Pennsylvania Water Resources Research Center, Penn State Institutes of Energy and the Environment
Annual Technical Report
FY 2006

Introduction

The FY 2006 Annual Report for the Pennsylvania Water Resources Research Center at Penn State University includes annual update information about three research projects and one technology transfer project supported by the 104B base funding program and one supplemental project. Base funded projects are competitively awarded, one-year, exploratory or seed grants related to some critical water resource need. The first research project was headed by Dr. Thorsten Wagener with Civil and Environmental Engineering at Penn State and led to an improved approach for predicting hydrologic response of ungauged catchments which uses independent streamflow indices in a regionalized uncertainty framework to predict or constrain flow estimates, rather than the commonly-used approach of estimating model parameters based upon watershed characteristics. In a second research project, Dr. Steve Mauro with Mercyhurst College showed that shiga toxin DNA in Presque Isle State Park beach and lake waters, an indicator of microbes that cause dysentery, was widespread, but not well related to commonly measured virus and bacteria counts which are typically monitored to protect public health. In the third research project, Dr. Rachael Brennan with Civil and Environmental Engineering at Penn State demonstrated that crab shell chitin was a very effective substrate for treatment of acid mine drainage waters, which remain pervasive in the Commonwealth. In the technology transfer project, Bryan Swistock and Stephanie Clemens with the School of Forest Resources at Penn State found one-third of 450 private wells sampled around the state did not meet drinking water standards for bacteria, pointing to a need for greater homeowner education and improved rules for private well construction. All of these projects offer promise of improved water supply and/or water quality conditions for Pennsylvania residents in the future. A report on a supplemental research project conducted by Dr. Petra Tschakert with the Department of Geography at Penn State which dealt with soil carbon sequestration in dryland regions of Africa is also included.

Research Program

Award No. 05HQAG0076 Soil Carbon Sequestration in Drylands

Basic Information

Title:	Award No. 05HQAG0076 Soil Carbon Sequestration in Drylands
Project Number:	2005PA67S
Start Date:	6/1/2005
End Date:	11/30/2006
Funding Source:	104B
Congressional District:	5th
Research Category:	Not Applicable
Focus Category:	Management and Planning, Law, Institutions, and Policy, Agriculture
Descriptors:	arid-zone farming, land-use change
Principal Investigators:	Petra Tschakert

Publication

1. Tschakert Petra, Elisabeth Huber-Sannwald, Dennis Ojima, Michael Raupach and Erich Schienke (2007). Principles for Holistic, Adaptive Management of the Terrestrial Carbon Cycle at Local and Regional Scales, through Multi-Criteria Analysis. Global Environmental Change (in press).
2. Tschakert Petra (2007). Views from the Vulnerable: Perceptions on Climatic and Other Stressors in the Sahel. Global Environmental Change (in press)

ABSTRACT:
Community-based resource management and land rehabilitation programs through carbon offset activities have been promoted to restore degraded drylands and improve the livelihoods of the rural poor. However, smallholders often face considerable constraints that reduce adoption rates. There exists very little systematic research on carbon stocks and trends in relation to land use and land cover changes as well as livelihood needs in Africa. A holistic assessment is needed to simultaneously evaluate the biophysical, socio-economic, institutional and policy context for long-term carbon sequestration programs in drylands. This project provides detailed and experienced scientific input and capacity building in collaboration with researchers from Mali, Niger, Burkina Faso, and Ghana with respect to 5 key areas: 1) assessment of land use and land cover change based on a series of remotely sensed images and estimation of biomass for different land use/land cover classes; 2) soil and biomass carbon estimates and measurements in selected focus areas; 3) socio-economic and institutional assessment of management practices, technical knowledge, and adaptive capacity at the household and community level in selected focus areas; 4) biogeochemical modeling and evaluation of "best" management practices for water-constrained environments; and 5) capacity building, technical training, networking, and information exchange among all participants.

STATEMENT OF CRITICAL NEED:
Drylands cover nearly 40% of the world's land area and are home to over two million people (FAO, 2000). Dryland environments are characterized by a unique set of features that influence the biogeochemical potential for carbon sequestration. By definition, drylands are limited in their water supply, low and highly variable precipitation, and recurrent droughts. In addition, these water constraints are often accompanied by the occurrence of high temperatures at some points throughout the year. Thus, this generic deficiency of water severely constraints plant productivity that is the major driver for carbon sequestration. Most drylands contain very low quantities of soil carbon, usually ranging from 0.2% to less than 1% (Lal, 2002). Nevertheless, drylands have been supporting human populations for thousands of years. Today, an estimated one billion people depend on rural drylands for their livelihood, relying on rainfed and irrigated agriculture, livestock production, and forest/woodland products. People have adopted a diverse set of coping mechanisms to adapt to their risk-prone environment and, thus, spread and reduce risks.

However, due to increased human pressure on marginal lands and fragile resources in combination with persistent poverty among many dryland countries, particularly in the Sahel, traditional coping mechanisms are no longer sufficient to adapt to new and more severe risks and shocks, including climate change. Unsustainable land use and management practices together with ill conceived policies and weak structures of environmental governance, dryland degradation has reached alarming dimensions. To date, 70% of the world's drylands are affected by desertification. As a result, soil carbon has decreased significantly from an initially low base. In Senegal, for instance, estimated C losses over the last 35 years amounted to roughly 300 million tons (Woomer et al., 2004) or 71% since the beginning of agricultural activities in 1800 (Tschakert et al., 2004). On the other hand, due to longer residence times of C in dryland soils (Gifford et al., 1992) and the fact that many soils have been degraded, drylands may well have a significant potential to sequester carbon (Rosenberg et al., 1999).

Community-based resource management and land rehabilitation programs through carbon offset activities have been promoted to restore degraded drylands and improve the livelihoods of the rural poor. Afforestation and prolonged fallow periods in drylands, encouraged through increased water use during photosynthesis under elevated CO_2 concentrations as well as no- or reduced tillage which also prevents water losses have been put forward as most efficient land use and management practices. However, smallholders often face considerable constraints that reduce adoption rates. A holistic assessment is needed to simultaneously evaluate the biophysical, socio-economic, institutional and policy context for long-term carbon sequestration programs in drylands.

STATEMENT OF RESULTS OF BENEFITS:
The aim of this project is to provide detailed and experienced scientific input into a new initiative on carbon sequestration (Spatially Explicit Modeling of Soil Organic Carbon, "SEMSOC") in four West-African countries (Mali, Niger, Burkina Faso, and Ghana). SEMSOC, funded by USAID, is the expansion of a pilot study conducted in Senegal from 2000 to 2003. The project assists the partner

institutions in carrying out the various identified project activities, organize training workshops, support field work, facilitate the publication of research results, and assist the overall operation of national carbon teams. The results of this project will benefit the collaborating institutions to contribute to mitigation and adaptation research and gain relevant understanding for the mainstreaming of climate change into national development priorities

NATURE, SCOPE AND OBJECTIVES:
Based on initial planning workshops, hold with national experts in all four countries in January 2005, national work plans have been developed that encompass 5 key areas: 1) assessment of land use and land cover change based on a series of remotely sensed images and estimation of biomass for different land use/land cover classes; 2) soil and biomass carbon estimates and measurements in selected focus areas; 3) socio-economic and institutional assessment of management practices, technical knowledge, and adaptive capacity at the household and community level in selected focus areas; 4) biogeochemical modeling and evaluation of "best" management practices for water-constrained environments; and 5) capacity building, technical training, networking, and information exchange among all participants. The overall objective of SEMSOC is to explore conceptual and empirical approaches to link climate change mitigation research and activities related to terrestrial carbon management with observed adaptation trajectories of rural populations which can serve as a base line for evaluating potential adaptive capacity under more stressful climatic, demographic, and economic conditions. The results from the study are envisioned to help the four countries to position themselves more efficiently in the international climate change debate and in the emerging market of environmental service provision through improved land use and management.

Facilities and country partners:
- Ghana: EPA Ghana in Accra and University of Ghana in Legon
- Mali: Institut d'Economie Rurale (IER) in Bamako
- Niger: Institut National de Recherches Agronomiques du Niger (INRAN) in Niamey
- Burkina Faso : Institut National de l'Environnement et de Recherches Agricoles (INERA) in Ouagadougou

PRINCIPAL FINDINGS AND SIGNIFICANCE (1-2 pages only, be brief)

The final project synthesis workshop was held in Accra, Ghana from August 24 to August 26, 2006. A total of 26 participants were present, including 19 from Ghana, 2 from Niger, 2 from Burkina Faso, 1 from the USA, and the two project PIs (Tschakert and Gueye). The Mali colleagues were unable to attend due to last minute travel complications. The last day was devoted to next steps for the Ghana team, in anticipation of the Global Climate Change Grant (Project CC LONG).
The purpose of the meeting was to take stock of our achievements, discuss results, identify gaps and weaknesses, and agree on a final to plan analyze results and prepare a final synthesis. This was certainly the most productive of all meetings, even though it also clearly demonstrated the intellectual and methodological challenges the various country teams had been struggling with over the previous 14 months. Deficiencies were made explicit and guidelines for addressing them provided. The biggest challenge was, without any doubt, to get the model running for each site and, once results were available, to interpret them in a critical and meaningful way. Once again, the Ghana team was ahead of the other teams in all aspects of the project.

An overview of the workshop with individual presentations is available at
http://www.epa.gov.gh/climate/SEMSOC/Report/index.htm

The following activities have been completed in the various SEMSOC partner countries. It should be emphasized that the 4 countries have started project activities according to all five identified tasks with various levels of progress in each country (conditioned by arrival of research funds); Ghana was the first to receive funds, and also the only country that had completed preliminary goals on time and, hence, requested two additional funds to expand the work into other study areas.

a. Selection of study sites:

All four countries have selected two or three study sites for detailed work with respect to tasks 1-4. The main criteria for selection were “hotspots” of either vegetation improvement or degradation, different agro-ecological zones, different farming systems, and possibly different ethnic groups. The sites are described in detail in the country reports (Appendix 3). However, not all sites were finally addressed in all countries in a level outlined at the planning meeting, mainly due to delays in getting the work organized and harmonized between the task forces.

- Ghana: Ejura-Sekyedumase District (severely degraded), Assin Disrict (fairly well managed), and Bawku East District (very northeast, semi-arid, degraded)
- Mali: Kaniko and Try (Plateau de Koutiala), Dotan et Missira (monts mandingues),and Tendjé et Alasso (Hodh).
- Niger: Koure with 3 specific sites: Dallol (ancient river bed, high population pressure, poor soil), Zigui (the area of the giraffes, open savanna), and Niger river area (with rain-fed agriculture and irrigated agriculture)
- Burkina Faso: Koumbia/Houndé in the Sudanian zone; Nouaho/Boulgou in the Sahel-Sudanian zone; and Kaya/Binogo in the Sahelian zone

b. Land use/land cover analysis:

Land use classification for identified study areas in Ghana and Burkina Faso completed; in Mali and Niger partially completed. Thank’s to E. Tachie-Obeng for pushing this component forward.

c. Soil and biomass measurements:

Soil and biomass measurements were only carried out, as anticipated, in Ghana (all three study areas). Sample plots were established on the study sites and above ground biomass measured and soil samples taken. Samples were analyzed in the lab at the University of Ghana. Results are available for soil C, soil texture, particle size distribution, and above ground biomass content. The other countries relied on previously done soil classifications (although no direct C measurements and often no values for bulk density) and available biomass measurements from other studies, were available. The Ghana results are clearly the most useful (because most precise) as input into the model. Thanks To Stephen Bredu, M. Abekoe, and S. Adiku for their outstanding work.

d. Socio-economic and adaptation assessment:

As above, only the Ghana team completed a full suite of assessments and analysis of land use managements, socio-economic, policy and instiutional drivers for land use/management change as well as household and community level determinants of vulnerability/adaptive capacity to various stressors and shocks. It was also the only team that had taken advantage of the participatory methods workshop and actually used a series of methods on the study stites that differ substantially from the methods undertaken in the other countries (classic household surveys or community group discussions). The report put together by Regina Sagoe is outstanding and provides a tremendous amount of information for the two study areas where populations play and active role in carbon dynamics (the third location is a national forest where populations are excluded).

e. C modeling:

The modeling, the core of his project, proved to be a significant hurdle for all country teams. Despite several workshops through SEMSOC and other venues (SOCSOM), the participants felt not competent and sufficiently familiar with the model to run it without external assistance (A.M. Dieye). Much more practice would be required to prepare the necessary input input data for the model, understand its technical strengths and weaknesses, handle bugs, and critically interpret results. We certainly overestimated the learning curve for this component. Nonetheless, all countries did produce final model outputs, even though they vary in quality. While different land use/land management scenarios have been modeled over time, following the results from the image analysis, no model scenarios have yet been produced based on different future climate scenarios.

f. Information sharing and networking:

SEMSOC Ghana alone has produced a SEMSOC national link, thanks to the wonderful work of Helen Asiamah at EPA. (http://www.epa.gov.gh/climate/SEMSOC/semsoc.html). The site holds a wealth of information. Helen has also created an internal listserv for team members and a special SEMSOC email account.

STUDENTS SUPPORTED (name, major, degree)

- Amadou Moctar Dieye, Geography and GIScience, South Dakota State University, PhD (Major collaborator on the project, supported for travel and training workshops in West Africa)
- Ryan Updike, History, Pennsylvania State University, BA (undergraduate research assistant for P. Tschakert)

More manuscripts for publication will be developed after in 2007.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

- Petra Tschakert, Penn State University, Department of Geography. Departmental Colloquium. "The Day After Tomorrow: Perceptions of Climate Change and Other Risks in the Sahel." March, 2006.
- Petra Tschakert, University of Ghana, Regional Institute for Population Studies (RIPS), Legon, Ghana. Invited Brown Bag lecture. "Rural Livelihoods in Marginal Environments: Vulnerability and Adaptive Capacity." July 31, 2006.
- Amadou Moctar Dieye, Follow-up workshops on GEMS (and spatially explicit C modeling) held in Accra, Ghana, and Ouagadougou, Burkina Faso in June and July 2006. The objectives were to assist the countries in finalizing the land use/carbon models in their respective study sites. In Accra the participants came exclusively from Ghana's SEMSOC team, while the workshop in Ouagadougou was for the French speaking countries with participants from Burkina, Mali, and Niger. In each country two sites were selected and prior to coming to the workshop, participants were asked to collect and prepare all necessary data for the model, including historical land cover and land use, climate (temperature and precipitation), soils (texture, drainage, and water holding capacity), socio-economic and land management (fertilizer, fire, grazing, tree removal…). However, the data brought by the participants was not ready for the model owing to an inappropriate format and the lack of consistency. Three days was spent on reprocessing and reformatting the data. At the end, all countries were able to start the model for at least one site. Participants left with a clear plan to finalize the models in their two study sites, analyze the results, and write the reports.

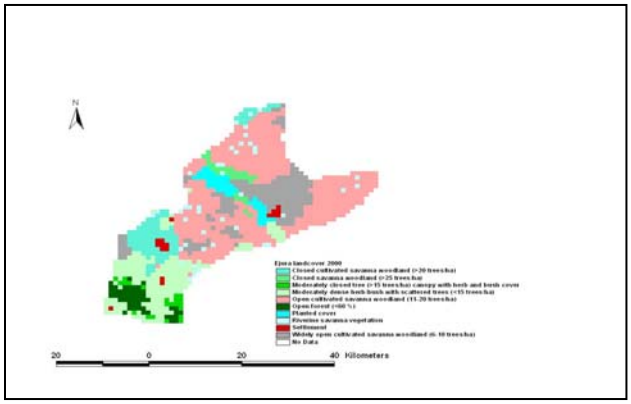
- Petra Tschakert, Invited Leader. "SEMSOC – An Overview and Synthesis." Spatially Explicit Modeling of Soil Organic Carbon (SEMSOC) Synthesis Workshop, Accra, Ghana, August 25-26, 2006.
- Petra Tschakert, AESEDA Representative. United Nations Framework Convention on Climate Change (UNFCCC), Conference of the Parties (COP-12), Nairobi, Kenya, November 6-12, 2006.
- Update of the web portal through EPA (http://www.epa.gov.gh/climate/SEMSOC/semsoc.html)
- Production of a poster presenting the major results from SEMSOC (see attachment)

AWARDS

USAID Global Climate Change Grant "Climate Change Collective Learning and Observatory Network Ghana", 3-year grant, $ 759,928 (PI P. Tschakert)

Also, we would appreciate one or two pictures related to your research that we could use on our website or for our annual report to the National Institutes for Water Research.

Vulnerability mapping and community risk assessment in Bawku East, Ghana (Source: Regina Sagoe)



Land cover classification from Landsat ETM+, 200, Ejura District, Ghana (Source: Emmanuel Tachie-Obeng)

Passive Remediation of Acid Mine Drainage Using Chitin

Basic Information

Title:	Passive Remediation of Acid Mine Drainage Using Chitin
Project Number:	2006PA63B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Treatment, Water Quality, Geochemical Processes
Descriptors:	acid mine drainage, passive treatment, permeable reactive barriers, chitin, remediation, heavy metals, sulfate reducing bacteria, water quality
Principal Investigators:	Rachel A. Brennan

Publication

1. Daubert, L.N. and R.A. Brennan (2007) Passive remediation of acid mine drainage using chitin. Environmental Engineering Science (in press).
2. Daubert, L.N. (2006) B.S. Honors Thesis, A laboratory investigation of passive remediation of acid mine drainage using chitin from crab shells. Department of Civil and Environmental Engineering, College of Engineering, The Pennsylvania State University, University Park, PA.
3. Robinson, Lora, M.A., Ph.D. Dissertation, Department of Civil and Environmental Engineering, College ofEngineering, The Pennsylvania State University, University Park, PA (in progress).
4. Brennan, R.A. (2007), Passive remediatiion of acid mine drainage using chitin, PA WRRI, The Pennsylvania State University, University Park, PA, 5 pp.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Streams contaminated by acid mine drainage (AMD) are complex environmental systems which require biological, chemical, and physical treatment steps for thorough remediation. In this work, a novel concept for treating AMD was investigated, in which the biological reduction of acidity, chemical enhancement of alkalinity, and physical sorption of metals occurred simultaneously using one multifunctional substrate: chitin from crab shells. In this research, crab shell chitin was evaluated as an alternative substrate for the treatment of acid mine drainage in both microcosm and column experiments.

Sacrificial duplicate microcosms were used to rapidly assess the ability of chitin to achieve remediation of AMD waters of varying acidity and metals contents. For use in these tests, AMD source water and benthic sediments were collected from three sites in Centre County, Pennsylvania: Beech Creek (BC); North Fork (NF); and Cherry Run (CR) (Figures 1 and 2). Microcosms were setup under anoxic conditions in 160-ml glass serum bottles containing 120-ml AMD water, 0.5-g sediment, and 0.25-g SC-20 chitin (Figures 3 and 4). Duplicate control microcosms without chitin were also setup. The bottles were incubated in the dark at room temperature and monitored periodically for pH, alkalinity, acidity, sulfate, and metals concentrations for 20 days. Continuous-flow column studies were then conducted to quantify sulfate reduction rates, metal removal capacities, substrate longevity, and optimal retention times when crab shell chitin was used as a barrier material for AMD treatment. Duplicate, clear PVC tubes measuring 4-ft in length and 1.5-inches in diameter were packed with a mixture of 500-g silica sand, 50-g soil, and 25-g chitin in the first 1 foot segment, and silica sand for the remaining 3 feet (Figure 5). A control column without chitin was also evaluated. Water from an AMD site was pumped through the columns vertically from bottom to top at a rate of 0.25 ml/min and monitored until metals were observed to breakthrough in the effluent. At the conclusion of the experiment, the columns were sacrificed and the sediment analyzed for precipitated metal concentrations as a function of distance throughout the columns.

Results from this study showed that in the presence of crab shell chitin, acidity decreased, pH and alkalinity increased, and dissolved metals decreased. In the microcosm tests, chitin increased the pH from 3.5 to near neutral in just 2 days. Steady alkalinity generation and acidity removal were observed at an average rate of 37.6 mg $CaCO_3$ /L-d. The activity of sulfate reducing bacteria was evident after 8 days of incubation at reduction rates of 12 – 24 mg SO_4^{2-}/L-d. No significant differences in performance were observed between the three evaluated sites. In the column tests, a retention time of 11.2 hours was enough to raise the pH from ≤ 3.5 to approximately 7.5. Alkalinity was generated at a rate of 48 ± 18 mg $CaCO_3$/d, and acidity was removed at a rate of 64 ± 23 mg $CaCO_3$/d. Greater than 95% of manganese, iron, and aluminum were removed from the water for 80, 109, and 125 days, respectively. Approximately 50 - 64% of the influent sulfate was removed throughout the column experiment. Physical adsorption of iron to chitin, chemical precipitation of aluminum hydroxide ($Al(OH)_3$), and biologically induced manganese sulfide (MnS) precipitation were the likely mechanisms of dissolved metals removal in this system.

This study demonstrated that crab shell chitin is a promising substrate for AMD treatment. Dissolution of calcium carbonate from chitin promotes rapid pH, alkalinity, and acidity changes, independent of the sites' characteristics. The activity of sulfate reducing bacteria is enhanced by the addition of chitin as a substrate. Metals can be effectively removed from AMD waters by physical sorption and precipitation in less than 12 hours of continuous flow treatment with chitin. The longevity of chitin in the column tests indicates that in general, approximately 1 liter of AMD water can be treated per gram of raw crab-shell chitin.

STUDENTS SUPPORTED (name, major, degree)

Linda Daubert*, B.S., Chemical Engineering

Mary Ann Robinson Lora, Ph.D., Environmental Engineering

(*No financial support, but participated early in the study in the form of an Honors Thesis.)

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Daubert, L. and R. A. Brennan. (2006) “A laboratory investigation of passive acid mine drainage treatment using chitin.” *Poster presentation (1st Place Winner in Engineering category)*, Undergraduate Research Exhibition, The Pennsylvania State University, University Park, PA, April 5.

Robinson Lora, M. A. and R. A. Brennan. (2007) "Passive remediation of acid mine drainage using chitinous materials: microcosm and column studies on three sites within central Pennsylvania." *Poster presentation (2nd Place Winner in Engineering category)*, The Graduate Exhibition, The Pennsylvania State University, University Park, PA, March 25.

Robinson Lora, M. A. and R. A. Brennan. (2007) "Natural chitinous material as a neutralizing agent and electron donor source for the passive remediation of acid mine drainage." *Poster presentation,* 10th Annual Environmental Chemistry Student Symposium, The Pennsylvania State University, University Park, PA, April 13.

Daubert, L. N., and R. A. Brennan. (2007) "Passive remediation of acid mine drainage using chitin." *Platform presentation*, In Situ and On-Site Bioremediation 9th International Symposium, Baltimore, MD, May 7.

AWARDS

Daubert, L. N., 1st place winner for poster presentation at the Undergraduate Research Exhibition, April 2006 (see citation above).

Robinson Lora, M. A., 2nd place winner for poster presentation at The Graduate Exhibition, March 2007 (see citation above).

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

Source:	National Science Foundation
Start date:	February 15, 2007
End date:	December 31, 2011
Title:	CAREER: Solving a Global Water Crisis in a Local Watershed: A Comprehensive Analysis of Chitin as a Multifunctional Substrate for the Treatment of Acid Mine Drainage.

FIGURES

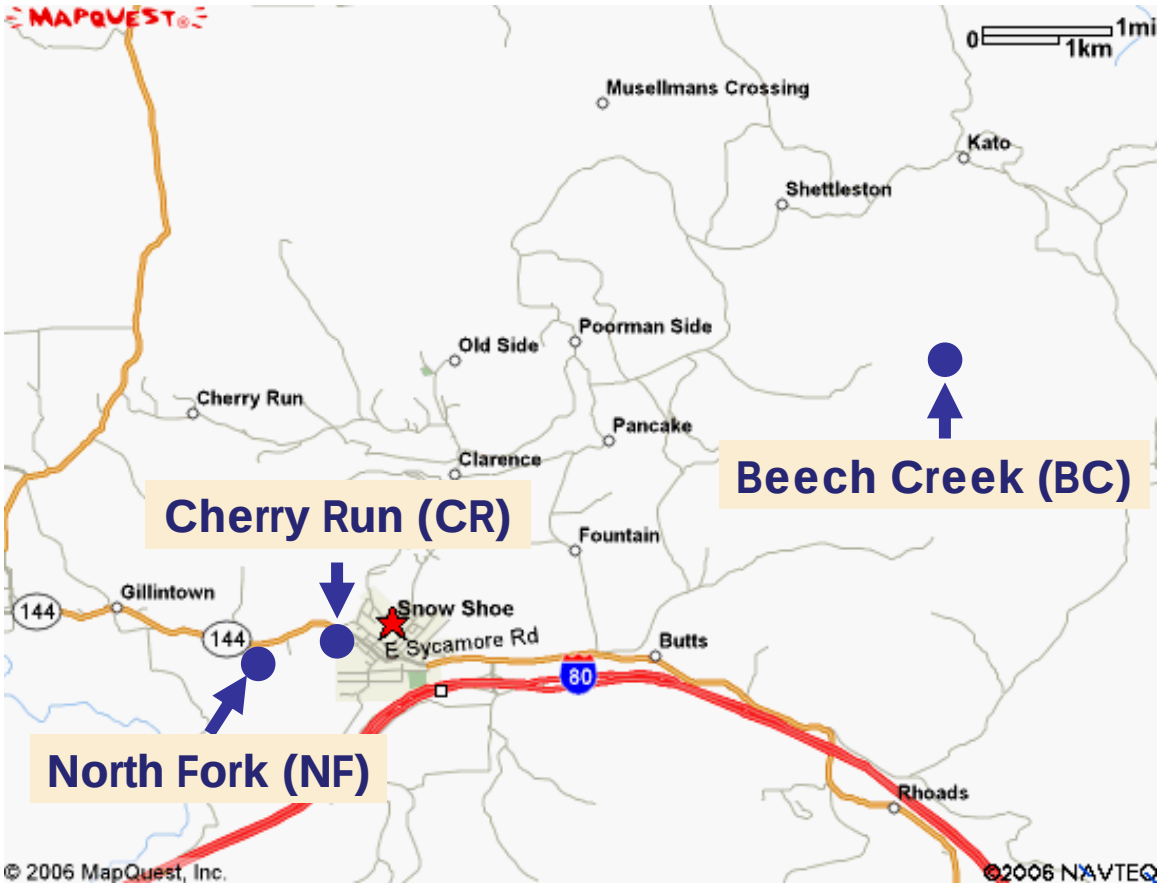


Figure 1. Map of AMD sampling sites in Centre County, PA (Source www.mapquest.com).


Figure 2. Photograph of Beech Creek, PA, one of the selected sampling sites.

Figure 3. From left to right: a crab, the main source of commercially available chitin; processed SC-20 grade crab shells to be used in this study; and the chemical structure of two chitin monomers (N-acetylglucosame, NAG) connected by a β-1,4-linkage.

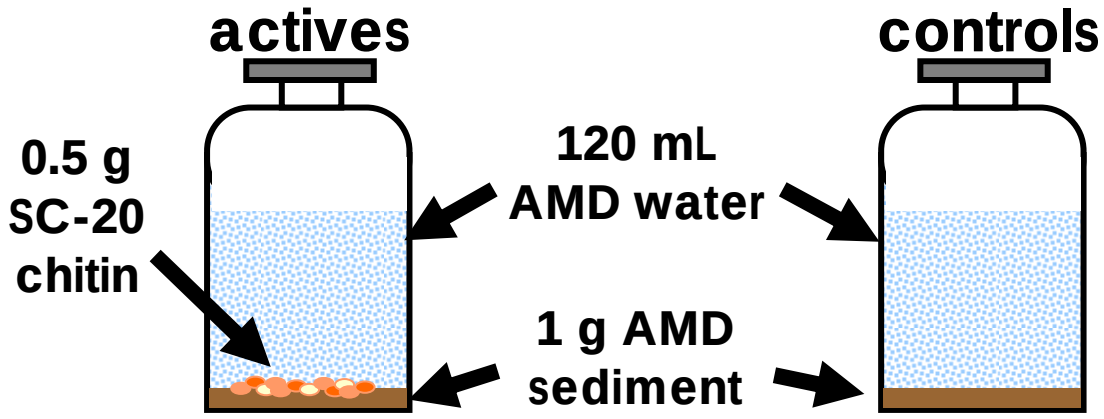


Figure 4. Schematic of the microcosm experiments.

Figure 5. Photograph of continuous flow columns in the laboratory to test the effectiveness and longevity of chitin for the remediation of acid mine drainage.

Identification and Enumeration of Pathogenic Bacteriophages in the Waters Surrounding Presque Isle State Park

Basic Information

Title:	Identification and Enumeration of Pathogenic Bacteriophages in the Waters Surrounding Presque Isle State Park
Project Number:	2006PA64B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	3rd
Research Category:	Water Quality
Focus Category:	Methods, Non Point Pollution, Water Quality
Descriptors:	bacteriophage, water pathogens, aquatic ecosystem, human health, novel methodology
Principal Investigators:	Steven A Mauro

Publication

1. Smith, Cody and Steven Mauro (2007). Distribution and abundance of shiga toxin indicators in beach waters, in final program of the American Society for Microbiology General 107th Meeting, American Society for Microbiology, Washington, DC, N-202.

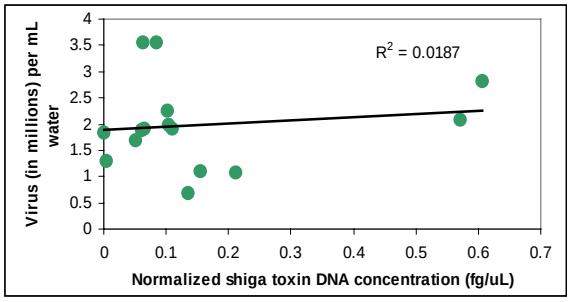
Principal findings and significance

In the summer, fall, and winter months of 2006, our work utilized molecular techniques to identify and enumerate indicators of pathogenic bacteriophages in the waters of and surrounding Presque Isle State Park. The main body of our work focused on utilizing real-time PCR on DNA isolated from beach and stream water samples to quantify the shiga toxin gene, a common indicator of bacteriophages that reside in enterohaemorrhagic *E.coli* responsible for food and water related dysentery.

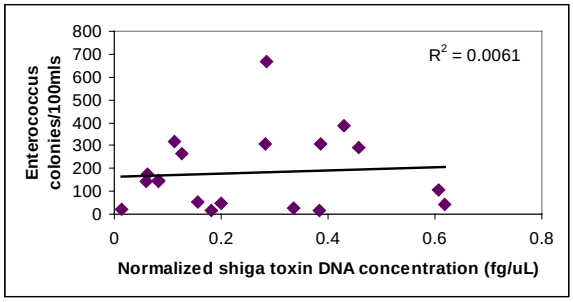
An overall summary of our results finds that a surprisingly large percentage of samples tested positive for the presence of shiga toxin DNA. Specifically, 26% of the over 100 water samples screened contained the shiga toxin marker indicative of the bacteriophages responsible for causing dysentery. However, no sample location continually tested high for shiga toxin DNA, and there was no predictable pattern in the temporal or spatial distribution of this pathogenic bacteriophage indicator. Together, these results suggest that pathogenic bacteriophages are present in our waterways, but are originating and distributed through a currently unknown mechanism.

The high percentage of samples that tested positive for shiga toxin DNA prompted us to examine how the abundance of this indicator of pathogenic bacteriophages relates to numbers of common indicators of microbial pollution, such as total viral and bacterial counts. Our results find no correlation between the amount of shiga toxin DNA in a sample to the number of virus (Figure 1A below) or bacteria (Figure 1B below) in a sample.

Figure One- Abundance of shiga toxin DNA in water samples do not correlate with viral or bacterial numbers



(A.) The total number of viruses present in water samples do not correlate with stx gene frequency (the r-squared value of a linear regression is shown in the upper right corner). Each circle is one of the samples that tested positive for the stx gene.



(B) The total number of *Enterococci* bacteria present in water samples do not correlate with stx gene frequency (r-squared value of a linear regression is shown in the right corner). Each diamond represents one of the samples that tested positive for the stx gene. Other studies not shown demonstrate that total number of *E.coli* or three other bacteria tested also do not correlate with levels of shiga toxin DNA.

These results provide evidence that levels of bacteria that harbor shiga toxin positive bacteriophages will not be adequately accounted for through the use of common assays currently utilized to judge microbial quality in recreational waters. Our results highlight the need for further study that better define the source(s) and pathogenic potential of shiga toxin bacteriophages that we have shown already exist in our heavily

utilized beach and stream waters surrounding Presque Isle and to similarly test these waters for other pathogenic microbial agents.

Students Supported: Cody Smith (Biology major, Bachelor of Science, conferred 2007) and Jayme Dylewski (Biology major, Bachelor of Science, conferred 2007).

Presentations and other information transfer activities: Oral Presentations at: Regional Science Consortium 2nd Annual Meeting (Erie, PA, Fall, 2006), Pennsylvania Academy of Sciences 83rd Annual Meeting (Monroeville, PA, March 2007), Sigma Xi Annual Undergraduate Research Conference (Erie, PA, April, 2007), Our Lake Our Future conference on *E.coli* pollution (Erie, PA, May, 2007), Mercyhurst College Academic Celebration (Erie, PA, May, 2007),

Awards: None

Additional funding using USGS grant as seed money: None

Functional Classification of Susquehnna River Basin Watersheds in an Uncertainty Framework

Basic Information

Title:	Functional Classification of Susquehnna River Basin Watersheds in an Uncertainty Framework
Project Number:	2006PA66B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	5th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Surface Water, Models
Descriptors:	classification, wtershed response, predictions in ungauged basins, ensemble predictions, uncertainty
Principal Investigators:	Thorsten Wagener

Publication

1. Yadav, Maitreya, Thorsten Wagener, and Hoshin Gupta. (2007). Regionalization of consstraints on expected watershed response behavior for improved predictions in ungauged basins. Advances in Water Resources 30, 1756-1774.
2. Zhang, Zhenxing, Thorsten Wagener, and Patrick Reed. (2007). Ensemble streamflow predictions in ungauged basins combining hydrologic indices regiionalization and multiobjective calibration. Water Resources Research (in preparation).
3. Yadav, Maitreya, Thorsten Wagener, and Hoshin V. Gupta. (2006). Regionalization of dynamic watershed behavior. In Andreassian, Vazken, N. Chahinian, Alan Hall, Charles Perrin, John Schaake (eds.), Large sample basin experiments for hydrological model parameterization. Results of the Model Parameter Estimation Experiment (MOPEX) Paris (2004) and Foz de lguacu (2005) workshops. IAHS Redbook Publ. no. 307.
4. Wagener, Thorsten, Patrick Reed, Kathryn Van Werkhoven, Yong Tang, and Zhenxing Zang. (2007). Identification and evaluation of complex environmental systems models using global sensitivity analysis and evolutionary multiobjective optimization. In Advances in Hydroinformatics (in review).
5. Yadav, Maitreya. (2006). Regionalization of dynamic watershed behavior. MS Dissertation, Department of Civil and Environmental Engineering, Pennsylvania State University, University Park, PA, 95.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Summary

Rainfall-runoff models are standard tools for hydrologic analysis. These models are used for applications such as water resources studies and flood forecasting, or in support of ecological studies. Available watershed models range from parsimonious-lumped to complex distributed physically based representations. A problem common to all such models is that they all require some degree of parameter calibration to achieve reliable predictions, in which process the model parameters are adjusted (manually or automatically) until the observed and simulated watershed responses match as closely as possible. Even physically based models usually require some degree of calibration since it is difficult to estimate values for all of the parameters through field measurements. This occurs because the scale of measurement is usually smaller than the effective scale at which the model parameters are applied. Problems in hydrologic modeling are accentuated further when it comes to prediction in ungauged or altered (e.g. land use) basins, where sufficiently long streamflow time series for parameter estimation via calibration are typically not available.

Approaches to modeling the continuous hydrologic response of ungauged basins use observable physical characteristics of watersheds to either directly infer values for the parameters of hydrologic models, or to establish regression relationships between watershed structure and model parameters. Both these approaches still have widely discussed limitations, including impacts of model structural uncertainty. In this paper we introduce an alternative, model independent, approach to streamflow prediction in ungauged basins based on empirical evidence of relationships between watershed structure, climate and watershed response behavior. Instead of directly estimating values for model parameters, different hydrologic response behaviors of the watershed, quantified through model independent streamflow indices, are estimated and subsequently regionalized in an uncertainty framework. This results in expected ranges of streamflow indices in ungauged watersheds.

A pilot study using 30 UK watersheds distributed throughout England and Wales shows how this regionalized information can be used to constrain ensemble predictions of any model at ungauged sites. It was found that high pulse count, runoff ratio and the slope of the flow duration curve provided strong regionalizable constraints while still allowing for reliable predictions, i.e. most of the observed flow was captured by the ensemble. The dominant physical characteristics are climate (wetness index, P/PE), watershed topography (slope, DPSBAR) and subsurface geology and soils (base-flow index, BFIHOST). Using too many dynamical characteristics simultaneously often resulted in a rejection of all models. This new approach provided sharp and reliable predictions of continuous streamflow at the ungauged sites tested. In general, the approach yielded very promising results and has several advantages compared to the common regionalization of models.

The main advantages of this new approach to ensemble predictions in ungauged basins are that it (1) is applicable to any hydrologic model (lumped or distributed), (2) is not impacted by problems of parameter calibration or model structural error, (3) does not try to establish relationships between conceptual (effective) model parameters and watershed characteristics, and (4) yields increased understanding about the controls on watershed response behavior at the scale of interest, which could guide an improved approach to watershed classification.

STUDENTS SUPPORTED

Maitryea Yadav, Civil and Environmental Engineering, Graduate Spring 2006 with MS
Yaoling Bai, Civil and Environmental Engineering, PhD Student since Fall 2006

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Conference Presentations

Wagener, T., Reed, P., Werkhoven, K. van and Tang, Y. 2007. Identification and evaluation of complex environmental systems models using global sensitivity analysis and evolutionary multiobjective optimization. International Workshop on Advances in Hydroinformatics (HIW07), Niagara Falls, Canada, June 4-7th 2007. – Planned (Invited Keynote)

Wagener, T. 2006. Catchment classification and hydrologic similarity. Hydroecological Landscapes and Processes (HELP) Workshop – "Expert Workshop on Watershed Characterization Schemes for Canadian Forests", 9-11th November 2006, The University of Western Ontario, London, Ontario, CA. (Invited Plenary Speaker)

Wagener, T. 2006. Towards an uncertainty framework for PUB. USA PUB Workshop, 16-19th October 2006, Oregon State University, Corvallis, Oregon, USA. (Invited Talk)

Wagener, T., Yadav, M., and Gupta, H. 2006. Hydrologic ensemble predictions in ungauged basins. 2nd International Symposium on Quantitative Precipitation Forecasting and Hydrology, 4th-8th June 2006, Boulder, CO. (Invited Talk)

Yadav, M, Wagener, T. and Gupta, H.V. 2006. Regionalization of dynamic watershed response behavior. *Eos Trans. AGU, 87*(36), Jt. Assem. Suppl., Abstract H23D-15. (Poster)

Invited Seminars

Wagener, T. 2007. Catchment classification, hydrologic similarity and predictions in ungauged basins. Department of Geography, University of British Columbia, Canada.

Wagener, T. 2007. Catchment classification, hydrologic similarity and predictions in ungauged basins. Department of Civil and Environmental Engineering, University of Washington, Seattle, USA.

Wagener, T. 2007. Catchment classification, hydrologic similarity and predictions in ungauged basins. 3TIER Environmental Forecasting, Seattle, Washington, USA.

Wagener, T. 2006. Hydrologic model identification under uncertainty in gauged and ungauged catchments. Graduate School of Environmental Studies, Tohoku University, Japan.

Wagener, T. 2006. Catchment classification and hydrologic similarity. Cooperative Wetlands Center, Pennsylvania State University, USA.

Wagener, T. 2006. Catchment classification, hydrologic similarity and predictions in ungauged basins. Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, USA.

Wagener, T., Duffy, C., Reed, P., Tang, Y., Goodwin, K. and Yadav, M. 2006. Advancing hydrologic ensemble forecasting using distributed watershed models. National Weather Service - Hydrology Laboratory, Washington D.C., USA. (Combined presentation by all authors)

Gupta, H.V., Wagener, T., *Yilmaz, K. and *Yadav, M. 2006. Improved Distributed Watershed Modeling in Gauged and Ungauged Basins using the HL-RMS System. National Weather Service - Hydrology Laboratory, Washington D.C., USA.

AWARDS

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

Information Transfer Program

Rural Drinking Water Quality in Pennsylvania

Basic Information

Title:	Rural Drinking Water Quality in Pennsylvania
Project Number:	2006PA65B
Start Date:	3/1/2006
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Groundwater, Education, Water Quality
Descriptors:	groundwater, wells, educatiion, drinking water, volunteers
Principal Investigators:	Bryan Reed Swistock, Stephanie S. Clemens

Publication

1. Clemens, Stephanie, Bryan Swistock, and William Sharpe. (2007). The Master Well Owner Network: Volunteers Education Pennsylvania Well Owners. Journal of Extension (in press).

Principal Findings and Significance
Samples and survey information were collected from 450 private wells located in 52 counties throughout Pennsylvania. Samples were analyzed for coliform bacteria, *E. coli* bacteria, pH, lead, nitrate, arsenic, triazine pesticides, total dissolved solids (TDS) and hardness. Two survey forms were used to collect information about each private well including construction, maintenance, nearby land uses and homeowner opinions.

An additional online survey was used to collect data from another 837 private well owners across Pennsylvania from September 2006 through March 2007. Responses were collected from well owners in 63 of the 67 counties in the state. This survey was identical to the survey data collected from the well testing study above.

Well and Wastewater Characteristics and Management
Water well characteristics and management history were derived from both the well testing study (n=450) and the online well survey (n=839). The ranges reported in the bullets below represent the results from both studies.

- The average depth of wells from both studies was about 170 feet with maximum depths over 700 feet. Approximately 20% of well owners could not provide an estimate of well depth.
- The majority of wells (66% to 82%) had been drilled after 1970.
- Over 50% of the well owners in both studies were unable to estimate the amount of water delivered from their private well. A small percentage (4% to 7%) reported that their well had gone dry sometime in the past.
- Only 9% to 18% of well owners had a copy of their well completion report from the professional well driller that drilled their well.
- Most wells were poorly constructed. About 15% of the wells in both studies were buried in pits below the ground surface. Only 16% of wells had a sanitary well cap and 16% were also reported to have a grout seal around the casing. However, only 4% to 5% had both sanitary well construction features.
- 53% to 70% of the homes in these studies had some type of water treatment equipment installed on their private well. The average cost of water treatment equipment was $1,147 to $1,400 with a maximum of $7,000. Data from the well testing study found that about 10% of the wells with water treatment equipment had at least one piece of equipment that was not needed according to the water quality results. Water softeners were, by far, the most common type of water treatment installed on private wells across the state.
- About 50% of the well owners in both studies reported that they occasionally or regularly use bottled water for drinking instead of their well water.
- Over 90% of the homes in the well testing study had on-site wastewater disposal. About 70% of these were traditional septic tanks and leach fields. The remainder were mostly sand mounds with a small percentage of alternative systems. Nearly 30% of well owners with septic systems reported that their septic tank had never been pumped or maintained. Another 34% indicated that their tank was pumped infrequently (> 4 year interval).

Well Water Quality
The online survey of 839 private well owners found that 80% reported at least one water quality problem with their well water. Most of the reported problems were obvious aesthetic contaminants like hardness or iron. The water quality testing from 450 private wells found that 40% had raw water that failed to meet at least one health-based, primary drinking water standard. After accounting for those that have proper water treatment or drink bottled water, about 30 percent of the study participants were still drinking unhealthy water. The percent of homes that failed each water test were:

- 33% failed the drinking water standard for coliform bacteria
- 14% failed the drinking water standard for *E. coli* bacteria
- 18% failed the recommended drinking water standard for pH
- 6% failed the drinking water standard for lead
- 5% failed the recommended drinking water standard for total dissolved solids
- 3% failed the drinking water standard for nitrate
- 2% failed the drinking water standard for arsenic
- 1% failed the drinking water standard for triazine pesticides

Prevalence for most pollutants was similar to past studies with the notable exceptions of lead and nitrate. Lead contamination (6%) was much less prevalent than a similar well water quality study conducted by Penn State in 1990 when nearly 20% of private wells failed the lead drinking water standard. This suggests that the Federal Lead Ban of 1991 has been successful in reducing exposure to lead in private water systems. Reduced prevalence of nitrate may be due to under sampling of southeast counties which will be resolved through additional testing in 2007. The few wells with high arsenic levels were located in the glaciated regions of northern Pennsylvania which agrees with a recent study conducted by the U.S. Geological Survey.

Logistic regression was used to relate well water quality to well construction parameters and nearby land uses. Results suggest that some well construction components, including well depth, presence of casing above ground and slope around casing, were important factors in explaining the presence of coliform bacteria in wells. Nearby activities such as the distance to a pasture and the maintenance interval of the on-site septic system were also important variables. An additional 250 wells will be added to the database during 2007 to allow more robust statistical analyses of the causes of contamination for bacteria and other parameters. Regression results also indicated that nitrate concentrations in wells were correlated strongly with the distance to the nearest cornfield. Other results from this analysis include:

- Homes with a septic system were more likely to have bacterial contamination than those on centralized wastewater systems. This trend was more pronounced for *E. coli.*
- Wells at homes with septic systems that had malfunctioned were more than twice as likely to have bacterial contamination.
- Wells that had a history of turbidity problems were much more likely to have bacteria.

Well Owner Education and Opinions

In the absence of statewide regulations, education plays an important role in promoting proper management of private water supplies. However, while education can create awareness of problems and management strategies, it can only be successful if well owners translate this knowledge into actions. Data from this study indicate the following:

- About one third of the well owners in each study reported that their well water quality had never been tested. Fewer than 10% of well owners were following the standard recommendation to have their well tested annually.
- Only 30% of the well owners with drinking water that failed a primary drinking water standard were previously aware of the problem. Those well owners that were previously aware of problems were very likely to utilize water treatment or bottled water to avoid the problem, especially if the pollutant caused a health problem.
- The effect of education in producing well management actions was documented by comparing Master Well Owner volunteer wells to homeowner wells. Education did result in an increase in the use of sanitary well construction, frequency of water testing, use of certified labs and awareness of water quality problems.

- Despite all of the problems found with drinking water from private wells, 64% to 81% of well owners from these two studies reported that they were satisfied enough with their private well that they were unwilling to pay any fee for connection to a community water supply.
- Although most well owners were satisfied with their private well, more than half were concerned about the future of their well water quality or quantity. Specific concerns varied regionally but new housing development was consistently the top concern across the state.

The surveys from both the well study and the online survey included four questions to measure support among current well owners for state regulations related to private wells. Current well owners were generally supportive of all well regulations with 63 to 80 percent strongly or somewhat agreeing. The greatest support was for proper location of new wells and well driller certification requirements.

STUDENTS SUPPORTED

- Jessica Tillia, Environmental Resource Management, B.S., December 2006
- Shawn Rummell, PhD candidate in Ecology, 2006

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Results from this project were presented to well owners, Cooperative Extension educators, Master Well Owner volunteers and local government officials at the following activities:

- Master Well Owner Volunteer Training, March 11, 2006, Lewisburg, PA
- Master Well Owner Volunteer Training, April 29, 2006, Allentown, PA
- Master Well Owner Volunteer Training, May 20, 2006, Washington, PA
- Rural Water Quality in Pennsylvania, Lock Haven Rotary Club, June 6, 2006, Mill Hall, PA
- Well water sampling program, August 12, 2006, Williamsport, PA
- Master Well Owner display, August 17, 2006, Ag Progress Days
- Northeast Pennsylvania Water Quality Issues, Wayne County Extension Board Meeting, November 1, 2006, Honesdale, PA
- Northcentral PA Water Quality, Northcentral Landowners Banquet, November 5, 2006, Port Allegheny, PA
- Safe Drinking Water Clinic, November 15, 2006, Schuylkill County
- Safe Drinking Water Clinic, November 16, 2006, McKean County
- Water Quality and Management of Private Wells in Pennsylvania, PA Ground Water Association Winter Conference, January 26, 2007, Grantville, PA
- Using the Master Well Owner Network to Assess Well Water Quality and Management in Pennsylvania, USDA CSREES National Water Quality Conference, January 31, 2007, Savannah, GA

AWARDS

- Universities Council on Water Resources, Education and Public Service Award, 2007

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

- The Center for Rural Pennsylvania, $48,399, February 1, 2007 to January 31, 2008, The Effect of Management Practices on Rural Drinking Water Quality.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	0	0	1	5
Masters	1	0	0	0	1
Ph.D.	3	0	0	1	4
Post-Doc.	0	0	0	0	0
Total	8	0	0	2	10

Notable Awards and Achievements

Two awards recognizing outstanding contributions to science and education were granted during the past year to projects supported by the Pennsylvania Water Resources Research Center. The rural drinking water program developed by Dr. William E. Sharpe, Bryan Swistock and Stephanie Clemens with the School of Forest Resources and Institute for Research on Energy and the Environment at Penn State will receive the Universities' Council on Water Resources national award for Education and Public Service for 2007. Several different projects that contributed to this program, including the project described in this annual report, were funded at least in part by the Pennsylvania Water Resources Research Center over the past several years. A second award, for the Masters Thesis of the Year for 2006 granted by the Association of Environmental Engineering Science and Professors (AEESP) and sponsored by Montgomery-Watson-Harza Engineers was received by Berat Z. Haznedaroglu working with Dr. Metin Duran at Villanova University. The project Fatty Acid Methyl Ester Profiling of Indicator Organisms for Microbial Source Tracking has been supported by the water center in the past. Both awards indicate the high quality of programs being supported by the Pennsylvania Water Resources Research Center.

Publications from Prior Projects

1. 2004PA61B ("Spruce Creek Watershed Keystone Project") - Dissertations - Earley, Brent. 2006. Design of Erosion Control Structures and Critical Brown Trout Habitat within Halfmoon Creek. MLA. Department of Landscape Architecture. College of Arts and Architecture. Pennsylvania State University. University Park PA. 89 pages.
2. 2004PA61B ("Spruce Creek Watershed Keystone Project") - Dissertations - Walsh, Megan. 2006. Modeling Nonpoint Source Pollution in Warriors Mark Run Watershed Using the Arcview Generalized Watershed Loading function Model. MS thesis. Intercollege Program in Environmental Pollution Control. Pennsylvania State University. University Park PA. 92 pages.
3. 2005PA40B ("Nitrate Source Tracking: Combining Isotopic, Microbial, and Chemical Tracers in a Mixed Land-Use Watershed") - Dissertations - Buda, A.R. 2007. Tracing sources of stream nitrate in a central Pennsylvania mixed land-use basin. Ph.D. Dissertation. School of Forest Resources. The Pennsylvania State University. University Park, PA. 240 pages.

4. 2005PA41B ("Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution") - Articles in Refereed Scientific Journals - 1. Haznedaroglu, B.Z.; Yurtsever, D.; Lefkowitz, J.R.; and Duran, M. 2007, Phenotypic characterization of Escherichia coli through whole-cell fatty acid profiling to investigate host specificity, Water Research, 41(4), 803-809.
5. 2005PA41B ("Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution") - Articles in Refereed Scientific Journals - Stedtfeld, R. D.; Yurtsever, D., Duran, M.; Alm, E. W., and Hashsham; S.A. 2006, (peer reviewed literature review). Detection and Occurrence of Indicator Organisms and Pathogens, Water Environment Research, 78(10), 1054-1077.
6. 2005PA41B ("Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution") - Dissertations - Yurtsever, D., 2007, Microbial Source Tracking by Host-Specific FAME Profiles of Escherichia coli and Enterococcus Isolates, MS Thesis Civil and Environmental Engineering Department, College of Engineering, Villanova University, Villanova, Pennsylvania.
7. 2005PA41B ("Fatty acid methyl ester (FAME) profiles of Escherichia coli and enterococci for predicting sources of microbial pollution") - Other Publications - Haznedaroglu, B.Z. and Duran, M. 2007, Predicting Sources of Fecal Pollution Using Fatty Acid Methyl Ester Profiling, Watershed and Wet Weather Technical Bulletin, 12(1), 8-10.
8. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Dissertations - Ziemann, J., 2006, DNA source tracking of Cryptosporidium spp. oocysts in the Wissahickon Creek watershed of Philadelphia, PA, MS Dissertation, Department of Civil and Environmental Engineering, P.C. Rossin College of Engineering and Applied Science, Lehigh University, Bethlehem, PA, 98 pp.
9. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Water Resources Research Institute Reports - Jellison, K., 2006, Annual report: Source water protection from infectious Cryptosporidium spp. oocysts, PA Water Resources Research Center, Pennsylvania State University, University Park, PA, 5pp.
10. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Other Publications - Jellison, K., 2006, Cryptosporidium spp. Oocyst Source Tracking in the Wissahickon Creek Watershed, May 2005-June 2006, Report to the Philadelphia Water Department, Philadelphia, PA, 12 pp.
11. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Other Publications - Jellison, K., 2007, Cryptosporidium spp. Oocyst Source Tracking in the Wissahickon Creek Watershed, June 2006-December 2006, Report to the Philadelphia Water Department, Philadelphia, PA, 13 pp.
12. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Other Publications - Jellison, K., 2005, Interim report for fiscal year 2005: Source water protection from infectious Cryptosporidium spp. oocysts, Report to the Pennsylvania Infrastructure Technology Alliance, Lehigh University, Bethlehem, PA, 6pp.
13. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Other Publications - Jellison, K., 2006, Final report for fiscal year 2005: Source water protection from infectious Cryptosporidium spp. oocysts, Report to the Pennsylvania Infrastructure Technology Alliance, Lehigh University, Bethlehem, PA, 4pp.
14. 2005PA42B ("Source Water Protection from Infectious Cryptosporidium spp. Oocysts") - Other Publications - Jellison, K., 2006, Interim report for fiscal year 2006: Source tracking of infectious Cryptosporidium spp. oocysts in Wissahickon Creek, Report to the Pennsylvania Infrastructure Technology Alliance, Lehigh University, Bethlehem, PA, 3pp.

15. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Carrick, H.J., C.M. Godwin, M. Johnston-Greenwald, C. Rilk, A. Siefert, and C.J. Tzilkowski. 2007 Evaluation of water quality in a spring fed stream (Spring Creek, Pennsylvania) based upon benthic algae and macroinvertebrates. Journal of the Pennsylvania Academy of Sciences. 80: 71-78.
16. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Articles in Refereed Scientific Journals - Godwin, C.M., and H.J. Carrick. Spatio-temporal variation of periphyton biomass and production in a temperate, spring-fed stream. Aquatic Ecology. Accepted for publ.
17. 2004PA30B ("Nitrogen dynamics in the Spring Creek watershed (Pennsylvania, USA): Evaluating stream retention of point and non-point source loadings") - Dissertations - 2004-06 Mr. Casey Godwin: Temporal and spatial variation of periphyton in a temperate, cold water stream (Spring Creek, PA). M.S. in Ecology, Pennsylvania State University, 48 p.