 8), 1.5 M NaCl, 1% CTAB) and added to the filter. Filters were incubated at 37°C for 30 minutes and the samples transferred to 2.0mL microcentrifuge tubes. Samples were frozen at -80°C for 15 minutes and thawed at 37°C for 5 minutes three times, followed by incubation in a 37°C water bath for 30 minutes. 100µL of 10% SDS was then added and the sample incubated for 2 hours in a 65°C water bath. The microcentrifuge tubes were then filled to the top with phenol:chloroform:isoamyl alcohol(25:24:1) and centrifuged at 3000rpm for 5 minutes at 4°C. The top layer was transferred to a new microcentrifuge tube and the phenol:chloroform:isoamyl alcohol step repeated. The top layer was transferred to a new tube and combined with 0.6 volumes of room temperature 100% isopropanol. Samples were incubated at room temperature overnight and then centrifuged at 13,000rpm for 30 minutes. The isopropanol and buffer were removed and 1mL of 70% ethanol added. Samples were centrifuged at 13,000rpm for 10 minutes. The ethanol was removed, followed by a second addition of ethanol and centrifugation. The pellet was then allowed to dry and resuspended in 1x TE buffer. Pellets were allowed to dissolve for one hour at 4°C and then stored at -80°C.

16S amplification, barcoding, and sequencing. Forward primer 27F and reverse primer 334R with a unique barcode were used to amplify ~300bp sections of the 16S rRNA gene from 3 oyster and 2 water samples each month. Primers were obtained from the Institute for Genome Sciences. PCR amplification of samples was performed using the following conditions: 95°C for 5 minutes; 33 cycles of 95°C for 30 seconds, 52°C for 30 seconds, 72°C for one minute; 72°C for 7 minutes. PCR reactions were run on a 1.8% agarose gel. Bands were excised using the Qiaquick Gel Extraction kit. Samples were sent to IGS and sequenced using the Roche 454

Genome Sequencer FLX Titanium system. Operational taxonomic unit (OTU) analysis was performed using the Quantitative Insights into Microbial Ecology (QIIME) software (Caporaso et al. 2010).

Results and Discussion

Viral and bacterial abundance. Viral and bacterial abundance were measured from 5 oysters and one 10L water sample once per month. Samples were collected monthly from October 2010 to September 2011 at the Smithsonian Environmental Research Center (SERC). Viral and bacterial abundance were variable from month to month in both oyster and water samples (Fig. 1,2). Viral abundance was more stable in oyster extrapallial fluid samples during the year than in the water samples, where a decrease during the autumn and winter months was observed (Fig. 1B,C). Over the course of the study, viral abundance in oyster extrapallial fluid was significantly greater than the water (Fig. 1). This agrees with previous observations that viral retention times in oysters can be on the order of weeks (Acton, 1968). Bacterial abundance was also significantly greater in oyster extrapallial fluid over the course of the annual study (Fig. 2A), though both oyster and water samples showed similar seasonal fluctuations (Fig. 2B,C). The increased abundance of viruses and bacteria in oyster extrapallial fluid may be a result of favorable conditions within the oyster microenvironment for promoting bacterial growth.

Bacterial diversity and community composition. Bacterial diversity was determined per library by randomly sub-sampling 584 sequences without replacement to normalize for differences in library size between samples. Bacterial diversity was similar between oyster and water samples when estimated with the Chao1 index and the Shannon index of diversity (Fig. 3). However, Faith's Phylogenetic Diversity (the sum of the branch lengths on a phylogenetic tree for a given sample) was significantly greater in oyster samples (Fig. 3). This suggests that while oyster and water samples contain similar richness and evenness of bacterial operational taxonomic units (OTUs), the oyster samples contain a greater representation of bacterial groups across the bacterial phylogenetic tree. The proportions of observed bacteria within oyster and water samples support this observation. Oyster and water samples displayed differences in proportions of bacterial phyla and classes (Fig. 4). The majority of these taxonomic groups differing between samples were more abundant and evenly distributed in oyster samples (Fig, 4). In contrast, water samples were dominated by a few bacterial groups, namely alphaproteobacteria, flavobacteria, and cyanobacteria (Fig. 4). Combined with the increased bacterial abundance in oyster extrapallial fluid, these results suggest that the oyster microenvironment supports the growth of a wider range of bacteria than the water column.

Oyster and water samples were more similar within treatment groups than between them as determined by UniFrac distance (Fig. 5A). Oyster samples were more similar to other oyster samples than to water samples in an unweighted approach (Fig. 5A), which only takes into account the presence/absence of OTUs; the opposite was observed when samples were weighted (Fig. 5A). This suggests a distinct difference in the community composition and dynamics between these environments. The oyster microenvironment tends to maintain similar bacteria overtime, but the proportions of those bacteria fluctuate. In contrast, a few bacterial groups dominate the water samples, while the rare community members show increased variability. Unweighted oyster and water samples were more similar to other samples from the same month than from different months (Fig. 5B). Both oyster (Fig. 5C) and water (Fig. 5D) samples showed seasonal variability in community composition. Interestingly, differences between months were not observed in either oyster or water samples when using a weighted UniFrac approach (Fig. 5B).

Influence of local biogeography on community composition. Oyster and water samples were taken at four sites along the Choptank River (Fig. 6) in order to examine the impact of local biogeography on community composition. Oyster and water samples were clustered to identify the differences between them. Preliminary results indicate that local biogeography plays little role in the community composition, as similar communities were observed between the different sites (Fig. 7). However, more samples from each site will need to be analyzed before any conclusions can be drawn.

Future Work

DNA has been isolated from the Choptank River samples obtained in June 2011 and are being prepared for sequencing at the present time. Samples obtained from the disease monitoring stations collected in 2011 and 2012 are awaiting DNA isolation. Each sample from the disease monitoring stations will be paired with the health status of the sampled oyster. Libraries of both healthy and infected oysters will be compared within and between sample sites to look for changes in bacterial communities that correlate with disease.

Viral particle isolation and concentration from an individual oyster sample has been optimized. This approach will be used to examine the viral diversity within oyster samples collected during the annual study. In addition, this approach has been modified to concentrate viruses from oysters to create a viral metagenomic library. This summer, sites in the Delaware and Chesapeake Bays will be sampled with the goal of comparing viral metagenomes between oysters at different sites.

Conclusions and Project Implications

This study is a longitudinal examination of the relationship between microbial communities within the extrapallial fluid of *Crassostrea virginica* and surrounding water. Bacterial and viral abundances were greater in oyster samples than the surrounding water. While oyster and water bacterial communities were similarly diverse, they differed both compositionally - several OTUs were identified exclusively in oyster samples – and dynamically. Oysters bacterial communities appear to maintain a stable community, while water bacterial communities showed a greater fluctuation of genera that changed from month to month. Future work will explore the potential impacts of this unique commensal community and provide a greater understanding of how to better protect this keystone species.

Abstract

The Eastern Oyster, *Crassostrea virginica*, is an important economic and ecological resource along the east coast of North America. Since the 1950s, populations within the Chesapeake and Delaware Bays have been subject to outbreaks of MSX and Dermo, two diseases caused by parasitic protozoans. Interest in oyster microbiology has primarily focused on the causative agents of these two diseases, *Haplosporidium nelsoni* and *Perkinsus marinus*, respectively, as well as human pathogens associated with consumption of raw shellfish. Little is known about the commensal microbiome associated with oysters despite an increasing appreciation of the impacts of these communities on the biology and health of their metazoan hosts. In this study, the microbial communities within oyster extrapallial fluid and the surrounding water were compared monthly from October 2010 to September 2011. Bacterial and viral abundances were significantly greater in extrapallial fluid than water for three of the five months ($p < 0.05$). 16S rRNA gene amplification and high-throughput sequencing were leveraged to investigate bacterial community composition. Bacterial diversity was similar between environments when measured with both Shannon and Chao1 indices. However, bacterial community composition was different between extrapallial fluid and water samples, and phylogenetic diversity was greater in oyster extrapallial fluid ($p < 0.05$). Preliminary results indicate oyster-associated bacterial communities are similar across local sites. A better understanding of the unique microbial community commensal with the eastern oyster may provide new direction for improving the fitness of this species.

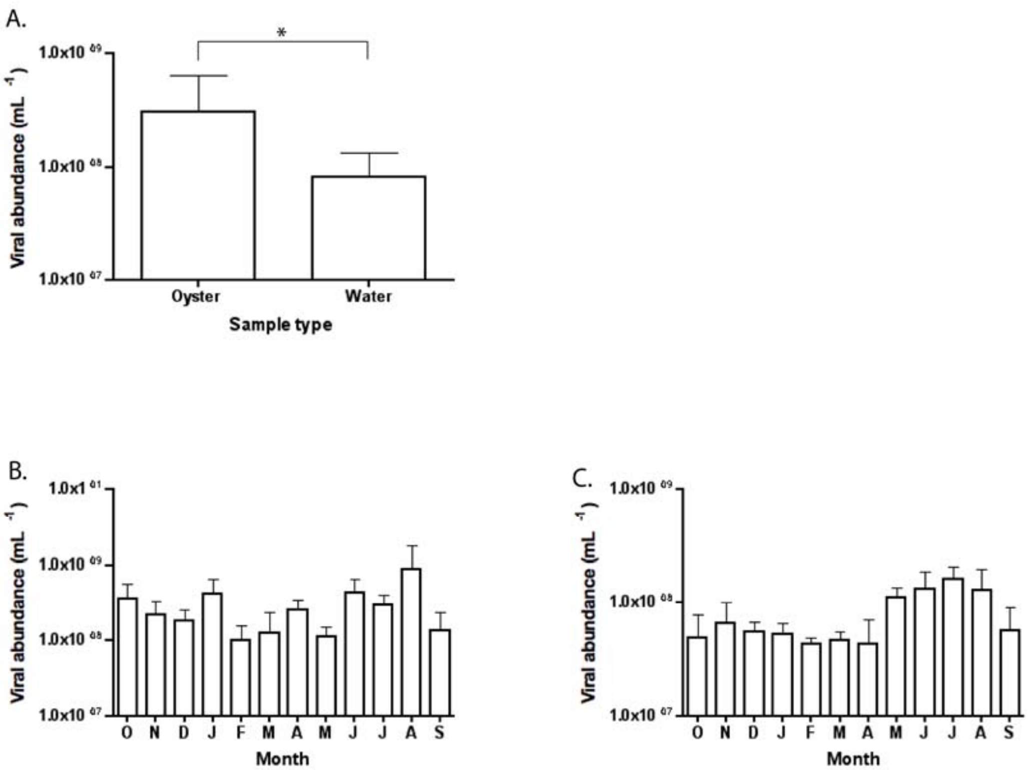

Figure 1. Viral abundance of oyster extrapallial fluid and water samples from the Smithsonian Environmental Research Center collected monthly from October 2010 to September 2011. Viral abundance was determined by direct counts with epifluorescence microscopy. A) Mean viral abundance of oyster extrapallial fluid (n=52) and water (n=48) samples collected during the annual study (Mann-Whitney, P<0.0001). B) Mean viral abundance of oyster extrapallial fluid collected during each month of the annual study. C) Mean viral abundance of water samples collected during each month of the annual survey.

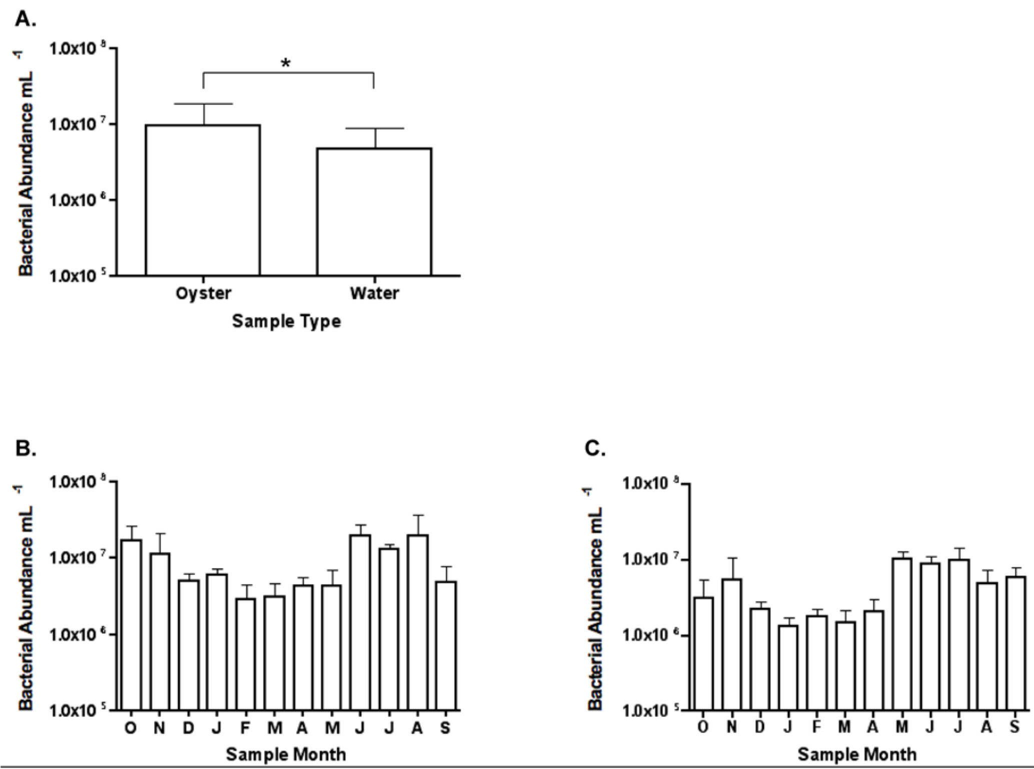

Figure 2. Bacterial abundance of oyster extrapallial fluid and water samples from the Smithsonian Environmental Research Center collected monthly from October 2010 to September 2011. Bacterial abundance was determined by direct counts with epifluorescence microscopy. A) Mean bacterial abundance of oyster extrapallial fluid (n=52) and water (n=48) samples collected during the annual study (Mann-Whitney, $P<0.001$). B) Mean bacterial abundance of oyster extrapallial fluid collected during each month of the annual study. C) Mean bacterial abundance of water samples collected during each month of the annual survey.

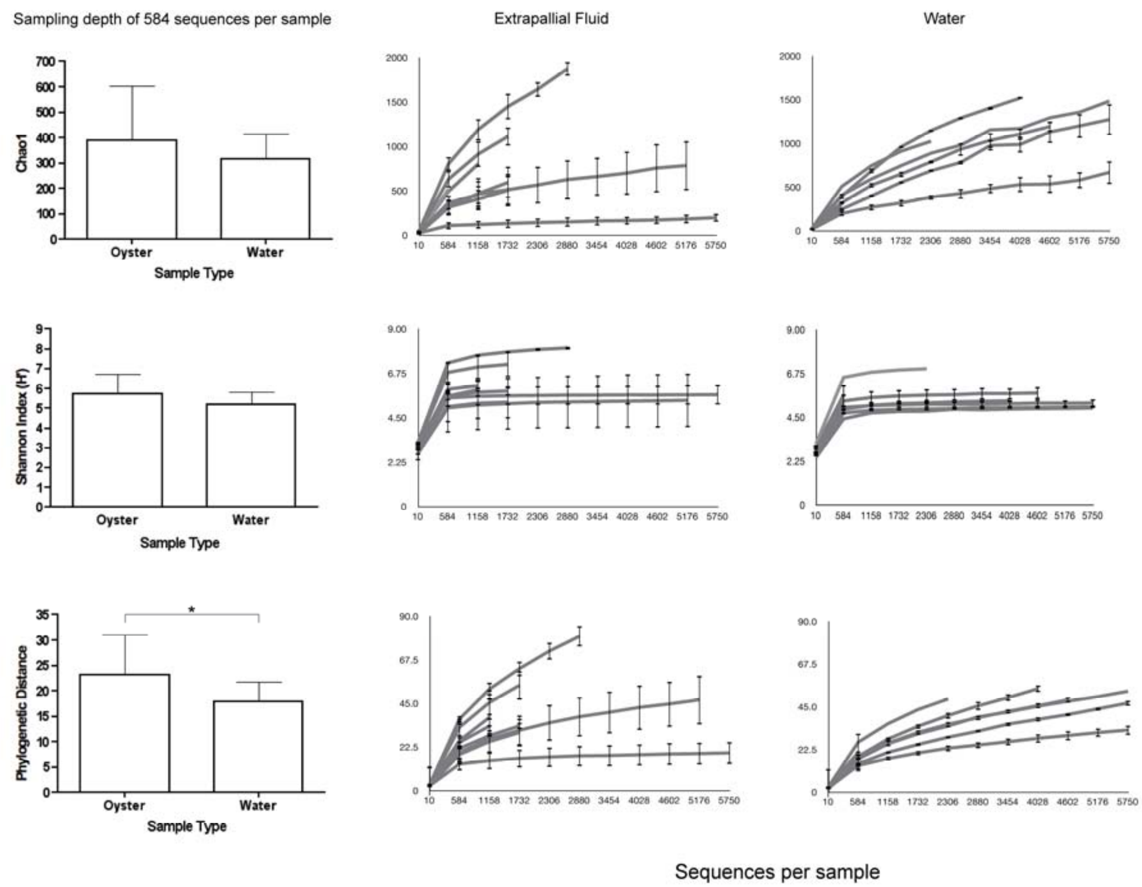

Figure 3. Diversity metrics of extrapallial fluid and water samples collected during the annual survey at SERC. Left: Mean diversity values at a sub-sampling depth of 584 sequences per sample. Mean Chao1 and Shannon indices were similar between oyster and water samples. Mean Phylogenetic Distance (Faith's Phylogenetic Diversity) was significantly greater for oysters at a sub-sampling depth of 584 sequences per sample (T-Test, $P<0.05$). Right: Rarefaction curves for oyster and water samples by sample month. Error bars indicate standard deviation within a sample month.

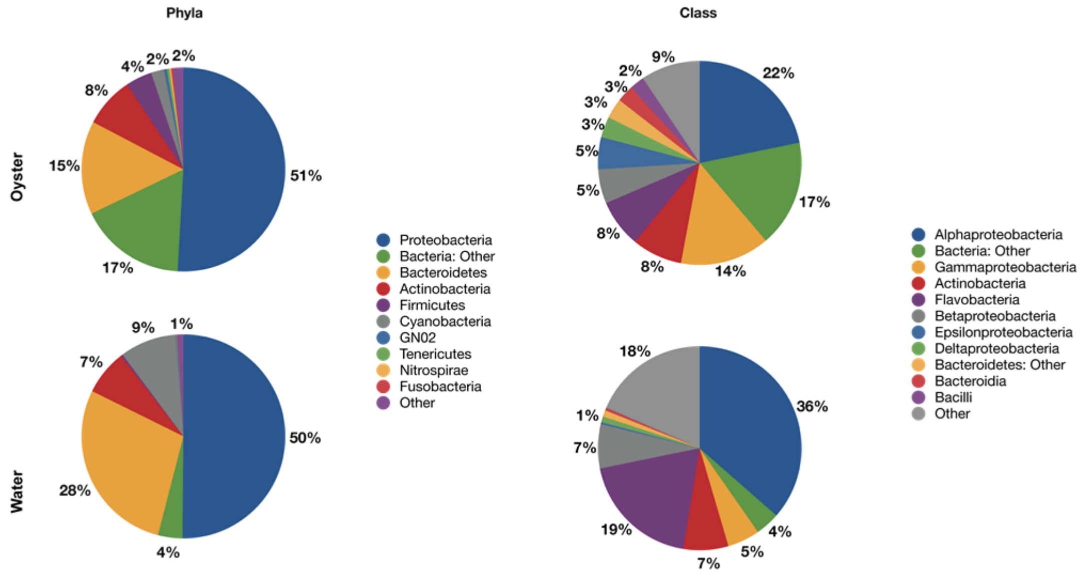

Figure 4. Mean bacterial taxonomic composition of oyster and water samples from the annual survey at the phyla and class level.

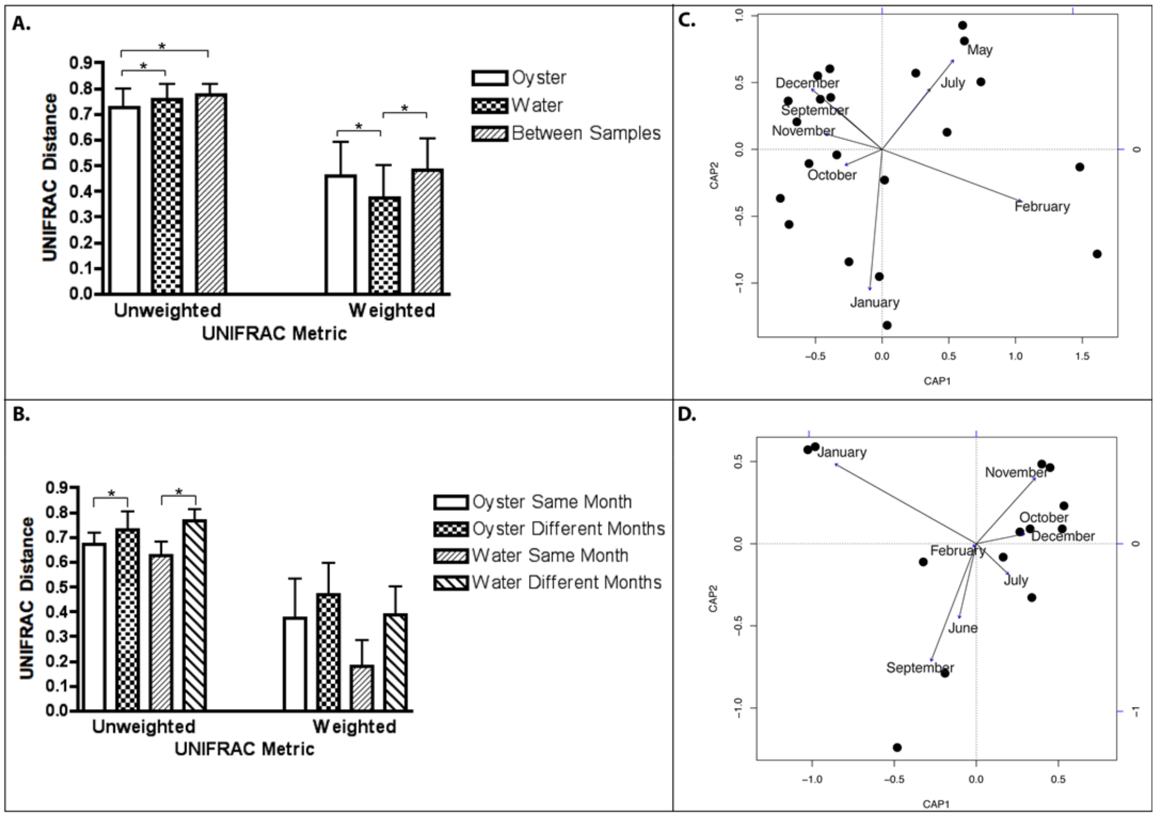

Figure 5. UniFrac distances and seasonal variations in bacterial communities of oyster and water samples. A) Unifrac distances within and between oyster and water samples over the course of the annual survey. Oyster samples were more similar to other oyster samples than to water samples using an unweighted UniFrac approach (Kruskal-Wallis, $P<0.01$). Water samples were more similar to other water samples than to oyster samples using a weighted UniFrac approach ($P<0.01$). B) Oyster and water samples were more similar to other samples from the same month ($P<0.01$) with unweighted UniFrac. C) Redundancy analysis plot of seasonal variability in oyster samples. D) Redundancy analysis plot of seasonal variability in water samples.

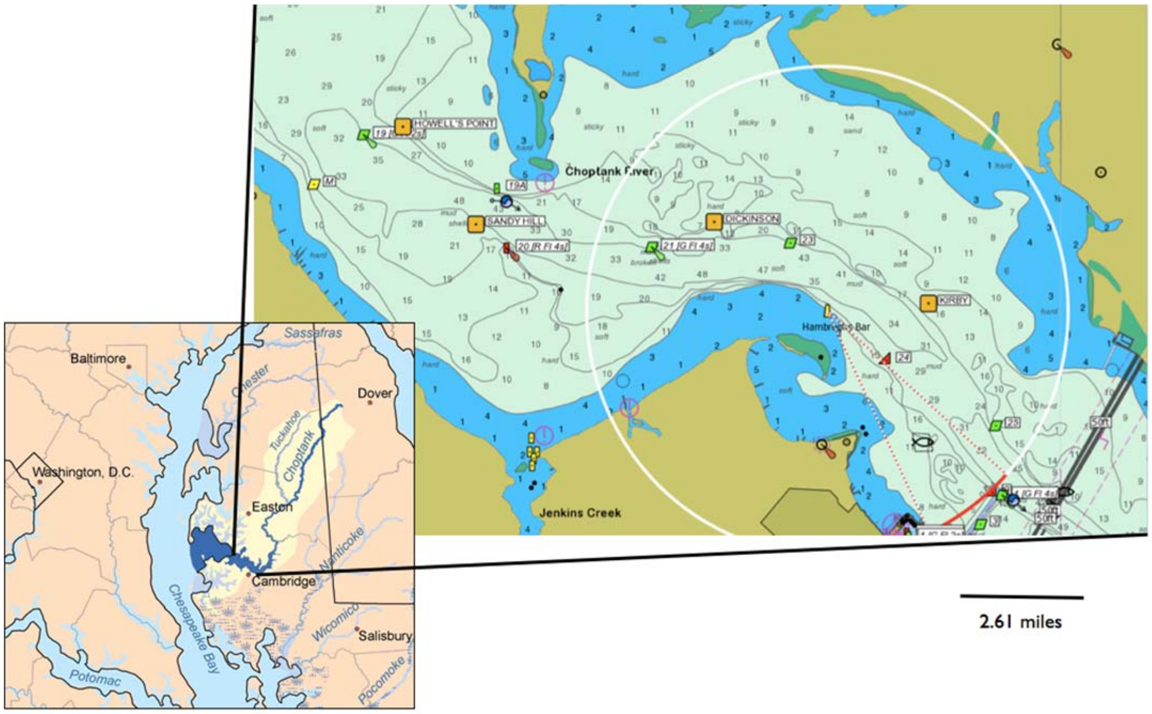

Figure 6. A map of the oyster bars sampled from the Choptank River in June 2011. Sampled bars are depicted by the yellow squares.

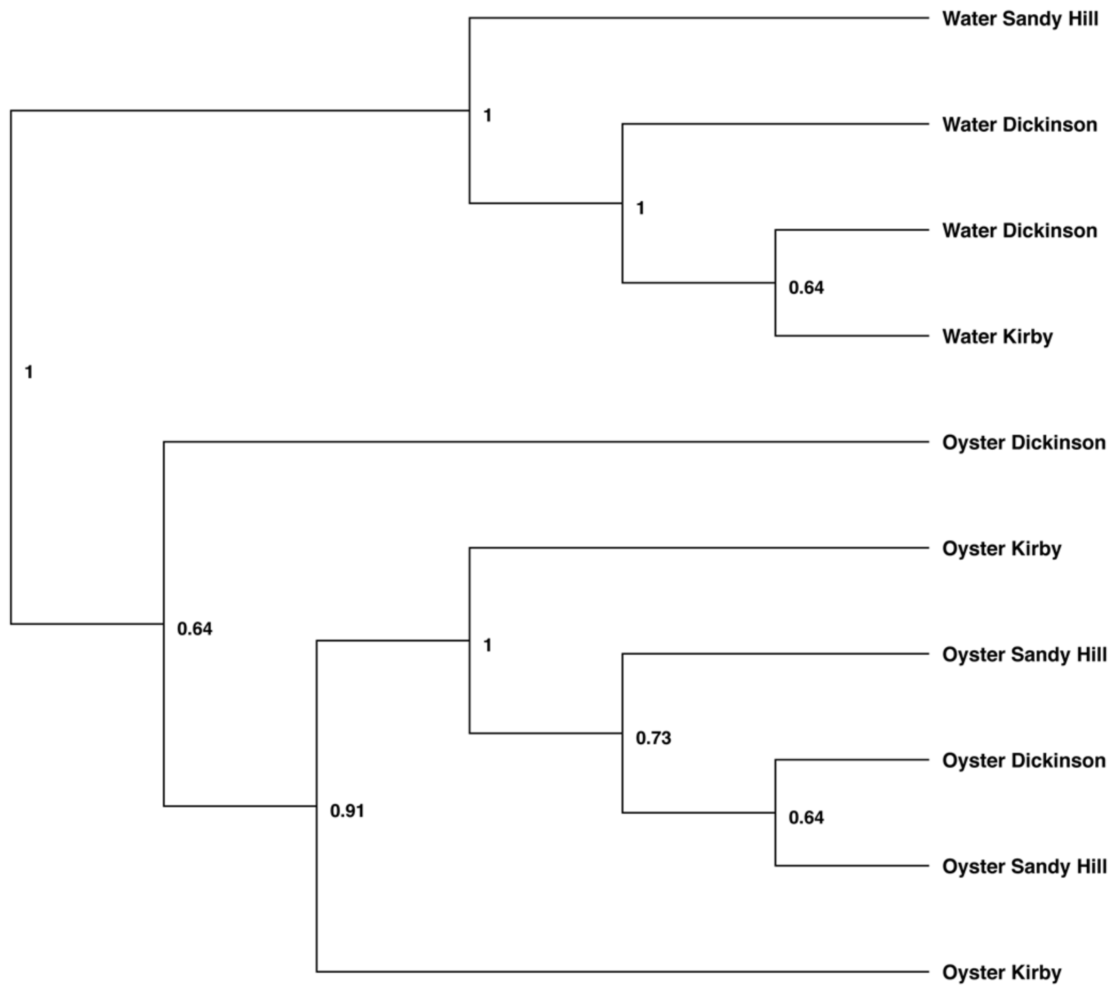

Figure 7. Unweighted Pair Group Method with Arithmetic mean (UPGMA) hierarchical clustering of Choptank River oyster and water samples. Nodes are named according to sample type and location. Oyster bars were Dickinson, Kirby, and Sandy Hill. Jackknife values are of 10 jackknife replicates with a sub-sampling depth of 3,000 sequences per sample.

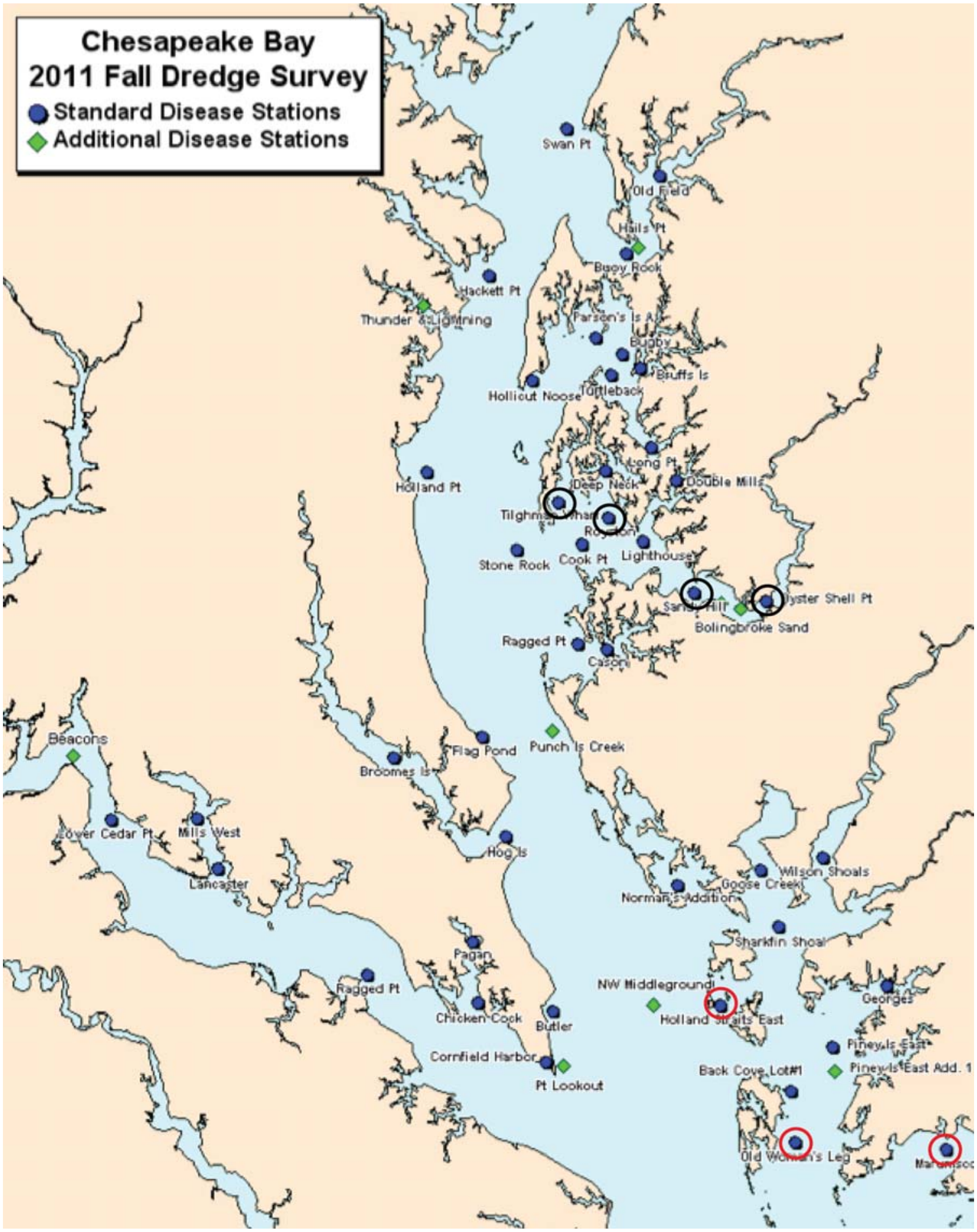

Figure 8. Disease survey sample locations. Sites with high *P. marinus* prevalence are circled in red. Sites with low *P. marinus* prevalence are in black. Adapted from (Tarnowski, 2012).

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Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed-Scale Model

Basic Information

Title:	Quantifying the Role of Carbon Amount and Quality for Transport of Contaminants on Our Landscapes: A Watershed-Scale Model
Project Number:	2010DE173B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Hydrogeochemistry, Nutrients
Descriptors:	None
Principal Investigators:	Shreeram P. Inamdar

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2. Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Winter09Spring10/WATERNEWSco-Spring2010.pdf , p. 7.
3. Dhillon, G. and S. Inamdar, 2012, Quantifying the Relative Contributions of Particulate and Dissolved C to the Total Carbon Export from the Catchment: A Watershed Scale Model Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 21 pages.
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Hurricane storms and large exports of organic carbon in catchment runoff: Entering uncharted waters?

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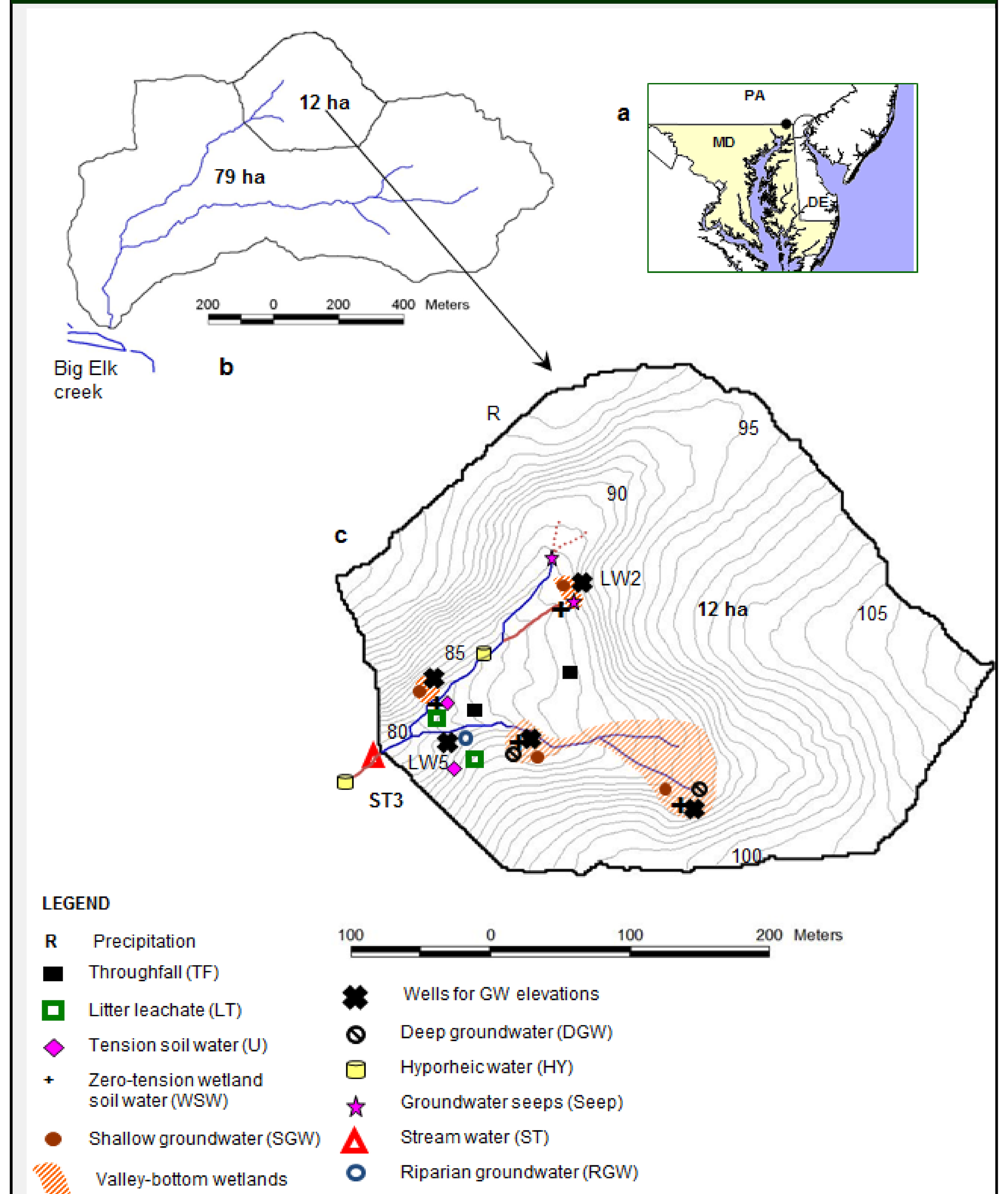
1. Abstract

Storm-event runoff exports and patterns of particulate (POC) and dissolved organic carbon (DOC) were investigated for a 12 ha forested catchment in the mid-Atlantic, Piedmont, region of USA. A total of 14 storm events were sampled over a 16-month period (September 2010 to December 2011) along with large, intense storms associated with three hurricanes – **Nicole** (September 30, 2010), **Irene** (August 27, 2011) and **Sandy** (October 29-30, 2012). DOC concentrations for storm events ranged from 0.7-18.3 mgL^{-1} while the POC concentrations were higher and ranged from 0.05 – 252 mgL^{-1}. Peak POC concentrations decreased with closely spaced, successive storm events whereas no such decrease in concentrations was observed for DOC. On the other hand, large events produced a dilution in DOC concentrations at peak flow whereas POC concentrations continued to increase. These results suggest that there are important differences in the storage pools and the leaching rates and kinetics for POC and DOC. Annual 2011 export of POC (37.7 kg C ha^{-1} yr^{-1}) from the 12 ha catchment was much greater than the corresponding DOC value (17.5 kg C ha^{-1} yr^{-1}). Stormflow contributed to 92% of the total C export and the three largest events in terms of precipitation contributed to 84% and 63% of the storm-event exports of POC and DOC, respectively. **Hurricane Irene alone contributed to 56% (21.2 kg C ha^{-1}) and 19% (3.3 kg C ha^{-1}) of the 2011 exports of POC and DOC, respectively. A precipitation threshold beyond which POC fluxes increased exponentially and rapidly outpaced the DOC values was also identified.** *Our study suggests that large, high-intensity storm events that are predicted to increase under future climate-change scenarios will dramatically alter the runoff C regime by enhancing the POC inputs to aquatic ecosystems.* Such shift in C forms could have important consequences for aquatic biota, atmospheric C cycling, and ecosystem and human health.

Hurricane Irene prior to landfall in 2011.

2. Study site



Sampling scheme within the 12 ha study watershed

3. Site description & sampling

Parshall flume at the 12 ha outlet.

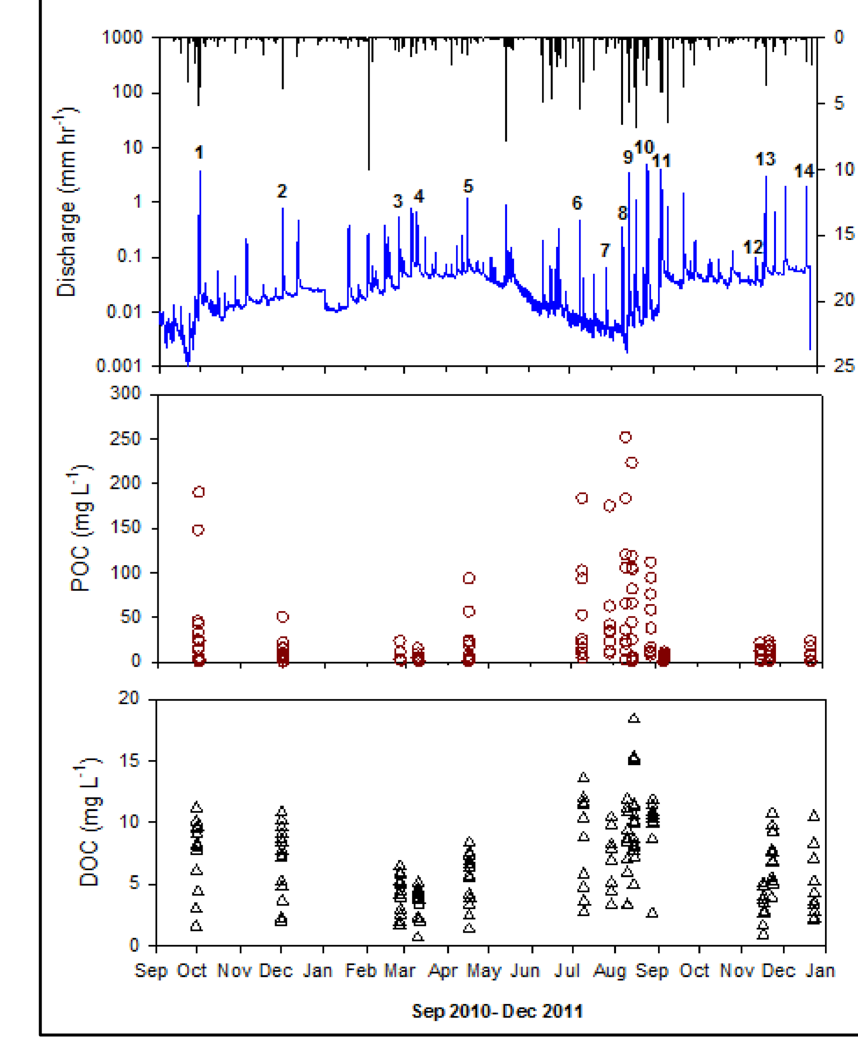
The study catchment is located in the Fair Hill Nature Preserve in Cecil County, Maryland, USA. The maximum daily mean temperature is 24.6°C (July) and the daily minimum is -0.6°C (January), with a mean annual temperature of 12.2°C. Mean annual precipitation in this region is 1231 mm.

Dominant tree species are *Fagus grandifolia* (American beech), *Liriodendron tulipifera* (yellow poplar), and *Acer rubrum* (red maple). Geology of the site includes pelitic gneiss and pelitic schist with subordinate amphibolite and pegmatite.

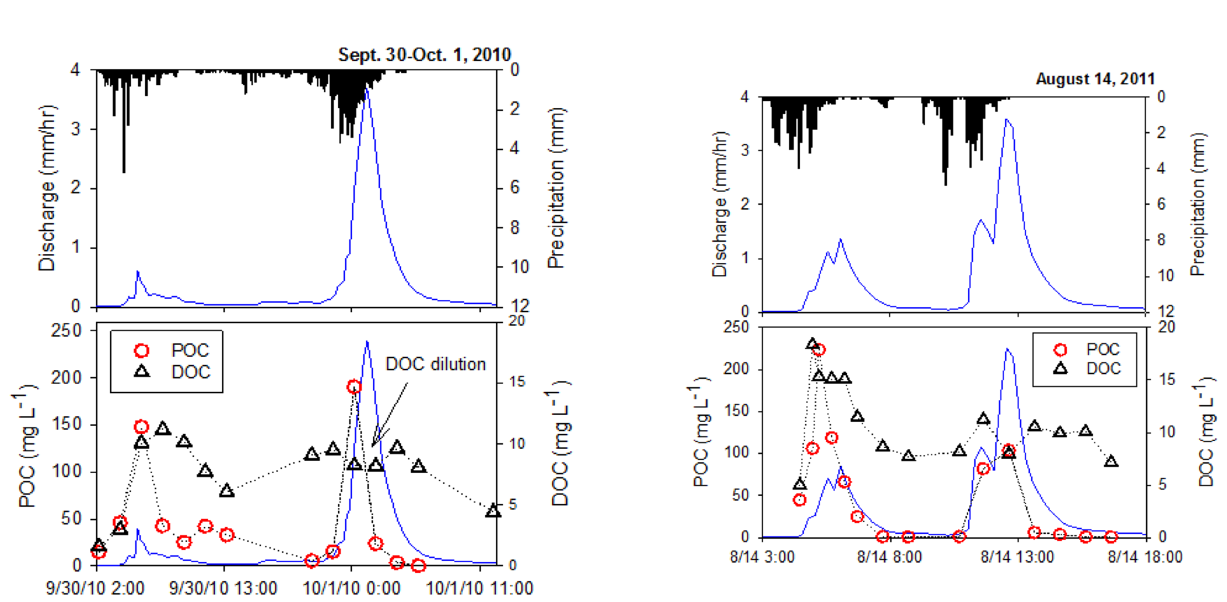
Stream flow discharge was monitored for the 12 ha catchment using a 6-inch Parshall flume and the water flow depths were recorded every 15 minutes using a Global Water (Inc.) logger and pressure transducer. POC (> 0.45 micron) and DOC data was available for 14 storm events collected over a 16 month period extending from September 2010 to December 2011 with baseflow sampling conducted once a month. DOC was measured using a Tekmar-Dohrmann Phoenix 8000 TOC analyzer, whereas % POC content of filtered sediment was determined using a Elementar VarioMax CN analyzer.

Mass fluxes of C were computed for the 12 ha catchment by multiplying stream discharge with measured POC and DOC concentrations.

4. Sampled storms and POC and DOC concentrations

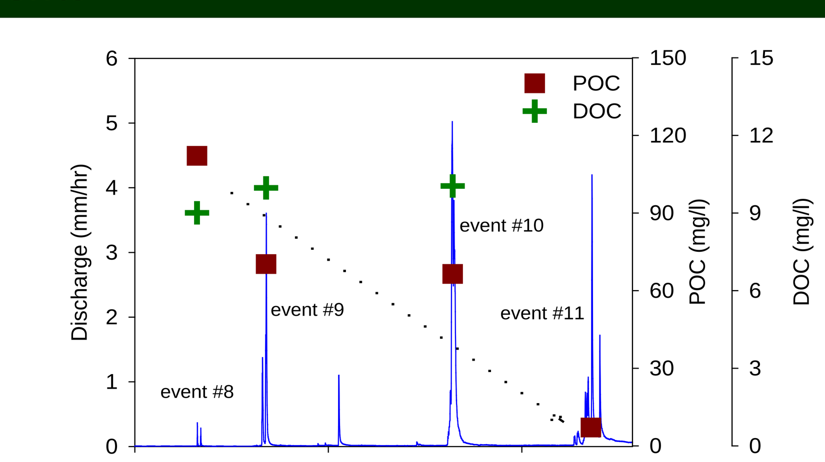


5. Within-event POC and DOC concentrations



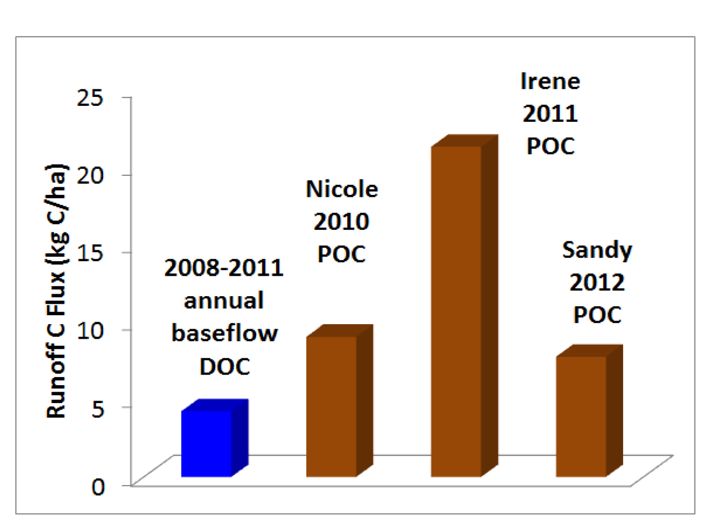
DOC dilution was observed at peak stream discharge, but POC concentrations continued to rise indicating important difference s in C leaching kinetics and sources.

6. POC and DOC changes with sequential events



Sequential events resulted in exhaustion of flow-weighted POC concentrations , but not DOC.

7. Average annual baseflow DOC versus hurricane-event POC

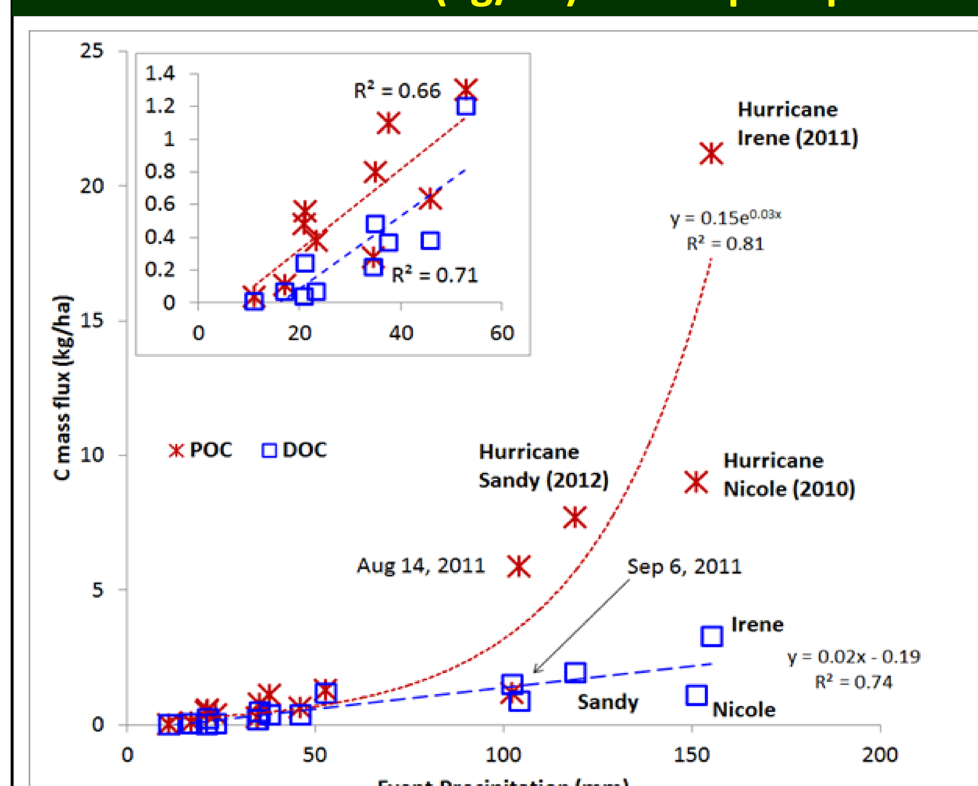


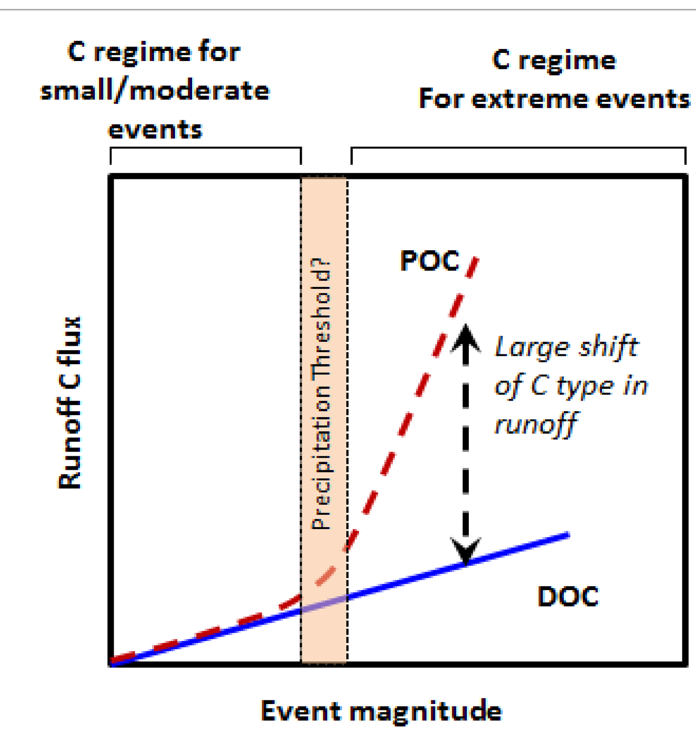
POC exports alone from the hurricane-associated events (7.72 - 21.2 kg $ha^{-1}yr^{-1}$) were nearly 2-5 times the average annual DOC export (2008-2011) for baseflow (4.22 kg $ha^{-1}yr^{-1}$)

This indicates that these events could have significant implications for the metabolism of downstream aquatic ecosystems.

Large allochthonous inputs of C from extreme storm events could flip receiving lentic ecosystems from net autotrophy to net heterotrophy status.

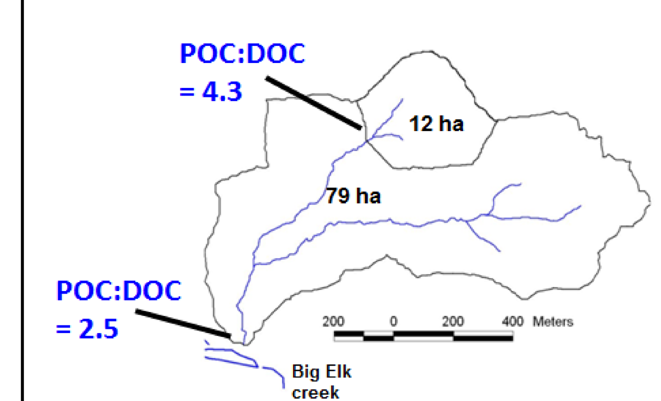
8. POC and DOC flux (kg/ha) versus precipitation





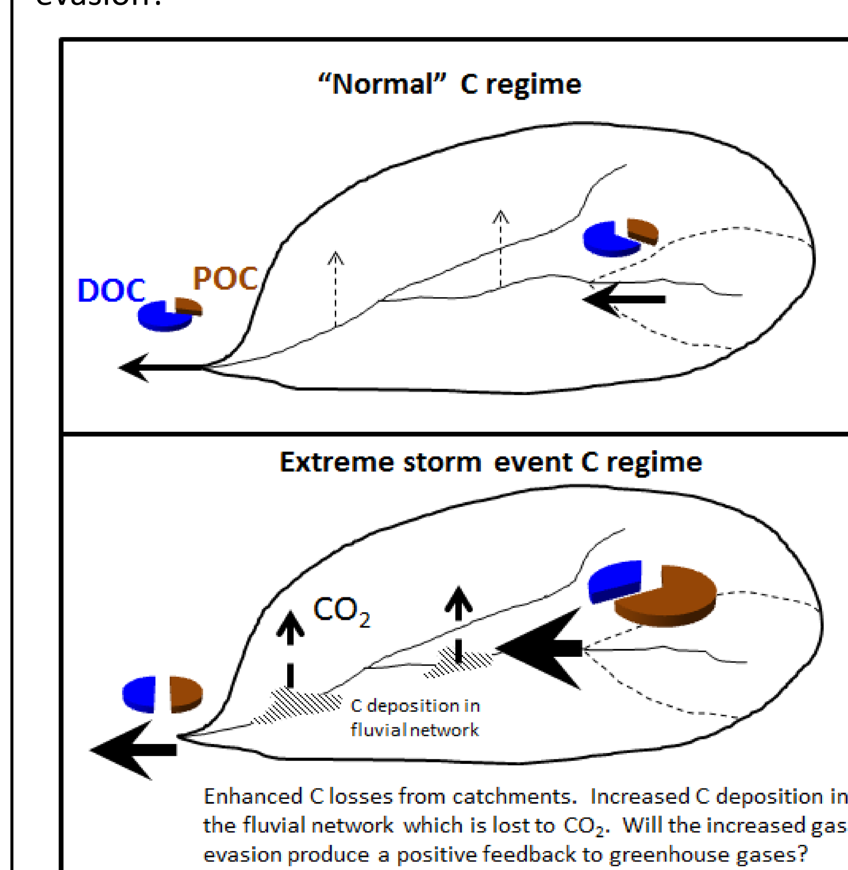
The rate of increase of POC versus DOC with large events was dramatically different. It appears that once a precipitation threshold (erosive energy associated with precipitation amount?) was exceeded POC exports increased exponentially while DOC supply was constrained to a linear increase.

9. Changes in POC:DOC with catchment scale and implications for lateral C flux and CO_2 evasion



Decrease in POC:DOC ratio from 12 to 79 ha scale suggests greater deposition of POC in headwater fluvial network.

Will this deposited POC contribute to enhanced CO_2 evasion?



ACKNOWLEDGEMENTS:

This study was partly funded by NSF grant # 0809205. The Delaware Water Resources Research Center (DWRC) provided a graduate assistantship to G. Dhillon. We also thank the Fair Hill Natural Resources Management Area and administration for providing access to the study site.

UD Watershed Team for Ecological Restoration

Basic Information

Title:	UD Watershed Team for Ecological Restoration
Project Number:	2010DE198B
Start Date:	1/27/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Management and Planning
Descriptors:	None
Principal Investigators:	Tom Thomas Sims, Anastasia Chirnside, Gerald Kauffman, Thomas McKenna, Maria Pautler

Publication

1. Pautler, M., ed., 2010, Delaware Water Resources Center WATER NEWS Vol. 11 Issue 1 The UD WATER PROJECT, http://ag.udel.edu/dwrc/newsletters/Summer10Fall10/WATERNEWSco-Fall2010.pdf , p. 2.

UD WATER Project for FY12

A multi-part breakout of a work plan was devised for the Piedmont and Coastal Plain watersheds. The following work was accomplished:

1) Intern ***Kate Aulenbach*** worked on "Hydrologic Response from a Developed Piedmont Watershed" with Dr. Luc Claessens of the ***UD's*** Department of Geography and Mr. Gerald Kauffman of the ***UD's Institute for Public Administration Water Resources Agency***.

Abstract

Stormwater runoff has the ability to erode Earth's surface, causing channels to form along its path from impervious areas to streams, rivers, etc. Large channels, known as gullies, can be examined to determine the extent of the effects of stormwater. This type of investigation can provide insight into the implementation of appropriate stormwater management practices. Therefore, the objectives of this analysis are to (1) quantify total suspended solids loads received over time and (2) determine temporal probable peak flow for gullies located in a Piedmont watershed. These aims were addressed by first delineating three sub-watersheds boundaries and land uses in a Piedmont region of Newark, Delaware where erosion due to stormwater runoff has caused the formation of gullies. Next, these land use data, along with additional known and calculated parameters, were subjected to models used to predict the temporal pollutant load and flow data experienced within the gullies. Through this investigation, it was determined that (1) increases in predicted loading and flow are resultant of increases in the appearance of specific high nutrient - and/or high metal-containing land cover and (2) as functions of land use, graphical results depicting pollutant load and flow over time were found to exhibit the same shape.

2) Intern ***Devika Banerjee*** worked on "Preliminary Design of an Interpretive Trail of Stormwater Management in a Piedmont Watershed" with Dr. Luc Claessens of the ***UD's*** Department of Geography and Mr. Gerald Kauffman of the ***UD's Institute for Public Administration Water Resources Agency***.

Abstract

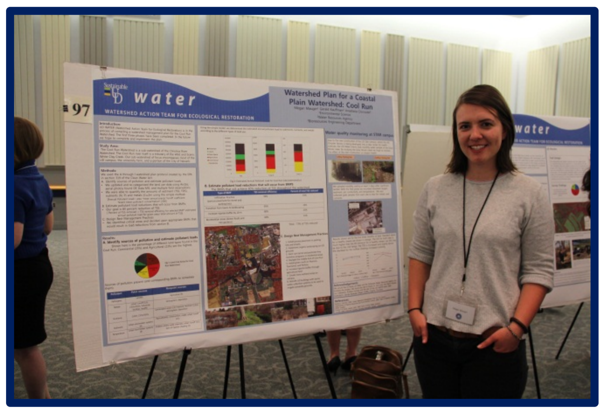
Objectives: 1) *Design a preliminary plan for an interpretive trial* – Design a trail to encompass the major gullies, highlighting the negative impacts of stormwater on campus; 2) *Spread greater awareness about stormwater watershed management* – Educate the public about stormwater management in relation to runoff, water

pollution, and various environmental impacts; 3) *Provide increased recreational opportunities* – Create additional walking and running trails in order to promote healthy activities outdoors.

Methods: 1) *Conducted a survey in relation to stormwater runoff on campus* – Encouraged University of Delaware students to participate in a 10-question survey in order to better understand the opinions and knowledge of current students; 2) *Designed a preliminary trail using Geographic Information Systems (GIS) and Google Earth in accordance to the U.S. National Park Service and U.S. Forest Service Criteria:* The 10% Guideline – Trail grade must be less than 10% in order to maintain tread stability and avoid erosion. Unsustainable trail grade will induce water management problems; Signage – Trail signage provides points of interest, guidance, and safety features along the length of the trail; Safety – Provide protection from natural hazards and conduct regular inspections of the premises, in order to ensure public safety; 3) *Chose specific locations for signage along the trail design* – Identified points of interest along the trail to highlight gullies, stormwater runoff, and forest quality; this trail design primarily features the gullies, drawing attention to the environmental impacts of such landforms.

Results: The interpretive trail design complied with the criteria of the U.S. National Park Service and the U.S. Forest Service. For The 10% Guideline, GIS was utilized to ensure that the slope did not exceed 10%. Points of interest along the length of the trail were identified for signage, featuring various landscapes. The trail design addresses safety concerns, avoiding steep and eroding gullies. The gullies, however, are incorporated into the trail design to increase awareness about stormwater runoff and environmental issues.

3) Intern ***Megan Mauger*** worked on "Watershed Plan for a Coastal Plain Watershed: Cool Run" with Mr. Gerald Kauffman of the ***UD's Institute for Public Administration Water Resources Agency***.

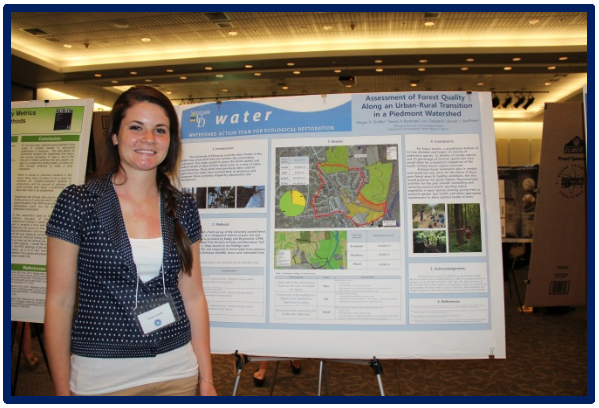


<u>Abstract</u>

The first three phases of an EPA "A through I watershed management plan" were completed for the Cool Run Watershed. The Cool Run is a 986-acre watershed which encompasses most of the University of Delaware campus, the CANR farm, and a portion of the city of Newark. Annual pollutant loads were estimated according to the land use categorization. Best management practices were decided upon in response to significant areas of pollution in order to reduce sediment load by 80%. We've provided a basis on which the plan can be completed and implemented.

4) Intern ***Megan Shaffer*** worked on "Assessment of Forest Quality along an Urban-Rural Transition in a Piedmont Watershed" with Dr. Luc Claessens of the ***UD's*** Department of Geography and Mr. Gerald Kauffman of the ***UD's Institute for Public Administration Water Resources Agency***.

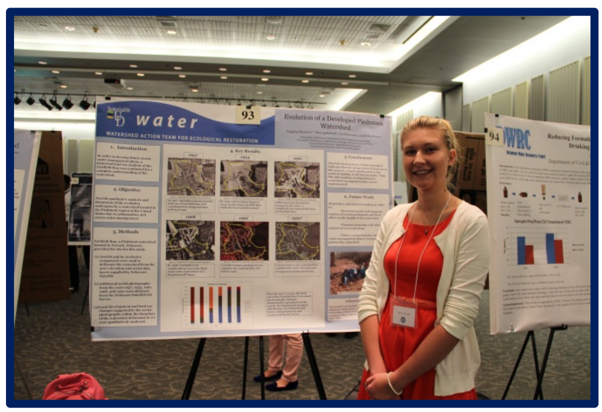
"I really enjoyed my time working as a UD WATER intern. It was great to work with people outside of my major and collaborate on a group project. Overall, I thikn the interns produced great work and I thank UD WATER for the opportunity." – Megan Shaffer



<u>Abstract</u>

We conducted a field survey of the university owned forest and assigned ratings in a comparative fashion of poor, fair and good based on criteria provided by Kaddy and Drummond (1996) and the Delaware State Park Division of Parks and Recreation Trail Committee. Maps based on our findings were constructed using GIS and compared to forest types from previous land use data from Delaware DataMIL. Areas were estimated from Google Earth. For future studies, a quantitative analysis of (1) tree diameter and height, (2) density of understory species, (3) density of canopy species, and (4) percentage of invasive species per area would allow for a statistical comparison of the health of these forest regions assessed. A future forest restoration plan is needed and would not only allow for the return of those poor forest areas to healthy conditions, but also would preserve the good regions. Recommended activities for this plan include: controlling and removing invasive plants; planting native vegetation in open spaces; pruning young trees to promote greater tree health; and other appropriate maintenance to allow optimal health of trees.

5) Intern ***Virginia Thornton*** worked on "Evolution of a Developed Piedmont Watershed" with Dr. Luc Claessens of the ***UD's*** Department of Geography and Mr. Gerald Kauffman of the ***UD's Institute for Public Administration Water Resources Agency.***



<u>Abstract</u>

In order to develop future stormwater management plans, a historical land use analysis of the Fairfield Run was conducted for a complete understanding of the watershed. ArcGIS and its ArcHydro component were used to delineate the watershed from the 2007 elevation and aerial data layers supplied by Delaware DataMIL. Additional aerial photographs from the years 1937, 1954, 1961, 1968m and 1992 were obtained from the Delaware DataMIL GIS Server. Land development and land use changes suggested by the aerial photographs within the boundary of the watershed delineated in the ArcGIS step were qualitatively analyzed. Over the past 70 years, the land use of the Fairfield Run Watershed has drastically changed – dominated by agriculture in the 1930s, developing into an equal distribution of residential and forest, and parking lots and commercial by the 2000s. The historical analysis of this watershed indicates that the progression of land use in this area developed significantly to the point of stability in the last 20 years. With this information, a comprehensive watershed management plan can be implemented.

The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed

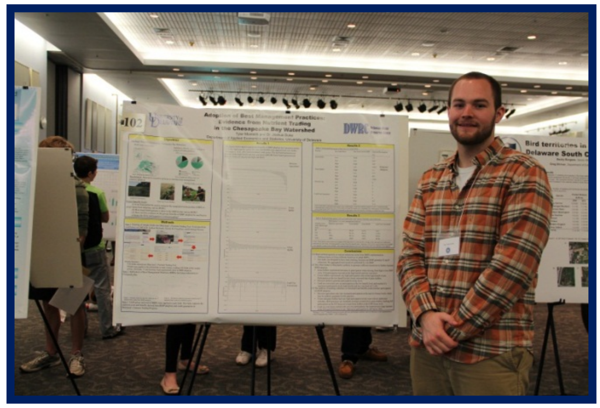
Basic Information

Title:	The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed
Project Number:	2012DE234B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Economics, Non Point Pollution, Law, Institutions, and Policy
Descriptors:	None
Principal Investigators:	Joshua Duke

Publications

1. Monteith, T., and J. Duke, 2013, The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 48 pages.
2. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.
3. Pautler, M., ed., 2012, Delaware Water Resources Center WATER E-NEWS Vol. 11 Issue 2, Spotlight on 2012-13 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Oct2012.pdf , p. 1.

Undergraduate Internship Project #1 of 7 for FY12



Intern ***Tyler Monteith's*** project, sponsored by the ***DWRC***, was titled "The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed." He was advised by Dr. Joshua Duke of the ***UD's*** Department of Applied Economics and Statistics.

"Funding through DWRC really gave me the opportunity to further develop my skills in independent research, a skill that I hope will prove valuable and help make me a much more viable candidate for any position." – Tyler Monteith

Abstract

This paper examines the effectiveness of a proposed nutrient offset trading market at increasing adoption rates of best management practices (BMPs) in the Chesapeake Bay Watershed. The analysis incorporates real agronomic data collected from farms on Maryland's Eastern Shore to accomplish three study objectives: (1) derive the farms' demand to adopt BMPs; (2) determine the heterogeneity of nutrient reductions for various farms; and (3) estimate the likely participation in the proposed program. Seventy-seven low-load fields were entered into the Maryland Nutrient Trading Tool where reductions were calculated from the planned installation of four management practices: Forest and grass buffers, decision agriculture, and land use conversion. Estimated costs of BMP adoption and credit values were applied to generate net benefits of adopting a BMP in the offset trading market, from which participation was then estimated. The results showed the trading tool creates heterogeneous reductions in nutrient loadings. Second, the incentives derived from the program are only likely to incentivize riparian buffer adoption, a practice that is likely already fully incentivized. This may lead to low participation rates within the program. Finally, adoption rates could be increased through the incorporation of unmeasured and additional benefits, though doing so could create a distortion within the market.

Developing Scientifically-Based Food Safety Metrics for Water Management and Irrigation Methods

Basic Information

Title:	Developing Scientifically-Based Food Safety Metrics for Water Management and Irrigation Methods
Project Number:	2012DE235B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Kalmia Kniel

Publication

1. Pautler, M., ed, 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #2 of 7 for FY12

Intern ***Lindsey Cook's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Agriculture and Natural Resources***, was titled "Developing Scientifically-Based Food Safety Metrics for Water Management and Irrigation Methods." She was advised by Dr. Kalmia Kniel of the ***UD's*** Department of Animal and Food Sciences.

Abstract

Water quality in agricultural watersheds is typically monitored using coliforms and perhaps detection of potentially harmful bacteria like *Escherichia coli*. These indicators may share information on potential fecal contamination, and are part of Good Agricultural Practices and proper management techniques to provide a safe product to the public when this water is used for irrigation. There may be differences in water quality standards for foliar and non-foliar application, and at different times of the year. Research has shown somewhat of a correlation between coliform and *E. coli* levels in water; however, the majority of science shows that coliforms are not an adequate indicator of potential *E. coli* presence. Other physical and chemical factors must be evaluated as well to provide information as to what conditions play a role in the survival of *E. coli* or other organisms that may present a hazard to public health. In this study, water sites of agricultural importance were assessed in order to draw potential correlations between biological, physical and chemical indicators along with the level of microbial activity. The testing site was an agricultural watershed with an effect on subsequent recreational water sources. It was shown that rainfall events with accumulations exceeding 0.5 inches under certain chemical conditions will likely also have an increase in the prevalence of coliforms and *E. coli*, potentially posing a risk to food safety and public health.

Water Quality Impacts of Landscape Best Management Practices that Enhance Vegetation

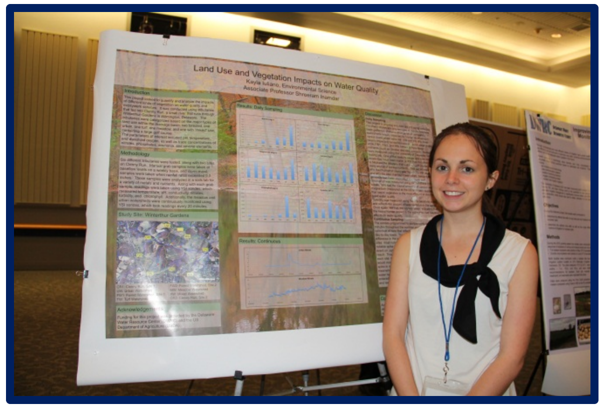
Basic Information

Title:	Water Quality Impacts of Landscape Best Management Practices that Enhance Vegetation
Project Number:	2012DE236B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Nutrients, Management and Planning
Descriptors:	None
Principal Investigators:	Shreeram P. Inamdar

Publication

1. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #3 of 7 for FY12



Intern ***Kayla Iuliano's*** project, co-sponsored by the ***DWRC*** and the ***UD College of Agriculture and Natural Resources***, was titled "Water Quality Impacts of Landscape Best Management Practices That Enhance Vegetation." She was advised by Dr. Shreeram Inamdar of the ***UD's*** Department of Plant and Soil Sciences.

"… I got into all but one [graduate school] program and was admitted to two of the top four programs in the country for public health. I was told that my research experience had made my application competitive. I can't say enough good things about the undergrad research program in terms of the experiences it gave me and the practical real-world work." – Kayla Iuliano

Abstract

The primary objective of this research was to quantify and analyze the impacts of different kinds of vegetation on water quality and ecosystem services. It was conducted using tributaries that fed into Clenny Run, a small river that runs through Winterthur Gardens in Wilmington, Delaware. The tributaries were categorized based on the major types of land use within the drainage basin: two forested, one urban, one turf, one meadow, and one with "mixed" use, containing a large golf course. The parameters of interest included pH, temperature, and dissolved oxygen, as well as trace concentrations of nitrates, phosphates, ammonia, and several elements. The six different tributaries were tested, along with two sites on Clenny Run. Manual grab samples were taken at baseflow levels on a weekly basis, and storm event samples were taken when rainfall rates exceeded 0.3 inches. These samples were analyzed in a soils lab for a variety of metals and nutrients. Along with each grab sample, readings were taken using YSI sondes, which measured temperature, pH, conductivity, nitrates, turbidity, and chlorophyll. Additionally, the meadow and urban watersheds were continuously monitored using YSI sondes, which took readings every 20 minutes.

Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip Irrigation

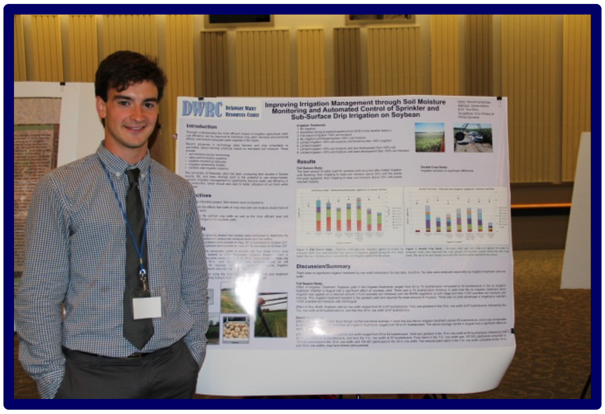
Basic Information

Title:	Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip Irrigation
Project Number:	2012DE237B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Engineering
Focus Category:	Irrigation, Water Supply, Water Quality
Descriptors:	None
Principal Investigators:	Tom Thomas Sims, Tom Thomas Sims

Publications

1. Kardashian, D., J.T. Sims, and J. Adkins, 2013, Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip Irrigation, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 18 pages.
2. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #4 of 7 for FY12



Intern ***Daniel Kardashian's*** project, co-sponsored by the ***DWRC*** and the ***UD College of Agriculture and Natural Resources'*** Carvel Center, was titled "Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip Irrigation." He was advised by Dr. Tom Sims and Mr. James Adkins of the ***UD's*** Department of Plant and Soil Sciences.

"Working on a farm is an experience I will never forget. Thank you for everyone who helped provide this opportunity for me." – Daniel Kardashian

Abstract

Through understanding the most efficient means of irrigation agricultural water use efficiency can be improved to maximize crop yield, minimize environmental effects, and ensure adequate water supplies in the future. The University of Delaware (UD) has been conducting farm studies in Sussex County, DE, and basic findings point to the potential to use sensor-based, precision irrigation management to significantly improve water use efficiency in crop production, which should also lead to better utilization of our fresh water resources. Field studies were conducted to determine the effects that width of crop rows and soil moisture levels have on soybean yield and to determine the optimal crop width as well as the most efficient level and method of irrigation for soybean yield. During the 2012 growing season two studies, one with full season soybeans and the other with double-crop soybeans, were conducted under eight different irrigation treatments to determine the response of soybeans to various soil moisture levels and row widths. For the full season study - *Effect of Irrigation Treatment*: Soybean yield in the irrigated treatments ranged from 63 to 70 bushels/acre compared to 54 bushels/acre in the no irrigation treatment. There was a 16 bushels/acre increase in yield over the no irrigation treatment when irrigation was applied on a reduced amount (>%30 available soil moisture) until the R5/R6 vegetative growth stage and then >%50 available soil moisture until maturity. This irrigation treatment resulted in the greatest yield and required the least amount of irrigation. There was no yield advantage in irrigating to maintain >%50 available soil moisture until mid-August. *Effect of Row Width:* Soybean yield by row width ranged from 61 to 67 bushels/acre. Yield was greatest in the 15-in. row width at 67 bushels/acre, followed by the 7-in. row width at 64 bushels/acre in, and then the 30-in. row width at 61 bushels/acre. For the double-crop study: *Effect of Irrigation Treatment*: Even though rainfall was below average in June and July the no irrigation treatment yielded 58 bushels/acre, which was comparable to all irrigation treatments. Yield from all irrigation treatments ranged from 58 to 61 bushels/acre. The above average rainfall in August had a significant effect on soybean yield. *Effect of Row Width*: Soybean yield by row width ranged from 55 to 64 bushels/acre. Yield was greatest in the 15-in. row width at 64 bushels/acre, followed by the 30-in. row width at 58 bushels/acre, and then the 7-in. row width at 55 bushels/acre. Final stand in the 7-in. row width was 107,000 plants/acre compared to 169,522 plants/acre in the 15-in. row width, and 154,427 plants/acre in the 30-in. row width. The reduced plant stand in the 7-in. row width, compared to the 15-in. and 30-in. row widths, may have limited yield potential.

Characterization of Viral Diversity within the Mantel Fluid of the Eastern Oyster, Crassostrea virginica

Basic Information

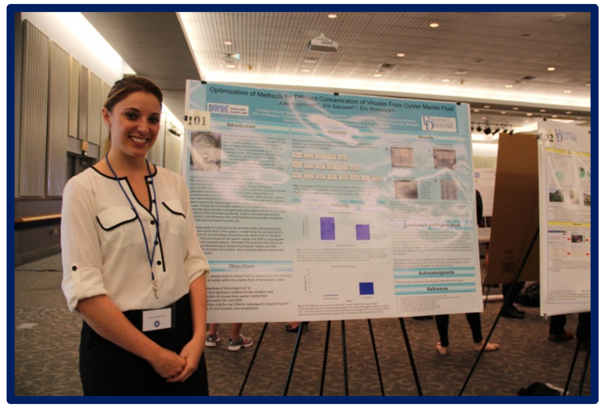
Title:	Characterization of Viral Diversity within the Mantel Fluid of the Eastern Oyster, Crassostrea virginica
Project Number:	2012DE238B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Biological Sciences
Focus Category:	Water Quality, Ecology, Toxic Substances
Descriptors:	None
Principal Investigators:	Eric Wommack, Eric Wommack

Publications

1. Hagemeyer, J., and K.E. Wommack, 2013, Characterization of Viral Diversity within the Mantel Fluid of the Eastern Oyster, Crassostrea virginica, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 7 pages.
2. Pautler, M. ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #5 of 7 for FY12

Intern ***Julia Hagemeyer's*** project, co-sponsored by the ***DWRC*** and ***UD's College of Earth, Ocean, and Environment***, was titled "Characterization of Viral Density within the Mantel Fluid of the Eastern Oyster, *Crassostrea virginica*." She was advised by Dr. K. Eric Wommack the ***UD's*** Department of Plant and Soil Sciences.



Abstract

The eastern oyster is a vital proponent of the estuarine environments along the Atlantic coast. It is considered a keystone species and is what keeps the water clean and provides shelter. This study looked into the microbial and viral communities that reside within these oysters' mantle fluids. In this study we looked at three different methods of oyster concentration: ultracentrifugation, direct flow filtration, and iron chloride flocculation. The method of ultra centrifugation proved to recover only 2.4% of the viruses in the sample and was not considered useful. We then optimized the direct flow filtration and were able to get recoveries as high as 185.2% (although we believe the samples may have been contaminated with bacterial DNA). Unfortunately this method did not amplify well with PCR so it also proved to be unhelpful. The last method that we optimized was the iron chloride flocculation. This method recovered up to 92% of the viruses and also amplified the best of any sample (but only once a dialysis step was included into the procedure). Overall we found that the best method at this time is that of iron chloride flocculation with a dialysis step (in order to remove PCR inhibition) to concentrate viruses and extract viral DNA from oyster mantle fluid. Unfortunately we also found that one oyster is not enough to provide sufficient DNA to sample, but a compilation of 15 oysters would be adequate. Ultimately this research may lead to an increased understanding of interactions between oysters and their microbial and viral communities, thus impacting efforts to restore this keystone species.

Water Quality Management in Urban Ecosystems

Basic Information

Title:	Water Quality Management in Urban Ecosystems
Project Number:	2012DE239B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Management and Planning, Ecology, Surface Water
Descriptors:	None
Principal Investigators:	Susan Barton, Jules Bruck

Publications

1. Schofield, T., S. Barton, and J. Bruck, 2013, Water Quality Management in Urban Ecosystems, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 5 pages.
2. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #6 of 7 for FY12

Intern ***Timothy Schofield's*** project, co-sponsored by the ***DWRC*** and the ***UD's*** Department of Plant and Soil Sciences, was titled "Water Quality Management in Urban Ecosystems." He was advised by Drs. Susan Barton and Jules Bruck of the ***UD's*** Department of Plant and Soil Sciences.

Abstract

Our goal with the Applecross site and the research conducted here was to demonstrate the ecosystem services that can be provided through a naturalized residential landscape. It also serves to demonstrate that the general public can find this style of landscape just as, if not more, attractive than typical suburban landscape. The landscape was installed in the spring of 2012. After installation we maintained the landscape in such a way that the plants would establish themselves as quickly as possible. During this period we observed storm water habits on the site and recorded these observations. We also observed plant health, growth, and tolerance of location. We recorded plants that performed exceptionally well and poorly in order to make better recommendations in the future. Finally we came to relative conclusions for this growing season about plant performance and how storm water was affected.

Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron

Basic Information

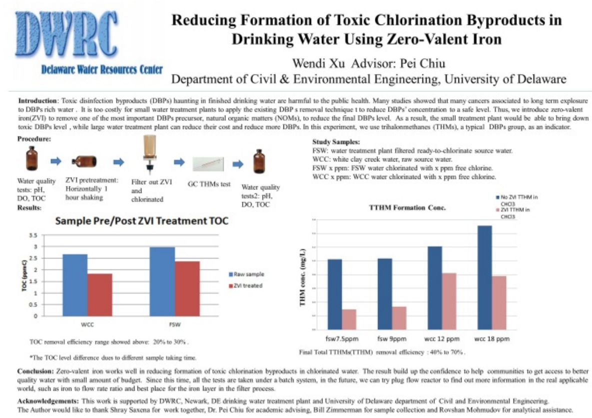
Title:	Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron
Project Number:	2012DE240B
Start Date:	6/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At large
Research Category:	Engineering
Focus Category:	Water Quality, Toxic Substances, Treatment
Descriptors:	None
Principal Investigators:	Pei Chiu, Pei Chiu

Publications

1. Xu, W., and P. Chiu, 2013, Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 8 pages.
2. Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, Introducing Our 2012-13 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 4.

Undergraduate Internship Project #7 of 7 for FY12

Intern ***Wendi Xu's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Engineering***, was titled "Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron." She was advised by Dr. Pei Chiu of the ***UD's*** Department of Civil and Environmental Engineering.



Abstract

Disinfectants such as chlorine and ozone are widely used in drinking water disinfection. They are strong oxidizing agents and very good at killing waterborne viruses. However, during the disinfection process, an array of toxic disinfection byproducts (DBPs) are formed. The natural organic matter (NOM) in the source water, while itself innocuous, is found to be a precursor to major DBPs – trihalomethanes (THMs). The formation of THMs happens when NOM is chlorinated together with source water. To address this problem in an affordable way, we introduced zero-valent iron to remove NOM before chlorination.

In previous experience, ZVI was already proven to have NOM removal efficiency between 4.5 and 6 logs in the column tests. In this project, we tested two water samples in the batch reactors. One sample came from the Newark, Delaware drinking water treatment plant. This sample represents typical ready-to-be-chlorinated water in the drinking water treatment facility. The other sample is nature source water, which was taken from White Clay Creek, Newark, Delaware.

All sample waters were held in 8-oz amber bottles during the experiment. Water samples were divided into ZVI treated group and control group. After testing several iron to water ratios, a 25g ZVI to 235mL sample water ratio was chosen as the final test ratio.

The experiment contained two sections: basic water quality tests and THMs test. In the water quality tests section, basic water qualities, including pH, dissolved oxygen (DO), and total organic carbon (TOC) were measured. Among them, TOC is the most important measurement that gave us the TOC – THMs formation ratio. In the THMs section, a proper chlorine amount was chosen to chlorinate water in a 7-day light free base. THMs were measured by following a GC-ECD THMs measurement procedure. By measuring the indicator DBPs, trihalomethanes, the two ZVI pre-treated water samples provided data to support that ZVI pretreatment could reduce the formation of DBPs by 40% to 70%. In the same time, TOC data suggested removal efficiency from 20% to 30%.

Previous research by the University of Delaware showed that zero-valent iron functions well in NOM removal work. Well researchers from Northwestern University provided results which showed that TOC is a major precursor of THMs. This project bridged these two theories together, and provided evidences to show that ZVI is effective in reducing final DBPs level.

DBPs have been regulated since 1979. They are carcinogenic, mutagenic, and teratogenic. Though it is much safer than to drink from surface water directly, there is a potential problem for long-term exposure. The large scale water treatment facilities usually do not have problems meeting the requirement. However, for the small scale treatment plant, DBPs removal process could be too costly. Compared with the other DBPs reduction techniques, ZVI is relatively cheap. As a result, ZVI can make DBPs treatment affordable for the small scale water treatment plant. If it can be applied, more people could get access to safe water at a lower cost.

Information Transfer Program Introduction

None.

DWRC Information Transfer

Basic Information

Title:	DWRC Information Transfer
Project Number:	2010DE197B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	At Large
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Supply, Education
Descriptors:	None
Principal Investigators:	Tom Thomas Sims, Maria Pautler

Publications

There are no publications.

Information Transfer Program

The following section describes all Delaware Water Resources Center information transfer activities during FY12, consolidating reporting into a single (extended) project **#2010DE197B**. Most activities from the DWRC's FY11 Information Transfer project (**#2010DE197B)** continued into this year.

The FY12 DWRC Information Transfer Activities include:

- Delaware Water Resources Center Electronic Publication WATER NEWS (2000 – 2006 = print; 2007 – present = electronic)
- Delaware Water Resources Center Electronic Newsletter WATER E-NEWS (2002 – present)
- Delaware Water Resources Center Website (3rd edition launched in 2009)
- Delaware Water Resources Center E-group / Courses Link (2002 – present)
- Delaware Water Resources Center Intern Project Poster Session / Advisory Panel Annual Meeting (2001 – present)
- Delaware Statewide Conference Co-sponsor and Participant (2001 – present, when held)

Basic Information:
Delaware Water Resources Center Electronic Publication WATER NEWS

Title:	"WATER NEWS"
Issues during FY12:	Volume 12 Issues 1 & 2 (Fall-Winter 2011 and Spring-Summer 2012)
Description:	Online 8-page newsletter published biannually by the Delaware Water Resources Center (In FY12 there was a one-time 12-page newsletter)
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	Dr. J. Thomas Sims, Director; Maria Pautler, Editor

WATER NEWS is received electronically by over 300 recipients in water-related academic, government, public and private agency, agriculture and industry positions in Delaware and the surrounding area as well as 100 nationwide contacts for water resource issues. It may be accessed via the Delaware Water Resources Center website at: http://ag.udel.edu/dwrc/newsletters.html.

FY12 topics included:

- DWRC Annual Luncheon and Poster Session – April 20, 2012
- Introducing Our 2012-13 Interns
- Spotlight on Graduate Research
- The UD WATER Project
- Spotlight on Undergraduate Internships
- DWRC History, Goals, Advisory Panel, Contacts

Basic Information:
Delaware Water Resources Center Electronic Newsletter WATER E-NEWS

Title:	“WATER E-NEWS”
Issues during FY12:	Sept. 2011, Oct. 2011, Mar. 2013, Apr. 2013
Description:	Brief online “highlights” newsletter published periodically by the Delaware Water Resources Center
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	J. Thomas Sims, Director; Maria Pautler, Editor

WATER E-NEWS is received electronically by over 300 recipients in water-related academic, government, public and private agency, agriculture and industry positions in Delaware and the surrounding area. The current issue and back issues dating to its August 2002 inception may be accessed via the DWRC website at: http://ag.udel.edu/dwrc/newsletters.html.

Featured in each issue of WATER E-NEWS are:

I. News items about the DWRC, including undergraduate internships and graduate fellowships
II. Jobs in Water Resources
III. Upcoming Water Conferences / Events
IV. Water Resources Information / Training

Basic Information: Delaware Water Resources Center Website

Title:	Website: http://ag.udel.edu/dwrc
Start Date:	Third edition; since February 2009
End Date:	Ongoing
Description:	Comprehensive site serving Delaware water resources community
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	Dr. J. Thomas Sims, Director; Maria Pautler, Administrator

The website contains:

- **Delaware Water Resources Center (DWRC) and Director's News:** Latest updates on DWRC activities and information on the DWRC's mission, history, and role in the National Institute of Water Resources (NIWR).
- **Delaware Water Concerns:** Summary of the major areas of concern related to Delaware's ground and surface waters, with links to key organizations and agencies responsible for water quality and quantity.
- **Projects and Publications:** Descriptions of DWRC's undergraduate internship and graduate fellows programs, annual conference proceedings, and project publications dating back to 1993. Abstracts from the undergraduate internship projects are prevalent to educate current undergraduates and faculty about the types of research that can be done under this program.
- **Advisory Panel:** Purpose, contact information and e-mail links for the DWRC's Advisory Panel.
- **Request for Proposals and Application Forms:** For undergraduate interns, graduate fellowships and other funding opportunities available through the DWRC.
- **Internships and Job Opportunities:** Information on undergraduate and graduate internships from a wide variety of local, regional, and national sources along with current job opportunities in water resource areas.
- **Water Courses and Faculty:** Link to search engine for current list of University of Delaware water resource courses. List of researchers at Delaware universities with an interest in water resources research; also, science and natural resource curricula links.
- **Water Resources Contacts:** Links to local, regional, and national water resource agencies and organizations categorized as government, academia, non-profit, and US Water Resource Centers.
- **Calendar:** Upcoming local, regional, and national water resources events sponsored by the DWRC and other agencies, such as conferences, seminars, meetings, and training opportunities.
- **Newsletters:** Access to DWRC newsletters dating back to 1993.
- **Annual and 5-year Reports:** DWRC annual and 5-year reports, dating to 1993.
- **KIDS' Zone:** Water resources activities and information for kids and teachers.

Basic Information: Delaware Water Resources Center E-group / Courses Link

Title:	Delaware Water Resources Center / Water Resources Agency E-group, originating from the online listing of Delaware water teachers and researchers found on the DWRC website: http://ag.udel.edu/dwrc/faculty_researchers.html
Start Date:	Since December 2001
End Date:	Ongoing
Description:	E-group and link to university water resources courses taught, serving Delaware water resources community
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	J. Thomas Sims, Director; Maria Pautler, Administrator

The online listing of approximately 70 researchers at the University of Delaware, Delaware State University, and Wesley College found on the Delaware Water Resources Center website at http://ag.udel.edu/dwrc/faculty_researchers.html forms the foundation for a broader e-group list maintained by the DWRC reaching additional academic, public, private, and government water community contacts, who are notified via an e-mail newsletter of events and job postings of interest in water resources.

The website also links to a search engine and site for water-related courses currently offered by the researchers.

The total list of e-group members numbered approximately 300 as of May, 2013.

Basic Information:
Delaware Water Resources Center Intern Project Poster Session /
Annual Advisory Panel Meeting

Title:	University of Delaware 2013 Undergraduate Research Scholars Poster Session with DWRC Advisory Panel Meeting
Date:	April 19, 2013
Description:	Undergraduate interns presented their 2012-2013 DWRC-funded projects following the annual meeting of the DWRC Advisory Panel
Lead Institute:	University of Delaware Undergraduate Research Program Co-sponsors: Delaware Water Resources Center, Charles Peter White Fellowship in Biological Sciences, Chemistry and Biochemistry Alumni Fellowship, College of Agriculture and Natural Resources, Howard Hughes Medical Institute, McNair Scholars Program, National Science Foundation, Northeastern Chemical Association, NUCLEUS, State of Delaware.
Principal Investigators:	Lynnette Overby, Director, UD Undergraduate Research Program (overbyl@udel.edu); J. Thomas Sims, Director, DWRC (jtsims@udel.edu)

On April 19, 2013, the undergraduate student interns who had been funded in 2012-2013 by the DWRC, accompanied by their advisors, presented the results of their research at an informal poster session sponsored by the University of Delaware Undergraduate Research Program. Over 90 UD Science and Engineering Scholars joined the DWRC interns to present to a crowd of over 500 visitors. The DWRC Advisory Panel also convened for lunch with the interns and their advisors and then held their annual meeting prior to the poster session. DWRC Director Tom Sims described the Center's plans for 2013-2014 with regard to research funding and public education outreach efforts.

Poster Presentations by 2012-2013 DWRC Undergraduate Interns – April 19, 2013

1) Cook, Lindsey. Poster Presentation April 19, 2013. Developing Scientifically-Based Food Safety Metrics for Water Management and Irrigation Methods. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

2) Hagemeyer, Julia. Poster Presentation April 19, 2013. Characterization of Viral Diversity within the Mantel Fluid of the Eastern Oyster, *Crassostrea virginica*. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

3) Iuliano, Kayla. Poster Presentation April 19, 2013. Water Quality Impacts of Landscape Best Management Practices That Enhance Vegetation. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

4) Kardashian, Daniel. Poster Presentation April 19, 2013. Improving Irrigation Management through Soil Moisture Monitoring and Automated Control of Sprinkler and Sub-Surface Drip

Irrigation. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

5) Monteith, Tyler. Poster Presentation April 19, 2013. The Returns to Best Management Practices: Evidence from Early Proposals for Nutrient Trading in the Chesapeake Bay Watershed. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

6) Schofield, Timothy. Poster Presentation April 19, 2013. Water Quality Management in Urban Ecosystems. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

7) Xu, Wendi. Poster Presentation April 19, 2013. Preventing Formation of Toxic Chlorination Byproducts in Water Using Zerovalent Iron. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

8) Aulenbach, Kate. Poster Presentation April 19, 2013. Hydrologic Response from a Developed Piedmont Watershed. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

9) Banerjee, Devika. Poster Presentation April 19, 2013. Preliminary Design of an Interpretive Trail of Stormwater Management in a Piedmont Watershed. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

10) Mauger, Megan. Poster Presentation April 19, 2013. Watershed Plan for a Coastal Plain Watershed: Cool Run. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

11) Shaffer, Megan. Poster Presentation April 19, 2013. Assessment of Forest Quality along an Urban-Rural Transition in a Piedmont Watershed. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

12) Thornton, Virginia. Poster Presentation April 19, 2013. Evolution of a Developed Piedmont Watershed. 2013. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	7	0	0	0	7
Masters	1	0	0	0	1
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	10	0	0	0	10

Notable Awards and Achievements

Research Program: The Delaware Water Resources Center (DWRC) has funded fourteen research grant projects during March 2012 through February 2013 that address state water resources priorities identified by the DWRC's Advisory Panel. Two of these projects are graduate fellowships with research focuses on 1) quantifying carbon amount and quality for transport of contaminants in landscapes and 2) microbiome of the eastern oyster. The remaining projects were undergraduate internships researching 1) water safety and food management; 2) viral diversity in oysters; 3) water quality in the landscape; 4) improving irrigation to field crops; 5) nutrient trading in the Chesapeake Bay Watershed; 6) water quality in urban ecosystems; 7) preventing formation of chlorination byproducts in water using zerovalent iron; and 8) the UD WATER Project (five undergraduate interns reporting).

Former DWRC Graduate Fellow Maryam Akhavan won a TOUGH (Transport of Unsaturated Groundwater and Heat) Symposium 2012 Student Fellow Award. (TOUGH is a suite of numerical codes/flow model computer programs developed primarily at Lawrence Berkeley National Laboratory (LBNL)). By winning this award, she was able to attend the symposium from September 17-19, 2012 at LBNL to present her paper "Importance of Overland Flow in Denitrification" while having her registration fee, airfare, and hotel costs covered. To learn more about TOUGH and her achievement, visit http://esd.lbl.gov/research/projects/tough/events/symposia/toughsymposium12/authorinstructions.html .

Publications from Prior Years

1. 2007DE97B ("Hydrogeologic Characterization of the Potomac Aquifer, Delaware") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 11 Issues 1&2, DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 6.
2. 2007DE100B ("Modeling Hydrologic and Geochemical Effects of Land-based Wastewater Disposal") - Articles in Refereed Scientific Journals - Akhavan, M., P.T. Imhoff, S. Finsterie, and A.S. Andres, 2012, Application of a Coupled Overland Flow-Vadose Zone Model to Rapid Infiltration Basin Systems, Vadose Zone Journal, 11(2), vzj2011.0140-vzj2011.0140.
3. 2007DE100B ("Modeling Hydrologic and Geochemical Effects of Land-based Wastewater Disposal") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 11 Issues 1&2, DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 7.
4. 2007DE100B ("Modeling Hydrologic and Geochemical Effects of Land-based Wastewater Disposal") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER E-NEWS Vol. 11 Issue 2, Spotlight on DWRC Graduate Research, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Oct2012.pdf , p. 2.
5. 2010DE186B ("The Impacts of Redefining Navigable Waters Under the Clean Water Act") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 11 Issues 1&2, DWRC Spotlight on Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 9.
6. 2011DE211B ("Hydraulic Properties of the Columbia Aquifer") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 11 Issues 1&2, DWRC Spotlight on Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 9.
7. 2011DE214B ("Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source ") - Articles in Refereed Scientific Journals - Levia, D.F., J.T. Van Stan, J.T., S.P. Inamdar, M.T. Jarvis, M.M. Mitchell, S.M. Mage, C.E. Scheick, and P.J. McHale, 2012, Stemflow and Dissolved Organic Carbon Cycling: Temporal Variability in Concentration, Flux, and UV-Vis Spectral Metrics in a Temperate Broadleaved Deciduous Forest in the Eastern United States, Canadian Journal of Forest Research, 42, 207-216.
8. 2011DE206B ("Sediment Transport through Historic Mill Dams of the Christina River Basin") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 3.
9. 2011DE208B ("Predation of Bacteria by the White Rot Fungi, Pleurotus ostreatus") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 3.
10. 2011DE209B ("Oyster Gardening in Delaware Inland Bays: Filtration as a Means to Remove Excess Nitrogen ") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 3.
11. 2011DE211B ("Hydraulic Properties of the Columbia Aquifer") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 3.
12. 2011DE212B ("Spatio-Temporal Hydrodynamic Variability in a Small Tidal Creek: DNERR St. Jones Reserve") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center

WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Luncheon and Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 2.

13. 2011DE214B ("Is Atmospheric Deposition and Washoff of Aluminum in Stemflow a Significant Source ") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 3.
14. 2011DE215B ("White Clay Creek Wild and Scenic Shad Restoration Project") - Other Publications - Pautler, M., ed., 2012, Delaware Water Resources Center WATER NEWS Vol. 12 Issues 1&2, DWRC Annual Luncheon and Poster Session - April 20, 2012, http://ag.udel.edu/dwrc/newsletters/Fall11Summer12/WATERNEWSco-Summer2012.pdf , p. 2.
15. 2007DE100B ("Modeling Hydrologic and Geochemical Effects of Land-based Wastewater Disposal") - Dissertations - Akhavan, M., 2012, Ph.D. Dissertation, Modeling Hydrologic and Geochemical Effects of Rapid Infiltration Basin Systems, Department of Civil and Environmental Engineering, College of Engineering, University of Delaware, Newark, Delaware.