



MA Water Resources Research Center

Annual Report 2016-2017

March 1, 2016 – June 30, 2017

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Cover photo by MF Hatte: Director Paula Rees sampling the Blackstone River

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<http://wrrc.umass.edu/about/annual-reports>

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Executive Summary

During the Fiscal Year 2017, the Massachusetts Water Resources Research Center, with its staff of 2.5 FTE, managed a \$519,329 budget covering 9 projects.

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

- **"The stable isotopic composition of shallow and deep ground waters in Massachusetts"** led by Dr. David Boutt of UMass Amherst established a regional-scale monthly record of the stable isotopic composition of surface and ground water in Massachusetts with the goal of assessing constraints on the seasonality of recharge, ground water residence times, sources of water to streams, and understanding the sensitivity of stream baseflow to seasonal hydrologic variability.
- **"Understanding the interaction of renewable energy generation and desalination within the water-energy system"** headed by Dr. Matthew Lackner at UMass Amherst investigated the interplay between renewable energy generation, desalination, and the water-energy system, with the goal of identifying the impact of renewable energy generation on water supplies and desalination.
- Dr. Sheree Pagsuyoin at UMass Lowell led a project entitled **"Adaptive drought vulnerability index for strategic emergency response (ADVISED) model"** to develop the conceptual framework to model the adaptive mapping of regional vulnerabilities to increasing drought severity in the northeastern United States.

The following projects were continued from last year:

- The **Acid Rain Monitoring project**, led by WRRRC 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 WRRRC 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 **Development of Pilot Extreme Flood Vulnerability Assessment Protocols under Present and Future Climatic Conditions for Roadway Stream Crossing Structures within the Deerfield River Watershed, Massachusetts**, led by WRRRC Director Paula Rees, started its final year of study to create a method for assessing the vulnerability of stream crossings to extreme floods.
- **Advancing agricultural water security and resilience under nonstationarity and uncertainty: A conversation among researchers, extension, and stakeholders on the evolving roles of blue, green and grey water**, led by WRRRC Director Paula Rees, continued to examine current water issues in agriculture.

The 104B Program also supported a multi-pronged Information Transfer project:

- Working with Drs. Paul Mathisen and Suzanne LePage of Worcester Polytechnic Institute, we organized two **Water Sustainability Management** breakout sessions at the **WPI Water Innovation Workshop**.
- Following upon the success of the past three years, we again assisted Dr. David Reckhow of UMass Amherst Civil and Environmental Engineering and a steering committee composed of his graduate students to organize the **New England Graduate Student Water Symposium (NEGSWS)**. This symposium brings undergraduate and graduate students engaged in water related research together from across the region to share their work, network, and interact with post docs, faculty, and industry representatives.

Introduction

This report covers the period March 1, 2016 to June 30, 2017, the 52nd year of the Massachusetts Water Resources Research Center (WRRRC). The Center was under the direction of Dr. Paula Rees, who held joint appointments as Director of the WRRRC and Director of Diversity Programs for the College of Engineering at the University of Massachusetts Amherst (UMass).

The goals of the Massachusetts Water Resources Research Center are to address water resource needs of the Commonwealth and New England through research, creative partnerships, and information transfer. Through the USGS 104B program, WRRRC aims to encourage new faculty as well as students to study water resources issues.

The USGS 104B Program Water Resources Institutes supported 3 new research projects:

"The stable isotopic composition of shallow and deep ground waters in Massachusetts" led by Dr. David Boutt of UMass Amherst established a regional-scale monthly record of the stable isotopic composition of surface and ground water in Massachusetts with the goal of assessing constraints on the seasonality of recharge, ground water residence times, sources of water to streams, and understanding the sensitivity of stream baseflow to seasonal hydrologic variability.

"Understanding the interaction of renewable energy generation and desalination within the water-energy system" headed by Dr. Matthew Lackner at UMass Amherst investigated the interplay between renewable energy generation, desalination, and the water-energy system, with the goal of identifying the impact of renewable energy generation on water supplies and desalination.

Dr. Sheree Pagsuyoin at UMass Lowell led a project entitled **"Adaptive drought vulnerability index for strategic emergency response (ADVISER) model"** to develop the conceptual framework to model the adaptive mapping of regional vulnerabilities to increasing drought severity in the northeastern United States.

The *Acid Rain Monitoring Project*, led by WRRRC 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, as did the project entitled *Development of Pilot Extreme Flood Vulnerability Assessment Protocols under Present and Future Climatic Conditions for Roadway Stream Crossing Structures within the Deerfield River Watershed, Massachusetts*, and the project *Advancing agricultural water security and resilience under nonstationarity and uncertainty: A conversation among researchers, extension, and stakeholders on the evolving roles of blue, green and grey water*.

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

Research Program

1. Adaptive Drought Vulnerability Index for Strategic Emergency Response (ADVISED) Model

Principal Investigators: Sheree Pagsuyoin

Start Date: 3/1/2016

End Date: 2/28/2017

Funding Source: 104B (2016MA450B)

Reporting Period: March 1, 2016 – February 28, 2017

Research Category: Climate and Hydrologic Processes

Problem and Research Objectives:

The Climate Change Adaptation Council predicts that the changing climate will trigger more frequent extreme weather events in Massachusetts, including more intense and short-term drought periods¹. The resulting altered timing of streamflows is also expected to further exacerbate existing stresses on available water supply across the state. Some of these predictions are already being experienced; for example, during a recent long moderate drought across the state, the town of Billerica imposed a 5-month ban (May-September 2015) on all outdoor water use during the day.

Droughts cause profound impacts on societies, of minor to catastrophic proportions. Because water is an essential resource in delivering goods and services, drought events can lead to tremendous economic losses that propagate through inherently interdependent economic sectors. When water scarcity necessitates reallocation or reduced consumption within the production line, the resulting operational disruptions can yield either short but intense economic consequences, or minimal but prolonged impacts, or negligible effects. As the demand for water continues to increase amidst a rapidly diminishing supply and amidst the present threat of climate change, drought mitigation measures must account for the varying vulnerabilities of economic sectors to different levels of drought severity.

The over-all objective of this research was to develop the conceptual framework for the Adaptive Drought Vulnerability Index for Strategic Emergency Response (ADVISED) Model, a visual and dynamic decision support tool for the adaptive mapping of regional vulnerabilities to increasing drought severity in Northeast United States. Specifically, the research aimed to:

(1) Develop a regional water input-output model (WIOM) to estimate the inoperability and economic losses that are incurred across interdependent sectors over time during prolonged periods of drought and increasing drought severity in Northeast US;

(2) Formulate a rating system, in the form of vulnerability indices, to evaluate the impacts of varying drought severity on the economic and operational performance of interdependent economic sectors;

(3) Integrate available drought-related databases with the WIOM¹ and the vulnerability rating scale² into a single platform – the ADVISED Model – that enables the visualization and dynamic spatial mapping of changes in drought vulnerabilities during the drought timeline;

(4) Identify gaps in available data that will enable the identification of regional and sector-specific vulnerabilities to drought;

(5) Evaluate the time-varying resilience of economic sectors across regions to different drought emergency mitigation strategies; and

(6) Apply the WIOM and the vulnerability rating scale to a case study of Massachusetts to analyze drought vulnerabilities across sectors and identify gaps in existing drought response emergency programs.

Methodology:

Framework for ADVISER Model

The ADVISER Model framework (Fig. 1) is designed for specific application in the Northeast United States, with a case demonstration for the state of Massachusetts. The modeled system consists of economic sectors functioning within a defined region. The core design of the project involves the assembly of a number of data sets (DBASE *i*) from different sources including those that are used in investment and land-use decisions, resource management, and drought emergency response. The consolidated data is compiled in a single platform to form the data layers of the modeling framework. These databases are then used as inputs to the WIOM to describe their direct and cascading impacts on the operation and performance of the economic sectors within the modeled system. WIOM results are visually and spatially represented on maps using the ADVISER Model, which is intended to inform policymakers. Scenario simulations with the ADVISER Model can be performed to explore the system's response to external perturbations (e.g., breakdown of water distribution network) and policy interventions (e.g., water reallocation). External perturbations can occur without policy intervention (P₁ in Fig. 1) and directly impact the WIOM inputs, or cause direct impacts to the WIOM inputs while affecting other perturbations (e.g., sudden heavy rainfall during water restrictions).

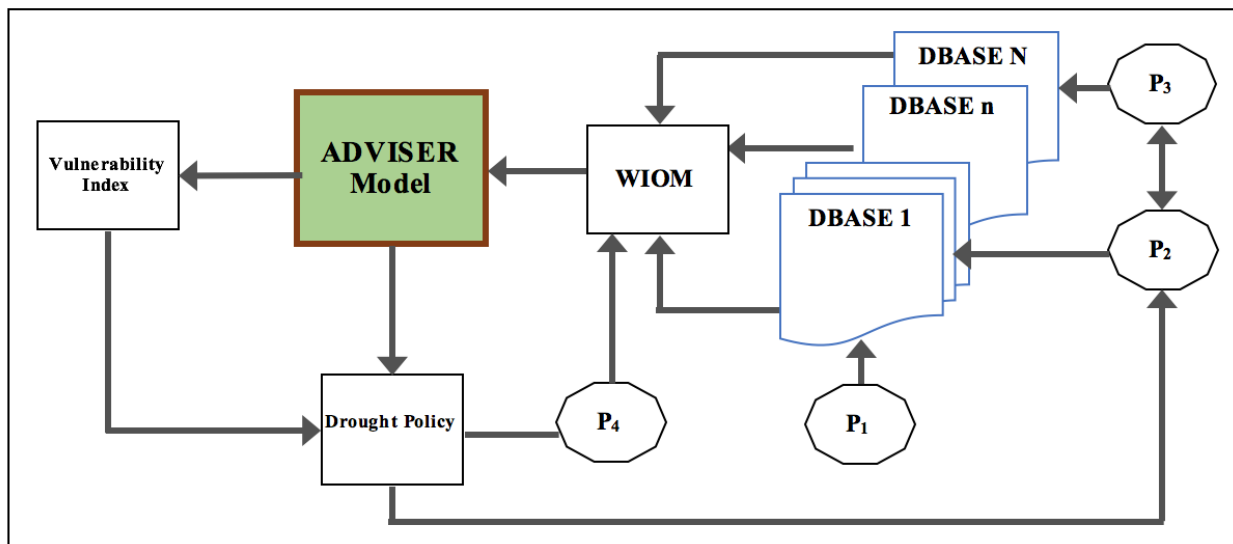


Fig. 1 Conceptual framework of the ADVISER Model showing system response and feedback loops for perturbations, P₁, (intervention or external perturbation). Note that perturbations can directly cause changes to the input values to the WIOM and/or cause other perturbations that directly affect WIOM inputs. Here, P₁ is an external perturbation that affects only the WIOM data inputs, P₂ is a policy intervention that also has an impact on external perturbations, and P₃ is an external perturbation that has both a direct effect on the WIOM data inputs and an effect on a policy intervention. P₄ is a policy intervention that affects only the WIOM inputs.

The ADVISER Model framework uses economic input-output (I-O) modeling to quantify drought vulnerability – represented in terms of two metrics *inoperability* and *economic loss* - to determine how drought affects the productivity and operation of interdependent sectors. Of particular attention in this research is the extension of the inoperability I-O model (IIM) for the analysis of drought management scenarios. The IIM – originally developed by Haimes and Jiang² – is a transformation of the economic I-O

model that utilizes a dimensionless variable called *inoperability*, which ranges between 0 and 1. An inoperability value of 0 corresponds to the undisrupted state of the system and a value of 1 corresponds to total system failure. The mathematical formulation is reproduced in Eq. (1).

$$\mathbf{q}_{DIIM}(t + 1) = \mathbf{q}(t) + \mathbf{K}[\mathbf{A}^*\mathbf{q}(t) + \mathbf{c}^*(t) - \mathbf{q}(t)] \quad (1)$$

The variables in the formulation in Eq. (1) are interpreted as follows: $\mathbf{q}(t)$ is a vector containing the inoperability values of each economic sector at time t , while $\mathbf{q}_{DIIM}(t + 1)$ represents the updated vector at the next time increment, $t + 1$. The term \mathbf{A}^* is the interdependency matrix that can be parameterized using I-O data as published by the US Bureau of Economic Analysis. The vector denoted by $\mathbf{c}^*(t)$ represents the perturbations to the economic sectors at time t . Finally, \mathbf{K} is the resilience coefficient matrix whose elements are related to the rates at which the systems recover to their ideal state after being exposed to a disruptive event. In this research, \mathbf{K} is assumed to be a diagonal matrix representing the sector-specific inherent resilience coefficients; nonetheless its product with the interdependency matrix \mathbf{A}^* , as implied in Eq. (1), gives rise to the concept of coupled resilience.

Massachusetts Case Study

The MA Drought Management Task Force monitors drought conditions in 6 regions: Western (DR I), Connecticut River (DR II), Central (DR III), Northeast (DR IV), Southeast (DR V), and Cape Cod and Islands (DR VI). Drought severity is ranked on 5 levels (Normal, Advisory, Watch, Warning and Emergency) based on 7 drought indices³. The ADVISER model was used in running drought scenario simulation for Massachusetts for a 180-day drought duration that reaches an Emergency level (reflective of the most recent drought in mid 2016-early 2017). The water reduction was assumed to be at 20%, which is within the range for water reduction levels for similar drought category in the states of VA and CA. Further, the simulated scenario was divided into three periods: 0-30 days when drought progresses from Normal to Emergency level, followed by a 30-day period of sustained Emergency level drought, and finally by a 120-day recovery period.

Data Collection and Synthesis

The economic data sets that were utilized in this study included (i) the regional I-O matrix comprising of 71 economic sectors as classified by the North American Industry Classification System, (ii) gross domestic product data from the US Bureau of Economic Analysis (BEA), (iii) local area personal income from BEA, and (iv) water input requirements of each sector derived from the *Use* matrix available through BEA. The drought scenarios that were considered in the case study were based on the Massachusetts drought severity classification, which takes into account several factors such as precipitation, streamflow, groundwater level, and reservoir level.

Visual Mapping

Data integration for the ADVISER Model consists of modules (including the WIOM calculations) written in MatLAB, equipped with a GIS-based Graphical-User Interface. All GIS shapefiles and associated data layers were obtained from the MA government website (mass.gov). The ADVISER modules enable the visualization, scenario building, and sensitivity analyses of the interdependent relationships of the economic sectors as a function of their dependence on available water supply.

Principal Findings and Significance:

ADVISER Model

Fig. 2 shows the graphical user interface of the ADVISER model software that was developed and written in MatLAB. The top left corner shows the user input parameters regarding the duration of the drought

event and the ensuing recovery period, the level of disruption in water availability (indicative of drought severity), and the desired simulation display (e.g., number of period intervals to be displayed). There is an option to display animation for the vulnerability metrics (inoperability and economic loss), one metric at a time. The displayed map shows the temporal values of the metrics for each county and sector for any given drought scenario that is simulated. The bottom right corner shows the top ten most vulnerable sectors (for each metric). This spatio-temporal visualization of drought severity and vulnerabilities is a useful tool for policymakers in evaluating the drought resilience of sectors and counties, from the onset of drought and through the ensuing recovery phase. It can also be used to evaluate the effect of implementing water management interventions which affect the level of water disruption.

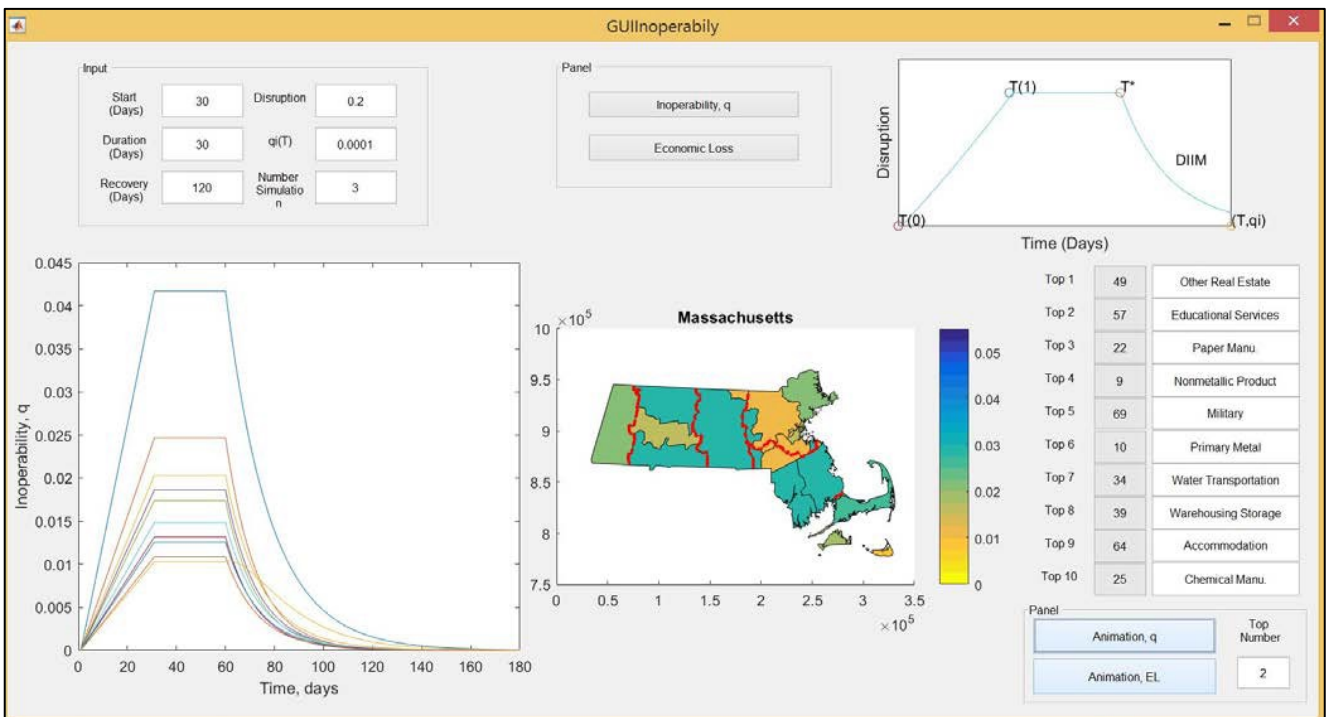


Fig. 2. Graphical User Interface of the ADVISER model

State-wide Drought Management

The current spatial categorization of drought regions in MA is more reflective of political boundaries than of watershed boundaries. Massachusetts has 28 primary watersheds, some of which are shared with neighboring states. Some towns are also serviced by several watersheds. The MA Drought Management Task Force plays only an advisory role regarding drought severity; towns implement corresponding mitigation strategies at their discretion. Drought severity is determined based on where the majority of 7 drought indices occur, and on additional data regarding expected incoming weather patterns. During our consultation meeting with the Mass DEP on 24 October 2016, it was emphasized that there is a need to revisit the categorization of both the drought regions and drought levels (e.g., classification based on water source). Drought is more intensely felt in areas where the main water source is groundwater, and some counties are supplied by water from neighboring counties (e.g., piped from western to eastern Mass.). Therefore, it can happen that one town is under drought, but the neighboring towns are also affected even if they are classified as not being under the same drought category level. Further, there needs to be some additional guidance across towns on drought mitigation

actions; currently, there is inadequate communication and sharing of drought mitigation strategies across towns.

Database Assembly

The availability of the assembly of databases (economic data from BEA and GIS data from mass.gov) is adequate to perform the case study for MA. The I-O data used in the MA case study was adapted from the national I-O. Some missing data (e.g., LAPI data for a few economic sectors in the state) can be addressed by adapting equivalent information from the national data (for counties, missing data can be adapted from state data).

Drought Scenario Simulation Results

Fig. 3 shows the top sector rankings for the inoperability (left) and economic loss (right) metrics for the 180-day drought scenario in MA. The manufacturing industry is well-represented in the rankings and the farming industry is absent. This is to be expected since the former is a major contributor to the state economy while the latter is not. For the inoperability metric, the real estate sector (S49) shows a markedly higher inoperability than the other sectors, highlighting the dependence of its operation on water availability. The chemicals sector (S25) exhibits a comparatively slower recovery during the recovery phase; also, its inoperability further increases at the onset of the recovery period before starting to return to normal. This phenomenon demonstrates the concept of “ripple effects” where the impacts of drought on sectors that provide inputs to the chemicals sector still affect its operation even as drought begins to ease. The top rankings for the economic loss metric differ from the top rankings for the inoperability metric. The estimated total economic loss for the state is \$69 million, of which nearly a third is incurred by 3 sectors: real estate (S49), utilities (S6), and chemicals manufacturing (S25). The economic loss incurred by the real estate sector is disproportionately larger than the rest of the sectors, indicating its high economic value to the entire MA economy.

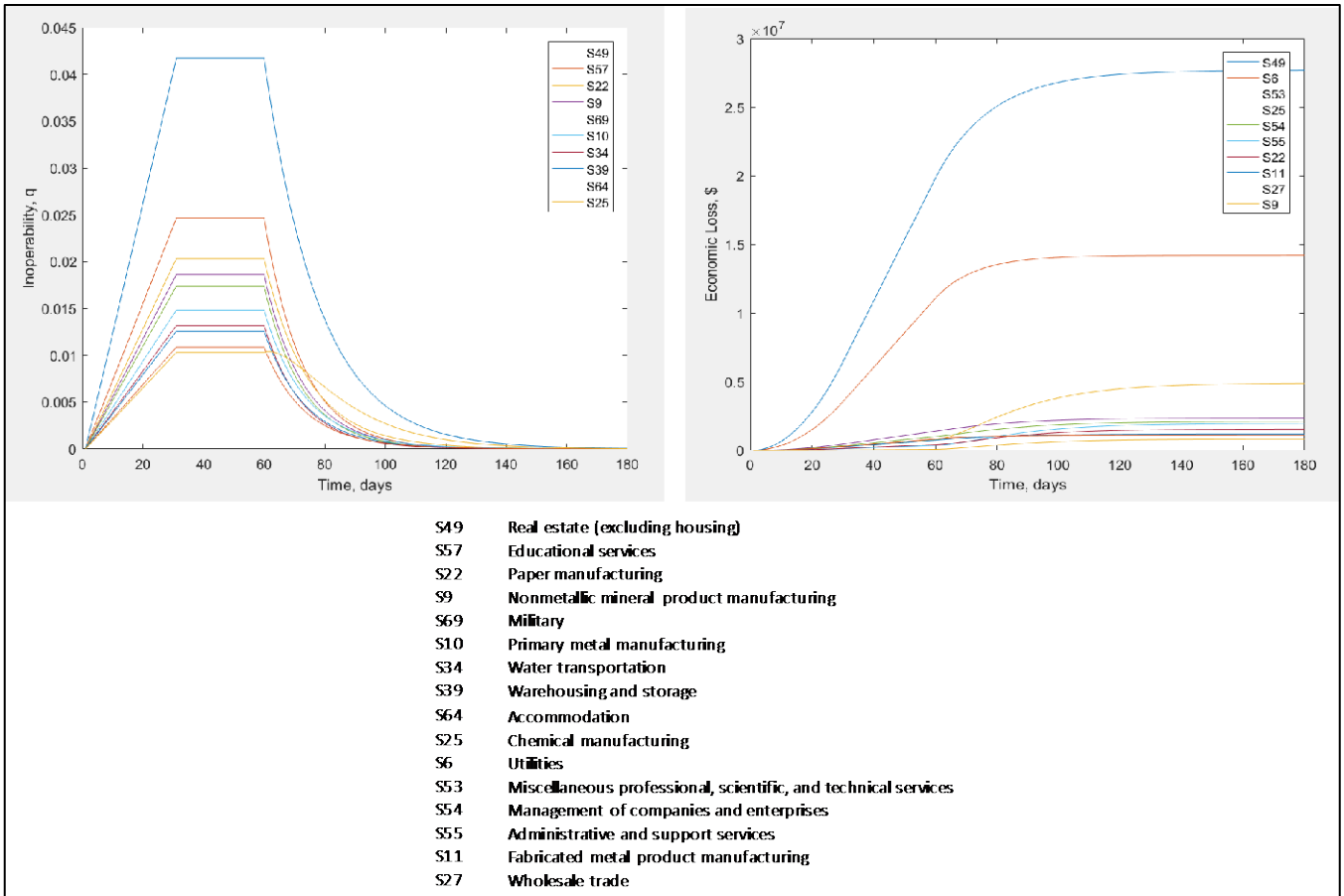


Fig. 3. Inoperability (left) and economic loss (right) rankings for the State of Massachusetts for a 180-day drought duration that reaches Emergency category.

Fig. 4 shows the spatio-temporal evolution of inoperability values (q) for 3 selected sectors: real estate (S49), non-metallic minerals manufacturing (S9) and chemicals manufacturing (S25). The highest inoperability values are observed in three drought regions: DR II (Connecticut), DR III (Central), and DR V (Southeast), and the most distinct differences in inoperability values are observed for the real estate sector. It can also be noted that the recovery of Bristol County in DR V (western side of DR V) is slightly faster not just for the real estate sector but also for the minerals and chemicals manufacturing sectors.

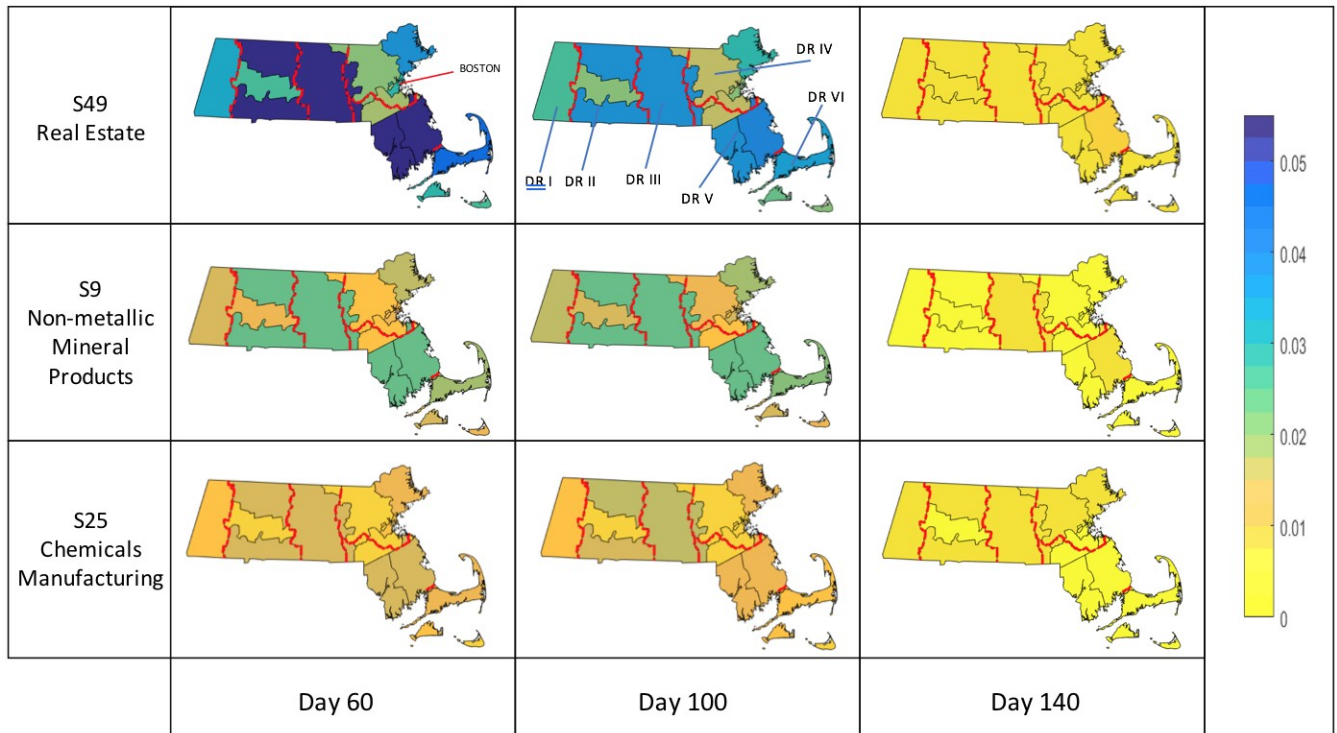


Fig. 4 Massachusetts case study results showing inoperability values by county for sectors S49, S9, and S25 for a 180-day drought duration. This drought simulation was based on the most recent 6-month drought (mid 2016 to early 2017) experienced in Massachusetts. The state is divided into 6 drought regions (DR): Western (DR I), Connecticut (DR II), Central (DR III), Northeast (DR IV), Southeast (DR V), and Cape Cod and Islands (DR VI).

Conclusions

In this research, we have developed the ADVISER model, a dynamic and visual decision support tool for drought risk analysis that integrates various modeling components including economic IO modeling, dynamic inoperability analysis, and visualization using GIS. The ADVISER model enables spatiotemporal assessment of the impacts of varying drought severity and duration on the regional economy while accounting for the inherent linkages across economic sectors. It also allows policymakers to evaluate the drought resilience of economic sectors, from the onset of drought and during the ensuing recovery phase. The case application to the state of Massachusetts demonstrates the utility of the framework in performing drought risk analysis for a region (state) and for its individual components (drought regions).

The case study shows that in comparison to the rest of the economic sectors in Massachusetts, the real estate sector incurs a disproportionately significant impact to its economy (economic loss metric) and operation (inoperability) as a result of severe short-term drought. Further, the rankings of the critical sectors and drought regions with respect to the two vulnerability metrics – inoperability and economic loss – differ for each metric; these differences should be interpreted carefully when formulating drought risk management strategies in the state. As measures of drought resilience, the inoperability and economic loss metrics provide insights on critical sectors and sub-regions and their ripple effects on the regional economy. Research findings can guide policies and strategies for enhancing drought resilience across sectors and the entire regional economy.

References

1. Executive Office of Energy and Environmental Affairs and Adaptation Advisory Committee (2011) Massachusetts Climate Change Adaptation Report. 128 pp.

2. Haimes YY, Jiang P (2001) Leontief-based model of risk in complex interconnected infrastructures. *J Infrastruct Syst* 7(1): 1-12.
3. Massachusetts Executive Office of Energy and Environmental Affairs and Massachusetts Emergency Management Agency (2013) Massachusetts Drought Management Plan. 41 pp.

Publications and Conference Presentations:

Pagsuyoin SA, Santos JR, Salcedo G (2017) Development of a Dynamic GIS-based Model for Evaluating Regional Drought Risks and Resilience (In preparation)

Pagsuyoin SA, Santos JR, Salcedo G, Yip C (2017) Spatio-Temporal Drought Risk Analysis Using GIS-based Input Output Modeling in Modeling Spatial and Economic Impacts of Disasters; Y Okuyama and Rose A, editors; Elsevier; In review

Pagsuyoin SA, Santos JR, Salcedo G (2016) ADVISER model: an adaptive decision tool for analyzing regional drought impacts; Proceedings of the Annual Meeting of the Society for Risk Analysis; 11-15 December 2016, San Diego, CA

2. The stable isotopic composition of shallow and deep ground waters in Massachusetts

Principal Investigators: David Boutt

Start Date: 5/1/2016

End Date: 4/30/2017

Funding Source: 104B (2016MA452B)

Reporting Period: March 1, 2016 – April 30, 2017

Research Category: Ground-water Flow and Transport

Problem and Research Objectives:

Surface and ground water in the Northeast US are heavily impacted by intense land-use changes, urbanization (Weiskel et al., 2007), and climatic changes (Hodgkins et al., 2002; Hodgkins et al., 2003, Huntington et al., 2004; Hayhoe et al., 2007). More emphasis is being placed on water suppliers, stakeholders, and environmental managers to assess water quantity and water quality with increasing confidence intervals for sustainable management (e.g. [minimum streamflow regulations](#)). However, an over-reliance on physical measures of hydrologic behavior (such as streamflow and water table elevation) that do not uniquely assess the connectedness, residence time, and age distribution of surface and ground waters (McDonnell et al., 2010) cloud decision-making and introduce significant uncertainty. Recently, advances in theory and instrumentation have allowed the use of geochemical tracers (such as H₂O, D and ¹⁸O) in combination with physical data to resolve discrepancies in measurements and reduce uncertainty in system conceptualization (IAEA, 2000). These tools and techniques have not yet been widely available to water suppliers.

The interpretation of stable isotope data in isotope hydrology relies on accurate, high-precision measurements of H and O isotopes of water samples (Brand et al 2009; Wassenaar et al 2012). With the advent of low-cost and high-throughput liquid water isotope analyzers based on cavity ring-down spectroscopy (CRDS, Berden et al 2000), hydrologic scientists can fully utilize these tools for assessment and management decisions with greater certainty. The applicability of stable isotopic tracers relies on robust understanding of the seasonal behavior of precipitation and the characterization of the isotopic behavior of surface and ground water isotopes.

Methodology, Principal Findings and Significance:

Database and sample Collection:

With support through the 104B program we have designed and built our isotope database. The current database consists of 1500 precipitation measurements across 15 stations, 2500 surface water measurements across 150 sites, and 2000 groundwater samples from 200 wells screened in overburden and bedrock wells. During the summer of 2016 alone we collected 800 new samples of surface water and groundwater. A map of new sample locations is presented in Figure 2. Significant effort was put into developing a network of collaborators at local watershed organizations. Through meetings with state entities –such as MA DCR – we are now having samples sent to us monthly from DCR and other cooperative water monitoring programs.

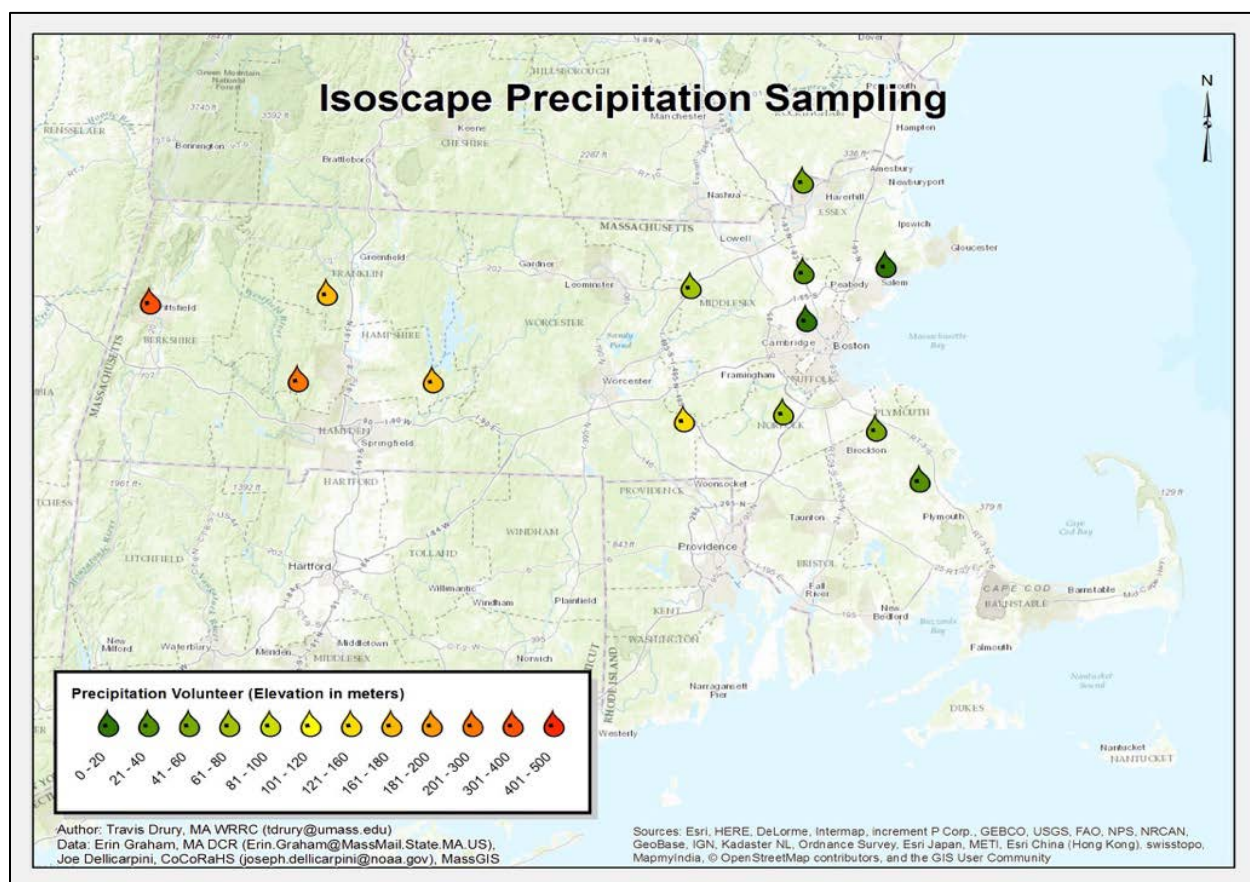


Figure 1: Precipitation sampling localities across the state of Massachusetts. Precipitation samples are composited bi-weekly at 14 proposed locations

Results:

Isotopic composition of the region varies significantly as a function of topography and season. Because of the coastal orientation of the region, there is a large variability in the mean ^{18}O - H_2O composition of precipitation due to locally dominant precipitation sources. Deuterium excess of precipitation in the range of 10 – 14 ‰ are typical. Five years of surface water samples across the region show a strong seasonal trend ranging from -10 to -3 ‰ $\delta^{18}\text{O}$ - H_2O . Surface waters depict seasonal evaporative enrichment in the heavy isotopes and demonstrate a similar magnitude of deuterium excess compared to the precipitation. During the winters of 2014 and 2015 typical seasonal trends are interrupted by distinctly depleted stream waters of the order of -12 to -11 ‰ $\delta^{18}\text{O}$ - H_2O . These excursions are

consistent with a source of water vapor to the region from more northerly (colder) regions. Mean stream water $\delta^{18}\text{O}$ - H_2O isotopic compositions show a strong relationship to upgradient drainage area. Groundwater compositions range from -12 to -5 ‰ $\delta^{18}\text{O}$ - H_2O across all the sites. A correlation between groundwater well elevation and $\delta^{18}\text{O}$ - H_2O is observed with higher elevation sites depleted in heavy isotopes with variations of 2-3 ‰ $\delta^{18}\text{O}$ - H_2O at any given elevation. Groundwater isotopic composition is distinct between overburden aquifer types (till, glacial fluvial) and bedrock suggesting that these aquifers are experiencing unique mixtures of recharge water. The development of this database and the resulting science will enable local and regional water stakeholders to manage and protect water resources while allowing hydrologists to explore regional and globally relevant scientific questions.

The Database in Action

Through our partnership with MA DCR Quabbin watershed environmental quality team, we prototyped isotopic baseflow separation using data collected from the network during a precipitation event in June of 2016. Figure 3 summarizes the data collected during this event that plots total stream discharge (blue) and isotopic composition of the stream water during the event. A gray bar shows a composite analysis of the precipitation that fell during the storm (~ -4 ‰ $\delta^{18}\text{O}$ - H_2O). Before the storm, streamflow isotopic composition was about -9 ‰ $\delta^{18}\text{O}$ - H_2O . The isotopic composition of the stream water gradually increases to -7.2 ‰ $\delta^{18}\text{O}$ - H_2O and then falls back towards the pre-event composition. Using a two endmember mixing model based on the isotopic composition of precipitation and that of the pre-event stream water we estimate that proportion of new water in the stream (the precipitation) is the red line on the hydrograph. Summing up the area of the curve it turns out that about 75% of the discharge during the event was old water stored in the catchment and hydraulically pushed out of the ground by infiltrating new water. This type of information is important to consider when interpreting run-off events from a water quality perspective.

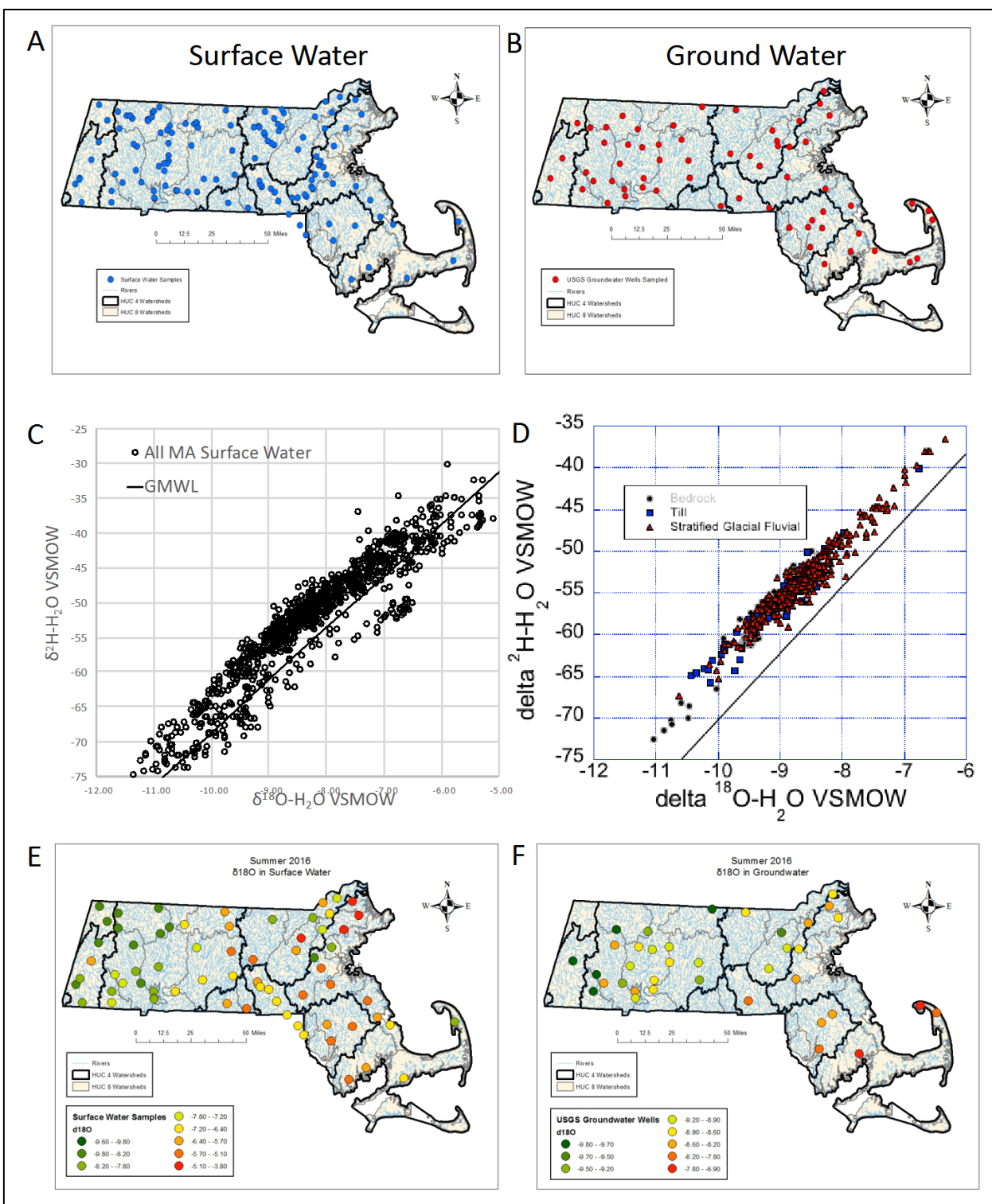


Figure 2: (A) Spatial distribution of where surface water samples were taken across Massachusetts B) Spatial distribution of where surface water samples were taken across Massachusetts C) Relation of O18 and H2 values for all MA surface waters, plotted against the GMWL D) Relation of O18 and H2 values for bedrock type found in MA, plotted against the GMWL E) Spatial distribution of d18O values of surface water across Massachusetts F) Spatial distribution of d18O values of groundwater across Massachusetts

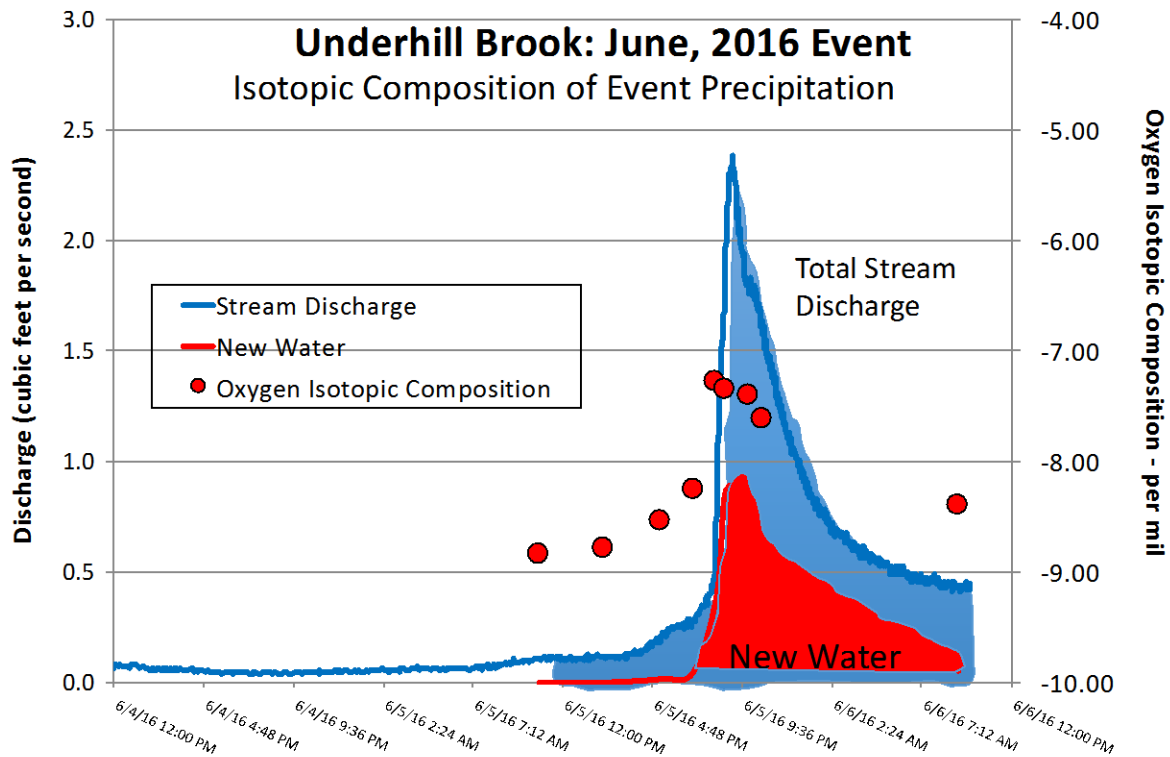


Figure 3: The isotopic composition of Underhill Brook vs the composition of the precipitation indicates that after the storm event the discharge composition was not dominated by new water.

Publications and Conference Presentations:

Boutt, D.F. The Massachusetts Water Isotope Mapping Project: An Integrated Precipitation, Surface Water, and Ground Water IsoScape for Improved Understanding of Hydrologic Processes, Abstract PP24B-07, presented at 2016 Fall Meeting, AGU, San Francisco, Calif., 12-16 Dec.

3. Understanding the interaction of renewable energy generation and desalination within the water-energy system

Principal Investigators: Matthew Arenson Lackner

Start Date: 6/1/2016

End Date: 8/15/2016

Funding Source: 104B (2016MA454B)

Reporting Period: June 1, 2016 – August 15, 2016

Research Category: Engineering

Problem and Research Objectives:

The goal of this project was to develop new and innovative research focused on the coupled,

interdependent behavior of renewable energy generation and water desalination through system modeling and resource analysis. Water and energy systems are inextricably linked. In this “water-energy nexus,” energy is used to create and move water, and water is used in energy production. The cooling systems of thermal power plants are the largest withdrawer of water in the U.S. In fact, in 2010 approximately 40% of fresh water in the U.S. was consumed by the cooling systems of thermal power plants. Renewable energy (RE) generation, such as wind and solar energy, has the potential to decouple water and energy, and instead can bring about a virtuous feedback cycle that positively impacts water supplies, while also reducing greenhouse gas emissions and other environmental impacts. At a basic level, as RE penetration levels increase, fossil and nuclear power sources are potentially displaced, resulting in less fresh water cooling demands, increased water supplies, lower desalination demand, and thus a further decrease in energy demand. Our project investigated this interplay between RE generation, desalination, and the water-energy system. In this project, we proposed two research topics to begin to better understand the coupling between RE, desalination, and the water-energy system. These were: (1) System modelling of the water-energy system using a range of RE generation and desalination scenarios; and (2) Resource correlation of renewable energy sources, water supply, and water utilization.

Methodology:

(1) This project used a case study approach, and focused on California. We used recent data and projections to create various scenarios of RE generation for the next 20-30 years. We considered several conservative (“business as usual”) and more aggressive RE and carbon free generation scenarios. Using projections of total electricity generation, we modeled the displaced thermal energy under various sources, allowing us to calculate the relative fresh water saved under each scenario. We modeled the displaced desalination demand (as well as the projected increase in desalination over time), followed by the reduced energy consumption. This analysis resulted in estimates of the marginal increase in fresh water supply under various RE generation scenarios. This analysis is consistent with that of other work, but is unique in its consideration of the growth in desalination and the coupling between desalination and energy demands. (2) We analyzed historical long-term data and determined correlations between renewable energy sources (solar and wind), water supply, and water utilization in California, enabling us to draw conclusions about the impact of RE generation on water supplies and desalination. To do this, we also investigated the sensitivity of solar and wind resources as well as precipitation to El Niño Southern Oscillation (ENSO) events and how these resources vary in different regions of California. Use of long-term data enabled us the study of the large-scale climatological relationships and behaviors of these resources in a large number of ENSO (El Niño and La Niña) years.



Fig. 1. Geographical positions of the selected locations on the map of California.

Principal Findings and Significance:

(1) The analysis revealed that further penetration of RE based electricity generation (especially PV and wind energy because of negligible water requirements) in California provides substantial potential to reduce water demands in the power sector by decoupling water and energy. Also, the results showed that although use of carbon capture technologies for fossil fuel power plants has a tremendous potential to mitigate environmental concerns in California, it cannot address the water-energy issues in the power sector. The results showed that in addition to reduction of greenhouse gas emissions, accelerated penetration of RE power plants will be beneficial in managing existing fresh water resources more efficiently, resulting in an increase of fresh water supplies and decrease of construction of new desalination plants in the future. The findings of this research provide insight to decision and policy makers on the impacts of future electricity generation via PV and wind power plants on desalination demands, and managements of the water-energy system.

(2) The results showed that the correlations between the resources are geographically variables; however, these daily correlations or anti-correlations are generally weak, suggesting weak complementary trends between solar, wind and hydropower in California. The conducted analysis indicated the strong relationships of El Niño and La Niña events with the variations of solar and wind energy production, as well as precipitation in most locations of California. Also, the possible influences of some ENSO events on these resources were geographically and seasonally dependent. Furthermore,

the degree to which these resources were linked to ENSO depended on the intensities of ENSO and geographical locations. Our results indicated that ENSO is highly influential on the magnitude and variability of these resources suggesting that ENSO can be a potentially useful prognostic tool for California solar and wind energy and even hydropower planning.

Publications and Conference Presentations:

Mohammadi K., Lackner M., Ray P., Study of inter-correlations of solar radiation, wind speed and precipitation under the influence of El Niño Southern Oscillation (ENSO) in California, to be submitted to Energy Journal or Renewable Energy Journal.

4. Acid Rain Monitoring Project

Principal Investigators: Marie-Françoise Hatte

Start Date: January 1, 2017

End Date: June 30, 2017

Funding Source: Massachusetts Department of Environmental Protection and Bureau of Waste Prevention

Reporting Period: January 1, 2017 – June 30, 2017

Research Category: Water quality

Introduction:

This report covers the period January 1, 2017 to June 30, 2017, the sixteenth 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 ponds¹ 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 seventh year of monitoring for those added ponds.

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.

Methodology:

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

¹ 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)

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 2, 2017.

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 (North Watuppa Lake in Fall River) this year.

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 Derek Smith, 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 Bristol County, 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 2017, 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 149 sites to be monitored, 77 ponds and 72 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 143 sites (70 ponds and 69 streams) including 25 of our long-term sites.
3. There was one quality control problem this year, resulting in the failure of UMass Boston lab to pass pH. This reduced the data we could analyze for pH to include only 138 sites. Additionally, the UMass Soils labs initially sent results for cations that were mostly below detection limit. Unexpectedly, the UNH lab sent results for 4 cations in addition to the 3 anions they were contracted to analyze. This provided a comparison basis with the UMass results and showed a large discrepancy. UMass then explained that they had changed their method this year, but since they had kept the samples refrigerated since their first analysis, they re-analyzed them, with very different results, which we used for this year's dataset.
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 Volunteermatch.org, a press release which was picked up by at least two Massachusetts newspapers, 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 (Table 1). As the Holden lab was not available this year, we used instead the Upper Blackstone Water Pollution Abatement District's lab in Millbury. Unfortunately, due to an equipment issue, Bristol Community College was unable to analyze samples, but they plan to volunteer again next year. The Bristol samples were kept refrigerated. The next day (April 3rd), Travis Drury picked up and brought those samples to UMass Amherst, where he analyzed at EAL immediately.

Table 1: Volunteer Laboratories

Analyst Name	Affiliation	Town
Joseph Ciccotelli	Ipswich Water Treatment Department	Ipswich
Amy Johnston	UMass Boston	Boston
Mark Putnam	MDC Quabbin Lab	Belchertown
Dave Bennett	Cushing Academy	Ashburnham
Krista Lee	Cape Cod National Seashore	South Wellfleet
Kimberly Newton and Mary Rapien	Bristol Community College	Fall River
Bob Bentley	Analytical Balance Corp	Middleborough
Dave Christensen	Westfield State University	Westfield
Debra LaVergne	Upper Blackstone Water Pollution Abatement District	Millbury
Carmen DeFillippo	Pepperell Waste Water Treatment Plant	Pepperell
Cathy Wilkins	Greenfield High School	Greenfield
Travis Drury	UMass Amherst Environmental Analysis Lab	Amherst

5. The ARM web site and searchable database were maintained and updated. 2017 pH, ANC, color, 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 (138 and 143 sites, respectively) and for color and 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, color, 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 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 2: Trend analysis results for pH and ANC, April 1983 – April 2017
(Number of sites)

	All sites		Ponds		Streams	
	pH	ANC	pH	ANC	pH	ANC
Increased	41	48	20	30	21	18
Decreased	5	2	3	1	2	1
No Change	92	93	46	43	46	50
Total	138	143	69	74	69	69

Those results are graphed as percentages of all sites in Figure 1.

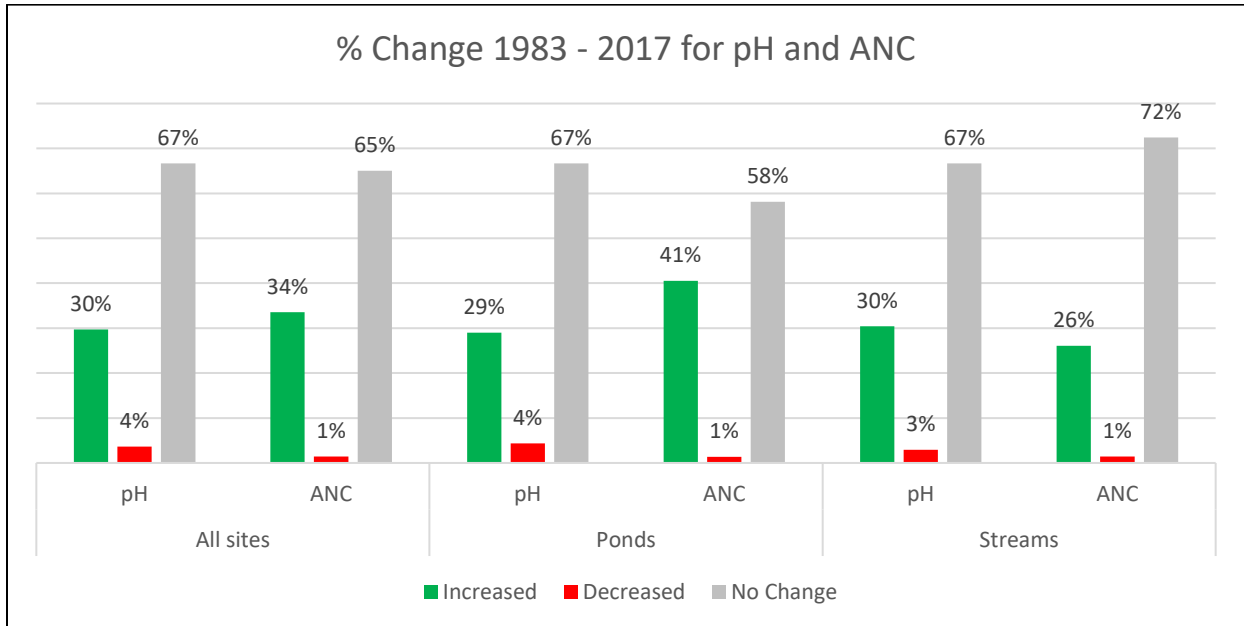


Figure 1. Percent change in number of sites for pH and ANC, from trend analysis, April 1983-2017

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: 30% of the sites saw an increase in pH and 34% had an increase in ANC.

This year, unlike previous years, we note a slightly different picture than previous years between ponds and streams. Practically the same percentage of streams and ponds (29% and 30%) saw an increase in pH, while for ANC, the situation remains that more ponds (30%) than streams (26%) saw an increase. Overall, in 2017 we saw less improvement in pH and ANC than in previous years. There are also more sites this year that experienced a decrease in pH (5) and in ANC (2) over the 34-year study period.

There was snow on the ground in early April this year, and this might explain the small change to more acidic conditions. It will be interesting to see if this trend continues or not in 2018.

Ions

Trend analyses were run for the 25 long-term sites that were analyzed for eleven ions. Results are shown in Table 3 and Figure 2.

Table 3: Trends for number of sites with increases or decreases in ion concentration and color April 1983 – April 2017

	Increased	Decreased	No Change
Mg	9	0	16
Mn	1	4	20
Fe	0	4	21
Cu	10	0	15
Al	3	3	19
Ca	4	1	20
Na	11	0	14
K	15	0	10
Cl	14	0	11
NO3	12	1	12
SO4	0	22	3
Color	20	0	5

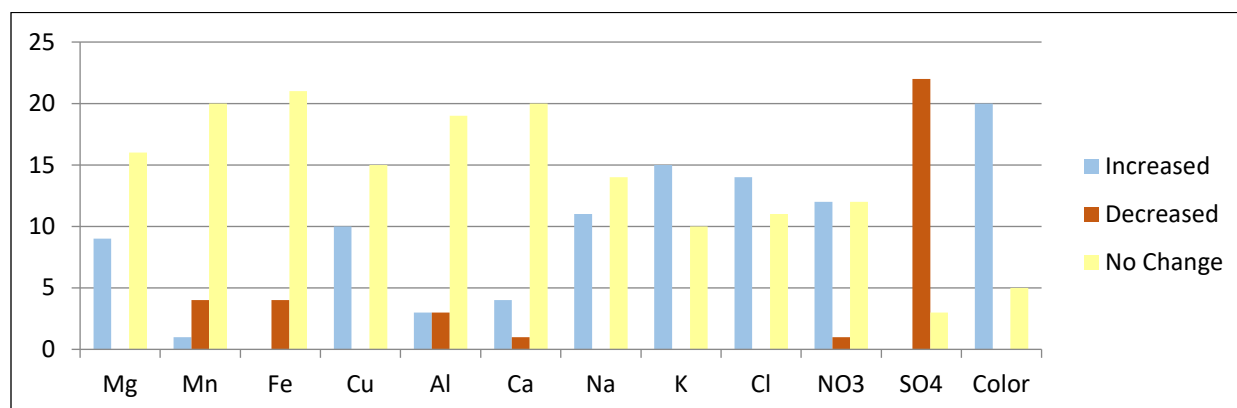


Figure 2: Results of trend analysis for ions and color at 25 long-term sites, April 1983-2017

Shown is how many sites showed an increase (blue), decrease (orange), or no significant change (yellow) over the period 1983 – 2017

Results are somewhat different from previous years. While there are still more sites that show no significant change either up or down, all cations except Iron display some significant increase over the years, with Sodium still in the higher range, though Potassium is now leading in increases. As this year we had an unexpected opportunity to compare analytical results for four cations (Mg, Ca, Na, and K), we noticed that the UMass lab results are often higher than the University of New Hampshire lab. Using the UNH analyses would have resulted in fewer statistically significant increases, particularly for Potassium. We have used the UMass Soils lab since 2013 and propose to use UNH for cations in the future.

For anions, we continue to see a very significant downward trend in Sulfate (22 sites). Nitrates, on the other hand, show more increasing than decreasing, and it is unknown at this time whether it is due to increasing vehicular emissions, or a result of climate change – smaller and less persistent snowpacks result in fine root damage and reduced microbial activity. This can result in losses of nutrient elements, most notably Nitrogen in the form of NO_3^- .

Color is still increasing in most of our sites, which is consistent with a recovery of natural alkalinity.

Discussion

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.

5. Blackstone River Water Quality Monitoring Study

Principal Investigators: Paula Rees

Start Date: 2/26/2004

End Date: Ongoing

Funding Source: Upper Blackstone Water Pollution Abatement District

Reporting Period: 7/1/2016 – 6/30/2017

Research Category: Water quality

Problem and Research Objectives:

Since plant upgrades were completed in 2009, the Upper Blackstone Water Pollution Abatement District (Upper Blackstone) has conducted water quality monitoring of the Blackstone River to assess the river's response to reduced nutrient concentrations in the wastewater treatment facility (WWTF) effluent. The river monitoring program was initiated in 2010 and expanded in 2012, with consistent year to year monitoring at the same river sites to build a multi-year data record. In 2015 and 2016, the river monitoring program included monthly water quality sampling for nutrients and chlorophyll-a, as well as periphyton surveys. Additionally, a macroinvertebrate survey was completed in 2015.

While Upper Blackstone's monitoring program has always followed strict sample collection and analysis procedures, the 2015 and 2016 sampling seasons were also conducted under a Quality Assurance Plan (QAP) approved by the Massachusetts Department of Environmental Protection (MassDEP). The Water Resources Research Center at the University of Massachusetts (UMass), who conducts the monitoring on behalf of Upper Blackstone, worked closely with MassDEP data quality managers and scientists to finalize the QAP. Having the approved QAP in place allows MassDEP to use the data in the agency's watershed assessments.

The Blackstone River water quality data collected as part of the Upper Blackstone's monitoring program are publicly available for download through the CUAHSI Hydrologic Information System (HIS) databases and servers (his.cuahsi.org).

Methodology:

River sampling for nutrients and chlorophyll-a was conducted from April through November at 9 Blackstone River main stem sites located in Massachusetts and Rhode Island, including three Rhode Island sites which were co-sampled with the Narragansett Bay Commission's (NBC) ongoing monitoring program.

Principal Findings and Significance:

River sampling for nutrients and chlorophyll-a was conducted from April through November at 9 Blackstone River main stem sites located in Massachusetts and Rhode Island, including three Rhode

Island sites which were co-sampled with the Narragansett Bay Commission's (NBC) ongoing monitoring program (snapshot.narrabay.com).

Median summer time (June through September) streamflow in 2015 and 2016 was below average, based on recorded streamflow at the United States Geological Survey (USGS) Blackstone River gage in Millbury, MA. Streamflow in 2016 was the lowest since post-upgrade routine monitoring was initiated in 2012. The 2015 and 2016 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 facility upgrades.

Reductions in the total phosphorous (TP) and total nitrogen (TN) load leaving the Upper Blackstone facility are reflected in lower river phosphorous and nitrogen concentrations and loads. An analysis of 2012-2016 concentration data indicated statistically significant decreasing concentration trends at two stations for TP and four stations for TN. Figure 2 shows estimates of TP and TN mass, in pounds per day, transported along the river based on historical, 2015 and 2016 concentrations and streamflow during low river flow periods. The graph shows phosphorous and nitrogen loads in the river from upstream of Upper Blackstone in Millbury, MA (left side of graph) to the river outlet at Slater Mill in Pawtucket, RI (right side of graph).

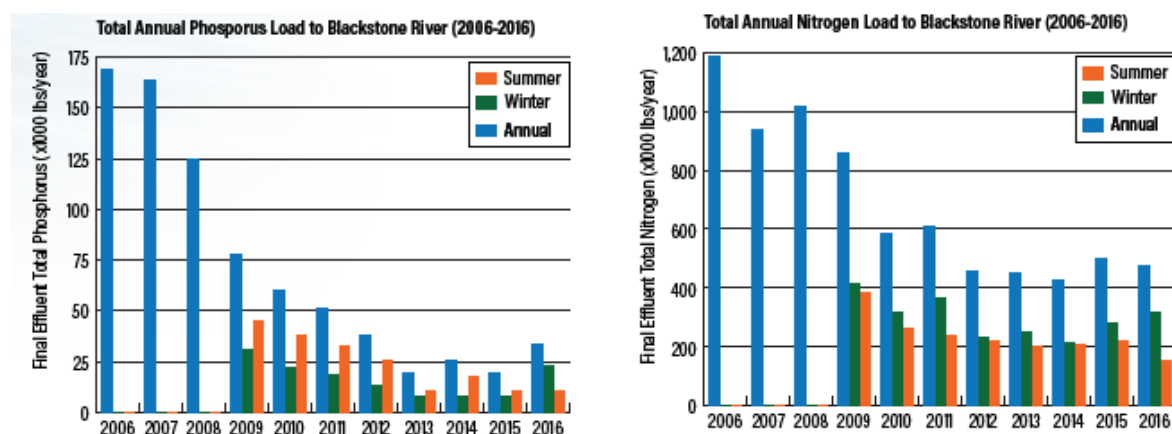


Figure 1. Phosphorous and nitrogen loads in 2016 were reduced 80% and 60% respectively, compared to 2006 levels.

A comparison of historical, and 2015 and 2016 chlorophyll-a concentrations is shown in Figure 3. The reduction in the amount of nutrients in the river, because of Upper Blackstone's improvements, has resulted in lower chlorophyll-a concentrations, particularly in Rhode Island where most of the large impoundments exist. However, in 2016, higher than typical chlorophyll-a concentrations were observed at the Massachusetts sites, both upstream and downstream of Upper Blackstone. In addition to nutrients in the water column, other factors such as water temperature and increased exposure to sunlight make conditions within impoundments and low river flow stretches more amenable to algae growth, which is reflected in higher chlorophyll-a concentrations. In 2016, streamflow and precipitation were below average and air temperatures were above average, likely influencing the observed chlorophyll-a concentrations.

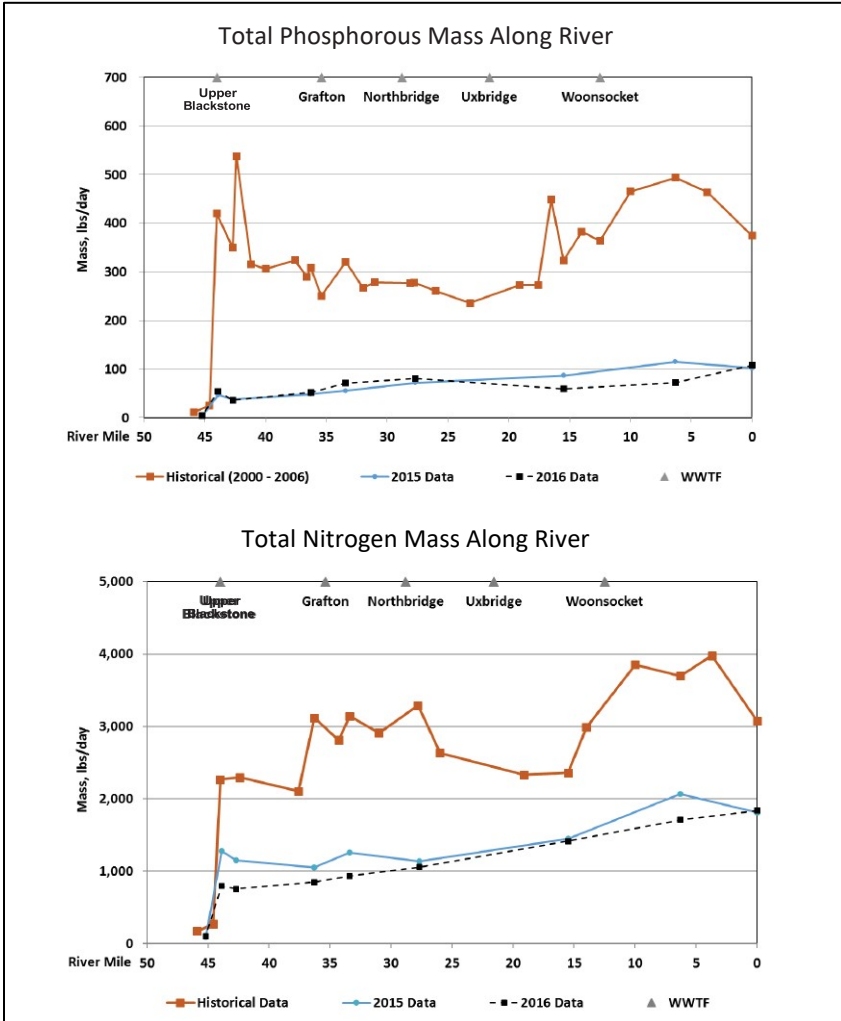


Figure 2. The 2016 total phosphorous and total nitrogen loads in the river were approximately 80% and 55% lower, respectively, than historical loads.

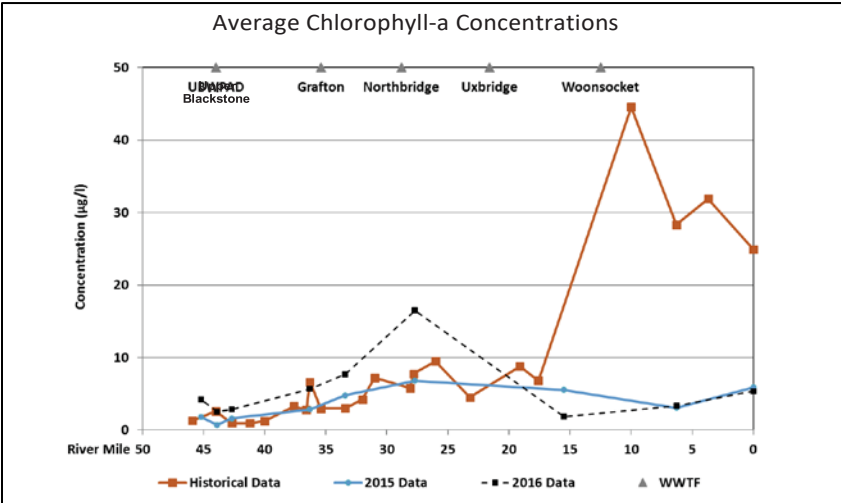


Figure 3. Continued reductions in phosphorous loads have led to reduced algal growth in the river as measured by chlorophyll-a, although higher than typical chlorophyll-a concentrations were observed in Massachusetts in 2016.

The 2015 and 2016 sampling programs included periphyton surveys in July, August and September of each year. Periphyton refers to the micro-community that lives on or attached to the submerged surfaces in a river. The periphyton surveys were performed at 4 river locations including 3 sites sampled by MassDEP in 2008. The range of reported periphyton concentrations from the 2012 - 2016 survey results are shown in boxplot format in Figure 4, with data from 2015 and 2016 highlighted using symbols. Periphyton concentrations from the 2015 survey are consistent with data collected in 2012 and 2013 and are less than reported 2014 concentrations. Results from the 2016 survey indicated higher than typical periphyton concentrations. MassDEP has moved towards using 200 mg/m² as the maximum benthic chlorophyll amount marking the transition from intermediate biological productivity conditions (mesotrophic) to high biological productivity conditions (eutrophic). Most of the reported periphyton concentrations from the 2012-2016 Blackstone River monitoring program are below 200 mg/m².

Year to year periphyton concentrations vary, not only in response to nutrient levels in the river water, but also in response to shading and river streamflow conditions. Normandeau Associates, the scientists conducting the periphyton survey on behalf of Upper Blackstone, have noted changes in the periphyton community over the 2012 – 2016 period including the disappearance of sewage fungus downstream of the effluent channel.

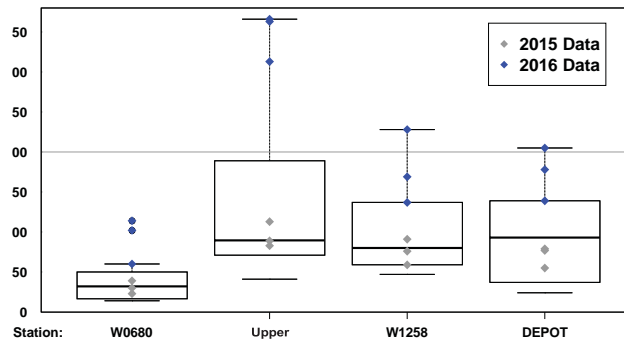


Figure 4. Over the past five years, most reported periphyton concentrations were below MassDEP's threshold of 200 mg/m².

A macroinvertebrate survey- a type of biological monitoring used to evaluate ecological health – was conducted in 2015 to compare river conditions to those observed by MassDEP in a 2008 survey. The 2015 macroinvertebrate surveys indicated noticeable improvement downstream of Upper Blackstone. All the sites – both upstream and downstream of the effluent channel – were classified as either slightly impaired or moderately impaired, an improvement over the severe to moderate impairment noted by MassDEP in 2008.

6. Advancing agricultural water security and resilience under nonstationarity and uncertainty: A conversation among researchers, extension, and stakeholders on the evolving roles of blue, green and grey water

Principal Investigator: Paula Rees, Water Resources Research Center, UMass Amherst

Start Date: 09/30/2013

End Date: 08/20/2017

Reporting Period: 07/01/2016 – 06/30/2017

Funding Source: USDA NIFA

Falkenmark and Rockström first introduced the green-blue water paradigm in 2004. Since then, it has gained widespread acceptance in the international and U.S. water management communities. The blue-green-grey framework has enormous implications for water-resource assessment and agricultural water management. Production of food and other forms of biomass for human uses is the largest component of the human freshwater budget. The perspective of blue, green and grey water management is likely to be a key tool in addressing world agricultural challenges.

The Massachusetts Water Resources Research Center (WRRC) organized a special track of the 2014 joint National Universities Council on Water Resources (UCOWR), National Institutes for Water Resources (NIWR), and Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) Conference to provide a global overview of the state of our knowledge about the blue-green-grey framework for agricultural management as well as new innovations it has brought about. Funding for the track was provided from USDA-NIFA. Tufts University hosted the conference June 18 – 20, 2014, and played a key role in also helping organize the blue-green-grey conference track. Development and organization of the conference track was a collaborative effort between the WRRC, members of the grant Scientific Advisory Board, and the conference steering committee.

Through discussion and dialogue, the conference track helped identify needs, opportunities, and challenges for future research, extension programming, and education around the Blue, Green, Grey water management paradigm. Beyond the academics and agency staff that traditionally attend UCOWR conferences, Extension Educators and their stakeholders--the agriculture producers that are directly impacted by policies and regulations, were invited to participate. The registration of sixty-five participants, including invited speakers, was sponsored by the grant. Additional participants were drawn from the 250+ conference registrants. The track was also broadcast live through a webinar. In the summer of 2014, the presentations were posted on YouTube after minor editing: <https://www.youtube.com/channel/UCNHed1-hYBIEWfVL2e9BgXA>. Further details about the track and speakers are available at <http://wrrc.umass.edu/events/blue-green-grey-water-agriculture>.

Over the last year, WRRC staff member Marie-Françoise Hatte transcribed all of the presentations within the USDA funded track from notes taken at those talks, abstracts submitted, and videos of the actual talks. These are compiled as extended proceedings, and will be published in booklet format and on our website. As part of this work, we identified several presentations where progress in a project was imminent. We contacted the researchers and invited them to submit articles on their state-of-the-art work in the field to be published in a special issue of the Journal of Contemporary Water Research & Education (JCWRE). We also contacted some of the 2014 speakers and other experts in the field and organized a follow-up session on Blue, Green, and Grey Water and Agriculture at the June 2017 UCOWR conference in Fort Collins, CO.

7. Development of Pilot Extreme Flood Vulnerability Assessment Protocols under Present and Future Climatic Conditions for Roadway Stream Crossing Structures within the Deerfield River Watershed, Massachusetts

Principal Investigators: Paula Rees, Scott Jackson, Stephen Mabee, UMass Amherst; Benjamin Letcher, USGS Conte Lab; Michael Rawlins, Northeast Climate Science Center.

Start Date: 1/1/2014

End Date: 12/30/2017

Funding Source: Massachusetts Department of Transportation

Reporting Period: 7/1/2016 – 6/30/2017

Research Category: Floods

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:

- Culvert condition. 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
- Climate Change and Associated Geomorphic Impacts. 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
- Potential disruption of local services or emergency response routes. 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.)
- River and stream continuity. 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

Work this year was completed toward obtaining 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
- A suggested methodology for future implementation in other basins, which is optimized to minimize implementation costs and estimation uncertainties.
- An interactive map-based tool, the Stream Crossing Explorer, to identify crossings selected by a number of parameters such as type, vulnerability, etc. The tool is available at <http://sce.ecosheds.org/>

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
 Paul Southard, recent BS, Geosciences

Information Transfer and Outreach

Workshop Series

The Water Resources Research Center helped organize two meetings on the topic of water. One event was a Water Sustainability Management double session at the Water Innovation Workshop organized at WPI under the auspices of NSF, and the second event was the New England Student Water Symposium. Both are described below.

8. Water Innovation Workshop

Principal Investigators: Paula Rees, UMass Amherst; Paul Mathisen, WPI

Start Date: 3/1/2016

End Date: 2/28/2017

Funding Source: USGS

Reporting Period: 7/1/2016 – 6/30/2017

Introduction:

The Water Innovation Workshop brought the industry, academic, and government communities together at Worcester Polytechnic Institute (WPI) on October 24, 2016 to discuss water supply abundance, access, and safety. This workshop was sponsored by the National Science Foundation (NSF) and was conducted as a partnership between WPI, the Massachusetts Water Resources Research Center (MA WRRRC), the United States Geological Survey (USGS), SENCER (Science Education for New Civic Engagements and Responsibilities), the New England Water Innovation Network (NEWIN), the U.S. Water Partnership, and the Campus Compact organizations from Massachusetts, Maine, Connecticut, New Hampshire, and Rhode Island. Over 200 people registered for the event.

Dr. Winston Soboyejo, Dean of Engineering at WPI, opened the day with his keynote speech “Water Innovation for Global Development.” After the keynote, attendees attended breakout sessions related to specific areas of the water sector including municipal waste water, storm water, infrastructure and data analysis, drinking water contaminants, industrial water needs across food and energy, and water sustainability management. In the afternoon, after two breakout sessions, 17 graduate and undergraduate students presented research posters. The conference concluded with a dinner and poster awards.



Figure 1: Dr. David Reckhow (UMass) speaking at a breakout session

Water Sustainability Management Breakout Session

The Massachusetts Water Resources Research Center co-organized the water sustainability management breakout sessions with WPI's Dr. Paul Mathisen. The sessions were split into a morning timeslot (11:30am – 12:30pm) which focused on identifying and prioritizing market driven needs, and an afternoon session (2:00pm – 3:00pm) which focused on collaborating and developing market driven solutions to the needs identified in the morning session. During each session, Dr. Mathisen led the discussion while Travis Drury, MA WRRRC, recorded notes on the discussion.

During the morning session, four guests discussed how their organizations view sustainable water management. Vandana Rao from the Massachusetts Executive Office of Energy and Environmental Affairs spoke about their focus on responding to the extremes of droughts and floods with some attention also being paid to water quality. Peter Weiskel talked about the United States Geological Survey's priorities of providing reliable water quantity data and minimizing losses due to natural disasters and how they plan to do that with next generation basin assessments in a changing climate. Steve Estes-Smargiassi discussed the Massachusetts Water Resources Authority's focus on maintaining drinking water resources to match changing public demand. Finally, W. Josh Weiss of Hazen and Sawyer gave an overview of a One Water concept, which removes institutional silos and recognizes the interconnectedness of wastewater, drinking water, recreation, and storm water.

After the speakers, the session was opened up to the audience for a discussion to help identify and prioritize market driven water resource needs. Some ideas brought up included the need for more reservoirs like the Quabbin to increase storage, more efficient use of water such as grey water for waste removal, communicating water issues more clearly with utility customers.

The afternoon water sustainability management breakout session was a group discussion to promote collaboration and develop market driven solutions to the needs identified in the morning session. Many attendees expressed the need for more cooperation. For example, communities can work together by sharing best practices they successfully implement, storm water coalitions could help pool resources regionally even beyond state boundaries, and holistic projects that incorporate drinking water, storm water, and wastewater can remove competition for resources. Other ideas included federal agencies incentivizing large-scale sustainable planning with funding allocations and developing a large historical database for regional models to be produced. At the end of the afternoon session, many attendees expressed their desire to continue the conversation at a later date. A handout (Figure 3) was given to all attendees to obtain contact information and identify topics to discuss at future events. The handouts were collected and the information stored by Dr. Mathisen.

Water Innovation Workshop
October 24, 2016

Water Sustainability Management Breakout Session

The goals of this workshop are to identify the preeminent concerns regarding sustainable use of water resources and to foster collaborative projects to solve those concerns. To help with us reach these goals, please complete this short questionnaire.

What is your primary concern regarding the sustainable use of water resources?

What project or approach from this breakout session do you feel would be most helpful in addressing your concern?

Are you interested in collaborating with others from this breakout session on projects in the future?

If so, please leave your contact information below so we can help facilitate collaborations.

Name:

Organization:

E-mail Address:

Figure 2: Questionnaire

Some of the key concerns raised are included in Figure 3. These notes illustrate the breadth and complexity of the concerns related to water sustainability management. The participants' suggestions for best approaches included efforts to better understand events (e.g. the drought), identification of barriers to integrated planning, and the use of the "one water" perspective in planning. Participants recognized the need for water sustainability, resources management, and water planning, and expressed the need for continued collaboration in this area.

Workshop Feedback – Primary Concerns

- Developing robust solutions that incorporate uncertainty in future conditions/scenarios
- Agreement as to what this (i.e. sustainable water resources) really means (i.e. quality/quantity; drinking water/wastewater/stormwater)
- Managing for extremes; upgrading the infrastructure
- Development of next generation basin models, discretized in space and time, to enable sustainable water management
- Disconnected efforts to address connected problems
- Certainly priority should be on quality, but without storage, quantity cannot meet the long term (3+ years) water during periods of stress
- We should think @ 50 k/ft level to see problems and viable solutions
- Maintaining sufficient volume for critical needs
- Limiting/eliminated waste water
- Water usage monitoring and conservation promotion via data – tracking and goals

Figure 3: Workshop Feedback Primary Concerns



Figure 4: Undergraduate and Graduate Poster

9. New England Graduate Student Water Symposium 2016

Principal Investigators: Paula Rees, David Reckhow, UMass Amherst;

Start Date: 3/1/2016

End Date: 2/28/2017/2017

Funding Source: USGS 104B program

Reporting Period: 7/1/2016 – 6/30/2017

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 third year in 2016. The conference was organized by a team of UMass graduate students with help from the Massachusetts Water Resources Research Center. 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. Due to the unique draw of a student-only conference and low costs, approximately 180 people attended the conference from 39 institutions and organization from New England and surrounding area (Table 1). Attendees came to the NEGSWS conference from eight U.S. states—Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Rhode Island—and four Canadian provinces—British Columbia, Nova Scotia, Ontario, and Quebec.

Table 1: Institutions and organizations represented at the symposium

Clarkson University	Syracuse University
Columbia University	Tighe & Bond
Cornell University	Tufts University
Dalhousie University	United States Geological Survey
Environment Canada	University of British Columbia
Harvard University	University of Connecticut
Hazen and Sawyer	University of Guelph
Holyoke Community College	University of Maine
Lafayette College	University of Massachusetts Amherst
Lehigh University	University of Massachusetts Boston
Manhattan College	University of Massachusetts Dartmouth
McGill University	University of Massachusetts Lowell
MIT	University of New Hampshire
Montclair State University	University of Rhode Island
NJIT	University Polytechnique of Montreal
Northeastern University	Wesleyan University
Pennsylvania State University	Worcester Polytechnic Institute
Salem State University	Wright-Pierce
Smith College	Yale University
State University of New York at Buffalo	

The conference opened Friday September 9, 2016 with an informal dinner which allowed

attendees to check in at registration and network with faculty, sponsors, and other students before the presentations began the next day.

On Saturday September 10, 2016, the morning began with a keynote address by Dr. Robert Hirsch, Research Hydrologist at USGS (“Reflections on Water Resources in a Changing World”). Technical presentations began after the keynote and continued through Sunday. All presentations were given by undergraduate and graduate students, but post docs, alumni, faculty, and industry representatives were invited to attend. Presentations were grouped into the following topics: water and wastewater treatment, flood management, water quality, water resources data and decision making, surface water modeling, water resources planning, water chemistry, and environmental engineering.



Figure 1: Friday evening NEGSWS dinner

Saturday’s events also included a poster session, a mobile water quality lab demonstration, and a panel session (“Intersections between water and industry”) during which representatives from our industry sponsors and local governments spoke about their careers as they relate to water resources.

On Sunday, two more sessions of technical presentations were held before the closing and awards ceremony. Awards were given to students who presented during a technical or poster session based on voting by student attendees and sponsors.

Overall, there were 55 technical presentations and 45 posters presented by graduate students from universities across northeastern North America.

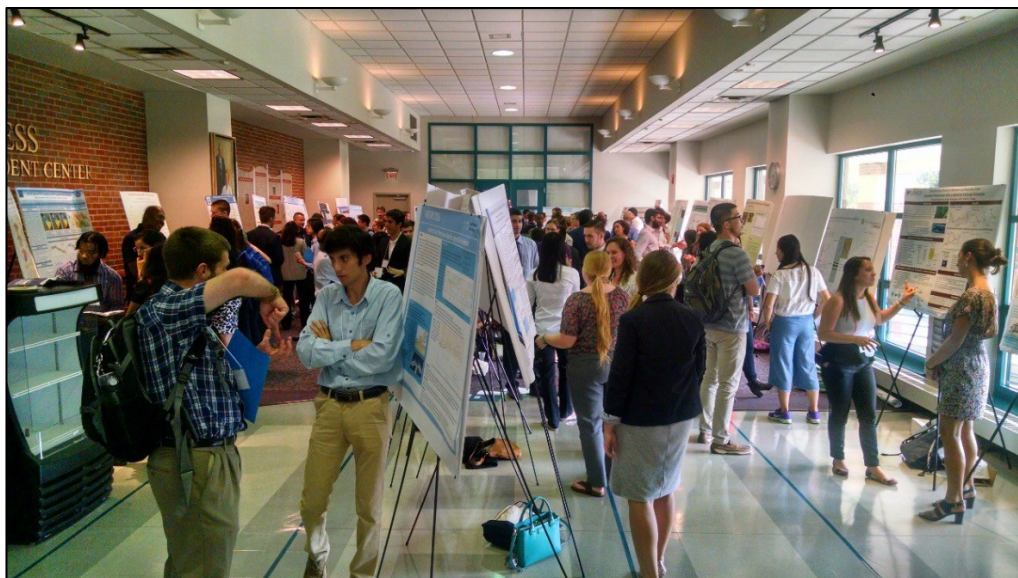


Figure 2: Poster presentations



Figure 3: Group Photo of NEGSWS 2016 Attendees



Figure 4: NEGSWS 2016 schedule (page 1)

Sunday, September 11th

7:30am – 9:00am	Registration – <i>Marcus Lobby</i>
8:30am – 10:00am	Technical Session 3 Water and Wastewater Treatment 3 Biological Treatment – <i>Marcus 131</i> Water Resources Planning – <i>Marston 211</i> Water Chemistry – <i>Marston 132</i>
10:00am – 10:15am	Break – <i>Marcus Lobby</i>
10:15am – 11:45am	Technical Session 4 Water and Wastewater Treatment 4 Drinking Water Treatment – <i>Marcus 131</i> Environmental Engineering – <i>Marston 211</i> Water and Wastewater Treatment 5 – <i>Marston 132</i>
11:50am – 12:10pm	Closing and Awards – <i>Marcus 131</i>



Figure 5: NEGSWS 2016 schedule (page 2)

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

Environmental Analysis Laboratory

Reporting Period: July 1, 2016 – June 30, 2017

Funding Source: Fees

The Environmental Analysis Laboratory (EAL) was created in 1984 by WRRRC 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 9 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
7/19/2016	LSWA		1	1
8/12/2016	LSWA		1	1
9/13/2016	LSWA	1		1
10/28/2016	FOLW	1		1
3/30/2017	NRWA	2		2
4/06/2017	LSWA	1	1	2
6/27/2017	LSWA		1	1
	Total	5	4	9

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. In this reporting period, we performed 65 analyses for two volunteer groups, (5 chlorophyll and 60 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
8/05/2016	FOLQ	1		1
9/07/2016	FOLQ	1		1
10/26/2016	FOLQ	1		1
10/28/2016	FOLW		60	60
5/24/2017	FOLQ	1		1
6/9/2017	FOLQ	1		1
	Total	5	60	65

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* and total phosphorus analyses for the Upper Blackstone Pollution Abatement District (UBWPAD).

Undergraduate Student Support

Derek Smith (Environmental Science)

Financial Overview

Center revenues come strictly from grants and contracts. The University of Massachusetts contributes 20% of the salary for a half-time Director and also provides physical facilities for the WRRRC.

Total revenues amounted to \$519,329

USGS 104B: \$ 92,335 broken down as follows:
 \$17,444 Administration
 \$16,729 Workshops
 \$5,021 Lackner research Project
 \$30,000 Pagsuyoin research project
 \$23,141 Boutt research project

MA DOT \$222,582
 Blackstone River \$103,215
 USDA \$27,948
 UMass (Director) \$31,001
 ARM Project \$29,926
 EAL \$12,322

