Pennsylvania Water Resources Research Center
Annual Technical Report
FY 2017

Introduction

OVERVIEW

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 keeping with the land grant mission of the host Universities, each institute serves a tripartite mission 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 (IEE). The PA-WRRC continues to receive support contributions from IEE, 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. A request for proposals for this competition was broadly disseminated. The projects supported via small grants allowed faculty to conduct research, to engage students in training, and/or to provide public education regarding water 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 PROJECTS

Four projects supported during FY17 were research-oriented, addressing unanswered questions in water resources and seeking solutions to water challenges.

1. Principal investigator William Burgos and co-investigator Lara Fowler from Penn State University led a project entitled "Impact of Spreading Oil & Gas Wastewater as Road Treatments on Groundwater Quality." This research showed that oil and gas wastewaters spread on roads in the northwestern Pennsylvania have salt, radioactivity, and organic contaminant concentrations often 100's to 1000's times above drinking water standards.

2. Principal investigator Alfonso Mejia from Penn State University led a research project entitled "Toward Improved Predictability of Subseasonal to Seasonal Streamflow in the Middle Atlantic Region." This research shows that subseasonal to seasonal climate forecasts can be used to anticipate streamflow and nutrient loads from the James River into the Chesapeake Bay several weeks in advance, 2 to 8 weeks

3. Principal investigator Heather Murphy from Temple University led a research project entitled "Evaluating septic systems as a source of enteric pathogens in private water supply wells of Pennsylvania." This research showed that household septic systems can be a source of human fecal contamination in Pennsylvanian private wells; and that rainfall can impact the presence of contamination over time.

4. Principal Investigator Yufeng Xie from Penn State University's Capitol Campus at Harrisburg, along with co-investigator Hao Tang from Indiana University of Pennsylvania led a research project entitled "Impacts of Shale Gas Produced Water on Water Utilities: Disinfection Byproduct Formation." This research showed that shale gas extraction wastewater contributed to disinfection byproduct formation upon chlorination.

EDUCATIONAL IMPACT

10 graduate students and 6 undergraduate students were supported or partially supported as part of the PA-WRRC 104B projects described above, multiple academic institutions across Pennsylvania. The lead PI of the 104B project is in parenthesis. Graduate Students

Masters and Other students

1. (Boyer) Brian Redder, Department of Ecosystem Science and Management, Penn State University. Masters student. 2. (Boyer) Andrea Ferich, Department of Ecosystem Science and Management, Penn State University. Masters student. 3. (Xie) Kodi Webb, Environmental Pollution Control Program, Penn State Harrisburg, Masters student. 4. (Xie) Kuan Huang, Environmental Engineering Program, Penn State Harrisburg, Masters student. 5. (Xie) Linlin Tang, Environmental Pollution Control Program, Penn State Harrisburg, Masters student. 6. (Burgos) Kyle Ganow, Penn State Law, JD student.

Ph.D studnets 1. (Burgos) Travis Tasker, Department of Civil and Environmental Engineering, Penn State University, PhD student 2. (Mejia) Sanjib Sharma, Civil and Environmental Engineering, Pennsylvania State University, PhD student 3. (Mejia) Susana Garcia, Civil and Environmental Engineering, Pennsylvania State University, PhD student 4. (Murphy) Shannon McGinnis, Department of Epidemiology & Biostatistics, Temple University, PhD student

Undergraduate Students 1. (Murphy) Alexander Cagle, Department of Earth and Environmental Studies, Temple University, undergraduate student 2. (Murphy) Madison Heaton, Department of Biology, Temple University, undergraduate student 3. (Murphy) Jessica Serpe, Department of Earth and Environmental Studies, Temple University, undergraduate student 4. (Murphy) Erin Huder, Department of Epidemiology & Biostatistics, Temple University, undergraduate student 5. (Murphy) Kodi Lawrence, Department of Environmental Engineering, Temple University, undergraduate student 6. (Murphy) Aurora Trainor, Department of Epidemiology & Biostatistics, Temple University, undergraduate student

INFORMATION TRANSFER ACTIVITIES

Information from the research projects described above were disseminated to broader audiences, via both publications and presentations at meetings and conferences. In addition, PAWRRC worked with the Institutes of Energy and Environment on the Penn State Campus to advance an initiative called Water Resources and Education at Penn State (WREAPS), and to support additional small grants (using IEE, not 104B funds) related to water resources on the Penn State campus.

Using 104B administrative funds, we co-sponsored the following conferences and events;

1. Pennsylvania Groundwater Symposium, May 2017, State College, PA (260 attendees)

2. Penns Valley Conservation Association CrickFest, Coburn, PA, September 2017

3. Mid-Atlantic Water Conference, October 2017, Shepherdstown, WV

4. Susquehanna River Symposium, November 2017, Lewisburg, PA

PAWRRC Director Boyer provided the following presentations during the FY17 project period (March 2017 to February 2018): Invited presentations:

1. (Invited Seminar) Boyer EW. Water Pollution in Pennsylvania. Bucknell University, Center for Sustainability and the Environment, February 2018

2. (Invited Keynote Speaker). Boyer EW. Nitrogen in Catchments of the United States: Current Problems and Future Solutions. American Geophysical Union, Catchment Science Symposium, New Orleans, LA, December 2017.

3. (Invited Seminar) Boyer EW. Nitrogen Cycling & the Food-Energy-Water Nexus: Toward Advancing Nutrient Pollution Solutions. Kent State University, Palmer Geology Lecture Series, December 2017

4. (Invited Plenary Speaker). Boyer EW. Nutrient Pollution in the Susquehanna and Delaware Watersheds, from the Headwaters to the Bays. 12th Annual Susquehanna River Symposium, Lewisburg, PA, Nov 11, 2017.

5. (Invited Panelist). Boyer EW. Addressing Water Issues through Research. National Institutes of Water Resources, Mid-Atlantic Water Conference, Shepherdstown, WV, October 201

Contributed research presentations:

1. Bryant RB, AL Allen, AR Buda, PR Kleinman, EW Boyer, FM Hashem, MD King, SS Tzilkowski, LC Kibet, SA Klick, LS Saporito, and EB May. Terrestrial Sources of Urea: Allochthonous or Autochthonous? Association for the Sciences of Limnology and Oceanography, Honolulu, HI, February 2017.

2. Miller M, E Boyer, T Russo, and H Lin. Lateral Flow Analysis and Hydropedologic Functional Units. Shale Hills Critical Zone Observatory, Annual Meeting, Penn State University, University Park, PA, May 2017.

3. Harvey J, D Scott, E Boyer, and J Gomez-Velez. Hydrologic Connectivity of River Corridors within Conterminous United States. HydroEco 2017, University of Birmingham, UK, June 2017.

4. Risch MR, JF DeWild, DA Gay, L Zhang, EW Boyer, and DP Krabbenhoft. Atmospheric Mercury Deposition to Forests in the Eastern United States. 13th International Conference on Mercury as a Global Pollutant. Providence, RI, July 2017.

5. Brunette R., D Gay, and EW Boyer. The Importance Of Quality Assured Field And Analysis Data Supporting The NADP Mercury Deposition Network For Policy Makers, Modelers, And Research Scientist And Other End Users. National Environmental Monitoring Conference, Washington, DC, August 2017.

6. Boyer EW. Inputs of Pollutants to Watersheds via Atmospheric Deposition, With Implications for Human Health and Aquatic Life. NIWR Water Conference, Water Research: Building Knowledge and Innovative Solutions. Shepherdstown, WV, Oct. 2017.

7. Redder B, A Buda, and E Boyer. Transport and Transformations of Nitrogen in Groundwater Seeps Along the Stream Corridor of an Agricultural Watershed. NIWR Water Conference, Water Research: Building Knowledge and Innovative Solutions. Shepherdstown, WV, October 2017.

8. Boyer EW, HE Golden, JN Galloway, RB Alexander, G Schwarz, J Gomez-Velez, JW Harvey, D Scott, and N Schmadel. Coupled Hydrological, Biogeochemical, and Geomorphic Processes Affecting Nutrient Loadings in Fluvial Networks. Geological Society of America, Seattle, WA, October 2017.

9. Najjar RG, M Herrmann, RB Alexander, DJ Burdige, WJ Cai, EA Canual, RF Chen, MA Friedrichs, RA Feagin, J Holmquist, X Hu, M Kemp, K Kroeger, MR Mulholland, CH Pilskaln, J Salisbury, P St. Laurent, H Tian, M Tzortziou, Z Wang, R Zimmerman, E Boyer, D Butman, P Griffin, A Hinson, A Mannino, L McAllister, W McGillis, S Signorini, and P Vlahos. Carbon budget of tidal wetlands, estuaries, and shelf

waters of Eastern North America. Coastal and Estuarine Research Federation, Providence, RI, Nov. 2017.

Research Program Introduction

None.

Toward Improved Predictability of Sub-seasonal to Seasonal Streamflow in Pennsylvania

Basic Information

Title:	Toward Improved Predictability of Sub-seasonal to Seasonal Streamflow in Pennsylvania
Project Number:	2017PA230B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	5
Research Category:	Climate and Hydrologic Processes
Focus Categories:	Water Quality, Water Quality, Climatological Processes
Descriptors:	None
Principal Investigators:	Alfonso Mejia

Publications

There are no publications.

PROJECT REPORT
Pennsylvania Water Resources Research Center

PROJECT TITLE & PRINCIPAL INVESTIGATOR(S)

Toward Improved Predictability of Subseasonal to Seasonal Streamflow in the Middle Atlantic Region

PI: Alfonso I. Mejia
The Pennsylvania State University
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SHORT ONE-SENTENCE SOUND BYTE OF THE PROJECT OR FINDINGS

This research shows that subseasonal to seasonal climate forecasts can be used to anticipate streamflow and nutrient loads from the James River into the Chesapeake Bay several weeks in advance, 2 to 8 weeks.

PROBLEM and RESEARCH OBJECTIVES

Streamflow quantity and quality are vital to the economy and well-being of the Middle Atlantic Region (MAR) since streamflow is a primary source of freshwater to many industries and communities in the region. To ensure and monitor the availability of streamflow, it is necessary to predict streamflow at a range of temporal and spatial scales. Normally, streamflow predictions in the MAR have been performed at the weather (<14 days) or climate (>1 year) scales, with the subseasonal to seasonal (S2S) scale (between 14 days and several months) representing an important research and operational gap. **The main objective of this project is to overcome this prediction gap by producing and evaluating S2S streamflow and nutrient load predictions for selected basins in MAR.**

Historically, S2S streamflow predictions in the MAR have been of low quality, mainly because of the lack of skillful climate predictions in the S2S range. Indeed, the S2S range represents a new and rapidly growing frontier for progress and advancements in weather and climate research. Recent progress in S2S climate predictions (associated with the use of better models, higher-resolution outputs, and improved data assimilation methods and observing systems) suggest that improve S2S streamflow predictions may be attainable in the MAR. To test this, the proposed research is using outputs from the latest S2S climate models, NOAA's Climate Forecast System Version 2 (CFSv2), to force a distributed hydrological model and generate S2S streamflow predictions for the period 2002-present. This period is selected to match the available multisensor precipitation estimates (MPEs) data. The MPEs are being used to verify the climate predictions and to generate hydrological hindcasts for comparison purposes. Within the MAR, the S2S hydrological forecasting approach is being applied at 8 different gauge locations in the James River basin, which is a major tributary to the Chesapeake Bay.

METHODOLOGY

The methodology consists of the following steps:

- Obtain CFSv2 precipitation and temperature reforecasts from NOAA's National Centers for Environmental Prediction (NCEP) web server. The reforecasts are obtained at the daily resolution for the period 2002-present for all the initialization times available (every 4 days). In addition, we combine the daily reforecasts from two consecutive initialization times into an 8-member ensemble forecast.
- Statistically preprocess (i.e., bias-correct and interpolate to the grid resolution of the distributed hydrological model, 4 km^2) the CFSv2 precipitation and temperature forecasts.
- Verification of the raw and statistically preprocessed (bias-corrected) precipitation and temperature forecasts against gridded observations for precipitation (MPEs) and temperature. The statistical preprocessing is done using heteroscedastic censored logistic regression (HCLR) for precipitation and heteroscedastic logistic regression (HLR) for temperature.
- Setup and calibrate distributed hydrological model (NOAA's HL-RDHM)
- Force HL-RDHM with observed, raw and statistically preprocessed climate forecasts over the period 2002-present to generate 3 different streamflow products, respectively: 1) simulated, 2) raw forecasts, and 3) postprocessed streamflow forecasts. The latter are produced by statistically postprocessing the raw streamflow forecasts using HCLR to remove systematic biases.
- The simulated and raw streamflow forecasts are also used to generate simulated and postprocessed water quality variables. This is done using HCLR as a statistical model to simulate (forecast) water quality variables using the simulated (forecasted) streamflow. That is, the simulated streamflow is used as predictor and the water quality variables as the predictand.
- Verification of the streamflow and water quality products using the Continuous Ranked Probability Skill Score (CRPSS) and other performance metrics.

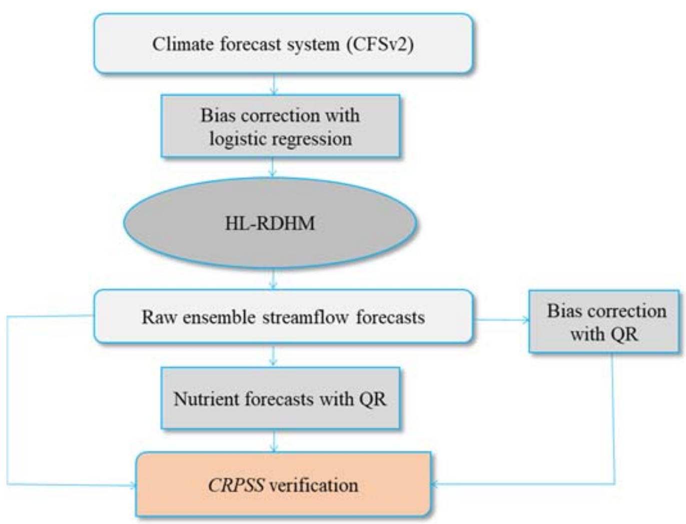

Figure 1. Schematic of the methodology being used to generate the S2S streamflow and nutrient load forecasts in the MAR.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Thus far, the three primary findings are as follows:

- The S2S precipitation and temperature forecasts are skillful up to 1.5 and 2 months, respectively, after preprocessing. In contrasts, the raw forecasts exhibit skill only up to 1 month in the case of precipitation and 1.5 months in the case of temperature.
- The postprocess streamflow forecasts are skillful up to 2 months. However, the skill shows a relatively strong dependence on spatial scale so that the smaller river basins considered have positive skill up to 1 month.
- Following from the previous two findings, the nutrient load and suspended sediment forecasts tend to be skillful up to month 2. The water quality forecasts show more consistent behavior across spatial scales than the streamflow forecasts.

Our application of the proposed forecasting approach to the James River basin in the MAR reveals that S2S streamflow and water quality forecasts can be skillful several months in advance. Thus, it seems possible to use S2S to improve and inform water-related management and operation decisions in the MAR.

STUDENTS & POSTDOCS SUPPORTED

- Sanjib Sharma, Civil and Environmental Engineering, Pennsylvania State University, Graduate Student
- Susana Garcia, Civil and Environmental Engineering, Pennsylvania State University, Graduate Student

PUBLICATIONS

None so far.

INFORMATION TRANSFER ACTIVITIES

None so far.

DATA AVAILALBILTY

The data will be available from the PI as requested. We will use Penn State Data Commons to share the data.

AWARDS & ACHEIVEMENTS (of PIs, students, or staff on the project)

None.

PHOTOS OF PROJECT

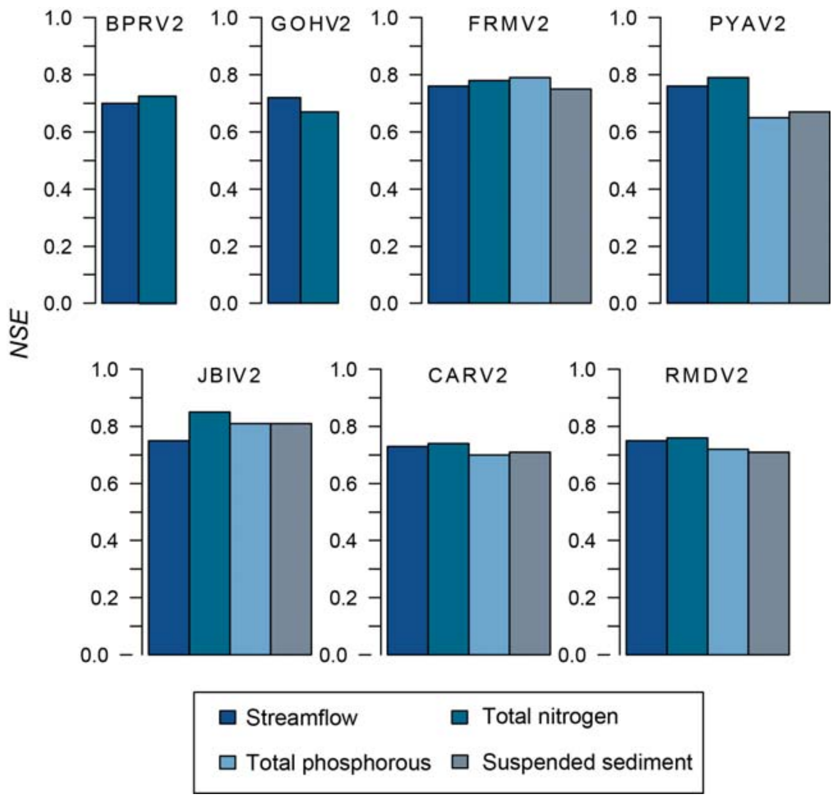

Figure 2. Performance of modeling approach in simulation mode at monthly timescale for streamflow, total nitrogen load, total phosphorous load, and suspended sediment for 7 gauged locations in the James River basin. The performance is measured using the Nash-Sutcliffe efficiency (NSE) index.

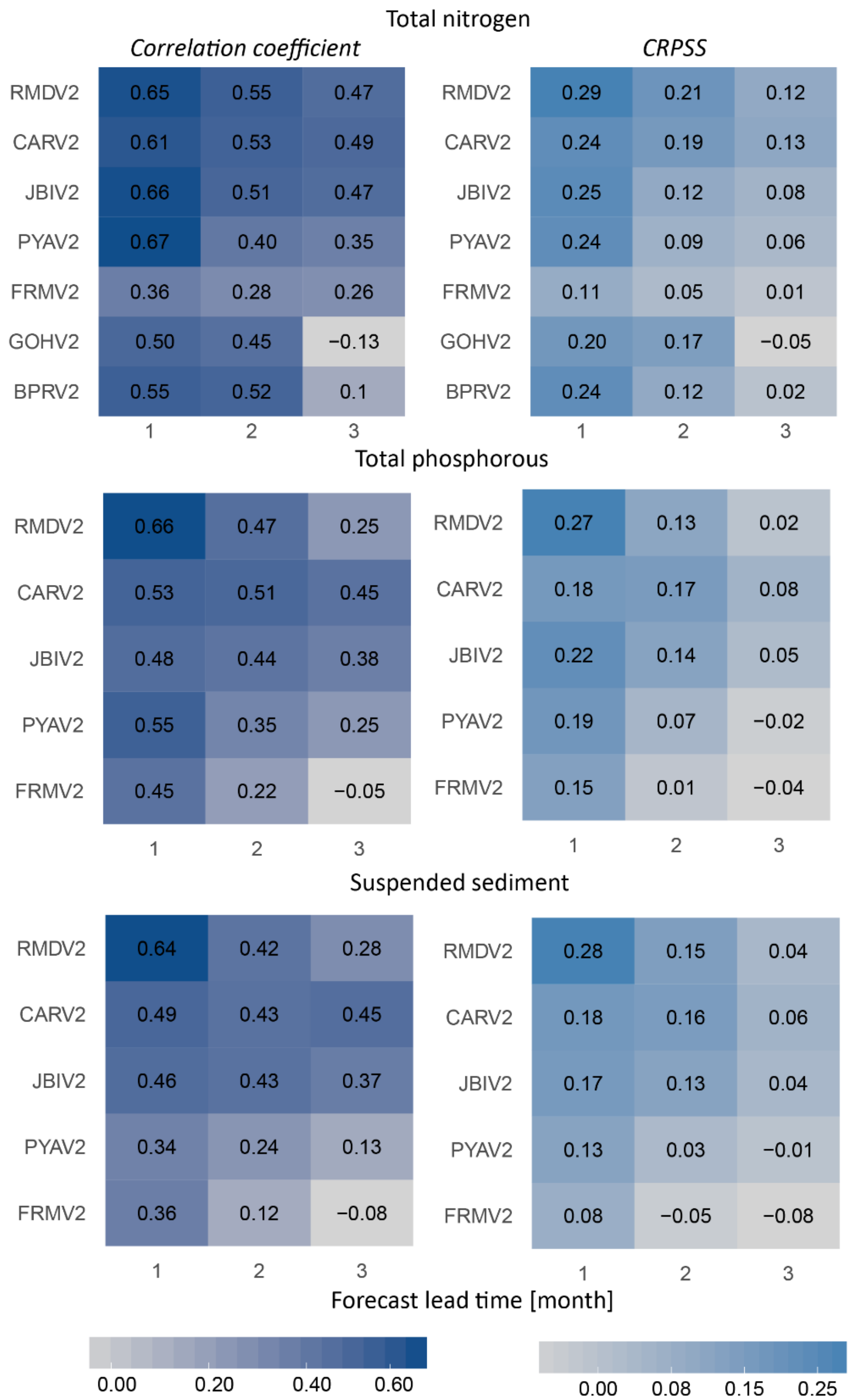

Figure 3. Forecast skill of the total nitrogen, total phosphorous, and suspended sediment forecasts from 1-3 months forecast lead times at 7 gauged locations in the James River basin. The performance is measured using the correlation coefficient and Continuous Ranked Probability Skill Score (CRPSS).

Evaluating Septic Systems as a Source of Enteric Pathogens in Private Water Supply Wells of Pennsylvania

Basic Information

Title:	Evaluating Septic Systems as a Source of Enteric Pathogens in Private Water Supply Wells of Pennsylvania
Project Number:	2017PA231B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	2
Research Category:	Water Quality
Focus Categories:	Groundwater, Water Quality, Education
Descriptors:	None
Principal Investigators:	Heather Murphy

Publications

There are no publications.

PROJECT REPORT
Pennsylvania Water Resources Research Center

PROJECT TITLE & PRINCIPAL INVESTIGATOR(S)

Evaluating septic systems as a source of enteric pathogens in private water supply wells of Pennsylvania

PRINCIPAL INVESTIGATOR:

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SHORT ONE-SENTENCE SOUND BYTE OF THE PROJECT OR FINDINGS

This research showed that household septic systems can be a source of human fecal contamination in Pennsylvanian private wells; and that rainfall can impact the presence of contamination over time.

PROBLEM and RESEARCH OBJECTIVES

Pennsylvania (PA) has the second highest number of private water supply wells in the US, with approximately 3 million people relying on well water (Fleeger, 1999). Private wells are not regulated by the U.S. Environmental Protection Agency or any other authority, and thus the burden is on the homeowner to test and treat their water accordingly. Between 1971 and 2008, 30% of all waterborne outbreaks in the US were associated with the consumption of untreated groundwater. PA had the second highest number of outbreaks during this time period. The CDC recently identified that the burden of disease associated with private wells in the US is unknown and could be significant. Based on previous research (Murphy *et al.*, 2016)**, I estimate that there could be 81,000 cases of acute gastrointestinal illnesses (AGI) per year in PA due to private well water.** The social and economic burden of waterborne AGI can account for numerous lost work/ school days, higher health care costs and the potential development of longer-term health complications. In this project, I am investigating whether septic systems are the source of enteric pathogens found in private wells and how rainfall events may be contributing to their occurrence in groundwater supplies. This research will help State and Federal regulators establish guidelines to support households in the protection or treatment of their private well to ultimately protect public health.
To better understand the health risks associated with the consumption of domestic groundwater supplies, it is crucial to understand the occurrence of microbial pathogens in groundwater as well

as the factors that contribute to pathogen presence in groundwater supplies such as geology, location and design of septic systems, well construction, and rainfall events.

Collection of microbial water quality information is necessary to design more targeted public health studies, and to inform risk assessment models so that appropriate recommendations for public health interventions can be conceived. This study investigated the temporal variability of pathogen presence and human-specific fecal contamination in groundwater supplies in PA. To date, few studies have examined the presence of pathogens in groundwater. Among those studies, the majority have focused on spatial variability of pathogens in groundwater (1 sample collected at many wells) and only a couple have looked at the temporal variability of pathogens presence in wells over time (Allen et al. under review).

There were two key hypotheses of this research:

1. Septic systems are contaminating groundwater supplies with enteric pathogens, specifically enteric viruses in fractured rock aquifers in rural PA.
2. A temporal shift exists between the detection of microbial indicator organisms and enteric pathogens following rainfall events in groundwater wells in fractured rock aquifers because of different transport mechanisms in the subsurface environment.

These hypotheses were tested by investigating the mechanisms contributing to the leaching of septic systems and resulting microbial contamination of private groundwater wells. The key research activities were as follows:

1. Three wells with a history of microbial contamination and evidence of human specific fecal contamination were selected for an intensive water quality monitoring over a 6-month period. The wells were selected among wells that were sampled preliminarily from May-July 2016. Water samples were collected weekly from households and analyzed for human enteric viruses and DNA markers of human excreta. Weekly sampling was selected so that the temporal variability of water quality in the wells over time could be more adequately characterized.
2. Fluorescent dye tracer studies were conducted at the same households to investigate whether the household septic system is the source of fecal contamination in the household well.

METHODOLOGY

<u>Site Selection</u>

Pennsylvania has the second largest number of households in the US served by untreated private well water and is tied with Florida as the state with the largest number of AGI outbreaks related to groundwater (Wallender *et al.*, 2014). Additionally, the geology in PA consists of an abundance of fractured rock, which is very vulnerable to the intrusion of pathogens, particularly viruses. Consequently, PA is an ideal state in which to conduct this type of study.

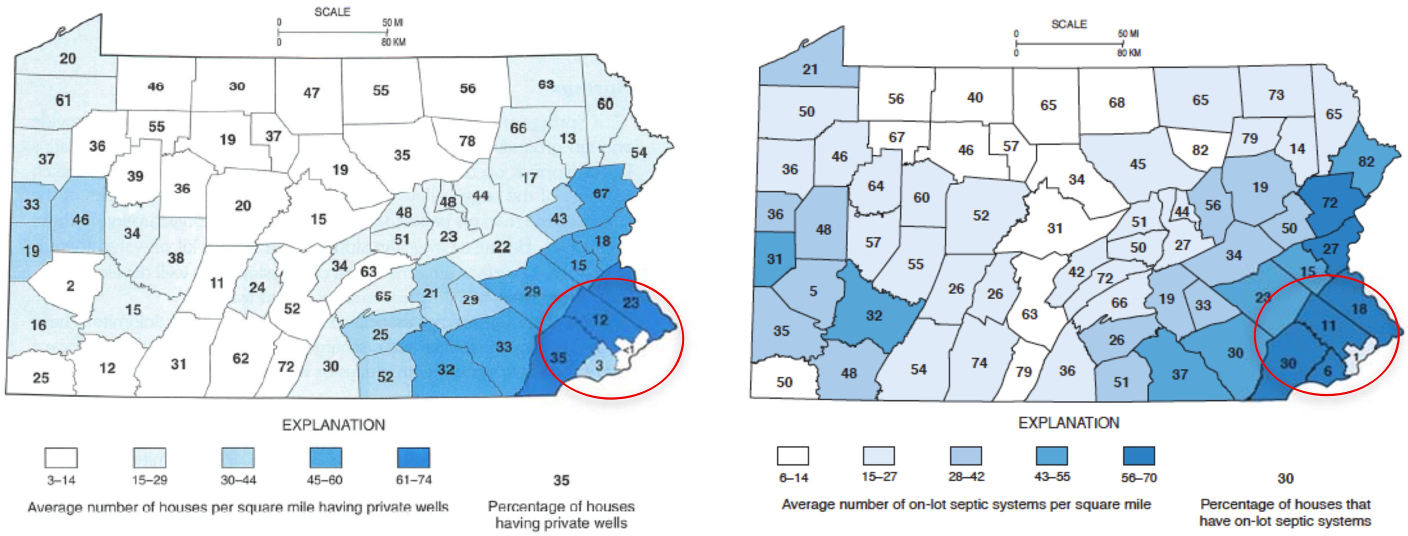


Figure 1. (a) Average number of homes per square mile having private wells (and % of homes served by a private well)(Fleeger, 1999) (b) Average number of on-site septic systems per square mile in PA (and % of homes with on-site septic systems)(Fleeger, 1999) (proposed study counties circled in red)

In this study, households were selected Bucks and Montgomery counties. These counties were selected for the following reasons:

1. Density of Private Wells

These three counties have the highest density of private wells per square mile in all of PA (61-74 homes per square mile have a private well (Figure 1a)).

2. Density of Septic Systems per square mile

These three counties have the highest density of on-site septic systems per square mile in all of PA (56-70 on-site septic systems exist per square mile in these counties (Figure 1b)). Septic system density is important as leaking septic systems represent a significant potential source of entry of human enteric pathogens into groundwater.

3. Geology

The geology of Bucks, and Montgomery counties contain largely fractured rock which has been shown to be problematic for the transport of pathogens directly into aquifers

<u>Sampling Plan</u>

Three domestic groundwater wells were selected, 1 in Montgomery County and 2 in Bucks county. The sites were selected using preliminary data collected in the Summer of 2016 to target wells that showed evidence of human fecal contamination and the presence of viruses. Samples were collected weekly from June-November 2017 (n=72) from these three wells. In this study, it was decided to focus on fewer wells with more frequent sampling, instead of many wells with less frequent sampling. This approached was chosen for several reasons:

1. There is evidence that microbial contamination of groundwater supplies varies over time and that at one point in time a groundwater well can be free of microbial contaminants, but at a later stage during the same year, the same well can test positive for microbial indicator organisms. For example, in a study in New Jersey, (Atherholt et al., 2015) reported that in bedrock, 21%, 33% and 43% of wells tested once, twice or three times in

a 1 year period were positive for total coliforms. This was consistent with findings from preliminary work conducted by the PI in Pennsylvania in the summer of 2016.

2. To date, there are no published studies on the weekly variability of microbial indicator organisms and pathogens in groundwater supplies. More frequent sampling will help us begin to understand the temporal variability of microbial quality of groundwater supplies and whether a temporal shift exists between the detection of microbial indicator organisms and human pathogens. Preliminary data collected by the PI and work by Allen et al. (under review) suggest that rainfall events may contribute to the intrusion of pathogens in groundwater supplies. Preliminary work by the PI and her collaborators have shown that 10-14 days following a rainfall event, spikes in enteric viruses and fecal markers can be observed in groundwater wells, regardless of well depth. These lag times are different for enteric viruses and indicator bacteria. Since indicator bacteria are used to assess water quality, it is important to understand how these organisms, when detected, relate to the presence of pathogenic organisms in groundwater. It is widely recognized that total coliforms and *E.coli* do not correlate with human pathogens; however, these organisms may be predictive of future pathogenic contamination. This has yet to be established or explored rigorously in groundwater supplies. The PI believes that weekly sampling is required to understand the impact rainfall may have on microbial water quality and to draw any conclusions regarding potential temporal relationships between indicator organisms and enteric pathogens.
3. Analysis of pathogens in water supplies is extremely costly and time intensive, therefore we are limited in the number of total samples that can be analyzed with the study budget.

Sample Collection

Three private wells were selected among five wells studied in between May-August 2016. At that time, wells were selected based on the ability to collect an untreated water sample, representative of the homeowners' well. For each well studied, the following information was collected from the homeowner when available: well depth, casing length, date of construction, and estimated yield. One of the three households selected for the present study had information about their well, while the other two did not. For one of the two wells, the research team measured the well depth using established protocols. For the third well, the well access is buried in a confined space chamber and was inaccessible and therefore well depth was never measured. Data was also collected regarding the design and age of the household septic system as well as information regarding when it was last emptied. The distance from the septic tank and well was also recorded.

Samples were collected in accordance with USEPA Standard Operating Procedure for Groundwater Sampling (USEPA, 2013). In the event that the clearance under the tap was insufficient for sample collection, sterile inert tubing was connected to the tap to facilitate sample collection. Prior to sample collection, water was purged for 15 minutes to ensure that no standing water is present in the plumbing. A water sample was analyzed at the time of sample collection for pH, conductivity, turbidity, temperature, and dissolved oxygen.

All samples were collected directly from an outdoor tap (where possible) into pre-rinsed sample bottles according to USEPA Methods and Standard Methods for the Examination of Water and Wastewater (APHA, 2012). Samples were stored on ice and delivered directly to the Water , Health and Applied Microbiology Lab (WHAM Lab) in the College of Public Health at Temple

University for analysis. Samples were collected for general water quality analysis and for the analysis of *E. coli* and total coliforms using culture-based techniques. At the time of sampling, large volumes (~800L) of water were filtered using dead-end ultrafiltration (Mull & Hill, 2012). Ultrafilters were stored on ice and refrigerated for no more than 48 hours before they were eluted and concentrated at Temple University following the established methods. Concentrated samples were frozen at -80°C until they were shipped on dry ice overnight to the USDA-USGS laboratory in Marshfield, Wisconsin to be analyzed using RT-qPCR for the following targets: human *Bacteroides*, human polyomavirus, pepper mild mottle virus, *Campylobacter jejuni, Salmonella, eneterohemorrhagic E.coli, norovirus GI & GII, adenovirus, and enterovirus.*

<u>Dye tracer studies</u>

Dye tracer studies using fluorescein dye were conducted at 2/3 households during the study period to investigate potential subsurface connections from the household septic system to their household well. Following methods outlined by *(*Borchardt *et al.*, 2011), fluorescein dye was poured down the household toilet and then the water in the well water monitored for fluorescence using a fluorometer equipped with a data logger. One more dye tracer study at the third household is on-going (April- May 2018). The last tracer study was delayed as we had to wait for freezing temperatures to subside in the Philadelphia region before starting our last tracer study.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Preliminary Results- Microbiological water quality

Three wells were monitored weekly for 6 months (n=72). Of the samples collected, 59/72 were positive for total coliforms and 24/72 were positive for *E.coli*. Two of three wells tested positive on all sampling events for total coliforms and the third well tested positive for 11/24 samples. All wells tested positive for human sewage markers, Human *Bacteroides (13/72)* and pepper mild mottle virus (5/72). All wells were positive on multiple occasions for human *Bacteroides* and on at least one occasion for the pepper mild mottle virus. This evidence suggests that human sewage from septic systems located near the household wells are impacting groundwater supplies.

Data collection was completed in November 2017, and we received the final qPCR results from the external laboratory on April 20th, 2018, therefore data analysis is on-going. We will be looking at the temporal relationships between rainfall occurrence, and subsequent occurrence of both traditional fecal indicator organisms (*E.coli* & coliforms) as well as human sewage markers.

Preliminary Results- Dye tracer studies

We conducted two dye tracer studies at 2/3 households and the third study is on-going. The first dye tracer study was inconclusive (i.e. no dye was detected in the well water after injection in the septic system). This household well was 670 ft deep and it was unclear whether the fluorescein probe was placed at an appropriate depth to be able to detect any dye. Following this tracer test, we modified our monitoring system and built a continuous monitoring device that would allow us to better monitor the well water for fluorescence using water from the outside tap (see images below). We subsequently used our modified monitoring device to conduct the second dye tracer study. In this study, fluorescein dye was found leaking out of the back of the septic system into a local creek after approximately 3 weeks. It was subsequently found in the homeowners' groundwater after approximately 4 weeks. This tracer study confirmed that the household's septic system was the source of human contamination in their household well. The third dye tracer study is on-going and we are also repeating the inconclusive tracer study that was done at the first household using our new monitoring device.

It is estimated that over 1 million private septic systems are currently operating in the commonwealth of Pennsylvania and serving over 3.5 million people. This research draws attention to the current construction guidelines and practices for maintaining private residential septic systems and wells.

Further research is planned by the PI to identify failures in the septic system design and/or well construction as well as studies to model the transport of the sewage from septic system to groundwater well. Additionally, the PI is collaborating with Environmental Law experts to test what possible policy/ legal strategies could be used to better support homeowners in the management of their private wells and septic system.

STUDENTS & POSTDOCS SUPPORTED

Student	**Department**	**University**	**Level**
Shannon McGinnis	Epidemiology & Biostatistics	Temple University	PhD (graduate)
Alexander Cagle	Earth and Environmental Studies	Temple University	Undergraduate
Madison Heaton	Biology	Temple University	Undergraduate
Jessica Serpe	Earth and Environmental Studies	Temple University	Undergraduate
Erin Huder	Epidemiology & Biostatistics	Temple University	Undergraduate
Kodi Lawrence	Environmental Engineering	Temple University	Undergraduate
Aurora Trainor	Epidemiology & Biostatistics	Temple University	Undergraduate

PUBLICATIONS

1. Murphy, Heather M. ; Jingwei, Wu; Ryan, Blunt; Alexander, Cagle; Shannon, McGinnis; Donna, Denno; Susan, Spencer; Joel, Stokdyk; Aaron, Firnstahl; Mark A, Borchardt. 2018. Are septic systems the source of enteric pathogens in private wells in rural PA? *Under preparation-to be submitted to Groundwater in July 2018*

2. Murphy, Heather M.; Alexander, Cagle; Shannon McGinnis; Jessica Serpe; Kodi Lawrence; Laura Toran; Heather M. Murphy. 2018. *Under preparation*

*** Awaiting final data from dye tracer study to finalize the publications and data analysis*

INFORMATION TRANSFER ACTIVITIES

Oral Presentations:

Murphy, Heather M.;Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt; 2017. *Could Septic Systems be the Source of Human Fecal Markers in Private Wells in Rural Pennsylvania?* Pennsylvania Groundwater Symposium-Penn State University.

Murphy, Heather M.; Jingwei Wu; Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt. 2017. *The impact of septic systems and rainfall events on groundwater quality in private wells in rural Pennsylvania, USA*- University of North Carolina Water and Health Conference, Chapel Hill, North Carolina.

Murphy, Heather M; Ryan Blunt; Alexander Cagle; Jingwei Wu; Shannon McGinnis; Donna M. Denno; Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt. 2018. *The impact of rainfall accumulation on the leaching of septic systems into groundwater supplies in rural Pennsylvania*, Pennsylvania Groundwater Symposium-Penn State University.**Accepted for an oral presentation, however had to decline because of a travel conflict.

Cagle, Alexander; Shannon McGinnis; Jessica Serpe; Kodi Lawrence; Laura Toran; Heather M. Murphy. 2018. *Dye Tracer Study in Rural Pennsylvania- Confirmation that household septic system is impacting homeowner's groundwater and local surface water bodies.* Global Water Alliance Annual Conference 2018, Villanova University, Pennsylvania.

Poster Presentations

Cagle, Alexander; Jingwei Wu; Ryan Blunt; Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt; Heather M. Murphy. 2018. *Are septic systems the source of human fecal contamination in private wells in rural Pennsylvania?* Global Water Alliance Annual Conference 2018, Villanova University, Pennsylvania.

Murphy, Heather M.; Jingwei Wu; Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt. 2017. *Could septic systems be the source of human fecal markers in private wells in rural Pennsylvania, USA.* University of North Carolina Water Microbiology Conference/ International Water Association (IWA)- Health Related Water Microbiology Conference- Chapel Hill, North Carolina.

Cagle, Alexander; Jingwei Wu; Ryan Blunt; Susan Spencer; Aaron Firnstahl; Joel Stokdyk; Mark Borchardt; Heather M. Murphy. 2017. *Are septic systems the source of human fecal contamination in private wells in rural Pennsylvania?* Temple University College of Public Health Research Day.

DATA AVAILALBILTY

All the data generated from this study will be made publicly accessible through publishing in refereed academic journals. Raw data not included in the manuscript will be included in Supplementary Contents that will be published online.

AWARDS & ACHEIVEMENTS

Alexander Cagle- Accepted to do a PhD at Clemson University
Jessica Serpe- Temple University Merit Scholar
Kodi Lawrence- Temple University Merit Scholar
Aurora Trainor- Temple University Merit Scholar
Madison- Temple University Merit Scholar
Alexander Cagle- Temple University Merit Scholar

ADDITIONAL FUNDING ACQUIRED USING THE USGS GRANT AS SEED MONEY

The data generated in this USGS funded grant will be used as pilot data for a National Science Foundation (NSF) submission in late 2018. In addition, this data is being included in an NIH R34 grant re-submission to the National Institute of Infectious Diseases and Asthma (NIAID) in May 2018. This NIH grant received favorable scores in the last round and the PI is hopeful that it may be funded after this next submission with the inclusion of the pilot data generated from these USGS funds.

PHOTOS OF PROJECT

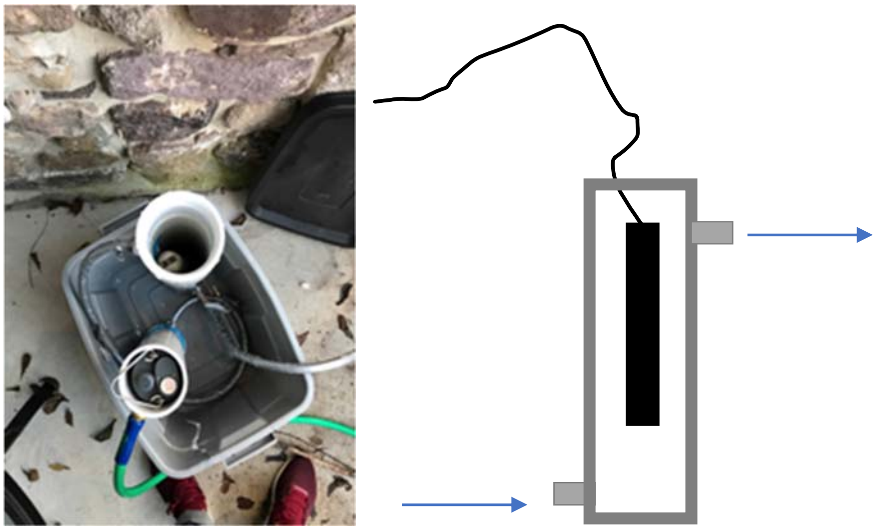


Figure 1. Online fluorescein/ conductivity monitoring device

Figure 2. Fluorescein dye detected at end of septic system leach-field and water sample collected downstream from creek

Impacts of Shale Gas Produced Water on Disinfection Byproduct Formation in Water Utilities

Basic Information

Title:	Impacts of Shale Gas Produced Water on Disinfection Byproduct Formation in Water Utilities
Project Number:	2017PA232B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	11
Research Category:	Water Quality
Focus Categories:	Toxic Substances, Treatment, Water Quality
Descriptors:	None
Principal Investigators:	Yuefeng Xie

Publications

There are no publications.

PROJECT REPORT
Pennsylvania Water Resources Research Center

PROJECT TITLE & PRINCIPAL INVESTIGATOR(S)

Impacts of Shale Gas Produced Water on Water Utilities: Disinfection Byproduct Formation

Principle Investigator: Yuefeng Xie
Co-Investigator: Hao Tang, Department of Chemistry, Indiana University of Pennsylvania

SHORT ONE-SENTENCE SOUND BYTE OF THE PROJECT OR FINDINGS

This research showed that shale gas extraction wastewater contributed to disinfection byproduct formation upon chlorination.

PROBLEM and RESEARCH OBJECTIVES

Disposal of high-salinity shale gas produced water is a major challenge where underground injection is not available or restricted in some regions of Pennsylvania. Illegal disposal, inadequate treatment, and leaks of such water to environment pose human health risks. As the concerns regarding the quality of drinking water sources influenced by shale gas explorations due to contamination of halides, metal ions, and radioactivity are growing, it is important to explore such burden on downstream utilities exerted by the produced water. With respect to the compliance with the Disinfectants and Disinfection Byproduct (DBP) Rule promulgated by U.S. Environmental Protection Agency (EPA), we conducted an investigation into impacts of shale gas produced water on DBP formation from a non-bromide perspective. Specifically, because metal ions are usually found at high levels in produced water, our focus was to evaluate the influence of metal ions and anions in produced water on the formation and speciation of DBPs in both real and surrogate waters.

METHODOLOGY

Real water samples were collected from the Swatara Creek, Susquehanna River, Middletown Reservoir, and a domestic wastewater treatment plant in Middletown, Pennsylvania. Surrogate stock solutions were prepared by citric acid and humic acid anhydrous sodium. Working surrogate solutions were prepared by diluting the stock solutions to maintain a total organic carbon (TOC) level of 3 mg/L. Since studies have suggested that organic compounds in produced water were insignificant for DBP formation after discharged into surface water (Parker et al., 2014), synthesized produced water was used in this research based on water quality parameters obtained from Warner et al. (2013). The produced wastewater was debrominated by continuous ozonation using a Triogen LAB 2B Ozone Generator at room temperature (21 °C). The color change from colorless to faint yellow suggested bromide was converted into bromine. Air was purged through the ozonated solution to strip off excess bromine. Individual metal ion stock solutions were prepared with Ca^{2+}, Mg^{2+}, and Ba^{2+} in forms of nitrate salts at the same concentrations as they appeared in produced water.

Prior to chlorination, water samples were buffered at pH 8 with 2 mL/L borate buffer (1.0 M boric acid and 0.26 M sodium hydroxide, pH = 8) (Zhao et al., 2016). Produced water and debrominated produced water were added into various water samples with a spiking percentage of 0, 0.005%, 0.01%, 0.05%, or 0.1% by volume. Each sample was chlorinated at a free chlorine dose of 12 mg/L by applying hypochlorite stock solution. The stock solution was standardized by DPD Colorimetric Method with a HACH DR/890 Colorimeter (Loveland, CO, USA) each time before use (Baird et al., 2017). Chlorinated samples were then incubated in absence of light at room temperature (21 °C). After 24 hours, water samples were measured for both pH and free chlorine residual. Excess particulate sodium sulfite was applied as a chlorine quenching agent for chloral hydrate analyses while granular ammonium chloride was used for all other DBPs. Samples were extracted immediately after dechlorination following EPA Methods 551.1 and 552.3.

PRINCIPAL FINDINGS AND SIGNIFICANCE

After investigating the effects of produced water, with bromide and non-bromide species, on the formation of DBPs when spiked into surface waters at different percentages, our results showed that the introduction of debrominated produced water led to increased formation of chlorinated DBP species in select surface water and wastewater. As the spiking percentage of debrominated produced water increased, the chlorinated DBP species increased. Substantial increase of chloroform (920%), DCAA (830%), and chloral hydrate (3,600%) were observed at spiking percentage of 0.03% when using citric acid as an organic precursor. The contributions of individual cations to DBP formation followed a sequence of magnesium > calcium > barium at high spiking percentage due to the different catalytic effects of their chelates with organic precursors. The study of anions suggested that the discharge of treated produced water containing elevated sulfate may further enhance DBP formation as a result of its higher ionic strength. The significance of this study lies in the fact that in addition to bromide concerns from produced water, non-bromide species also contributed to DBP formation. The gas produced water management decision should consider the negative impacts from both bromide and non-bromide species to better protect the receiving water resources. Considering the commercial wastewater treatment plants are deficient in removing bromide and those non-bromide species, the research will improve our understanding of the produced water management and help incentivize treatment of produced water to a quality of discharge or external reuse, especially in areas with limited access to disposal wells and/or local water scarcity. In addition to water utilities, the results of the study will assist shale gas producers in better managing their wastewater as well.

STUDENTS & POSTDOCS SUPPORTED (of all who worked with at least partial support from the project, using this format: Student Name, Department Name, University Name, (undergraduate, graduate, or post-doc)

Kodi Webb, Environmental Pollution Control Program, Penn State Harrisburg, Graduate Student
Kuan Huang, Environmental Engineering Program, Penn State Harrisburg, Graduate Student
Linlin Tang, Environmental Pollution Control Program, Penn State Harrisburg, Graduate Student

PUBLICATIONS (follow style formats on the next page)

Kuan Huang, Hao Tang, Yuefeng Xie, 2018, Impacts of shale gas production wastewater on disinfection byproduct formation: an investigation from a non-bromide perspective, *Water Research* (Submitted, see attached manuscript)

Huang, Kuan, 2018, Impacts of shale gas production wastewater on disinfection byproduct formation, MS Dissertation, Environmental Engineering Program, Penn State Harrisburg, Harrisburg, Pennsylvania (see attached MS thesis)

INFORMATION TRANSFER ACTIVITIES (e.g., presentations, seminar series, videos, etc.)

Yuefeng Xie, "Impacts of natural gas production wastewater on drinking water supply", Chemistry Seminar, Indiana University of Pennsylvania, October 4, 2017.

Kuan Huang, "Impacts of shale gas production wastewater on disinfection byproduct formation: an investigation from a non-bromide perspective", Graduate Exhibition, Penn State University, March 25, 2018.

Kuan Huang, "Impacts of shale gas production wastewater on disinfection byproduct formation: an investigation from a non-bromide perspective" (Poster presentation), 13th Annual Student Research Symposium at Penn State Harrisburg, April 18, 2018.

Kuan Huang, "Impacts of shale gas production wastewater on disinfection byproduct formation: an investigation from a non-bromide perspective" (Oral presentation), 13th Annual Student Research Symposium at Penn State Harrisburg, April 19, 2018.

Yuefeng Xie, Kuan Huang, Linlin Tang, and Hao Tang, "Impact assessment and control of natural gas production wastewater on disinfection byproduct formation" (Invited Plenary Speech), The 2nd IWA Disinfection and Disinfection By-Products Conference, Beijing, May 14-18, 2018.

DATA AVAILALBILTY
Your plans for making all data from the project publicly accessible

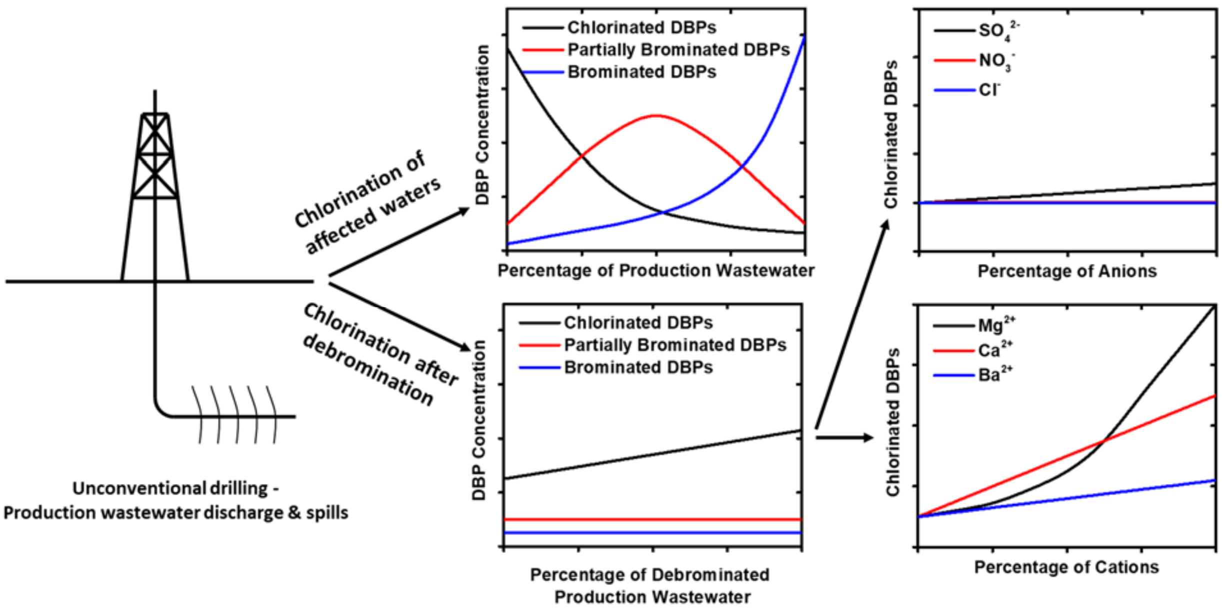
Data from the project will be publicly accessible via the supplemental information in the paper that is currently being reviewed by *Water Research*.

AWARDS & ACHEIVEMENTS (of PIs, students, or staff on the project)

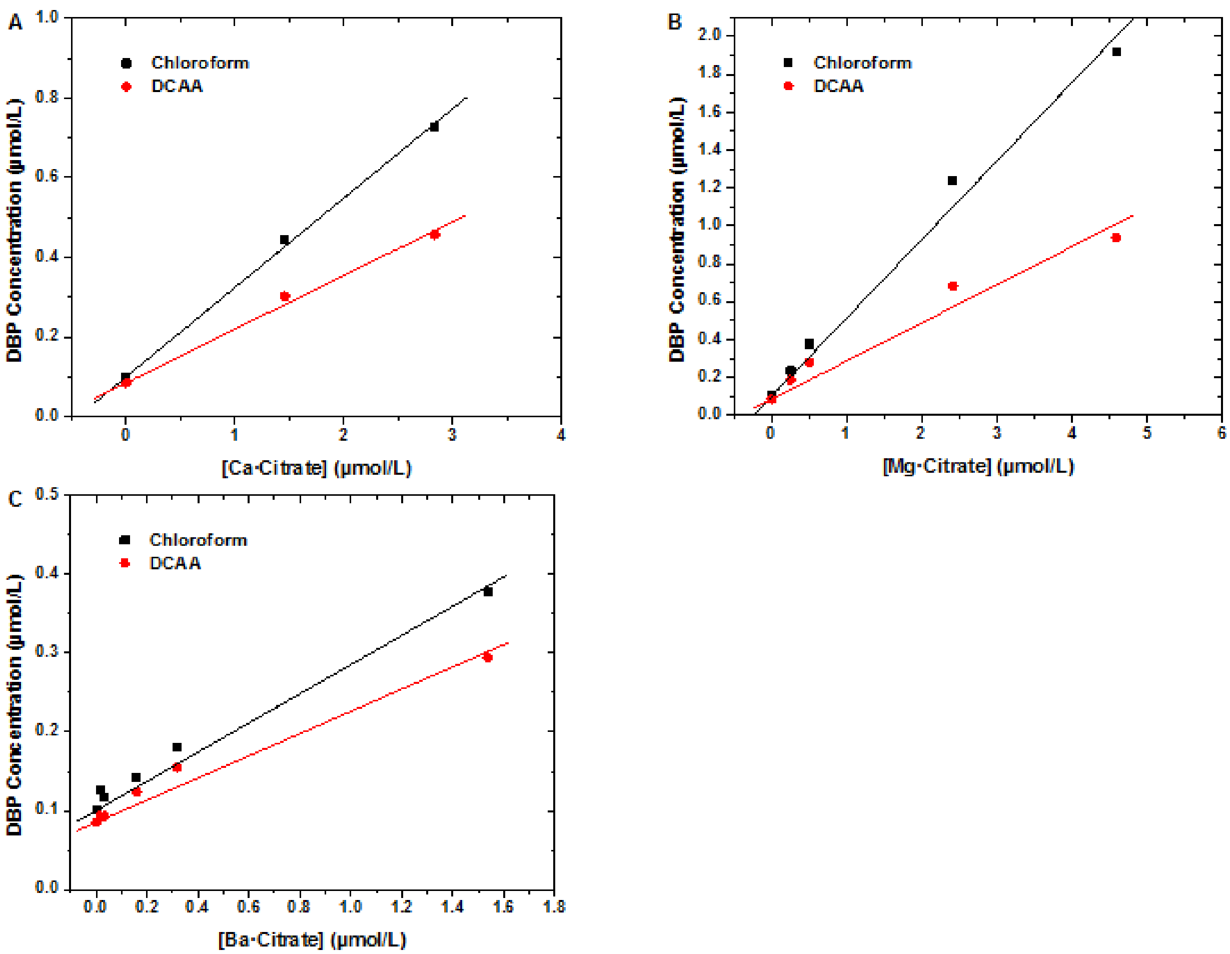
Kuan Huang, The first place at the Penn State Harrisburg Information Literacy Awards, April 2018.

PHOTOS OF PROJECT

Please include 2 graphics or photos with captions, if possible. These may be used in our annual report, web page, and/or brochure, and may be used by the National Institutes of Water Resources.



Chlorination of water under the influence of produced water leads to the formation of various disinfection byproducts, the amounts of which are affected by both bromide and non-bromide species, especially the metal ions.



Metal ions impact DBP formation through the formation of chelates

Impact of Spreading Oil & Gas Wastewater as Road Treatments on Water Quality

Basic Information

Title:	Impact of Spreading Oil & Gas Wastewater as Road Treatments on Water Quality
Project Number:	2017PA233B
Start Date:	3/1/2017
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	5
Research Category:	Water Quality
Focus Categories:	Water Quality, Law, Institutions, and Policy, None
Descriptors:	None
Principal Investigators:	William Burgos

Publications

There are no publications.

PROJECT REPORT
Pennsylvania Water Resources Research Center

PROJECT TITLE & PRINCIPAL INVESTIGATOR(S)

Impact of Spreading Oil & Gas Wastewater as Road Treatments on Groundwater Quality

William Burgos, Professor of Environmental Engineering, Department of Civil and Environmental Engineering, The Pennsylvania State University, 212 Sackett Building, University Park, PA 16802, wdb3@psu.edu, phone: (814)-863-0578.

Lara Fowler, Senior Lecturer, Penn State Law, Assistant Director for Outreach and Engagement, Institutes of Energy and the Environment, The Pennsylvania State University, University Park, PA 16802, lbf10@psu.edu, phone: (814) 865-4806.

SHORT ONE-SENTENCE SOUND BYTE OF THE PROJECT OR FINDINGS

This research showed that O&G wastewaters spread on roads in the northwestern Pennsylvania have salt, radioactivity, and organic contaminant concentrations often 100's to 1000's times above drinking water standards.

PROBLEM and RESEARCH OBJECTIVES

Throughout the U.S., road managers work to alleviate adverse effects caused by dust from gravel roads by spreading dust suppressants. Spreading conventional oil and gas (O&G) wastewaters to treat roads is common in Pennsylvania, particularly in northwestern PA. There are concerns with spreading O&G wastewaters on roads. Wastewater contaminants may threaten environmental and public health by leaching into surface or ground water, accumulating around roads, modifying adjacent soil chemistry, or migrating in air and dust.

The objectives of this research were to: 1) identify states that spread O&G wastewater on roads, and then review their associated regulations, 2) document the spatial and temporal trends of spreading O&G wastewater on roads in Pennsylvania as a demonstrative case study, 3) determine the chemical characteristics of O&G wastewater spread on roads, 4) evaluate the mobility of O&G wastewater contaminants after road application and rainwater leaching, and 5) measure the human toxicity potential of O&G wastewaters used on roads.

METHODOLOGY

Regulatory review and data collection. Road spreading and beneficial reuse regulations for all 50 states were reviewed by using the LexisNexis law database and contacting O&G state regulators throughout the United States. Wastewater volumes applied to roads were determined by reviewing data on the PA DEP O&G reporting website or digitizing monthly spreading reports collected from Pennsylvania through public records requests. Certificate of analyses for wastewaters applied to roads in New York and Pennsylvania were also collected from public records requests.

Inorganic analyses of O&G wastewaters spread on roads in Pennsylvania. O&G wastewaters were collected in 10 L high density polypropylene containers from storage tanks in 14 townships throughout northwestern, PA that were to be spread on roads in the summer 2017. Elemental analyses of wastewaters were performed on a Thermo Scientific iCAP 6000 inductively coupled plasma optical emission spectrophotometer (ICP-OES) for Na, Ca, Mg, Sr, and K, Thermo X-Series 2 mass spectrophotometer (ICP-MS) for Ba, Fe, Pb, Cd, Cr, Cu, and As, and Dionex ICS-1100 ion chromatography (IC) with an AS18 column for Cl and Br at the Pennsylvania State University. Before elemental analyses, samples were filtered (0.45 µm) and diluted in 2% nitric acid or 18MΩ ultrapure water (Thermo Scientific Barnstead Nanopure) to reach a dilution factor of 2000 for Na, Ca, Mg, Sr, and K, 100 for Cl, Br, and SO_4, or 50 for all other metals. Radioactivity was measured on a small anode germanium detector (Canberra Instruments).

Organic analysis of O&G wastewaters used on roads. Organic compounds were extracted from O&G wastewater samples using dichloromethane (DCM) per pH adjustment to pH<2 with H_2SO_4 and pH>10 with NaOH (EPA method 3510C: Separatory Funnel Liquid-Liquid extraction). Extracts were analyzed for diesel and gas range organics using comprehensive two-dimensional gas chromatography coupled to a time-of-flight mass spectrometer (LECO Pegasus 4D GCxGC-TOFMS).

Evaluating contaminant leachability after spreading O&G wastewaters on roads. Laboratory experiments were conducted to determine the mobility of contaminants in O&G wastewaters applied to road materials. O&G wastewater was applied to road aggregate collected from Erie County, PA based on its measured water retention capacity (0.2 mL/gram). Four O&G wastewaters were applied to the sieved road aggregate, dried (50ºC), and leached with synthetic rainwater (pH=4.2) for 18 hours according to the EPA synthetic precipitation leaching procedure (SW-846 Test Method 1312). Experiments were run in duplicate and leachates were tested for Cl, Br, Na, Mg, Ca, Sr, Fe, and Pb according to the analytical methods above. A modified leaching method was used to test the mobility of radium and organics after treating road aggregate with O&G wastewaters. Higher application volumes (0.9 mL/gram) were applied to aggregate and smaller volumes of synthetic water were used to increase the measurable radium and organic concentrations in solid and liquid phases.

Evaluating the potential human toxicity of O&G wastewaters spread on roads. Potential human toxicity of O&G wastewaters spread on roads was evaluated using five commercial bioassays: aryl hydrocarbon receptor (AhR), pregnane-X receptor (PXR), estrogen receptor alpha (ERα), nuclear factor erythroid 2–related factor 2 (Nrf2), and nuclear factor kappa-light-chain-enhancer of activated B cells. All bioassays were purchased from INDIGO Biosciences (State College, PA) and were used according to the manufacturer's protocols.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Spreading conventional O&G wastewaters on roads could release more radium to the environment than any other O&G wastewater disposal option. In Pennsylvania, more O&G wastewater is disposed of by wastewater treatment plants (180 million liters in 2016) than road spreading (40 million liters in 2016). However, treated effluents from these facilities contain median radium concentrations of 14.5 pCi/L, levels that are close to the national primary drinking water MCL of 5 pCi/L radium. In contrast, the O&G wastewaters spread on roads in northwest Pennsylvania had a median radium concentration of 1,230 pCi/L. In 2016, based on median radium concentrations, approximately 52 millicuries (mCi) of radium were spread on roads whereas 2.6 mCi of radium were discharged through O&G wastewater treatment facilities. Although less O&G wastewaters is spread on roads, the release of radium could be much higher than the release of radium from wastewater treatment facilities.

Most contaminants in O&G wastewater applied to roads were leached with synthetic rainwater (chloride, bromide, sodium, magnesium, calcium, and strontium). In contrast, a few contaminants were retained in the road aggregate at greater than 99% (iron and lead) after rainwater leaching. Both radium and diesel range organics (DRO) displayed intermediate behavior. The majority of DRO (>75%) applied to roads was retained after rainwater leaching. After one application of O&G wastewater to road aggregate, 50% of was retained. After multiple applications of O&G wastewater, radium retention to road aggregate plateaued and more radium leached with rainwater. Radium in O&G wastewaters will accumulate in roads following spreading events but likely at concentrations below regulatory standards.

At least 13 U.S. states allow the “beneficial use” of O&G wastes (e.g., wastewaters, sludges, oils) for road maintenance, dust suppression, or de-icing. At least six of the thirteen states with regulations for road spreading require a certificate of analysis before O&G waste is permitted for use on roads. However, there are no universal standards that limit the contaminant concentrations in O&G wastewaters applied to roads. The Pennsylvania Department of Environmental Protection (PA DEP) tracks road spreading by requiring spreaders to complete monthly reports that document O&G wastewater volumes spread on roads. Since 2008, an average of 35 million liters/year of O&G wastewater were spread on roads in 21 counties in Pennsylvania.

O&G wastewaters spread on roads in the NY and PA are chloride-rich fluids with sodium, calcium, magnesium, and strontium comprising greater than 90% of the total cation charge equivalents. Notably both the TDS and total radium concentrations are elevated compared to the 500 mg/L TDS and 5 pCi/L radium standards for drinking water, with median values over 293,000 mg/L and 1,230 pCi/L, respectively. Considering the chloride concentrations in the 14 O&G wastewaters tested and 53 certificate of analyses compiled from state records, these fluids require 730 to 1,600 times dilution to prevent drinking water quality degradation around road spreading locations.

Bioassays also indicated that these wastewaters contain organic micropollutants that could promote cancer and salts that are toxic to aquatic organisms like *Daphnia Magna*.

STUDENTS & POSTDOCS SUPPORTED (of all who worked with at least partial support from the project, using this format: Student Name, Department Name, University Name, (undergraduate, graduate, or post-doc)

Travis Tasker, Department of Civil and Environmental Engineering, Penn State University (Ph.D. student)

Kyle Ganow, Penn State Law (J.D. student)

PUBLICATIONS (follow style formats on the next page)

Tasker, T.L., W.D. Burgos, P. Piotrowski, L. Castillo-Meza, T.A. Blewett, K.B. Ganow, A. Stallworth, P.L.M. Delompré, G.G. Goss, L.B. Fowler, J.P. Vanden Heuvel, F. Dorman and N.R. Warner. 2018. Environmental and human health impacts of spreading oil and gas wastewater on roads. *Environmental Science & Technology*. Accepted April 2018.

INFORMATION TRANSFER ACTIVITIES (e.g., presentations, seminar series, videos, etc.)

Tasker, T.L., P. Piotrowski, L. Castillo, T. Blewett, T., K. Ganow, P. Delompre, P., J. Vanden Heuvel, F. Dorman, N. Warner, W.D. Burgos. Oil and gas wastewater spreading on roads and associated environmental and human health impacts. American Chemical Society National Meeting, New Orleans, LA, March 20, 2018.

Burgos, W.D. The 'Unconventional' Energy – Water Nexus: Marcellus Shale gas development in Appalachia. Weston Roundtable Series, Center for Sustainability and the Global Environment, Nelson Institute, University of Wisconsin, Madison, WI, April 26, 2018.

DATA AVAILALBILTY
Your plans for making all data from the project publicly accessible

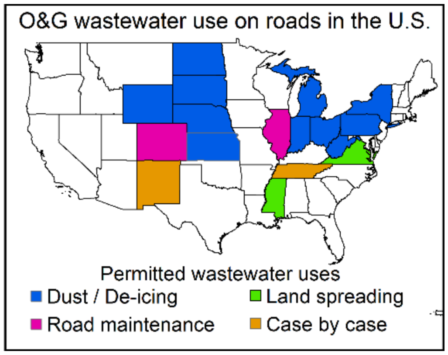
All project data will be reported in the article accepted by *Environmental Science & Technology*, and all raw data will be available in the Supporting Information published along with the article. We have requested that the publisher, American Chemical Society, provide this article as an Open Access publication.

AWARDS & ACHEIVEMENTS (of PIs, students, or staff on the project)

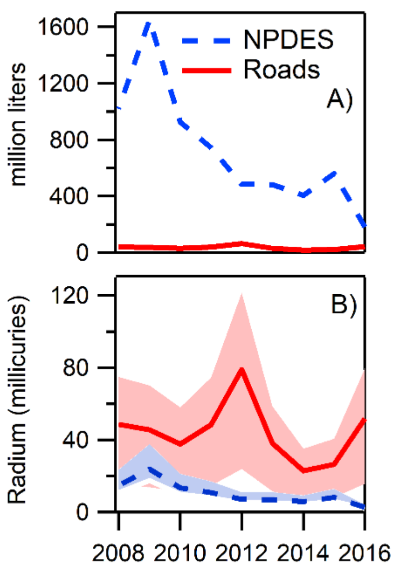
None to report.

PHOTOS OF PROJECT

Please include 2 graphics or photos with captions, if possible. These may be used in our annual report, web page, and/or brochure, and may be used by the National Institutes of Water Resources.



Caption - U.S. states with regulations for spreading oil and gas (O&G) wastewaters on roads.



Caption - A) Volumes of O&G wastewater spread on roads or discharged through wastewater treatment plants with NPDES permits in Pennsylvania. B) Annual radium loads to the environment based on radium effluent concentrations reported for O&G wastewater treatment facilities and radium concentrations in 14 O&G wastewaters spread on Pennsylvania roads in 2017 (this study). Blue and red shaded regions represent loads based on the 25th – 75th percentile radium concentrations. Solid and dotted lines represent median loads.

Information Transfer Program Introduction

None.

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	0	6
Masters	4	0	0	0	4
Ph.D.	6	0	0	0	6
Post-Doc.	0	0	0	0	0
Total	16	0	0	0	16

Notable Awards and Achievements