Water Resources Center
Annual Technical Report
FY 2009

Introduction

Delaware Water Resources Center

June 1, 2010

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 2009.

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 2/3 of the state's wetlands are freshwater, and 1/3 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 53 as of 2009 . Of those, nine are all or almost all stormwater, and six sites have no activity or greatly reduced activity. NPDES permitting programs have been expanded to address pollution in stormwater runoff from concentrated animal feeding operations (“CAFOs,” 348 permittees), construction (2238 permittees as of April 2009), and ongoing industrial activities (406 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 Technology Available” 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 unknown. 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 2009 Evaluation Report - Delaware 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. Nothing is 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, 2008 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 five lakes/ponds and portions of 12 rivers in 2002. The primary pollutant is polychlorinated biphenyl (PCB). Chlorinated pesticides, dioxins, and mercury have also been identified. Though PCB's have long been banned they are persistent in the environment and are transported from land to waters through runoff to settle in waterbody sediments where they enter the aquatic food chain.

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 94% of Delaware's rivers and streams to not fully support the swimming use; 65% 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 high permeability 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.

Salt Water Intrusion: Problems with private wells occur sporadically from seasonal salt water 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.

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 Inland Bays and Nanticoke watershed 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.wr.dnrec.delaware.gov/Services/Pages/WatershedAssessment.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.wr.dnrec.delaware.gov/Information/OtherInfo/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 303(d) list is 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 stretches into 2010. 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.wr.dnrec.delaware.gov/Information/OtherInfo/Pages/WatershedAssessmentTDMLs.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 first PCS in the State, developed to address the TMDLs in the Inland Bays watershed, has been finalized and can be found at: http://www.dnrec.state.de.us/water2000/Sections/Watershed/ws/ib_pcs.htm. PCSs for the Appoquinimink, Broadkill, Christina, Murderkill, Nanticoke, St. Jones, and Upper Chesapeake (Chester and Choptank) watersheds have been drafted and will each go through a public review process in the near future. In the Inland Bays, Nanticoke, Murderkill, and Appoquinimink watersheds, the Tributary Action Team (TAT) process and the development of a draft PCS has taken many years. An expedited process was developed to shorten the PCS development process, which was used in the Christina, St. Jones, Broadkill, Chester, and Choptank watersheds. A Team is currently being developed in the Mispillion and Cedar Creek watersheds and additional teams are expected to be formed in other impacted watersheds over the next several years. To follow progress of the TATs or get more information about them, go to: http://www.dnrec.state.de.us/water2000/Sections/Watershed/ws/.

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 are 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 Soil and Water Conservation 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.swc.dnrec.delaware.gov/district/Pages/NPS.aspx, and information on Delaware's Coastal Management Program is available at: http://www.swc.dnrec.delaware.gov/coastal/Pages/CoastalPrograms.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 under review again by the Regulatory Advisory Committee. 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 overnments. 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 Marine and Earth Studies, 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 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, Associate 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 15- to 16-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 Institute for Soil and Environmental Quality at UD, the UD Departments of Biological Sciences, Bioresources Engineering, 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; Human Services, Education and Public Policy; 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 two Ph.D. graduate fellows supported during the period of this report, one is in the UD College of Earth, Ocean, and Environment and the other is in the UD College of Engineering. Their research focuses on hydrogeologic characterization of the Potomac Aquifer, Delaware, and modeling hydrologic and geochemical effects of land-based wastewater disposal.

(2) Undergraduate Internship Program: We initiated a highly successful undergraduate internship program in 2000. In the first nine years, 95 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, and Institute of Soil and Environmental Quality, 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 FY09 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 and a statewide water resources conference.

2009-2010 DWRC Fellowship and Internship Research Program

Two fellowships were funded for the third year in 2009-2010 based on satisfactory progress reporting to the DWRC Advisory Panel:

a) Hydrogeologic Characterization of the Potomac Aquifer, Delaware

Graduate Fellow: Claudia Velez; Advisors: Susan McGeary, Department of Geological Sciences, College of Earth, Ocean, and Environment, University of Delaware; and Peter McLaughlin, Delaware Geological Survey.

b) Modeling Hydrologic and Geochemical Effects of Land-based Wastewater Disposal

Graduate Fellow: Maryam Akhavan; Advisors: Paul Imhoff, Department of Civil and Environmental Engineering, College of Engineering, University of Delaware; and Scott Andres, Delaware Geological Survey.

Ten internships were awarded for 2009-2010 based on a review of proposals submitted by potential undergraduate interns and their advisors to the DWRC Advisory Panel:

a) Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest

Undergraduate Intern: Anna Bevan; Advisor: Delphis Levia, Department of Geography, College of Arts and Sciences, University of Delaware.

b) Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation

Undergraduate Intern: Victoria Bryan; Advisor: Steven Dentel, Department of Civil and Environmental Engineering, College of Engineering, University of Delaware.

c) Characterizing the Microbiome of the Eastern Oyster *Crassostrea virginica*

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

d) Newly Constructed Wetland Management: Year One

Undergraduate Intern: Aaron Hallett; Advisor: Chad Nelson, Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware.

e) Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil

Undergraduate Intern: Brian Jayne; Advisor: Anastasia Chirnside, Department of Bioresources Engineering, College of Agriculture and Natural Resources, University of Delaware.

f) Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware

Undergraduate Intern: Kelsey Lanan; Advisor: Tom McKenna, Delaware Geological Survey.

g) Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey

Undergraduate Intern: Emily Olson; Advisors: Clara Chan and Holly Michael, Department of Geological Sciences, College of Earth, Ocean, and Environment, University of Delaware.

h) Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal

Undergraduate Intern: Jennalee Rufft; Advisor: A. Scott Andres, Delaware Geological Survey.

i) Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs

Undergraduate Intern: Michael Ruppel; Advisor: Joshua Duke, Department of Food and Resource Economic, College of Agriculture and Natural Resources, University of Delaware.

j) Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources

Undergraduate Intern: Suneil Seetharam; Advisor: Shreeram Inamdar, Department of Bioresources Engineering, College of Agriculture and Natural Resources, University of Delaware.

Research Program Introduction

None.

Graduate Fellowship: Modeling Hydrologic and Geochemical Effects of Land-Based Wastewater Disposal

Basic Information

Title:	Graduate Fellowship: Modeling Hydrologic and Geochemical Effects of Land-Based Wastewater Disposal
Project Number:	2007DE100B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At Large
Research Category:	Water Quality
Focus Category:	Acid Deposition, Hydrogeochemistry, Groundwater
Descriptors:	
Principal Investigators:	Paul Imhoff, Maryam Akhavan, Alan Scott Andres

Publications

1. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 6.
2. Akhavan, M., P.T. Imhoff, and A.S. Andres, 2010, Modeling Hydrologic and Geochemical Effects of Land-Based Wastewater Disposal Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 13 pages.

Modeling Hydrologic and Geochemical Effects of Land-Based Wastewater Disposal

April 23, 2010

Principal Investigators:
Maryam Akhavan, Department of Civil and Environmental Engineering
A. Scott Andres, Delaware Geological Survey
Paul T. Imhoff, Department of Civil and Environmental Engineering

1. Background

Land-based wastewater treatment is the controlled application of wastewater to soil to remove constituents in the wastewater. In this system physical, chemical, and biological mechanisms within the soil matrix are used to treat the wastewater. A Rapid Infiltration Basin System (RIBS), also known as a Soil Aquifer Treatment system (SAT) or "infiltration-percolation" (Pound et al. 1973), is one of three major land treatment techniques commonly used for land-based wastewater treatment.

A RIBS typically treats a much larger volume of wastewater per unit area of land than other land-based methods. In this system, wastewater that is treated using primary, secondary, or advanced treatment techniques is applied to shallow basins constructed in permeable deposits of soil or sand. The wastewater is treated as it moves through the soil matrix by sorption, ion exchange, precipitation, and microbial degradation processes, if a RIBS is operated in a way appropriate for site conditions. Vegetation typically is not used for treatment in a RIBS, so no vegetation is planted in the basin. However, weeds and grasses may grow within the basins. Such vegetation may cause organic matter and fine-grained mineral matter to accumulate on the soil surface, altering soil porosity and interfering with soil aeration. These processes affect the hydraulic properties and the treatment performance of a RIBS; however, the impact of vegetation on a RIBS performance has not been previously investigated.

A RIBS is operated in repetitive cycles of flooding, infiltration, and drying. Key operational parameters include the ratio of wetting to drying time and the hydraulic loading rate, which affect pollutant residence time and nitrogen and phosphorus loads to the aquifer. They also alter water saturation and air content of the soil, which have an impact on nitrogen removal via denitrification (DNF). The optimum values of the wetting-drying cycle ratio and the hydraulic loading is expected to vary with the quality of applied wastewater, soil type, treatment objective, and climate.

Wastewater is typically distributed by surface spreading in a RIBS and basins are not usually completely flooded. They are only partially flooded because the discharge areas are typically designed larger than the areas required for treatment. Use of a low loading rate and overdesign of the required infiltration area in many RIBS causes non-homogeneous distribution of wastewater. In these cases, areas located farthest from the discharge valves are flooded only after the infiltration capacity of areas nearest the discharge valves is exceeded. Overland flow to more

distant areas of the infiltration beds is determined by hydraulic loading, infiltration, subsurface percolation, and subsurface lateral flow. Hence, consideration of surface flow coupled with subsurface flow is essential for simulating water movement and contaminant transport under the basin.

Wastewater treatment system effluents contain a number of potential groundwater and surface water contaminants, with the types of contaminants dependent on the performance of the treatment system. These contaminants can include a complex mixture of organic compounds, suspended solids, nitrogen (N), phosphorus (P), and other substances. If a RIBS is not designed appropriately, these constituents may enter groundwater or surface water and contaminate them. N and P compounds are usually enriched in applied wastewater and are of particular concern. These pollutants may accumulate in both the unsaturated and saturated zone and eventually contaminant groundwater and nearby surface water bodies.

2. Objectives

This study will elucidate the effect of different wastewater application rates and soil parameters on the hydraulic performance and treatment efficiency of RIBS. The results should provide important information that can lead to improved guidelines for the design and operation of RIBS. The overall objectives of this study are to evaluate the role of 1) soil development on RIBS performance, 2) subsurface porous media properties on RIBS performance, and 3) RIBS operating conditions on RIBS performance. For these objectives, the following hypotheses will be tested:

1-1) Soil development under vegetation for most permeable soils including coarse-grained soils leads to a low-permeable surface layer that reduces the infiltrability of a RIBS significantly.

1-2) Soil development under vegetation enhances DNF by providing a source of degradable carbon and interfering with soil aeration.

1-3) Soil development under vegetation enhances P removal by lowering the pore water velocity and increasing detention time.

2-1) Wastewater discharge in a heterogeneous media increases the probability of groundwater contamination by N and P since preferential flow may occur and allow wastewater to reach groundwater quickly.

2-2) Discharging wastewater on sandy soil (high permeable soil) leads to higher basin capacity and less contaminant removal, because water is quickly drained and pore water velocities are high. Conversely, discharging wastewater on loamy sand soil (less permeable soil) leads to less basin capacity and higher contaminant removal.

3-1) Discharging a fully nitrified effluent at the basin would have a counterproductive effect on DNF reactions; the presence of some amount of ammonia N is a required source of reductant for DNF.

3-2) DNF and N removal efficiency are higher in summers than winters because of greater microbial activity at higher temperatures.

3-3) Hydraulic loading rates as well as flooding duration can be designed to achieve optimal N and P removal rates. For example, the effluent discharge rate directly effects pore water velocities, and the flooding period has a direct impact on the saturation time. Both factors influence N and P removal.

3. Methodology

This study uses several different computer programs in conjunction with field data from a recently completed Delaware Geological Survey (DGS) study. Water and gas flow simulations are conducted using TOUGH2 (Pruess et al. 1999) and iTOUGH2 (Finsterle 1999). TOUGHREACT (Xu et al. 2004) and TOUGHREACT-N ((Maggi et al. 2008) (Gu et al. 2009)) will be used for modeling transport of N and P. The process-based TOUGHREACT-N incorporates environmental factors including soil temperature, soil moisture, and soil pH on microbial activity and N transformation to model its fate and transport. Field data from the DGS project are being used as input data for the simulations and for comparison to simulation results.

A two dimensional, axisymmetric, radial flow domain has been used as the model domain for most simulations to date. Soil development under vegetation is represented in the model as a thin surface layer with hydraulic properties specified for surface soils. Critical input data needed for these simulations are model parameters describing the pressure-saturation-permeability relationship for both gas and water in the surface soil and underlying porous media. Two approaches are used for obtaining these data: using data from the DGS field study or literature-reported data from field studies conducted at sites having similar soils, or using pedotransfer functions (PTF) to predict soil hydraulic properties. For understanding the effects of soil development under vegetation in different soil types, the PTF approach is applied. Properties

of 12 USDA soil textural classes are provided using the Rossetta database (Schaap et al. 2001). The hydraulic properties of the sandy loam textural class are used for the soil layer that develops under vegetation.

A key task in the last year has been to modify iTOUGH2 to include surface water flow. A diffusion wave (non-inertial wave) form of the Saint-venant equations was used to describe surface water flow. In this form of the Saint-venant equations, the inertial terms are neglected. This approach is more precise than the kinematic wave approximation, where inertial terms and the hydraulic head gradient are both neglected. For coupling the surface flow model to the subsurface flow model, a full coupling (simultaneous) scheme is used, the same approach employed in Weill et al. (2009). In this method, both systems –surface and subsurface– are solved together simultaneously.

Three test cases are used for validation of the new coupled code. These are overland flow model validation (Test 1), subsurface flow model validation (Test 2), and integrated surface/subsurface flow validation (Test 3). In order to obtain the optimum values for the wetting and drying cycles and hydraulic loading rate, alternative loading cycles and application rates are tested for different soil types and conditions.

4. Results and discussion

Validation of code for coupled overland-subsurface flow

Three test cases were used to validate the coupled overland-subsurface flow changes made in the iTOUGH2 code. In Test 1, a 30-min rainfall with 1.4×10^{-5} m/s intensity was simulated over a 183 m long parking lot (Figure 1). This test case examined only the utility of the surface water flow portion of the code. The discharge rates at the outlet at different times were compared with a 1D analytical solution of the kinematic wave approximation for surface water flow and the results of another code that used the same method for integration of surface and subsurface flow (Weill et al. 2009). There was good agreement between the iTOUGH2 and the Weill model predictions, which is shown in Figure 2. The diffusive wave approach, used in both codes, resulted in a smoother rise to the maximum outflow rate than the analytical solution. This occurred because of the diffusive term, which was absent in the more approximate analytical solution but included in both iTOUGH2 and the Weill code.

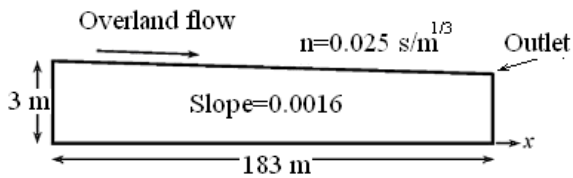


Figure 1. Schematic of the test case.

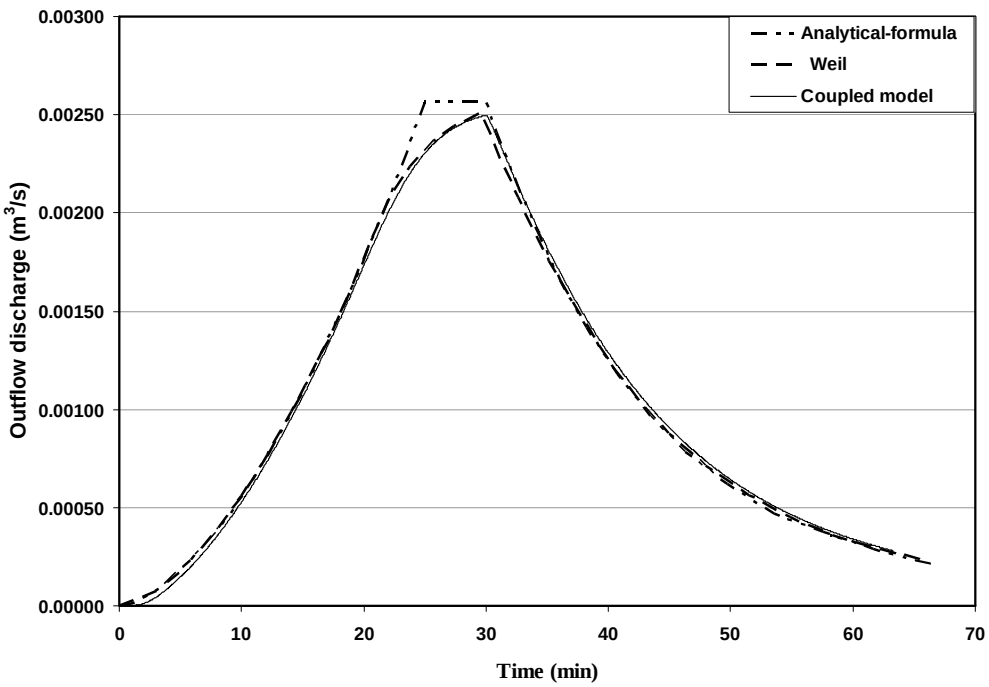


Figure 2. Comparison between the modified iTOUGH2 code, Weil (Weill et al. 2009), and the analytical solution

To verify that the subsurface flow portion of the modified code was correct, in Test 2 groundwater flow through a one-dimensional saturated soil column was simulated. Data from the model results were then used to compute the saturated hydraulic conductivity of the soil, K_s, which was known. Equation 1 was used to calculate the saturated hydraulic conductivity of the soil from the simulation.

$$K_s = \frac{L}{t_1} ln\left(\frac{b_0 + L}{b_1 + L}\right) \tag{1}$$

where b_0 is ponding depth at the initial time, b_1 is the ponding depth at $t = t_1$, and L is the soil column length. The results at different times were in excellent agreement with the known K_s, which was defined as an input parameter in the model.

In Test 3 the experiment conducted by (Abdul and Gillham, 1984) was used to verify the integrated surface/subsurface flow code. Weill et al. (2009) also used this experiment to verify their code. The experiment was conducted in a Plexiglas sandbox 140 cm long, 120 cm high and 8 cm wide (Figure 3). The outlet of the system was located at the toe of the slope, and the initial conditions were defined by an equilibrium head distribution with the water table located at the toe of the slope. A 1.2×10^{-5} m/s constant rainfall rate was applied for 20 min across the entire surface. For code verification, the outflow at the toe of the slope predicted by the code was compared with experimental measurements and Weil's simulation results (Figure 4). The fluxes presented in this figure were normalized by the rainfall flux imposed at the surface. Good agreement between the iTOUGH2 simulation and Weil's simulation was observed for this case too. There were some differences, though, between both simulations and the actual laboratory data, which is likely due to the approximations inherent in application of the diffusive wave form of the Saint-venant equations.

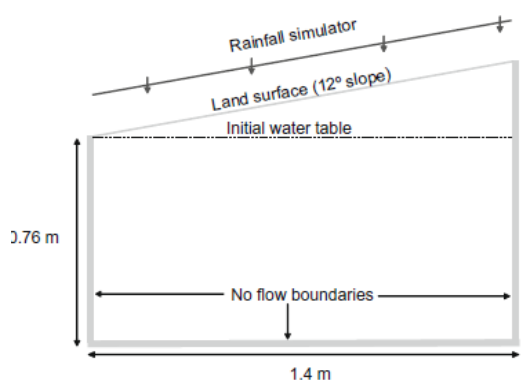


Figure 3. The Abdul and Gilham system. Figure taken from Weill, S., Mouche, E., and Patin, J., *Journal of Hydrology*, 366(1-4), 9-20, 2009.

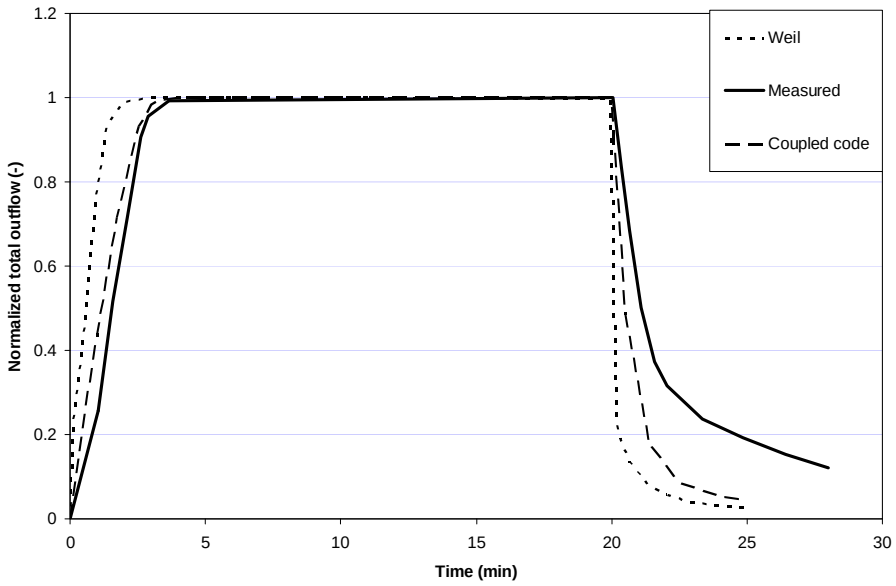


Figure 4. Simulated (Weil and iTOUGH2 codes) versus measured flow

Examination of alternative hydraulic loading cycles on a RIBS performance

The impact of alternative hydraulic loading cycles on a RIBS performance was examined. Figure 5 shows the model domain considered for these simulations, a two dimensional, axisymmetric, radial domain that was 14 m in radius and 20 m in depth. The RIBS was assumed to be circular with the radius of 6 m, and wastewater was discharged through a discharge valve located at the centre of the basin. Atmospheric pressure and no-flow boundary conditions were applied to the top and bottom boundaries of the model, respectively. The boundary on the right hand side of the domain was specified as constant hydraulic head.

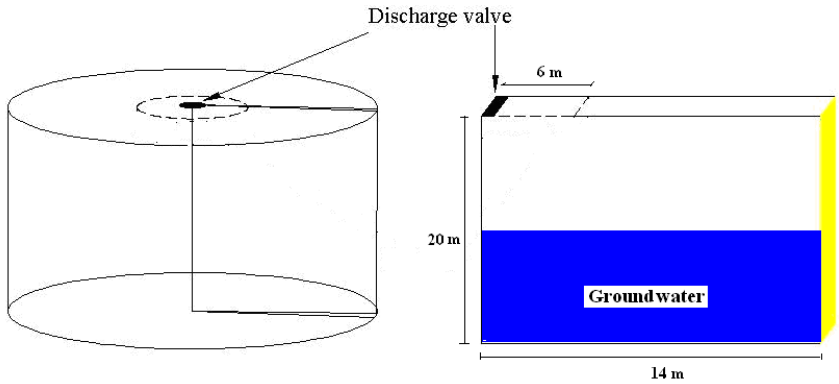


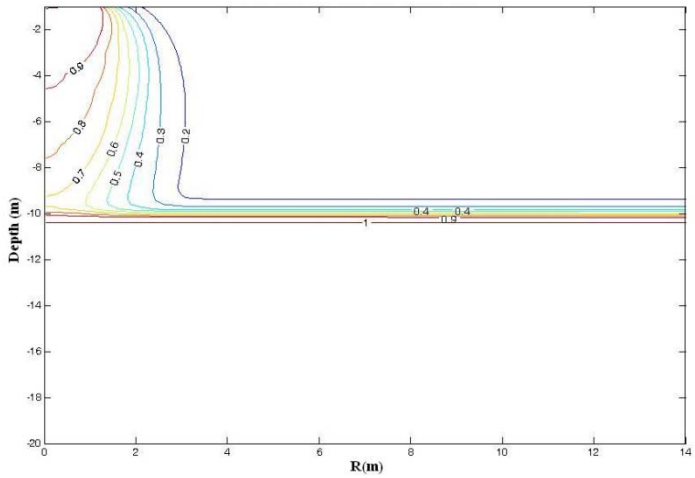
Figure 5. Schematic diagram of the conceptual radial model domain

The impact of three different hydraulic loading cycles were examined, which are described in Table 1. Because of the impact of water saturation and air content of the soil on DNF reactions, water saturation contours and water content profiles of the soil through time were compared for these three cycles.

Figure 6 shows the maximum water saturations achieved at each point in the domain over a 7 day-period for each of the three loading cycles. Figure 7 shows the water saturation versus time at a section located 1m from the centre of the basin. The figures indicate that using a long flooding cycle (12h cycle) causes a higher-saturated water front to reach the greatest depth.

Table 1. Different cycles of flooding/drying

Simulation ID	Operation time		Discharge rate (kg/s)	Total discharged water (m^3)
	Day 1	Day 2-7		
12h-cycle	12h flooding 12h drying	Drying	0.393	16.96
8h- cycle	8h flooding-8h drying -8h flooding	Drying	0.294	16.96
2h- cycle	2h flooding-2h drying-… 2h flooding-2h drying	Drying	0.393	16.96



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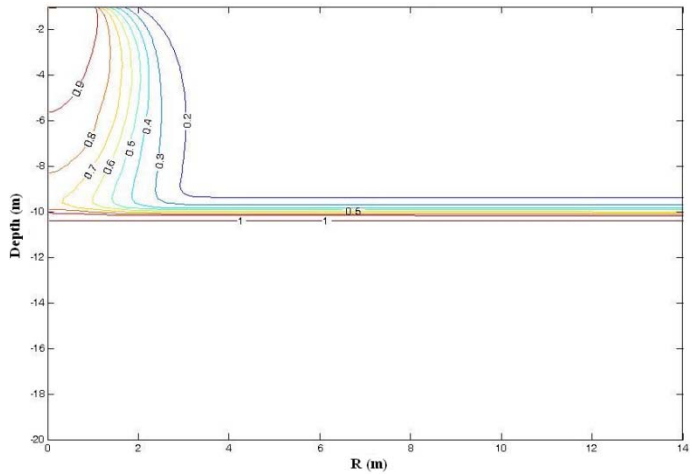

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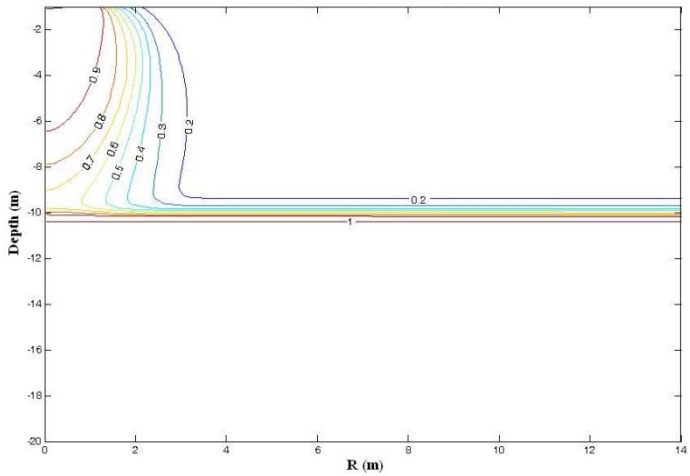
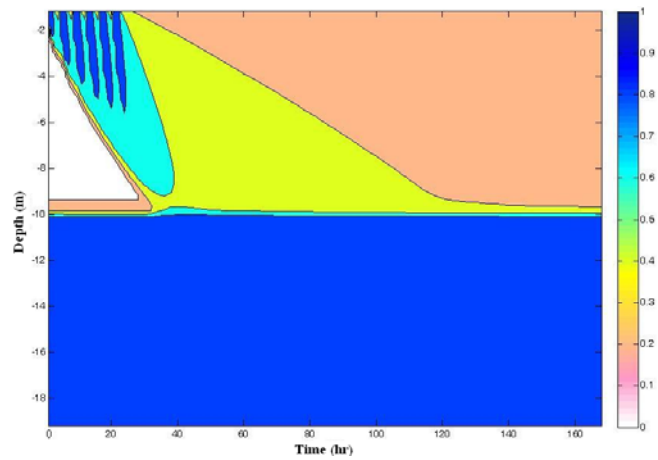
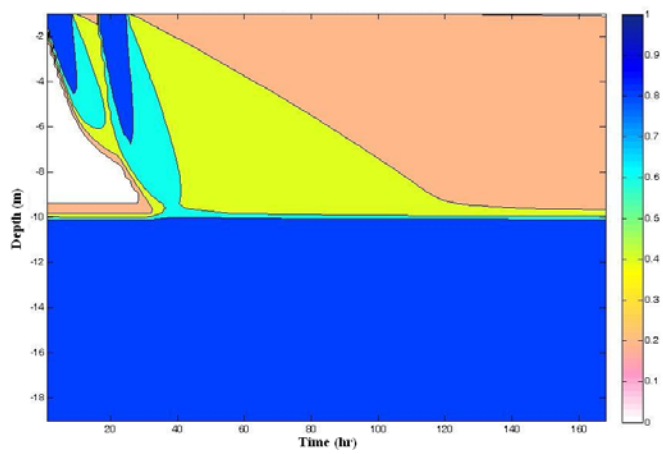


(c)

Figure 6. Maximum water saturation in 7 days a) 2h, b) 8h, and c) 12h cycles.



(a)



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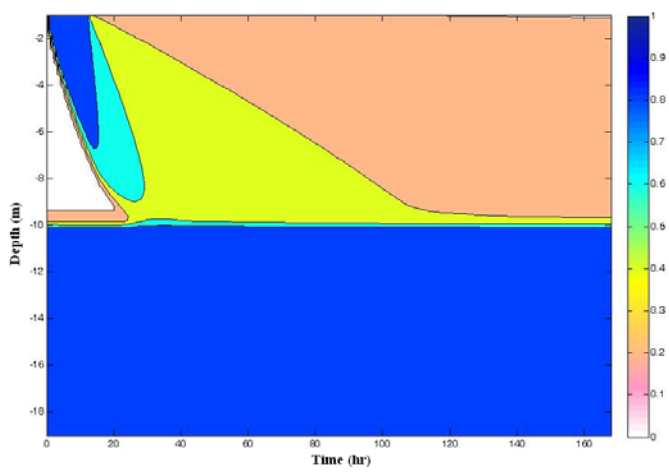

(c)

Figure 7. Water saturation profile at $r = 1\,\text{m}$ from the centre of the basin for a) 2h, b) 8h, and c) 12h cycles. Darker colors represent higher water saturations.

4. Conclusions and project implications (Accomplishments to Date)

1- After studying different approaches for coupling overland flow and subsurface flow, the most accurate one that was appropriate for RIBS was chosen and implemented in the iTOUGH2 code.

2- Three test cases were simulated to verify the modified code. The results demonstrated that the code changes were implemented properly.

3- Different groups of simulations were performed to assess the effect of vegetation, soil types, and operation methods on hydraulic aspect of RIBS.

- For simulating the effect of vegetation on hydraulic aspect of RIBS, water retention parameters predicted by PTF for sandy loam textural class were used. The results for this group of simulations were not presented in this report due to some ongoing convergence problems that have limited the duration of the simulations. Additional code modifications may be needed to simulate these cases for long time periods.

  The effect of vegetation was previously investigated without consideration of overland flow. In those simulations, a constant ponding depth was considered as a top boundary condition for the flooding period. These results indicated that vegetation growth in coarser sandy soil decreased the steady state infiltration rate, but did not have a significant effect on the infiltration rate in finer sandy soils.
- For understanding the effects of different operation methods on RIBS performance, three different cycles of flooding and drying were tested. The results indicate that using a long flooding cycle causes the saturated water front to extend to greater depth than shorter cycles.
- Although the effect of different cycles of wetting /drying on the DNF and P removal processes cannot be clearly understood from the water flow simulations alone, these results indicate that hydraulic loading will affect water distributions and most likely RIBS

treatment performance. Future work will simulate the fate of N and P using TOUGHREACT-N.

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Graduate Fellowship: Hydrogeologic Characterization of the Potomac Aquifer, Delaware

Basic Information

Title:	Graduate Fellowship: Hydrogeologic Characterization of the Potomac Aquifer, Delaware
Project Number:	2007DE97B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At Large
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Supply, Water Quality, Toxic Substances
Descriptors:	
Principal Investigators:	Susan McGeary, Peter McLaughlin, Claudia Velez

Publications

1. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 1 DWRC Spotlight on Graduate Research, http://ag.udel.edu/dwrc/newsletters/Summer09Fall09/WATERNEWSco-Fall2009.pdf , p. 6.
2. Zullo (Velez), C., S. McGeary, and P.P. McLaughlin, 2010, Hydrogeologic Characterization of the Potomac Aquifer, Delaware Progress Report, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 7 pages.

Progress Report
Delaware Water Resources Center Graduate Fellowship Project:
"Hydrogeologic Characterization of the Potomac Aquifer, Delaware"

Submitted by

Claudia Zullo
Graduate Fellow
Department of Geological Sciences, University of Delaware
clave@udel.edu

Dr. Susan McGeary
Advisor, Chair and Associate Professor
Department of Geological Sciences
smcgeary@udel.edu

Dr. Peter P. McLaughlin, Jr.
Advisor, Senior Scientist
Delaware Geological Survey, University of Delaware
ppmclau@udel.edu

April 23, 2010

Introduction

The Potomac Formation of northern Delaware is the second most used aquifer in Delaware and the most important confined aquifer, providing nearly 20% of the groundwater used each year in the state (Wheeler, 2003). The purpose of this study is to develop a better understanding of the geologic framework of the Potomac aquifers in the area of the Chesapeake and Delaware Canal through a multidisciplinary investigation that integrates geophysical and geological data. This study will delineate the distribution and extent of aquifer sands, and thereby help to better understand aquifer connectivity and fluid flow pathways. The methodology will employ a novel combination of tools, combining seismic reflection imaging of subsurface geology with analysis of wireline geophysical data from boreholes, collection of core data from the subsurface geologic units, and application of the concepts of sequence stratigraphy. The resulting geologic framework will be tested against hydrological data and observations from the Potomac aquifer. The resulting understanding of aquifer architecture will have significant application to issues in *water supply*, notably a framework of aquifer volume and connectivity for water-use allocations, and in *water quality*, particularly the identification of potential ground-water contaminant pathways below industrial sites in the Delaware City area.

Objectives

Overall project objectives are:

1) Collect approximately 30 km of intersecting seismic profiles in a 12 km by 12 km area across the buried Potomac Formation down to a depth of about 150 to 300 m (modified slightly from original proposal);
2) Collect 3.5 km of conventional seismic data in farm fields in the study area (newly added objective);
3) Process the seismic reflection data to image subsurface stratigraphy in each profile;
4) Drill two new coreholes and collect geophysical logs at new coreholes and wells,
5) Correlate prominent reflections with the existing and new core, well-log, and geohydrologic database;
6) Interpret the seismic profiles and borehole data to create a 3-dimensional model of the subsurface fluvial architecture within a sequence-stratigraphic framework.

Specific goals for the year 2009 – 2010 are:

1. Produce final processed images for seismic facies interpretation and stratigraphic correlation with existing geophysical logs and new core
2. Drill a corehole and obtain a complete set of geophysical logs
3. Make a facies classification using the core and correlate it with the seismic data using the set of geophysical logs through the generation of a synthetic seismogram
4. Interpret the seismic sections
5. Create cross sections and maps by correlating the interpreted seismic sections with existing geophysical logs in the study area

Methodology

The methodology used to characterize the hydrogeology of the Potomac aquifer in this project includes:

- Seismic data collection with conventional seismic equipment and a land streamer system.
- Seismic facies analysis using amplitude, frequency, and continuity of the reflections.
- Stratigraphic correlation of well logs using pattern matching and marker beds.
- Coring near the collected seismic lines to characterize the lithofacies and calibrate them to seismic character.
- Synthetic seismogram construction to correlate well logs with seismic sections
- Facies mapping, using seismic data and available well data, to show the distribution of the sand bodies of the Potomac Formation.

Summary of accomplishments for this reporting year (through 23 April, 2010)

A number of significant scientific accomplishments were made during the past year, including the following:

- ***Seismic data processing completed.*** Processing was completed at the beginning of the fall semester (2009). The theoretical resolution for this data is 2 m to 4 m with frequencies ranging from 130 Hz to 160 Hz with velocities 1650 m/s to 1900 m/s which is sufficient to resolve aquifer sands in the Potomac Formation ranging from 10 m to 20 m thick.
- ***Drilling of corehole completed***. A five hundred feet corehole was drilled with the DGS drilling rig in collaboration with DGS staff and Geology Department students in August 2009 at the Summit Marina, C&D canal area. The location of the corehole was 70 m away from one of the seismic lines. A complete set of geophysical logs, including a sonic log, was obtained.
- ***Facies Classification completed.*** During the fall semester I made a facies classification of the core samples and made a classification of geophysical log patterns corresponding to those facies. Six facies were identified: paleosols, lake, frequently flooded lake/abandoned channel, levee/splay, splay channel, and active channel (Figure 1).
- ***Core-seismic tie completed***. At the beginning of 2010, the sonic log was used to produce a synthetic seismogram to correlate the seismic data and the core. The synthetic seismogram is an important tool for interpretation, providing ground truth for the interpretation of the seismic section. On the basis of this tie, I made a preliminary seismic attribute characterization (Figure 2 and Figure 3).
- ***Seismic section interpretation underway.*** Currently I am tracing seismic horizons to subsequently identify seismic facies bounded by a given set of horizons. We are in the process of evaluating the acquisition of a seismic interpretation software for this purpose. It is expected that the seismic section interpretation will be completed between now and the end of my fellowship term (June 30, 2010).

- ***Selection of existing geophysical logs for maps and cross sections.*** This task will be performed concurrently with the seismic section interpretation and be completed between now and the end of my fellowship term (June 30, 2010). Gamma, resistivity, and spontaneous potential logs of wells more than 200 ft deep will be selected.

In addition to those accomplishments, in the last year I had two papers accepted and presented at national scientific meetings. Both were given as posters in technical poster sessions and the abstracts published in the meting proceedings. I also had a poster presentation at a student expo.

1. Velez, C. C, McLaughlin, P. P, McGeary, S. E, Sargent, S. L (2009), Land Streamer Seismic Data from Northern Delaware: a Viable Alternative for Imaging Aquifers in Suburban Areas, *Eos Trans. AGU*, *90*(52), Fall Meet. Suppl., Abstract NS13A-1136
2. Velez, C., McLaughlin, Peter. P, McGeary, Susan, Sargent, Steven L (2010), Seismic Imaging of a Cretaceous Fluvial System, AAPG Annual Convention and Exhibition, Abstracts Volume, Abstract 728937, p. 264.
3. Velez, C., McLaughlin, Peter. P, McGeary, Susan, Sargent, Steven L (2009), Seismic Imaging of a Cretaceous Fluvial System: Results from an Ongoing Study of the Potomac Formation in Northern Delaware, AAPG-SEG Student Expo, Houston, TX.

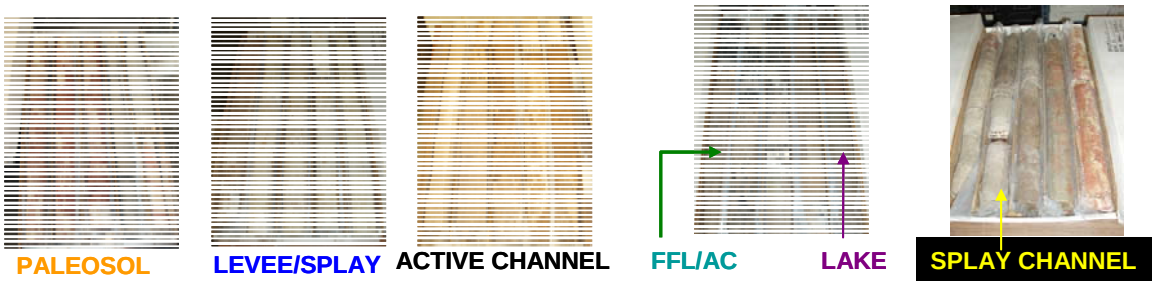
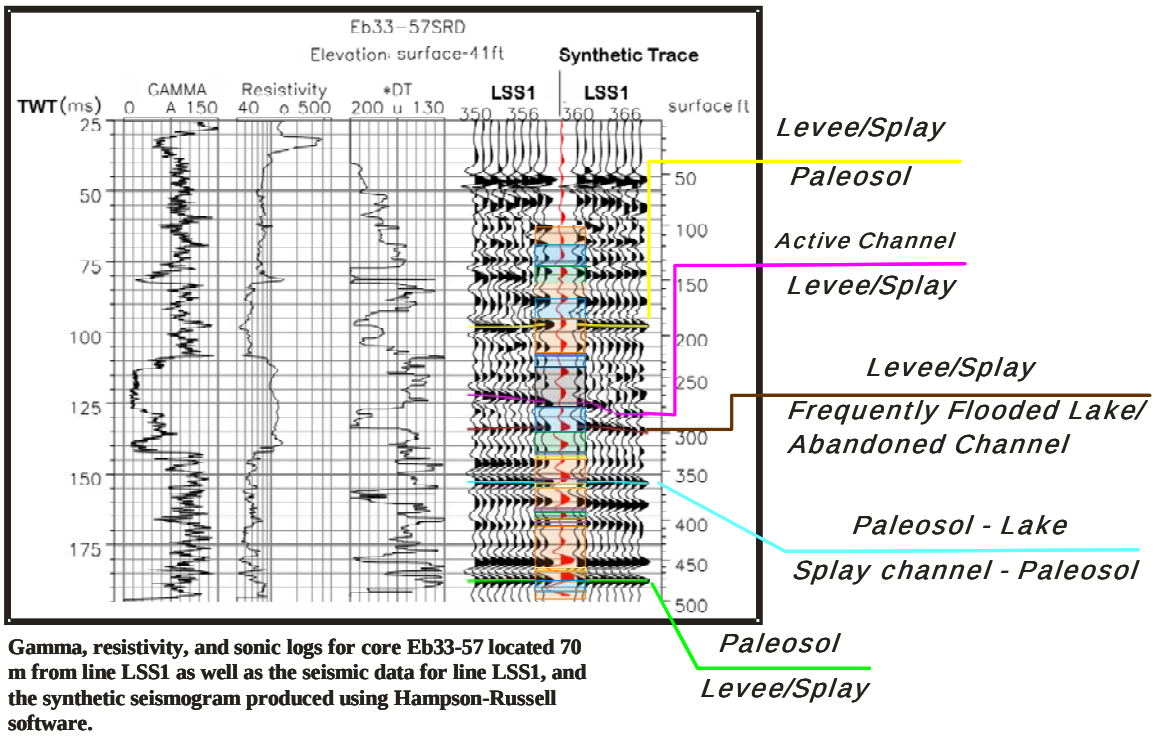


Figure 1. Facies classification for the Summit Marina core. FFL/AC= frequently flooded lake/abandoned channel. The paleosol (3 - 55 ft) and lake (2 - 8 ft) facies consist mostly of clay and silt with small percentages of clayey-very fine sands present in the paleosols. The levee/splay (10 - 20 ft) and frequently flooded lake/abandoned channel (7 – 30 ft) facies consist of sand, and interbedded/interlaminated sand, silt, and clays. The splay channel (2 – 4 ft) and active channel (44 ft) consist of very fine to medium sand, and fine to coarse sand with some silt and clay. In terms of aquifer/aquitard character the paleosol and lake facies would likely function as aquitards; and the active channel facies comprise the best aquifer lithologies.



Gamma, resistivity, and sonic logs for core Eb33-57 located 70 m from line LSS1 as well as the seismic data for line LSS1, and the synthetic seismogram produced using Hampson-Russell software.

Figure 2. Core-seismic tie. The resistivity log shows a thick zone of aquifer character from 223.1 to 330.4 ft, and a thin one from 139 to 152.5 ft. The thick zone is resolved in the seismic section, but the thin zone is not resolved. Most of the paleosol facies, which are over 4 m thick and show aquitard character on the resitivity log, are also resolved on the seismic section. These findings suggest that either aquifer or aquitards thicker than 4 m (13 ft) can be resolved in the seismic data.

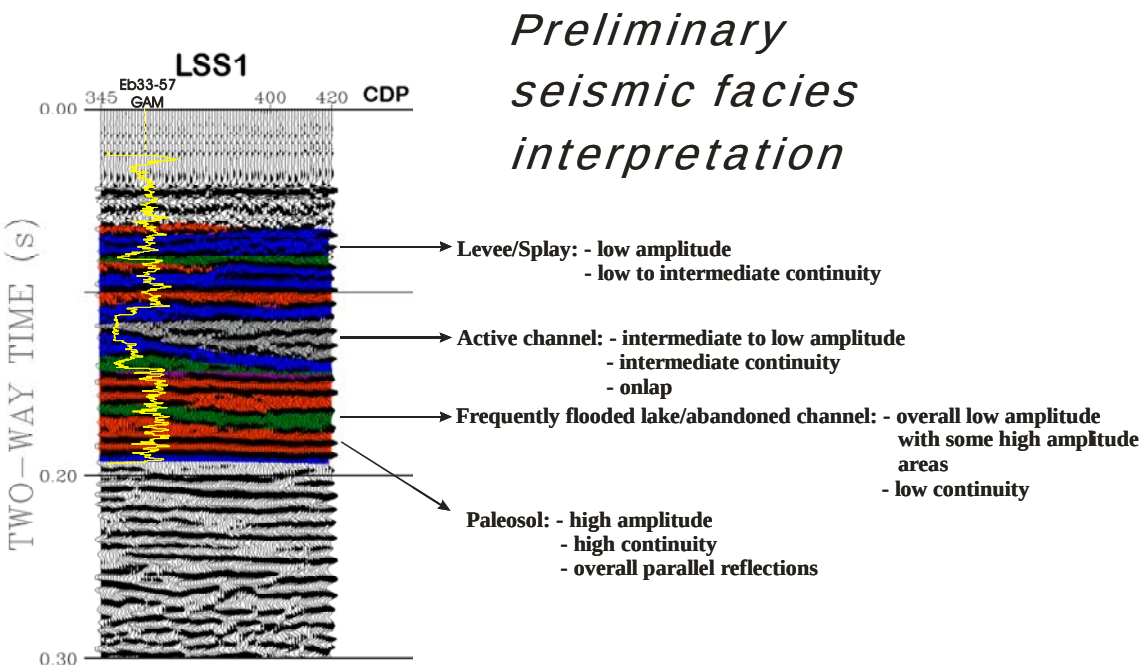


Figure 3. Integrated facies classification. Each of the facies based on lithology is characterized by a set of seismic attributes that allows us to make a seismic facies classification. This classification can be extrapolated along the seismic section to delineate the geometry and determine the extent of each facies. This preliminary interpretation suggests that the aquitard character is defined by high amplitude and high continuity of the reflections, and that the aquifer character is defined by intermediate to low amplitude, and low to intermediate continuity of the reflections.

References

Wheeler, J.C., 2003, Freshwater use in Delaware, 2000: Report FS 0111-03, 2 p.

Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest

Basic Information

Title:	Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest
Project Number:	2009DE151B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geochemical Processes, Nutrients, Hydrology
Descriptors:	
Principal Investigators:	Delphis Levia, Anna Bevan

Publications

1. Bevan, A. and D. Levia, 2010, Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest, Delaware Water Reources Center, University of Delaware, Newark, Delaware, 4 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.

Undergraduate Internship Project #1 of 10 for FY09

Intern ***Anna Bevan's*** project, sponsored by the ***DWRC***, was titled "Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest." She was advised by Dr. Delphis Levia of the ***UD's*** Department of Geography.

Abstract

The overarching goal of the project is to better understand how base cations are cycled from a deciduous forest canopy. Using a combination of field and laboratory techniques, our study has shown that both throughfall and stemflow chemistry change within individual precipitation events as a function of originating sources. Dry deposition and canopy leaching were the two primary sources for base cations in the experimental forest. Sodium (Na) is primarily derived from dry deposition wash-off, whereas magnesium (Mg), calcium (Ca), & potassium (K) are primarily leached. Our study suggests that the alterations in canopy fluxes of base cations during individual precipitation events may be responsible for the temporal and spatial heterogeneity of nutrient routing to the forest floor.

Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil

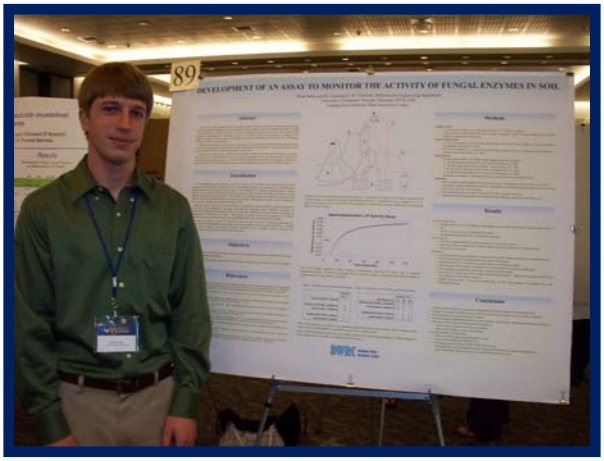
Basic Information

Title:	Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil
Project Number:	2009DE153B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Biological Sciences
Focus Category:	Wastewater, Water Quality, Toxic Substances
Descriptors:	None
Principal Investigators:	Anastasia Chirnside, Brian Jayne

Publications

1. Jayne, B., and A. Chirnside, 2010, Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 8 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2009, Delaware Water Resources Center WATER E-NEWS Vol. 8 Issue 5 Spotlight on 2009-10 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Oct2009.pdf , p. 2.

Undergraduate Internship Project #2 of 10 for FY09



Intern ***Brian Jayne's*** project, sponsored by the ***DWRC***, was titled "Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil." He was advised by Dr. Anastasia Chirnside of the ***UD's*** Department of Bioresources Engineering.

"Through my research, I developed an appreciation for organisms as seemingly simple as fungi for their abilities to aid us in some of our most complex environmental problems." – Brian Jayne

Abstract

The white rot fungus, *Phanerochaete chrysosporium*, produces non-specific enzymes, including lignin peroxidase (LiP) and manganese-dependent peroxidase (MnP), that are able to degrade various environmental pollutants. The goal of this research was to develop an assay to monitor and accurately measure the activity of LiP and MnP during treatment of contaminated soil. The process consisted of growing the fungus in a packed-bed reactor and collecting the effluent, which contained extracellular enzymes. The effluent could be tested for enzyme activity using a continuous spectrophotometric assay of the oxidation of substrate. The enzyme solutions were added to dry soils and mixed. Various buffer solutions were then added to the soil samples to attempt to extract the enzymes back out of the soil. These buffer solutions included 100 mM phosphate buffer, 500 mM acetate buffer, 50 mM acetate buffer, and 50 mM bicarbonate buffer. These samples were centrifuged, and the liquid was analyzed using the spectrophotometric assay. During further experimentation, these centrifuged liquids were saturated to 80% with $(NH_4)_2SO_4$ to precipitate the enzymes and leave smaller interfering molecules dissolved. This purification step was used on both extracted buffer solutions and fresh extracellular enzyme solution.

Results were variable and indecisive throughout the research. None of the buffer solution extraction trials resulted in measurable enzyme activity. There were indications, however, that some activity may have been present at times, so extraction by treatment with a buffer solution may be a feasible practice. The purification steps with extracted buffer solutions also did not result in measurable enzyme activity. Purification steps on fresh extracellular enzyme solution that had not been added or extracted from soil demonstrated inconsistent but measurable enzyme activity. Activity was found in both redissolved pellet solution from $(NH_4)_2SO_4$ precipitation as well as the supernatant of this reaction. This suggests that some enzyme precipitation and interaction did occur; thus, the purification steps may also be feasible with further research. Several recommendations for future work are provided, such as proper cold storage of enzyme solutions, renewed fungus growth reactor, and reduced dilution of the enzymes in the soil from the addition of large buffer solution quantities.

Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs

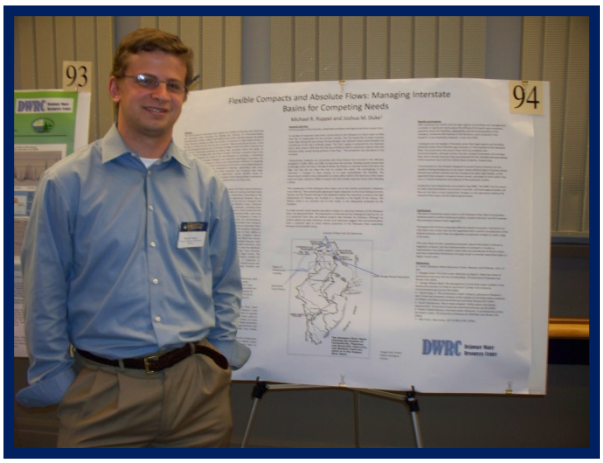
Basic Information

Title:	Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs
Project Number:	2009DE154B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Social Sciences
Focus Category:	Ecology, Water Quantity, Economics
Descriptors:	
Principal Investigators:	Joshua Duke, Michael Ruppell

Publications

1. Ruppel, M. and J. Duke, 2010, Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 36 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2010, Delaware Water Resources Center WATER E-NEWS Vol. 9 Issue 1 Spotlight on 2009-10 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Feb2010.pdf , p. 1.

Undergraduate Internship Project #3 of 10 for FY09



Intern ***Michael Ruppel's*** project, co-sponsored by the ***DWRC*** and the ***UD's*** College of Agriculture and Natural Resources was titled "Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs." He was advised by Dr. Joshua Duke of the ***UD's*** Department of Food and Resource Economics.

"With the assistance of Dr. Duke, I was able to develop a research question that would allow me to further explore connections between law, economics and environmental management. The DWRC's generous funding allowed me to study this intersection in the context of the Delaware River Basin Compact, an important river governance law that required further analysis, specifically in the context of other federal environmental laws. Our work, which concluded that compacts may not be as efficient as previously suggested, has important ramifications for interstate water management. My experience with the DWRC was beneficial to developing my research and analytical skills, and provided me with an opportunity to engage in significant and timely research, an experience that I will draw on greatly in future academic and professional endeavors." – Michael Ruppel

Abstract

The article frames an interstate water dispute as a conflict of interests with distinctive but associated water demands. By defining the interests of environmentalists, municipal water drinkers, anglers and residents, the article critically analyzes the ability of the interstate compact to allow the transfer of resources to high-valued parties in the face of a Supreme Court Decree and a powerful federal environmental law, in this case the Endangered Species Act. As instream ecological needs and other national river interests are increasingly protected by federal laws, questions about the ability, or need, of states to manage their river basins through interstate compacts need to be answered. The compacts are found to be well-equipped at providing a centralized scientific authority for complex ecological and especially hydrological questions, yet the Delaware River Basin Compact is shown to be substantively inefficient in assigning rights to high-valued parties, and the institutional environment surrounding Delaware River management is shown to be composed of absolute rightholders who have difficulty transferring flow rights. The article concludes that compacts that make tangential mention of future needs for watersheds cannot actually create an institutional environment where future values matter unless they provide a mechanism allowing those new interests to be recognized substantively once they arise.

Newly Constructed Wetland Management

Basic Information

Title:	Newly Constructed Wetland Management
Project Number:	2009DE155B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Water Quality
Focus Category:	Wetlands, Hydrology, Ecology
Descriptors:	
Principal Investigators:	Chad Nelson, Aaron Hallett

Publications

1. Hallett, A. and C. Nelson, 2010, Newly Constructed Wetland Management: Year One, Delaware Water Resources Center, University of Delaware, Newark, Delaware.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2010, Delaware Water Resources Center WATER E-NEWS Vol. 9 Issue 2 Spotlight on 2009-10 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Mar2010.pdf , p. 1.

Undergraduate Internship Project #4 of 10 for FY09

Intern ***Aaron Hallett's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Agriculture and Natural Resources***, was titled "Newly Constructed Wetland Management: Year One." He was advised by Mr. Chad Nelson of the ***UD's*** Department of Plant and Soil Sciences.

"I look forward to returning to watch the wetland develop as an ecosystem in the future. It is clear to me that wetlands are dynamic, evolving spaces, and I am eager to watch this one develop." – Aaron Hallett

Abstract

Wetlands are an extremely important part of our environment; their ability to clean water and act as sponges to protect us from floods is only the beginning. Because wetlands have historically been drained to transform the land into more lucrative cropland, there has been an overall loss of wetland area. However, since 1972, the United States government has had a policy of "no net loss" of wetlands, meaning if permits are given to drain a wetland for a given purpose, the loss of the original wetland is "mitigated" by the creation of new wetland areas. The challenge in newly-created wetlands is working to achieve the complex services, both biological and mechanical, that are offered by naturally-occurring wetlands, and to achieve relative stability in the new ecosystem within a reasonable period of time.

To study this establishment period for newly-created wetlands, the University of Delaware College of Agriculture and Natural Resources (UD CANR) joined forces with the Delaware Department of Natural Resources and Environmental Control (DNREC) to transform a roughly two-acre wet pasture into a managed wetland to improve and protect water quality at the headwaters of the Cool Run Creek watershed. Primary goals in the project were to improve water quality and enhance habitat; the site also serves as a research, teaching, and demonstration area. For this project I was involved in the design, execution, and establishment of the new plantings. View corridors were created to retain a sense of place by allowing visitors to still see the farm structures beyond the wetland. A pathway gives visitors and students access to habitat that is often unreachable without hip waders.

It is important to recognize that with newly constructed wetlands there is a great deal of management required in the first few years. Without such management the goals intended for the site are unlikely to be achieved. In this study I was directly involved in the establishment and monitoring of the new wetland, where I was able to learn firsthand about the factors and challenges involved. Top among these are selection of appropriate plant species, budgeting and logistics of executing a planting design, and follow-up monitoring and care addressing invasive plant species, water levels, and animal browse and use of wetland habitat. In this study I track the key challenges encountered during the first year of establishment and offer perspective on how these challenges are best met.

Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation

Basic Information

Title:	Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation
Project Number:	2009DE157B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Engineering
Focus Category:	Water Supply, Treatment, Water Use
Descriptors:	
Principal Investigators:	Steven K Dentel, Victoria Bryan

Publications

1. Bryan, V. and S. Dentel, 2010, Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 9 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.

Undergraduate Internship Project #5 of 10 for FY09

Intern ***Victoria Bryan's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Engineering***, was titled "Addition of Fine Particles Mitigates Flux Decline in Direct Contact Membrane Distillation." She was advised by Dr. Steven Dentel of the ***UD's*** Department of Civil and Environmental Engineering.

Abstract

Direct contact membrane distillation (DCMD) is a method of desalination that may be of increasing importance as fresh water sources decline worldwide. Membrane fouling is a key issue that arises during desalination. It is caused by salt precipitation on the membrane surface and/or in the membrane pores and results in decreased performance and water quality. In an attempt to mitigate membrane fouling, aluminum oxide, silica, and kaolinite clay fine particles were added separately to a saltwater solution to act as a precipitation surface for the salts. The flux observed with silica and clay in solution was high and increased gradually over 150+ hours. The flux of aluminum oxide in solution declined gradually and became equal to the flux of DI water after approximately 280 hours. Based on these results, it is reasonable to say that the addition of fine silica and kaolinite clay particles can mitigate flux decline in direct contact membrane distillation. These results could help DCMD become a more cost efficient process and therefore a more widely used process.

Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey

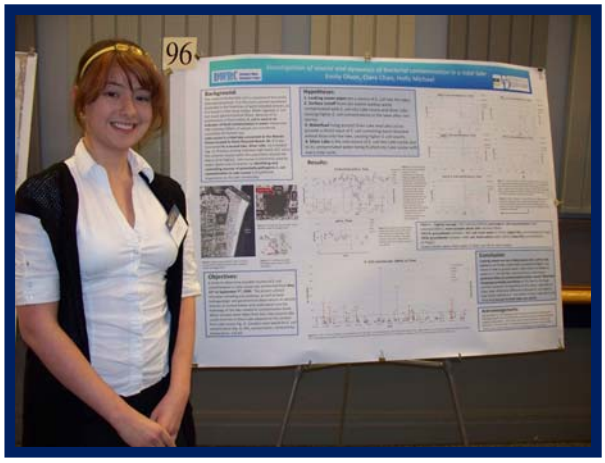
Basic Information

Title:	Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey
Project Number:	2009DE159B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Toxic Substances
Descriptors:	
Principal Investigators:	Clara Chan, Emily Olson

Publications

1. Olson, E., C. Chan, and H. Michael, 2010, Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 24 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 10 Issue 1 DWRC Spotlight on 2009-10 Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/Summer09Fall09/WATERNEWSco-Fall2009.pdf , p. 3

Undergraduate Internship Project #6 of 10 for FY09



Intern ***Emily Olson's*** project, co-sponsored by the ***DWRC*** and the ***UD's College of Earth, Ocean, and Environment***, was titled "Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake in Point Pleasant Beach, New Jersey." She was advised by Drs. Clara Chan and Holly Michael of the ***UD's*** Department of Geological Sciences.

Abstract

The coliform *Escherichia coli* is bacterium of the family *Enterobacteriaceae*. *E. coli* is the most common facultative anaerobe in the intestines of warm blooded animals and it is found in their fecal matter. When ingested, *E. coli* can cause gastrointestinal illness. Because of its prominence in fecal matter, *E. coli* is used as an indicator of fecal contamination in water. An investigation into the amount of fecal contamination and its sources in a tidal lake, Lake Louise in Point Pleasant Beach, NJ, was launched over the summer of 2009. Lake Louise is connected to the Atlantic Ocean through the Manasquan River, and it is also connected to a second lake, Silver Lake, via a conduit. Previous testing indicated high levels of *E. coli* in the summer season when the population around the lake is at its highest. Lake Louise is commonly used for water sports and recreation, so identifying and controlling sources of potentially pathogenic *E. coli* contamination in Lake Louise is of particular importance to the lake community. The project utilized microbial sampling and analyses, as well as basic hydrogeologic and geochemical observations to identify sources of contamination and understand how the hydrology of the lake related to contamination levels. Water samples were taken from four sites around Lake Louise and one in Silver Lake adjacent to the conduit from Lake Louise. Groundwater sampling, drain water sampling, and a 7x7 matrix sampling of the lake were performed as well. Samples were tested for *E. coli* concentration, NO_3 concentration, conductivity, temperature, and pH in order to determine if the source of contamination to Lake Louise was 1) leaking sewers, 2) surface runoff, 3) waterfowl, or 4) Silver Lake. It was determined that groundwater would not likely transport *E. coli* from a leaking sewer to the lake. Rain events often correlated with spikes in *E. coli* concentrations at all sites, making rainfall runoff a likely source of contamination to Lake Louise. Based on observation and literature on the subject, waterfowl have the potential to directly contribute *E. coli* into the lakes by depositing their fecal matter on shore and in the water. The testing site in Silver Lake had consistently higher *E. coli* concentrations than the sites in Lake Louise, which indicates that water flushed from Silver Lake each tidal cycle is a source of E. coli into Lake Louise. However, calculations show that Silver Lake does not input enough *E. coli* into Lake Louise to be the sole source of contamination. Further studies into the sources of contamination in both Lake Louise and Silver Lake are recommended.

Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal

Basic Information

Title:	Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal
Project Number:	2009DE163B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At large
Research Category:	Water Quality
Focus Category:	Water Quality, Acid Deposition, Treatment
Descriptors:	
Principal Investigators:	Alan Scott Andres, Jennalee Rufft

Publications

1. Rufft, J. and A. Andres, 2010, Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 21 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2009, Delaware Water Resources Center WATER E-NEWS Vol. 8 Issue 4 Spotlight on 2009-10 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Sep2009.pdf , p. 1.

Undergraduate Internship Project #7 of 10 for FY09

Intern ***Jennalee Rufft's*** project, co-sponsored by the ***DWRC*** and the ***Delaware Geological Survey*** was titled "Physical Characterizations of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal." She was advised by Mr. A. Scott Andres of the Delaware Geological Survey.

Abstract

The physical characterizations of Rapid Infiltration Basin Systems (RIBS) are imperative to the efficiency of wastewater disposal because of the information gained from knowing the paths of water through the basin. High rates of hydraulic conductivity are supposed to be present in the basins and consistent throughout RIBS sites. Without the knowledge of what type of soils lie beneath the surface and how these soils react to millions of gallons of wastewater introduced over time, RIBS may not properly treat wastewater and consequentially infiltrate poorly treated wastewater into the underlying aquifer and possibly nearby potable water supply wells. If the wastewater infiltrates too slowly the RIBS become an above ground hazard with non-aesthetic smells as well as dangerous contaminants/bacteria settling above ground instead of being treated below.

Double-Ring Infiltration testing performed at the Cape Henlopen site has given an explanation of how the wastewater is transferring through the ground and at what rate from the surface. Coupling of the double ring test with a moisture profiling instrument and data logging pressure sensors shows moisture content of the soil at different depths and calculates the change in depth of water above ground. The medium between fast and slow infiltration provides useful knowledge for future RIBS sites and advances in wastewater disposal by showing what types of soil work for wastewater disposal via RIBS and where problems are occurring. The knowledge can then be applied when picking a new RIBS site and can be monitored for changes over time.

Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources

Basic Information

Title:	Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources
Project Number:	2009DE164B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At Large
Research Category:	Water Quality
Focus Category:	Hydrogeochemistry, Solute Transport, Water Quality
Descriptors:	
Principal Investigators:	Shreeram P. Inamdar, Suneil Seetharam

Publications

1. Seetharam, S., S. Inamdar, and H. Bais, 2010, Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 11 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.

Undergraduate Internship Project #8 of 10 for FY09

Intern ***Suneil Seetharam's*** project, co-sponsored by the ***DWRC*** and the ***UD's*** Institute of Soil and Environmental Quality was titled "Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources." He was advised by Dr. Shreeram Inamdar of the ***UD's*** Department of Bioresources Engineering.

"My research thus far has been an incredible experience in which I have been able to learn information that cannot be taught in a classroom. Also, throughout my research I have been able to meet and work with extremely nice and intelligent people." – Suneil Seetharam

Abstract

The objective of this project was to determine the dissolved organic content (DOM), specifically phenols and flavonoids, in runoff water from various watershed sources. This analysis was performed using various spectroscopy techniques in order to quantify the amount of phenols and flavonoids in the water samples. This analysis provided a thorough understanding of how the watershed functions. The results of this study were that the litter leachate and throughfall water samples had the highest flavonoid and phenol content due to their direct exposure to fresh and decomposed organic matter. Rain water had the lowest phenol and flavonoid content, and stream water had intermediate levels of phenol and flavonoid content since it is a mixture of water from all the watershed sources. Furthermore, after performing an analysis of a storm event on the stream, it was concluded that the water from the litter leachate and from the throughfall was the first to enter the stream. The water from the rest of the sources entered the stream after this initial wash off. Using this information, the types of pollutants that are transported in the watershed and the sources that these pollutants come from can be determined. This allows efficient and effective control of pollutants which originated in a watershed.

A Comprehensive Management Plan to Reduce Nonpoint Pollution of the Cool Run Watershed on the University of Delaware Campus

Basic Information

Title:	A Comprehensive Management Plan to Reduce Nonpoint Pollution of the Cool Run Watershed on the University of Delaware Campus
Project Number:	2009DE166B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Water Quality
Focus Category:	Wetlands, Management and Planning, Non Point Pollution
Descriptors:	
Principal Investigators:	Anastasia Chirnside, Nicole Dobbs

Publications

There are no publications.

No work was done on project 2009DE166B due to academic pressures on and minor surgery for the undergraduate student.

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Characterizing the Microbiome of the Eastern Oyster, Crassostrea virginica

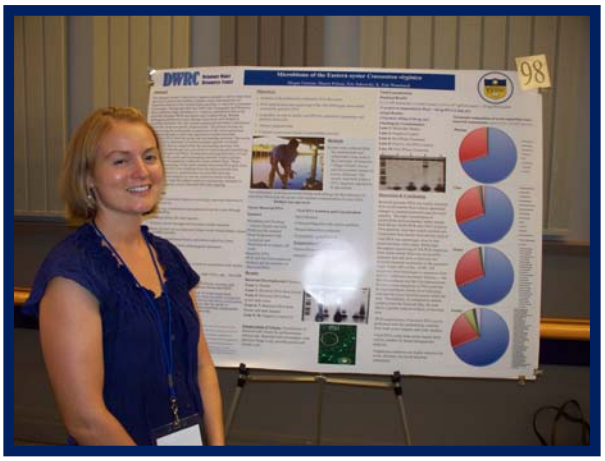
Basic Information

Title:	Characterizing the Microbiome of the Eastern Oyster, Crassostrea virginica
Project Number:	2009DE167B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Biological Sciences
Focus Category:	Ecology, Non Point Pollution, Water Quality
Descriptors:	
Principal Investigators:	Eric Wommack, Megan Furman

Publications

1. Furman, M. and E. Wommack, 2010, Characterizing the Microbiome of the Eastern Oyster, Crassostrea virginica, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 7 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.
3. Pautler, M., ed., 2009, Delaware Water Resources Center WATER E-NEWS Vol. 8 Issue 5 Spotlight on 2009-10 DWRC Undergraduate Internships, http://ag.udel.edu/dwrc/newsletters/WATERENEWS-Oct2009.pdf , p. 1.

Undergraduate Internship Project #9 of 10 for FY09



Intern ***Megan Furman's*** project, co-sponsored by the ***DWRC*** and the ***UD's Department of Plant and Soil Sciences***, was titled "Characterizing the Microbiome of the Eastern Oyster (*Crassostrea virginica*)." She was advised by Dr. Eric Wommack of the ***UD's*** Department of Plant and Soil Sciences.

"The Delaware Water Resources Center grant has helped me become closer to my goal as a wetland biologist in addition to initiating valuable research. Our project took flight with the addition of this grant and continues to contribute to the knowledge of the ecology of the Eastern oyster through its microbial interactions. My experience participating in this scientific process is invaluable." – Megan Furman

Abstract

The Eastern oyster *Crassostrea virginica* occupies a native range from the Gulf coasts to the northern Atlantic coasts, represents an important fishery in the United States and plays a vital role in estuarine ecosystems. During and after the 1960's the Chesapeake and Delaware bays suffered huge declines in *C. virginica* populations due to the protistan diseases MSX and dermo and overharvesting. Human pathogens and known oyster diseases have been well studied in scientific literature. Yet, the normal commensal microbial communities within the oyster are poorly characterized. Our project focuses on characterizing the community composition of the oyster associated microbiota through a multi step approach to isolate microbial prokaryotic DNA from the oyster and surrounding seawater. The results are analyzed to determine if oysters maintain specific microbial communities that are unique from the surrounding seawater. Our preliminary methodology was successful in extracting and quantifying both bacterial and viral DNA. Enumeration and quantification of viral abundance in the oyster and surrounding seawater found a greater abundance of viral particles within the oyster mantle fluid. High-throughput sequencing of the small subunit ribosomal RNA gene from oyster bacterial DNA was inhibited from the polysaccharide rich mantel fluid. However, amplification was possible from the surrounding water samples as was the characterization of these communities by high-throughput amplicon sequencing. Attempts to amplify and sequence oyster bacterial DNA are ongoing.

Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware

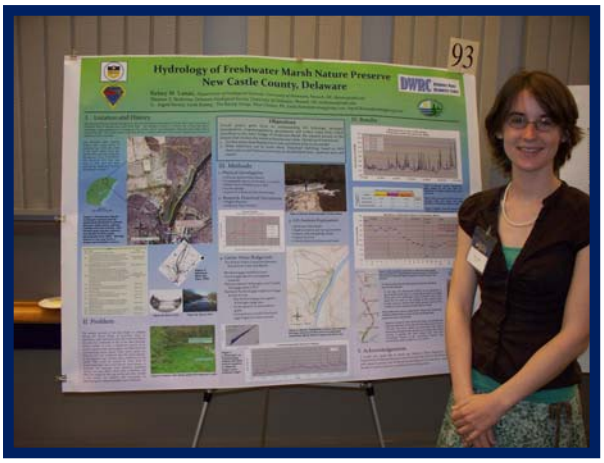
Basic Information

Title:	Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware
Project Number:	2009DE168B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At-Large
Research Category:	Not Applicable
Focus Category:	Hydrology, Ecology, Water Quantity
Descriptors:	None
Principal Investigators:	Thomas McKenna, Kelsey Lanan

Publications

1. Lanan, K. and T. McKenna, 2010, Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware, Delaware Water Resources Center, University of Delaware, Newark, Delaware, 14 pages.
2. Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2 Introducing Our 2009-10 Spring Interns, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 5.

Undergraduate Internship Project #10 of 10 for FY09



Intern ***Kelsey Lanan's*** project, co-sponsored by the ***DWRC*** and the ***Delaware Department of Natural Resources and Environmental Control***, was titled "Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware." She was advised by Mr. Tom McKenna of the Delaware Geological Survey.

"My internship with the DWRC has been a truly wonderful experience. Now, as I go on to pursue a masters' degree, I will have many of the research skills I need!" – Kelsey Lanan

Abstract

Reed canary grass, an invasive species, is overtaking native vegetation in Freshwater Marsh Nature Preserve located adjacent to Brandywine Creek in Rockland, Delaware. This may be a sign of drier conditions in the marsh caused by drier climate, higher elevation due to sediment deposition, or lower river level due to dam failure. A breach in Rockland Dam, located 300 feet downstream of the marsh was first documented by available photography in 2002, and was likely initiated during the flooding caused by Hurricane Floyd in 1999. The unbreached portion of the dam is at an elevation of 129 feet and the base elevation of the breach is at least 1.5 feet lower in elevation. The marsh surface is up to 8 feet above the baseflow water level in Brandywine Creek at an elevation of 131 to 136 feet (NAVD88). Since drier conditions affect the diverse wildlife inhabiting the marsh, including a population of endangered bog turtles, this research focuses on characterizing some of the pertinent hydrologic processes controlling water flow and storage in the marsh. Research included physical investigation, research of historical documents, GIS analysis and exploration, and analysis of the surface water connection between the creek and marsh. Brandywine Creek inundates the marsh less than 4% of the year, so the major source of water to the marsh must come from other sources, most likely groundwater and small streams from adjacent uplands. The recent dam breach appears to have caused erosion of streams connecting the marsh with Brandywine Creek resulting in a lowering of base-level for the marsh which is consistent with an evolution towards drier conditions. The historical height of the dam appears to have been as high as 134 feet, and the sediment underlying the marsh may have been deposited in the still waters behind the dam.

Information Transfer Program Introduction

None.

DWRC Information Transfer

Basic Information

Title:	DWRC Information Transfer
Project Number:	2009DE200B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	At Large
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Supply, Education
Descriptors:	None
Principal Investigators:	J. 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 FY09, consolidating reporting into a single project **#2009DE200B**. Most activities from the DWRC's FY08 Information Transfer project (**#2008DE115B)** continued into this year.

The FY09 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)

Basic Information:
Delaware Water Resources Center Electronic Publication WATER NEWS

Title:	"WATER NEWS"
Issues during FY08:	Volume 9 Issue 2 (Winter 2008 – Spring 2009) Volume 10 Issue 1 (Summer – Fall 2009)
Description:	Online 8-page newsletter published biannually by the Delaware Water Resources Center
Lead Institute:	Delaware Water Resources Center
Principal Investigators:	Dr. J. Thomas Sims, Director; Maria Pautler, Editor

WATER NEWS is received electronically by over 275 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.

FY09 topics included:

- DWRC Annual Luncheon and Poster Session – April 24, 2009
- Introducing Our 2009-10 Interns
- Spotlight on Undergraduate Internships and Graduate Research
- Delaware Environmental Institute Opening Event
- Delaware Nature Society Events
- Scientists Visit from China Agricultural University – August, 2009
- DWRC History, Goals, Advisory Panel, Contacts

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

Title:	"WATER E-NEWS"
Issues during FY08:	Mar. 2009 Apr. 2009 Sep. 2009 Oct. 2009 Feb. 2010
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 275 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 July 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.
- **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.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 275 as of February, 2010.

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

Title:	University of Delaware 2010 Undergraduate Research Scholars Poster Session with DWRC Advisory Panel Meeting
Date:	April 23, 2010
Description:	Undergraduate interns presented their 2009-2010 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, Howard Hughes Medical Institute, Northeast Chemical Association, Charles Peter White Fellowship, Chemistry and Biochemistry Alumni Undergraduate Research Fellows Program, Dean's Fund for Transforming Undergraduates: Exploring a Career in Cancer Genetics, Milton H. Stetson Memorial Undergraduate Research Scholarship, McNair Scholars Program
Principal Investigators:	Lynnette Overby, Director, UD Undergraduate Research Program (overbyl@udel.edu); J. Thomas Sims, Director, DWRC (jtsims@udel.edu)

On April 23, 2010, the ten undergraduate student interns who had been funded in 2009-2010 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 100 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 2010-2011 with regard to research funding and public education outreach efforts such as statewide water forums.

Poster Presentations by 2009-2010 DWRC Undergraduate Interns – April 23, 2010

1) Bevan, Anna. Poster Presentation April 23, 2010. Biogeochemistry of Base Cations in a Broadleaved Deciduous Forest. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

2) Bryan, Victoria. Poster Presentation April 23, 2010. Fine Particle Addition Mitigates Flux Decline in Direct Contact Membrane Distillation. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

3) Furman, Megan. Poster Presentation April 23, 2010. Characterizing the Microbiome of the Eastern Oyster, *Crassostrea virginica*. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

4) Hallett, Aaron. Poster Presentation April 23, 2010. Newly Constructed Wetland Management: Year One. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

5) Jayne, Brian. Poster Presentation April 23, 2010. Development of an Assay to Monitor the Activity of Fungal Enzymes in Soil. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

6) Lanan, Kelsey. Poster Presentation April 23, 2010. Hydrology of Freshwater Marsh Nature Preserve, New Castle County, Delaware. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

7) Olson, Emily. Poster Presentation April 23, 2010. Investigation of Source and Dynamics of Bacterial Contamination in a Tidal Lake. 2010 University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

8) Rufft, Jennalee. Poster Presentation April 23, 2010. Physical Characterization of Rapid Infiltration Basin Systems (RIBS) Used for Wastewater and Stormwater Disposal. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

9) Ruppel, Michael. Poster Presentation April 23, 2010. Flexible Compacts and Absolute Flows: Managing Interstate Basins for Competing Needs. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

10) Seetharam, Suneil. Poster Presentation April 23, 2010. Quality of Dissolved Organic Matter (DOM) in Runoff from Various Watershed Sources. 2010. University of Delaware Undergraduate Research Scholars Poster Session, University of Delaware, Newark, Delaware.

Basic Information:
Delaware Statewide Conference Co-sponsor and Participant

Title:	Special Conference: "Delaware Environmental Institute Opening Event"
Date:	October 23, 2009
Description:	DWRC information was available during the conference; Complete article is found in DWRC Summer – Fall 2009 WATER NEWS at http://ag.udel.edu/dwrc/newsletters/Summer09Fall09/WATERNEWSco-Fall2009.pdf , page 2
Lead Institute:	Delaware Environmental Institute Co-sponsors: Delaware Water Resources Center, Center for Applied Coastal Research, Center for Climate and Land-Surface Change, Center for Energy and Environmental Policy, Center for Environmental Genomics, Center for Integrated Biological and Environmental Research, Center for Managed Ecosystems, Center for Remote Sensing, Center for the Study of Metals in the Environment, Christina River Basin Critical Zone Observatory, Delaware Geological Survey, Disaster Research Center, Gerard J. Mangone Center for Marine Policy, Halophyte Biotechnology Center, Institute of Soil and Environmental Quality, University of Delaware Energy Institute, Water Resources Agency.
Principal Investigators:	Donald Sparks, Director, Delaware Environmental Institute (dlsparks@udel.edu); J. Thomas Sims, Director, DWRC (jtsims@udel.edu)

The DWRC co-sponsored the inaugural event of the Delaware Environmental Institute, held on October 23, 2009 at Mitchell Hall on the University of Delaware campus in Newark, Delaware. Notable speakers included Delaware Governor Jack Markell, UD president Patrick Harker, Delaware Department of Natural Resources and Environmental Control secretary Collin O'Mara, EPA regional administrator William Early, Princeton University professor Francois Morel (who spoke on the acidification of the oceans), and Cary Institute of Ecosystem Studies president William Schlesinger (who spoke of how ecosystem science and biogeochemistry help solve environmental problems). More than 200 people were in attendance.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	10	0	0	0	10
Masters	0	0	0	0	0
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	12	0	0	0	12

Notable Awards and Achievements

Research Program: The Delaware Water Resources Center (DWRC) has funded twelve research grant projects during March 2009 through February 2010 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) hydrogeologic characterization of the Potomac Aquifer, Delaware and 2) modeling hydrologic and geochemical effects of land-based wastewater disposal. The remaining ten projects were undergraduate internships researching 1) biogeochemistry in a forest; 2) flux in direct contact membrane distillation; 3) microbiome of the eastern oyster; 4) wetland management; 5) assay to monitor activity of fungal enzymes in soil; 6) hydrology of a freshwater marsh; 7) bacterial contamination in a tidal lake; 8) physical characterization of rapid infiltration basin systems (RIBS); 9) managing interstate basins; and 10) quality of dissolved organic matter in runoff.

Publications from Prior Years

1. 2003DE32B ("Fate and Transport of Arsenic in Poultry Litter Amended Delaware Soils: Impacts on Water Quality") - Dissertations - Seiter, J.M., 2009, "The Fate and Speciation of Arsenic in Soils and Poultry Production Systems," Department of Plant and Soil Sciences, College of Agriculture and Natural Resources, University of Delaware, Newark, Delaware, 327 pages.
2. 2008DE121B ("Water Quality and Bacterial Monitoring at Delaware Inland Bays Oyster Gardening Sites, Delaware") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 2.
3. 2008DE123B ("The Effect of Riparian Forested Corridors on Fish Biodiversity in Suburban and Agricultural Landscapes") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 2.
4. 2008DE125B ("Spatial and Temporal Integration of Pollution History in the Christina River Basin Using Sediment Cores from Bread and Cheese Island") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 2.
5. 2008DE126B ("Effects of Water Quality on Oyster Growth (Crassostrea virginica) in the Floating Oyster Aquaculture Gear in Delaware's Inland Bays") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.
6. 2008DE127B ("Delaware Coastal Zone Act: Impact on Water Quality") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.
7. 2008DE128B ("Zero-valent Iron and Other Additives to Enhance Biofiltration of Water") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.
8. 2008DE129B ("Exploring Direct Contact Membrane Distillation (DCMD) as for Water Purification") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.
9. 2008DE130B ("Direct Contact Membrane Distillation of Brackish and Contaminated Water Sources for Sourcing Potable Water") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.
10. 2008DE131B ("Removal and Inactivation of Pathogenic Enteric Viruses and Parasites from Water Using Zero-valent Iron") - Other Publications - Pautler, M., ed., 2009, Delaware Water Resources Center WATER NEWS Vol. 9 Issue 2, DWRC Annual Poster Session - April 24, 2009, http://ag.udel.edu/dwrc/newsletters/Winter08Spring09/WATERNEWSco-Spring2009.pdf , p. 3.