Pennsylvania Water Resources Research Center Annual Technical Report FY 2011

Introduction

The Pennsylvania Water Resources Research Center (PA-WRRC), founded in 1964, is authorized by Congress as one of the nation's 54 water resources research institutes comprising the National Institutes of Water Resources (NIWR). In the spirit of the Land Grant mission of the host Universities, each of the institutes emphasize the role of University research, education, and outreach in advancing pressing problems in water quality and quantity. The program is administered by the U.S. Department of the Interior through the U.S. Geological Survey, in a unique Federal-State-University partnership. The PA-WRRC is located on the University Park campus at the Pennsylvania State University. There, PAWRRC resides within the Penn State Institutes of Energy and the Environment (PSIEE). The PA-WRRC continues to receive significant support contributions from PSIEE, which funds the Director's time spent in water center administration and provides additional staff support for administrative, accounting, communications, and research functions.

The PA-WRRC receives USGS 104B federal base funding that is distributed via a small grants competition to researchers at academic institutions across Pennsylvania. In FY2011, a request for proposals for this competition was broadly disseminated. Given the level of funding available, we were able make 5 awards, intended to be one-year seed grants allowing faculty to initiate new research programs on problems important to Pennsylvania. None of the federal funding was used to pay overhead costs, and PA-WRRC matched every dollar of its base appropriation with at least two dollars from non-federal sources.

Research Program Introduction

Four projects supported during FY11 were research-oriented. In the research category of water quality, principal investigator (PI) Emily Elliott and colleagues assessed the influence of nutrient sources to urban streams through fingerprinting with triple nitrate isotopes. In the research category of climate and hydrological processes, PI Jason Kaye and colleagues quantified the nitrogen retention capacity of legacy sediments and hydric soils before & after restoration. In the research category of biology, PI Theo Light and colleagues explored the severity of estrogenic effects associated with the exposure of fish to emerging contaminants. Finally, in the research category of groundwater flow and transport, PI Li Li and colleagues began to develop a subsurface reactive transport model for exploring potential water quality problems associated with the development of the Marcellus Shale.

USGS Award No. G09AP00118 Long-term Responses of Stream Chemistry to Changes in Atmospheric Deposition in Mid-Appalachian Forests of Pennsylvania

Basic Information

Title:	USGS Award No. G09AP00118 Long-term Responses of Stream Chemistry to Changes in Atmospheric Deposition in Mid-Appalachian Forests of Pennsylvania
Project Number:	2009PA120S
Start Date:	7/1/2009
End Date:	6/30/2014
Funding Source:	Supplemental
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Elizabeth Boyer, David Russell DeWalle

Publications

1. Boyer, E.W., J.W. Grimm, K.S. Horner, J.S. Lynch, and M.A. Borden (2010). Atmospheric Deposition in Pennsylvania: Spatial and Temporal Variations 2009. Report prepared for the Pennsylvania Department of Environmental Protection by the Pennsylvania Water Resources Research Center, 255 p.
2. Boyer, E.W., J.W. Grimm, K.S. Horner, and M.A. Borden (2010). Atmospheric Mercury Deposition in Pennsylvania in 2009. Report prepared for the Pennsylvania Department of Environmental Protection by the Pennsylvania Water Resources Research Center, 65 p.
3. Boyer, E.W., J.W. Grimm, K.S. Horner, J.S. Lynch, and M.A. Borden (2010). Atmospheric Deposition in Pennsylvania: Spatial and Temporal Variations 2009. Report prepared for the Pennsylvania Department of Environmental Protection by the Pennsylvania Water Resources Research Center, 255 p.
4. Boyer, E.W., J.W. Grimm, K.S. Horner, and M.A. Borden (2010). Atmospheric Mercury Deposition in Pennsylvania in 2009. Report prepared for the Pennsylvania Department of Environmental Protection by the Pennsylvania Water Resources Research Center, 65 p.

PROJECT TITLE & PRINCIPAL INVESTIGATORS

Long-term Responses of Stream Chemistry to Changes in Atmospheric Deposition in Mid-Appalachian Forests of Pennsylvania

Elizabeth W. Boyer, Department of Ecosystem Science & Management, Pennsylvania State University

PROBLEM & RESEARCH OBJECTIVES

This research project seeks to quantify and understand the unique long-term response of stream chemistry to reductions in atmospheric deposition that have been observed over the past three decades on five forested catchments in the Mid-Appalachian mountain region of Pennsylvania (PA). These catchments are part of the US Environmental Protection Agency's (USEPA) Long-Term Monitoring of Ecosystems (LTM) program. This network of forested, headwater catchments serves to determine status and trends in stream water quality in the eastern USA region, in response to chronic acidification via atmospheric deposition and to other vectors of change such as climatic variability.

Here, five acid-sensitive catchments in the Appalachian mountains of Pennsylvania are studied to quantify trends in surface water physical and chemical properties, in response to the effects produced by changing emissions of atmospheric pollutants on the biogeochemical cycles within the stream catchments. For forested streams of this region, the primary effects of atmospheric pollutants will be associated with acidic deposition and climate change. Responses of mid-Appalachian streams to acidic deposition involve chronic or episodic changes in the acid-base status of surface waters. Surface water acidification occurs when concentrations of strong-acid anions (sulfate and nitrate) increase relative to concentrations of base cations (calcium, magnesium, potassium, and sodium ions) in a stream. The result of this shift in acid-base status will be a depression in stream pH, possibly to a range associated with adverse effects on fish and other aquatic life. Responses of mid-Appalachian streams to climate change may be manifest in a number of ways. Increasing temperatures and shifting rainfall patterns will affect all aspects of the water cycle in these catchments. Changes in water flux through catchment soils can produce trends in surface water chemistry. Changes in episodic (storm) flow can alter chemical equilibria in streams. Changes in stream temperature can have enormous significance for freshwater organisms, and can affect temperature dependent chemical reactions.

METHODOLOGY

The five study catchments are located on the Northern Appalachian Plateau in the state of Pennsylvania. These catchments can be characterized as relatively undisturbed, mixed-hardwood forest basins. The basins are second-order streams that were not glaciated during the last major period of glaciation, and range from 5-11 km^2 in area, and from 701 to 893 m in maximum elevation. Benner Run and Linn Run catchments are part of state forest land administered by the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry. Baldwin Creek, Stone Run and Roberts Run basins are located on lands managed by the Pennsylvania Game Commission. Arrangements have been made with these agencies to access these lands on a regular basis to conduct this study.

We conducted stream sampling, stream gaging, and laboratory for monthly samples from these five forested streams, which are acid-sensitive and are poorly buffered. On each stream water sample, we measured the following items:

Table 1: Summary of analytical laboratory water quality techniques.

Parameter	Methodology	Equipment
Temperature	Resistance thermometry	YSI Telethermometer
pH	EPA Electrometric (150.1)*	Beckman 360
ANC-Gran titration	EPA Titrimetric*	Radiometer automated titration unit
Specific Conductance	EPA Specific Conductance (120.1)*	YSI Conductance Meter Model 32
Sulfate, nitrate and chloride	EPA Ion Chromatography (300.0)*	Dionex Ion Chromatography Unit ICS 3000
Ammonium	Automated Phenate Method**	SEAL AQ2 Discrete Analyzer
Dissolved Metals		Perkin Elmer Atomic Absorption Spectrophotometer, Model 5100
Calcium	EPA AA Direct Aspiration (215.1)*	"
Magnesium	EPA AA Direct Aspiration (242.1)*	"
Potassium	EPA AA Direct Aspiration (258.1)*	"
Sodium	EPA AA Direct Aspiration (273.1)*	"
Aluminum – total dissolved	EPA AA Furnace (202.2)*	"
Silica	Molybdate –Reactive Silica**	SEAL AQ2 Discrete Analyzer
DOC	EPA 415.2 (low level)*	OI Analytical TOC Analyzer 1010
DIC	EPA 415.2 (low level)*	OI Analytical TOC Analyzer 1010

* Method referenced to US EPA (1983)
** Method referenced to Clesceri et al. (1998)

PRINCIPAL FINDINGS AND SIGNIFICANCE

As forested ecosystems of the eastern USA continue to adjust to dynamic changes in atmospheric deposition, long term monitoring is critical in order to understand effects on water quality. We continued measuring basic stream chemistry and stream flow in five forested streams of Pennsylvania, to further establish a record of change.

Acid deposition can have serious effects on aquatic ecosystems. For example, acidified waters can impair the ability of fish gills to extract oxygen from water and change the mobility of certain trace metals (e.g., aluminum, cadmium, manganese, iron, arsenic, mercury), which in turn can place fish and other species sensitive to these metals at risk (NAPAP, 1991). The susceptibility of a water body to acidification depends on the ability of the water and catchment soils to neutralize the acid deposition it receives. The best measure of this ability is acid neutralizing capacity (ANC), which characterizes the amount of dissolved compounds that will counteract acidity. Every body of water has a measurable ANC, which depends largely on the surrounding catchment's physical characteristics, such as geology, soils, and size. The ANC of a body of water reflects the relative proportions of positive and negative ions entering the water from sources such as atmospheric inputs and the soil and bedrock surrounding and underlying the water body. The higher the ANC, the more acid a water body can neutralize and the less susceptible it is to acidification. Considering long term results over the past three decades in the five study catchments, gradual decreases in stream sulfate and increases in ANC levels in streams have been noted, largely in response to the reductions in emissions associated with the Clean Air Act Amendments of 1990.

Similarly, nitrogen (N) retention efficiency, the percentage of N inputs from the atmosphere and other sources that are stored in catchment soils or lost to the atmosphere via denitrification, is an important characteristic of forest catchment ecosystems that controls delivery of N to receiving waters. Nitrogen budget studies in forested ecosystems reveal that retention efficiencies on relatively-undisturbed forested catchments commonly exceed 70% and may reach $\geq$ 90%. In these Pennsylvania catchments, N retention efficiency generally increased over the last few decades associated with declining atmospheric deposition during this period.

STUDENTS & POSTDOCS SUPPORTED

The project is related to the work of two students who helped with the project in FY2011: Undergraduate student intern Brendan Reed, and Phd student Lida Iiavorivsia.

Assessing the Influence of Nutrient Sources to Urban Streams Through the use of Triple Nitrate Isotopes

Basic Information

Title:	Assessing the Influence of Nutrient Sources to Urban Streams Through the use of Triple Nitrate Isotopes
Project Number:	2011PA154B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	14
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	Emily Elliott

Publications

There are no publications.

Pennsylvania Water Resources Research Center
FY2011 Final Report

PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Assessing the influence of nutrient sources to urban streams through the use of triple nitrate isotopes

Emily M. Elliott, University of Pittsburgh

STATEMENT OF REGIONAL OR STATE WATER PROBLEM:

Like many "Rust Belt" cities, Pittsburgh's industrial history has left it with a legacy of pollution and an underfunded, aging infrastructure. Thirteen percent of Pennsylvania stream miles are impaired enough to significantly alter stream ecology (NRC 2005). Western Pennsylvania's water quality problems are often associated with acid mine drainage, the result of Pennsylvania's coal mining legacy. However, a report by the National Research Council stated that "the most pressing water quality problem [in Southwest Pennsylvania's urban core] is degradation of the microbiological quality of streams due to Combined Sewer Overflows (CSOs), Sanitary Sewer Overflows (SSOs) and discharge from separate stormwater systems in wet weather conditions" (NRC 2005). In Pittsburgh, this situation has led to a Federal Consent Decree in which the U.S. EPA and Pennsylvania Department of Environmental Protection require the Allegheny County Sanitation Authority to remediate sewage inputs to streams and rivers and "restore" one or more affected urban waterways in the city. The situation in Pittsburgh is representative of many urban communities, as combined sewer systems serve approximately 772 communities inhabited by about 40 million people in the US (USEPA 2009).

In addition to sewage inputs, urban areas are often dominated by impervious surfaces and storm sewer systems that accumulate and directly route pollutants, including atmospherically deposited nitrogen (AD) to streams, circumventing regions where nutrient processing occurs naturally (Driscoll, Whitall et al. 2003; Hatt, Fletcher et al. 2004; Wollheim, Pellerin et al. 2005). In regions with storm sewers, wet and dry AD washes into receiving waters from the land surface during rain (Wollheim, Pellerin et al. 2005; Burns, Boyer et al. 2008). The role of AD as a nutrient source is of particular concern in Southwestern Pennsylvania, which receives some of the highest rates of nitrate deposition nationwide (17- 21 kg/ha/yr). In order to both examine nitrate contamination sources and assess the influence each has on urban nutrient pollution, we will determine the isotopic composition of nitrate in water samples from NMR.
In addition to contributions to the scientific literature, we expect this work to contribute toward the fulfillment of goals indentified in the Watershed Monitoring and Advocacy plan, a strategic plan put forth by the Nine Mile Run Watershed Association (NMRWA), a volunteer group that "ensures[s] the restoration and protection of the Nine Mile Run Watershed through citizen engagement, demonstration projects, and advocacy." The strategic plan specifically requires that an appropriate program be created and implemented to monitor environmental conditions and impacts of programs using accepted environmental standards and sampling protocols. This proposed project will fulfill this goal of the NMRWA and moreover provide the NMRWA with data to benchmark progress and record environmental conditions, both to delineate the successes of current restoration efforts and guide future work. This project will document sources of

water quality impairment, including sewage overflows, provide the information required to make informed advocacy decisions, and create a foundation of data that will help establish the NMRWA as an effective advocate/partner in watershed transformation at the regional level.

Further, the recent consent decree, issued by the US EPA, requires the Allegheny County Sanitation Authority to “undertake measures necessary to comply with the Clean Water Act, including the Clean Streams Law” which mandates restoration of Pittsburgh waterways. This research will help inform the restoration process by distinguishing spatial and temporal variations in pollution inputs and determining the viability of “stream restoration” as a water quality management strategy. Finally, this research will serve as a template for monitoring water quality in other restored urban streams throughout the US.

NATURE, SCOPE, and OBJECTIVES:

Excess nitrate contributes to the overall degraded quality of streams in densely populated, human-engineered regions, compounding existing problems of pollution in urban landscapes. Urban centers, such as Pittsburgh, potentially contribute significant amount of nutrient pollution to large river systems, via concentrated emissions from industry, vehicles, and electric generating utilities, as well as from human-produced sewage. However, the relative contributions from multiple nitrate sources form a complicated mixture that is difficult to unravel with simple concentration chemistry. **The goal of this research is to quantify the relative proportions of atmospherically and sewage sourced nitrate contributing to urban surface water impairment through analysis of triple nitrate isotopes** (δ^{15}N, δ^{18}O, and mass-independent Δ^{17}O of nitrate).

In order to complete this study, water samples from Nine Mile Run, an urban stream in Pittsburgh, PA, were analyzed for nitrate concentrations and triple nitrate isotopes. To date, isotopic analysis of δ^{15}N & δ^{18}O has been completed on two years of bi-weekly stream samples (n=200) and two intensively-sampled storms (July 2008 & July 2010 n=32). Additionally, isotopic analysis of Δ^{17}O has been completed on a subset of bi-weekly baseflow samples (n=28) and both summer storms. Further analysis of the remainder of the baseflow samples and two winter storm samples is ongoing.

PRINCIPAL FINDINGS AND SIGNIFICANCE

These results indicate that the primary source of baseflow pollution is nutrient contamination from sewage resulting from cross-connections between the stream and leaking sewers. In order to quantify potential contributions of sewage to NMR, we used an inverse modeling approach to approximate N inputs and watershed N retention. The results of this analysis indicate that sewage-sourced nitrate contributes from 3 to 14 kg $ha^{-1}yr^{-1}$ to NMR inputs, equivalent to nearly 50% of the total nitrate load to the watershed (Divers et al., in revision for *Environmental Science & Technology*). Initial analysis of Δ^{17}O anomalies in bi-weekly samples suggests that AD is present in trace amounts during baseflow (generally less than 5%).

In comparison, during stormflows, nitrate originates from a mixture of sewers and atmospheric deposition wherein dry-deposited AD is washed from impervious surfaces. Initial isotopic analysis of $\Delta^{17}O$ and $\delta^{15}N$ from two storms sampled (July 20, 2008 and July 8, 2010) in NMR indicate that during high storm discharge events, AD can contribute up to 42% of the total nitrogen load to the stream. Ongoing $\Delta^{17}O$ analysis will help determine AD and sewage inputs influence streamwater nitrate concentrations on longer timescales (i.e. seasonally).

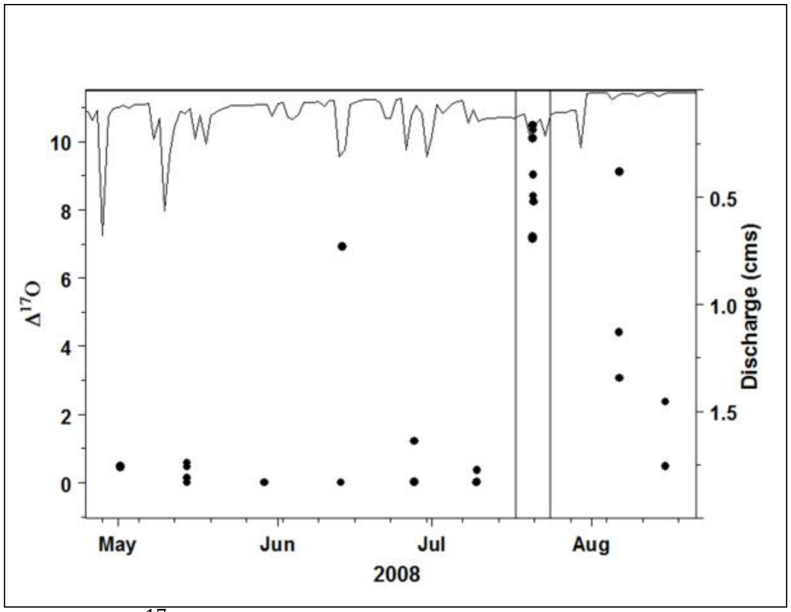


Figure 1 $\Delta^{17}O$ values for baseflow and July 20, 2008 storm (in rectangle). Also shown is stream discharge, for reference.

The results of this research will directly impact our understanding of the sources, effects, and remediation of nutrient pollution in Pennsylvania's urban streams. The primary product resulting from this project will be data that documents water quality and ecosystem health in NMR and establishes a baseline against which future changes in water quality can be measured. Furthermore, the data and interpretations will be provided to Pittsburgh and Allegheny County residents, NMRWA, the Pittsburgh Parks Conservancy, and scientists and policy makers via the NMRWA website (www.ninemilerun.org) in order that they may use the data for future urban revitalization projects and understanding Frick Park, an important regional asset.

STUDENTS & POSTDOCS SUPPORTED

Marion Divers, Ph.D. Candidate,
Kathleen Tuite, B.S., December 2011
Mollie Kish, B.S. Candidate

PUBLICATIONS

Divers, M.T., E.M. Elliott, and D.J. Bain, Constraining nitrogen inputs to urban streams from leaking sewer infrastructure using inverse modeling: Implications for DIN retention in urban environments. In revision for *Environmental Science & Technology*.

Tuite, Kathleen. 2011. "Determination of atmospheric nitrogen deposition within an urban watershed using ion exchange resins". Pennsylvania Water Resources Research Center, University of Pittsburgh, PA, 36pp.

PRESENTATIONS

- Elliott, EM. 2011. From the landscape to the continent: Gaining insight into the sources and fate of atmospheric reactive nitrogen emissions using stable isotopes. Abstract B411-03. Fall Meeting, American Geophysical Union, San Francisco, CA, 5-9 December, 2011.
- Sikora, MT, Elliott, EM, Bain, DJ. 2011. Constraining nitrogen inputs to urban streams from leaking sewer infrastructure using inverse modeling: Implications for urban water quality. Abstract H51P-06. Fall Meeting, American Geophysical Union. San Francisco, Calif., 5-9 Dec. 2011.
- Elliott, EM. Investigating Atmospheric-Terrestrial-Hydrologic interactions of reactive nitrogen using stable isotope geochemistry. Department of Geography & Environmental Engineering, Johns Hopkins University. November 15, 2011. Invited.
- Elliott. EM. Investigating atmospheric-terrestrial-hydrologic interactions of reactive nitrogen using stable isotope geochemistry. School of the Environment and Natural Resources. Ohio State University, Columbus, OH. May 12, 2011. Invited
- Elliott, EM. New frontiers in reactive nitrogen isotope geochemistry: Implications for water & air quality, ecosystem & human health. Department of Geology & Geography, West Virginia University, Morgantown, WV. April 1, 2011. Invited
- Elliott, EM. Reactive nitrogen emissions, deposition, and impact on water quality and human health. Department of Civil and Environmental Engineering, University of Pittsburgh, April 8, 2011. Invited

PHOTOS OF PROJECT

Figure 2: Eutrophication from nutrient excess in Nine Mile Run, Pittsburgh PA

Figure 3: Stormwater outfalls and mainstem of Nine Mile Run, Pittsburgh, PA

Quantifying the Nitrogen Retention Capacity of Legacy Sediments and Hydric Soils Before and After Restoration

Basic Information

Title:	Quantifying the Nitrogen Retention Capacity of Legacy Sediments and Hydric Soils Before and After Restoration
Project Number:	2011PA156B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Category:	Sediments, Nutrients, Water Quality
Descriptors:	None
Principal Investigators:	Jason Kaye

Publications

There are no publications.

Pennsylvania Water Resources Research Center
FY2011 Final Report

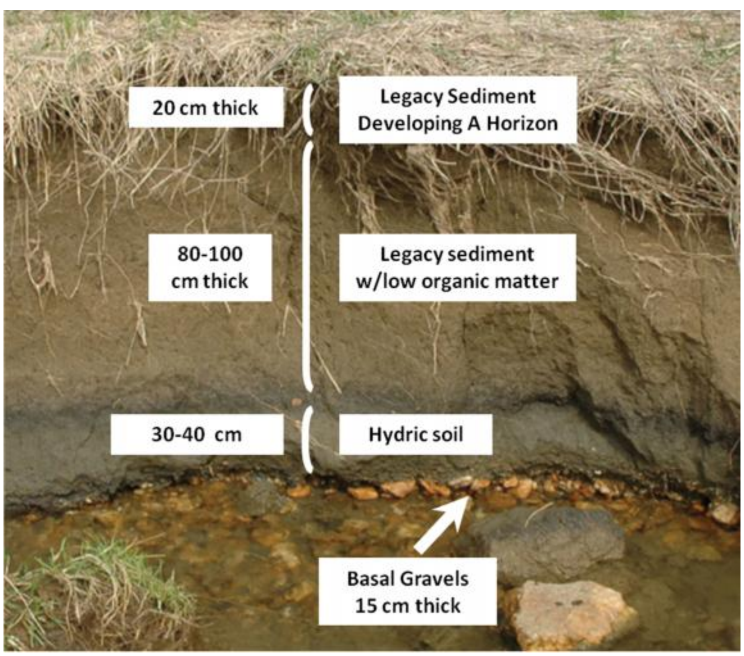
PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Quantifying the nitrogen retention capacity of legacy sediments and hydric soils before and after restoration

Dr. Jason Kaye, Associate Professor of Soil Biogeochemistry, The Pennsylvania State University, jpk12@psu.edu, 814-863-1614.

KEYWORDS: Legacy sediment, Nitrate, Restoration, Isotope tracer, Best Management Practice

STATEMENT OF WATER PROBLEM: The water problem that this proposal focuses on is eutrophication, and specifically how regionally prevalent legacy sediments alter the transfer of NO_3^- from soils to streams. We use our research site, Big Spring Run (BSR), as the case for describing the nature of the problem. As in many stream banks of the mid-Atlantic Piedmont region, the stream banks along BSR consist of four principle stratigraphic units (Fig. 1), which from bottom to top include: (1) basal gravels; (2) pre-settlement hydric soils; (3) post-settlement alluvium and colluvium (the latter informally called "Legacy Sediments"); and (4) newly developing A horizon (Walter and Merritts, 2008). The basal gravels, are composed of angular to subangular quartz cobbles, which are interpreted to derive from Pleistocene periglacial lag deposits. These gravels are overlain by a 30-40 cm dark, organic-matter-rich hydric soil, which apparently formed in a fluvial wetland environment over the last 10,000 years (Merritts, et al., 2005; Walter and Merritts, 2008). Legacy sediments were deposited on top of the hydric layer



during the historic, post-settlement period marked by deforestation, land clearing, and plowing of uplands and valley slopes. This period of accelerated soil erosion coincided with the construction of numerous milldams in the mid-Atlantic. Dams created reservoirs that flooded valley bottoms and acted as efficient sediment retention ponds. Behind the former milldam on BSR, a gradient of legacy sediment depth now exists with sediments thickest near the location of the dam, and tapering off upstream away from the dam. In the top 20 cm of the legacy sediment, an organic-matter-rich A horizon is developing (Fig. 1). Beneath the A horizon, and continuing down to the surface of the hydric layer is a ~80-100 cm thick layer of legacy sediment with lower organic matter content (relative to the A horizon above and hydric below).

Legacy sediments introduce two key problems for water quality. First, stream bank erosion is a significant non-point source of sediment that can impair downstream waterways (Trimble 1997) and in the mid-Atlantic, legacy sediments constitute a substantial volume of sediment stored in stream corridors. Lancaster County is recognized as a hotspot for high sediment and nutrient yields to the Chesapeake Bay, and bank erosion of legacy sediments is a major source of these pollutants (Merritts and Walter, 2003). Second, legacy sediments alter flowpaths for water and dissolved nutrients from uplands to streams. At BSR, trees planted to improve riparian function have all died, suggesting that traditional riparian zone BMPs may fail on legacy sediments. Given their prevalence in PA, there is a critical need to understand how N flows through legacy sediments to improve predictions and management of N transport from uplands to streams. We propose to fill that need by assessing NO_3^- retention in BSR sediment.

A portion of BSR (Fig. 2) has been proposed by the Pennsylvania Department of Environmental Protection (PA-DEP) as a test site for implementing and monitoring a new "floodplain and wetland restoration" Best Management Practice (BMP) (Hartranft, 2007). BSR was selected because of the well-defined legacy sediment accumulation, because it is in a rural setting experiencing little land-use change, and because it was already a site for which much baseline data had been obtained (Legacy Sediment Workgroup, 2006). Previous studies have shown that the geomorphic stability of restored streams may be improved after restoration (Mayer et al., 2009). Restored sites transport less sediment and halt the lateral migration of the streams. Based on these findings, the proposed BMP seeks to re-establish the natural function and condition of the stream, wetland, floodplain, and riparian zones within the site.

In July of 2011, legacy sediments will be removed throughout a portion of the BSR watershed, which will expose the buried wetlands and reconnect the original floodplain hydrology of the site. This restoration effort represents a unique opportunity to assess the effects of watershed restoration on ecological function. The identification of BMPs to mitigate the impacts of legacy sediments on streams and wetlands is an important goal for resource managers in the Mid-Atlantic region (Mayer and Forshay, 2009).

NATURE, SCOPE, and OBJECTIVES: We have noted that legacy sediments affect water quality in two ways: 1) by direct inputs of sediment into streams, and 2) by affecting the transfer of dissolved nutrients from soils to streams. The scope of this proposal involves #2; we seek to quantify the effects of legacy sediment on the transfer of nutrients from soils to streams at one site in PA. Our research site is a reach within BSR because the extensive background information and scheduled restoration make this site ideal for testing our three **<u>hypotheses</u>**:

Hypothesis 1: Prior to restoration, three soil layers that are typical of legacy sediment areas (surface legacy sediment enriched in organic matter, subsurface legacy sediment low in organic matter, and buried hydric soil) will differ in their ability to remove NO_3^- from soil solutions.
Rationale for Hypothesis 1: We expect that differences in organic matter content and microbial activity among these layers will lead to large differences in NO_3^- retention. If soil layers vary in NO_3^- retention then it follows that different hydrologic flowpaths will lead to different efficacy of NO_3^- filtering as upland N moves to streams. Monitoring at the site has revealed four potentially important flowpaths: 1) saturation from the surface downward (from heavy local rain), 2) saturation from the hydric soil upward (from rising water tables), 3) lateral flow through the hydric layer only (as water moves along the soil-bedrock interface from uplands into the sediment), and 4) lateral flow through the hydric layer plus subsurface legacy sediment (same as 3, but with a greater soil volume saturated). We will test Hypothesis 1 by extracting intact soil columns that include the three soil layers of interest and then experimentally manipulating the flow of isotopically labeled nitrate ($^{15}NO_3^-$) to mimic these 4 flowpaths.

Hypothesis 2: Drought followed by rewetting will cause variations in NO_3^- flushing from the different layers.
Rationale for Hypothesis 2: Studies at several scales have shown that drought leads to pulses of NO_3^- that can impact water quality. A regional scale synthesis has shown high NO_3^- following drought in streams throughout the mid-Atlantic (Kaushal et al., 2010). Research by a Ph.D. student of the PI has shown that in a small catchment in Maryland, a pulse of NO_3^- moves from surface soils to subsoils following drought. Finally, our own preliminary data from BSR (described below) show that soil drying induces a large pulse of NO_3^- in surface soils. Our column studies will build on these preliminary data by assessing whether drought-induced NO_3^- pulses in surface soils are flushed to deeper layers, and how/if they are retained in other layers. We will test Hypothesis 2 by allowing the soil columns described above (for testing Hypothesis 1) to dry, and then rewetting them with N-free water. The pulse of $^{15}NO_3^-$ that occurs following rewetting will reveal flowpaths likely to carry NO_3^- rich water to streams following drought.

Hypothesis 3: Following restoration, the previously buried hydric layer will increase its NO_3^- retention capacity (relative to the pre-restoration hydric layer).
Rationale for Hypothesis 3: State (PA-DEP) and federal (EPA) agencies are interested in testing the efficacy of legacy sediment restoration as a BMP for improving water quality. Restoration removes legacy sediment to expose the buried hydric layer. We will test Hypothesis 3 by removing legacy sediment and then immediately extracting an intact core of the entire hydric layer. We will pass $^{15}NO_3^-$ through the hydric layer and by comparing results to those from columns used to test Hypothesis 1, we can quantify changes in hydric layer NO_3^- retention that occur when legacy sediments are removed. These experiments will provide preliminary data to assess how newly exposed hydric layers may retain NO_3^- following restoration.

These hypotheses contrast the dominant geomorphic (soil layers), climatic (drought), and cultural (restoration) sources of variation in NO_3^- retention capacity in legacy sediment and buried hydric soils. We propose to test these hypotheses using large soil columns that are engineered to allow experimental flowpath manipulations and $^{15}NO_3^-$ additions.

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Significance: Legacy sediments were deposited during the historic, post-settlement period due to intense land clearing, deforestation, and the construction of numerous milldams. These dams occur in high concentrations in the mid-Atlantic region, and constitute substantial volumes of sediment stored in stream corridors. Legacy sediments introduce two key problems for water quality. First, streambank erosion is a significant non-point source of sediment that can impair downstream waterways (Trimble, 1997). Second, legacy sediments alter flowpaths for water and dissolved nutrients from uplands to streams. Understanding how uplands and legacy sediment accumulation zones act to remove N before entering streamwaters is important in predicting downstream effects of legacy sediments. To investigate the fate of N as it moves across the landscape and through the soil profile laboratory studies were conducted on intact soil cores collected from Big Spring Run (BSR) in Lancaster, Pennsylvania. This site at BSR has acted as an infrastructure for research and education because a growing group of researchers, students, and stakeholders are focusing efforts on this watershed as a primary case study in science-based legacy sediment remediation via stream restoration.

Lancaster County, where BSR is located, is recognized as a hotspot for high sediment and nutrient yields to the Chesapeake Bay, and bank erosion of legacy sediments is a major source of these pollutants (Merritts and Walter, 2003). As in many streambanks of the mid-Atlantic Piedmont region, the streambanks along BSR consist of three principle stratigraphic units, which from bottom to top are: (1) pre-settlement hydric soils, which formed in a fluvial wetland environment that persisted for over 10,000 years prior to settlement; 2) post-settlement alluvium and colluvium (the latter informally called “Legacy Sediments”); and (3) newly developed A horizons, which are also classified as legacy sediments (Merritts and Walter, 2003; Merritts et al., 2005; Walter and Merritts, 2008).

Principal Findings: We are still in the data analysis phase of this project, so here we report key progress to date, rather than a major synthesis of key findings. We first extracted intact soil columns from Big Spring Run (BSR) that extended from the surface soil into the legacy sediment and down to the basal gravels that existed below the buried hydric layer. However, due to excessive compaction, we altered our sampling scheme. Instead, intact soil columns were extracted for each of the 3 significant soil layers at BSR (surface, legacy, and hydric). Isotopically labeled nitrate ($^{15}NO_3^-$) was added to each column to quantify NO_3^- retention in the different soil layers. Following the addition of the isotopically labeled solution the columns were allowed to dry for a month and then rewet with N-free water in order to quantify the drought-induced loss of $^{15}NO_3^-$ each layer. These experiments allowed the quantification of changes in nitrogen (N) in each separate soil layer, which will provide critical information for 1) assessing sources and sinks of N along streams impacted by legacy sediments, 2) improving the efficacy of riparian buffers on legacy sediments, and 3) understanding the effects of past land use on contemporary N flow from soils to streams.

Our specific **activities** (and their timeline) were:
May 2011: Purchased PVC and fabricated columns.
June 2011: First attempt at extracting soil columns from BSR – lots of compaction, so had to rethink sampling procedure.

July 2011: Successful extraction of soil columns from BSR – cores of each separate layer, as opposed to one core containing all layers; brought them to PSU. Inserted moisture/temperature probes into each core.
November/December 2011: Traced the fate of $^{15}NO_3^-$ through the columns before drought.
January 2012: Traced the fate of $^{15}NO_3^-$ through the columns upon rewetting after drought. Measured concentrations of NO_3^- and NH_4^+ in leachates and soil extracts.
February 2012: Prepared soil and water samples for ^{15}N analysis.
March 2012: Solid samples sent to Boston University for ^{15}N analysis, and liquid samples sent to U.C. Davis for ^{15}N analysis.
April 2012: Received ^{15}N data from U.C. Davis.
May 2012: Received ^{15}N data from Boston University. Data analysis started.
Projected for the future – June/July 2012: Write manuscript.

STUDENTS & POSTDOCS SUPPORTED: Graduate Student – Julie Weitzman, Soil Science & Biogeochemistry Dual Degree, Ph.D.; Undergraduate Student – Lena Harper, Environmental Resource Management, B.S.; Undergraduate Student – Marian Kochin, Environmental Resource Management, B.S.; Undergraduate Student – Tom Bassett, Environmental Resource Management, B.S.

PUBLICATIONS: None to date.

PHOTOS OF PROJECT


Walmart
Hydric #4
Legacy A

Fish Exposure to Emerging Contaminants in Municipal Wastewater: Can Dietary Sewage Contribution Predict Severity of Estrogenic Effects?

Basic Information

Title:	Fish Exposure to Emerging Contaminants in Municipal Wastewater: Can Dietary Sewage Contribution Predict Severity of Estrogenic Effects?
Project Number:	2011PA158B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	19
Research Category:	Ecological Processes
Focus Category:	Ecology, Wastewater, Water Quality
Descriptors:	None
Principal Investigators:	Theo Light

Publications

There are no publications.

Pennsylvania Water Resources Research Center
FY2011 Final Report

PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Fish exposure to emerging contaminants in municipal wastewater: can dietary sewage contribution predict severity of estrogenic effects?

Theo Light, Ph.D. and Todd M. Hurd, Ph.D., Department of Biology, Shippensburg University, Shippensburg, PA

KEYWORDS: emerging contaminants, pharmaceuticals, endocrine disruption, estrogenic effects, intersexuality, reproductive anomalies in fish, municipal wastewater, stable isotopes, white sucker, *Catostomus commersoni*

STATEMENT OF WATER PROBLEM

A number of organic contaminants, including pharmaceuticals, personal care products, plasticizers, pesticides and herbicides, and their breakdown products, have been shown to have endocrine activity and the potential for endocrine disruption in a range of vertebrates, even at very low concentrations (Sumpter and Johnson 2005; Vajda et al. 2007). Fish appear to be particularly vulnerable due to their constant environmental exposure, particularly in the presence of effluent from wastewater treatment plants (Sumpter and Johnson 2005). Effects include altered sex ratios (e.g., Vajda et al. 2007) and high proportions of intersex fish (generally apparent males with testicular oocytes; Blazer et al. 2007, Vajda et al. 2007).

In 2006, the United States Geological Survey (USGS) surveyed a number of small streams in south-central Pennsylvania for pharmaceuticals and antibiotics at sites upstream and downstream of wastewater treatment plants (WWTPs) and animal-feeding operations. This survey, part of a larger effort in cooperation with the Pennsylvania Department of Environmental Protection (DEP), sought to document concentrations of a number of emerging contaminants in both streamwater and wellwater across Pennsylvania (Loper et al. 2007). Thirteen pharmaceuticals and eleven antibiotics were detected at least once in the survey; stream sites receiving municipal wastewater had the highest number of detections and highest concentrations of detected contaminants. Although this survey was not designed to specifically assess the potential for endocrine disruption, several of the detected pharmaceuticals have potential estrogenic effects (Loper et al. 2007), and the presence of so many detectable pharmaceuticals suggests others more directly linked to endocrine disruption are likely present as well.

The objectives of this study are to examine fish (probably white sucker, *Catostomus commersoni)* in several of the same streams surveyed by USGS for reproductive anomalies that could be indicative of exposure to endocrine disrupting contaminants. We also plan to assess dietary exposure to sewage-derived organic matter using stable isotopes of carbon and nitrogen, and to determine whether these two potential indicators of contaminant exposure are correlated with one another. Finally, we will examine the operations of each WWTP in the study and relate key aspects of their operation, as well as degree of dilution of effluent in the receiving stream (Sumpter and Johnson 2005), with the effects detected in fish.

NATURE, SCOPE, AND OBJECTIVES

This study will involve field and lab research in three small wastewater-influenced streams in south-central Pennsylvania to determine the frequency and severity of reproductive anomalies in fish, as well as the proportion of fish diets assignable to sewage-derived organic matter. Specific objectives:

(1) Determine the sex ratio of white sucker in Middle Spring, Mountain Creek, and Killinger Creek upstream and downstream of wastewater effluent sources.
(2) Determine the presence and severity of intersexuality in white sucker in all three streams upstream and downstream of effluent sources.
(3) Using stable isotopes of carbon and nitrogen, determine the proportion of fish diet that can be ascribed to sewage-derived C and N, and relate that to the incidence and severity of reproductive anomalies.
(4) Determine the proportion of stream flow attributable to the effluent source in each season and relate to the incidence and severity of reproductive anomalies.

METHODS, PROCEDURES, AND FACILITIES.

Sample sites will be selected upstream and downstream of effluent release points in three south-central Pennsylvania streams: Middle Spring and Mountain Creek in Cumberland County, and Killinger Creek in Lebanon County. All three are relatively small (2^{nd}-4^{th} order) streams in the lower Susquehanna River drainage in which treated wastewater makes up a significant portion of discharge at downstream sites. Of the wastewater-affected south-central PA sites sampled for pharmaceuticals by the USGS, these represent accessible streams which have a range of detection levels, from low (Mountain Creek) to high (Killinger Creek). We will make collections three times: in spring (April/May), summer (July/August) and fall (September/October) to detect any seasonal variability in effluent effects and fish reproductive condition. Basic physical (average width and depth, velocity, discharge, temperature) and chemical (pH, specific conductance, dissolved oxygen) data will be recorded at each site using meters owned by Shippensburg University. Conductance will also be tested in or as close as possible to the effluent release point for use in determining the proportion of downstream discharge attributable to wastewater effluent using a two-source mixing model (Lentek-Klemunes and Hurd, submitted). This determination will be compared to one based on direct measures of discharge upstream and downstream of the WWTP.

Fish will be sampled by single-pass electrofishing, using an Appalachian Aquatics backpack electroshocker (Model AA-24) owned by Shippensburg University. Our expectation is that we will focus on white sucker *(Catostomus commersoni)* as they are common in most small streams (including degraded sites) in our area and have been used successfully in studies of effluent effects on sex ratios and intersexuality in other studies (e.g., Vajda et al. 2007). However, since one source (V. Blazer, pers. comm.) suggests they may not be particularly sensitive to environmental estrogens, we will make a final determination of focal species after examining a test collection of fish collected from the

Middle Spring effluent site in fall 2010. Other abundant species in Middle Spring and Mountain Creek which could potentially be substituted include various minnows (Cyprinidae) and sculpins (*Cottus* sp.). Centrarchids such as smallmouth bass, the focus of much of Dr. Blazer's recent work (e.g., Blazer et al. 2007), are not abundant in these streams.

Fish for gonad examination and stable isotope analysis (20 per site on each collection date) will be anaesthetized in the field using clove oil and ethanol, then killed with a blow to the head. They will be returned to the lab on ice, measured (total and standard length) and weighed for calculation of condition index and correlation with other measures. An initial sex determination will be made based on gonad appearance; the gonads will then be removed from the fish and embedded in paraffin. The tissues will be sliced with a microtome and stained with hematoxylin and eosin (H and E). Gonads will be sliced in 5 cross sections from different regions and examined using a light microscope. The severity of intersexuality will be graded on a 0-4 scale using methods described by Blazer et al. (2007). A small sample of tail muscle will be saved from each fish and frozen (-20ºC) for later preparation for isotope analysis. All samples, slides, and photographs will be coded with a fish identification number associated with all measures for that individual to allow for later statistical analyses.

Muscle tissue and for stable isotope analysis will be dried at 55-60ºC for 24-48 hours, then ground and homogenized using a mortar and pestle. Samples will be shipped to the Cornell Stable Isotope Laboratory, where they will be analyzed for $\delta^{13}C$ and $\delta^{15}N$ with a Europa Scientific GEO 20-20 isotope ratio mass spectrometer. Additionally, we will obtain samples of sewage-derived particulate organic matter (SDPOM) either from WWTP personnel at each site (from the blanket particulate layer in the final clarifier) or by filtering effluent water through a pre-combusted glass filter. These samples will be air-dried, then prepared as above for stable isotope analysis and shipped to Cornell for analysis.

We will calculate the relative contribution of sewage-derived organic matter (SDPOM) in white sucker diets by measuring isotopic signatures of consumers at downstream sewage-exposed sites and comparing them to that of the sewage and of upstream white sucker (deBruyn & Rasmussen 2002). This approach uses a two-source, single tracer mixing model to determine relative contribution of the sources to a common sink (Eq. 1);

$$1.0\,(\delta R_{downstream}) = X\,(\delta R_{SDPOM} + b) + (1-X)\,(\delta R_{upstream} + b) \qquad \text{Eq. 1}$$

where δR is the relative stable isotope abundance in fish below outfall ($\delta R_{downstream}$), in sewage derived particulate organic matter (δR_{SDPOM}), and in fish from the upstream reference area ($\delta R_{upstream}$); b is the trophic step factor; and X is the proportion of sewage-derived element R in fish. We will assume a trophic shift of 0 for $\delta^{13}C$ and 3 for $\delta^{15}N$ (deBruyn & Rasmussen 2002).

PRINCIPAL FINDINGS AND SIGNIFICANCE

Emerging contaminants in Pennsylvania waters include pharmaceuticals, personal care products, and other common chemicals with potential endocrine activity. Recent concern about these contaminants has focused on their presence in treated wastewater and effects on fish, which may be particularly vulnerable due to their constant environmental exposure. Affected populations may show altered sex ratios or the presence of intersex (usually testicular oocytes [TO]). A recent USGS survey (Loper et al. 2007) examined a number of small streams in south-central Pennsylvania for pharmaceuticals and antibiotics at sites upstream and downstream of wastewater treatment plants (WWTPs). Thirteen pharmaceuticals and 11 antibiotics were detected at least once in the survey; stream sites receiving municipal wastewater had the greatest number of detections and highest concentrations of detected contaminants.

The objectives of this study were to examine fish in three of the same streams surveyed by the USGS for reproductive anomalies that could indicate exposure to endocrine disrupting contaminants. We also assessed dietary exposure to sewage-derived organic matter using stable isotopes of carbon and nitrogen, and attempted to determine whether these two potential indicators of contaminant exposure were associated with one another. Stable isotope signatures also served as an indicator of site fidelity. A distinct shift in ratios of heavy to light stable isotopes of carbon and nitrogen (in the direction of greater enrichment of heavy isotopes) is commonly seen in organisms living downstream of sewage effluent. Finding that shift in downstream fish (especially any intersex fish) would demonstrate they had indeed been exposed to sewage effluent. We hypothesized that (1) we would find stable isotope shifts in downstream fish indicating some dietary sewage exposure, (2) if we found intersex fish, they would be found only downstream of WWTPs, and would have stable isotope signatures indicating sewage exposure, and (3) intersex fish would have isotope ratios indicating *greater* dietary sewage exposure than other downstream fish.

We initially collected fish of three species (white sucker *Catostomus commersoni*, mottled sculpin *Cottus bairdi*, and eastern blacknose dace *Rhinichthys atratulus).* However, only blacknose dace were found consistently in all streams and sites and (usually) in sufficient numbers to allow us to collect 20 adults at each site and sampling occasion, so they became our focal species. We collected dace upstream and downstream of municipal wastewater treatment plants in Middle Spring and Mountain Creek (both of Cumberland County) and Quittapahilla Creek (Lebanon County). Temperature, pH, and specific conductance were measured at each site. Up to twenty sexually mature dace were collected at each site in May, July, and October 2011 using a backpack electrofisher. Fish were euthanized (using a dilute solution of clove oil and ethanol in water) on site and transported back to the lab on ice. In the lab, gonads of all male fish and most females were removed and prepared for histology using standard methods, then sliced, stained, and examined for abnormalities on a compound microscope at 100x. A portion of each fish tail was frozen and later dried and prepared for stable isotope analysis, which was carried out at the Cornell Stable Isotope Laboratory. Carbon and nitrogen stable isotope ratios for downstream fish were compared to those of upstream fish and organic matter from the blanket layer of the final clarifying tank at each of the WWTPs to estimate the proportion of sewage derived carbon and nitrogen in the diets of downstream fish.

Stable isotope analysis indicated dietary sewage uptake by blacknose dace in all three streams, with the greatest enrichment in the Quittapahilla Creek and least in Mountain Creek. All three creeks showed significant enrichment of both carbon and nitrogen at all sampling dates, with the exception of carbon in Middle Spring in fall. We estimated that a mean of about 41±5% (±1 SE) of dietary carbon was derived from sewage in the Quittapahilla, and 23±12% in Middle Spring. Estimates for Mountain Creek, where both upstream and downstream values were close to the sewage value, were too variable to estimate with any confidence. Blacknose dace, which have a diet of about 25% algae and 75% aquatic invertebrates, are probably gaining most of this sewage-derived carbon second-hand, by feeding on invertebrates that consume detritus directly. Filter-feeding and deposit feeding invertebrates in Middle Spring just below the WWTP have previously been shown to derive up to nearly 80% of their carbon from sewage sources (Lentek-Klemunes 2008).

We found evidence of intersex (TO) in three male fish, all downstream of WWTP discharges, but no evidence of altered sex ratios in downstream fish. One intersex dace was collected in summer in the Quittapahilla and two in Middle Spring, one in spring and one in fall. Intersex in these three fish was confirmed by Vicki Blazer of the USGS Leestown Science Center, Fish Health Branch. This was consistent with our hypothesis, but the association of intersex with downstream collection site was only marginally significant (Fisher's exact test, $P = 0.093$). This is, to our knowledge, the first documentation of intersex in blacknose dace. Since it is a common and often abundant species in eastern streams and smaller rivers, is tolerant of degraded conditions, and is easy to collect by seining or electrofishing, it has the potential to serve as an indicator of xenoestrogen contamination in smaller streams where known estrogen-sensitive species such as black basses may rarely occur.

With only three intersex fish, we don't have strong evidence for or against our third hypothesis. One of those fish (collected in fall in Middle Spring) did have a significantly more enriched carbon signature than the rest of the downstream fish from that site and collection date ($t_{12} = -3.58$, $P = 0.004$), but the other two did not, showing values close to the mean downstream value in both cases. Intersex in gonochoristic fish is probably a result of a combination of genetic sensitivity to estrogen and timing of exposure, with some studies indicating a narrow window of sensitivity in early development, so these more stochastic factors are likely more important than overall exposure in determining which fish are affected to a detectable degree.

With the extension of our project into this year, we plan to focus further collection on Middle Spring, and perhaps Three Square Hollow Run in Cumberland County, which was surveyed by Loper et al. (2007) and is affected by runoff from a confined agricultural feeding operation. We will collect more blacknose dace immediately downstream of the Shippensburg WWTP, but also add collection points further downstream to see how far downstream intersex can be detected. We also plan to directly examine stomach contents of selected fish to more accurately estimate the trophic position of dace in the food web.

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Sumpter, JP and AC Johnson. 2005. Lessons from endocrine disruption and their application to other issues concerning trace organics in the aquatic environment. Environmental Science and Technology 39(12): 4321-4332.

STUDENTS & POSTDOCS SUPPORTED

Lauren E. Kesslak, Biology, MS expected May 2012
Tammy Smith, Biology, MS student (volunteer, continuing)
Pat Bower, Biology, MS student (volunteer, continuing)

PUBLICATIONS

Kesslak, Lauren E. 2012. *The effects of wastewater exposure on blacknose dace (Rhinichthys atratulus) in South-Central Pennsylvania*, MS Thesis, Department of Biology, Shippensburg University, Shippensburg, PA, 48 pp.

PRESENTATIONS

Kesslak, Lauren E., Tammy Smith, and Theo Light. Fish exposure to emerging contaminants in municipal wastewater: can dietary sewage contribution predict severity of estrogenic effects? Presented at the 2012 annual meeting of the Pennsylvania Academy of Science, Allentown, PA, March 31.

OTHER INFORMATION TRANSFER ACTIVITIES

Either Lauren or Theo will present our results at the Middle Spring Watershed Association's May, 2012 meeting.

NOTABLE AWARDS & ACHEIVEMENTS

Lauren Kesslak was recently accepted to the Ph.D. program in Fisheries at West Virginia University, with a research assistantship to support continuing work on the effects of emerging contaminants on fish health.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY

SU College of Arts and Sciences Faculty-Led Research Fund, $570. April 2011-June 2012. Fish exposure to emerging contaminants in municipal wastewater: can dietary sewage contribution predict severity of estrogenic effects?

PHOTOS OF PROJECT

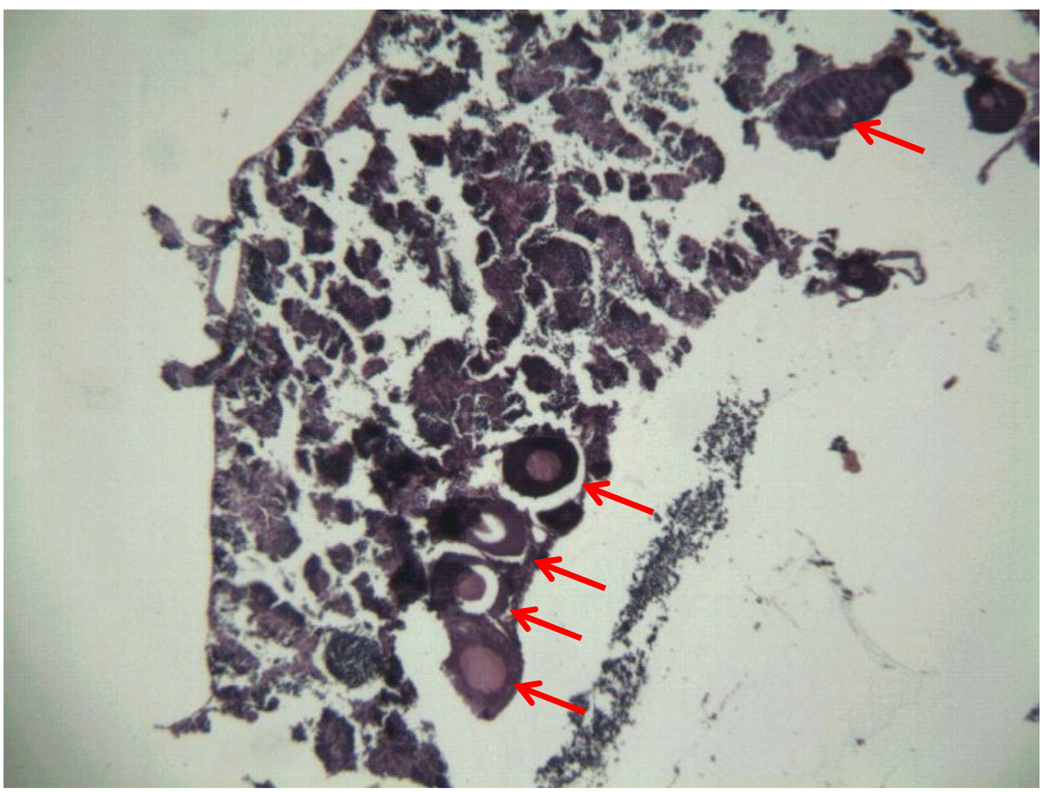

Figure 1: Gonad of an intersex blacknose dace from Middle Spring, showing primary oocytes (red arrows) in the testis of a male-appearing fish.

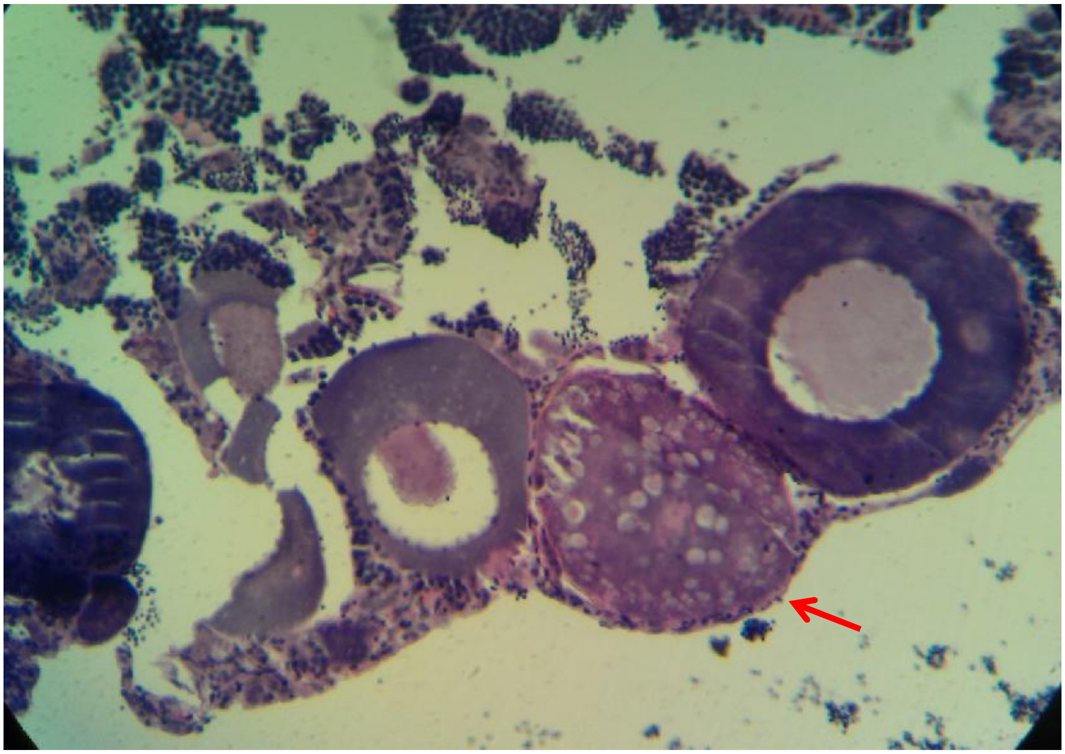

Figure 2: Gonad of an intersex blacknose dace from Middle Spring, showing primary and secondary oocytes (red arrow) in the testis of a male-appearing fish.

Figure 3: Electrofishing in Middle Spring Creek at Bard Road, Shippensburg. (L => R: Lauren Kesslak, Theo Light, and Tammy Smith)

Development of a Subsurface Reactive Transport Model for Predicting Potential Water Quality Problems in Marcellus Shale

Basic Information

Title:	Development of a Subsurface Reactive Transport Model for Predicting Potential Water Quality Problems in Marcellus Shale
Project Number:	2011PA159B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	5
Research Category:	Ground-water Flow and Transport
Focus Category:	Water Quality, Models, Hydrogeochemistry
Descriptors:	None
Principal Investigators:	Li Li, Susan Brantley

Publications

There are no publications.

Pennsylvania Water Resources Research Center
FY2011 Final Report

PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Development of a Subsurface Reactive Transport Model for Predicting Potential Water Quality Problems at Marcellus Shale

Li Li, Dept. Energy and Mineral Engineering, Penn State University; and Susan L. Brantley; Dept. of Geosciences, Penn State University

KEYWORDS:
Marcellus Shale, reactive transport model, geochemistry, water quality, contamination

STATEMENT OF REGIONAL OR STATE WATER PROBLEM:
Understanding the potential water quality problems during the development of Marcellus Shale is important to the general public who has been very concerned about the potential environmental impacts. The general public will be interested in how, at what level, at what time frame, and under what conditions water quality will be deteriorated by natural gas production from tight shale. A fast and cost-effect way of such estimation is a model that is capable of helping us understand and predict the coupled flow, transport, and reaction processes that could potentially lead to water quality problems. As such, it is very important to develop such a model to help understand, predict and potentially manage water quality problems.

STATEMENT OF RESULTS OR BENEFITS.
The outcome of this proposal will be a reactive transport model and a database of reactions important for water quality issues in Marcellus Shale. The model and the database that can be used as a tool to understand the coupled flow, transport, and reaction processes involved in groundwater contamination problem at Marcellus Shale. They can also be used to predict and potentially manage conditions that could minimize or even avoid water contamination during the development of Marcellus Shale.

NATURE, SCOPE, and OBJECTIVES of the project**,** including a timeline of activities.
The goal of this work is to develop a model that can be used to understand, quantify, and predict reactive transport processes that could potentially lead to water quality deterioration during the development of Marcellus Shale formation.

METHODS, PROCEDURES, and FACILITIES.

Li will be responsible for developing the reactive transport model based on the generic code CrunchFlow. Li has used CrunchFlow for more than 5 years and has published more than 5 high impact papers using CrunchFlow code. Li and Brantley will work together to understand the chemical weathering and water chemistry data of Marcellus Shale to identify important geochemical reactions associated with water quality and to use the existing data to validate the model. Li maintains a suite of computers adequate for the task of reactive transport modeling in this proposal. In addition, for computationally expensive tasks, high-performance computing resources are available through EMS Earth and Environmental Systems Institute (EESI) and Institute for Cyber Science (ICS) at Penn State. Brantley's group maintains excellent experimental facilities for water and solid geochemistry analysis. If more data are needed these can easily be obtained.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The development of Marcellus Shale can lead to potential environmental problems. In particular, the interaction between Marcellus Shale rocks and water, including hydraulic fracturing and flow back water, is a big concern. The ultimate goal of this work is to establish a reaction network and a reactive transport model to predict the potential impact of Marcellus Shale development on water quality.

We are currently in our first step in establishing the reaction network involved in water rock interactions in Marcellus Shale and in developing thermodynamic and kinetic database for the reactions. We use the soil and aqueous geochemistry data collected by Dr. Ryan Mathur's students in Juniata College at Huntingdon, PA, as part of research within the Shale Hills Critical Zones Observatory (CZO). Based on their data, the primary parent rock mineral composition is listed in Table 1. With this mineral composition, the reaction network involved is listed in Table 2. The reactions include the dissolution of primary minerals, including pyrite, albite, quartz, and clays (illite, chlorite, smectite). The precipitation of secondary minerals occurs as a result of the primary mineral dissolution. These include the precipitation of kaolinite, iron hydroxide, and carbonate. The general form of reaction rate laws for the mineral dissolution and precipitation reactions are listed in Table 3.

With the above established reaction network and thermodynamic and kinetic database, we are in the process of matching the weathering data listed in Table 4 to validate the model. We use existing generic reactive transport code CrunchFlow (Steefel and Maher, 2009). Reactive surface areas of different minerals were used as matching parameters. The following is among the major findings:

- With the presence of dissolved oxygen, pyrite oxidative dissolution plays a pivotal role in determining the water chemistry of the system. The pore water maintains a pH range of 4-6, which is consistent with the pore water data collected.
- The dissolution of primary minerals leads to the precipitation of kaolinite. The low pH maintained by pyrite dissolution increase the dissolution rates by several orders of magnitude.
- The oxidative dissolution of pyrite leads to the precipitation of iron hydroxide.

These findings are significant in terms of implications for the predicting impacts of water rock interactions on water quality. This is because a similar set of reactions exist when hydraulic fracturing or flow back fluid interacts with Marcellus shale rocks. After fully matching the weathering data, we will obtain a more quantitative understanding on the water rock interactions and will have the predicting capability for Marcellus shale water rock interactions.

Table1. Initial minerals in the parent rock

Mineral	Volume Fraction (%)
Quartz	34.4
Illite	39.2
Pyrite	1.0
Smectite	9.7
Albite	2.1
Chlorite	12.2
TiO_2	0.8

Table 2. Mineral dissolution reactions and their corresponding equilibrium constants at 25°C.

Mineral Dissolution Reaction	$Log(k_{eq})$
Quartz = $SiO_{2\,(aq)}$	**-3.999**
Illite + 8 H^+ = 0.25 Mg^{2+} + 0.6 K^+ + 2.3 Al^{3+} + 3.5 $SiO_{2\,(aq)}$ + 5 H_2O	**9.026**
Albite + 4 H^+ = Na^+ + Al^{3+} + 3 $SiO_{2\,(aq)}$ + 2 H_2O	**2.76**
Kaolinite+ 6 H^+ = 2 Al^{3+} + 2 $SiO_{2\,(aq)}$ + 5 H_2O	**6.81**
Smectite + 6 H^+ = 0.33 Mg^{2+} + 0.165 Ca^{2+} + 1.67 Al^{3+} + 4 $SiO_{2\,(aq)}$ + 4 H_2O	**2.49**
Siderite + H^+ = Fe^{2+} + HCO_3^-	**-0.19**
Pyrite + H_2O + 3.5 O_2 = 2 H^++ 2 SO_4^{2-} + Fe^{2+}	**107.67**
Chlorite+ 16 H^+ = 0.55 Mg^{2+} + 3.45 Fe^{2+} + 2 Al^{3+} + 3 $SiO_{2\,(aq)}$ + 12 H_2O	**14.996**
$Fe(OH)_3$ + 2H^+ = 0.25 $O_{2\,(aq)}$ + Fe^{2+} + 2.5 H_2O	**-27.235**

Table 3. TST rate laws of the minerals

Mineral	Rate Law	Reference
Quartz	$R= 10^{-11.5} [H^+]^{0.35}+ 10^{-13.39} + 10^{-10.5} [OH^-]^{0.5}$	(Brantley et al. 2008)
Illite	$R= 10^{-11.72} [H^+]^{0.6}+ 10^{-15.06} + 10^{-12.31} [OH^-]^{0.6}$	(Kohler, Dufaud et al. 2003)

Kaolinite	$R= 10^{-12.19} [H^+]^{0.55} + 10^{-14.36} + 10^{-10.71} [OH^-]^{0.75}$	(Huertas, Chou et al. 1999)
Albite	$R= 10^{-8.7} [H^+] + 10^{-11.5} + 10^{-14.6} [H^+]^{-0.4}$	(Chou and Wollast 1985)
Smectite	$R= 10^{-12.66} [H^+]^{0.21} + 10^{-16} + 10^{-12.22} [OH^-]^{0.33}$	(Golubev, Bauer et al. 2006)
Siderite	$R= 10^{-4.6} [H^+]^{0.75} + 10^{-8.65}$	(Duckworth and Martin 2004)
Pyrite	$R= 10^{-8.19} [H^+]^{-0.11} [O_2]^{0.5}$	(Williamson and Rimstidt 1994)
Chlorite	$R= 10^{-9.79} [H^+]^{0.49} + 10^{-13} + 10^{-10.76} [OH^-]^{0.43}$	(Alekseyev 2007)

Table 4.Elemental chemistry and corresponding t values for soils collected on Marcellus shale in central Pennsylvania

Sample	Depth range	Depth	Al_2O_3	BaO	CaO	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO_2	∑(oxides)	Total N	Total C	Total H	LOI*
	cm	cm	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
CE A 1	0-10	5	11.6	0.07	0.29	5.00	2.34	0.56	0.22	0.12	66.3	1.11	87.6	0.32	3.37	0.94	12.4
CE A 2	10--20	15	14.8	0.07	0.23	6.98	3.07	0.73	0.23	0.12	65.8	1.11	93.1	0.13	0.72	0.64	6.9
CE A 3	20-26	23	15.6	0.07	0.24	5.87	3.29	0.74	0.21	0.07	66.2	1.12	93.4	0.13	0.57	0.69	6.6
CE A 4	26-34	30	16.9	0.06	0.25	7.67	3.44	0.80	0.22	0.09	61.8	1.03	92.3	0.12	0.40	0.72	7.7
CE A 5	34-44	39	17.0	0.06	0.22	7.93	3.49	0.79	0.22	0.09	62.1	1.04	92.9	0.12	0.40	0.71	7.1
CE A 6	44-52	48	16.9	0.06	0.20	6.73	3.50	0.85	0.23	0.09	63.3	1.06	92.9	0.11	0.30	0.73	7.1
CE A 7	52-60	56	16.5	0.06	0.15	9.99	3.35	0.82	0.23	0.13	60.5	1.01	92.7	0.12	0.34	0.79	7.3
CE A 8	60-65	62	17.9	0.06	0.12	5.34	3.68	0.80	0.26	0.06	64.7	1.09	94.0	0.12	0.26	0.69	6.0
CE A 9	65-71	68	17.0	0.06	0.09	6.89	3.49	0.85	0.24	0.07	63.6	1.06	93.4	0.11	0.29	0.62	6.6
CE A 10	71-82	76	17.1	0.06	0.07	6.72	3.58	0.82	0.24	0.07	63.3	1.06	93.0	0.12	0.26	0.69	7.0
CE A 11	82-89	85	18.1	0.06	0.05	4.14	3.85	0.81	0.25	0.05	65.0	1.09	93.4	0.13	0.26	0.69	6.6
CE A 12	89-98	93	18.0	0.06	0.06	5.74	3.78	0.85	0.24	0.06	63.6	1.08	93.5	0.12	0.42	0.75	6.5
CE A 13	98-109	104	17.6	0.07	0.05	5.13	3.75	0.86	0.24	0.07	64.4	1.08	93.3	0.12	0.29	0.67	6.8
CE A 14	109-115	112	17.1	0.06	0.04	5.80	3.58	0.87	0.23	0.05	63.8	1.06	92.6	0.12	0.33	0.74	7.4
CE A 15	115	115	17.8	0.07	0.04	5.70	3.73	0.89	0.24	0.06	63.7	1.07	93.3	0.12	0.33	0.69	6.7

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STUDENTS & POSTDOCS SUPPORTED
Peyman Heidari, Petroleum and Natural Gas Engineering, PhD student.

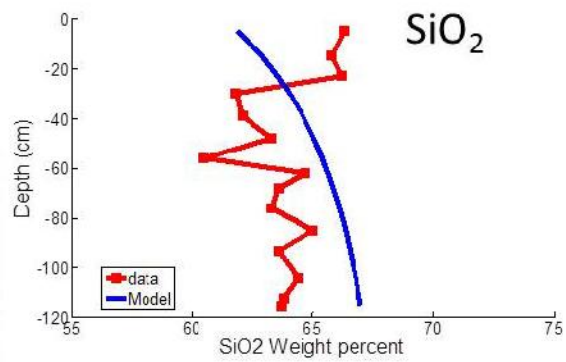
PUBLICATIONS
This is our first year on this project; no publication from this project yet.

ADDITIONAL FUNDING ACQUIRED USING USGS GRANT AS SEED MONEY
(source, amount, starting and ending dates, title)
PI Li Li is developing a CAREER proposal titled "Energy and Sustainability: Water rock interactions at Marcellus Shale."

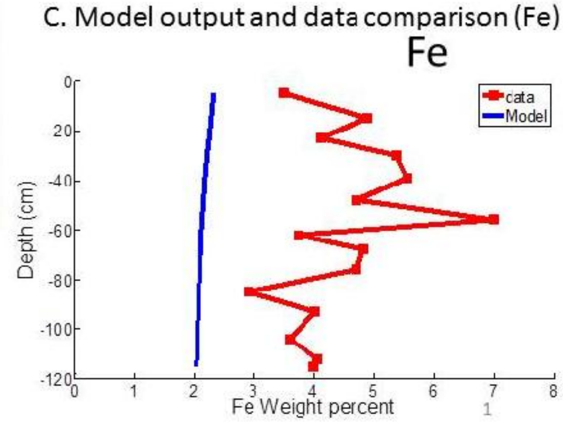
PHOTOS OF PROJECT

A. Marcellus shale weathering to soil near Huntingdon, PA

B. Model output and data comparison (SiO_2)



C. Model output and data comparison (Fe)



by Peyman Heidari, Li Li, Susan Brantley (PSU)

Information Transfer Program Introduction

One project supported during FY11 was information-transfer oriented, making research based information available to stakeholders statewide. In the research category of social sciences, PI Charles Abdalla and colleagues aimed to understand municipal officials' decisions to lease watershed lands for Marcellus Shale gas exploration, and helped to provide educational information and programs to assist municipal leaders and their constituencies.

Understanding Municipal Officials Decisions to Lease Watershed Lands for Marcellus Shale Gas Exploration

Basic Information

Title:	Understanding Municipal Officials Decisions to Lease Watershed Lands for Marcellus Shale Gas Exploration
Project Number:	2011PA155B
Start Date:	3/1/2011
End Date:	2/29/2012
Funding Source:	104B
Congressional District:	5
Research Category:	Social Sciences
Focus Category:	Management and Planning, Water Supply, Water Quality
Descriptors:	None
Principal Investigators:	Charles Abdalla

Publications

There are no publications.

Pennsylvania Water Resources Research Center
FY2011 Final Report

PROJECT TITLE AND PRINCIPAL INVESTIGATORS

Understanding Municipal Officials' Decisions to Lease Watershed Lands for Marcellus Shale Gas Exploration

Charles W. Abdalla, Ph.D., Professor of Agricultural and Environmental Economics, Penn State University, University Park, PA

KEYWORDS
Marcellus shale, water quality, water quantity, gas drilling

STATEMENT OF WATER PROBLEM

Natural gas–rich Marcellus shale occurs below parts of Pennsylvania, West Virginia, Maryland, New York, Ohio, and Virginia (Figure 1). Its development as a potentially significant source of energy illustrates how energy policies and trends can drive changes in land and water use and public policies, including at the municipal level. The expanding demand for energy in the US, along with new drilling technologies such as horizontal drilling and hydraulic fracturing ("fracing"), have whetted mineral exploration companies' interest in drilling into these gas reserves. Uncertainty exists as to how big the Marcellus shale gas play will become. The economic slump in 2008 slowed leasing activity. Nevertheless, leasing activity increased again in 2009, as did drilling and fracing of gas wells in Pennsylvania and also in West Virginia. Although the full impacts of Marcellus shale drilling remain to be seen, it appears that development of this shale is rapidly transitioning from an exploratory to a production phase in Pennsylvania and perhaps soon in additional states in the region.

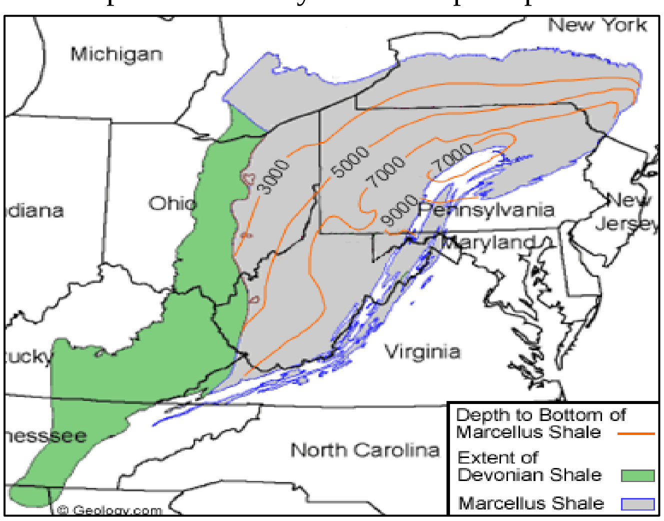


Figure 1. Location of the Marcellus Shale formation. Source: Geology.com http://geology.com/articles/marcellus-shale.shtml

Water is critical to extracting gas from the Marcellus shale. The shale around most new gas wells must be fraced to release the trapped gas so it can be brought to the surface. This process for a deep vertical well may use 500,000 to more than 1 million gallons of water. A horizontal Marcellus well may use 3 - 4 million gallons of water. If the Marcellus is like other shale gas plays, some wells may need to be hydro-fractured several times over their productive life (typically 5–20 years). These large water withdrawals may have important watershed and ecological effects. The distribution of Marcellus shale within major watersheds of Pennsylvania in Figure 2.

The permitting, drilling and fracing of Marcellus gas wells has accelerated in the last two years. Pennsylvania's Department of Environmental Protection (PA DEP) issued about 2,000 new permits for Marcellus shale drilling in 2009. The agency is expected to issue about 5,200 permits in 2010.

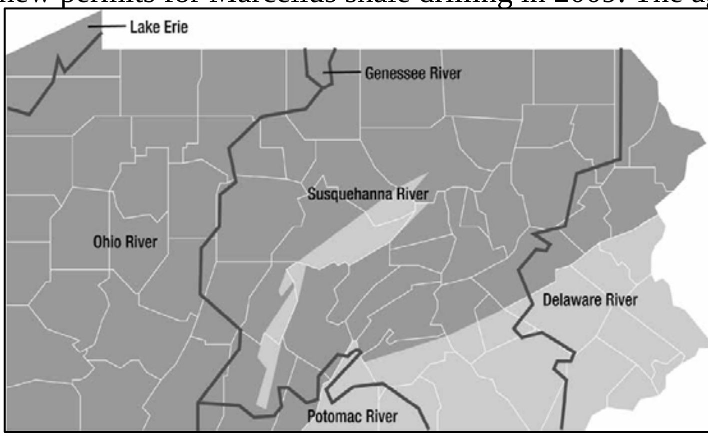


Figure 2. Distribution of Marcellus shale in Pennsylvania with major river basins overlain. Source: Abdalla, C., and J. Drohan. 2010.

The U.S. Geological Survey has identified described three major water resource concerns from production of gas from application of deep and horizontally drilling and fracing of the Marcellus shale in the Northeast and Mid-Atlantic Region. These concerns are: 1) supplying water for well construction without impacting local water resources; 2) safely transporting fluids and supplies avoiding degradation of small watersheds and streams as substantial amounts of heavy equipment and supplies are moved around on rural roads; and 3) determining proper methods for the safe disposal of the large quantities of potentially contaminated fluids recovered from the wells (Soeder and Kappel, 2009).

Water Supply. Thus far, most withdrawals in for Marcellus gas wells in Pennsylvania have been from surface water sources. Large withdrawals could also affect nearby drinking water sources and other uses. Putting water to one use may mean that it is not available for another use, thereby increasing the potential for conflicts between water users.

The Susquehanna River Basin Commission has estimated that at full development the total annual water withdrawal by drillers into the Marcellus shale in the basin will be about 10 billion gallons per year. While that amount may be manageable, environmental and water resource management agencies are concerned because gas wells are often in remote areas, where the closest water source may be an ecologically sensitive, small forested stream. Generally speaking, regional and state water managers played "catch-up" in 2008 and 2009 with the fast-moving industry after a number of water-related Marcellus shale drilling incidents. Several streams in Pennsylvania were dewatered for drilling and/or fracing.

Transporting fluids and supplies. An important challenge is to transport the large quantities of fluids and supplies without avoiding degrading watersheds and streams. Substantial amounts of heavy equipment and supplies must be moved around on roads, many of them rural, in order roads to drill and frac a well. For example, some spills have occurred. DEP fined Cabot Oil and Gas Corp. $56,650 for three spills totaling 8,000 gallons of a chemical used in the fracking process within one week in Dimock, Susquehanna County.

Wastewater disposal. An important challenge is the safe and economical disposal of the large quantities of potentially contaminated fluids recovered from the wells. Sand, gas, and chemicals are added to water used for fracing to extract gas. Wastewaters may also contain brine and other contaminants such as radioactive radon released from the underground rock formation. The chemicals used may include oils, gels, acids, alcohols, and various manufactured organic chemicals. Therefore, the storage, treatment, and return of these waste fluids to the environment are important water quality concerns. Wastewater fluids must be treated appropriately before disposal. Drilling and fracing water and other wastewaters are being transferred between river basins, and this may further complicate permitting and big-picture water management to ensure a consistent regulatory approach statewide. In addition, accidents involving trucks hauling wastewaters may degrade water supplies near roadways as well as create other problems.

Other environmental, health and safety concerns. Methane gas migration from Marcellus drilling in Dimock Susquehanna County, caused several private drinking water wells to explode and fouled nine other wells. Pennsylvania DEP says that for at least three Dimock wells, gas wells were improperly sealed during the early stages of drilling. This is not a new issue to well drilling in Pennsylvania, but it is new to Dimock and some other regions seeing Marcellus development. PA DEP is in the process of strengthening regulations governing the casing (lining to protect groundwater and allow the safe operation of the well) of Marcellus shale wells to protect groundwater.

The appeal to municipalities of leasing watershed lands. A 2008 survey by the Pennsylvania Sustainable Water Infrastructure Task Force found that Pennsylvania is facing nearly $11 billion in unmet drinking water infrastructure needs. In addition, local public water suppliers were found to need significant money for ongoing operation and maintenance costs. The need for new investments is evidenced by the overflows, leaking and deteriorated collection systems, deferred rehabilitation and replacement work, and shortage of treatment capacity that plague the state's water systems. Because it is difficult to raise rates or taxes from customers or residents to cover these costs, some municipalities have become very interested in leasing mineral rights under watershed lands in regions of the state underlain with Marcellus shale. However, the uncertainty about the potential benefits and costs (environmental including water quality, and health and safety), make this a complex and often controversial decision. Much of the current information about municipal leasing of watershed land is anecdotal. To adequately educate and assist municipal leaders and their constituencies, greater documentation of such municipal activities, the motivations behind it, and leader's knowledge of possible impacts, is needed. This project seeks to fill that gap.

NATURE, SCOPE, AND OBJECTIVES OF THE PROJECT

The proposed project's main objectives are to increase understanding of a) municipal officials' motivations to lease mineral rights under their watershed lands; b) municipal officials' knowledge of the expected short-term and long-term benefits and environmental costs, particularly to water quality, of leasing watershed lands; and c) the processes used by municipal officials for balancing expected benefits and costs.

In addition, the knowledge base acquired from the project will be used to generate information for use in a broader research proposal, perhaps for the Northeast/Mid-Atlantic Region where Marcellus shale is located, and for dissemination to audiences through Extension/Outreach mechanisms and to professionals through presentations and publications.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The principal findings relate to: 1) timing, 2) communication, 3) resources and networking, 4) monitoring water quality, and 5) balancing missions of providing safe affordable water with revenue from leasing watershed land. Opportunities for assisting municipalities considering leasing of watershed lands in the future are identified within each of the five areas below.

1) Timing. The timing of municipal decisions was found to be the most important variable affecting lease decision-making and outcomes. Municipalities approached earlier had less information and thus made relatively poorer decisions yielding less satisfactory outcomes. Municipalities that made decisions later and with more information based on their own or others' experiences, made better decisions. Extrapolating from this trend, we can expect improved decisions to result as more information continues to be spread about outcomes of leasing and shale gas drilling.

2) Communication. Improved communication among all parties will likely increase the level of trust surrounding decisions to lease municipally owned watershed lands. If trust increases, more informed decisions will result, and parties will be more satisfied with outcomes. Recommendations for improved communication include: a) Industry representatives should provide advance warning of their actions and respect municipality's property boundaries; b) Municipal officials should make as much information as possible available in a timely way to citizens through different means well in advance of decisions. Also, the credibility of information will be increased by involvement of neutral third parties; c) Given the complexity and rapidly changing nature of Marcellus shale development, citizens may need to be patient as they participate and give input to municipal decisions. Municipal officials may not yet have the information that citizen desire, or may lack control to implement options that some citizens desire.

3) Resources and Networking. Water providers' resources influenced their ability to make informed decisions about leasing. Smaller ones relied on communication with neighboring communities, expertise from training/educational organizations and/or grant resources from

state agencies and in-house staff and/or volunteers. Larger providers had more in-house staff and the wherewithal to purchase expertise to aid decision-making. Networking with neighboring communities was an important factor in learning about the shale gas exploration process, especially for smaller water providers that had been approached more recently. Three recommendations stem from the municipal resources/networking finding: a) Increased resources, possibly for training/networking and/or development of source water protection plans, would likely increase the quality of decisions of small and mid-sized water providers, b) Arrangements that allow more experienced systems to share expertise with less well-equipped suppliers directly or indirectly would increase the quality of decisions of small and mid-sized water providers, and c) Regionalization of systems may offer benefits of extending knowledge of watershed leasing although it is perceived by some to have costs as well.

4) Monitoring Water Quality. All municipalities studied indicated that they remained true to their mission of supplying adequate supplies of high quality water to customers. Due to this interest and the risks of water contamination from shale gas development, all saw the importance of water quality monitoring. Previously, some municipalities had not factored monitoring costs into their leasing decisions. The municipalities were in various stages of developing their water quality monitoring efforts, were using different approaches of different levels of sophistication, and funding sources, and had varied levels of experience to develop baseline measures of water quality. The following suggestions are made regarding water monitoring that government agencies and other organizations should: a) Increase their funding of regional or water quality baseline studies, b) Develop more training programs to do or improve baseline studies, and c) Encourage municipalities to include the full costs of water monitoring in leases; and d) Develop a more systematic protocol for collecting and analyzing water quality monitoring so that it is more consistent, credible and defensible.

5) Balancing missions of providing safe affordable water with revenue from leasing watershed land. The municipalities in the sample were confronted with the dilemma of wanting financial benefits from shale gas exploration while remaining true to their original mission of providing safe and affordable supplies of water to their customers. Complicating matters, most communities in the sample needed to replace aging water or sewer infrastructure. Often, their declining customer base and/or economic status prevented making these needed investments. The opportunity to lease watershed lands thus provides a way of obtaining revenues to cover these or other costs and assists the municipality. However, any unanticipated or uncovered costs of problems related to shale gas exploration, drilling or production, can reduce or even negate (especially if the costs are on-going), the revenues generated from leasing. Several recommendations flow from this finding: a) Municipalities should examine their mission statements to see how natural gas drilling fits into their organization's goals; b) Efforts should be undertaken by municipalities, or their state level professional associations, to identify and estimate in quantitative economic terms the impact of problems from shale gas development on their communities, including on consumer confidence, and the effect of water supply loss or water supply decline on community development.

Future research/outreach opportunities. Strengths of the study which could be followed up in future research included the: a) Analytical framework and the interview guide outline derived from it; b) Relative ease with which common themes and findings were identified from a relatively small sample, c) Identification of lessons learned (e.g., networking, education) that are capable, in many cases, of being directly shared with other municipalities, and d) Ability to identify other key municipal decision variables (e.g., sales of water to the gas industry, funding of related infrastructure needs like wastewater systems both within and between municipalities, new methods of leasing such as electronic auctions, and water system regionalization).

Proposal Development. The following sources have been identified for follow-up research or outreach extension proposals: US Department of Agriculture's National Institute of Food and Agriculture-funded Mid-Atlantic Water Center for Rural Pennsylvania, the Heinz Foundation and the Colcom Foundation, regional offices of the US Geological Survey, and the Chesapeake Research Consortium/Scientific and Technical Advisory Committee of the EPA's Chesapeake Bay Program.

STUDENTS & POSTDOCS SUPPORTED

Renata Rimsaite, Agricultural Economics, Masters of Science, Penn State University
Patrick Boynton, Penn State U. Schreyer Honors College (undergrad), Bachelor of Arts

PRESENTATIONS

Abdalla, Charles W. "Municipal Roles in Water-Related Aspects of Shale Gas Development in Pennsylvania" Penn State Extension Marcellus Shale Extension Webinar Series, March 15, 2012, 92 participants.
http://extension.psu.edu/naturalgas/webinars/recorded/municipalitys-roles-water-use-protections/charlie-abdalla-march-15-2012-powerpoint-2

OTHER INFORMATION TRANSFER ACTIVITIES

An abstract for a presentation at the October 2012 Pennsylvania Planning Association's Annual Meeting and additional in-person and web-based Penn State Extension presentations are in development. An executive summary of the final report will be sent to interviewees, state or regional agency representatives that assisted with the research and other interested parties. During Summer 2012, a paper will be written for submission to a professional conference or refereed academic journal.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	1	7
Masters	4	0	0	0	4
Ph.D.	3	0	0	1	4
Post-Doc.	0	0	0	0	0
Total	13	0	0	2	15

Notable Awards and Achievements

See individual project descriptions.