

**Water Resources Research Center  
Annual Technical Report  
FY 2016**

# Introduction

This report covers the period March 1, 2016 to February 28, 2017, the 51st year of the Massachusetts Water Resources Research Center (WRRC). The Center is under the direction of Dr. Paula Rees, who holds joint appointments as Director of the WRRC 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, WRRC aims to encourage new faculty as well as students to study water resources issues.

In fiscal year 2016, three new research projects were supported through the USGS 104B Program:

- "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 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.

Finally, the Water Resources Research Center supported three UMass Amherst students to travel to meetings to further their research in water resources.

## **Research Program Introduction**

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

# Adaptive Drought Vulnerability Index for Strategic Emergency Response (ADVISER) Model

## Basic Information

<b>Title:</b>	Adaptive Drought Vulnerability Index for Strategic Emergency Response (ADVISER) Model
<b>Project Number:</b>	2016MA450B
<b>Start Date:</b>	3/1/2016
<b>End Date:</b>	2/28/2017
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	MA-003
<b>Research Category:</b>	Climate and Hydrologic Processes
<b>Focus Category:</b>	Drought, Management and Planning, Economics
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Sheree Pagsuyoin

## Publications

1. Pagsuyoin SA, Santos JR, Salcedo G (2017) Development of a Dynamic GIS-based Model for Evaluating Regional Drought Risks and Resilience (In preparation)
2. 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
3. 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

## **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 periods<sup>1</sup>. 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 is 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 aims 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 WIOM<sup>1</sup> and the vulnerability rating scale<sup>2</sup> 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 ADVISED Model**

The ADVISED 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 ( $P_1$  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).

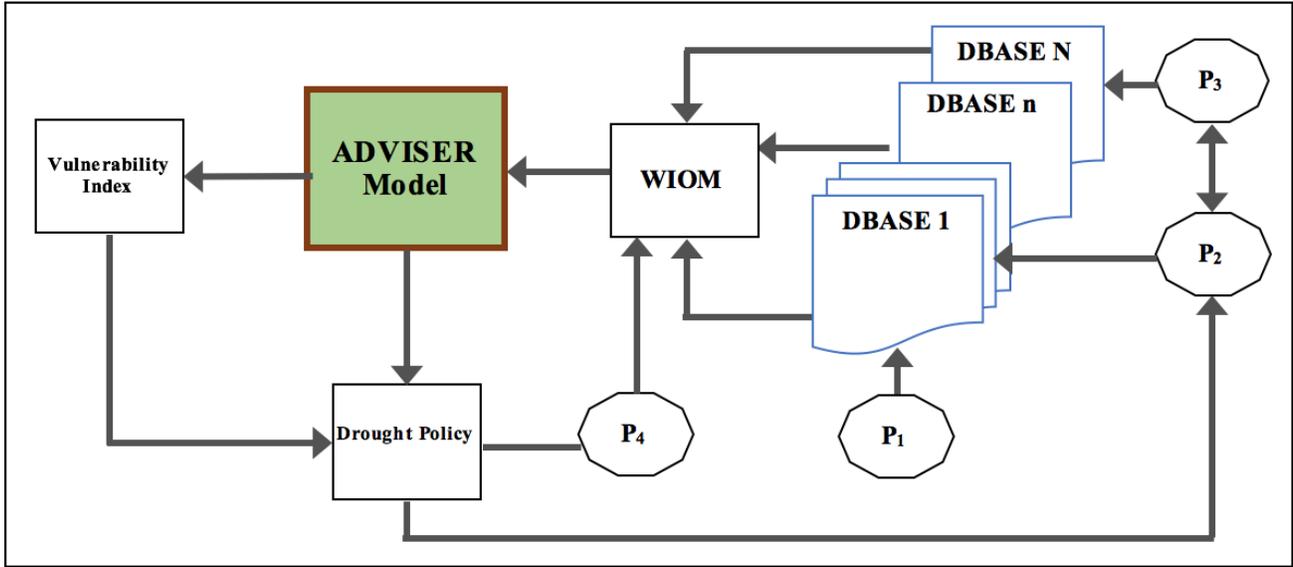


Fig. 1 Conceptual framework of the ADVISER Model showing system response and feedback loops for perturbations,  $P_i$ , (intervention or external perturbation). Note that perturbations can directly cause changes to the input values to the WIOM and/or cause other perturbations that directly affect WIOM inputs. Here,  $P_1$  is an external perturbation that affects only the WIOM data inputs,  $P_2$  is a policy intervention that also has an impact on external perturbations, and  $P_3$  is an external perturbation that has both a direct effect on the WIOM data inputs and an effect on a policy intervention.  $P_4$  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 Haines and Jiang<sup>2</sup> – 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 indices<sup>3</sup>. 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.

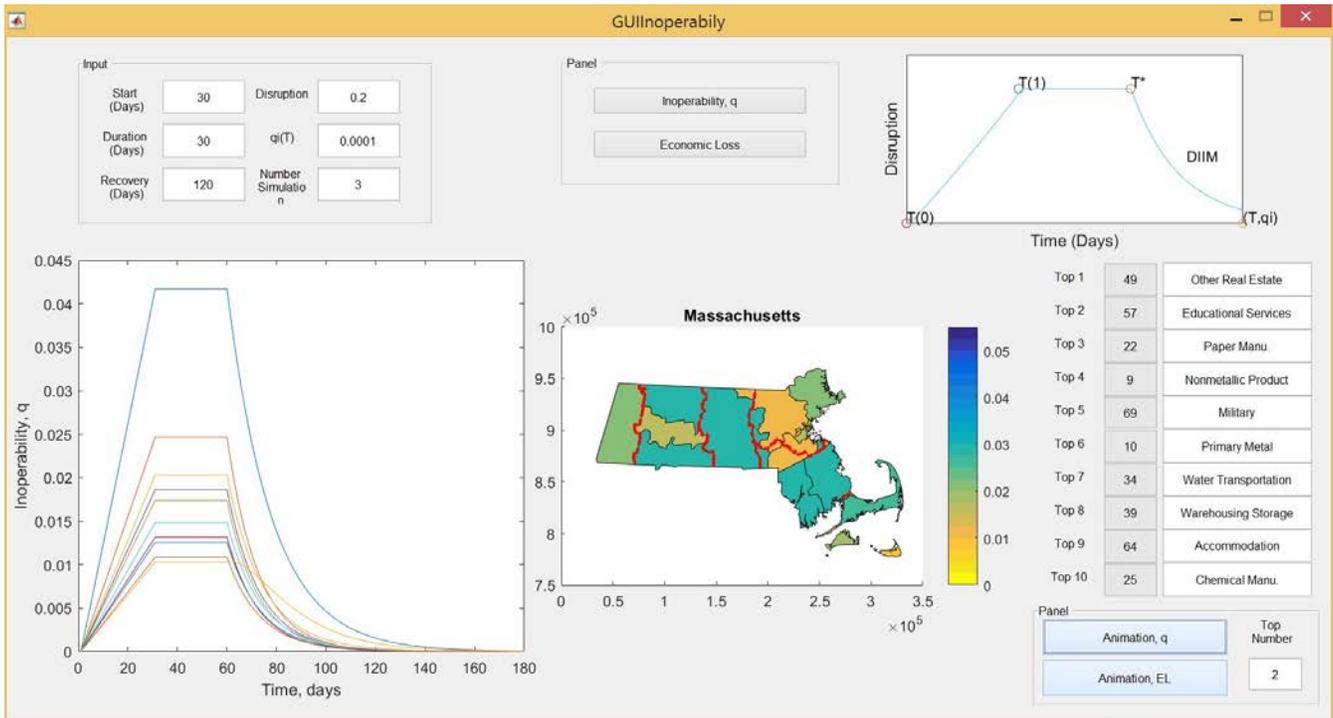


Fig. 2. Graphical User Interface of the ADVISER model

### State-wide Drought Management

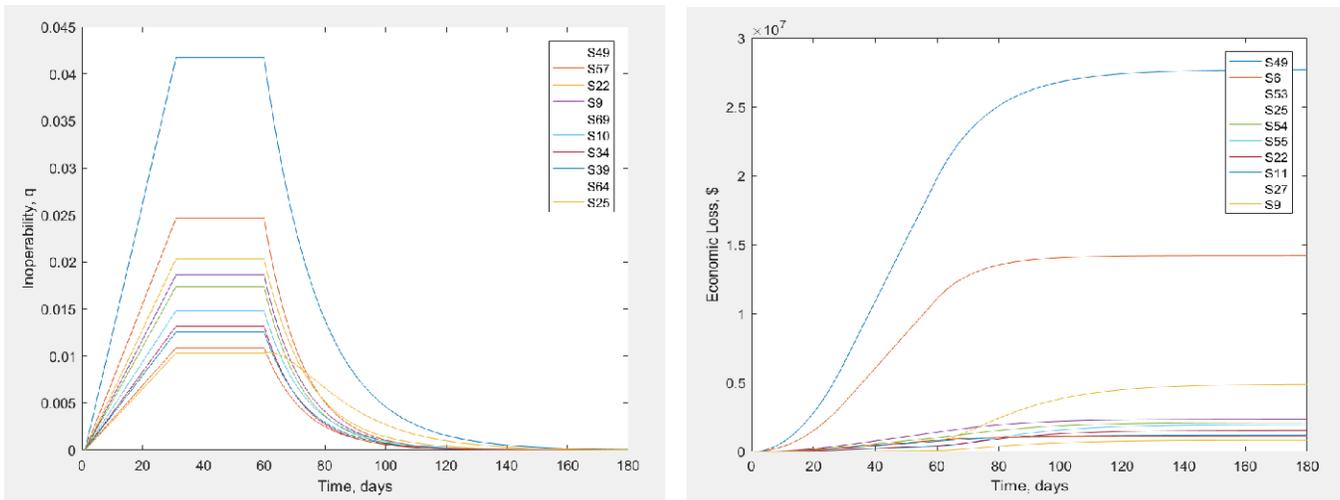
The current spatial categorization of drought regions in MA is more reflective of political boundaries than of watershed boundaries. Massachusetts has 28 primary watersheds, some of which are shared with neighboring states. Some towns are also serviced by several watersheds. The MA Drought Management 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.



- S49 Real estate (excluding housing)
- S57 Educational services
- S22 Paper manufacturing
- S9 Nonmetallic mineral product manufacturing
- S69 Military
- S10 Primary metal manufacturing
- S34 Water transportation
- S39 Warehousing and storage
- S64 Accommodation
- S25 Chemical manufacturing
- S6 Utilities
- S53 Miscellaneous professional, scientific, and technical services
- S54 Management of companies and enterprises
- S55 Administrative and support services
- S11 Fabricated metal product manufacturing
- S27 Wholesale trade

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.

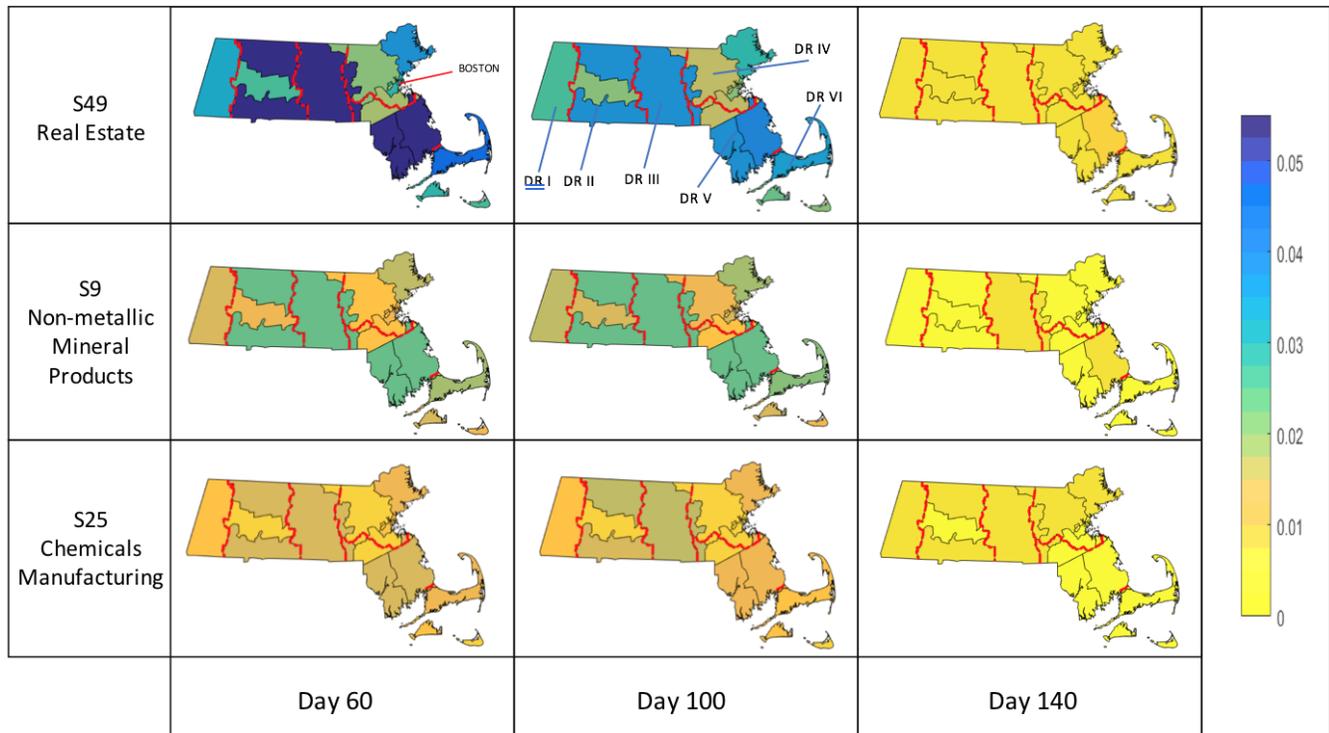


Fig. 4 Massachusetts case study results showing inoperability values by county for sectors S49, S9, and S25 for a 180-day drought duration. This drought simulation was based on the most recent 6-month drought (mid 2016 to early 2017) experienced in Massachusetts. The state is divided into 6 drought regions (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. Haines 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.

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

### Basic Information

<b>Title:</b>	The stable isotopic composition of shallow and deep ground waters in Massachusetts
<b>Project Number:</b>	2016MA452B
<b>Start Date:</b>	5/1/2016
<b>End Date:</b>	4/30/2017
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	MA-002
<b>Research Category:</b>	Ground-water Flow and Transport
<b>Focus Category:</b>	Groundwater, Geochemical Processes, Hydrogeochemistry
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	David Boutt

### Publication

1. 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.

## 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, Hunntington 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 H<sub>2</sub>O, D and <sup>18</sup>O) in combination with physical data to resolve discrepancies in measurements and reduce uncertainty in system conceptualization (IAEA, 2000). These tools and techniques are 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 rely 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

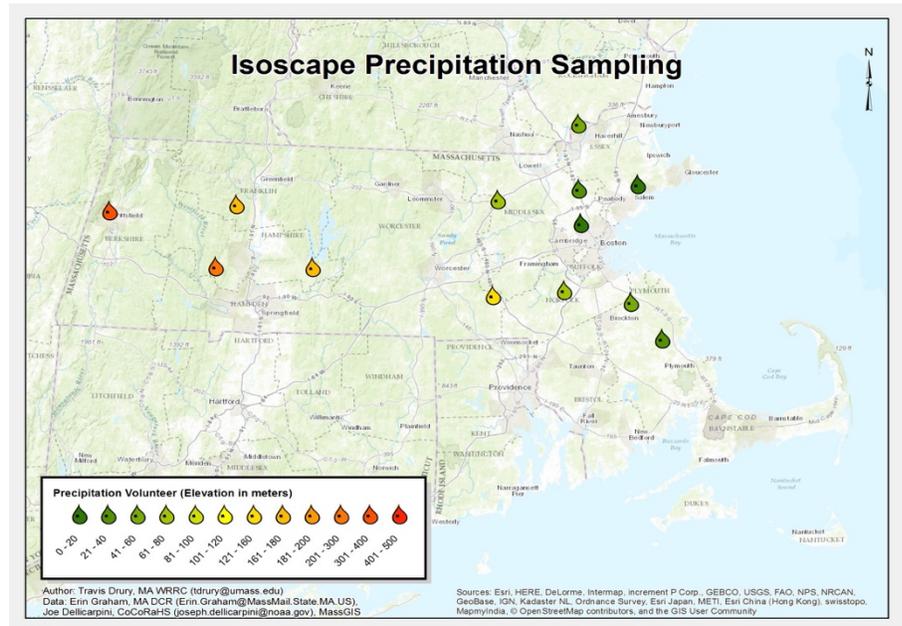


Figure 1: Precipitation sampling localities across the state of Massachusetts. Precipitation samples are composited bi-weekly at 14 proposed locations

with state entities –such as MA DCR – we are now having samples sent to us monthly from DCR and other cooperative water monitoring programs.

**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  $^{18}\text{O}$ - $\text{H}_2\text{O}$  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 ‰  $\delta^{18}\text{O}$ - $\text{H}_2\text{O}$ . 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 ‰  $\delta^{18}\text{O}$ - $\text{H}_2\text{O}$ . These excursions are consistent with a source of water vapor to the region from more northerly (colder) regions. Mean stream water  $\delta^{18}\text{O}$ -  $\text{H}_2\text{O}$  isotopic compositions show a strong relationship to upgradient drainage area. Groundwater compositions range from -12 to -5 ‰  $\delta^{18}\text{O}$ - $\text{H}_2\text{O}$  across all the sites. A correlation between groundwater well elevation and  $\delta^{18}\text{O}$ - $\text{H}_2\text{O}$  is observed with higher elevation sites depleted in heavy isotopes with variations of 2-3 ‰  $\delta^{18}\text{O}$ - $\text{H}_2\text{O}$  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 protect water resources while allowing hydrologists explore regional and globally relevant scientific questions.

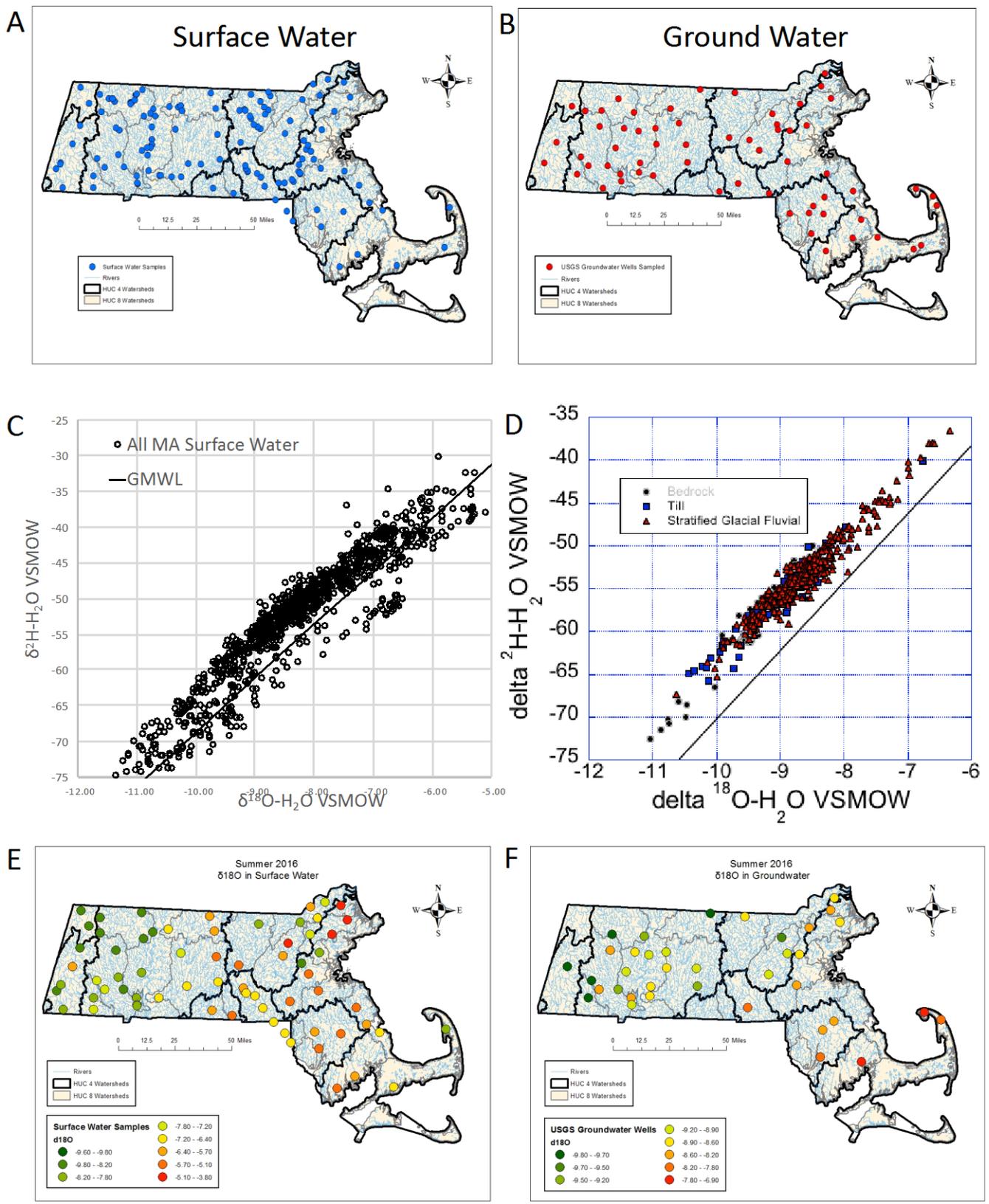
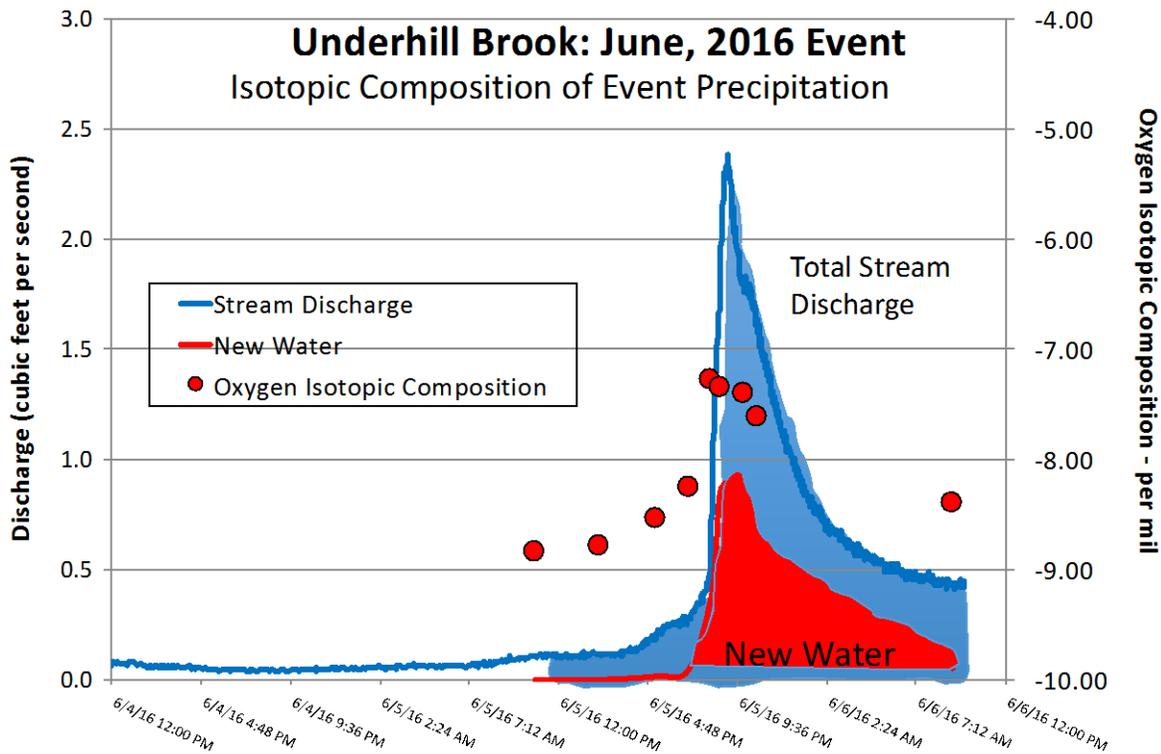


Figure 2: (A) Spatial distribution of where surface water samples were taken across Massachusetts B)

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

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. δ<sup>18</sup>O-H<sub>2</sub>O ‰). Before the storm, streamflow isotopic composition was about -9 δ<sup>18</sup>O-H<sub>2</sub>O ‰. The isotopic composition of the stream water gradually increases to -7.2 δ<sup>18</sup>O-H<sub>2</sub>O ‰ and then falls back towards the pre-event composition. Using a two end-member 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 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.

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

## Basic Information

<b>Title:</b>	Understanding the interaction of renewable energy generation and desalination within the water-energy system
<b>Project Number:</b>	2016MA454B
<b>Start Date:</b>	6/1/2016
<b>End Date:</b>	8/15/2016
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	MA-002
<b>Research Category:</b>	Engineering
<b>Focus Category:</b>	Water Supply, Water Use, Models
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Matthew Arenson Lackner

## Publication

1. Mohammadi, Kasra, Lackner, Matthew, Ray, Patrick, 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.

**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.

## **Information Transfer Program Introduction**

Progress results for our Information Transfer activities are summarized for the reporting year in the following section.

# Water Resources Symposia

## Basic Information

<b>Title:</b>	Water Resources Symposia
<b>Project Number:</b>	2016MA451B
<b>Start Date:</b>	3/1/2016
<b>End Date:</b>	2/28/2017
<b>Funding Source:</b>	104B
<b>Congressional District:</b>	MA-002
<b>Research Category:</b>	Not Applicable
<b>Focus Category:</b>	Water Quantity, Water Quality, Treatment
<b>Descriptors:</b>	None
<b>Principal Investigators:</b>	Paula Sturdevant Rees

## Publications

There are no publications.

## **2016 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.

### **Water Innovation Workshop**

10/24/2016

Worcester Polytechnic Institute

#### **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 WRRC), 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.



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

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.

### **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 WRRC, 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

Disconnected efforts to address connected problems

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 Presentations**

## New England Graduate Student Water Symposium 2016

9/9-11/2016

University of Massachusetts, Amherst

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.

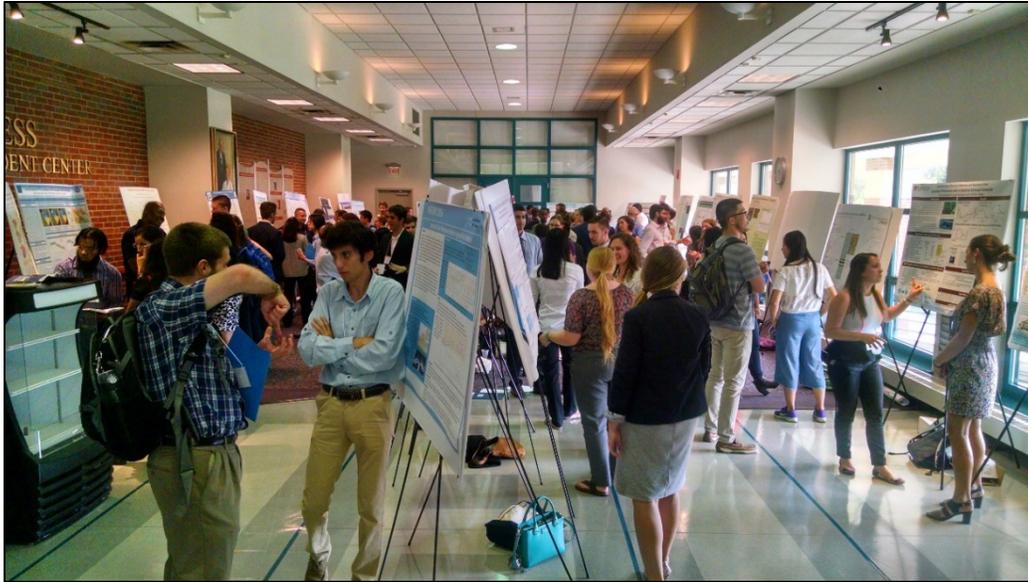


**Figure 1: Friday evening NEGSWS dinner**

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**



## New England Graduate Student Water Symposium 2016

### Friday, September 9th

5:30pm – 6:00pm

**Registration** – *Marcus Lobby*

6:00pm – 9:00pm

**Dinner** – *Engineering Quad*

### Saturday, September 10th

7:30am – 9:00am

**Registration** – *Marcus Lobby*

8:30am – 9:45am

**Welcome and Keynote** – *Elab2 Auditorium*  
Dr. Robert Hirsch (Research Hydrologist at USGS)  
Reflections on Water Resources in a Changing World

9:45am – 10:00am

**Break** – *Marcus Lobby*

10:00am – 11:30am

**Technical Session 1**  
Water and Wastewater Treatment 1 Resource Recovery – *Marcus 131*  
Flood Management – *Marston 211*  
Water Quality – *Marston 132*

11:30am – 11:45am

**Group Photo** – *Marcus Front Steps*

11:45am – 1:00pm

**Lunch** – *Worcester Dining Commons*

1:00pm – 2:00pm

**Panel Session: Intersections between water and industry** – *Marcus 131*  
Heather Doolittle (Staff Engineer at Tighe & Bond)  
Liza Faber (Assistant Engineer at Hazen and Sawyer)  
Chi Ho Sham (Ph.D. VP and Chief Scientist at Eastern Research Group)  
James R. Laurila (P.E. and Director of Water Operations at Springfield Water and Sewer Commission)

2:00pm – 2:15pm

**Break** – *Marcus Lobby*

2:15pm – 3:30pm

**Technical Session 2**  
Water and Wastewater Treatment 2 Innovative Methods – *Marcus 131*  
Water Resources Data and Decision Making – *Marston 211*  
Surface Water Modeling – *Marston 132*

3:30pm – 5:30pm

**Poster Session** – *Gunness Student Center in Marcus*  
**WATERS Demo 1 and 2** (4:15pm and 5:00pm) – *Elab2 301*

6:30pm – 9:30pm

**Dinner** – *The Hangar – 10 University Dr. Amherst MA 01002*

### Sunday (other side)

Figure 4: NEGSWS 2016 schedule (page 1)

## Sunday, September 11th

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



Figure 5: NEGSWS 2016 schedule (page 2)

# USGS Summer Intern Program

None.

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

## **Notable Awards and Achievements**

## Publications from Prior Years

1. 2014MA421B ("Investigating effects of annual winter lake drawdowns on fish and macroinvertebrate assemblages and diet") - Other Publications - 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.
2. 2014MA426B ("Going With or Against the Flow: Choices for Flood Mitigation Response in Massachusetts") - Articles in Refereed Scientific Journals - Consoer, M. & Milman, A., 2017, Opportunities, Constraints and Choices for Flood Mitigation in Rural Areas: Perspectives of Municipalities in Massachusetts, *Journal of Flood Risk Management*, 11 APR 2017, DOI: 10.1111/jfr3.12302 (available on-line, forthcoming in an issue)
3. 2014MA22B ("Fate, transport, and remediation of PFOS, PFOA, perchlorate, and 1,4-dioxane at the Eastham MA landfill") - Other Publications - Weber, A. K.; Barber, L. B.; LeBlanc, D. R.; Vecitis, C. D. Transport Of Poly- and Perfluoroalkyl Substances in Groundwater, Cape Cod, MA, 2016. SETAC North America 37th Annual Meeting, November 2016, Orlando FL.
4. 2014MA22B ("Fate, transport, and remediation of PFOS, PFOA, perchlorate, and 1,4-dioxane at the Eastham MA landfill") - Other Publications - Barber, L.B., Weber, A.K., LeBlanc, D.R., Hull, R.B., Sunderland, E.M., and Vecitis, C.D., 2017, Poly- and perfluoroalkyl substances in contaminated groundwater, Cape Cod, Massachusetts, 2014-2015 (ver. 1.1, March 24, 2017): U.S. Geological Survey data release, <https://doi.org/10.5066/F7Z899KT>.
5. 2014MA429G ("Controls on the stable isotopic composition of shallow and deep ground waters in the Northeast US: Implications for stream baseflow") - Articles in Refereed Scientific Journals - Boutt DF, 2017, Assessing hydrogeologic controls on dynamic groundwater storage using long-term instrumental records of water table levels. *Hydrological Processes*. 2017;31:1479–1497. <https://doi.org/10.1002/hyp.11119>