MA Water Resources Research Center

Annual Report 2015-2016

March 1, 2015 – June 30, 2016

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Acid Rain sampling Photo by MF Hatte

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Executive Summary

During the Fiscal Year 2016, the Massachusetts Water Resources Research Center, with its staff of 3 FTE, managed a $742,270 budget covering 16 projects.

The USGS 104b program funded four new research projects. These four projects cover timely issues in water resources research as follows:

- "**Microbial attenuation of non-point source pharmaceutical and personal care products pollution from antiquated septic systems in coasts communities**" led by Dr. Caitlyn Butler of UMass Amherst to determine the fate and transport of pharmaceuticals and personal care products (PPCPs) in septic system drainage soils and assess the impact of those PPCPs on the soils' microbial communities. The research helped determine treatment effectiveness and has the potential to identify chemical "effectiveness" markers for evaluating on-site septic systems across the county.
- "**Enhancing the flux of ultrafiltration membranes using nanofibers**" headed by Dr. Jessica Schiffman at UMass Amherst to establish a "greener" antifouling strategy to control biofilms on high flux ultrafiltration membranes used to remove pollutants from wastewater. UF membranes functionalized with nanofibers hold potential to broadly impact water quality by offering a scalable system of providing longer-lasting high-quality water to local municipals and underdeveloped communities.
- Dr. Pia Moisander at UMass Dartmouth led a project entitled "**Influence of nutrients on Microcystis blooms in the Charles River watershed"** to investigate the importance of major nutrients on toxic cyanobacteria formation, in order to guide nutrient management for harmful algal bloom mitigation.
- Finally, Dr. Chul Park at UMass Amherst led the project "**Removal of water-borne pathogens and heavy metals using novel biogranules**" to elucidate heavy metal removal and pathogen inactivation by algal biogranules in wastewater treatment. The research developed a method that will permit simple but robust treatment processes for both which can be easily adopted for not only municipal wastewater treatment but various types of agriculture wastewater treatment on site.

The four following projects were extended from FY14:

- Natural Resources Conservation Research Assistant Professor and Massachusetts Cooperative Fish and Wildlife Research Assistant Unit Leader Allison Roy led "**Investigating effects of annual winter lake drawdowns on fish and macroinvertebrate assemblages and diet**" at UMass Amherst.
- Harvard University Environmental Engineering Associate Professor Chad Vecitis researched the "**Fate, transport, and remediation of PFOS, PFOA, perchlorate, and 1,4-dioxane at the Eastham MA landfill**."
- Assistant Professor Anita Milman of UMass Amherst Natural Resources Conservation finished a study called "**Going with or against the flow: Choices for flood mitigation response in Massachusetts**."
- Worcester Polytechnic Institute Civil and Environmental Engineering Associate Professor Paul Mathisen worked on "**Assessing the effectiveness of a biofiltration facility and associated groundwater flow in protecting water quality of a water supply reservoir**."

The 104B Program also supported two Information Transfer projects:

- Working with Drs. Anita Milman and Eve Vogel of UMass Amherst Environmental Conservation and Geosciences, respectively, we organized a workshop on **Water, Society, and Politics**; and following last year's very successful **Northeast Water Engineering and Science Symposium,** we again assisted Dr. David Reckhow of UMass Amherst Civil and Environmental Engineering and a steering committee composed of his graduate students to organize this undergraduate and graduate student conference.
- Jerry Schoen of UMass Amherst Water Resources Research Center led the effort to bring back online and update the **Massachusetts Water Watch Partnership web site**, a valuable source of information for nonprofit organizations, environmental agencies, schools and others practicing or working with citizen science programs to monitor water resources.

The IWR – funded project "RiverSmart Communities and Federal Collaborators: "**Attuning Federal Agencies and Programs with the State, Regional, and Local Efforts to Support Ecologically Restorative Flood Prevention and Remediation in New England**" continued under PI Eve Vogel of UMass Amherst Geosciences.

The *Acid Rain Monitoring project*, led by WRRC Associate Director Marie-Françoise Hatte, was continued for another year in order to document trends in surface water acidification in Massachusetts.

The *Blackstone River Water Quality Modeling* project, led by WRRC Director Paula Rees, continued to track river quality in the Blackstone River and study the impacts of the City of Worcester's wastewater treatment plant on the river.

The *Flood Vulnerability Assessment for Roadway Stream Crossing Structures, Deerfield River Watershed, Massachusetts*, led by WRRC Director Paula Rees, started to develop risk-based and data driven protocols for assessing the present and future extreme flood vulnerability of roadway crossing structures within the Deerfield River Watershed.

WRRC staff also participate actively in two projects on campus: *The Stream Continuity Project*, headed by Scott Jackson of Environmental Conservation to inventory fish and wildlife barriers caused by road crossings; and the *RiverSmart Communities Project* headed by Dr. Christine Hatch and Dr. Eve Vogel of Geosciences, to help New England communities manage rivers and riverside landscapes, as well as our own actions and expectations, so people and communities become more resilient to river floods.

This year's projects supported 29 students: seven students pursued a PhD degree, six were working toward a Master of Science, and sixteen were undergraduate students.

Introduction

This report covers the period March 1, 2015 to June 30, 2016[1], the 51st year of the Massachusetts Water Resources Research Center (WRRC). The Center is under the direction of Dr. Paula Rees, who holds a joint appointment as Director of the WRRC within the College of Natural Sciences and as Director of Diversity Programs within the College of Engineering at the University of Massachusetts Amherst.

The USGS 104B Program Water Resources Institutes supported 4 new research projects:

"**Microbial attenuation of non-point source pharmaceutical and personal care products pollution from antiquated septic systems in coasts communities**" led by Dr. Caitlyn Butler of UMass Amherst; "**Enhancing the flux of ultrafiltration membranes using nanofibers**" headed by Dr. Jessica Schiffman at UMass Amherst; "**Influence of nutrients on Microcystis blooms in the Charles River watershed"** led by Dr. Pia Moisander at UMass Dartmouth; and "**Removal of water-borne pathogens and heavy metals using novel biogranules** led by Dr. Chul Park at UMass Amherst.

The following four projects, awarded 104B grants last year, were extended and finished this fiscal year: "**Going with or against the flow: Choices for flood mitigation response in Massachusetts**" led by Dr. Anita Milman of UMass Amherst; "**Assessing the effectiveness of a biofiltration facility and associated groundwater flow in protecting water quality of a water supply reservoir**" headed by Dr. Paul Mathisen at Worcester Polytechnic Institute; Dr. Allison Roy at UMass Amherst led a project entitled "**Investigating effects of annual winter lake drawdowns on fish and macroinvertebrate assemblages and diet**," and Dr. Chad Vecitis at Harvard University led the project "**Fate, transport, and remediation of PFOS, PFOA, perchlorate, and 1,4-dioxane at the Eastham MA landfill**."

The 104B Program also supported two Technology Transfer project:
For our Workshops project, we worked with Drs. Anita Milman and Eve Vogel of UMass Amherst Environmental Conservation and Geosciences, respectively to organize a **workshop on Water, Society, and Politics**; and following last year's very successful **Northeast Water Engineering and Science Symposium**, we again assisted Dr. David Reckhow of UMass Amherst Civil and Environmental Engineering and a steering committee composed of his graduate students to organize this undergraduate and graduate student conference.

Jerry Schoen of UMass Amherst Water Resources Research Center led the effort to bring back online and update the Massachusetts Water Watch Partnership web site, a valuable source of information for nonprofit organizations, environmental agencies, schools and others practicing or working with citizen science programs to monitor water resources.

The Institutes for Water Resources funded a final year of the project "RiverSmart Communities and Federal Collaborators: Attuning Federal Agencies and Programs with the State, Regional, and local Efforts to Support Ecologically Restorative Flood Prevention and Remediation in New England" led by Eve Vogel of UMass Amherst.

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[1] The USGS reporting year covers March 1 to February 28, while the University of Massachusetts and the Commonwealth of Massachusetts fiscal years run from July 1 to June 30. Projects funded by the State are reported for the period July 1 2015 - June 30, 2016.

The *Acid Rain Monitoring Project*, led by WRRC Associate Director Marie-Françoise Hatte, was continued for another year in order to document trends in surface water acidification. The *Blackstone River Water Quality Modeling* project also continued.

Other projects WRRC contributes to include the continued collaboration with UMass Extension on the *Stream Continuity Project*, led by Scott Jackson of Environmental Conservation, as well as *RiverSmart Communities* and *Farms, Floods, and Fluvial Geomorphology* led by Christine Hatch of Geosciences.

Progress results for each project are summarized for the reporting year in the following sections.

Research Program

This year's research included four new projects, focusing on fate and transport of pharmaceuticals and personal care products on septic systems; wastewater pollution removal, and toxic algal blooms. Projects that continued from last year covered the effects of lake drawdowns on fish and macroinvertebrates assemblages, fate and transport of groundwater contaminants, flood mitigation, and biofiltration treatment of groundwater.

1. Investigating effects of annual winter lake drawdowns on fish and macroinvertebrate assemblages and diet (2014MA421B)

Principal Investigators: Allison Hunt Roy and Stephen DeStefano, UMass Amherst Environmental Conservation
Start Date: 3/1/2014
End Date: 2/29/2016
Funding Source: USGS (104B)
Reporting Period: March 1, 2015 – February 29, 2016
Research Category: Biological Sciences

Problem and Research Objectives:
Annual wintertime water level drawdowns are a common management practice in lakes, ponds, and reservoirs in the Northeastern US. In Massachusetts, at least 100 waterbodies undergo or have used annual winter drawdowns for a variety of purposes, including: control of nuisance aquatic vegetation, maintenance and protection of structures (e.g., docks, retaining walls, impoundments), hydroelectric power, and spring flood storage. Despite the widespread use of annual winter drawdowns, waterbody water levels are rarely monitored. Furthermore, our understanding of the effects of winter drawdowns on littoral and benthic zone ecology is limited especially in Massachusetts where drawdown amplitudes are relatively mild (<3m) compared to other locations (e.g., Canada, Scandinavia) where amplitudes can exceed 10m and have attracted more scientific investigation. Our objectives are to: (1) quantify the intra-annual water level fluctuations of winter drawdown and non-drawdown waterbodies along a gradient of historical drawdown amplitude, (2) quantify littoral zone habitat structure, (3) determine the benthic invertebrate assemblage composition in multiple habitats in these waterbodies, (4) and quantify diet niche breadth of common fish species using stable isotopes and gut content analysis.

Methodology:
Objective 1
We installed non-vented pressure transducer loggers at 16 lakes in 2014 and 5 lakes in 2015. The loggers were set to continuously record water level and water temperature every 2 hours for 3-5 years. We

calculated hydrologic metrics that represent magnitude, duration, timing, and rate of change for the drawdown and refill in each lake. Lakes were surveyed for bathymetry in 2015, and this was used to calculate maximum extent of lake bed exposure and water volume loss during drawdown.

Objective 2

In July and August of 2014 we sampled physical habitat in 16 lakes that encompassed a gradient of drawdown amplitude (0–2.5 m). Of these 16 lakes, three served as reference conditions with no history of annual winter drawdowns. Within each lake, we established two, 20-m sites with 50-m buffers of similar land cover representing a developed and forested shoreline condition. At each site we sampled large wood (density, branching complexity, diameter), macrophytes (e.g., cover, biovolume, complexity, stem abundance, biomass), and substrate texture (substrate heterogeneity, leaf litter cover) using a quadrat-transect method at three fixed depths (0.5m, 1m, 2m).

O*bjective 3*

We sampled macroinvertebrate composition in 11 lakes in 2015 (3 more will be added in 2016). The lakes represent three drawdown amplitude classes: 1) deep drawdown (1.5–2m), 2) shallow drawdown (<1m), and 3) no drawdown. We collected macroinvertebrates in three habitats: stony bottom, macrophyte bed, and soft bottom (i.e., predominantly silt and detritus) at 5 locations within the lake. Macroinvertebrates were preserved in ethanol and brought back to the lab for sorting and identification.

Objective 4

We sampled 11 lakes in 2015 (3 more will be added in 2016) to characterize fish diets and food webs using stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) and gut content analysis. We selected 5 fish species that consume littoral zone invertebrates and are found in different positions in the food web: chain pickerel, largemouth bass, pumpkinseed, yellow perch, and bridle shiner. Fishes were collected using a boat electroshocker, minnow traps, and beach seines. We aimed to collect 15 individuals within each size class per species per lake. We also collected dominant littoral macroinvertebrates to characterize the macroinvertebrate isotopes and long-lived primary consumers (e.g., mussels and snails) to serve as the algal baselines in each lake. All organisms were frozen and brought back to the lab for processing. In the lab, fish muscle tissue, macroinvertebrates sorted by family and functional group, and mussel and snail tissue were dried, ground, and shipped to the University of California Davis for analysis in a continuous flow isotope ratio mass spectrometer.

Principal Findings and Significance:

With respect to Objective 1, we found that winter drawdowns result in much different hydrology than natural water level fluctuations. For the 11 drawdown lakes, there was a range in magnitude (0.31–1.51 m), rate of drawdown (0.009–0.107 m/day), and rate of refill (0.005–0.122 m/day) for winter 2014-15. The magnitude of drawdown translates to different shoreline exposure depending on the bathymetry of the lake. It is likely that the rapid rates of drawdown do not allow slow-moving taxa such as mussels to relocate, and we have initial evidence that mussels have been extirpated from exposed areas. Most of the drawdowns in the study began before Nov 1st and did not return to full pool level by April 1st, as recommended by the Generic Environmental Impact Report. The timing of reduction and refill relative to spawning or other critical life stages may lead to population and ecosystem-level changes.

For Objective 2, we found that winter drawdowns and localized shoreline development significantly alter littoral zone habitat particularly at 0.5m and 1m depths, which are closer to shore and exposed during winter drawdowns. Our preliminary results indicate that macrophyte biomass and biovolume decreased and substrate heterogeneity increased with drawdown amplitude, with an additive negative effect of herbicide use. However, macrophyte structural complexity, small and large wood density, and leaf litter cover showed no discernible trend with drawdowns. Moreover, there was significantly more submerged littoral wood along forested shorelines compared to developed shorelines. These changes in habitat are likely to translate into differences in macroinvertebrate and fish assemblages that inhabit littoral zones.

We are currently still processing samples for Objectives 3 and 4. Collectively, the results of this project will provide information on the effect of winter drawdown stress and disturbance on lake physical habitat (e.g., macrophytes, sediment), macroinvertebrate assemblages, and food webs. These results will allow future lake management to make more informed decisions concerning changes in winter drawdown regimes.

Student Support:
- Jason Carmignani was supported by matching funds and is pursuing a Ph.D in the Organismic and Evolutionary Biology program at the University of Massachusetts.
- Gillian Gundersen (BS Environmental Science) was supported on matching funds as undergraduate student technician in summer 2014.
- Kathryn Stankiewicz (BS Environmental Science) was supported on matching funds as undergraduate student technician in summer 2015.

Follow-on Funding:
Massachusetts Division of Fisheries and Wildlife FY2015, $45,000
Massachusetts Division of Fisheries and Wildlife FY2016, $50,000

Publications and Conference Presentations:

The following conference presentations were made:

Carmignani J.R. and A.H. Roy (Talk). "*Do Annual Winter Drawdowns Alter the Physical Habitat Structure and Complexity of the Littoral Zone?"* New England Association of Environmental Biologists Conference, Bartlett NH, March 2015.

Carmignani J.R. and A.H. Roy (Talk). "*Do Annual Winter Lake Drawdowns Alter the Physical Habitat Structure and Complexity of Shallow Littoral Zones*?" Society for Freshwater Science Meeting, Milwaukee WI, May 2015.

Carmignani, J., A.H. Roy, and K. Stankiewicz (Talk). *"Freshwater Mussel Distribution in Shallow Depths of Winter Drawdown Lakes."* New England Association of Environmental Biologists Conference, Rockport ME, March 2016.

Stankiewicz, K., J. Carmignani, and A.H. Roy (Poster). "*Hydrologic Characteristics of Annual Winter Water-Level Drawdowns in Massachusetts.*" New England Association of Environmental Biologists Conference, Rockport ME, March 2016.

Carmignani, J., and A.H. Roy (Talk*). "Impact of Winter Drawdowns on Mussel Distributions in Massachusetts (USA) Lakes."* Society for Freshwater Science Meeting, Sacramento CA, May 2016.


Stiles Reservoir during a winter drawdown


Measuring large wood branching complexity


Staff gauge and water level data logger in PVC housing during a winter drawdown.


stimating macrophyte cover and biovolume using quadrats.

2. Fate, transport, and remediation of PFOS, PFOA, perchlorate, and 1,4-dioxane at the Eastham MA landfill (2014MA422B)

Principal Investigator: Chad David Vecitis, Harvard University Environmental Engineering
Start Date: 3/1/2014
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Water Quality

Problem and Research Objectives:
The Cape Cod groundwater aquifer is the residents' sole source of drinking water. Thus it is vitally important to preserve the groundwater quality. Located just a few miles north of East Falmouth, MA, the Joint Base Cape Cod (JBCC) is the location of the well-documented Ashumet Valley Plume, which has groundwater contamination from both historical secondary wastewater disposal and fire training area

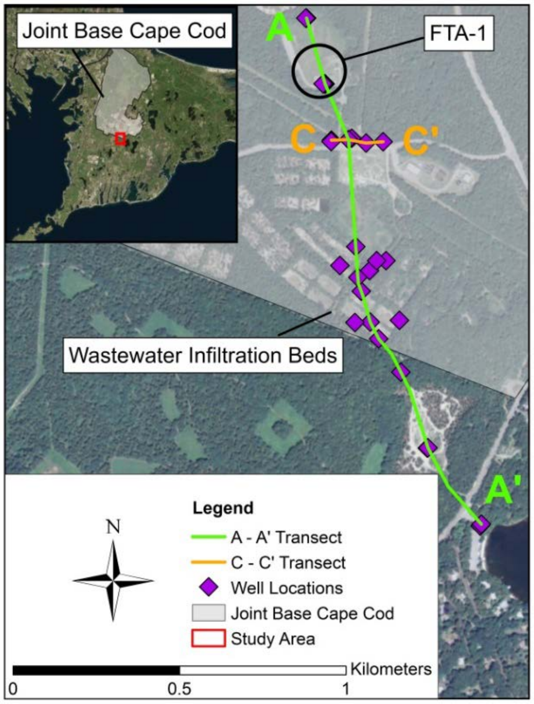
activities. In addition to the known contaminants on the site, including trichloroethylene and tetrachloroethylene, we also suspected there would be a widespread contaminant plume of poly- and perfluoroalkyl compounds (PFASs) as a result of the aqueous film-forming foams (AFFFs) used in the fire training area. AFFFs were used to fight hydro- and chloro- carbon fires during training exercises from 1970 – 1985 and are a complex mixture of chemicals including large quantities of PFASs (generally 1-5%). PFASs are thermally stable synthetic organic contaminants, are likely carcinogenic, and have been shown to correlate with thyroid disease and immune deficiencies. The Environmental Protection Agency recently released new health advisory limits of 70 ppt for perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA), two commons types of PFAS. PFASs typically have high water solubility (mobility) and are very persistent. Our research objectives were to determine the extent of PFAS contamination at the JBCC, investigate the transport properties of PFASs and develop an effective remediation technology. The results from this study will be widely applicable to air force bases, airport hangars, and other municipal point sources across the country with similar AFFF contamination issues. The funding from WRRC allowed us to start this project and obtain follow-up funding from the 2015 Milton Fund at Harvard. Two other proposals (NSF and NIEHS) are under review. Ultimately, this funding has produced 1 publication (in progress) and presentations at 2 conferences. This progress report outlines the final state of the project.

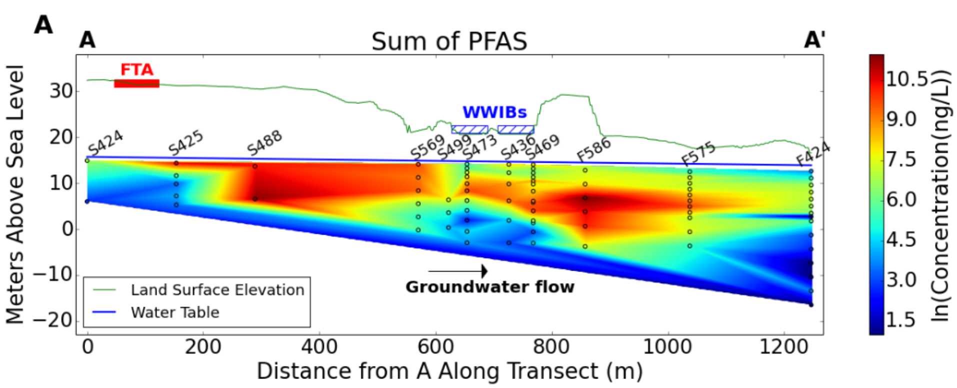
Methodology:
All work was done in collaboration with the USGS Cape Cod Toxic Substances team. In the summer of 2014 we conducted an initial field sampling effort at the JBCC. Based on prior knowledge of the field site, a selection of 9 wells was sampled with HDPE bottles both at and downgradient the fire training area where large quantities of AFFF may have been spilled. A vertical profile was also sampled in December 2014 at one well downgradient of the fire training area in what is known as the wastewater infiltration beds. This allowed us to obtain a more detailed subsurface understanding of PFAS concentrations. After groundwater sampling, samples were kept at 4˚C until analysis, at which point they were shaken and sub-sampled between 5-10 cm below the surface to ensure a representative sample. 750 µL (unless further dilution was needed) of sample was added to 720 µL of methanol and 30 µL of internal standard in polypropylene centrifuge vials and centrifuged at 13,000 rpm for 20 minutes. After centrifugation, 0.8 ml of supernatant was extracted and transferred to polypropylene autosampler vials and analyzed within 24 hours with an Agilent 6460 LC-MS/MS with online SPE.

In addition to groundwater analysis, initial sorption experiments were designed to understand PFAS transport at the site. A core from the JBCC was obtained through our USGS collaboration and dried and sieved to 2.36 mm. 40 ml of groundwater from a background well with no detectable PFAS concentrations was added to 15 g of the homogenized core section and spiked with PFAS concentrations between 0.5 and 5 µg/L. These batch reactors were then placed on a shaker table for an equilibration period of 10 days after which both the aqueous and solid phases of these batch reactors were sampled. The resulting data was fitted with a Freundlich isotherm.

In the summer of 2015, a total of 7 sediment cores (3 from the fire training area at different depths, 3 from the wastewater infiltration beds at different depths and 1 background core) were retrieved from the field site. Over 300 groundwater samples were collected at the field site and ancillary chemistry (pH, temperature, specific conductivity, dissolved oxygen, dissolved organic carbon, etc.) was measured. In situ sediment/water distribution coefficients were determined with these cores to enable transport calculations. TOC and quantitative mineralogy were performed at the USGS laboratory in Boulder, CO.

Principal Findings and Significance:
PFAS concentrations reached over 90 µg/L and the highest concentrations were found within 1 km of the fire training area. The detailed sampling in 2015 enabled the creation of a 2-dimensional transect of the subsurface PFAS plume as shown below:





Low levels of PFAS (above the detection limit) were found up to approximately 8 km downstream. The vertical profile taken within the wastewater infiltration bed area displayed a large increase in PFASs in a zone that also had low dissolved oxygen (DO). In this low DO zone, we found elevated PFOS concentrations. This may indicate that PFOS was preferentially sorbed onto solid oxide surfaces and were subsequently released as oxides were reduced (causing dissolution). Alternatively, we propose that the historical loading of wastewater infiltration beds caused DOC loading onto the sediments and enhanced PFOS sorption. DOC has been slowly released to the aquifer, allowing PFOS to be released as well. This has implications for how water geochemistry and mineralogy can impact PFAS transport.

An additional complication to PFAS transport is the transformation of perfluoroalkyl acid (PFAA) precursors into terminal PFAA. This occurs naturally over long time scales (decades). Once PFAA are formed, they will not further degrade under environmental conditions. In order to investigate how perfluoroalkyl acid concentrations could change over time, we implemented a precursor oxidation method (previously developed in the literature) that degraded any precursors within the groundwater to determine the oxidation products in contaminated samples. Results indicate that there is an increase in short-chained perfluoroalkyl acids, including perfluorobutanoate (PFBA), perfluoropentanoate (PFPeA) and perfluorohexanoate (PFHxA), after oxidation. A major finding was that there was a linear relationship (slope ~3) between these three compounds before and after oxidation for all samples throughout the PFAS plume. This indicates that PFAS precursors (or intermediates) are transported with the plume. This is a major finding, as precursors are generally considered to be less mobile than PFAA. The wastewater plume may be increasing mobility of the precursors and should be investigated in more detail.

Two distinct PFAS sources were identified from compositional differences. The vadose zones at the fire training area and wastewater infiltration beds display two distinct PFAS compositions. This indicates that statistically identifying sources based on composition is possible. The fire training area and wastewater infiltration beds have been in inactive since 1985 and 1995, respectively, but are still a continuous source of PFAS to groundwater. This highlights the need for soil remediation technologies.

Summary of major findings and significance:

- The most comprehensive groundwater research field effort to date has been completed and has resulted in a high resolution cross section of the PFAS plume. This will be invaluable to the field, as subsurface sampling is typically limited by the number of wells. All data will be made available in the journal article.

- Precursor oxidation experiments indicate PFAA precursors or their intermediates are transported at the same rate as PFAAs throughout the plume, contrary to literature expectations. PFAA precursors can increase the total PFAA groundwater concentrations upon breakdown, and must therefore be studied further.

- Differential transport was observed with PFOA and shorter chained species compared to PFOS. This is theoretically expected, but has not been previously documented.

- Compositional analyses close to the water table at the fire training area and wastewater infiltration beds indicate there are two separate, compositionally distinct PFAS sources. The vadose zones at both sources are still a source of PFAS to the groundwater decades after PFAS inputs have ceased. This suggests vadose zones are long-term sources and that source tracking can be done via "fingerprinting" PFAS compositions. Soil remediation technologies are needed for vadose zone clean-up.

Outlook. Future work is still needed to gain a thorough understanding of PFAS transport. We plan to continue our investigation of these questions through controlled column experiments in the laboratory with sediment collected during coring. While it is necessary to understand PFAS transport in aquifers, it is also essential to design more effective remediation methods. As PFASs are resistant to degradation due to the strong electronegativity of fluorine, treatment is difficult. We previously proposed to improve upon an existing electrochemical carbon nanotube (CNT) filter by coating the CNTs with tin oxide doped with antimony and bismuth for stability. Initial experiments both with and without this coating were unsuccessful, primarily because the necessary anode potential needed to degrade the compounds could not be reached without destroying the CNT. Follow-up experiments are being conducted with nafion combined with CNT and PVDF combined with CNT, as these mixtures are reportedly more stable and can withstand high voltages. The experiments are promising, as we have been able to reach an anode potential of nearly 7 volts, which is likely to degrade most PFAS compounds. These studies will continue to progress. The CNT filter should be far more effective than conventional filters due to the high surface area, which will enhance PFAS sorption to the surface. PFASs will then theoretically be degraded through direct electron transfer followed by decarboxylation and defluorination.

In summary, the funding through WRRC has been instrumental in jump-starting this research, which has evolved into a full PhD project for Andrea Weber, the primary student investigator. Below, we list all funding, conferences and achievements that have resulted in part due to this funding opportunity.

Student Support:
One graduate student was funded during this work: Andrea Weber is currently a third year graduate student pursuing her PhD in Environmental Engineering.

Notable Achievements and Awards:
Andrea Weber received the Student Poster Grand Prize Award at the Fluoros 2015 conference at the Colorado School of Mines (July 12-14).

Follow-on Funding:
- 2015 Harvard Milton Fund Award: $39,565
- National Institute of Environmental Health Sciences (NIEHS) – Superfund Research Program: Under review
- National Science Foundation (PD-15-1440) – Under Review

Publications and Conference Presentations:
Weber, A. K.; Barber, L. B.; LeBlanc, D. R.; Vecitis, C. D., (in progress), Geochemical and hydrological factors controlling subsurface transport of poly- and perfluoroalkyl substances, Cape Cod, Massachusetts. *Environmental Science and Technology.*

Weber A. K., Vecitis C. D., Barber L. B., LeBlanc D. R., Poly- and Perfluoroalkyl Substances: Fate and Transport at the Joint Base Cape Cod. Poster Presentation at Fluoros 2015, July 2015, Golden CO.

Weber A. K., Barber L. B., LeBlanc D. R., Schwartz, E. S. J., Vecitis C. D., Poly- and Perfluoroalkyl Substances: Transport Phenomena and Implications for Water Resources. Presentation at New England Graduate Student Water Symposium, September 2016, Amherst MA.

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3. Going With or Against the Flow: Choices for flood mitigation response in Massachusetts (2014MA426B)

Principal Investigator: Anita Milman, UMass Amherst Environmental Conservation
Start Date: 3/01/2014
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Social Sciences

Problem and Research Objectives:
While research has highlighted the importance of motivation (Blennow and Persson, 2009) and identified barriers to flood management (Burch, Sheppard et al. 2010), we still lack basic understandings of how adaptation decisions are made. Yet these decisions will be a key determinant of future impacts. Better understandings of the criteria used by decision-makers and the situational factors influencing those priorities are important for informing scientific analyses of projected impacts, for developing decision support tools, and for estimating future action. Thus this research project aims to delineate processes by which flood management decisions are made at the local level.

Methodology:
To delineate the processes for flood management at the local level, we interviewed representatives from 32 municipalities across western Massachusetts (6 town administrators, 10 select board members, 9 conservation or planning directors, 3 public works officials and 5 emergency management officials) and from 18 towns in Southern Vermont (including 11 select board chairs, 6 select board members, 5 town managers, 1 zoning administrator, 1 planning board members, 1 town administrators, 2 town clerks, 1 road commissioner, 4 emergency operations directors, and a FEMA coordinator. Interviews included both a structured and a semi-structured methodology. Semi-structured approaches were used to collect information on the institutional features of town government as it relates to flood mitigation and comparisons on local perspectives and approaches to structural and nonstructural flood mitigation measures, including opinions on what would work best in their communities. Structured card sorting and talk-out loud methods were used to elicit a ranking of criteria used in decision-making. Interviews have been transcribed and we are in the process of using Nvivo to code and analyze the data.

Principal Findings and Significance:
Our results highlight how the social and physical characteristics of rural municipalities lead them to focus on structural flood mitigation. Interactions with state and federal agencies hinder municipal mitigation efforts, while collaborations with third parties facilitate action. Overall, flood mitigation by rural municipalities is reactionary and ancillary, leaving municipalities vulnerable to future flood events. These results point to the importance of tailoring government policies and programs to rural areas as well as potential limitations of integrated flood management.

We also develop a conceptual framework that presents the ‘fit’ between top-down federal/state policies and the local-level context as comprised of three components: Receptivity, Ease of Participation, and Design. We explain how these components and their interactions influence local-level action. This analysis points to how careful consideration of the components of ‘fit’ may lead to greater local-level uptake of top-down adaptation policies.

Student Support:
One Ph.D. student in Environmental Conservation was supported by the grant or matching funds.

Publications and Conference Presentations:
Consoer, M. & Milman, A. (under review), Opportunities, Constraints and Choices for Flood Mitigation in Rural Areas: Perspectives of Municipalities in Massachusetts, Submitted to *Journal of Flood Risk Management*.

Paul, M. & Milman, A. (under review), Adapting Across Scales: Fit and Planned Adaptation to Flooding, Submitted to *Journal of Environmental Planning and Management*.

This research will form the basis of chapters in two Ph.D. dissertations: Mark Paul (Economics) and MacKenzie Consoer (Environmental Conservation)

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4. Assessing the effectiveness of a biofiltration facility and associated groundwater flow in controlling stormwater quality (2014MA427B)

Principal Investigator: Paul Mathisen, Worcester Polytechnic Institute Civil and Environmental Engineering
Start Date: 3/1/2014
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Water Quality

Problem and Research Objectives:
Problem: Stormwater runoff contributes significant loads of nutrients, bacteria, metals and other contaminants to surface water supplies throughout the US. These loads can have significant impacts on drinking water sources or aquatic habitats. Increases in the frequency and intensity of precipitation events, an anticipated effect of climate change, may further exacerbate the impacts of this runoff. Control of these stormwater discharges is therefore a critical concern for water supply managers across the United States.

To control the volume and quality of the runoff discharging to surface water bodies, a wide variety of Best Management Practices (BMPs) has been developed. Examples include grassed swales, riparian buffers, detention ponds, biofiltration basins, and many other approaches. Of these approaches, biofiltration approaches have been widely employed due to their ability to control flow and water quality. Common designs for biofiltration basins make use of a forebay for sediment control, a larger biofiltration basin with vegetation and a sand layer to provide treatment, and a subdrain that discharges to surface water. Some of these basins are unlined, such that a portion of the discharge seeps into groundwater, potentially providing additional treatment. For all of these cases, the transformations that govern the effluent quality are complex and not well-characterized, and few field investigations have been completed to provide insight into these processes. As a result, the effectiveness of biofiltration basins (and many other similar BMPs) in protecting groundwater and surface water supplies is difficult to quantify.

Overall goal and research objectives:
The overall goal of this research is to determine the contribution of infiltration and subsurface transport in mitigating the impacts of stormwater discharges on groundwater and surface water supplies. The specific objectives are to:

(1) develop an understanding of the significance of infiltration in relation to the discharges from these basins,
(2) determine the role of groundwater flow and transport in reducing the concentrations of contaminants in stormwater runoff , and
(3) evaluate the effectiveness of biofiltration basin design in reducing contaminant discharges to surface water bodies, and develop recommendations for improved design procedures for these basins.

Specific considerations include the impacts of recharge and infiltration on groundwater quality, and the associated role of subsurface transport and transformation in reducing contaminant loadings to surface water bodies.

Methodology:
The overall methodology for this project included a combination of site selection and preparation, and field monitoring, sampling, and analysis. Specific requirements for these components of the research are included the following paragraphs.

Site selection and preparation: The field site selected for this project is located in West Boylston, MA, which is in the watershed for the Wachusett Reservoir. The Massachusetts Department of Conservation and Recreation (DCR) has constructed a number of structural stormwater BMPs to protect water quality for the Wachusett Reservoir, a main component of the water supply system serving the Boston metropolitan area. This research involved an investigation of the processes associated with a biofiltration Best Management Practice (BMP) located in West Boylston, MA. The basin treats runoff from an 9-acre watershed with two roadways (Routes 12 and 110) and surrounding residential and commercial land uses. Water exits the basin by either seepage directly to groundwater or by seepage through a two-foot filtration bed to an outfall pipe draining outside of the basin. This setup allows for the assessment and comparison of these design elements in reducing stormwater pollution to adjacent water supplies.

A set of monitoring wells was also installed to provide information on groundwater flow and quality. The well locations are shown in Figure 1. At Location 1, a well is included to provide geochemical background information. At Locations 2, 3, and 4, well nests were installed, each with 2 monitoring wells (one shallow and one deep). The well nests at Locations 2 and 3 provide information on water quality downstream of the basins, and Location 4 provided information farther downstream, adjacent to the reservoir.

Figure 1: Monitoring well locations

Field monitoring, sampling, and analysis: Field monitoring included quantification of the flow and water quality in the basin inflow, the ponded area within the basin, the discharge drain, and groundwater leaving the basin. Monitoring of water level and water quality in the installed groundwater wells provided information on the quality and response time associated with the transport to groundwater. By quantifying the water budget (relating change in storage to the difference between inflow and outflow), we were able to estimate the basin outflow to groundwater. In addition to water budget analysis for the basin, modeling included the use of HydroCAD to characterize inflows to the basin, as well as the basic hydraulic and storage properties of the basin.

Monitoring included the installation of boxes with v-notch weirs, the Hydrolab units, ISCO samplers, and an In Situ temperature-pressure/depth probe. The Hydrolab water quality sondes provided real-time estimates of dissolved oxygen, conductivity, pH, turbidity, temperature, and depth. Use of the depth measurements in conjunction with the v-notch weirs provided accurate flow measurements. Samples were collected periodically in the inflow, outflow, and ponds of the basin (including the biofiltration pond). Groundwater samples were collected using a Keck groundwater pump for a deep well and a Geotech peristaltic pump wells immediately downgradient of the biofiltration basin. The samples were analyzed for dissolved oxygen, suspended solids, pH, alkalinity, DOC, anions (PO^{4-}, NO^{3-}, SO^{4-}, Cl^{-}) and cations (Fe^{2+}, Mg^{2+}, Ca^{2+}, Na^{2+}) , bacteria (total coliform and E. coli), and selected heavy metals. Laboratory analysis of the parameters made use of a Dionex ICS 2100 Ion Chromatography (IC) system for anions, a Perkin-Elmer Atomic-Absorption (A/A) spectrophotometer for most cations, and Hach DR-6000 spectrophotometer for ammonium and total phosphorus analysis. Dissolved oxygen was determined using a Thermo Electron Orion 3 star DO benchtop meter, pH was determined using a standard Accumet Basic AB15 pH meter and alkalinity was obtained using a gran alkalinity approach. Total organic carbon was obtained using a Shimadzu 5000A TOC analyzer and E. coli were determined using standard methods with the IDEXX Quantitray system. Suspended solids were also obtained following standard methods (EPA 160.2). Detailed comparisons between concentrations in the basin inflows, outflows, and monitoring wells provided a basis for quantifying the effects of the basin and loads transported to groundwater and surface water. To understand the response of groundwater subsequent to storm events, the groundwater wells were monitored more frequently (i.e. daily, whenever possible) immediately after the storm events.

Monitoring in 2014 and 2015 included 5 storms. The dates of the storms were on May 16th -17th, July 15th- 16th, August 13th, October 16th, and October 22nd - 24th. Partial data sets were obtained for the May and July storms. More detailed data sets for the inflows and outflows were obtained for the August and October storms. As such, the latter two storms were analyzed in more detail. For the purposes of this report, selected parameters for groundwater sampling site 2 are included to illustrate the nature of the results.

Findings and Significance:
The field program provided quantitative data on the flows and transformations that occur in the discharge and within the groundwater downstream of the biofiltration basin.

Flow and infiltration findings: Figure 2 shows the evolution of the cumulative volume associated with the basin throughout a storm in October, 2014. The plot includes curves for the inflow, basin storage, outflow via the discharge pipe, and outflow via infiltration. The infiltration was also confirmed via monitoring downstream, as indicated in Figure 3, where the response to the local infiltration was clearly evident in the water levels immediately down-gradient of the biofiltration basin. The results demonstrated that stormwater infiltration to groundwater is an important component to consider for BMP design. However, analysis of the flow data showed that infiltration to groundwater was comparable to discharge through the outfall.

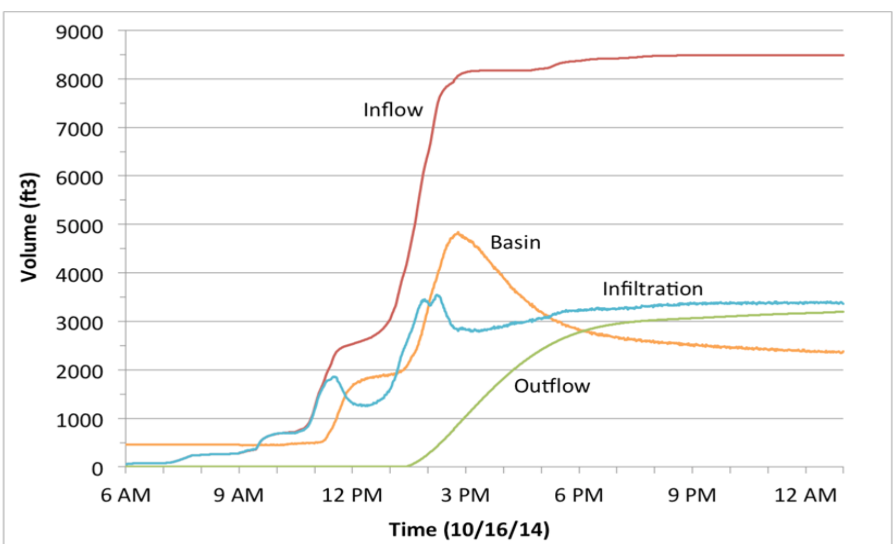

Figure 2: Cumulative Volumes for October Storm

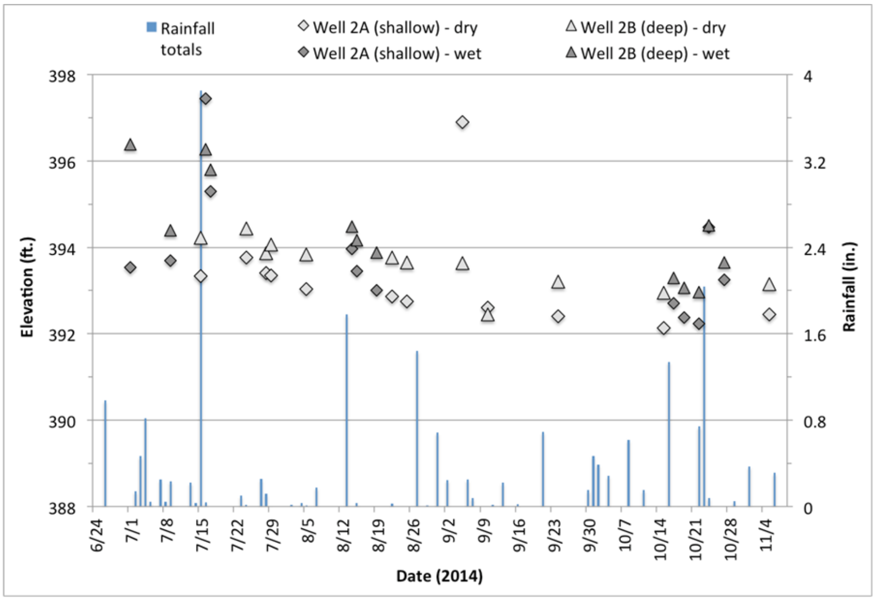

Figure 3: Groundwater levels at Well Location 2

Water quality findings: The water quality results also illustrated the nature of the transformation of chemical constituents in the area of the basin. For the purposes of this report, some results are presented for total phosphorus. The surface water phosphorus concentrations shown in Figure 4 are variable throughout this storm and are generally low and similar in magnitude for the inflow and outflow. The total phosphorus concentrations shown for groundwater in Figure 5 are also low (except for one measurement in Well 2). The dissolved phosphorus concentrations were found to be very low in the basin inflow and outflow and below detection for essentially all groundwater samples, demonstrating the role of the subsurface in controlling phosphorus. In general, the flow path through the outfall was effective in removing sediments, but was found to have limited capacity for water quality treatment, since only small changes in stormwater quality occurred between the culvert inflow, basin, and outfall samples. The signatures of stormwater infiltration could still be seen in the wells, indicating that the infiltration from the stormwater basin can impact groundwater quality. Moreover, the groundwater pathway was found to impact the chemistry of the constituents, and was particularly effective in removing bacteria and phosphorus. Any water quality impacts were in the vicinity of the biofiltration basin, and did not have any adverse impacts on surface water bodies downstream of the basin.

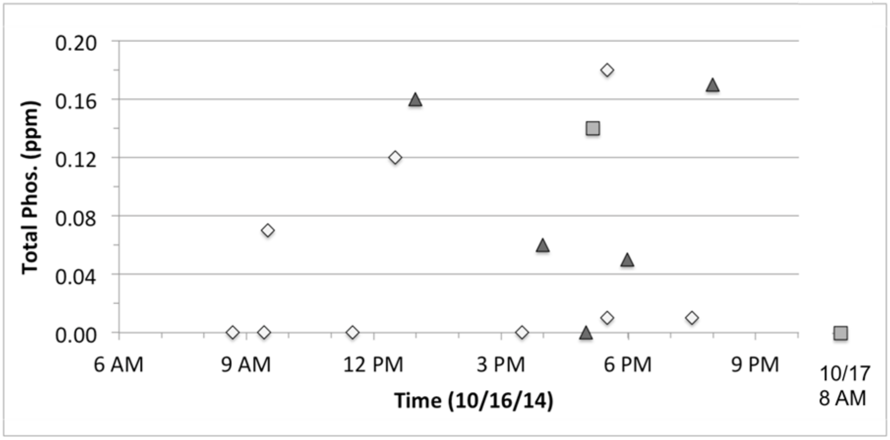

Figure 4: Total phosphorus in basin October Storm

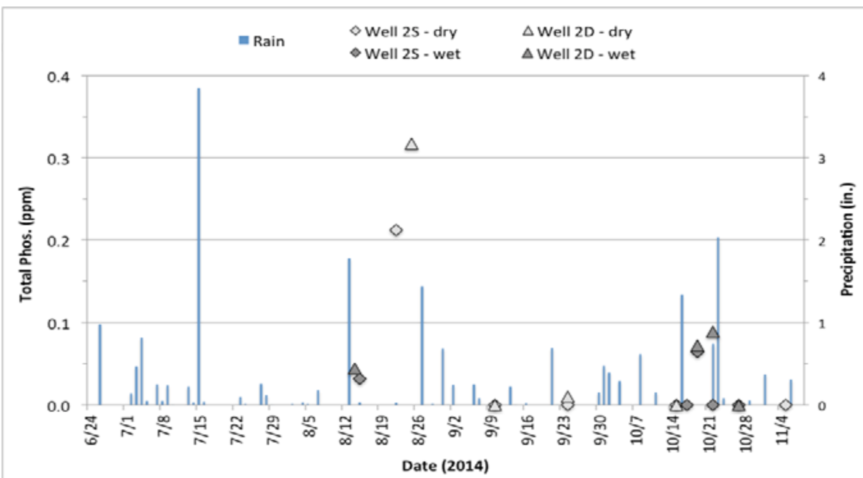

Figure 5: Total phosphorus in groundwater at Location 2

Significance: Overall, the results demonstrate the value of groundwater recharge as a component of BMP design, and provide a basis for a number of specific design recommendations related to biofiltration basins. The contributions include information on stormwater quality from roadways, insight into the role of infiltration for unlined basins, an improved understanding of the transformations in groundwater and the use of stormwater recharge for controlling stormwater quality.

Student Support:
This project has supported one Environmental Engineering graduate student (Jacquelyn Tupper), who completed her MS thesis with support from this grant. The project has also provided opportunities for one additional undergraduate student and another graduate student, also in Environmental Engineering, to further develop and understanding of stormwater quality and gain experience. The undergraduate student helped with some field work and sample collection. The additional graduate student was actually working on another project addressing stormwater quality (focusing on sodium, chloride, and metals), but she also completed some analyses using additional samples from this site.

Follow-on Funding:
There is no follow-on funding at this time. However, follow-on funding and additional research projects will be considered in the summer of this year. However, we do have plans in place to continue our collaboration with the MA DCR on additional projects addressing best management practices to control stormwater quality. Three undergraduate students plan to complete their WPI Major Qualifying Project (MQP) in the 2016/7 academic year on BMP design for highway runoff. This project will address runoff from Route 190, a state highway that passes through the watershed for the Wachusett Reservoir.

Publications and Conference Presentations:
Assessing the impacts of a biofiltration facility and associated groundwater flow on surface water quality" by Jacquelyn E. Tupper, MS Thesis, Worcester Polytechnic Institute, May 2015.

Tupper Jacquelyn and Paul Mathisen, (in preparation), Quantifying infiltration from an unlined Biofiltration Best Management Practice (BMP) and associated impacts on groundwater, anticipated submission to J. of Hydrologic Engineering or possibly J. of Hydrologic Monitoring, summer of 2016.

Tupper Jacquelyn and Paul Mathisen, (in preparation), Characterizing the effects of an unlined Biofiltration Best Management Practice (BMP) on surface water and ground-water quality, anticipated submission to J. of Contaminant Hydrology, anticipated submission in summer of 2016.

Figure 6: Surface water sample locations: (a) inflow, (b) outflow, and (c) basin, along with another location (d) farther downstream in the Wachusett Reservoir

Figure 7: Graduate student working at the Gate 27 field site:
(a) preparing to monitor the inflow (b) groundwater sampling

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5. Enhancing the Flux of Ultrafiltration Membranes using Nanofibers (2015MA436B)

Principal Investigator: Jessica Schiffman, UMass Amherst Chemical Engineering
Start Date: 3/01/2015
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Water Quality

Problem and Research Objectives:
Ultrafiltration (UF) membranes are widely considered the "state-of-the-art" material for water treatment and wastewater reuse; they can effectively remove emulsified oils, metal hydroxides, colloids, emulsions, dispersed material, suspended solids, and waterborne pathogens from drinking water. In Massachusetts, UF is used for direct filtration applications and synergistically as a pre-treatment for reverse osmosis systems. This project embarked on a new generation of UF membranes that are surface-functionalized with nanomaterials that do not affect the membrane's flux. We used surface topography as an environmentally benign approach to change the active layer of the membrane, and potentially, reduce biological fouling. Our specific aims were to systematically electrospin fibers from a robust polymer familiar to water purification membranes, polysulfone. In-house fabricated polysulfone UF membranes enhanced by a thin, porous, and robust layer of fibers were characterized for retention of high flux, molecular weight cut-off (MWCO), and biofouling. Our long term goal is to establish a "greener" antifouling strategy for high flux UF membranes.

Methodology:
In-house (hand-cast) polysulfone UF membranes and commercial control membranes were characterized and served as the base membranes. We enhanced the membranes using a thin, ultra-porous, and robust layer of fibers using a layering technique. Electrospun polysulfone fibers were first optimized to have an average fiber diameter of 1.0 µm. This was accomplished by varying the electrospinning pre-curser solution (polymer concentration, solvent) and electrospinning apparatus conditions (advance speed, separation distance, environmental parameters). All materials were

characterized using scanning electron microscopy and contact angle. MWCO, pure water flux, and protein adsorption/rejection of the UF membranes (with and without nanofibers) were characterized.

Principal Findings and Significance:
To synthesize polysulfone nanofibers, an 18 wt% polysulfone solution in a 1:1 mixed solvent system of tetrahydrofuran and *N*-*N*-dimethylformamide was employed. These nanofibers exhibit a smooth cylindrical shape without beads and have an average fiber diameter of 1.0 ± 0.4 µm and a contact angle of 112 ± 5 °. The electrospinning time was optimized so that the nanofiber layer would be consistent, 48 ± 13 µm thick. Adding the nanofiber layer to the membranes did not affect their size selectivity; and a MWCO greater than 100 kDa was observed which is consistent with the values reported by the commercial supplier of the control membranes. Previously, the addition of polymers, nanoparticles, and polymer layers decreased this flux. The result with electrospun nanofibers is exciting as the addition of the nanofiber layer increased the membrane thickness but did not decrease the flux. Observing the nanofiber enhanced membranes, their permeability increased across all pressures tested. The pure water permeability was 561, and 830 L m^{-2} h^{-1} bar^{-1} for the control membranes and the nanofiber-enhanced membranes, respectively. This result suggests that the fiber morphology is playing a role in water transport. The functionality of the additional nanofiber layer was investigated under static and flow conditions using bovine serum albumin (BSA) protein. The BSA did not attach to the nanofiber layer and because the BSA is smaller than the MWCO of the membranes, it was able to quickly pass through the membranes. In sum, electrospun nanofibers can effectively be used to functionalize the surface of ultrafiltration membranes and importantly, size selectivity of the ultrafiltration membranes persists with the addition of the nanofiber layer. The full methods and results from this work are currently being prepared for submission to a peer-reviewed journal.

Student Support:
As a result of this grant, there were 4 students that were given research opportunities.
1. Kerianne Dobosz, PhD Student in Chemical Engineering
2. Christopher Kuo-Leblanc, Double Major: B.S. in Chemical Engineering, B.S. in Mathematics
3. Griffin Hurley, B.S. in Chemical Engineering
4. Tyler Martin, B.S. in Chemical Engineering

Notable Achievements and Awards:
Kerianne Dobosz has been awarded a fellowship to develop UF membranes for protein separations from the Biotechnology Training Program (BTP) funded by the National Institute of Health (1 T32 GM108556-01A1) with additional matching funds from UMass. Additionally, two undergraduates have gained first-hand lab experience at the interface of nanomaterials and environmental engineering.

Follow-on Funding:
Kerianne Dobosz has been awarded a Biotechnology Training Program (BTP) fellowship (2015-2017), which is supported by the National Institute of Health (1 T32 GM108556-01A1) with additional matching funds from UMass Amherst.

Publications and Conference Presentations:

Dobosz, K.M., Kolewe, K.W., Schiffman, J.D. "Green materials science and engineering reduces biofouling: Approaches for medical and membrane-based technologies" *Frontiers in Microbiology* ***2015,*** *6:86,* DOI: 10.3389/fmicb.2015.00086

Dobosz, K.M., Kuo-LeBlac, C.A, Martin, T.J., Schiffman, J.D. “Enhanced flux of ultrafiltration membranes via surface-modification with nanofibers” In Preparation

Schiffman, J.D. “Engineering antifouling bioinspired materials” Symposium on Additive Manufacturing and Innovative Technologies. Invited Keynote. 2015. Linz, Austria.

Dobosz, K.M., Kuo-Leblanc, C.A., Schiffman, J.D., “Electrospun nanofibers enhance the performance of ultrafiltration membranes” MRS Fall Meeting, Poster. 2015. Boston, MA.

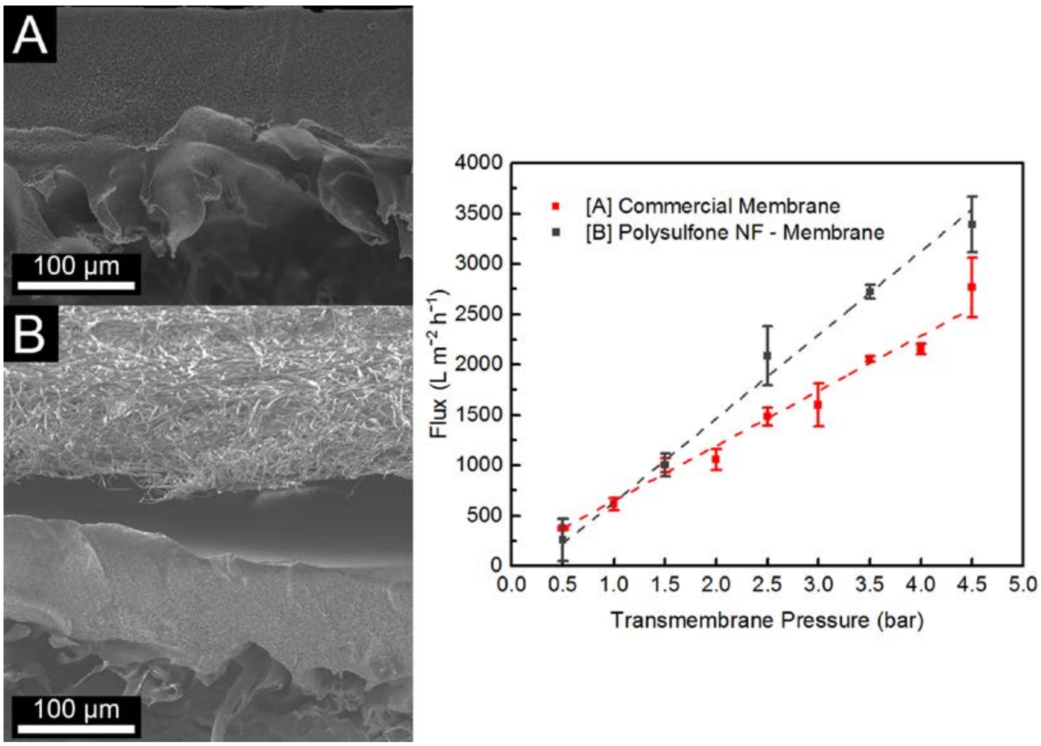


Figure 1. (Left) Scanning electron micrograph cross-sections of the [A] commercial control membrane and the [B] polysulfone nanofiber-enhanced membranes. (Right) Pure water flux versus transmembrane flux for the commercial control membrane (red) and the polysulfone nanofiber-enhanced membranes (black).

6. Microbial attenuation of pharmaceuticals from antiquated septic systems in coastal communities (2015MA437B)

Principal Investigator: Caitlyn Butler, UMass Amherst Civil and Environmental Engineering
Start Date: 3/01/2015
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Engineering

Problem and Research Objectives

In the US, greater than one fifth of all homes depend on onsite systems, especially septic systems consisting of a septic tank followed by a drain field, to treat wastewater. While these onsite systems can be a cost- and energy-effective option for wastewater treatment, there is a strong need for improved understanding of the treatment processes and better management of such systems. The communities on Cape Cod are disproportionately served by on-site septic system with as many 97% of households employing them for wastewater treatment. The impact of on-site septic systems extends further to the entire New England region. According to the U.S. Census Bureau, the region has one of the highest percentages of homes with on-site wastewater treatment systems. When inadequately managed, septic systems can result in reduced performance and become non-point sources of environmental contamination.

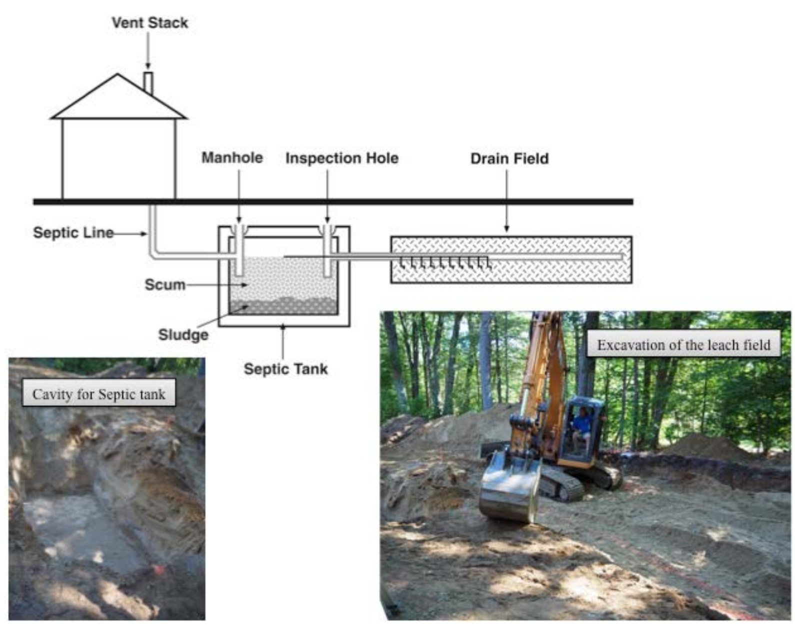


Figure 1. A layout of a domestic septic system and the site preparation for the installation of a septic system in Marlborough, MA

On-site septic systems achieve poor nitrogen removal and are difficult to regulate. Only 1,800 of the 123,000 septic systems on Cape Cod are modern alternative systems that can accommodate some nitrogen removal. Nutrient release, particularly nitrogen, is a significant problem in the coastal estuaries and marine environments throughout Cape Cod , causing eutrophication (Cambareri et al., 2009). Eutrophication facilitates excessive algae growth and when the algae decay, oxygen is consumed, causing the death of indigenous plants and animals. The result is detrimental to the ecosystems and tourism industry on Cape Cod as it is not only odorous and ugly but significantly impacts the populations of mollusks and fish harvested for human consumption.

In addition to nutrient removal, the removal of pharmaceuticals and personal care products (PPCPs) has been a rising concern in water and wastewater treatment. A wide range of PPCPs are detected in domestic wastewater and are often not removed by centralized municipal wastewater treatment plants.

PPCP removal in wastewater occurs mostly through microbial transformation and most of the known processes take place only under aerobic conditions. Anaerobic transformation and removal of PPCPs with the anaerobic septic system environment is largely understudied. A White Paper published by the Barnstable County Department of Health and Environment expressed concern of PPCPs discharge from septic system drain field leaching into groundwater used as drinking water. This is particularly concerning due to the U.S. Environmental Protection Agency (EPA) designation of Cape Cod as having a sole-source aquifer, which indicates that all on-site wastewater discharge sites are hydraulically connected to drinking water supplies (Heufelder, 2012).

Wastewater treatment, whether centralized or on-site, must be effective in both nutrient removal and overall reduction of potentially toxic PPCP-related compounds to ensure high quality of water resources. Even though a large number of houses in New England rely on septic systems, there is limited information on the performance of on-site septic systems with respect to both treatment goals. In particular, the role of microorganisms in the transformation of PPCPs in septic systems is largely unexplored. Additionally, the inhibiting effects of PPCPs on nitrifying microorganisms (Bolong et al., 2009) indicate another level of complication for achieving the two treatment goals simultaneously. Therefore, **the goal of this proposed work** was to better understand the fate of PPCPs within septic systems, which include septic tanks and drain fields, while also measuring nitrogen removal to determine whether both treatment goals are met. We have addressed this work with two objectives: **Objective #1:** *To assess the impacts of PPCP presence in septic tank effluents on the soil microbial community in drain fields* and **Objective #2:** *To determine the occurrence and fate of parent PPCP compounds and metabolites of microbial transformation as well as of nitrogen species in septic system drain field soils.*

Methodology:

Construction of Septic System

A lab-based septic system was constructed, consisting of a septic tank, distribution box and a drain field (Figure 2). The tank was fed continuously with effluent from the primary clarifier at the Amherst Wastewater Treatment Plant by peristaltic pump at a flowrate of 13 mL/min. The tank held 20 gallons (76 L) of wastewater with a hydraulic retention time (HRT) of 4 days. A 4 day HRT is consistent with the operation of many domestic septic tanks and compliant with the Massachusetts Department of Environmental Protection 310 CMR (Code of Massachusetts Regulations) 15.404, which specifies that the retention time of a septic system must be at least 24 hours. The effluent was discharged to the distribution box and then to a waste tank during the preliminary stabilization period. The distribution box was ultimately connected to 8 soil columns.

Eight soil columns were constructed in order to mimic the drain field of a septic system. The soil used in these columns was commercial grade sand from Home Depot chosen for its low organic content Additionally, sandy soils are representative of soil composition in Cape Cod. The columns had duplicates of four soil conditions chosen to explore the role of microorganisms in PPCP transformation: 1. unmodified soil, 2. soil inoculated with microorganism contained in primary effluent from a wastewater treatment plant, 3. autoclaved soil, and 4. autoclaved soil inoculated with microorganism from primary effluent. The soil columns were first subjected to a stabilization period for 10 days during which they supplied 16 mM phosphate buffered minimal growth media (Srinivasan et al., 2016) containing 1000 mg COD/L as acetate in a recirculated batch mode. During the batch recirculation operations, samples were collected at t= 0,1,2,4 hrs, then 1, 3, 7 and 10 days. After acetate was completely consumed, a second phase of batch operation was imposed. During this stabilization period, a growth media spiked with 100 µg/L of 4 representative PPCPs: ibuprofen, carbamazepine (antiepileptic drug), trimethoprim and sulfamethoxazole (antibiotics) was fed to each column at a flowrate of 1.64 mL/min. The sampling schedule after the stabilization period was hourly for the first day, daily for the first week and three times a week for the remaining weeks.

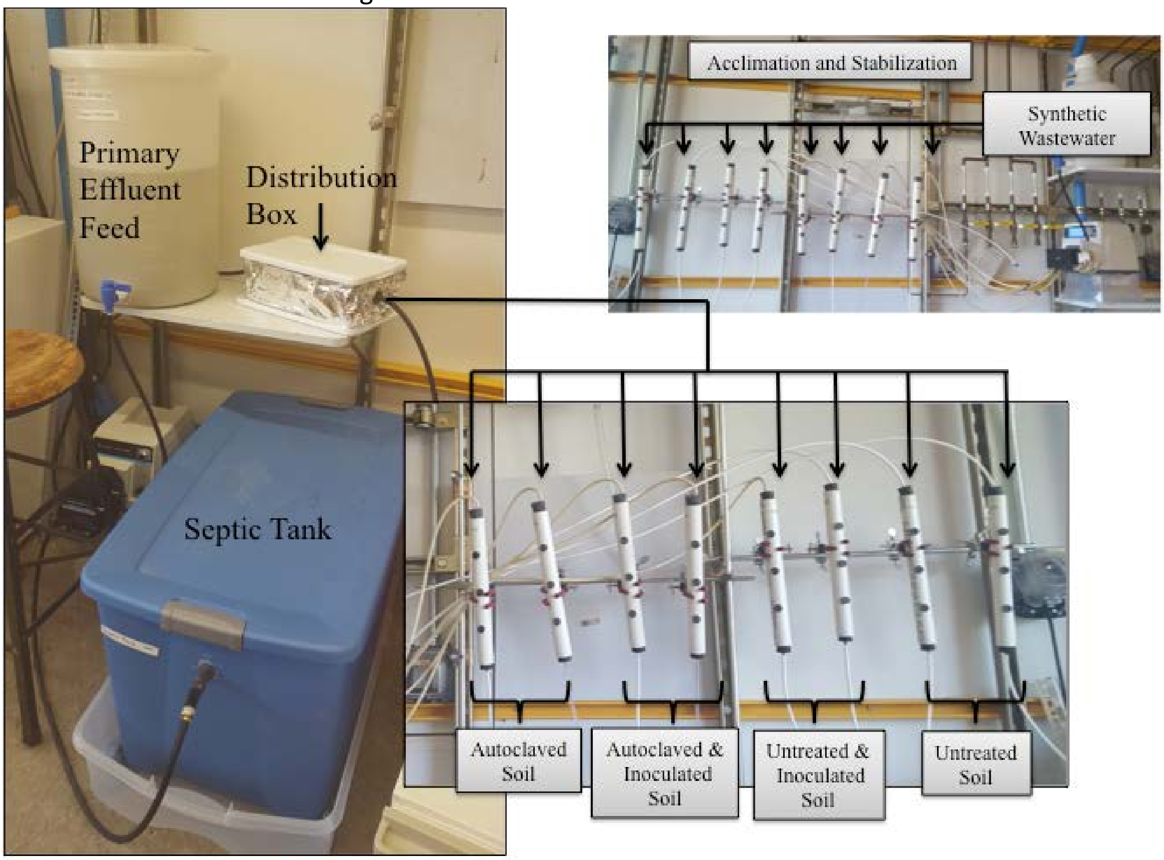


Figure 2. A picture of the septic system model in the lab. Column operation during acclimation and stabilization is presented in the inset figure.

Batch Studies

Batch studies mimicking the drain field soil environment were conducted in order to reinforce the biological impacts of pharmaceuticals in the soil in a more controlled environment. Soil conditions tested in duplicates were (i) autoclaved sand, (ii) autoclaved sand inoculated with microorganisms from primary effluent, (iii) autoclaved topsoil, (iv) autoclaved topsoil inoculated with microorganisms from primary effluent, (v) unmodified topsoil, and (vi) unmodified topsoil inoculated with microorganisms from primary effluent. Synthetic wastewater media comprising of 100 mg/L acetate and a 16 mM phosphate buffer was used in this two-week study. The media was spiked with 100 µg/L of three pharmaceuticals: sucralose (artificial sweetener), trimethoprim and sulfamethoxazole (antibiotics). These three compounds are being investigated since they are representative of diverse classes of pharmaceuticals present in the effluent of septic systems. A sample from each batch reactor was taken every 2-4 days over the course of the experiment.

Analytical Methods

Influent and effluent samples from the septic tank were collected weekly for a 6-month period. For the septic tank assessment, Total suspended solids (TSS), volatile suspended solids (VSS), and chemical oxygen demand (COD) were measured for both influent and effluent samples following Standard Methods (Clesceri et. al, 1998). Dissolved oxygen (DO) concentrations were measured from influent and effluent as well as inside the tank with a Thermo Scientific Orion Rugged Dissolved Oxygen DO probe. Measurements of pH and temperature of the septic tank content were also conducted weekly.

Ibuprofen, sucralose, carbamazepine, trimethoprim and sulfamethoxazole were detected using Electrospray Ionization Ultra Performance Liquid Chromatography Tandem Mass Spectrometry (ESI-UPLC/MS/MS) on a Waters Acquity UPLC connected to a Waters Quattro Premier MS instrument. Solvents A and B for the mobile phase of positive mode ESI that detected sucralose, carbamazepine, trimethoprim and sulfamethoxazole were 0.05% formic acid in 1 g/L ammonium formate solution and UPLC-grade methanol/acetonitrile (1:1) with 0.1% formic acid. Solvents A and B for the mobile phase of negative mode ESI that detected ibuprofen were 40 mg/L aqueous ammonium acetate and 100% UPLC grade methanol. The UPLC gradient elution and MS/MS parameters used were based on EPA Method 1694. Data collection was performed by multiple reaction monitoring (MRM) mode using Waters MassLynx software. Standard curves for the analytes were constructed using pure PPCP compounds and used for the quantification of unknown experimental samples.

DNA-based Molecular Methods

Composite soil samples from batch and column experiments were collected for DNA extraction and sequencing. Composite samples were prepared by consolidating multiple samples spatially distributed through the batch or column environment. DNA was also extracted from an operating septic system drain field in Marlborough, Ma and 'virgin' soil from a newly installed septic system drain field in Southampton, MA. DNA extractions were performed using MoBio PowerSoil DNA Extraction Kits following the manufacturer's guidelines. Presence of DNA was verified by agarose gel and the quality of the extracted genomic DNA was assessed using a NanoDrop measuring the A_{260nm}/A_{280nm} and A_{260nm}/A_{230nm} ratios. After genomic DNA quality was verified, samples were sent to Research and Testing Laboratory (Lubbock, TX) for Next Generation Sequencing of the 16S rDNA gene using the Illumina MiSeq platform.

Principal Findings and Significance:

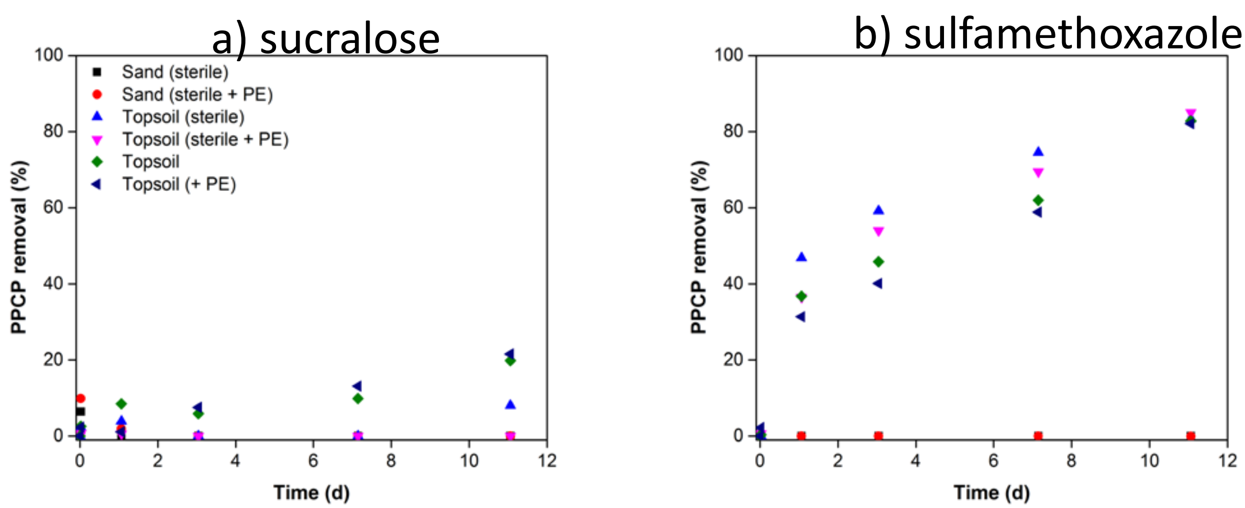
Objective #1: *To assess the impacts of PPCP presence in septic tank effluents on the soil microbial community in drain fields.*

Working hypothesis: A subset of microorganisms within the indigenous soil microbial communities is responsible for the observed PPCP transformation in the septic system drain field. Observed concentrations of individual PPCPs are low enough to not result in significant shifts in the microbial community structure. However, a mixture of multiple PPCPs results in an increase in the overall toxicity to indigenous microbial populations and causes an enrichment of the microbial communities that can transform these complex compounds. Shifts in soil microbiota could have impacts on higher-order organisms within the ecosystem.

Preliminary Batch Results – Removal of PPCPs in soil batch reactors was tested with or without prior inoculation with primary effluent-derived microorganisms. Over a 11-day period, there was little removal of sucralose (Figure 3a) in all soil types tested. Sucralose removal approached 20% after 11 days in reactors containing unmodified topsoil with and without inoculation with primary effluent. These results suggest that sucralose was largely recalcitrant and only slightly removed by soils with higher contents of complex organic compounds as autoclaved soils tend to have more labile organic matter. This removal was likely due to adsorption rather than biodegradation.

Sulfamethoxazole was removed by up to 80% in 11 days in batches containing topsoil but not sand (Figure 3b). Prior inoculation with primary effluent appeared to not have a large effect on removal efficiency of sulfamethoxazole, suggesting that the primary mode of removal was physicochemical adsorption rather than biodegradation. The difference in sulfamethoxazole removal rates over the initial 7 days of the experiment between batches containing autoclaved and unmodified topsoil suggests that its adsorption may be dependent on the chemical nature of the organic matter present in the soil.

Trimethoprim was rapidly and completely removed within 1 day in all batches containing topsoil (Figure 3c). In batches with unmodified topsoil, the complete removal of trimethoprim was observed within 30 minutes of PPCP addition. Trimethoprim was also removed by up to 97% in 11 days in batches containing sand. Primary effluent-inoculated sand samples resulted in a lower trimethoprim removal (80%), possibly due to changes in the surface chemistry of sand particles by the colonization of microorganisms. These results suggest that trimethoprim was removed via physicochemical mechanisms (e.g., adsorption) rather than biodegradation. While these results indicate that physicochemical removal is more likely than biodegradation, these trends were likely due to the chemical characteristics of the three PPCPs tested and the microbial community of the inoculum. The subsequent lab-scale septic system experiments were designed to determine the importance of the microbial community for the fate and transport of a wider variety of PPCPs.



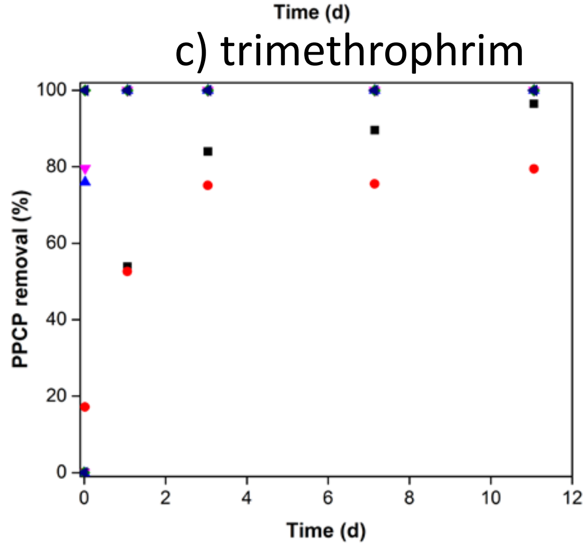


Figure 3. Removal of three PPCPs (a: sucralose, b: sulfamethoxazole, c: trimethoprim) in soil batch reactors over 11 days. All conditions were tested in duplicate reactors. PE: primary effluent.

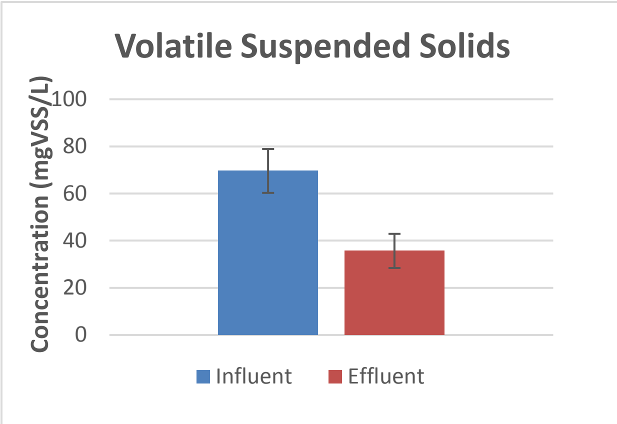
Microbial Ecology of Soil Communities – DNA was extracted from batch microbial communities leach fields and the quality was verified (Table 1). DNA will also be extracted for soil from new and existing septic systems and the column experiments described below. For cost conscientiousness (the greater the number of samples processed, the lower the cost per sample), we are aggregating the DNA extracted from this study from both batch and column experiments and field data to be sequenced one time. At the time this report was written, the raw data results of the sequencing analysis were pending.

Table 1. A Subset of the Quantity and Quality of Extracted Genomic DNA

Sample	DNA Concentration (ng/μL)	A_{260nm}/A_{280nm} (Target: >1.8)
Autoclaved Sand (1)	1.9	2
Autoclaved Sand (2)	1.4	1.9
Autoclaved & Inoculated (1)	1.4	4.4
Autoclaved & Inoculated (2)	2.6	2.1
Untreated Sand (1)	2.5	2.7
Untreated Sand (2)	1.7	2.7
Untreated and Inoculated (1)	4.5	1.7
Untreated and Inoculated (2)	2.3	1.8

Objective #2: *To determine the occurrence and fate of parent PPCP compounds and metabolites of microbial transformation as well as of nitrogen species in septic system drain field soils.*
Working hypotheses: Microbial transformation of PPCPs is not synonymous with removal or detoxification, and metabolites of microbial PPCPs transformation may persevere beyond the drain field. The majority of nitrogen removal occurs via nitrification (biological conversion of ammonia to nitrite and nitrate) in the drain field instead of in the septic tank; the nitrogen removal in drain field soils is not negatively affected by simultaneous PPCP transformation.

Stabilization of Septic Tank Operation- To better understand and confirm transformation of PPCPs in the septic system drain fields, we must first establish the role of the individual components of the septic systems. A lab-based model septic system was constructed including a septic tank, distribution box and 'drain field' soil columns (Figure 2). The septic tank portion of this set-up has been in operation for 6 months. After 4 weeks of stabilization, the septic tank achieved steady-state performance. The primary effluent used as influent for the septic tank contained 80-125 mg VSS/L, 80-150 mg COD/L and a 1-6 mg DO/L dissolved oxygen (DO). The septic tank achieved 49% reduction in VSS and 20% reduction in COD (Figure 4). DO was significant reduced in the septic tank as expected and remained less than 0.2 mg DO/L, near the detection limited of the DO probe.



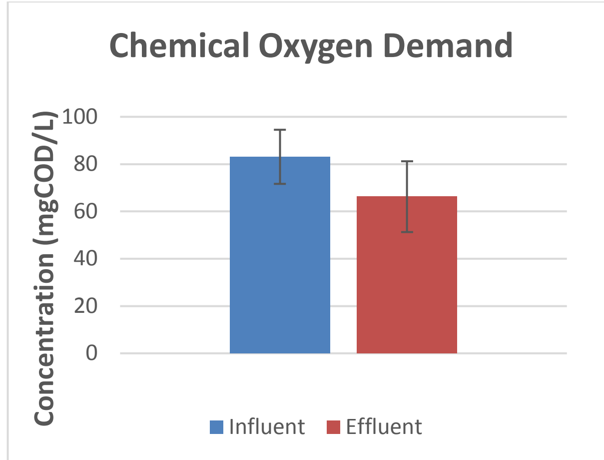


Figure 4. Average volatile suspended solids and COD removal in the septic tank collected over a 6 month period.

Transformation of PPCPs in Leach field soil – Acetate was completely consumed within 10 days of start-up in each of the 4 styles of column configurations each operated in duplicate – 1. autoclaved sand, 2. autoclaved sand inoculated with microorganisms from primary effluent of the Amherst Wastewater Treatment Plant, 3. untreated sand and 4. untreated sand inoculated with primary effluent. As an initial assessment of PPCP transformation potential by the soil and inoculated microorganisms, the soil columns were fed with a synthetic growth media spiked with 100 µg/L of 4 representative PPCPs: ibuprofen, carbamazepine (antiepileptic drug), trimethoprim and sulfamethoxazole (antibiotics). These experiments are currently ongoing. Throughout these experiments, soil samples will be collected and the genomic DNA will be extracted for microbial community analysis. After 2 months of operation with the PPCP-spiked synthetic growth media, the columns will be connected to the lab-based septic tank and fed with tank effluent. The septic tank will be supplied with primary effluent from the Amherst Wastewater Treatment Plant spiked with 100 µg/L of the 4 previously described PPCPs.

Challenges

This project has faced a number of challenges since the award period started in March 2015. The PI, Dr. Butler was on parental leave during the Spring 2015 semester. Co-PI Dr. Ikuma transitioned to a new position at Iowa State University in July 2015. Ms. Washington, the graduate research assistant, struggled academically since she started in June 2015. She was encouraged by the PIs to focus on succeeding in her courses and as a result was less productive with her research. Additionally, a key piece of equipment the UPLC was out-of-service for a period during the Fall 2015 semester and we had unanticipated challenges with DNA extraction procedures in January and February 2016. Had this award been eligible, it would have benefitted from a no-cost extension. We continue to pursue the research objectives outlined in this work and Drs. Butler and Ikuma plan to seek further funding to support efforts to explore microbial transformations of PPCPs in septic systems.

Conclusions and Significance

The goal of this work is to demonstrate the impact of the microbial communities within the drain field in remediating nutrients and detoxifying PPCPs in on-site septic systems. Early data suggests microorganisms play a role in the PPCP transformation in soils associated with septic system leach fields. On-going efforts will elucidate the key microbial communities involved. Non-point nitrogen and PPCP release from antiquated septic systems is not unique to Cape Cod. Seasonal, coastal communities from

Maine to South Carolina with a high septic system usage jeopardize sensitive coastal ecosystems vulnerable to eutrophication and PPCPs effects. Other rural communities relying on septic systems that discharge into potential drinking water sources also pose an elevated risk for both ecosystem and human health. Our long-term research goal is to provide sufficient information on nutrient removal and PPCP detoxification within on-site septic systems. This information could motivate and provide a scientific basis for replacing or repairing antiquated septic systems. Upgrading septic systems in areas that cannot adequately support centralized treatment systems could significantly improve the water quality.

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Student Support:

Lark Washington was partially supported by this project during the 2015-2016 academic year to pursue a Master of Science degree in Environmental Engineering. Ms. Washington was also supported by a Civil and Environmental Graduate Diversity fellowship and diversity resources from the graduate school. Through these efforts, Lark was fully supported for the duration of the project.

Follow-on Funding:

Drs. Ikuma and Butler will be pursuing funding from the Water Environment Research Foundation this summer using the background data acquired through this study. If awarded, this funding would provide up to two years of funding for the support of additional research.

Publications and Conference Presentations:

Ikuma, K., Kim, S., Reckhow, D., Butler, C., 2015, Removal and Transformation of Pharmaceuticals and Personal Care Products by Onsite Wastewater Treatment Systems, Association of Environmental Engineering and Science Professor Conference, Yale University, New Haven, CT June 2015

7. Influence of nutrients on Microcystis blooms in the Charles River watershed (2015MA438B)

Principal Investigator: Pia Moisander, UMass Dartmouth Biology
Start Date: March 1, 2015
End Date: February 29, 2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Water Quality

Problem and Research Objectives:

There were two major goals of this research: 1) to investigate the spatio-temporal distribution of potentially toxin-producing cyanobacteria in the Charles River during the growth season, and 2) to investigate the influence of nutrients on overall growth limitation of phytoplankton in the Charles River, in parallel with relative influence on potentially toxic species of cyanobacteria.

Methodology:

Sample collection and experimental setup

Samples were collected from four stations in the Charles River biweekly from mid-June to the end of October (a total of 9 times) in 2015 (Figures 1, 2).

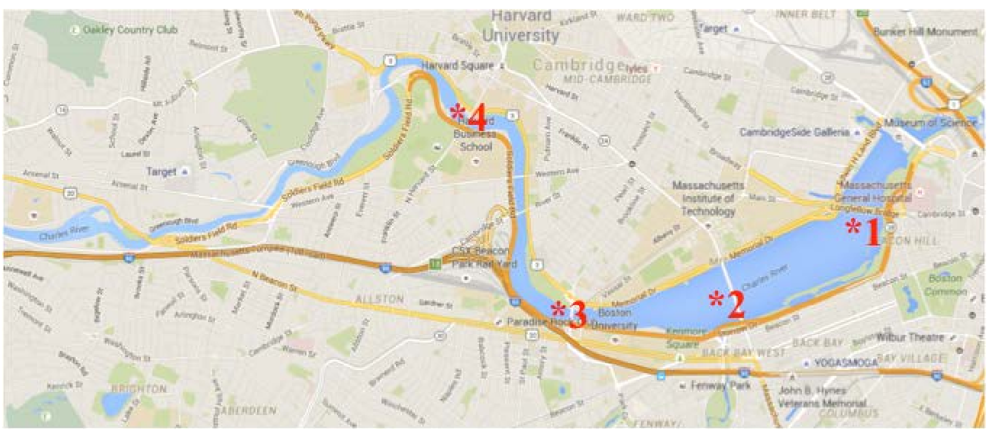

Figure 1. Sampling locations on the Charles River.

The sampling was collected from a small outboard motor boat, in collaboration with the Charles River Watershed Association (CRWA). The samples were collected with a water sampler (Wildco) into acid washed polycarbonate bottles, kept in a cooler with blue ice and immediately brought back to UMass Dartmouth. The water was then filtered to preserve materials for several analyses. For determination of chlorophyll *a* and dissolved inorganic nutrient concentrations, 50 mL of the water sample was filtered on GF/F glass fiber filters that were blotted dry, then frozen in clean microcentrifuge tubes at -20°C. The flow-through was saved in a clean microcentrifuge tube that was frozen at -20°C, to be processed for measurements of inorganic nutrients. For determination of the composition and abundance of potentially toxic cyanobacteria, water was filtered on 0.2 µm membrane filters to collect DNA. The filters were placed in sterile bead beater tubes and immediately frozen at -20°C. In addition, samples were preserved for microscopic observation by preserving 30 mL with Lugol's solution in polyethylene bottles. Subsamples were also filtered on GF/F filters for collection of material for determination of microcystin in the particulate matter. The GF/F filters were frozen in foil packages at -20°C.

Nutrient amendment bioassays were conducted monthly for water sampled from two of the stations. A total of five bioassay experiments were conducted (June, July, August, September, October), of which the June experiment was considered a pilot study (data not shown). For each experiment, 300 mL of water was distributed to 24 acid-washed polyethylene bottles from each site. Six of these bottles per site received either no nutrient additions (control), nitrogen (added as nitrate+ammonium; N), phosphorus (P), or N+P. Triplicates of each treatment from each site were incubated at the light intensity of 55 µmol m^{-2} s^{-1} ("low light"), and the second set was incubated at 129 µmol m^{-2} s-1 ("high light") in incubators at a 15:9 Light:Dark cycle at 25°C, using color temperature 6500K (daylight) light bulbs. The bottles were incubated for a total of 72 h (3d), and the bottles were then removed from the incubation and contents preserved for the same analyses as samples collected during the seasonal time series. We also initiated culture isolates by inoculating samples from blooms into BG-11 or Z80 media, to attempt to enrich non-N_2 fixing or N_2 fixing cyanobacteria, and kept the vials in natural light on a lab window in ambient room temperature. The attempts were successful and we obtained enrichment cultures of *Anabaena* and *Aphanizomenon* spp. (see below, Fig. 3).

Analytical methods

Chlorophyll *a* concentration was measured fluorometrically using previously published methods (Moisander et al. 2010). Briefly, the samples were thawed, then 5 mL of 90:10 acetone:water solution (vol:vol) was added. Samples were briefly sonicated to break the cells using a tip sonicator, then kept in the freezer overnight. The samples were vortexed again, and the extract was then cleared by filtering it through a GF/F filter attached to a syringe filter, then read using a Turner 10-AU fluorometer, and diluted for the measurement if necessary. The dissolved nutrient analyses have been arranged to be conducted at the laboratory of Dr. Brian Howes (School of Marine Science and Technology, UMass Dartmouth). DNA was extracted using previously published methods (Moisander et al. 2008). Briefly, a Plant Minikit (Qiagen) was used with modifications. The first buffer from the kit was first added (lysis buffer), and the samples then underwent three freeze-thaw cycles (10 min at -80°C, then 5 min at 65°C). The samples were then subjected to homogenization in a bead beater (Mini-Beadbeater-8, full speed for 2 min). 45 µL of Proteinase-K solution was added, and the tubes were then incubated for 1 h at 55°C. The rest of the steps followed the manufacturer's protocol. We conducted quantitative polymerase chain reaction (qPCR) to quantify the presence of *Microcystis aeruginosa* in the system through the summer, using previously published methods (Moisander et al. 2012). According to reports from the CRWA, and our microscopic observations, however, the dominant bloom-forming cyanobacteria were *Anabaena* spp. and *Aphanizomenon* spp., both N_2 fixing cyanobacteria that are potentially toxic. Since these reports and observations suggested *M. aeruginosa* was not present or its abundances were lower than the two other cyanobacteria, it was relevant to shift the focus to these major bloom forming species that are also potentially toxic. We conducted PCR targeting the N_2 fixation gene *nifH* to characterize the major N_2 fixing components in the blooms.

Principal Findings and Significance:

The data from the seasonal time series showed that there was an increase in overall phytoplankton biomass at the downstream stations 1 and 2 until mid-September, after which the biomass rapidly decreased to early season levels (Figure 2). These two stations, located in the wider, more slow flowing part of the river (Figure 1), developed the highest phytoplankton biomass of the four stations. Stations 3 and 4 that were located in the narrow part of the river had a more similar pattern, with a relatively stable maximum biomass from mid-August to mid-September. These data suggest that the downstream, wide portion of the river was more susceptible for developing bloom conditions during the late summer than the upper, riverine sections.

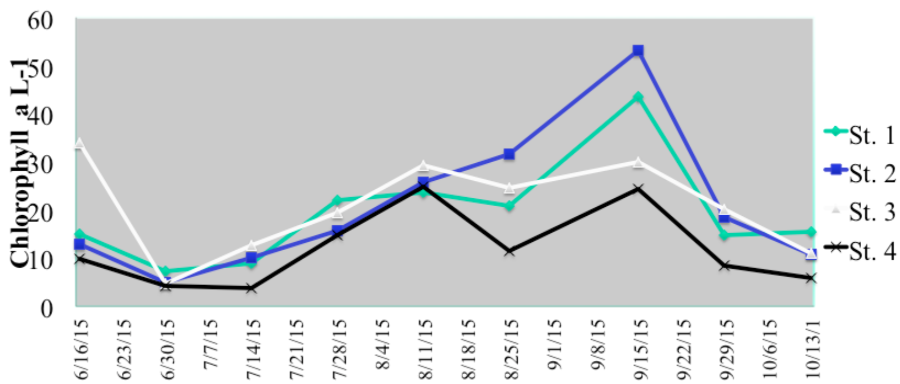

Figure 2. Chlorophyll *a* concentration (L^{-1}) in the Charles River through the summer and fall of 2015 at the four stations.

After alignment with known, previously published culture isolates and environmental samples, sequences recovered from the samples and enrichment cultures fell into several clusters (Figure 3). One of the clades was closely related with previously published *Anabaena aphanizomenoides* and *A. sphaerica* cultures. A second clade fell in a cluster with closest relatives of *Aphanizomenon*. A third cluster containing sequences both from our enrichment culture and a sample from the time series was most closely related with other previously reported *Anabaena* spp. A few *nifH* sequences were present that matched non-cyanobacterial reference sequences, suggesting presence of potentially N_2-fixing heterotrophic bacteria or archaea. This result allowed us to compare the sequences to current quantitative PCR primers and probes we have in our lab and we determined that the Charles River populations are distinct from these. Quantifying the *Anabaena* and *Aphanizomenon* in our samples would thus require developing new qPCR assays. This was beyond the scope of this study but we hope to continue characterizing the samples and the Charles River *Anabaena* and *Aphanizomenon* with follow-up funding.

Although reports from CRWA and our own general microscopic surveys suggested that *Microcystis* was not a dominant cyanobacterium in the blooms, we wanted to check for its presence using quantitative PCR. qPCR specific to the *Microcystis aeruginosa cpc*BA (phycocyanin gene intergenic spacer) was conducted to determine abundances of *M. aeruginosa* on the seasonal time series (Figure 4). Surprisingly, the results showed presence of *M. aeruginosa* at all stations. The highest abundances were detected at stations 1 and 2 – the two downstream sites. The highest abundances in Station 2 occurred during the highest phytoplankton abundances in August and September, but at station 1 the abundance increased already in July (Figure 4). Ongoing work is investigating responses of *Microcystis* in the bioassay experiments under the different nutrient additions.

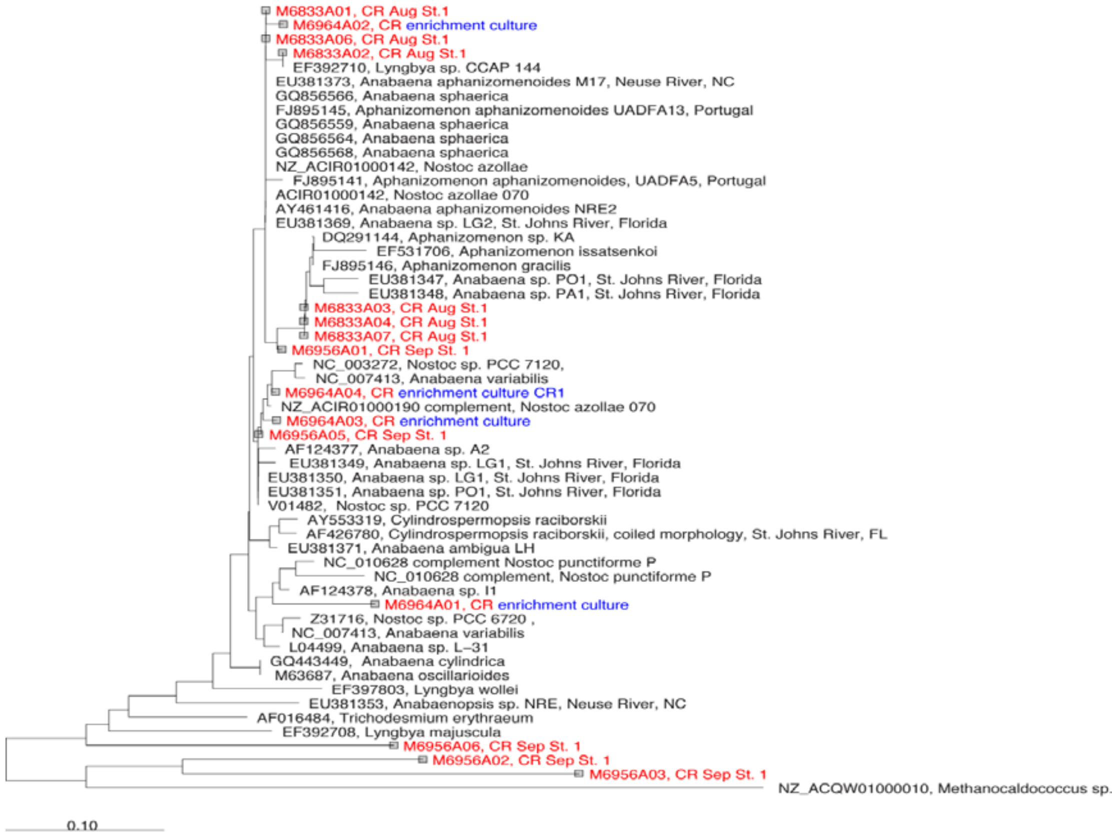

Figure 3. Phylogenetic neighbor-joining tree showing the relationship of *nifH* sequences from samples collected from the Charles River (CR), with previously published sequences from the public databases (NCBI, GenBank). The CR sequences are shown in red and sequences from our enrichment cultures are in blue.

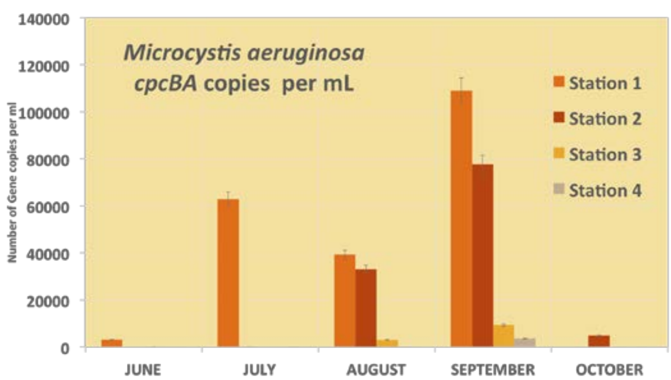

Figure 4. Abundance of *Microcystis aeruginosa* during the summer season of 2015 in the Charles River based on quantitative PCR (copies of *cpc*BA mL^{-1}). The numbers shown are based on preliminary analyses. Each gene copy corresponds to approximately one cell, with the assumption that there is one genome per cell.

The enrichment experiments showed variability in responses to nutrients and light (Figure 5, Table 1). The data show that throughout the season, phytoplankton increase was observed if both N and P were provided. However, the primary nutrient limiting phytoplankton growth varied through the season. P was the primary nutrient limiting phytoplankton growth during early and late season, while N limitation was observed at both stations in August or September (Table 1, Figure 5). Interestingly, N limitation was seen only in low light in August, and only in high light in September, suggesting light and nutrient availability in combination influenced competitive fitness of different phytoplankton species.

Table 1. Summary of nutrient limitations observed under low and high light. Shaded boxes show significant differences based on results from one-way ANOVAs (tested separately for each light level and site).

	Low light			**High light**		
	N	**P**	**NP**	**N**	**P**	**NP**
July station 1		■	■		■	■
July station 3		■	■			■
August station 1	■		■			■
August station 3	■		■			■
Sept station 1			■	■	■	
Sept station 3			■	■		■
Oct station 1			■			■
Oct station 3		■	■		■	■

Figure 6: Field Sampling on the Charles River

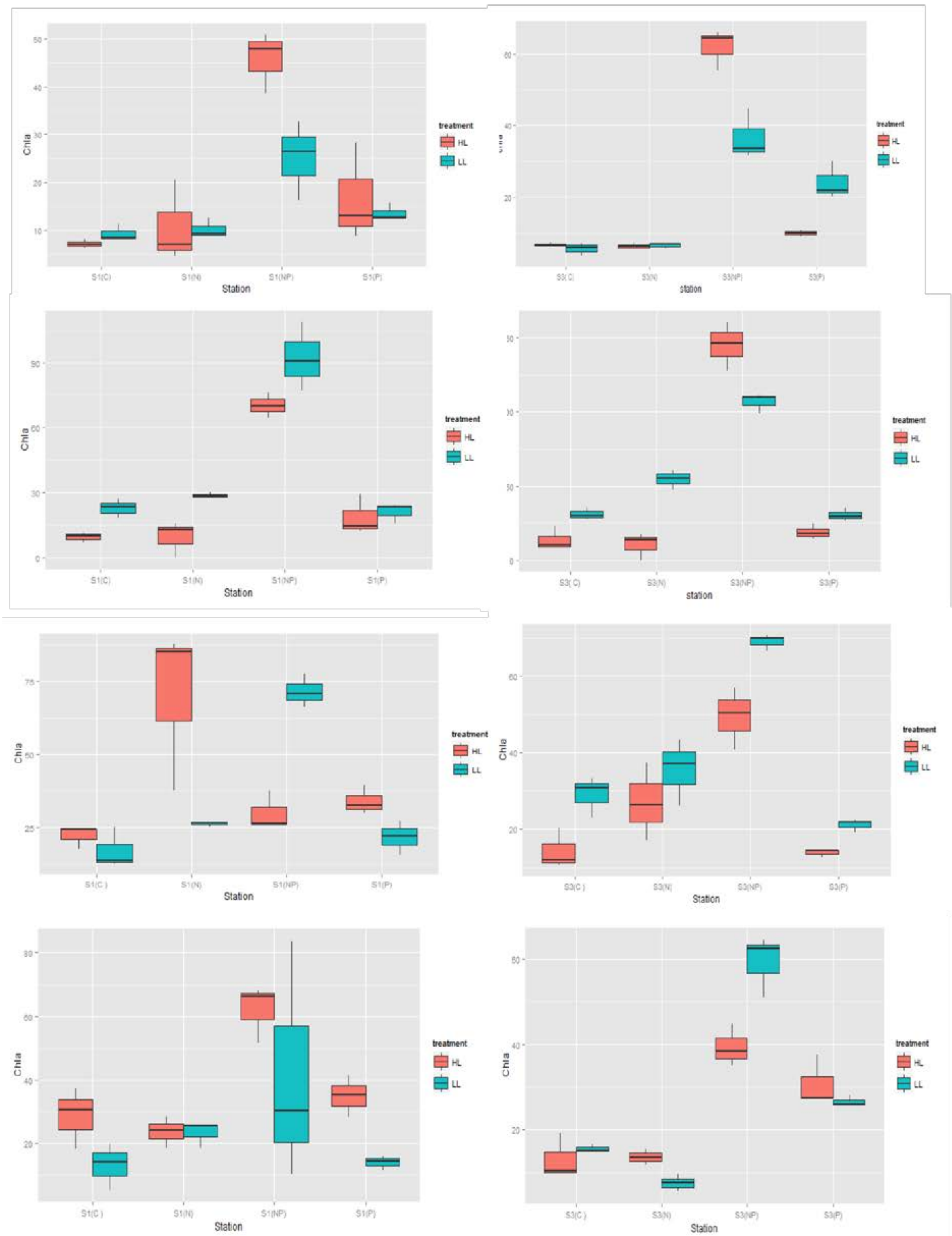

Figure 5. Chlorophyll *a* results from the bioassay experiments shown with box plots. Left panels: station 1; Right hand side panels: Station 3. July, August, September, and October experiments are shown from top to the bottom. C, control; N, nitrogen addition; P, phosphorus addition; NP, N+P addition; LL, low light; HL, high light (Kaushik et al., in prep).

References:

Kaushik K, Cianciola E, Moisander, PH. *In preparation*. Influence of nutrients and light intensity on cyanobacterial blooms in a temperate urban river. To be submitted to Harmful Algae

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Student Support:

Kate Massoud, a University of Massachusetts Dartmouth undergraduate majoring in Biology (rising Junior during the summer of 2015) was supported from these funds during the summer of 2015. She conducted the majority of the field sampling and contributed to the sample processing in the lab. Kumari Kaushik, a graduate student in the Biomedical Engineering and Biotechnology at University of Massachusetts worked on the project. She is pursuing a M.S. degree at the University of Massachusetts Dartmouth. She completed the majority of the lab analyses and the experimental work in the lab. Ms. Kaushik received some additional support from the Department of Biology toward this research. While conducting the research she was enrolled in the program with research credits but her tuition, fees, and stipend were not covered from this award. She will be completing her M.S. degree in the Fall of 2016. Meaghan Daley (M.S., research technician at the University of Massachusetts Dartmouth) contributed to the field sampling in this project, with funds from this award. Ms. Daley is a recent graduate (M.S. degree) from the University of Massachusetts Boston.

Four different interns supported by the Charles River Watershed Association, coordinated by Elisabeth Cianciola at CRWA, helped with the field sampling.

Follow-on Funding:

I submitted a pre-proposal to the Massachusetts Environmental Trust in the fall of 2015 proposing follow-up work, but this proposal was not invited for a full proposal. Future funding will be pursued to MET and other regional and federal opportunities. Ms. Kaushik also received $500 from the UMass Dartmouth toward this research. The Community Rowing, Inc. (Brighton, MA) provided access to a boat and the gas for the field sampling.

Publications and Conference Presentations:

Kaushik K, Cianciola E, Moisander PH (in preparation), Influence of nutrients and light intensity on cyanobacterial blooms in a temperate urban river. To be submitted to *Harmful Algae.*

Kaushik K, Moisander PH*. Influence of nutrients and light intensity on toxic and non-toxic cyanobacterial blooms in the Charles River, MA*. Sigma Xi conference, North Dartmouth, MA, Apr 2016. *Poster.*

8. Removal of water-borne pathogens and heavy metals using novel biogranules (2015MA440B)

Principal Investigators: Chul Park, UMass Amherst Civil and Environmental Engineering, and Yasu Morita, UMass Amherst Microbiology
Start Date: 3/1/2015
End Date: 2/29/2016
Reporting Period: March 1, 2015 – February 29, 2016
Funding Source: USGS (104B)
Research Category: Water Quality

Problem and Research Objectives:
Pathogens and heavy metals are primary threats to water quality around the world. Each year, water-borne diseases cause over four billion episodes of human illness and 1.8 million deaths, mainly due to drinking water contaminated with pathogens and heavy metals[1]. In the Northeast U.S., combined sewer overflows (CSOs) due to aging sewer infrastructure, and rural runoffs take place regularly and are the primary sources that deposit pathogens and heavy metals into surface water[2]. Since surface water, including river water, is the main source of drinking water in the region[2], these contaminant-laden runoffs pose a risk for water-borne diseases and threaten public health.

In algae-based processes, algal biomass could directly or indirectly remove pathogenic microorganisms and heavy metals from wastewater, providing an opportunity to remove the two most potent pollutants together, which cannot be achieved by the activated sludge process. However, ineffective separation of algal biomass from water has limited our ability to use algae-based processes for centralized domestic wastewater treatment or decentralized systems with limited land availability. We recently developed the oxygenic photogranule process in which algae and bacteria make easily-settling granular biomass[3], thus enabling us to overcome challenges associated with both algae-based and activated sludge processes. During our preliminary research, we recognized a significant potential of photogranules to remove pathogens and heavy metals from wastewater due to unique genetic, physiological, and physicochemical characteristics of algae and bacteria cohabitating in granular biomass.

The main objectives of this research were to investigate the removal of pathogens and heavy metals from wastewater using photogranules and to develop the oxygenic granule process for both central and decentralized systems to treat wastewater. To accomplish our objectives, we convened a research team composed of researchers from Environmental Engineering and Microbiology departments at the University of Massachusetts Amherst. The specific aims of this interdisciplinary research were to:

1) Study the heavy metal removal by the oxygenic photogranule process.
2) Study the efficacy of photogranules in inactivating water-borne pathogenic microorganisms.
3) Investigate continuous wastewater treatment by the oxygenic photogranule process.

Methodology:
1. Operation of the oxygenic photogranule process
We have operated two oxygenic photogranule systems in the laboratory to treat primary effluent wastewater from a local wastewater treatment plant (WWTP) and to produce photogranule biomass that can be used to study the removal of pathogens and heavy metals. The system was operated in lab-scale glass reactors with a working volume of 1.5 L. The system treated 2 L of wastewater each day corresponding to 0.75 d hydraulic retention time (HRT). There were four cycles of wastewater treatment per day. Each cycle (6 h) consisted of settling, decanting, influent feeding, and reacting periods. Each cycle also had periodic light cycles of 3.5 h/2.5 h light/dark conditions. We regularly characterized

photogranule biomass and measured several water quality indicators for both influents and effluents to study the maintenance and performance of the oxygenic photogranule process.

2. Sampling of influent and effluent of the full-scale activated sludge system

To compare the effectiveness of removing pathogens and heavy metals between the oxygenic photogranule process and conventional activated sludge system, we also conducted regular sampling and analysis of influents and effluents from a local WWTP operating the activated sludge system. Note that we used the primary effluent wastewater to feed the bench-scale oxygenic photogranule system. This primary effluent is also the feed to the activated sludge system in a full-scale WWTP. Hence, we could compare removal efficiency based on the same source of wastewater treated in the field by the activated sludge process and in the laboratory by the bench-scale oxygenic photogranule process.

3. Enumeration of pathogenic bacteria using culture-based measurement

Microbial indicators for pathogenic bacteria, including total coliforms, fecal coliforms, and fecal *Streptococci*, were quantified in both influent wastewater and effluent water samples. Samples were collected in 50 mL sterile plastic tubes. All samples were brought to the microbiology laboratory and processed in a dark box within one hour of collection. Selective growth media for three different bacterial groups were freshly prepared, poured into sterile petri dishes and left to solidify. Using the membrane filtration technique, 1 mL of serially diluted samples was filtered and placed onto the plate. Plates were incubated at 37 ˚C (for total coliforms, fecal *Streptococci*) and 45 ˚C (for fecal coliforms) for 24-48 h. The number of growing colonies was counted and recorded based on Standard Methods[4]. The total bacterial count (cfu/100 mL) was finally calculated as follows:

$$\text{Bacterial colony }/100\text{ ml} = \frac{\text{Bacterial colony counted}}{\text{ml of sample filtered}} \times \frac{\text{Number of colony right in confirmatory test}}{\text{Number of total confirmatory test colony}} \times 100$$

4. Enumeration of pathogenic bacteria using non-culture based technique

For non-culture based microbial enumeration, we used the quantitative PCR (qPCR) technique during this research project. Both influent and effluent samples were collected and processed through a 0.22 µm PVDF membrane filter. The membranes were re-suspended in sodium chloride Tris EDTA (STE) buffer with 1% SDS. DNA was extracted from each filter by phenol/chloroform extraction procedure. An extra DNA purification step was done using Genomic DNA Clean & Concentrator-10 (Zymo Research). The samples were then diluted for quantitative analysis. qPCR was performed using the various primers (Table 1), and Apex qPCR 2x Master Mix Low ROX. The Mx3005P Real Time PCR system was used and data was analyzed with MxPro QPCR software. The DNA calibration curves were generated with the appropriate sets of DNA (extracted *E. coli* gDNA was used for *E. coli* primers) for each primer set to determine relative amounts within each water sample. The thermocycle was set for 40 cycles of 95 °C for 30 s, 59 °C for 1 m, and 72 °C for 1 m.

5. Heavy metals determinations

Influent and effluent samples of the oxygenic photogranule reactor were collected three times a week for heavy metals analysis. Water samples were filtered through a 0.45 µm membrane syringe filter and acidified using nitric acid (HNO_3) to adjust to a pH value of 3-4. The samples were stored in acid-washed plastic tubes. Concentrations of heavy metals were measured using Inductively Coupled Plasma Mass Spectrometer system (ELAN ICP-MS, PerkinElmer) as shown in Standard Methods[4].

Table 1. Various primers used for the qPCR analysis in this research.

Primer			Reference
16S rRNA	F	CCGGATCCGTCGACAGAGTTTGATCITGGCTCAG	Rawlings, 1995[5]
	R	CCAAGCTTCTAGACGG ITACCTTGTTACGACTT	
E. coli uidA	F	ACGCGTGGTTACAGTCTTGCG	Maheux *et al.,* 2009[6]
	R	AAAACGGCAAGAAAAAGCAG	
Enterococcus	F	TCA ACC GGG GAG GGT	Layton *et al.,* 2010[7]
	R	ATT ACT AGC GAT TCC GG	
Enterococcus faecalis SodA	F	ACT TAT GTG ACT AAC TTA ACC	Layton *et al.,* 2010[7]
	R	TAA TGG TGA ATC TTG GTT TGG	

Principal Findings and Significance:

1. Investigate the oxygenic photogranule system for wastewater treatment.

We evaluated the use of oxygenic photogranules for wastewater treatment. Two sequencing batch reactors were seeded with granules and fed with primary effluent wastewater collected from a local WWTP. Because of oxygenic activity of photogranules, the reactors were operated without external aeration (i.e., mechanical aeration). Dissolved oxygen during the light period ranged between 0.4–3.8 mg/L. Photogranules settled rapidly with an average settling velocity of 6.0±1.6 m/h. This enabled us to operate the system with 15 min of settling, compared to 2–3 h in the activated sludge process, potentially reducing the footprint of wastewater treatment. The combination of rapid biomass settling and continuous generation of photogranules permitted the complete decoupling of hydraulic retention time (0.75 d) and solids retention times (21–42 d), allowing for a high-rate wastewater treatment based on volumetric loads.

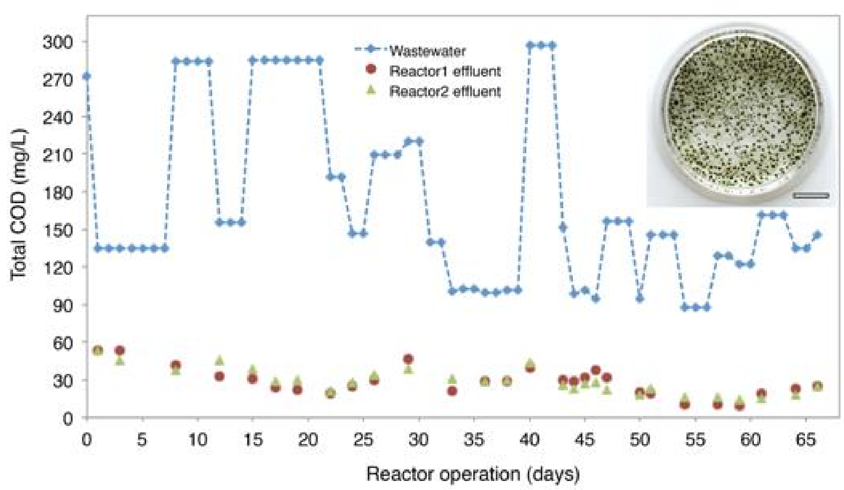

Figure 1. Oxygenic photogranules for wastewater treatment. Removal of chemical oxygen demand (COD) by two bench-scale oxygenic photogranule reactors without aeration. The reactors were operated in four cycles per day with 2.5 h/3.5 h dark and light periods. The HRT was 0.75 d, treating primary effluent wastewater collected from a local wastewater treatment plant. Inserted is the photo of reactor oxygenic photogranules in a petri dish. Scale bar is 1 cm.

The reactor operations tested achieved effective wastewater treatment. Despite fluctuation in influent, the average effluent total chemical oxygen demand (COD) was below 30 mg/L, meeting typical requirements for municipal wastewater treatment in the developed world (Figure 1).

2. Removal of pathogenic bacteria

Microbial enumeration based on both standard culture method (Figure 2) and qPCR analysis (Figure 3) showed that the oxygenic photogranule system achieved higher efficiency in the removal of pathogenic bacteria compared to the activated sludge system at the local wastewater treatment plant.

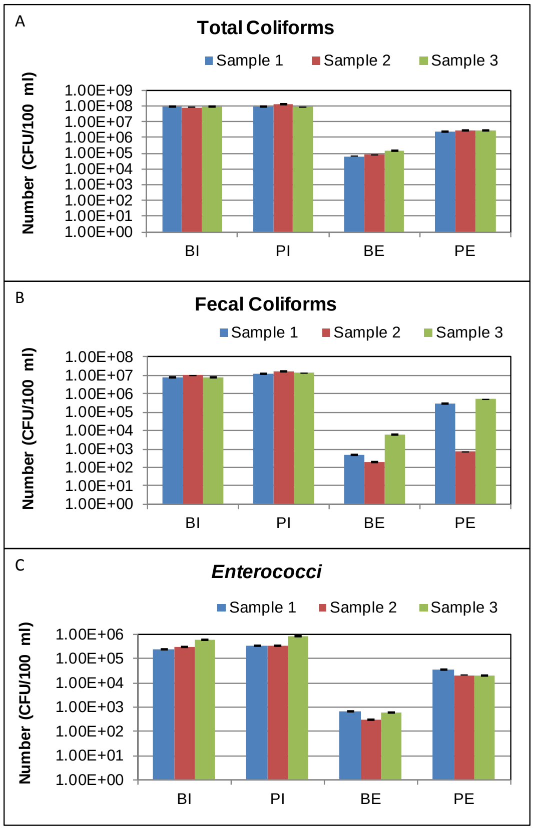

Figure 2. Counts (CFU/100 mL) of total coliforms, fecal coliforms and *Enterococci* bacteria in influent and effluent samples of the oxygenic photogranule system treating real wastewater compared to the activated sludge system at a local wastewater treatment plant. A) Total coliforms. B) Fecal coliforms. C) *Enterococcci* bacteria. Sample 1, Sample 2 and Sample 3 represent three independent sampling points that were taken in three different days during the operation. BI: bench-scale photogranule system influent, BE: bench-scale photogranule system effluent, PI: Plant influent (field activated sludge system), PE: Plant effluent (field activated sludge system).

Based on the culture-based method, the oxygenic photogranule system removed a considerably higher quantity of fecal coliform and *Enterococci* bacteria than the activated sludge process. Particularly for fecal coliform bacteria, the bench-scale oxygenic photogranule system showed removal efficiency greater than 99.99%. This highly effective removal of fecal coliform bacteria by the oxygenic photogranule process is supported by the similar removal efficiency shown by the qPCR analysis for E. *coli*. These results support our hypothesis that the microalgal community in photogranules led to the effective removal of pathogenic bacteria indicated by fecal coliform bacteria. Examples from the literature also support our observations. Araki et al. (2000)[8,9] showed that environmental factors that were favorable for algal growth were unfavorable for the living of coliform bacteria. In addition, extracellular substances secreted by cyanobacteria and algae could inactivate coliform bacteria and certain pathogenic bacteria (Moawad, 1968)[9]. Chlorella, one of the major green algae species present in the photogranule, are also known to produce and release natural antibiotics, termed chlorellin, which exhibit inhibitory activity against certain types of bacteria, including fecal coliform bacteria and human pathogen *Staphylococcus aureus*[11,12]. Our results and examples from the literature, therefore, suggest that the oxygenic photogranule process has greater efficiency of removing pathogenic bacteria compared to the activated sludge system.

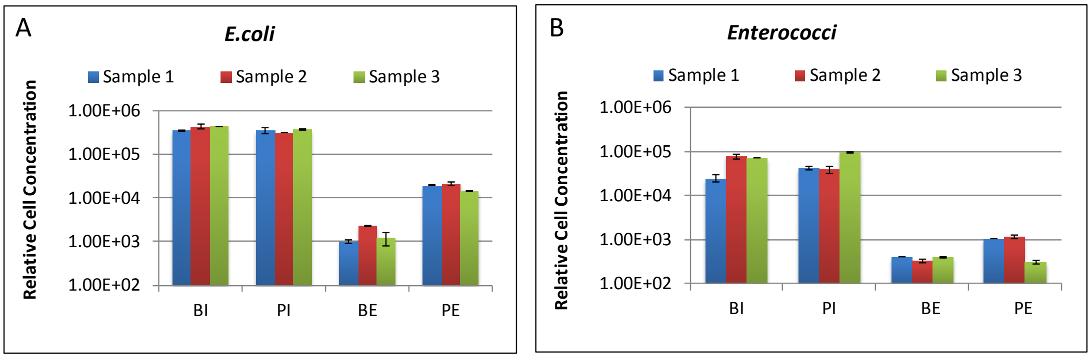

Figure 3. qPCR analysis of influent and effluent samples from the oxygenic photogranule system treating real wastewater compared to activated sludge system at the local WWTP. A) Relative abundance of *E. coli* from each sample. B) Relative abundance of *Enterococcus*. Sample 1, Sample 2 and Sample 3 represent three independent sampling points that were taken in three different days during the operation. BI: bench-scale photogranule system influent, BE: bench-scale photogranule system effluent, PI: Plant influent (field activated sludge system), PE: Plant effluent (field activated sludge system). The relative cell concentration represents a prediction for the number of cells/mL in each sample.

3. Removal of heavy metals by the oxygenic photogranule process

The heavy metal concentration in influent wastewater, to both bench-scale oxygenic photogranule and field activated sludge systems, was on average 171, 152, 64, and 34 µg/L for Fe, Mn, Zn, and Cu, respectively (Figure 4): the ranges of these heavy metals in influent wastewater were 85-274, 100-198, 29-204, and 16-59 µg/L. Although heavy metals are potent inhibitors of enzymes involved in photosynthesis, some species of algae and cyanobacteria are able to sequester them by adsorption and avoid toxic effects of heavy metals (Ginn and Fein, 2008[13]). Our photogranule system showed a higher efficiency of removing heavy metals compared to the activated sludge process. We found that the removal efficiency of the photogranule system for various heavy metals was 94-96% for Mn, 76-80% for Fe, 79-70% for Zn, and 49-54% for Cu, all of which were greater than the removal efficiency shown by the activated sludge system (Figure 4). These results also suggest that the oxygenic photogranule process can solve the current bottleneck in the field of sorption of heavy metals because previous physical and chemical treatment methods are expensive and ineffective for removing low concentrations of heavy metals from wastewater.

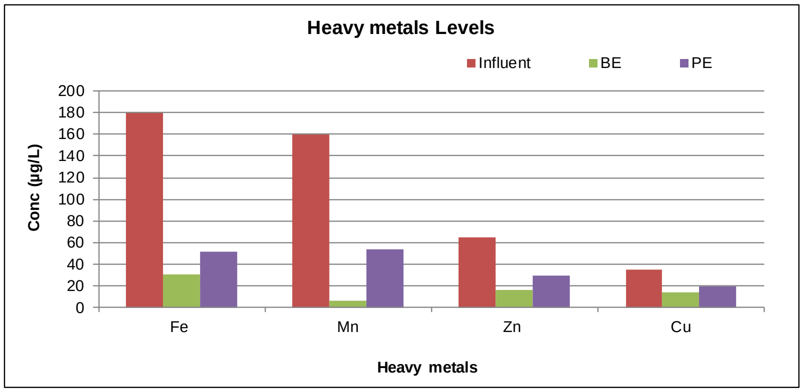

Figure 4. Levels of heavy metals in influent and effluent samples from oxygenic photogranule systems treating real wastewater compared to the activated sludge system at a local wastewater treatment plant. Influent: influent wastewater, BE: effluent of the bench-scale oxygenic photogranule system, PE: Plant effluent (activated sludge).

Overall, the current research has shown promising results that the oxygenic photogranule process can be used for treating wastewater without mechanical aeration, which currently causes the highest energy demand in wastewater treatment. Effective settling and removal of photogranules from water has also enabled us to operate the photogranule process in a high-flowrate wastewater treatment, overcoming the major challenge associated with previous algae-based wastewater treatment processes. This research also conducted two sub-studies designated to investigate the removal of pathogenic bacteria and heavy metals from wastewater using the oxygenic photogranule process. Due to unique physicochemical and biological properties of photogranules, we were able to demonstrate that the photogranule system provides an excellent means to remove these two most potent water pollutants effectively, which cannot be achieved by the traditional activated sludge system. The current research has provided a meaningful foundation for our ongoing and future research on the oxygenic photogranule process for wastewater treatment along with removing potent wastewater pollutants.

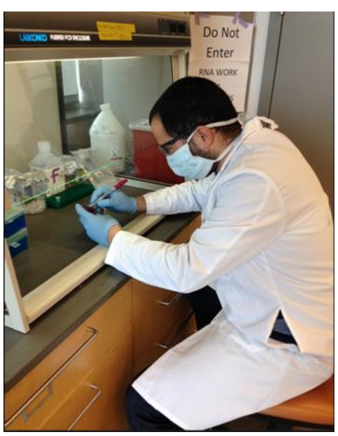

Figure 5: Ahmed Abouhend (Ph.D. student, Civil and Environmental Engineering) preparing microbial enumeration of pathogenic bacteria

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Student Support:

1) Abeera Ansari: Ph.D. student, Department of Civil and Environmental Engineering, University of Massachusetts Amherst
2) Ahmed Abouhend: Ph.D. visiting student, Department of Civil and Environmental Engineering, University of Massachusetts Amherst
3) Kathryn Rahlwes: Ph.D. student, Department of Microbiology, University of Massachusetts Amherst

Notable Achievements and Awards:

Dr. Chul Park from Civil and Environmental Engineering and Dr. Yasu Morita from Microbiology established their interdisciplinary collaboration through the current research project. The project also supported underrepresented minority students, including two female students working toward their PhD degrees and two international graduate students from Asia and Africa.

Follow-on Funding:
The PIs are currently working to submit research proposals developed from the current project to the national and international funding agencies. One proposal will be submitted to NSF and the other will be submitted to the private foundation programs that support research work designated for improving sanitation in less developed countries.

Publications and Conference Presentations:
Abouhend, A., Rahlwes, K., Morita, Y., and Park, C. (In preparation) Removal of pathogenic microorganisms and heavy metals in wastewater using the oxygenic photogranule process. To be submitted to *Water Research*.

Over this summer, we will also submit the abstracts to the regional and national conferences focusing on water quality. These conferences are WEFTEC (Chicago, September 2017) and NEWEA (Boston, January 2017).

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9. RiverSmart Communities and Federal Collaborators: Attuning Federal Agencies and Programs with the State, Regional, and local Efforts to Support Ecologically Restorative Flood Prevention and Remediation in New England (2014MA433S)

Principal Investigator: Eve Vogel, UMass Amherst Geosciences
Start Date: 1/27/2014
End Date: 8/7/2016
Reporting Period: July 1, 2015– June 30, 2016
Funding Source: USACE IWR through USGS (104S)
Research Category: Climate and Hydrologic Processes

Problem and Research Objectives:

The Problem: Damaging River Floods, and Three Fundamental Challenges.
New England residents, landowners, infrastructure and businesses located along the region's often-narrow river valleys are frequently impacted by damaging floods that accompany heavy rains. Tropical Storm Irene was but one recent, drastic event; in 2011 in Vermont alone it affected 500 miles of state highways, 200 bridges, 960 culverts, and caused more than $175 million of damage. Damaging floods are likely to become more common and costly, as climate scientists predict more intense storms and increased annual precipitation in the Northeast.

Unfortunately, three fundamental challenges make managing floods and addressing flood damage particularly challenging in New England. First, common structural approaches to flood mitigation and post-flood restoration in the region can increase flood hazards downstream, and re-create infrastructure vulnerable to future flood events. These approaches also often are environmentally damaging and require increased expenditures for environmental mitigation and restoration.

Second, jurisdictional authority is particularly fragmented in New England, because of the history of early small town settlement and incorporation, and the "home rule" traditions of several of the states. There are over 1500 towns and cities in the six New England states, each of which has at least some independent authorities over land and water use and regulation. Many of these have only a few hundred residents, and operate with volunteer governing bodies and only skeletal staff. Jurisdictional fragmentation is also more challenging because the federal government, which often plays a unifying role in river management in other parts of the country, has historically played a relatively small and distant role here, partly because the region was developed before the rise of many major federal land and water agencies, and partly because of frequent political insistence on state and local independence.

The third fundamental challenge is that governmental agencies at all levels as well as nonprofit agencies are facing a funding squeeze from reduced federal and state government budgets.

Objective: Ecologically restorative flood prevention and remediation, based on fluvial geomorphological science, met through collaborations that stretch from local municipalities to federal agencies and programs

The following are three strategies, which address each of the challenges listed above:

a. Advance ecologically restorative flood prevention and remediation by orienting policy and practice to work with natural dynamic river processes;
Flood mitigation and protection can work *with*, rather than against, natural fluvial and geomorphological processes. The approach is to allow much-increased water and sediment sufficient room to flow, by building large-enough culverts and bridge spans; and to allow rivers to spread out and move laterally during major flood events wherever possible, by protecting river "corridors" or "meander belts." This approach is founded on the science of fluvial geomorphology. It can provide longer-term flood protection and concurrently support environmental, fish, and wildlife goals.

b. Collaborate with and across a wide array of jurisdictions and agencies in ways that are effective and accessible, from small remote New England municipalities to federal agencies.
In New England, in order to achieve ecologically restorative flood hazard management, collaborations must be accessible even to small remote and rural municipalities, which often bear the worst flood damage. Though these communities have both the need and the jurisdictional authority to manage land and water resources, they often lack needed institutional capacity, and technical and financial resources. Federal agencies, in contrast, often have capacity and some resources, but may not be able to provide individualized support and response for every community. Systems of nested and interconnected inter-agency relationships are needed to link these.

c. Build institutions and approaches that can achieve better ecologically restorative and flood prevention results with limited budgets.
Both of the above strategies must be accomplished with limited budgets, and fortunately, can also be resource-efficient. Inter-agency collaborations can use resources in complementary rather than repetitive ways, and target resources where they can provide the greatest benefit. Flood risk assessment, remediation and prevention that are shaped to predict and adapt to natural dynamic river processes can last long-term without the need for costly structural repairs or the risk of amplified downstream damage.

The importance of federal agencies and programs – including FEMA, USACE, NRCS, USFWS and others – is clear. However, research has suggested that several of these agencies and programs are perceived or experienced by people working in small, often remote New England towns as cumbersome, ineffective and difficult to access.

A project objective is to advance improved coordination and mutual assistance between federal agencies and federal programs, on the one hand, and local, state and regional ones on the other. Federal programs have a great deal to offer; with multi-level coordination, education and attention to the needs of specific localities, these resources can be made accessible to and effective for small communities.

Methodology:

A. RiverSmart Communities and Federal Collaborators: Model Case Studies.

Researchers are preparing a report of three case studies analyzing collaborations in which federal agencies and programs have worked successfully with state, regional, local and/or nonprofit efforts in New England to promote ecologically restorative flood prevention and remediation. In each of the case studies, federal agencies and programs meet one or more of the three fundamental challenges listed at the start of this section. Our research is oriented toward understanding specifically how they achieve these results – with what institutional structures, programs, funding mechanisms, etc. specifically, they:

a) Advance ecologically restorative flood prevention and remediation by orienting policy and practice to work with natural dynamic river processes;
b) Collaborate with and across a wide array of jurisdictions and agencies in ways that are effective and accessible, from small remote New England municipalities to federal agencies;
c) Employ approaches that can achieve better results with limited budgets.

Case Study 1. US Army Corps of Engineers New England District / The Nature Conservancy (TNC-USACE) Connecticut River Partnership – barrier-crossing collaborations with demonstrated analytical and policy success

Project summary: Under two partnerships, the USACE New England District and TNC are working together to provide more natural river flows, functions, connectivity and habitat. There have been two key efforts thus far: developing a basin-wide hydrologic flow model, and rewriting road-stream crossings standards for ACOE permits across New England. The flow model and its analyses may help develop new flow strategies for management of the ACOE's flood control dams, as well as other major dams in the basin. The model is also being applied in the current FERC relicensing process of five privately owned mainstem hydropower projects. The road-stream crossings standards are now in use by ACOE permitting in all six New England states.

Our investigations: We are investigating how and with what institutional, programmatic and on-the-ground effects TNC and USACE have been able to work with each other as well as across an array of stakeholders and jurisdictions.

Case Study 2. USACE Silver Jackets Program: Federal collaborators helping to manage flood hazard risk.

Project summary: The USACE's Silver Jackets (SJ) program brings together federal agencies, including USACE and FEMA, with state and sometimes regional and local agencies, into a unified forum to address a state's flood hazard risk management priorities. Teams are state-based and led. SJ provides a formal and consistent structure and support for interagency collaboration. Significantly for our purposes, the Silver Jackets approach emphasizes addressing "life-cycle flood risk."

Our investigations: We are investigating possible benefits and approaches for SJ in New England. Among New England's six states, New Hampshire has the most active team, which uses the name Post Incident Response and Recovery Team, or PIRRT. We are examining the process by which PIRRT was established, its early activities, and results thus far. We are also investigating how further development of SJ teams in

New England might improve inter-jurisdictional coordination and river flood prevention and remediation.

Case Study 3. NRCS: Providing communities with Easy-to-Access Technical and Financial Support
Project summary: The Natural Resource Conservation Service (NRCS) works directly with towns, conservation districts or other political subdivisions, when neither the state nor the local community is able to repair a damaged watershed by itself. Our interviews in the Deerfield River suggest that among federal agencies, the NRCS is perceived as particularly accessible, responsive, efficient and cost-effective by community leaders.

Our investigations: We are investigating the factors contributing to NRCS success in serving local communities and how replicable these factors might be. What institutional structures and relationships, policies and programs make the NRCS so readily accessible and responsive to community leaders in the Deerfield watershed, and so efficient and low-cost? Do NRCS projects also meet the goal of making post-flood recovery attuned to natural river processes?

B. RiverSmart Communities and Federal Collaborators: Applied Flood Prevention, Mitigation and Remediation Conversations with Communities.
Researchers participated in a series of community meetings and interviews. From those, they distilled first community needs and ideas related to flood prevention, mitigation and remediation in an applied setting, the Deerfield River watershed (VT and MA), then federal agency and legislative opportunities, constraints, and possible solutions to better meet these needs or follow these ideas.

Community Conversations about Irene: voices from the watershed.
Researchers conducted interviews with and/or attending meetings of town select boards, regional agencies, and state and federal agencies and NGOs already working closely within the Deerfield river watershed, particularly those who have been involved with Tropical Storm Irene issues. Discussions focused on local experiences, perspectives and lessons learned on the three fundamental challenges and solutions to advancing ecologically restorative flood prevention and remediation. Community representatives discussed their assessments and experience, emphasizing data and assessments of on-the-ground needs, their technical and funding needs, experience with federal agency assistance, and their thoughts about how federal agencies could more readily meet the three fundamental challenges identified by this project. Using examples from the Deerfield River, community members distilled recommendations for federal agencies to meet the three challenges to ecologically restorative flood prevention and remediation.

***C. RiverSmart Communities & Federal Collaborators: Recommendations*.**
Researchers developed a series of white papers and a glossy report based on the model case studies, community meetings, and workshop discussions. These papers and report describe specific ways federal agencies, personnel and programs should and can be structured and targeted to work more effectively, economically and sustainably with state, regional and local agencies and programs in New England to effect ecologically restorative flood prevention and remediation. Recommendations will include specific measures for policy or regulatory change, as well as improved implementation of existing policies and programs.

Principal Findings and Significance:

Findings resulted in five policy recommendations that, with modest fiscal resources and limited regulatory change, can make the most immediate and long-term difference for the future safety and wellbeing of New England communities. Our policy recommendations are:

1: Develop and implement fluvial hazard assessment, mapping, and user access systems across the New England states

2: Support upgrades of stream crossing infrastructure vulnerable to flood damage

3: Support river-smart community planning and mitigation

4: Prepare and disseminate outreach materials and training on river dynamics, lessons for river flood hazards, and river-smart best management practices

5: Support Regional Intermediaries to provide river flood planning and response services to municipalities and landowners.

A report was written (publishing expected in June 2016) to help New England's communities and their residents, as well as the governments that serve them, to better deal with and adjust to river floods. It points to practical policy solutions at federal, state and regional levels that can support New England communities to become what we call *river-smart (managing rivers and riverside landscapes, as well as our own actions and expectations, so people and communities are more resilient to river floods. Specifically: reducing flood severity, flood damage, and flood costs by understanding and accommodating the natural dynamics of rivers and river floods).* The report is entitled **"**Supporting New England Communities to Become River-Smart: Policies and Programs that can Help New England Towns Thrive Despite River Floods" and can be viewed at https://extension.umass.edu/riversmart/reports**.** A website **(**https://extension.umass.edu/riversmart/**)** was created and updated to include this project and our findings.

Student Support:
Masters student Peter Huntington (UMass Amherst Geosciences)

Undergraduate students Laurel Payne (BS, Smith College Environmental Science and Policy) and Daphne Chang (BA, Mount Holyoke College Environmental Studies)

Follow-on Funding:
An additional $10,195 in funding for research was obtained via a McIntire-Stennis grant through UMass Extension to support Masters Student Nicole Gillette to work on this and related projects 20 hours/week through Fall 2015.

Publications and Conference Presentations:

Vogel, Eve and Nicole Gillett, 2016: Possible physical geographies: Toward a proliferation of creative, progressive and sustainable environmental policy and management., Assn of American Geographers Annual Conference, San Francisco, Mar 29 2016.

10. Acid Rain Monitoring Project

Principal Investigator: Marie-Françoise Hatte, MA Water Resources Research Center, UMass Amherst
Start Date: January 1, 2015
End Date: June 30, 2015
Reporting Period: January 1, 2015– June 30, 2015
Funding Source: MassDEP
Descriptors: Acid Deposition; Surface Water Quality; Volunteer Monitoring

Introduction

This report covers the period January 1, 2016 to June 30, 2016, the fifteenth year of Phase IV of the Acid Rain Monitoring Project. Phase I began in 1983 when about one thousand citizen volunteers were recruited to collect and help analyze samples from nearly half the state's surface waters. In 1985, Phase II aimed to do the same for the rest of the streams and ponds[2] in Massachusetts. The third phase spanned the years 1986-1993 and concentrated on a subsample of streams and ponds to document the effects of acid deposition to surface waters in the state. Over 800 sites were monitored in Phase III, with 300 citizen volunteers collecting samples and doing pH and ANC analyses. In 2001, the project was resumed on a smaller scale: about 60 volunteers are now involved to collect samples from approximately 150 sites, 26 of which are long-term sites with ion and color data dating back to Phase I. In the first years of Phase IV (2001-2003), 161 ponds were monitored for 3 years. Between Fall 2003 and Spring 2010, the project monitored 151 sites twice a year, mostly streams, except for the 26 long-terms sites that are predominantly ponds. Since 2011, reduced funding eliminated our October sampling and monitoring now occurs in April only. In 2011, we also stopped monitoring some of the streams in order to add and revisit ponds that were monitored in 2001-2003. This year is the sixth year of monitoring for those added ponds. One major change this year was a change in staff at the Water Resources Research Center, as Elizabeth Finn left the University of Massachusetts and Travis Drury was hired in the Research Fellow position that includes running the Acid Rain Monitoring project.

Goals

The goals of this project are to determine the overall trend of sensitivity to acidification in Massachusetts surface waters and whether the 1990 Clean Air Act Amendment has resulted in improved water quality.

Methods

The sampling design was changed in 2011 to monitor both streams and ponds, and that design continues to date. In 2001-2003 mostly ponds were monitored. In Fall 2003 the sampling scheme switched to streams to evaluate their response to air pollution reductions. In 2011 the site list was modified to include both ponds and streams. Half of the streams monitored since 2003 were kept, and half of the ponds monitored in 2001-2003 were added back. The streams that were removed were chosen randomly within each county. Ponds that were reinstated on the sampling list were chosen at random within those counties and by ease of accessibility to replace the removed streams. Because those sites were chosen without a preconceived plan, they can be considered picked at random.

One collection took place this year, on April 3, 2016.

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[2] Note: The term stream in this report refers to lotic waters (from creeks to rivers) and the term ponds refers to lentic waters (lakes and ponds, but not marshes)

Methods were unchanged from previous years: Volunteer collectors were contacted six weeks before the collection to confirm participation. Clean sample bottles were sent to them in the mail, along with sampling directions, a field sheet/chain of custody form, and directions including latitude and longitude coordinates along with maps to the sampling sites. Volunteers collected a surface water sample at their sampling sites either from the bank or wading a short distance into the water body. They collected water one foot below the surface, upstream of their body, after rinsing their sample bottle three times with pond or stream water. If collecting by a bridge, they collected upstream of the bridge unless safety and access did not allow it. They filled in their field data sheet with date, time, and site code information, placed their samples on ice in a cooler and delivered the samples to their local laboratory right away. They were instructed to collect their samples as close to the lab analysis time as possible. In a few cases, samples were collected the day prior to analysis because the lab is not open on traditional "ARM Sunday." Previous studies by our research team have established that pH does not change significantly in 24 hours when the samples are refrigerated and stored in the dark.

Volunteer labs were sent any needed supplies (sulfuric acid titrating cartridge, electrode, buffers), two quality control (QC) samples, aliquot containers for long-term site samples, and a lab sheet one week to ten days before the collection. They analyzed the first QC sample (an unknown) in the week prior to the collection and called in their results to the Statewide Coordinator. If QC results were not acceptable, the volunteer analyst discussed possible reasons with the Statewide Coordinator and made modifications until the QC sample analysis gave acceptable results. On collection day or the day after, volunteer labs analyzed the second QC sample before and after the regular samples, and reported the results on their lab sheet along with the regular samples. Analyses were done on their pH-meters with KCl-filled combination pH electrodes. Acid neutralizing capacity (ANC) was measured with a double end-point titration to pH 4.5 and 4.2. Most labs used a Hach digital titrator for the ANC determination, but some used traditional pipette titration equipment. Aliquots were taken from 25 long-term sites to fill two 50mL bottles and one 50mL tube per site for later analysis of ions and color. These aliquots were kept refrigerated until retrieved by UMass staff. Note that one of our 26 long-term sites was not sampled (Great Pond in Wellfleet on Cape Cod) again this year, the third year in a row. We will endeavor to find new volunteer collectors on the Cape to make sure this important site is sampled again in the future.

Aliquots, empty bottles, and results were collected by the ARM Statewide Coordinator between one and three days after the collection. The Cape Cod National Seashore lab mailed those in, with aliquot samples refrigerated in a cooler with dry ice.

The Statewide Coordinator reviewed the QC results for all labs and flagged data for any lab results that did not pass Data Quality Objectives (within 0.3 units for pH and within 3mg/L for ANC). pH and ANC data were entered by one ARM staff and proofread by another. Data were entered in a MS excel spreadsheet and uploaded into the web-based database at http://63.135.115.71/acidrainmonitoring/. Data were also posted on the ARM web page at http://wrrc.umass.edu/research/acid-rain-monitoring-project.

Water Resources Research Center's Travis Drury, with the help of senior student Brooke Andrew, managed the Environmental Analysis Lab (EAL) and provided the QC samples for pH and ANC to all of the volunteer labs. EAL also provided analysis for pH and ANC for samples from Hampshire and Franklin Counties, and color analysis for the long-term site samples. The UMass Extension Soils Laboratory analyzed the samples from the long-term sites for cations, and University of New Hampshire's Water Quality Analysis Laboratory, under the direction of Jody Potter, analyzed the samples from the long-term sites for anions.

Aliquots for 25 long-term sites were analyzed for color on a spectrophotometer within one day; anions within two months on an Ion Chromatograph; and cations within one month on an ICP at the UMass Extension Soils Laboratory on the UMass Amherst campus. The available data was sent via MS Excel spreadsheet to the Statewide Coordinator who uploaded it into the web-based database.

The Project Principal Investigator plotted the data to check for data inconsistencies and gaps. She then analyzed the available April data from 1983 through 2016, using the statistical software JMP (http://www.jmp.com/software/) to run bivariate analyses of pH, ANC, and ions against date. This yielded trends analyses with a fitted X Y line, using a 95% confidence interval.

Results

1. There were 150 sites to be monitored, 77 ponds and 73 streams. Of those, 19 ponds and 7 streams are "long-term" sites that are sampled every year and analyzed for color and a suite of ions in addition to pH and ANC.

2. Sampling was completed for 145 sites (72 ponds and 73 streams) including 25 of our long-term sites.

3. There were some quality control problem this year, resulting in the failure of UMass Boston lab to pass pH and ANC. This reduced the data we could analyze to only include 139 sites. We also had an issue at the UMass EAL, and had to discard our color analyses. This was due to the change in lab staff and has been corrected for next year.

4. The network of volunteers was maintained and kept well informed on the condition of Massachusetts surface waters so that they would be able to participate effectively in the public debate. This was accomplished by e-mail and telephone communications, as well as through updates via an internet listserv. 49 volunteers participated in this year's collection. Several new volunteer collectors were recruited to replace ill or retiring volunteers via several internet listservs and by word of mouth.
   There were 11 volunteer labs across the state, in addition to the EAL at UMass Amherst, in charge of pH and ANC analyses. As the Holden lab was not available this year, we used instead the Upper Blackstone Water Pollution Abatement District's lab in Millbury. Work-study student Brooke Andrews continued to manufacture QC samples and perform pH and ANC analyses at the UMass Amherst lab.

5. The ARM web site and searchable database were maintained and updated. 2016 pH, ANC, and ion data that met data quality objectives were added to the web database via the uploading tool created in previous years. The database was evaluated for quality control and uploading errors were corrected.

6. The data collected was analyzed for trends in pH and ANC in April months (139 sites) and for ions (25 sites), using the JMP® Statistical Discovery Software (http://www.jmp.com/software/). Trend analyses (scatter plots, regression, and correlation) were run on pH, ANC, and each ion separately, predicting concentration vs. time.

Data Analysis Results

pH and ANC

Trend analysis for pH and ANC
Table 2 displays the number of sites out of a maximum of 139 that show a significant change over time for pH or ANC. If the difference was not statistically significant ($p>0.05$), the sites are tabulated in the 'No Change' category.

Table 1: Trend analysis results for pH and ANC, April 1983 – April 2016

	All Sites		Ponds		Streams	
	pH	**ANC**	**pH**	**ANC**	**pH**	**ANC**
Increased	43	53	17	29	26	24
Decreased	6	1	1	0	5	1
No Change	90	85	49	38	41	47
Total	139	139	67	67	72	72

Those results are also graphed in Figure 1.

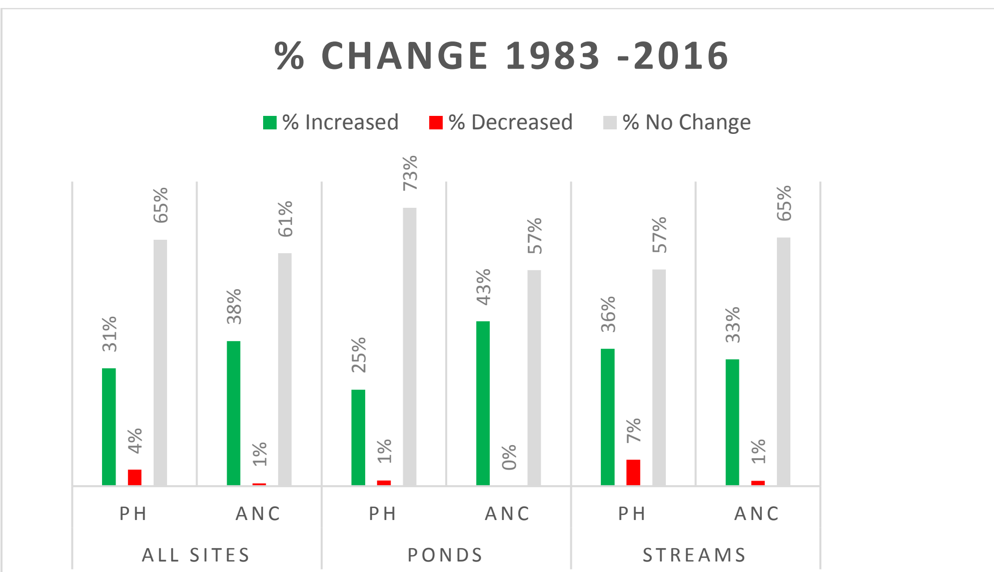

Figure 1. Percent change in number of sites for pH and ANC, from trend analysis, April 1983-2016

This trend analysis indicates that for most sites, neither pH nor ANC changed significantly over time. However, for those sites that show a significant change, many more show an increase than a decrease in value: 31% of the sites saw an increase in pH and 38% had an increase in ANC.

We again note a difference between ponds and streams. More streams (36%) than ponds (25%) saw an increase in pH, while for ANC, more ponds (43%) than streams (33%) saw an increase. Only one site, Torrey Creek in Seekonk (Bristol County) showed a decrease in ANC, while 1 pond and 5 streams showed a decrease in pH over the 33-year study period.

Now in our sixth year of monitoring both ponds and streams, we continue to see a positive trend in ponds and streams, which seem to be improving a little more each year. This year we saw less snowfall than in the past three years, though it actually snowed on collection day. We therefore did not catch a snowmelt acid pulse this year.

Ions

Trend analyses were run for the 25 long-term sites that were analyzed for eleven ions.

Table 2 and Figure 2 show the results of the trend analysis for all parameters.

Table 2: Trend analysis results for ions and color April 1983 – April 2016

	Increase	Decrease	No Change
Mg	6	0	19
Mn	1	4	20
Fe	0	4	21
Cu	5	0	20
Al	2	3	20
Ca	3	2	20
Na	11	0	14
K	8	0	17
Cl	15	0	10
NO_3	8	1	16
SO_4	0	22	3

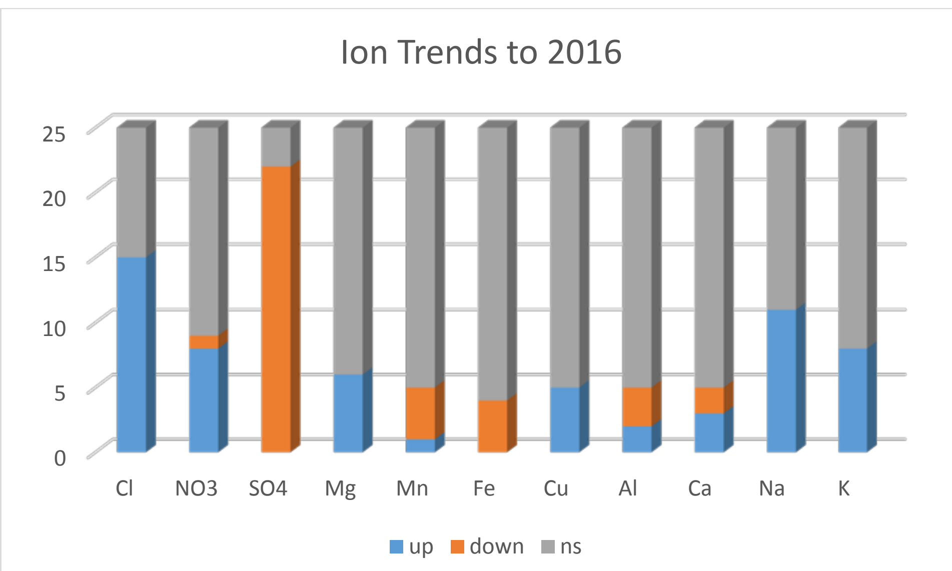

Figure 2: Results of trend analysis for ions at 25 long-term sites, April 1983-2016
Shown is how many sites showed an increase (up), decrease (down), or no significant change (ns) over the period 1983 – 2016

Results are similar to previous years, with most cations showing no significant change over the years, or if they do, the change is a decrease more often than an increase, except for Sodium where 10 sites show an increase. This is probably tied to the increase of Chloride (15 sites), due to road salting practices in Massachusetts. We continue to see a very significant downward trend in Sulfate (22 sites). We will need several more years of data to confirm or disprove an increase in nitrates in our surface waters. As our color analysis was flawed this year, we cannot confirm whether color is still increasing in most of our sites.

Discussion

This was our fourth year with new laboratories for the analysis of ions, and trends seem to be confirmed. The continued trend in decreasing sulfate confirms that the Clean Air Amendment of 1990 is having a positive effect in the quality of the Commonwealth's surface water quality. Road salting in the winter continues to affect the concentration of sodium and calcium in the water bodies. Continued monitoring will help tease out whether nitrate pollution is countering the beneficial effect of decreased sulfates.

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11. Blackstone River Water Quality Monitoring Study

Principal Investigator: Dr. Paula Rees, MA Water Resources Research Center, UMass Amherst
Start Date: 2/26/2004
End Date: On-going
Reporting Period: July 1, 2015 – June 30, 2016
Funding Source: Upper Blackstone Water Pollution Abatement District
Research Category: Water Quality Modeling; Watershed Management

Research Objectives
The Upper Blackstone Water Pollution Abatement District (UBWPAD, the District) sponsors a water-quality monitoring program to track river quality in the Blackstone River and to study the impacts of the wastewater treatment plant on the river. In 2015, UMass again conducted a water quality-monitoring program along the main stem of the Blackstone River. The objective of the program was to collect data to continue to assess the response of the river to reduced nutrient concentrations in the District wastewater treatment plant effluent. CDM Smith helps with program oversight, management, and implementation.

The District provides wastewater treatment to the City of Worcester and surrounding communities including Auburn, Cherry Valley Sewer District, Holden, Millbury, Rutland, and West Boylston. The District's advanced biological nutrient removal (BNR) process, constructed as part of a $180 million facility upgrade, produces a high quality effluent that has helped to improve the water quality of the Blackstone River. The BNR process at the facility reduces the amount of phosphorus in the District's discharge; excess phosphorus can contribute to excessive growth of algae in the river. The treatment process also provides nitrogen removal. Too much nitrogen can stimulate excessive algae growth in Narragansett Bay, the water body into which the Blackstone River ultimately flows.

The study includes monthly water quality sampling for nutrients and chlorophyll *a*. Three Rhode Island sites are co-sampled with the Narragansett Bay Commission (NBC). Sampling was conducted from April through November. In addition, three synoptic periphyton-sampling surveys were conducted in coordination with Normandeau Associates to capture a more in-depth "snapshot" of river biological response to improved water quality during critical hydrologic conditions. The periphyton sampling occurred roughly monthly July through September, targeting summer low flows in the river when periphyton biomass levels are expected to be high relative to other periods of the year. Periphyton sampling was performed at four sampling locations over a short period (1 day) of relatively steady hydrologic conditions. Normandeau Associates also conducted a macroinvertebrate survey at five locations in the watershed during low flows in August.

The 2015 water quality-monitoring program was designed to:

- Build upon earlier work conducted by the Massachusetts Department of Environmental Protection (MassDEP) and the U.S. Geological Survey (USGS);
- Evaluate periphyton growth in the Blackstone River in terms of biomass (mg m^{-2} chl *a*);
- Collect data to assess changes in riverine nutrient and chlorophyll *a* concentrations and fluxes through comparison against historical data; and,
- Collect data to assess changes in riverine periphyton growth through comparison against historical data.

Summary

The District has been proactive about maintaining a water quality-monitoring program to track the impacts of the plant upgrades on river quality. The 2015 sampling program was designed to provide additional data to help assess response of the river to reduced nutrient concentrations in the UBWPAD effluent since Fall 2009, when plant upgrades designed to meet the 2001 permit limits went online. Review of the 2015 sampling results indicates:

- The total annual load of nitrogen from the District's facility has been reduced by over 60% from nearly 1.2 million pounds per year in 2006 to about 400,000 pounds per year in 2015. The District also operates the facility to remove nitrogen year-round even though it has only a seasonal nitrogen permit limit.
- The annual reduction in phosphorus load to the river is even more dramatic at over 85%, from more than 160,000 pounds per year to less than 20,000 pounds per year. Again, the District operates the facility to optimize phosphorus removal year-round even though wintertime limits are much less stringent.
- Median summer time (June through September) streamflow in 2015 was below average, based on recorded streamflow at the USGS gage in Millbury, MA, and the second lowest since post-upgrade routine monitoring was initiated in 2012. The 2015 river sampling results were compared with historical data collected during similar low river flow conditions prior to 2009, as well as with low river flow data from 2012 through 2014 to evaluate the changes in river water quality following the District's facility upgrades.
- Reductions in the total phosphorous and nitrogen loads leaving the UBWPAD facility are reflected in lower river phosphorous concentrations and loads. Phosphorous and nitrogen loads in 2015 were approximately 85% and 60%, respectively, compared to 2006 levels.
- The reduction in the amount of nutrients in the river, because of UBWPAD treatment improvements, has resulted in lower chlorophyll *a* concentrations than in the past. In addition to nutrients in the water column, other factors such as water temperature and

increased exposure to sunlight also make conditions within impoundments and low river flow stretches more amenable to algae growth, which is reflected in higher chlorophyll *a* concentrations.

- The 2015 periphyton sampling program included periphyton surveys in July, August, and September. Periphyton refers to the micro-community that lives on or attached to the submerged substrata in a river or stream. The periphyton surveys were performed at 4 river locations including 3 sites sampled by the Massachusetts Department of Environmental Protection (MassDEP) in 2008. The 2015 survey results are consistent with data collected in 2012 and 2013 and are less than reported 2014 concentrations. The concentrations were below the nuisance threshold identified by MassDEP (200 mg/m^2) and decreased downstream of the District.
- A macroinvertebrate survey – a type of biological monitoring used to evaluate ecological health – was conducted in 2014 and 2015, to compare river conditions to those observed by Massachusetts Department of Environmental Protection (MassDEP) in a 2008 survey. The 2014 and 2015 macroinvertebrate surveys indicated noticeable improvement downstream from the UBWPAD discharge, compared to 2008 MassDEP sampling results. Based on the 2015 survey results, all the sites – both upstream and downstream of the District's effluent channel – were classified as either "slightly impaired" or "moderately impaired," an improvement over the severe to moderate impairment noted by MassDEP in 2008.

Next Steps

The District plans to continue water quality monitoring in the Blackstone River in 2016 to track the impacts of reduced nutrient concentrations in UBWPAD plant effluent. Blackstone River data collected in 2015 is being added to the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) database, which is sponsored by the National Science Foundation (www.cuahsi.org). The data are publicly available for download through the CUAHSI Hydrologic Information System (HIS) databases and servers (his.cuahsi.org). See http://www.ubwpad.org for the detailed results of sampling program.

Student Support: 1 Undergraduate, College of Natural Sciences

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12. Flood Vulnerability Assessment for Roadway Stream Crossing Structures, Deerfield River Watershed, Massachusetts

Principal Investigator: Dr. Paula Rees, MA Water Resources Research Center, UMass Amherst
Start Date: 7/1/2014
End Date: 6/30/2017
Reporting Period: July 1, 2015 – June 30, 2016
Funding Source: Mass. Dept. of Transportation
Research Category: Floods, Stream Continuity

UMass Amherst, on behalf of MassDOT, is developing risk-based and data driven protocols for assessing the present and future extreme flood vulnerability of roadway crossing structures within the Deerfield River Watershed. These protocols incorporate consideration of a range of potential climatic and natural system stressors and risk factors, including present and future flood hydrologic conditions, geomorphic stability, ecological system accommodation, structural flood resilience, and transportation/emergency response service disruption impact. It is UMass Amherst and MassDOT's intent that the proposed protocols will serve to augment and improve MassDOT's current inspection/maintenance, system planning and project development processes, and thereby help assure the present and future safety and resilience of the state's inventory of bridges and culverts.

Goals of study

The goal of the project is to develop a systems-based approach to improve the assessment, prioritization, planning, protection and maintenance of roads and road-stream crossings that:

- Complements existing MassDOT project development and bridge design business processes;
- Provides a decision-making tool that can be used during project planning and development phases; and
- Familiarizes and engages other agencies, such as the Massachusetts Department of Environmental Protection (MassDEP), the Army Corps of Engineers (ACOE), and the Federal Emergency Management Agency (FEMA), with this approach.

A proactive approach for upgrading structures to account for climate change may be more cost effective than responding to road and crossing failures, which may occur due to inaction. An integrated approach - accounting for culvert condition, geomorphic and climate change impacts, future development, river stream continuity (aquatic and wildlife organism passage), and potential disruption of local services in the decision making process - will reduce uncertainties and improve prioritization schemes compared to vulnerability assessments that focus solely on climate change.

MassDOT already has an effective statewide Bridge Inspection program that provides rigorous hands-on bridge structural and site safety inspection coverage for over 11,100 bridges and culverts. The intent of this project is not to replace the existing statewide inspection program, but rather to complement this program by collecting additional data, in particular for closed bottomed structures less than 10 feet in length. If MassDOT has already inspected a culvert, their report will be reviewed and the project team will defer to DOT's overall categorization of poor, critical, or not at risk.

Objectives

The project team is exploring a variety of methods for conducting a climate change vulnerability assessment of culverts throughout the Deerfield River watershed. Our project includes:

1. Vulnerability assessment for roads and road-stream crossings under present climate conditions affecting streamflow
2. Vulnerability assessment for roads and road-stream crossings under future climate conditions affecting streamflow
3. Integration of vulnerability factors due to future hydrologic and hydraulic conditions, geomorphic response, and aquatic stream continuity and fragmentation into a decision support tool that complements, supports, and augments present MassDOT system planning, project development, and bridge/culvert inspection processes.

In assessing climate change vulnerability of the transportation system, the Federal Highway Administration (FHWA) considers three factors (FHWA, 2012): ***exposure*** (whether the asset is in an area experiencing direct impacts of climate change), ***sensitivity*** (expected response of the asset to this impact), and ***adaptive capacity*** (ability of the transportation system to cope with the impacts). Our assessment explicitly accounts for exposure and sensitivity by considering system response to changes in precipitation predicted by various future climatic conditions. Sensitivity of both hydraulic risk and geomorphic risk to predicted climate change is being evaluated. While the project team is laying the foundation for assessing adaptive capacity, additional work will be needed to take this to a higher level.

Beyond providing a vulnerability assessment specific to the Deerfield, our aim is to identify the strengths, weaknesses and sensitivities of the various methodologies utilized to analyze each objective. Based on this information, the project team will provide recommendations for a transportation vulnerability assessment framework that could systematically and cost-effectively be applied to the rest of the Commonwealth.

Linked Considerations

Procedurally, UMass Amherst proposes to advance this project through the progressive development of four linked components:

- <u>Culvert condition</u>. As a complement to the state's bridge inspection program, apply a rapid condition assessment of culverts to identify those that are most at risk of failure due to structure or stream degradation and lateral or vertical movement of stream channels

- <u>Climate Change and Associated Geomorphic Impacts</u>. Develop a process for identifying elements of transportation infrastructure that are vulnerable to failure during storm events due to changes in precipitation patterns as the result of climate change. This will include direct vulnerability due to resulting extreme flows as well as indirect vulnerability due to geomorphic responses to changes in climate such as erosion and landslides, or system-wide adjustments in river morphology

- <u>Potential disruption of local services or emergency response routes</u>. Incorporate vulnerability assessment with an assessment of the associated potential of a failure to disrupt local services or infrastructure (fire and police protection, access to hospitals, water supply, utilities, etc.)

- <u>River and stream continuity</u>. Implement a process for assessing transportation related barriers to aquatic and wildlife continuity and identify those sites where mitigation of those barriers would do the most good for fish, other aquatic organism, and wildlife population persistence.

While not a major focus of the proposed work, local future development is another factor impacting vulnerability being considered.

The work builds upon field-based and landscape-scale assessments of roads, road-stream crossings, streams and watersheds that have been developed at UMass Amherst over that past ten years. The significant and unique aspect of this work is that it will insert climate change uncertainty, stream continuity issues and geomorphic condition into the decision-making process for road and stream crossing planning and vulnerability assessment.

Deliverables

This effort will yield the following deliverables:

- Electronic maps (GIS) rating potential vulnerabilities for roads and road-stream crossings under current climate conditions

- Electronic maps (GIS) rating potential vulnerabilities for roads and road-stream crossings under future climate conditions
- Electronic maps (GIS) showing high threat sites based on vulnerability (three maps total, one each based on current, mid- and late-century climate conditions) and the potential to disrupt local services or emergency response routes (one map, as this ranking will not change based on climate conditions)
- Electronic maps (GIS) ranking road-stream crossings based on potential to restore river and stream connectivity via road-stream crossing replacement or upgrade based on current climate conditions
- A decision support matrix - ranking each road-stream crossing based on condition, exposure, sensitivity, ecological passage, and transportation/emergency service disruption potential – to facilitate prioritization of MassDOT management actions that address significant threats to regional ecosystem continuity and/or the safety of the state transportation network imposed by adverse climatic changes. UMass will work with MassDOT to ensure the ranking system complements their existing management systems
- There is some precedence for the Federal Emergency Management Agency (FEMA) to approve reimbursements for upgrades (versus replace in kind) when such plans are in place prior to a structure failure. Because FEMA is actively working to develop these guidelines, a summary of the FEMA policies under development will be a project deliverable
- A suggested methodology for future implementation in other basins, which is optimized to minimize implementation costs and estimation uncertainties.

Partners

Partners in the project include the Massachusetts Water Resources Research Center, the UMass Amherst College of Natural Sciences (departments of Geosciences and Environmental Conservation), the College of Engineering (civil engineering), and the College of Computer and Information Science; UMass Extension; the MA Office of the State Geologist, the Northeast Climate Science Center climatologist; the USGS Conte Lab; Trout Unlimited; and Milone and MacBroom Consultants.

Student Support:
Gordon Clark, MS, Environmental and Water Resources Engineering
Miranda Cashman, BS, Geosciences
Jennifer Jurnack, BS, Geosciences
Sarah Osgood, BS, Geosciences
Paul Southard, recent BS, Geosciences

Information Transfer and Outreach

As part of the WRRC Outreach and Education program, we worked with several faculty on the UMass Amherst campus as well as off campus experts to organize two training/educational gatherings.

13. 2015 Workshop Series (2015MA442B)

Principal Investigator: Paula Rees, UMass WRRC
Start Date: March 1, 2015
End Date: February 29, 2016
Funding Source: USGS (104B)

The Water Resources Research Center helped organize two meetings on the topic of water at the University of Massachusetts Amherst. The two events were combined into a three-day event coinciding with the WRRC's 50^{th} anniversary celebration. One event was the Water Society Politics Workshop, and the second event was the New England Student Water Symposium. Both are described below.

Water, Society, and Politics Workshop

Description:
Dr. Anita Milman and Dr. Eve Vogel of the University of Massachusetts Amherst, Departments of Environmental Conservation and Geosciences, respectively, with the help of the Water Resources Research Center and the New England Graduate Water Symposium, organized a half day workshop in Amherst on September 11, 2015 on the topic of water, society, and politics.

From the global to the household level, societal processes have shaped and been shaped by material flows of water resources. Humans have adjusted to hydrologic patterns, have intervened to change those patterns, and at times, have attempted to restore or undo those very changes. These dynamics are driven by the intersections of cultures, histories, institutional structures, power relations, and economics. As such, water is an integral part of international relations, politics, economics, environmental disputes, and technological innovation.

The aim of the Water, Society, and Politics workshop was to examine the contributions of social sciences in unveiling the relationships between societies and water resources with an eye to how the social and the physical can be co-examined and integrated to improve understandings and inform practice. Objectives included fostering communications within the Five Colleges among social scientists working on water and other environmental issues; promoting synergies between social science and natural science/engineering water-related research at UMass; opening channels to foster interdisciplinary water research and teaching on campus; and supporting young scholars and graduate students working on environmental issues in the social science fields.

The half-day workshop included presentations by three invited guest lecturers, each of whom is an expert in a different aspect of water, society, politics, followed by an interactive discussion among attendees on how to foster integration of the physical and social sciences in research and practice related to water resources. Attendees included 184 participants, including graduate students, faculty, and interested members of the public.

Impacts:

The workshop was instrumental in bringing together individuals from a variety of disciplines to discuss the multi-faceted nature of water resources. During the talks, each invited speaker presented his/her research and how his/her work contributes broader understandings of water resources. Each speaker also provided his/her own perspective on the following three questions:

1. What do you see as the most important contributions of your approach to social science for natural/physical scientists/engineers to be aware of?
2. Practically speaking, what suggestions do you have for integrating social science and physical/natural sciences in deeper, more reflective, productive ways?
3. How can integrated research help foster the applicability/utility of science in decision-making arenas?

During the last session, audience members also submitted questions and participated in an interactive discussion on these three topics. During the discussion session and after the workshop, attendees described how the meeting opened their eyes to new ways of thinking about bridging the social and physical sciences and made them excited about such integration in the future. While there was no structured evaluation of the workshop impacts, during the discussion a number of Ph.D students said interdisciplinary integration should be included sooner in their academic studies and they are going to approach their advisors about including interdisciplinary chapters in their dissertations, and one asked a social scientist from the meeting to join her thesis committee. Other audience members commented that the presentations gave them ideas for projects and papers they are involved in and that they were interested in finding ways to participate in interdisciplinary work in the future.

UMass attendees included faculty as well as students, mainly from the sciences and engineering. Dr. Lave's talk was scheduled as the Geosciences Lecture Series that day and many came from that department. The symposium brought these scientists and engineers a richer sense of the range of social sciences approaches in dealing with water issues. Many voiced interest in follow-up discussions and further events.

In term of fostering integration of the physical and social sciences in research and practice related to water resource, the following key recommendations emerged:

- Relationships between collaborators are key. Collaborators need to jointly see the value of interdisciplinary work. The speakers and audience members who had participated in what they considered to be successful interdisciplinary work attributed that success to all parties having a specific problem they wanted to address and all parties recognizing that the only way to address that problem was through an interdisciplinary approach.
- Shared knowledge helps. While it is not necessary for the social scientist to be able to solve differential equations related to groundwater hydrology or for a hydrologist to be able to conduct contingent valuation surveys, when collaborators have some background or experience in the other field, it makes them more able to communicate and to understand the value of one another's work. Inclusion of interdisciplinary elements in the academic curricula could be a seed for the development of future interdisciplinary collaborations.
- Repeated interactions and a long-term commitment are important. Interdisciplinary work can take time. Moreover, through repeated engagement, collaborators are better able to understand and communicate with one another. This symposium is an excellent step in the process and should be followed with other events and discussions.

Lead Organizers:

- Anita Milman, Environmental Conservation, University of Massachusetts Amherst
- Eve Vogel, Geosciences, University of Massachusetts

Invited Speakers:

- **Dr. Chris Sneddon** is a professor of Geography and Environmental Studies at Dartmouth College. His research examines how to reconcile human activities with the long-term resilience of socio-ecological system, with a focus on social conflicts over water in the US and internationally. His work on the transformation of river basins due to large-scale development has included multi-scalar examination of the political ecology of the Mekong River Basin, and the social dimensions of dam removal in New England.

- **Dr. Kelli Larson** is a professor in the School of Geographical Sciences and Urban Planning at Arizona State University. Her research examines environmental governance, with a focus on the intersection of water and land management practices. Her work on desert and urban environments focuses on risk perceptions, policy attitudes and behavior changes and their relationship to resource management decisions.

- **Dr. Rebecca Lave** is a professor in the Department of Geography at Indiana University Bloomington. Rebecca is pioneering a new field called critical physical geography in which she combines the concepts and methods of political ecology, science and technology studies, and fluvial geomorphology. Her work focuses on the contradictory relations among markets, science, and the state embodied in attempts to manage, conserve, and restore rivers and streams.

Workshop Schedule:

12:30 – 12:45	Welcome
12:45 – 1:00	Introduction: Water, Society, Politics
1:00 – 1:50	Risk Perceptions and Policy Attitudes: Implications for Collaborative Water Governance – *Dr. Kelli Larson, Arizona State University*
2:00 – 2:50	Transforming the Mekong: Scientific Knowledge and Geopolitical Change, 1955 to 2015 – *Dr. Chris Sneddon, Dartmouth College*
3:00 – 3:20	Break
3:20 – 4:10	Marketing Environmental Science and Management: Stream Mitigation Banking in the U.S. – *Dr. Rebecca Lave, Indiana University Bloomington*
4:10 – 4:20	Short Break
4:20 – 5:20	Discussion: Fostering Deeper Integration of Social Science Insights and Questions into Water Research
5:20 – 5:30	Final Words

New England Graduate Student Water Symposium

National conferences provide valuable presentation experience and networking opportunities. Unfortunately, the cost of travel, lodging, and registration presents substantial obstacles for most graduate students. To address this problem, the New England Graduate Student Water Symposium was created in 2014 and ran for its second year in 2015. Conference costs were kept low, and this year, thanks to the support of conference sponsors, registration was free for students and two nights of hotel accommodations were provided to presenters and student coauthors for a small $20 fee.

The conference kicked off Friday September 11, 2015, in conjunction with MA WRRC's other symposium, "Water, Society and Politics," followed by a dinner celebrating the 50th anniversary of the Massachusetts Water Resources Research Center, open to all conference registrants.

On Saturday September 12, 2015, technical presentations and poster presentations started and continued Sunday September 13, 2015. All presentations were given by undergraduate and graduate students, but post docs, alumni, faculty, and industry representatives were invited to attend.

Presentation topics ranged from water and wastewater treatment process, through water quality issues, to hydrology and water resources. A special session, mirroring the Friday workshop on Water, Society and Politics, saw presentations in the area of environmental studies, environmental conservation, and politics.

Saturday's events included a poster contest, dedicated networking time, and a keynote presentation by USGS research hydrologist, Dennis LeBlanc ("Managing wastewater disposal on Cape Cod to improve water quality and maintain the hydrologic balance").

219 people participated in the conference, from 59 institutions. Forty-six universities were represented, as was one government agency (USGS), 5 companies, and 3 non-profit organizations. Attendees came from 4 countries, 11 US states and 3 Canadian provinces (see Table 1).

Table 1: Institutions Represented at the Symposium

Institution/Company	From
Clarkson University	NY
Clean Membranes	MA
Colby-Sawyer College	NH
Connecticut River Watershed Council	MA
Cornell University	NY
Dalhousie University	NS
Dartmouth College	NH
Drexel University	PA
École Polytechnique de Montréal	QC
Environmental Partners Group, Inc.	MA
Harvard University	MA
Hazen and Sawyer	CT
IFIC Bank Ltd	Bangladesh
Indiana University Bloomington	IN
Johnson State College	VT

Keene State College	NH
Kleinfelder Inc.	MA
Lafayette College	PA
Lehigh University	PA
Lyndon State College	VT
Manhattan College	NY
Massachusetts Institute of Technology	MA
McGill University	QC
McMaster University	ON
Montclair State University	NJ
Mount Holyoke College	MA
New Jersey Institute of Technology	NJ
NEWIN	MA
Northeastern University	MA
Pennsylvania State University	PA
Rensselaer Polytechnic Institute	NY
Shandong Jianzhu University, China	China
Smith College	MA
Syracuse University	NY
Target Australia Sourcing	Australia
Texas A&M University-Kingsville	TX
The Cadmus Group, Inc.	MA
Tufts University	MA
Universite Laval	QC
University at Buffalo, State University of New York	NY
University of Connecticut	CT
University of Maine	ME
University of Massachusetts Amherst	MA
University of Massachusetts Dartmouth	MA
University of Massachusetts Lowell	MA
University of New Hampshire	NH
University of Rhode Island	RI
University of Vermont	VT
USGS	MA
Water Supply CItizens Advisory Committee	MA
Westfield State University	MA
Worcester Polytechnic Institute	MA
WRRC - MA	MA
WRRC - Uconn	CT

WRRC - UNH	NH
WRRC - URI	RI
WRRC - UVM	VT
Yale University	CT

Table 2: Symposium Program

2015 New England Graduate Student Water Symposium

Saturday, September 12

7:00 – 8:45	**Breakfast**
9:00 – 10:30	**Concurrent Technical Sessions I**
	Water and Wastewater Treatment I
	Water, Society, and Politics
	Water Quality I
10:45 – 11:45	**Keynote:** Managing wastewater disposal on Cape Cod to improve water quality and maintain the hydrologic balance, Denis LeBlanc, USGS Research Hydrologist -
11:45 - 1:15	**Lunch**
1:15 - 1:30	**Group Photo**
1:30 – 2:30	**Concurrent Technical Sessions II**
	Water and Wastewater Treatment II
	Environmental Engineering I
	Water Quality II
2:45 – 3:45	**Concurrent Technical Sessions III**
	Water and Wastewater Treatment III
	Environmental Engineering II
	Water Quality III
4:00 – 5:00	**Poster Session and Networking**
6:30	**Dinner**

Sunday, September 13

7:00 – 8:45	**Breakfast**
9:00 – 10:30	**Concurrent Technical Sessions IV**
	Water and Wastewater Treatment IV
	Hydrology
	Microbiology
10:45 - 12:00	**Concurrent Technical Sessions V**
	Water and Wastewater Treatment V
	Water Resources
	Nanotechnology
12:15 – 1:00	**Closing Remarks**

68 technical presentations were delivered in 15 sessions on the topics of Water and Wastewater Treatment; Water, Society and Politics; Water Quality, Environmental Engineering, Hydrology, Microbiology, Water Resources, and Nanotechnology. 52 posters were presented and judged by conference sponsors and faculty. The winners were :

A Study of Dissolved De-icers Rates of Infiltration and Percolation: An Experimental Approach, by Mikaela Rice, Rudolph Hon, Barry Shaudt, and Constantin Andronache of Boston College

Management of Sediment in Paradise Pond, Northampton, Massachusetts by Maya Domeshek, Miatta Ndama, Robert Newton, Molly Peek, Marney Pratt, Marcia Rojas, Lizzie Sturtevant, and Lyn Watts of Smith College.
Proceedings of the symposium can be found at
http://www.negsws.com/wp-content/uploads/2016/05/NEGSWS_2015_proceedings.pdf

Figure 1: Some attendees of the Symposium

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14. Massachusetts Water Watch Partnership web site redesign (2015MA442B)

Principal Investigator: Jerry Schoen, UMass WRRC
Start Date: March 1, 2015
End Date: February 29, 2016
Funding Source: USGS (104B)

Problem and Objectives:
Since the early 1990s, the Massachusetts Water Watch Partnership (WWP) web site has been a valuable source of information for nonprofit organizations, environmental agencies, schools and others practicing or working with citizen science programs. The WWP site contained information on how to organize and design a monitoring program, what sampling parameters and associated methods to use, data management and presentation strategies, and quality assurance practices that can help ensure a successful program. Collectively, these materials helped over 100 organizations in Massachusetts, the Northeast and beyond conduct water quality monitoring programs that aided in resource management decisions by federal, state, local government agencies and program managers. These programs

improved public understanding of the value and condition our surface water resources. The WWP site was taken offline in 2012, due to a lack of resources with which to maintain the site. However, in the years since, the Water Resources Research Center (WRRC) has received numerous communications from these same stakeholders, expressing concern over the unavailability of the site, and requesting its return.

In response to these concerns, WRRC staff updated the WWP web site and brought it back on line, under the umbrella of the WRRC web site.

Methodology:
WRRC staff conducted a detailed review of the existing, archived WWP site to determine which material from the archived site to transport to the new site in original or updated form. The new site now provides content in these topical areas:
o Sampling program design and organization;
o Sampling parameters, field and laboratory monitoring protocols and standard operating procedures;
o Guidance documents on quality assurance project plans (QAPPs), data management, and reporting results;
o Links to environmental agencies, organizations and other resources of value to volunteer monitoring groups;
o Lists of sampling equipment commonly used by volunteer water monitoring programs, and suppliers for this equipment.

Principal Findings and Significance:
The project went well, all tasks completed. The web site can be found here:
http://www. umass. edu/mwwp/index. html

Beth Armour of UMass Extension and UMass student Grayson Kempster provided invaluable assistance in these tasks, by offering guidelines on site format and navigation (to ensure the site is consistent with other sites maintained by the College of Natural Sciences), and writing much of the code that translated WRRC-provided content into web format. The site was constructed to be mobile-friendly; i.e. it can be viewed on handheld devices.

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15. The Stream Continuity Project

WRRC staff Marie-Françoise Hatte works in a team led by Professor Scott Jackson at UMass Amherst Environmental Conservation on a project focused on improving aquatic connectivity across a thirteen-state region, from Maine to West Virginia. In this fiscal year, the North Atlantic Aquatic Connectivity Collaborative (NAACC) continued to expand and continued to:

1. develop unified protocols for road-stream crossing assessments that can help identify bridges and culverts that are problematic from an aquatic connectivity perspective,
2. maintain an online assessment training program,
3. maintain an online database that serves as a common repository for crossing assessment data,
4. maintain a website at streamcontinuity.org to provide guidance for stream crossing assessments as well as tools and information on where restoration projects are likely to have the greatest aquatic connectivity benefits and resiliency benefits,
5. maintain a tool to identify high priority watersheds and crossings for assessment, and

6. support efforts to conduct assessments throughout the region.

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16. RiverSmart Communities

WRRC staff Jerry Schoen and Marie-Françoise Hatte work in a team led by Dr. Christine Hatch and Eve Vogel at UMass Amherst Geosciences on RiverSmart Communities, an integrated research (both river science and social science) and extension project sponsored by the University of Massachusetts Center for Agriculture, Food and the Environment to address pressing needs in the Commonwealth. In the aftermath of Hurricane Irene, it was recognized that a greater understanding of challenges surrounding ecologically supportive and community resilient management of rivers and the lands surrounding them would help address flooding more effectively. As the initial research progressed, collaborations with other research and community groups developed, additional grants were obtained for related and complementary work. The projects we worked on this year are:

- **Farms, Floods and Fluvial Geomorphology**
  What is the role of farms in floodplains? What resources help farmers before and after floods? The goal of this project is to promote knowledge about the role of farms in the flood plain, natural fluvial and geomorphological processes, and apply that knowledge to a whole watershed to promote coordinated watershed management.
- **RiverSmart and Federal Collaborators**
  This project recognizes the significant role of federal agencies and programs in flood response and recovery, and undertakes specific workshops and research activities to optimize the partnership between federal agencies and state or local counterparts for the best possible resilient river management in New England.

Environmental Analysis Laboratory

Reporting Period: July 1, 2015 – June 30, 2016

Funding Source: Fees

The Environmental Analysis Laboratory (EAL) was created in 1984 by WRRC to assist the Acid Rain Monitoring Project (ARM) by analyzing more than 40,000 samples for a suite of 21 parameters. Since 1988, the Lab has provided services to a wide range of off-campus and on-campus researchers. EAL provided chemical analysis of water, soils, tissue, and other environmental media for University researchers, public agencies, and other publicly supported clients. The EAL currently conducts analysis of pH, alkalinity, dissolved oxygen, total phosphorus and chlorophyll *a* to support environmental research, management, and monitoring activities.

In this past year, EAL continued to provide laboratory support for the Acid Rain Monitoring Project, including a quality-control program for pH and alkalinity. The quality-control program for volunteer-monitoring groups continued for pH, alkalinity and dissolved oxygen. In this reporting period, we provided 11 quality control samples to three volunteer groups (see Table 1).

Table 1. Quality Control Samples Created for Volunteer Groups

Date	Client	DO QC	pH/ANC QC	Total
7/13/2015	LSWA		1	**1**
8/13/2015	LSWA		1	**1**
9/21/2015	LSWA		1	**1**
10/5/2015	LSWA		1	**1**
4/8/2016	NRWA	2		**2**
4/14/2016	LSWA		1	**1**
4/28/2016	LSWA	1		**1**
5/19/2016	LSWA		1	**1**
6/7/2016	LSWA		1	**1**
6/21/2016	FOLW	1		**1**
	Total	**4**	**7**	**11**

LSWA = Lake Singletary Association, Sutton, MA
NRWA = Nashua River Watershed Association, Groton, MA
FOLW = Friends of Lake Warner and the Mill River, Hadley, MA

EAL also continued to provide total phosphorus and chlorophyll *a* analyses to watershed groups through the MA DEP 319 program funded "Water Quality Analyses Support for Massachusetts Volunteer Monitors". In this reporting period, we performed 35 analyses for two volunteer groups, (5 chlorophyll and 30 TP analyses) (see Table 2).

Table 2: Volunteer Group Samples Analyzed

Volunteer Group Samples Analyzed under DEP 310 Grant				
Date	**Client**	**Chl-a**	**TP**	**Total**
7/15/2015	FOLW		2	**2**
8/13/2015	FOLW		6	**6**
9/2/2015	FOLQ	1		**1**
9/29/2015	FOLQ	1		**1**
9/30/2015	FOLW	2		**2**
10/21/2015	FOLQ	1		**1**
6/17/2016	FOLW		22	**22**
	Total	**5**	**30**	**35**

FOLW = Friends of Lake Warner and the Mill River, Hadley, MA
FOLQ = Friends of Lake Quannapowitt, Wakefield, MA
EAL also continued to provide Chlorophyll *a* analysis for the Upper Blackstone Pollution Abatement District (UBWPAD).

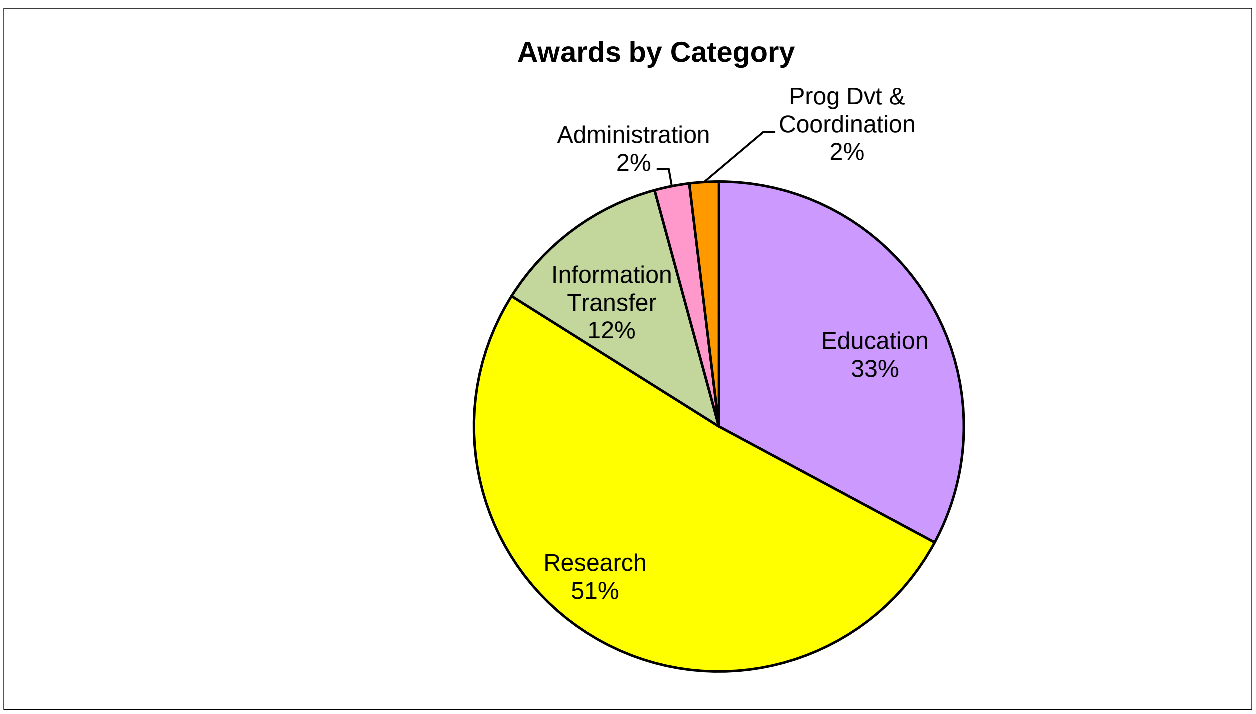
Undergraduate Student Support

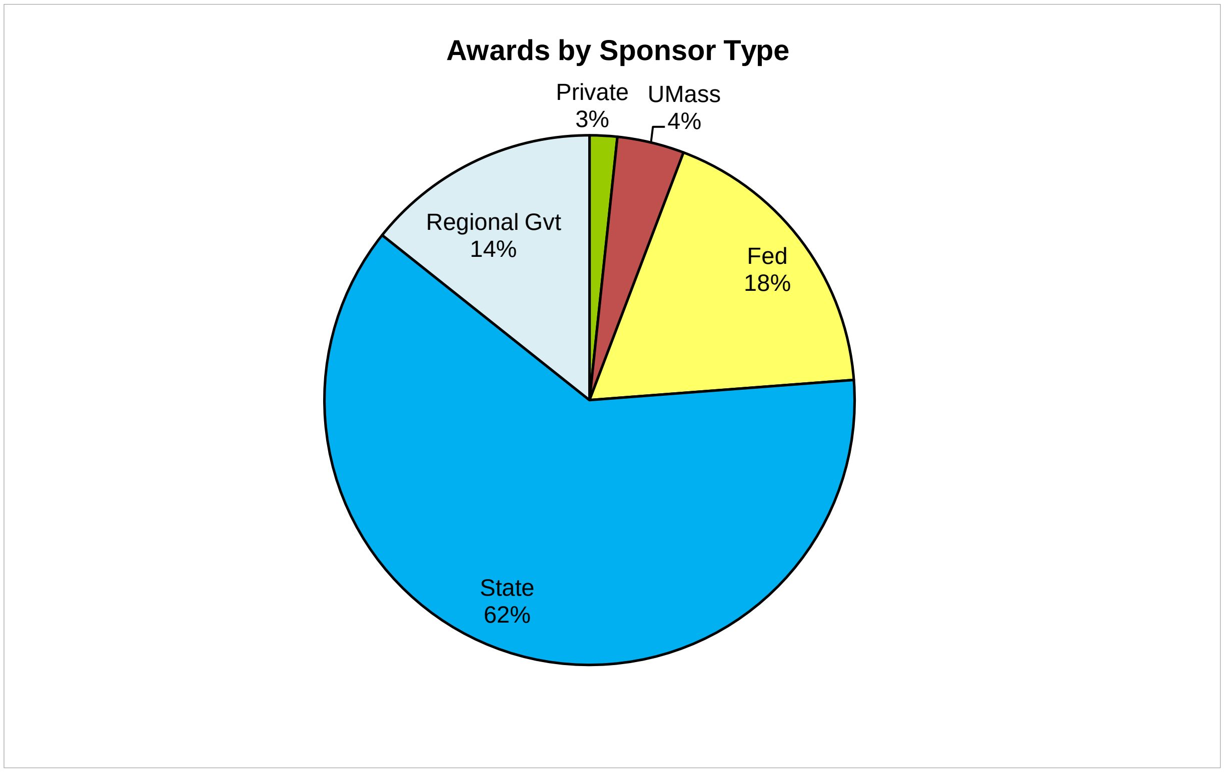
Brooke Andrews (Natural Resource Conservation) and Derek Smith (Environmental Science).

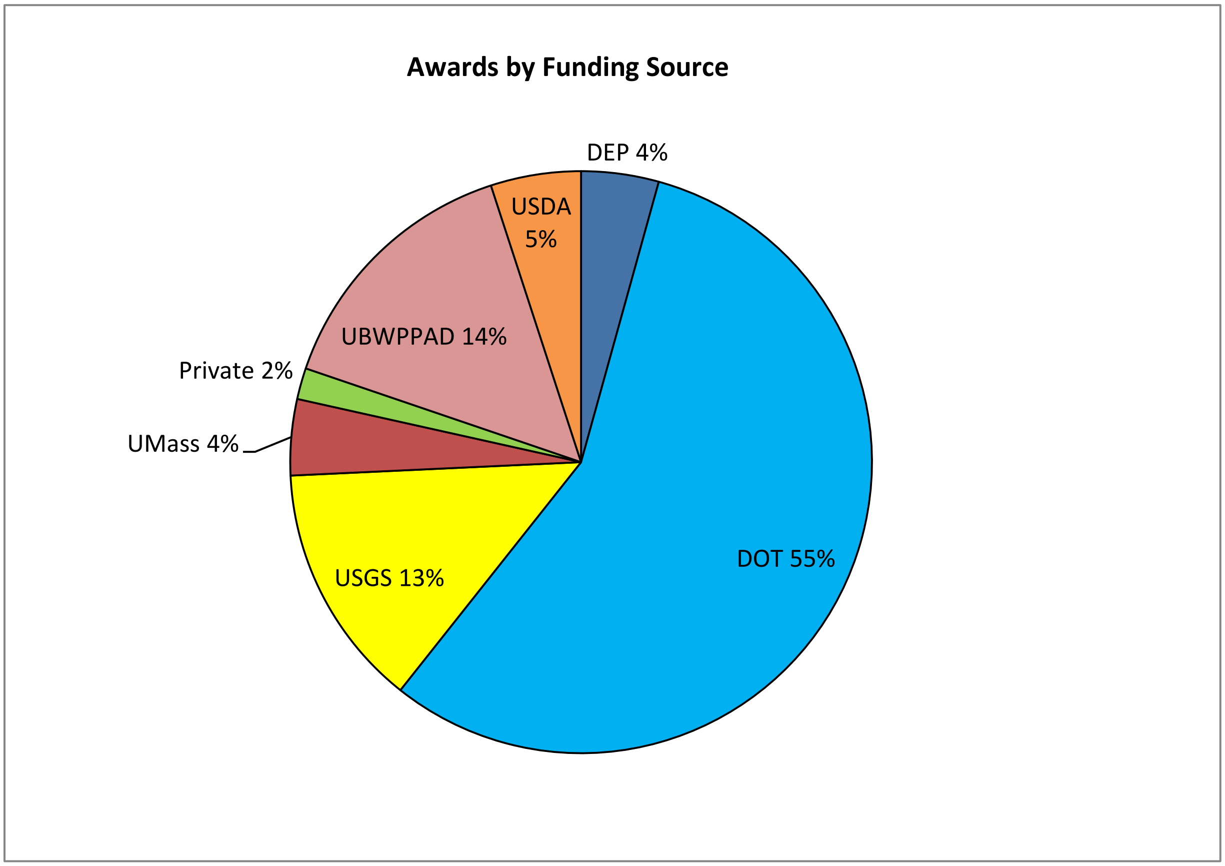
Financial Overview

Center revenues come strictly from grants and contracts. The University of Massachusetts contributes 16.7% of the salary for a half-time Director and also provides physical facilities for the WRRC.
Total revenues amounted to $742,270

USGS 104B:	$ 92,335 broken down as follows:
	$17,075 Workshops
	$17,046 Administration
	$5,000 Schiffman research Project
	$29,971 Butler research project
	$5,000 Moisander research project
	$13,500 Park research project
	$4,744 Schoen outreach project
MA DOT	$405,096
Blackstone River	$100,286
USDA	$34,070 NIFA conference
USGS IWR	$40,752 Vogel research project
UMass (Director)	$27,404
ARM Project	$29,264
EAL	$11,775




Awards by Sponsor Type
Private 3%
UMass 4%
Fed 18%
Regional Gvt 14%
State 62%


Awards by Funding Source
DEP 4%
USDA 5%
UBWPPAD 14%
Private 2%
UMass 4%
USGS 13%
DOT 55%