Pennsylvania Water Resources Research Center, Penn State Institutes of Energy and the Environment
Annual Technical Report
FY 2009

Introduction

OVERVIEW.

Authorized by Congress as one of the nation's 54 water resources research institutes, the Pennsylvania Water Resources Research Center (PA-WRRC) emphasizes the role of research, education, and outreach in advancing water issues. The PA-WRRC receives federal funding that is then distributed in a small grants competition to support research and information transfer projects at academic institutions across Pennsylvania -- all aimed at addressing water resources problems of importance in Pennsylvania. None of the federal funding is used to pay overhead costs or faculty salaries, and each institute matches every dollar of its base appropriation with at least two dollars from non-federal sources. All of the submitted proposals are peer-reviewed.

STUDENTS SUPPORTED. Within the research projects (4) and information-transfer projects (2) that were supported this fiscal year, twelve students (from three universities) were supported or partially supported. They are listed below in the format: (Principal Investigator of the USGS 104B project), Student name, Department, Academic Institution.

Undergraduates: (Bain) Katelin Fisher, Department of Geology and Planetary Science, University of Pittsburgh (Bain) Erin Wozniak, Department of Geology and Planetary Science, University of Pittsburgh (Brennan) Michael Shreve, Dept. of Civil & Environmental Engineering, Penn State University (Carrick) Erin Cafferty, Environmental Resources Management Program, Penn State University (Gilmore) Christopher A. Kulish, Civil Engineering, Bucknell University (Gilmore) Molly E. Pritz, Geology, Bucknell University (Swistock) Jennifer Oliver, Environmental Resource Management Program, Penn State University

Masters candidates: (Boyer) Lida Iavorivska, School of Forest Resources, Penn State University (Brennan) Erin Henry, Dept. of Civil & Environmental Engineering, Penn State University (Brennan) Abby Caporuscio, Dept. of Civil & Environmental Engineering, Penn State University (Carrick) Melissa May, School of Forest Resources, Penn State University

Doctoral (PhD) candidates: (Carrick) Keith Price, School of Forest Resources, Penn State University

Postdocs: (Brennan) Dr. Neil Brown, Department of Civil & Environmental Engineering, Penn State University.

Research Program Introduction

Four research-oriented proposals were supported in 2009-10, addressing unanswered questions in water resources. Dr. Daniel Bain, a new faculty member at the University of Pittsburgh, tackled issues of pollution from sewer overflows in urban areas of Western Pennsylvania, in a proposal entitled "Stream storm flow dynamics below combined sewer systems: human and runoff inputs. Dr. Rachel Brennan, an Assistant Professor in the Department of Civil & Environmental Engineering at Penn State University, considered new methods for reducing endocrine disrupting chemicals in water effluents, in a proposal entitled "An emerging technology for emerging contaminants: biocatalysis of endocrine disrupting chemicals in wastewater for beneficial reuse." Dr. Matthew Higgins, a Professor at Bucknell University, addressed concerns associated with water pollution stemming from the growth of natural gas exploration in Pennsylvania, in a proposal entitled "Characterization, treatment, and reuse of frac water related to horizontal hydraulic fracturing of Marcellus Shale in Pennsylvania." Dr. Hunter Carrick, an Associate Professor at Penn State University, explored methods to develop numeric criteria to guide nutrient controls for stream in Pennsylvania, in a project that had some additional support from Pennsylvania Sea Grant.

Developing Numeric Criteria to Guide Nutrient Controls for Streams in Pennsylvania

Basic Information

Title:	Developing Numeric Criteria to Guide Nutrient Controls for Streams in Pennsylvania
Project Number:	2009PA103B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	5th
Research Category:	Water Quality
Focus Category:	Methods, Nutrients, Water Quality
Descriptors:	None
Principal Investigators:	Hunter Carrick, John M. Regan

Publication

1. Carrick, H.J. 2010. Benthic algae-nutrient relationships in Mid-Atlantic streams. Limnology and Oceanography In preparation.

FY09 PROJECT REPORT (FINAL REPORT)
Pennsylvania Water Resources Research Center

Developing Numeric Criteria to Guide Nutrient Controls for Streams in Pennsylvania

Hunter J. Carrick[1], Keith J. Price[2], Melissa K. May[3], and John M. Regan[4]
[1] Associate Professor, School of Forest Resources, Penn State University
[2] Ph.D. Candidate, School of Forest Resources, Penn State University
[3] Graduate Assistant, M.S., School of Forest Resources, Penn State University
[4] Associate Professor, Department of Civil and Environmental Engineering, Penn State University

PRINCIPAL FINDINGS AND SIGNIFICANCE

Problem Statement

The presence of polyphosphate-accumulating organisms (PAO) in stream biofilms appear to be a very significant sink for P in streams, and therefore can represent an previously unaccounted source of P that can be transported downstream during large flushing events (e.g., Chesapeake Bay). The current project will build further on this success by establishing numeric reduction criteria by developing rapid, economical assays to directly measure the degree of P saturation in streams ecosystems throughout Pennsylvania.

Objectives

Our objectives will be met by carrying out a series of experiments using natural biofilms collected from streams of varying nutrient content and relative productivity. Biofilms were sampled seasonally (winter, spring, summer, and fall) from streams already identified as having low, moderate, and high nutrient content within each of the two ecoregions (Appalachian Plateau and Piedmont) in the state's Water Quality Network (see Carrick et al. 2008).

1. Measure the uptake rate for inorganic and organic P among seasons and ecoregions to evaluate their relative correspondence.
2. Evaluate the phylogenic identity of phosphorus accumulating organisms.
3. Recommend P criteria for Pennsylvania streams (annual versus seasonal and state-wide versus ecoregion specific)

Review of Major Findings

Correspondence between APA and P uptake

Phylogenic Identity of P-storing Organisms

We investigated whether this biological transformation among phylogenic groups should be included in stream P models. To date, the answer appears to be yes. Both prokaryote and eukaryotes are responsible for P-storage within the biofilms retrieved from these streams. We obtained positive hits for the presence of poly-phosphorus storage for both taxonomic groups using DAPI (4',6-diamidino-2-phenylindole, DAPI) staining. Moreover, the presence of poly-phosphorus using bulk chemical extraction confirms that substantial concentrations are present in

all the streams. Future plans include the use of genomic techniques to evaluate the presence of PAO in our samples.

P-criteria based upon Physiological Indicators

Alga biomass on natural (rock) substrata was consistently higher compared with that on artificial (tile) substrata, such that biofilms growing on tiles are more indicative of an early successional assemblage ($Z = -2.385$, $p = 0.017$, Table 1). Mean chlorophyll-a was 90.5 and 271.2 mg/m^2 on tile and rocks, respectively. Based on these relative differences between substrate biomass, we can reasonably categorize biofilm rock assemblages as 'late' succession communities and biofilm tile assemblages as 'early' succession (cf. Dent and Grimm 1999).

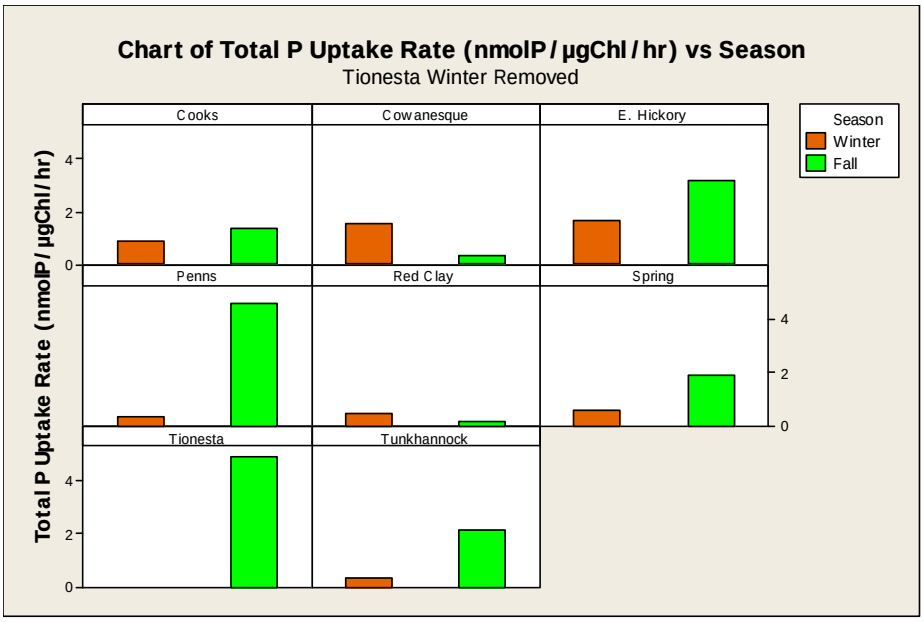
As anticipated, P uptake and APA was be positively correlated with each other as indicators of P limitation, and was negatively correlated with the productivity indicators. Four independent measures of biofilm nutrient metabolism were measured on tiles at each of the eight stream sites: C14 uptake (mgC µgChl-a^{-1} day^{-1}), P uptake (nmol P µg Chl-a^{-1} hr^{-1}), alkaline phosphatase activity (APA; nmol P µg Chl-a^{-1} hr^{-1}), and nitrate reductase (NR; nmol NO_2^- µg Chl-a^{-1} hr^{-1}). $Log_{10}(1+x)$ transformed site means for two sampling dates (n=16) were tested for correlation with each other and with two indicators of stream productivity – conductivity (µS/cm) and benthic biomass on rocks as chlorophyll-a (mg Chl-a m^{-2}) – using a correlation matrix in SPSS.

Table 2. Correlation matrix.

		Conductivity	Benthic Chl-a	C^{14}	P Uptake	APA	NR
Conductivity	Pearson Correlation	1	.505*	-.048	-.598*	-.562*	-.070
	Sig. (2-tailed)		.046	.865	.019	.029	.805
	N	16	16	15	15	15	15
Benthic Chl-a	Pearson Correlation	.505*	1	-.482	-.750**	-.665**	-.558*
	Sig. (2-tailed)	.046		.069	.001	.007	.030
	N	16	16	15	15	15	15
C14	Pearson Correlation	-.048	-.482	1	.620*	.624*	.771**
	Sig. (2-tailed)	.865	.069		.014	.013	.001
	N	15	15	15	15	15	15
P Uptake	Pearson Correlation	-.598*	-.750**	.620*	1	.903**	.719**
	Sig. (2-tailed)	.019	.001	.014		.000	.003
	N	15	15	15	15	15	15
APA	Pearson Correlation	-.562*	-.665**	.624*	.903**	1	.789**
	Sig. (2-tailed)	.029	.007	.013	.000		.000
	N	15	15	15	15	15	15
NR	Pearson Correlation	-.070	-.558*	.771**	.719**	.789**	1
	Sig. (2-tailed)	.805	.030	.001	.003	.000	

	N	15	15	15	15	15	15
*. Correlation is significant at the 0.05 level (2-tailed).			Positive correlation				
**. Correlation is significant at the 0.01 level (2-tailed).			Negative correlation				

As predicted, APA and P uptake had a strong positive correlation (Pearson correlation = 0.903, *p*= 0.000, n=15) and both variables had a negative correlation to conductivity and benthic chl-a (See Table 2). Interestingly, both P variables also had positive correlations with C^{14} uptake and NR, indicating that metabolism of C, N, and P may be closely linked.



A one-way ANOVA of total P uptake rate (nmolP/µgChl-a/hr) versus season indicated that those biofilms growing during the fall season were capable of greater realized P uptake compared to those biofilms in the winter season (F= 4.55, *p*= 0.05). This suggests that biofilms occurring in streams during the fall season provide a greater sink for stream P and may better restrain downstream nutrient transports.

STUDENTS & POSTDOCS SUPPORTED

Melissa May, MS Candidate, School of Forest Resources, Penn State University
Keith Price, PhD Candidate, School of Forest Resources, Penn State University
Erin Cafferty, Undergraduate, Environmental Resources Management Program, Penn State.

PUBLICATIONS

Carrick, H.J. 2010. Benthic algae-nutrient relationships in Mid-Atlantic streams. *Limnology and Oceanography*, In preparation.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Price, KJ and HJ Carrick. (2010) Biofilm Phosphorus Assimilation along a Stream Productivity Gradient: an In Situ Experiment. *Poster Presentation*. Pennsylvania Water Symposium. State College, PA.

Price, KJ and HJ Carrick. (2010) Influence of Stream Trophic State on Phosphorus Assimilation by Benthic Biofilms: Implications for Nutrient Management. *Invited Oral Presentation*. Pennsylvania Lake Management Society 20th Annual Conference. State College, PA.

Price, KJ and HJ Carrick. (2010) Assessing the Effects of Techniques used in Benthic Biofilm Phosphorus Uptake Studies. *Poster Presentation*. Gamma Sigma Delta Annual Graduate and Undergraduate Research Expo. State College, PA.

May, M and HJ Carrick. (2010) Nutrient effects on biofilms in PA streams: Linking biological indicators to land use. *Poster Presentation*. Pennsylvania Water Symposium. State College, PA.

May, M and HJ Carrick. (2010) Assessing nutrient limitation in streams: Correspondence between alternative measures of biofilm nutrient status. *Oral Presentation*. Pennsylvania Lake Management Society 20th Annual Conference. State College, PA.

AWARDS

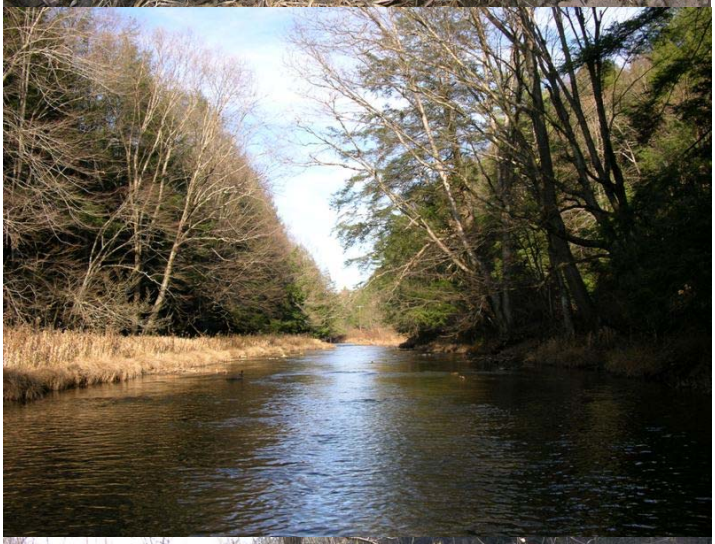
Price, KJ and HJ Carrick. (2010) Poster Award. Pennsylvania Water Symposium.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

(source, amount, starting and ending dates, title)

Drs. Carrick and Regan are collaborating on a proposal to extend this work. The proposal will be submitted to the National Science Foundation for the December call in 2010. The proposal will be a three-year project.

PHOTOS OF PROJECT.



An Emerging Technology for Emerging Contaminants: Biocatalysis of Endocrine Disrupting Chemicals in Wastewater for Beneficial Reuse

Basic Information

Title:	An Emerging Technology for Emerging Contaminants: Biocatalysis of Endocrine Disrupting Chemicals in Wastewater for Beneficial Reuse
Project Number:	2009PA93B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	5
Research Category:	Water Quality
Focus Category:	Toxic Substances, Treatment, Wastewater
Descriptors:	None
Principal Investigators:	Rachel A. Brennan

Publication

1. Henry, E., Caporuscio, A. F, and Brennan, R. A. (2010) "Optimum conditions for the biodegradation of endocrine-disrupting compounds in wastewater by Phanerochaete chrysosporium." Manuscript in preparation for Science of the Total Environment.

FY09 PROJECT REPORT (FINAL REPORT)
Pennsylvania Water Resources Research Center

An Emerging Technology for Emerging Contaminants: Biocatalysis of Endocrine Disrupting Chemicals in Wastewater for Beneficial Reuse

Rachel A. Brennan, Department of Civil & Environmental Engineering, Penn State University.

PRINCIPAL FINDINGS AND SIGNIFICANCE

As beneficial water reuse becomes a common practice throughout the world, concern over the effects of residual contaminants on aquatic ecosystems and human health is escalating. Found in everyday commercial items like plasticizers, pharmaceuticals, pesticides, and flame retardants, endocrine disrupting chemicals (EDCs) have been shown to disrupt hormone function in exposed organisms, causing adverse physiological problems. Typically, these contaminants are not completely removed during conventional wastewater treatment, and are discharged into receiving waters, where they can potentially harm ecosystems and reenter potable water supplies. Although some physical- and chemical-treatment methods exist for treating EDCs in wastewater, they are expensive and unattainable for the majority of the world. An inexpensive, sustainable treatment method is sorely needed for removing residual contaminants from wastewater effluent.

The overall goal of this research is to test the effectiveness of enzymatic biocatalysis for the reduction of EDCs in wastewater effluent using fungal mycelia. The white-rot fungus *Phanerochaete chrysosporium* (ATCC 24725) was chosen for this study based on its previously documented ability to degrade multiple environmental contaminants at high rates. It was theorized that with the application of *P. chrysosporium* mycelia to secondary wastewater treatment plant effluent, the enzymes lignin peroxidase (LiP) and manganese peroxidase (MnP) would be produced which would catalyze the removal of EDCs from solution. To begin to test this hypothesis, a series of continuously aerated batch tests were conducted in a standard factorial design to rapidly assess the ability of immobilized fungal mycelia to achieve enzyme production under different conditions. The variables evaluated included 1) indigenous microbial activity, 2) pH, and 3) organic carbon. Non-sterile and sterile treatments were compared to determine how indigenous wastewater microorganisms would affect fungal growth and enzyme activity. Comparisons were also made between the natural wastewater pH (~7.4) and the "optimum" pH for *P. chrysosporium* (~4.3). Finally, the addition of glucose was evaluated to determine if supplemental carbon is needed to support the growth and activity of *P. chrysosporium* in wastewater.

The principal findings and significance of this work include the following:

1. Growth and attachment *P. chrysosporium* occurred in non-sterile, aerated wastewater reactors under optimal pH conditions. Within these reactors, extracellular enzyme activity (LiP and MnP) was induced. In order to sustain and increase enzyme

activity, multiple supplementations and/or various concentrations of veratryl alcohol should be evaluated.

2. Adjusting the pH to the optimum range (4.0 – 4.5) is necessary to: 1) obtain and maintain attached growth; and 2) produce enzyme activity. In long-term batch experiments, reactors should be buffered to maintain a pH within the optimum range.

3. Glucose amendments only appeared to positively affect the attached growth of the sterile reactors that had been pH adjusted to 4.3. In future experiments, it should be possible to grow *P. chrysosporium* and produce enzyme activity without the addition of glucose.

Experiments currently in progress are evaluating the effects of wastewater treatment stage, temperature, nutrient supplementation, and traditional vs. sustainable support structures for mycelia attachment. After optimizing treatment conditions in batch mode, bioreactor studies will be conducted to quantify EDC removal rates, and confirm suitable hydraulic residence times when immobilized mycelia are used for EDC treatment. If successful, this work will be the first to utilize fungi-driven biocatalysis for the remediation of EDCs in wastewater, which could provide a more sustainable, cost-efficient alternative over traditional removal processes.

STUDENTS & POSTDOCS SUPPORTED

1. **Erin Henry**, "Optimization of conditions for the degradation of endocrine-disrupting compounds by white-rot fungi in large-scale wastewater applications", Department of Civil & Environmental Engineering, Penn State, M.S. expected December 2010.

2. **Abby Caporuscio**, "Enzymatic biocatalysis of endocrine disrupting chemicals in wastewater using *Phanerochaete chrysosporium*", Department of Civil & Environmental Engineering, Penn State, M.S. expected December 2010.

3. **Michael Shreve**, "Sustainable growth media for the fungal remediation of endocrine disruptors in municipal wastewater", B.S. Environmental Systems Engineering with Honors in Environmental Engineering, expected December 2010.

4. **Dr. Neil Brown**, "Pharmaceutical removal from wastewater using ecological processes", Department of Civil & Environmental Engineering, Penn State, research associate, 2008 – present.

PUBLICATIONS

1. Henry, E., Caporuscio, A. F, and Brennan, R. A. (2010) "Optimum conditions for the biodegradation of endocrine-disrupting compounds in wastewater by *Phanerochaete chrysosporium*." Manuscript in preparation for *Science of the Total Environment*.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

1. Brennan, R. A. (2010) “Using Living Machines to Remove Endocrine Disruptors from Wastewater.” *Invited seminar*, The Pennsylvania Water Symposium: Groundwater and Surface Water: A Single Resource, University Park, PA, May 6.

2. Henry, E., and Brennan, R. A. (2010) "Determination of optimum conditions for removal of endocrine-disrupting compounds by white-rot fungi in large-scale applications." *Poster presentation*, The Pennsylvania Water Symposium: Groundwater and Surface Water: A Single Resource, University Park, PA, May 6.

3. Caporuscio, A. F., and Brennan, R. A. (2010) "Magnificent mushrooms: enzymatic biocatalysis of endocrine disrupting compounds in wastewater using fungal mycelia." *Poster presentation*, The Pennsylvania Water Symposium: Groundwater and Surface Water: A Single Resource, University Park, PA, May 6.

4. Brennan, R. A. (2010) “You're Going to Drink *WHAT*???: Using Living Machines to Clean Contaminated Water.” *Invited seminar*, Penn State Lectures on the Frontiers of Science, sponsored by the Penn State Eberly College of Science and the Penn State Institutes of Energy and the Environment, The Pennsylvania State University, University Park, PA, Feb. 6.

AWARDS

1. Henry, E., and Brennan, R. A. (2010) "Optimum conditions for biodegradation of endocrine-disrupting compounds by white-rot fungi in large-scale wastewater applications." *Podium presentation (**Student Research Award Recipient**)*, Pennsylvania Water Environment Association 82nd Annual Technical Conference & Exhibition (PennTec 2010), State College, PA, June 14.

2. Caporuscio, A. F., Brown, N., and Brennan, R. A. (2010) "From silent spring to the forest floor: enzymatic biocatalysis of endocrine disrupting compounds in wastewater using fungal mycelia." *Poster presentation (**Student Research Award Recipient**)*, Pennsylvania Water Environment Association 82nd Annual Technical Conference & Exhibition (PennTec 2010), State College, PA, June 14.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

Source: Penn State Sustainability Seed Grant Program (PSIEE)
Start date: May 15, 2010
End date: June 30, 2012
Title: Life Cycle Assessment of Sustainable Wastewater Treatment Strategies: Toward the Development of an Enhanced Water-Energy Infrastructure

PHOTOS OF PROJECT

Figure 1. Support structures under consideration for mycelia attachment. From left to right: Jaeger Tri-packs ®, Fuzzy Filters™, rye grain, and wood chips.

Figure 2. Aerated batch microcosms used for testing fungal growth and enzyme production in wastewater.

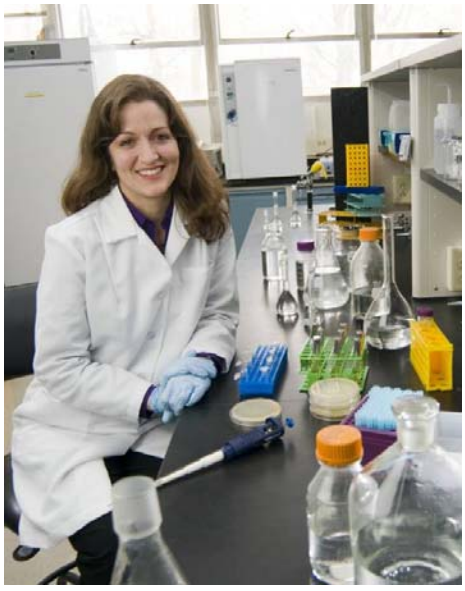


Figure 3. The principal investigator of this project, Dr. Rachel Brennan, in the lab.

Characterization, Treatment, and Reuse of Frac Waters related to Horizontal Hydraulic Fracturing of Marcellus Shale and Natural Gas Exploration in Pennsylvania

Basic Information

Title:	Characterization, Treatment, and Reuse of Frac Waters related to Horizontal Hydraulic Fracturing of Marcellus Shale and Natural Gas Exploration in Pennsylvania
Project Number:	2009PA95B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	10th
Research Category:	Engineering
Focus Category:	Water Use, Acid Deposition, Treatment
Descriptors:	
Principal Investigators:	Matthew J. Higgins, Kevin R. Gilmore

Publications

There are no publications.

FY09 PROJECT REPORT (FINAL REPORT)
Pennsylvania Water Resources Research Center

Characterization, Geochemical Modeling, and Membrane Treatment of "Frac Water" related to Horizontal Hydraulic Fracturing of Marcellus Shale

Kevin R. Gilmore[1,*], Carl S. Kirby[2], Christopher A. Kulish[1,**], Molly E. Pritz[2,**], Matthew J. Higgins[1]
[1]Department of Civil & Environmental Engineering. Bucknell University, Lewisburg, PA.
[2]Department of Geology. Bucknell University, Lewisburg, PA
*Corresponding Investigator: kevin.gilmore@bucknell.edu, 570-577-1615
**Undergraduate Student Researchers

PRINCIPAL FINDINGS AND SIGNIFICANCE

The Marcellus Shale natural gas has the potential to develop the region's economy and improve the nation's energy independence. However, water-related issues must be considered when developing this resource. This project included chemical characterization of hydraulic fracture flowback water, geochemical modeling of flowback water changes over the duration of a fracture event, and an evaluation of membrane treatment for reducing the total dissolved solids (TDS) concentration in flowback water.

Concentrations of TDS in five collected flowback water samples ranged from three to six times (110,000 to 210,000 mg/l) saltier than sea water (35,000 mg/l) (Figure 1) and were dominated by sodium, calcium, and chloride. A review of samples from throughout the commonwealth was conducted by examining reports on file with the Department of Environmental Protection (DEP), and these files showed similar results for TDS and other parameters, although TDS concentrations varied substantially. Bromide (Br^-) concentrations in collected samples ranged from 400 to 760 mg/l, demonstrating implications for formation of brominated disinfection byproducts during potable treatment of flowback-contaminated surface waters. Barium (Ba) and strontium (Sr) concentrations were also elevated (7,600 mg/l and 3,200 mg/l, respectively) in the collected samples. In DEP files, samples fell into one of two groups: concentrations of Ba and Sr were either linearly positively correlated to TDS concentration or were unrelated, suggesting different compositions of shale brines throughout the Commonwealth, or effects of different makeup water sources for fracturing. Low-level ($\alpha+\beta$) radioactive emissions above tap water background levels were detectable in liquid scintillation counts (Figure 2), but no high-energy gamma radiation was detected.

Prior to DEP's proposed permitting strategy in 2009, it appeared that treatment of flowback water would take the form of dilution through major (>1.0 MGD) publicly-owned treatment works (POTW) effluents. Hence, a watershed analysis based on TDS was conducted (Figure 3) to determine the number of gas shale wells that could be sustained in the West Branch Susquehanna River watershed. Assumptions and results are shown in Table 1, demonstrating that dilution of flowback water TDS into ordinary municipal wastewater will support only 16 gas

shale wells per year, a number that is drastically lower than the amount of drilling anticipated in the watershed.

Table 1. West Branch Susquehanna River TDS Mass Balance Analysis.

Parameter	Assumption or Value
Background river TDS	120 mg/l, measured
Flowback water volume	1 million gallons (MG) per well, assumed
Flowback TDS	150,000 mg/l, assumed
End-of-pipe TDS standard	500 mg/l, based on DEP permitting strategy
Baseload TDS concentration in POTW effluent	350 mg/l, measured locally
Number of wells that can be supported in watershed by POTW dilution	*16 wells per year*

Geochemical models created in PHREEQC Interactive suggested that organic complexes in the oil field brine that resides in the Marcellus formation itself aid in dissolution of ions such as barium and strontium into the flowback water. While equilibria reactions in the model explained some of the observed flowback water characteristics, the controlling factor in flowback water composition was the oil field brine concentration and the ratio of mixing with the injected slickwater.

Given the high salt concentrations and DEP's proposed interim permitting strategy reducing effluent TDS to less than 500 mg/l, TDS will be the parameter governing the choice of treatment technology for this brine. Due to the dominance of monovalent ions in the flowback water, conventional chemical precipitation (via elevated pH) treatment will not reduce the TDS concentration appreciably, although precipitation of scale-prone divalent cations may become commonplace prior to reuse of flowback water. Reverse osmosis (RO) permeation tests (1,000 psig) conducted on flowback water alone yielded negligible flux through polyamide desalination membranes. However, samples received by a regional pretreatment facility are often blends of flowback water and pit water (drilling mud with lower TDS), and dilution with the pit water can result in significantly lower initial TDS concentrations (64,000 mg/l, average of two samples). Membrane treatment of these blends was more successful, with flux as high as 22 gallons per square foot per day at 800 psi transmembrane pressure. Flux was proportional to initial TDS concentration. While approximately 95% reduction in TDS was achieved (Figure 4), permeate still did not meet the PA water supply criteria of <500 mg/l TDS, suggesting that if RO or other membrane separation is to be employed, multi-stage treatment may be required.

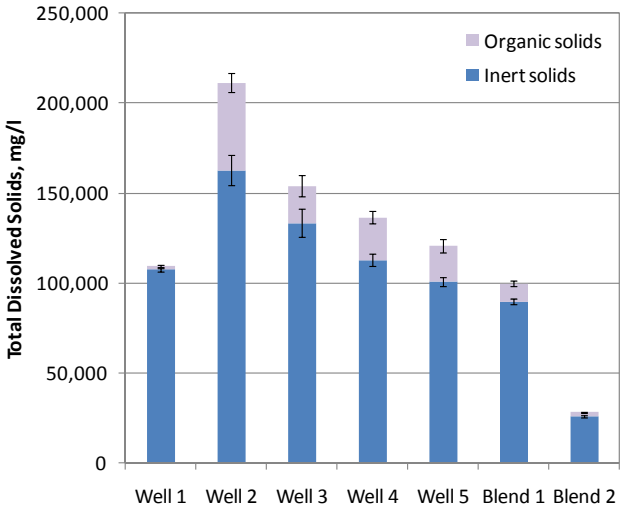


Figure 1. Flowback water TDS concentrations.

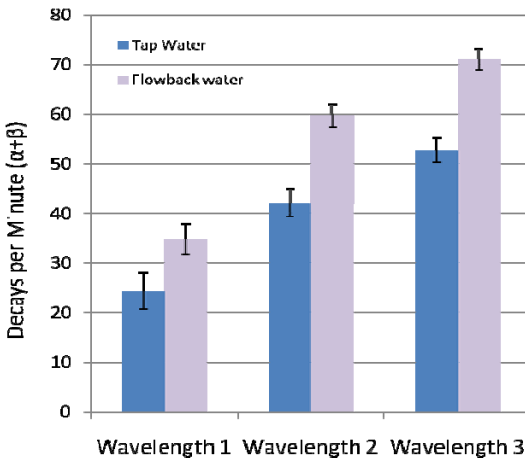


Figure 2. Flowback water radionuclides.

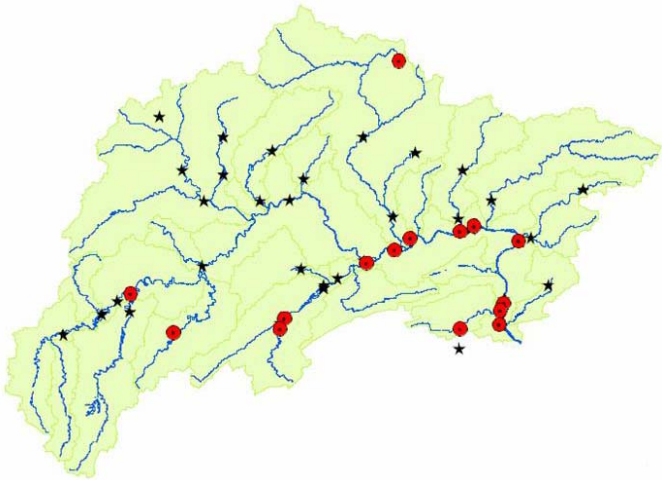


Figure 3. West Branch Susquehanna TDS Balance showing major POTWs and USGS gauging stations.

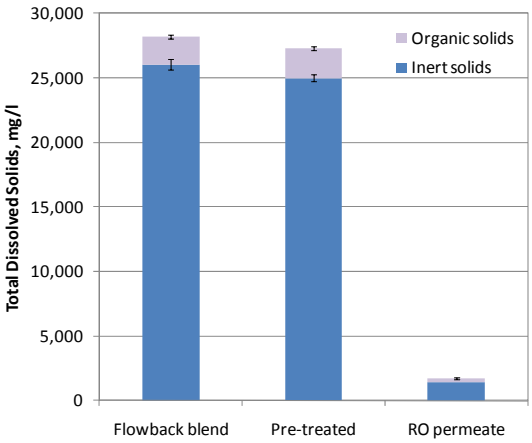


Figure 4. RO permeation of flowback-pit water blend, 800 psi, polyamide brackish desalination membrane.

STUDENTS & POSTDOCS SUPPORTED

Christopher A. Kulish, B.S. Civil Engineering, Bucknell, 2010.
Molly E. Pritz, B.S. Geology, Bucknell, 2010

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

Kulish, C. and K. Gilmore. (2010) Marcellus Shale natural gas wastewater characterization and treatment; Susquehanna watershed TDS analysis. Podium and poster presentations. Pennsylvania Water Environment Association (PWEA) PennTec Conference. State College, June 14-16, 2010.

Gilmore, K. (2010) Characterization, geochemical modeling, and membrane treatment of frac water. Invited presentation. PA WRRC Pennsylvania Water Symposium. State College, May 5-6, 2010.

Gilmore, K. (2010) Characterization and membrane treatment of Marcellus shale flowback water. Susquehanna River Heartland Coalition for Environmental Studies, Science of Marcellus Shale Summit. Williamsport, January 29, 2010.

Kirby, C. S. (2010) Marcellus Shale Hydrofracturing Water Geochemistry and Feasibility of Using Conductivity for Monitoring Streams, Susquehanna River Heartland Coalition for Environmental Studies, Science of Marcellus Shale Summit. Williamsport, January 29, 2010.

Kirby, C. S. (2010) Marcellus Fracwater Geochemistry and Stream Monitoring Feasibility, Marcellus Shale Natural Gas Stewardship: Understanding the Environmental Impact, *A Temple University Summit*, Philadelphia PA, April 18, 2010.

Kirby, C. S. (2010) Perspectives on Potential Environmental Impacts of Marcellus Shale Natural Gas Drilling, Bucknell Institute for Public Policy Marcellus Shale Symposium, Lewisburg PA, April 17, 2010.

Pritz, M. E. and Kirby, C. S. (2010) Geochemical investigation of Marcellus Shale natural gas hydrofracturing waters, combined annual meeting Northeastern / Southeastern Section of Geological Society of America, March 13-16, Baltimore MD.

Pritz, M. (2010) The Hydraulic Fracturing of the Marcellus Shale and Some Potential Environmental Impacts on Central Pennsylvania, presented to local League of Women Voters, Lewisburg PA, November 17, 2009

Pritz, M. (2010). Geochemical Modeling and Analysis of the Frac Water used in the Hydraulic Fracturing of the Marcellus Formation, Pennsylvania , Bucknell Institute for Public Policy Marcellus Shale Symposium, Lewisburg PA, April 17, 2010.

AWARDS

C. Kulish – Student Research Award, Pennsylvania Water Environment Association (PWEA) PennTec Conference. State College, June 14-16, 2010.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

None to date.

PHOTOS OF PROJECT

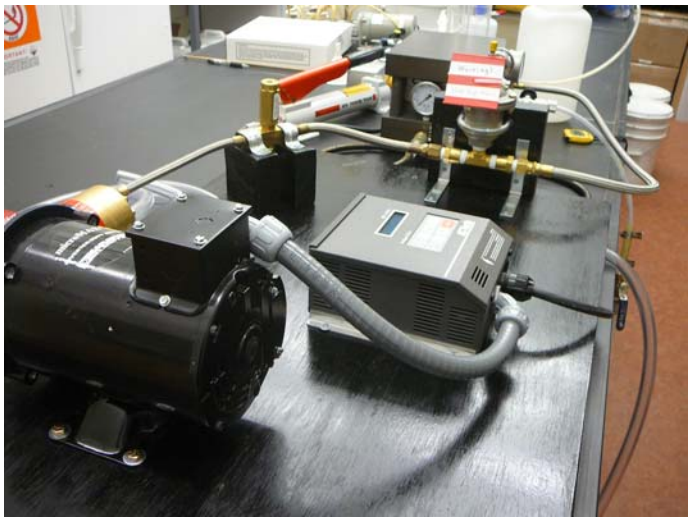


Figure 1. Lab-scale high pressure pumping system for reverse osmosis membrane treatment testing. (Photo by C. Kulish)

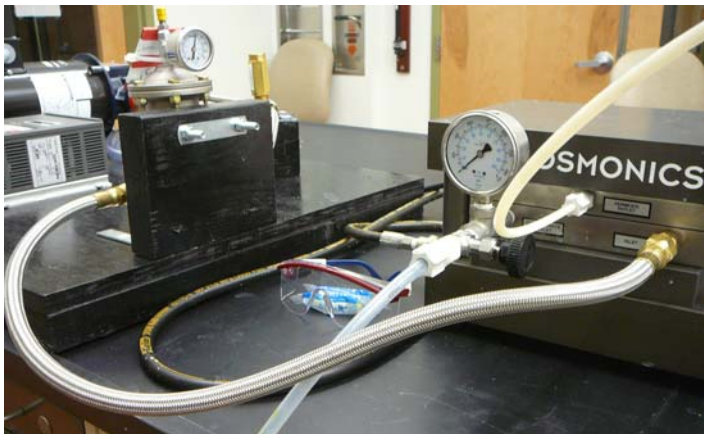


Figure 2. Lab-scale reverse osmosis membrane test apparatus. (Photo by C. Kulish)

Figure 3. Photograph illustrating residual salts remaining after sample evaporation.(Photo by K. Gilmore)

Stream Storm Flow Dynamics Below Combined Sewer Systems: Human and Runoff Inputs

Basic Information

Title:	Stream Storm Flow Dynamics Below Combined Sewer Systems: Human and Runoff Inputs
Project Number:	2009PA98B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	14th
Research Category:	Water Quality
Focus Category:	Water Quality, Hydrology, Surface Water
Descriptors:	None
Principal Investigators:	Daniel Bain

Publications

There are no publications.

FY09 PROJECT REPORT (FINAL REPORT)
Pennsylvania Water Resources Research Center

Stream Storm Flow Dynamics Below Combined Sewer Systems: Human and Runoff Inputs

Daniel Bain, Department of Geology and Planetary Science, University of Pittsburgh

PRINCIPAL FINDINGS AND SIGNIFICANCE

In the project proposal, we laid out three ambitious objectives. While these objectives were not met, clear progress was made on each. The objectives and summaries of progress for each below are included below:

1. Demonstrate fluoride (F) and temperature as tracers of domestic water inputs to urban fluvial systems. Demonstrating any hydrologic tracer is not a trivial task. However, our continued sampling and analysis continue to provide promising results. First, F concentrations remained between ~0.2 and 1.0 ppm (the level of F generally added to domestic water) throughout the project period, consistent with observations made prior to project funding. Unless, mechanisms dictating F concentrations in the water are coincidentally maintaining levels at ~1 ppm, this range of concentrations seems to indicate the presence of F derived from domestic water and waste water in NMR waters. Moreover, during periods characteristic of water line breaks (e.g., high suspended sediment and rapid discharge regression during dry weather) samples are positive outliers with F concentrations at or near the drinking water concentrations (Figure 1). This observation supports our contention that F can be utilized to identify domestic water contributions. However, some ambiguities remain, including the potential for F to precipitate with Ca or absorb to clay minerals. Therefore, we are currently seeking funding to analyze F concurrently with stable isotopes of water (δD and $\delta^{18}O$) and demonstrate the efficacy of the F tracer. With this additional demonstration, *F can be utilized* in any urban setting that fluorinates drinking water and does not have substantial mineral sources in local geology *to partition urban surface waters between domestic and meteoric sources.*

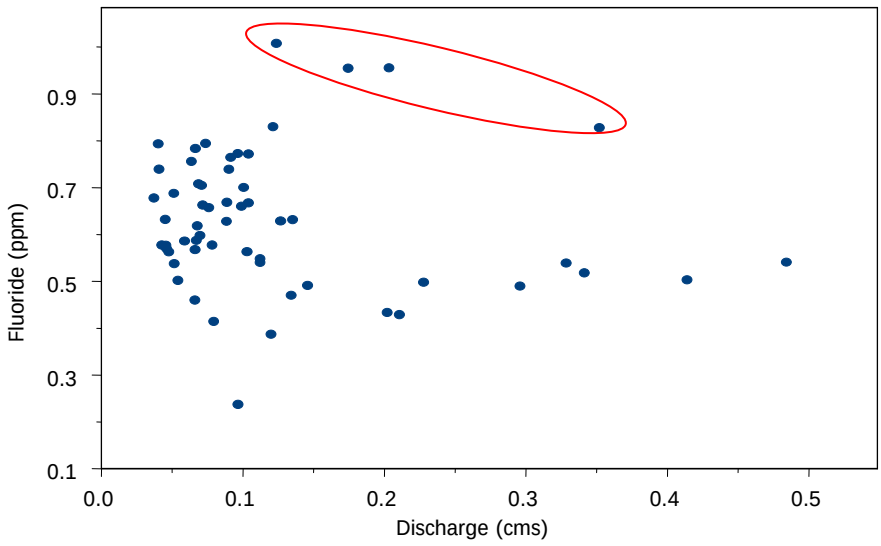


Figure 1 Fluoride Concentration vs. Discharge in Nine Mile Run just below its emergence from burial. Sample points circled in red all share a similar set of characteristics, including high suspended sediment load and rapid discharge regression during dry weather.

2. Collect high temporal density F concentration and temperature data in stream and sewer portions of Nine Mile Run, with particular attention to wet weather periods. A continuous, five minute interval record of temperature has been collected via instruments installed at several locations in Nine Mile Run. In particular, we have established coupled stations at the combined sewer outfall and immediately upstream of this outfall (Figure 2). This record indicates sufficient contrast to allow for mixing models based on temperature and therefore quantification of discharge contributed by the outflow during storm flow. A third temperature sensor downstream of the outfall was recently installed and should provide such a record in the near future. *Development of this method provides a cheap, reliable means to characterize and monitor combined sewer inputs to urban streams.* Temporally dense fluoride concentration measurements have proven to be less simple. Utilization of fluoride ion selective electrodes (F-ISE) in natural waters requires buffering and use of chelating ligands to reduce interferences. Much of our time has been spent in the lab evaluating available commercial mixtures with minimal success. We are currently seeking funding to allow the sustained effort of a graduate student and the acquisition of commercial, automated F-ISE packages to minimize engineering necessary on our end. In addition, this week we have collected samples through our first storm hydrograph using the automated water sampler installed with project funds. Analysis of these samples should provide data regarding F concentration dynamics during storm flow. *Ultimately, the combination of high temporal resolution CSO temperature monitoring and fluoride concentration should provide strong insight into urban hydrologic systems advancing both applied and mechanistic understanding.*

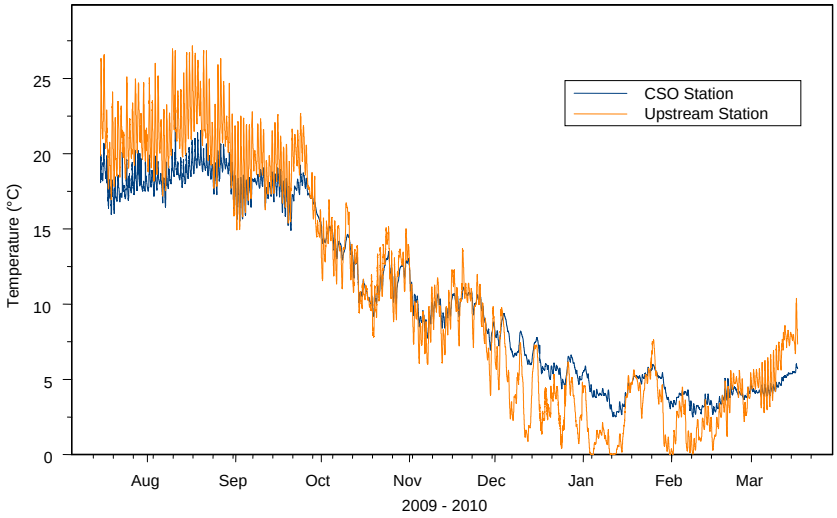


Figure 2 Five minute interval temperature record from coupled stations in Nine Mile Run. The blue line indicates temperature measured at a combined sewer outfall and the orange line in stream temperatures directly upstream of the outfall.

3. Use this data to determine the role of sewer inputs in Nine Mile Run's discharge and particularly to evaluate the impact of human water consumption on storm flow patterns. As noted above, these high temporal density records remain in progress. However, once collected, these data should provide a strong dataset for understanding urban hydrology and methodology that can be broadly applied.

Other findings:
Project funding allowed additional examination of metal concentrations in these samples. In particular, waters downstream of the slag in Nine Mile Run are enriched in aluminum and

potassium, potentially providing a means to evaluate the prevalence of slag throughout the region (a challenging task due to poor record keeping) and/or predict the ecosystem impacts of slag on local waters (e.g., how does this excess potassium impact instream biotic communities?) *These tracers of slag provide a tool for evaluating water-steel waste interactions in steel production regions around the world.*

STUDENTS & POSTDOCS SUPPORTED

Katelin Fisher, Department of Geology and Planetary Science, 2009 BS Geology (Currently a Masters Student, Department of Earth Sciences, Indiana University Purdue University at Indianapolis)
Erin Wozniak, Department of Geology and Planetary Science, 2010 BA Environmental Studies (Currently employed by the Friends of the Pittsburgh Urban Forest)

PUBLICATIONS

None yet.

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

E. P. Wozniak, K.R. Fisher, D. J. Bain "Tracing Domestic Water Inputs to Pittsburgh Streams", Poster presented at *Science Unplugged*, University of Pittsburgh, October 15, 2009

E. P. Wozniak, K. R. Fisher, M. T. Sikora, E. M. Elliott, D.J. Bain "Tracing Domestic Water Inputs to Pittsburgh Streams" Poster presented at *Pennsylvania Water Symposium*, Pennsylvania State University, May 6, 2010

D. J. Bain, M. T. Sikora, E. P. Wozniak, K. R. Fisher, E. M. Elliott "Adaptive Management in Urban Stream Restoration: Balancing Water Quality and Channel Structure" Invited Talk to be presented at *2010 Ecological Society of America Annual Meeting*, Pittsburgh, PA

AWARDS

None.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

University of Pittsburgh Office of Experiential Learning Small Grant for Undergraduate Research, $500, 9/1/2009-12/31/2009,"Tracing Domestic Water Inputs to Pittsburgh Streams"

NSF-Hydrological Sciences, $300,000, 5/1/2011-4/30/2014, "Development of Hydrologic Tracers For Characterizing Urban Catchment Hydrology" (submission planned 6/1/2010)

Information Transfer Program Introduction

Two information transfer projects were supported in 2009-10, making research based information available to stakeholders statewide. Dr. Bryan Swistock, a senior extension associate at Penn State University, along with the statewide team of water extension associates and educators, considered water resources planning for Pennsylvania in a proposal entitled "Water conservation training and public education." Dr. Elizabeth Boyer, Director of the Pennsylvania Water Resources Research Institute, will bring researchers together from across the state to network and to consider the role of research in advancing water resources issues, in the upcoming Pennsylvania Water Symposium (to be held May 2010). Furthermore, the PA-WRRC joined together with the Mid-Atlantic Water Resources Research Institutes (NY, PA, WV, MD, DC, VA) to host a conference on The Water-Energy Nexus: A Necessary Synergy for the 21st Century. The West Virginia WRRI took the lead on this collaborative effort.

Pennsylvania Water Resources Research Symposium

Basic Information

Title:	Pennsylvania Water Resources Research Symposium
Project Number:	2009PA108B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	5th
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Quality, Water Quantity, Water Use
Descriptors:	None
Principal Investigators:	Elizabeth Boyer, Bryan Reed Swistock

Publications

There are no publications.

FY09 PROJECT REPORT (PROGRESS REPORT)
Pennsylvania Water Resources Research Center

Pennsylvania Water Resources Research Symposium

Elizabeth W. Boyer and Bryan Swistock, School of Forest Resources, Penn State University.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The Pennsylvania Water Resources Research Center will hold a symposium highlighting water resources research in Pennsylvania. We will bring together a diverse audience of researchers from academia, government agencies, consulting firms, and NGOs. The objectives are fourfold:

1) *Consider the role of research:* To consider the role of research in advancing understanding of important water resources issues in Pennsylvania;
2) *Identify who's doing what:* To identify the scope of water resources research being conducted statewide;
3) *Enable networking:* To facilitate networking among researchers, enabling them to meet, discuss their work, and to share information and ideas.
4) *Facilitate future opportunities:* To foster collaboration, to encourage synthesis of data and results, and to discuss opportunities for further interdisciplinary water-related research.

In this fiscal year, we have:

1) Planned the conference theme: Ground Water and Surface Water, a Single Resource.
2) Planned a date, venue, and agenda for the symposium, to be held at the Penn Stater conference center on May 5-6 2010.
3) Raised funds for the symposium, to add to the funding from USGS, enabling a heavily subsidized registration fee. This is especially important to engage stakeholders in a time of economic constraints on travel. We have tentative additional support from the Pennsylvania Department of Environmental Protection, the Penn State Master Well Owner Network, the Penn State Environmental and Natural Resources Institute, the Penn State Earth and Environmental Systems Institute, and the Pennsylvania Groundwater Association.
4) Developed a web site for the symposium, online at: http://agsci.psu.edu/pa-water-symposium
5) Planned keynote speakers, from the U.S. Geological Survey and the Pennsylvania Department of Environmental Protection.
6) Solicited abstracts for oral and poster presentations.

STUDENTS SUPPORTED

Lidiia Iavorivska, MFR candidate, School of Forest Resources, Penn State University.

Water Conservation Training and Public Education

Basic Information

Title:	Water Conservation Training and Public Education
Project Number:	2009PA94B
Start Date:	3/1/2009
End Date:	2/28/2010
Funding Source:	104B
Congressional District:	5
Research Category:	Social Sciences
Focus Category:	Water Quantity, Water Supply, Education
Descriptors:	None
Principal Investigators:	Bryan Reed Swistock

Publications

There are no publications.

FY09 PROJECT REPORT (FINAL REPORT)
Pennsylvania Water Resources Research Center

Water Conservation Training and Public Education

Bryan Swistock and the Penn State Cooperative Extension statewide water team

PRINCIPAL FINDINGS AND SIGNIFICANCE

Prolonged, serious droughts in Pennsylvania over the past two decades have highlighted water quantity concerns throughout the state and resulted in passage of the Water Resources Planning Act in 2002. This Act includes the designation of Critical Water Planning Areas throughout the state where water use is projected to exceed availability. The new State Water Plan within the Act encourages new water conservation educational programs throughout the state but also targets educational needs for the critical water use areas.

Penn State Cooperative Extension has a long history of providing educational resources targeting various water resources issues. Previous water conservation educational programs have reached thousands of Pennsylvania residents, especially during serious droughts early in this decade. This project resulted in the development of a cohesive, statewide team of ten Cooperative Extension water specialists and county educators who can respond to current and future needs for public education related to water conservation. They developed a variety of water conservation publications, videos, and web resources which were used to deliver numerous programs targeting future Critical Water Planning Areas and other regions of the state. A new Water Resources Extension water conservation web site was created to house these publications, videos and other resources at: http://water.cas.psu.edu/water_conservation.htm. This combination of a dedicated team of trained educators and extensive water conservation educational resources creates a strong, statewide effort to promote water conservation education.

STUDENTS & POSTDOCS SUPPORTED

Jennifer Oliver, B.S., Environmental Resource Management, 2010

Jennifer Oliver was employed as a summer intern during 2009 to work on project deliverables including the community water conservation publication, the water conservation web site, and the scripts for the project videos.

PUBLICATIONS

A list of pubs that has stemmed from the project

Swistock, B., J. Oliver, J. Clark, D. Rizzo, S. Boser, P. Wulfhorst, T. McCarty. 2010. Water Conservation for Communities, Penn State Cooperative Extension, College of Agricultural Sciences. Publication No. AGRS-113, 26 pp.
http://resources.cas.psu.edu/WaterResources/pdfs/communitywaterconservation.pdf

PRESENTATIONS AND OTHER INFORMATION TRANSFER ACTIVITIES

A series of short (3-5 minute) web-based videos were produced including 1) Why Conserve Water? 2) Conserving Water Inside Your Home 3) Conserving Water Outside Your Home and 4) An Example of the Benefits of Household Water Conservation. These videos are housed on the Penn State Water Resources Extension web site at http://water.cas.psu.edu/water_conservation.htm.

Water conservation public education programs were delivered to a total of 1,235 participants throughout the state. Most of these programs were delivered in areas of the state where Critical Water Planning Areas are expected. One highlighted program was the training of Master Well Owner volunteers in Lebanon County. These volunteers are located in or near numerous Critical Water Planning Areas. They received several hours of training focusing on water conservation efforts in their communities. Specific locations, topics and attendees for all programs are given below:

1. March 25, 2009 - Water Conservation Inservice Training, University Park, PA, 14 Extension Educators
2. April 15, 2009 – Rain Barrel and Rain Garden Workshop, Westmoreland County, 35 participants
3. July 8, 2009 – Water Conservation and Management, Bedford County, 4 participants
4. July 8, 2009 and August 11, 2009 – Conserving Water Through Stormwater Management, Beaver County, 70 participants
5. August 18-20, 2009 - Ag Progress Days Water Conservation Display, Centre County, 110 participants
6. September 29, 2009 – Managing Water in Your Backyard, Lackawanna County, 40 participants
7. November 21, 2009, Master Well Owner Volunteer Training, Lebanon County, 21 Master Well Owner volunteers
8. January 10, 2010 – Household Water Conservation, Dauphin County, 32 participants
9. January 9-16, 2010 – Household Water Conservation, Pennsylvania Farm Show, Harrisburg, PA – 256 participants
10. January 26, 2010 – Household Water Conservation, York County, 150 participants
11. February 2010 - York County Annex – Water Conservation Display (unknown visitors)
12. February 24, 2010 – Saving Money and Your Septic System with Water Conservation, Webinar delivered statewide, 42 participants
13. March 13, 2010 – Water Conservation, Garden Wise, York/Lancaster County, 300 participants
14. March 1, 2009 – February 28, 2010 – Various water conservation questions and answers to project investigators via phone or email, 161 participants

A Household Water Conservation Home Study Course was also developed to allow for continuous online water conservation education at: (http://water.cas.psu.edu/conservationHS.htm)

This course includes a worksheet and narrated Photostories that guide the participant through the process of measuring their current water use, identifying water leaks, and reducing water use through appliances and behavior changes. The sections of the home study course include:

1. Why Conserve Water?
2. How Much Water Do You Use?
3. How to Conserve Household Water
4. Other (Septic and Money) Savings From Water Conservation

The home study course was completed during the project and will be advertised within Critical Water Planning Areas as they are designated through the Water Resources Planning Act.

A subset of about 15% of program participants (193 total participants) received an evaluation to document expected actions and impacts after attending a Penn State Cooperative Extension water conservation program. Evaluation of program participants determined that water conserving appliances and behaviors were occurring at various levels among private water supply owners. Only 25% reported owning a front-loading clothes washer while 50% owned low-flush toilets and/or low flow showerheads and/or faucets. Over 60% of participants were unaware of their current water use (lacked a water meter). Among outdoor water use, only 24% used soaker hoses for outdoor water use. Overall, 62% of program participants planned to take an action to reduce their water use or water loss from their property. Specific planned actions by program participants included:

- Promote groundwater recharge by reducing impervious area on my property – 50%
- Establish a rain garden to promote groundwater recharge – 49%
- Install a water meter to measure household water use – 16%
- Check for and fix household water leaks – 59%
- Install indoor water saving device – 41%
- Install rain barrels to capture runoff for outdoor water use – 47%
- Change water use habits – 59%

In addition to these planned actions, 72% of program participants planned to visit the Penn State water conservation web site to view videos and learn more about water conservation while 69% planned to tell others about what they had learned about water conservation.

AWARDS

None

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

None

PHOTOS OF PROJECT

Diane Oleson (Penn State Cooperative Extension, York County) educates two of the 256 farmers and homeowners that visited the Water Conservation exhibit during Ag Progress Days in August 2009.

Penn State Master Well Owner volunteers receive eight hours of training on water use and water conservation during November 2009. These volunteers provided further education to homeowners and farmers within several likely Critical Water Planning Areas in southcentral Pennsylvania.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	7	0	0	0	7
Masters	4	0	0	0	4
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	13	0	0	0	13

Notable Awards and Achievements