Iowa Water Center
Annual Technical Report
FY 2016

Introduction

The Iowa Water Center entered its eleventh year with Dr. Richard Cruse as director during this project year. Successful 104b and information transfer projects guided the continued stability of the Center in FY2016, and paved the way to allow the Center to undergo expansion in FY2017.

Research Program Introduction

In FY2016, the Iowa Water Center focused the RFP on nutrients and their impact on Iowa's waters and water management decisions. In addition to the typical seed grant program, IWC also sought applicants from graduate students nearing the end of their studies for a $5000 grant allowing them to complete additional research objectives of products beyond the scope of their current water related funded project. The two projects funded were "The role of iron mobility from anoxic sediments in stimulating harmful algal blooms", PI Elizabeth Swanner, Department of Geological & Atmospheric Sciences, Iowa State University and "Evaluation of subsurface drainage on P losses in the Black Hawk Lake Watershed, Iowa," PI Conrad Brendel under supervision of Michelle Soupir, Department of Agricultural and Biosystems Engineer, Iowa State University. $5,000.

Additionally, work continued on two previously funded national competitive grants administered through IWC. The first is “Development of a Comprehensive Hazard to Loss Modeling Methodology for the Residential Damage Associated with Inland Flooding from North Atlantic Tropical Cyclones,” PI Gabriele Villarini in the IIHR Hydroscience & Engineering at the University of Iowa, total federal funds: $248,556. The second project is “Prototype Multi-Jurisdictional Decision Making Web Platform for Integrated Water Resources Management: From Interagency Collaboration to Implementation in the Iowa-Cedar Watershed,” PI Marian Muste at the IIHR Hydroscience & Engineering at the University of Iowa, $180,865 awarded.

Development of a Comprehensive Hazard to Loss Modeling Methodology for the Residential Damage Associated with Inland Flooding from North Atlantic Tropical Cyclones

Basic Information

Title:	Development of a Comprehensive Hazard to Loss Modeling Methodology for the Residential Damage Associated with Inland Flooding from North Atlantic Tropical Cyclones
Project Number:	2014IA257G
USGS Grant Number:	G14AS00014
Start Date:	9/1/2014
End Date:	8/31/2016
Funding Source:	104G
Congressional District:	IA002
Research Category:	Climate and Hydrologic Processes
Focus Category:	Floods, Economics, Climatological Processes
Descriptors:	None
Principal Investigators:	Gabriele Villarini, Jeffery Czajkowski, Erwann MichelKerjan

Publications

1. Managing and Financing Extreme Events Project 2015 Annual Meeting, Wharton Risk Management and Decision Processes Center, Philadelphia, PA (October, 2015)
2. Czajkowski, J., G. Villarini, M. Montgomery, E. Michel-Kerjan, and R. Goska, Assessing current and future freshwater flood risk from North Atlantic tropical cyclones via insurance claims, Scientific Reports, 7, 1-10, 2017.
3. Aryal, Y.N., G. Villarini, W. Zhang, and G.A. Vecchi, Long term changes in flooding and heavy rainfall associated with North Atlantic tropical cyclones, submitted to Journal of Hydrology, 2017

Problem and Research Objectives

We propose to develop statistical models to describe the relation between inland flooding associated with North Atlantic tropical cyclones (TCs) and impacts (claims and losses) in the United States. This is a topic of high socio-economic relevance, but regretfully has received very little attention as most U.S. TC loss assessment efforts are focused on coastal areas. Its importance has unfortunately been highlighted in the recent past, with significant inland flooding associated with Hurricanes Irene (2011) and Isaac (2012). These hurricanes, however, are not isolated cases, but are representative of much larger set of events with large impacts (e.g., Pielke and Klein 2005; Pielke et al. 2008; Changnon 2008; Jonkman et al. 2009; Czajkowski et al. 2011, 2013; Mendelsohn et al. 2012; Peduzzi et al. 2012; Rappaport 2014).

The main outcomes of the proposed research are: 1) at a fairly granular level the identification of the areas that are more at risk from inland flooding from North Atlantic TCs; 2) the characterization of the extent and magnitude of these events; 3) the development of statistical models relating flood magnitude to direct economic losses importantly controlling for the associated exposure and vulnerability aspects over the period 2001-2012; 4) the use of the resulting empirical relationships to perform sensitivity analysis examining the potential impacts of pre-2000 TCs under the current level of exposure and vulnerability. The proposed work will provide information instrumental for the assessment and understanding of the changes in TC flood hazard (both in terms of spatial location and magnitude) over the 20th century, together with a quantification of the associated impacts.

Methodology

The goal of our work is to develop a data-driven climatology of inland flooding associated with North Atlantic TCs and to model the associated impacts in the United States. Significantly, we utilize a data-driven approach to flood hazard characterization based on discharge observations from a dense network of stream gaging stations, leveraging the wealth of discharge data collected and disseminated by the U.S. Geological Survey (USGS). Moreover, we have a unique access to the federally-run National Flood Insurance Program (NFIP) data - flooding in the United States is mainly insured by this public program - to allow for examination of flood claims, damage and relevant exposure data. The focus of our work is on the area of the continental United States east of the Rocky Mountains.

The analysis of flooding associated with TCs at the regional scale requires accounting for the dependence of discharge on drainage area. Here we follow the approach described in Villarini et al. (2014a) and normalize the peaks caused by TCs by the at-site 2-year flood peak. The selection of the 2-year return period is due to two main reasons: 1) it is roughly the discharge value corresponding to bankfull conditions, with values larger than it pointing to out-of-bank flow; 2) it can be estimated reasonably accurately from the data using a relatively small window. One of the issues with the flood ratio is that it does not generally provide information regarding the severity of the flood event. To address this issue and similar to Villarini et al. (2014a), we will use the flood status classification by the National Weather Service (NWS), and consider four categories in the analysis (see next section for results related to this issue). We define as flooding associated with a TC the largest flood peak measured by a station located within 500 km from the center of the storm during a time window of two days prior and seven days after the passage of the storm (e.g., Villarini et al. 2014a).

The four basic components of natural hazard risk assessment are: hazard, exposure, vulnerability and loss. In modeling the number of flood claims incurred (predictand), we develop statistical models in which the response variable is related to different predictors. For each impacted area of the storm, the covariates we are currently considering (amongst others) include the above-defined flood ratio and its NWS classification, the number of housing units, the total population, the number of flood insurance policies-in-force, event-specific storm fixed effects, geographic-specific impacted area fixed effects, and areas of high flood risk as designated by a 1996 Natural Disaster Study conducted by the Federal Emergency Management Agency on behalf of the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (https://www.npms.phmsa.dot.gov/DisasterData.aspx). These models will represent losses and insurance claims for 28 North Atlantic TCs for the 2001-2014 period.

Principal Findings and Significance

Over the past year, we have made significant progress to address the research question related to tropical cyclones (TCs) and flooding. In particular, we have worked towards addressing the following questions:

- What is the contribution of North Atlantic TCs to the magnitude and frequency of flooding and heavy rainfall across the United States?
- Can we detect temporal changes in the magnitude and frequency of TC-related flooding and heavy rainfall?
- What is the role played by ENSO and NAO in controlling flooding and heavy rainfall associated with U.S. landfalling TCs?

We use U.S. Geological Survey (USGS) daily discharge records from stream gauges with at least 50 complete years (a complete year is defined as a year with at least 330 daily observations) and ending no earlier than 2010. Figure 1 shows the record length and number of TCs passing within 500 km from any particular gauge. There are about 2,500 complete USGS stations affected by North Atlantic TCs. The record length ranges from 50 to 153 years and a large number of stations have discharge measurements from 1950 onwards. Precipitation analyses are based on the unified gauge-based daily observation data (Higgins et al. 2000) provided by the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC). These data provide daily accumulated precipitation with a 0.25° resolution from 1948 onwards.

The North Atlantic TC data were obtained from National Hurricane Center best track hurricane database (HURDAT2; Landsea and Franklin 2013). This dataset contains the name of storms, the latitude and longitude of their centers of circulation, maximum sustained wind speed (i.e., intensity), and minimum central pressure at six-hour intervals (00, 06, 12 and 18 UTC).

For any particular stream gauge, we selected TC-related annual maximum discharge (Q_{max_TC}) if the stream gauge was within 500 km from the storm center and the annual maximum discharge was measured within the time window of one day prior and five days after the passage of the storm. The choice of 500-km search radius is consistent with Villarini et al. (2014b) who showed that, for the North Atlantic, most of the TC rainfall is concentrated within a 5-degree (~500 km) radius. The 2-year return period flood (Q_2) for any station was calculated with respect to an 11-year moving window to mitigate the sampling errors associated with the estimation of quantiles from limited samples. We calculated Q_2 only for those periods that contained at least ten complete years. The Q_{max_TC} was divided by the corresponding Q_2, and the ratio, defined as flood ratio (FR), was used to analyze TC-flood characteristics at the regional scale. FR compares the TC flooding at a given location with respect to the reference at-site flood value and it can be used to compare TC-flooding across watersheds with different catchment sizes (e.g., Villarini et al. 2014a; Czajkowski et al. 2013, 2017; Rowe and Villarini 2013). Also, as Q_2 varies over time, it allows accounting for potential changes in flood frequency over these long records. Similarly, TC-related annual maximum daily precipitation (PPT_{max_TC}) for any particular pixel was selected if the pixel was located within 500 km from the center of circulation of the storm, and the annual maximum daily precipitation was recorded within the time window of one day prior and one day after the passage of the storm.

We examine the presence of trends in FR and PPT_{max_TC} using the Mann-Kendall test. This test is widely used in studies examining trends in extremes because it is non-parametric (i.e., it does not require any distributional assumptions) and is robust against outliers. We perform the analyses only at the stream gages or rainfall pixels that have at least five events associated with TCs. There are 550 stream gages and 3096 pixels that qualified for the analyses.

To analyze the frequency of TC-related flooding and heavy rainfall we use a peak-over-threshold (POT) approach. The threshold to identify flood events was selected such that there are two events per year on average; moreover, to avoid considering the same event twice, only one value within a 15-day window was selected. From all the POT events, TC-related peaks are selected as described for Q_{max_TC}, and the total number of POTs related to TC (Q_{POT_TC}) are calculated for all the available years. For precipitation, we select the 95th percentile of the non-zero precipitation distribution at each pixel. TC-related POT precipitation events were selected as in P_{max_TC} and the total number of heavy precipitation days over the threshold within any particular year is the frequency of heavy precipitation (P_{POT_TC}). We use Poisson regression to test whether there are trends in the frequency of TC-related flood (Q_{POT_TC}) and heavy precipitation (P_{POT_TC}) events. As in the FR and P_{max_TC}, we analyzed stream gages or pixels having a minimum of five years with at least one TC-related POT discharge (Q_{POT_TC}) or precipitation (P_{POT_PPT}) in a year. There are 920 gage stations and 5124 pixels that qualified for the analysis.

The role of ENSO and NAO on the occurrence of TC-related annual maximum flooding and precipitation is analyzed using logistic regression. For any particular year, the response variable is 1 or 0 based on whether the annual maximum discharge or daily precipitation was due to TCs or not, while the predictors are the values of the ENSO or NAO indices for that year:

$$\log\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 \quad (1)$$

where π is the probability of occurrence of TC-related annual maximum discharge or precipitation. The coefficients α, β_1 and β_2 are estimated using maximum likelihood. For ENSO, we use the Niño-3.4 index available from CPC (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml) averaged over the August-October period. Because the classic NAO is mostly a winter mode, we use the geographically varying "mobile" NAO index (Portis et al. 2001) averaged over the August-October period.

We use Poisson regression to quantify the effects of ENSO and/or NAO on the frequency of TC-related flooding and heavy precipitation. The number of Q_{POT_TC} or P_{POT_TC} per year represents the response variable, while ENSO and/or NAO are the predictors. We related the rate of occurrence parameter for the Poisson distribution for a given year with these two predictors using a logarithmic link function.

We consider four different models for both logistic and Poisson regression: 1) a base model with no predictors; 2) a model with NAO as the only predictor; 3) a model with ENSO as the only predictor; 4) a model with both NAO and ENSO. To select the best model, we use the Akaike Information Criterion (AIC; Akaike 1974), which represents a compromise between accuracy and parsimony.

Results

About 2400 complete USGS stations experienced at least one AM and/or POT due to North Atlantic TCs (Figure 2, top row). Stream gages in Florida show the highest fraction (>30%) of TC-related AMs followed by coastal North Carolina (~25-30%) and the Gulf Coast (~10%). The results for the POTs are similar, even though the fractional contributions are slightly larger. Results also show the mixed population of floods caused by different climatic processes in the region (e.g., Villarini 2016; Smith et al. 2011) with significant contributions by TCs.

We also examined the contribution of TCs to annual maximum and heavy precipitation events (Figure 2, bottom panels). Overall, the areas experiencing TC-induced extreme rainfall are consistent with those for flooding discussed before, even though the fractional contributions are larger. Large areas from the Gulf Coast to the U.S. North East show large fractions of AM precipitation due to TCs (~25% along the Gulf Coast to ~40 % in coastal Carolina/Virginia). The

TC-contribution to POTs is slightly lower compared to the AM precipitation, particularly in the coastal regions. This suggests that mechanisms other than TCs are largely responsible for heavy precipitation events in the region (e.g., Smith et al. 2011). These findings are also consistent with Khouakhi et al. (2017), who showed similar contributions to AM precipitation (~30%) and the contribution to POTs tend to be lower along the U.S. East Coast. The relatively small fractions of TC-flooding over the Carolinas are not qualitatively consistent with the general expectation from observed larger percentage of TC-related annual maximum precipitation over the region (e.g., Barlow 2011; Kunkel et al. 2010), indicating that other mechanisms (e.g., antecedent soil moisture conditions) play a significant role as well (e.g., Hellin et al. 1999; Sturdevant-Rees et al. 2001). The Appalachian Mountains represent a natural barrier, with higher (lower) TC-contributions to their east (west). As shown in Figure 2, the TC-contribution to heavy flooding and extreme precipitation events decreases as we move inland and the results are generally consistent with previous studies (e.g., Prat and Nelson 2013; Khouakhi et al. 2017).

The Mann-Kendall test and Poisson regression were used to determine whether TC-flood magnitude (FR) and frequency (Q_{POT_TC}) changed over time (Figure 3). While there are some sites with increasing/decreasing trends in the magnitude or frequency of TC-related flooding, there is not a strong signal pointing to temporal changes (results not significant at the 10% level). When we focus on precipitation (Figure 3, bottom panels), overall we arrive at similar conclusions; however, it is also worth pointing out that there are some regions to the west of the Appalachian Mountains and along the Gulf Coast that point to an increasing frequency in TC-related POT rainfall events, also consistent with Kunkel et al. (2010).

After analyzing the temporal changes in the magnitude and frequency of TC-related flooding and heavy precipitation and their spatial variations, we focus on the role played by NAO and ENSO in controlling the occurrence of these events. Figure 4 (left column) summarizes the results from logistic regression showing the control by NAO on the occurrence of TC-induced annual maximum flood event at different levels of significance. Most of the region shows negative values for the β coefficient (Figure 4a) implying that TCs are more (less) likely to produce annual maximum flow during the negative (positive) phase of the NAO. However, very few stations along the U.S. East Coast show statistically significant results. We find similar patterns and results when we examine the contribution of the NAO to POT flood events (Figure 5a). The analyses based on ENSO (Figures 4-5, panel b) indicate that TCs are more (less) likely to generate an annual maximum flood in the coastal region if they occur during the negative (positive) phase of ENSO. The results are similar for the frequency of these events, even though they are weaker (Figure 5b). These results suggest that ENSO plays a role not only in terms of TC frequency (e.g., Landsea 2000), but also in terms of their tracks (e.g., Bove et al. 1998; Kossin et al. 2010; Villarini et al. 2014a).

The results so far focused on treating NAO and ENSO as predictors in isolation from each other. However, when we consider both of them as potential predictors, their roles weaken (Figures 4-5, bottom panels) and a model with no predictors is generally selected. Therefore, these results further indicate that NAO and ENSO are not relevant predictors in explaining the frequency of TC floods and the probability of TC-annual maxima.

We further analyzed the control of NAO and ENSO on the occurrence of annual maxima and heavy precipitation events due to TCs (Figures 6 and 7). Overall, NAO and ENSO affect the probability of having an annual maximum associated with a TC in a manner similar to what observed for flooding (Figure 4). The strongest signal is east of the Appalachian Mountains for NAO and along the Gulf Coast (in particular in Texas) for ENSO, when we consider each predictor separately. The results from the multiple regression models support these conclusions (Figure 6, bottom panels), and suggest that these climate modes have limited influence in terms of TC-related annual maxima. On the other hand, the picture changes significantly when we focus on the frequency of TC-related POT events (Figure 7). During the negative phase of the NAO, we expect on average a larger number of POT events due to TCs across the eastern United States, in particular east of the Appalachian Mountains. ENSO, instead, plays a significant role in the Gulf Coast, in particular in Louisiana, Arkansas, Oklahoma and Texas, with more TC-related POT events to be expected during La Niña years. Broadly speaking, our findings are consistent with previous studies. For instance, Khouakhi et al. (2017) showed that TC-driven extreme rainfall events along the U.S. East Coast and the Gulf Coast of Mexico are more likely during La Niña years. Nogueira et al. (2012) found that TC rainfall in Texas is negatively (positively) correlated with El-Niño (La Nina) years.

The higher likelihood of TC-related precipitation events during the negative phase of NAO can be attributed to the variability in the storm track. During the negative phase of the NAO, large positive geopotential height anomalies and strong easterly steering flow at the mid-tropospheric level (500 hPa) over the North-West Atlantic (Figure 8) tend to deflect the storms towards the

United States. Thus, the changes in storm track cause the higher frequency of TC-related extremes along the U.S. East Coast. The negative phase of the NAO is associated with a weaker subtropical high displaced farther south and west. These conditions are favorable for the westward steering of TCs towards the United States (e.g., Elsner et al. 2001). TCs moving straight under the easterly steering flow south of the subtropical high tend to intensify at low latitude and cross the Caribbean route to North America (Elsner 2003). Similarly, ENSO affects the probability of TC-induced extreme precipitation due to the changes in cyclogenesis frequency through the changes in vertical wind shear and lower tropospheric vorticity. TC frequency in the North Atlantic basin decreases (increases) due to the larger (smaller) vertical shear during El Niño (La Nina) events (e.g., Landsea 2000; Shaman et al. 2009)

Summary and Discussion

In this study, flooding and heavy precipitation associated with North Atlantic TCs over the continental United States were analyzed using long-term observational records. We focused on long-term trends in the frequency and magnitude of extreme events associated with these storms and on the role of NAO and ENSO in modulating the probability of these extreme events. Our findings can be summarized as follows:

- TCs are responsible for significant fractions of flooding and extreme precipitation events over the eastern United States and the Gulf Coast. The TC-contribution to annual maximum flood events can be as large as 40% over Florida and influence of these storms decreases as we move inland. In terms of precipitation, we obtained similar results in terms of spatial distribution, even though the fractional contributions were larger. Overall, TCs contribute more to the annual maxima than to the POT flood events. Moving forward, these impacts are projected to change, with projected changes in TC-precipitation (e.g., Knutson et al. 2013; Villarini et al. 2014b) that could lead to significant economic impacts (Czajkowski et al. 2017).
- Our examination of the temporal changes in TC-flooding does not point to statistically significant changes in their magnitude or frequency. In terms of precipitation, we identified areas west of and along the Appalachian Mountains where the frequency of TC-POT events has been increasing during the study period.

Given the connection between TCs and NAO/ENSO, we examined the role played by these climate modes in controlling the frequency of POT events and the probability of having an annual maximum caused by these storms. Our analyses do not point to a strong connection between flooding and NAO or ENSO. On the other hand, we identified a much stronger relationship with respect to the frequency of heavy precipitation events. More specifically, we found that the NAO plays a significant role along the U.S. East Coast, while the role of ENSO is more towards the western part of the Gulf of Mexico, including Louisiana, Texas, Oklahoma and Arkansas. Therefore, given that NAO and ENSO influence flooding and heavy precipitation associated with TCs differently, it is likely that there are other non-climate related drivers (e.g., antecedent soil moisture conditions) that would explain these differences.

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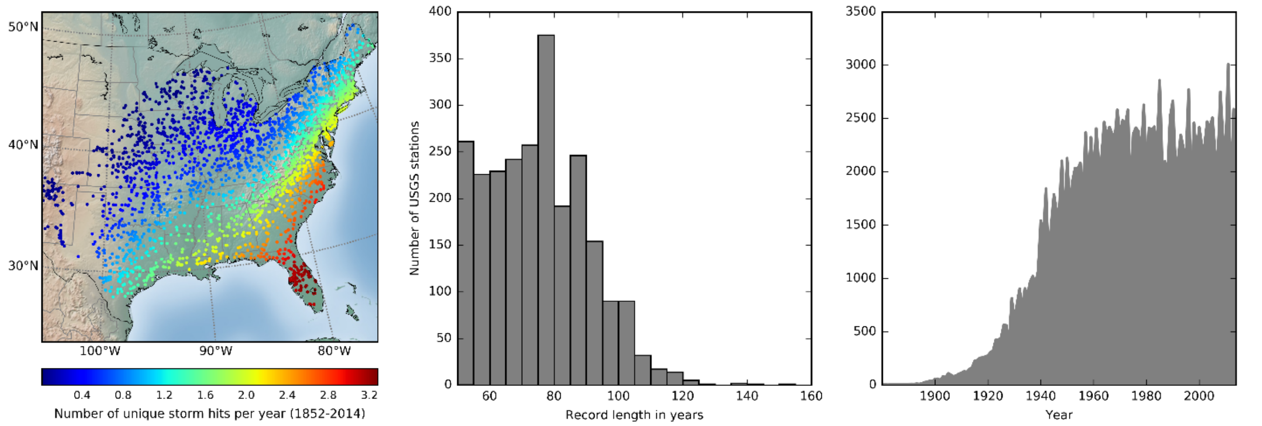

Figure 1: Average number of unique North Atlantic TC hits per year for each complete USGS stream gauge during 1852-2014 (left), histogram of the record length of the USGS stations (middle), and number of USGS sites with complete records for a given year (right).

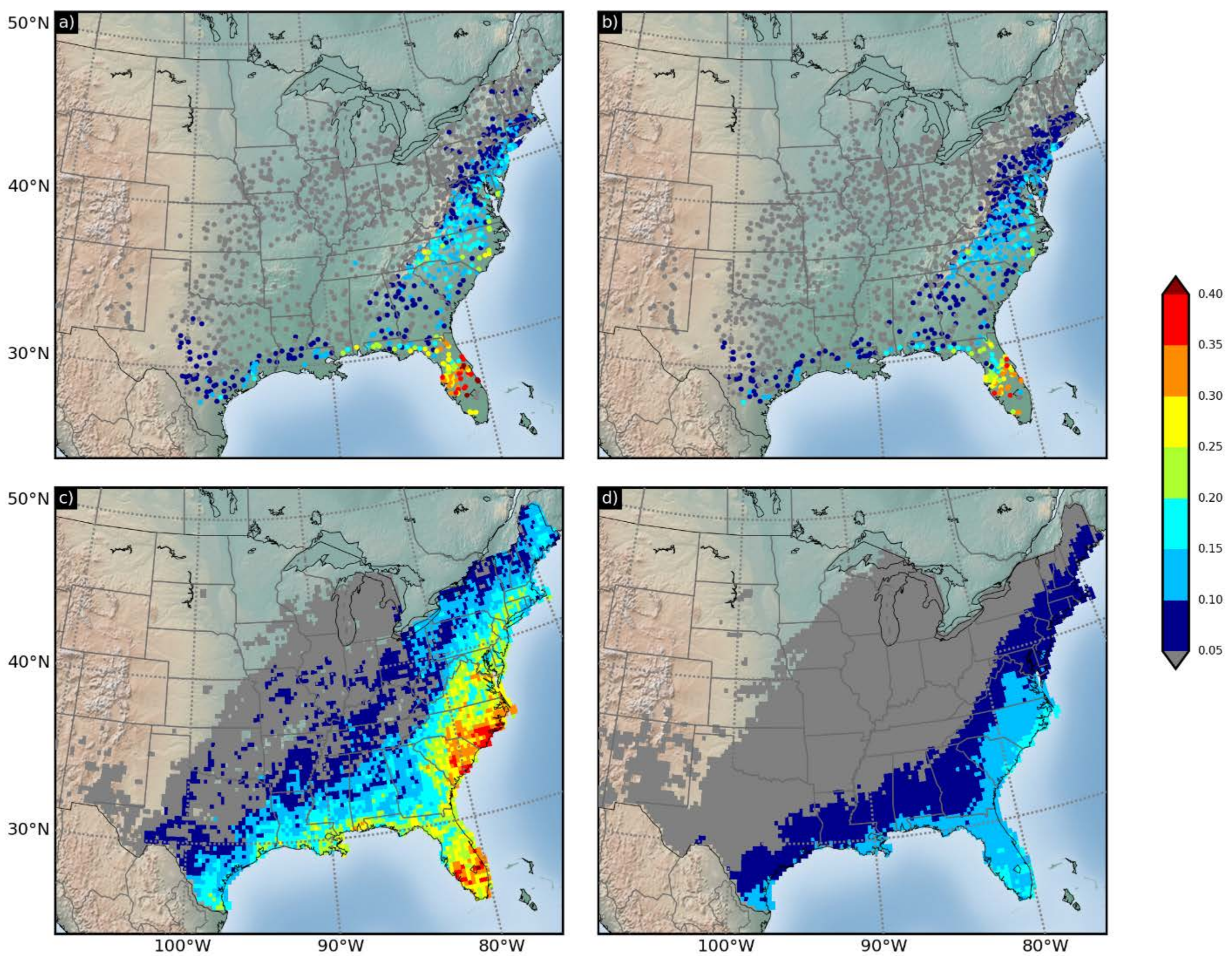

Figure 2: Fraction of AM (left panels) and POT (right panels) flooding (top row) and precipitation (bottom row) due to North Atlantic TCs.

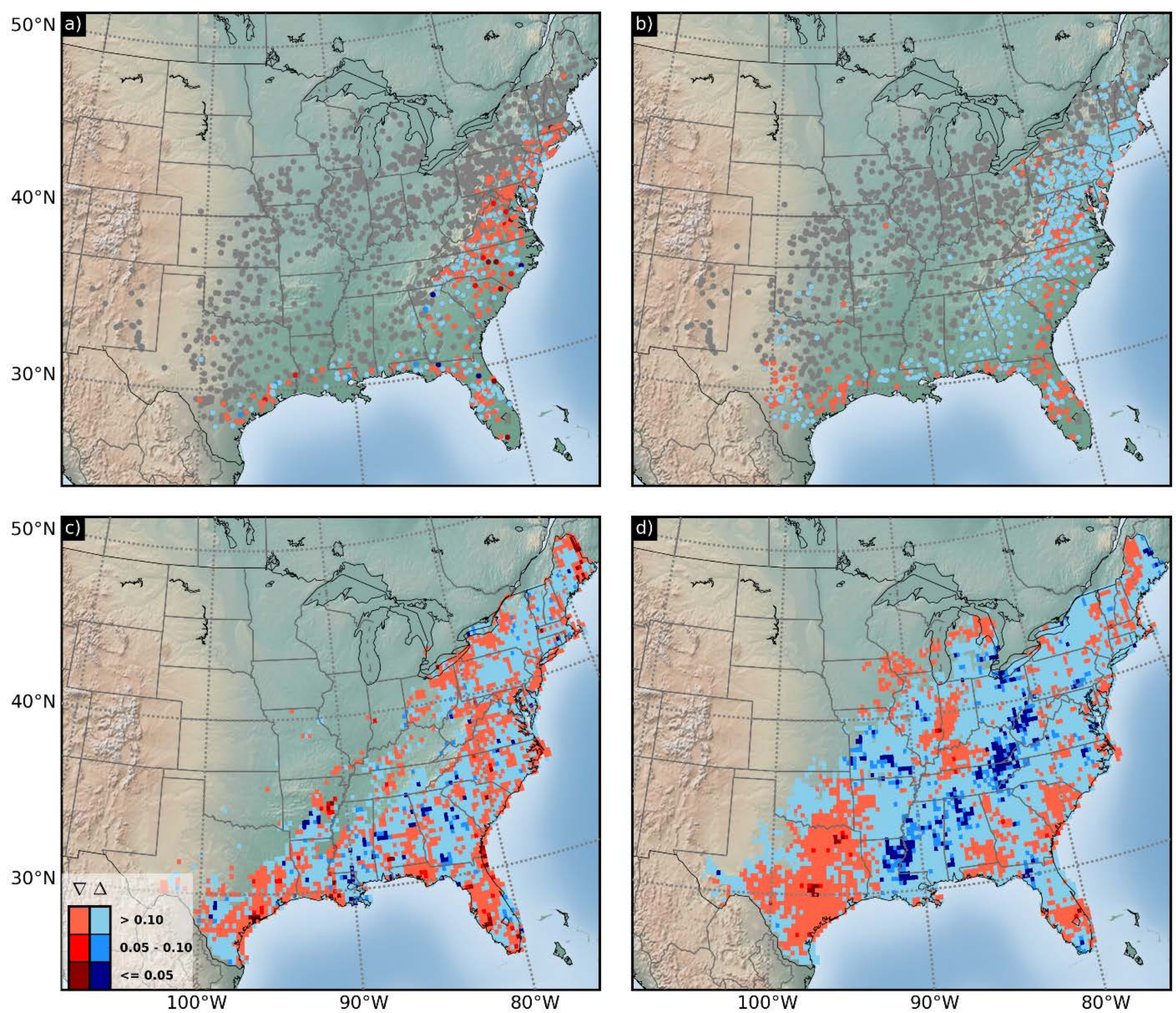

Figure 3: Top panels: trends in the flood ratio (left) and in the frequency (right) of TC-related floods. Bottom panels: trends in the annual maximum (left) and in the frequency (right) of TC-related precipitation. Stations (pixels) with at least five annual maximum discharge (precipitation) event due to TCs, and stations having at least five years with at least one TC-related POT event are shown.

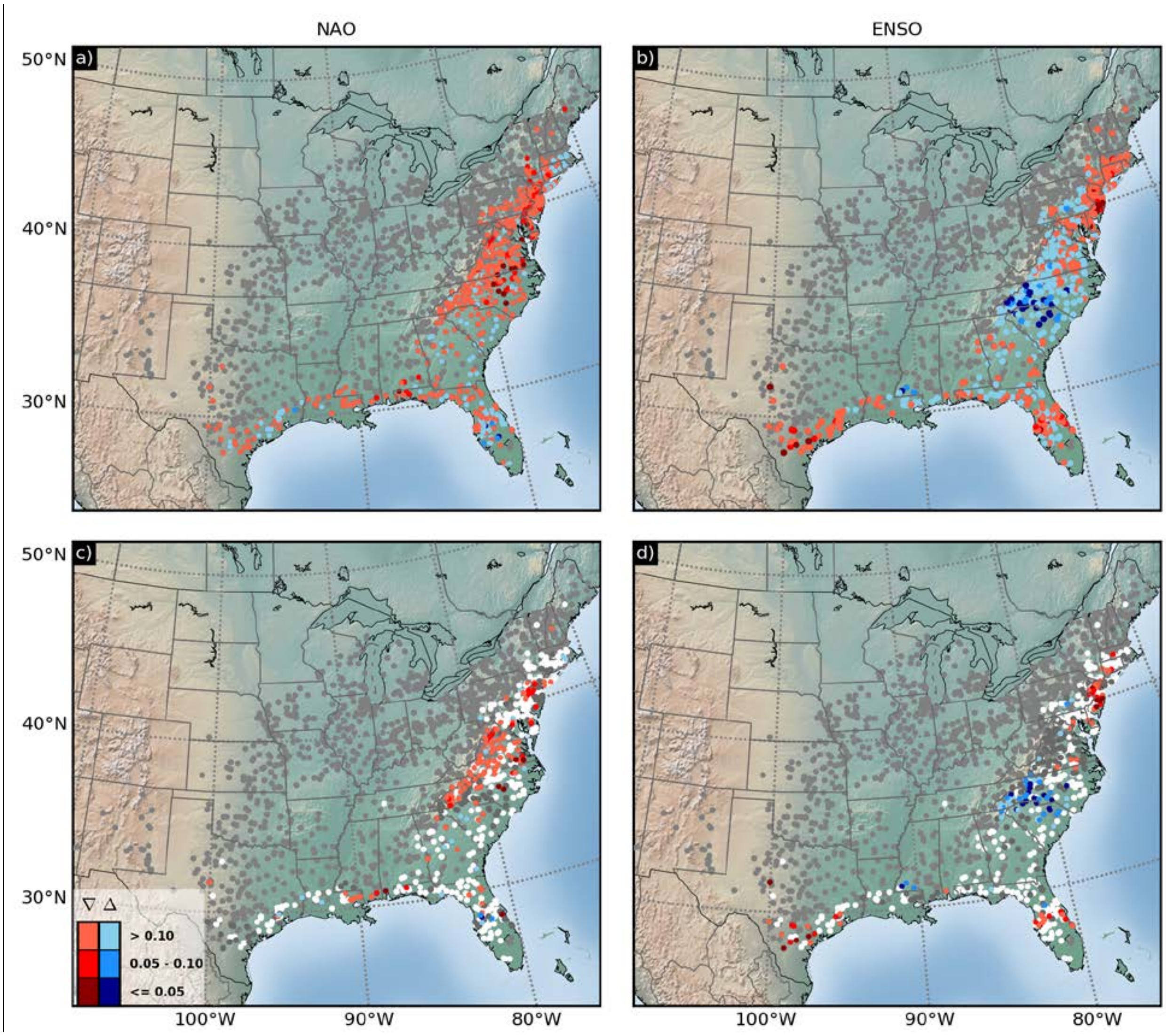

Figure 4: Top panels: role of NAO (left) and ENSO (right) to induce TC related annual maximum flow. Bottom panels: stations where a model with NAO as the only predictor (or a model with both NAO and ENSO) (left) and model with ENSO as the only predictor (or a model with both NAO and ENSO) is selected as the best model based on AIC. Points marked white are those where a base model with no predictors is selected as the best model. The difference between the top and bottom panels is that NAO and ENSO are used in isolation in the top panels, while they are both allowed to be selected as predictors in the bottom panels. Regression coefficients from logistic regression are shown at different level of significance.

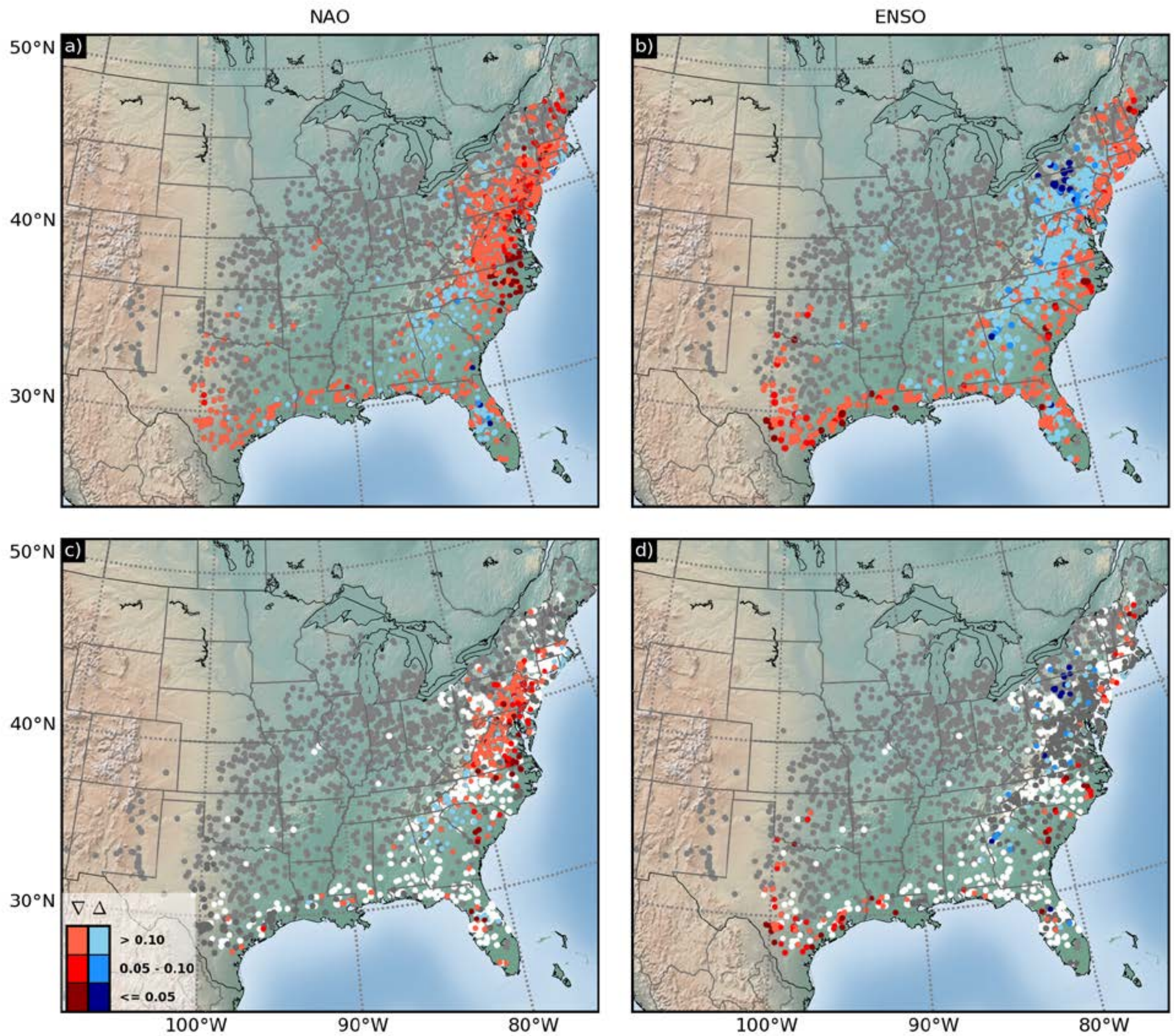

Figure 5: Same as Figure 4 but for the frequency of POT events associated with TCs. Results are based on Poisson regression.

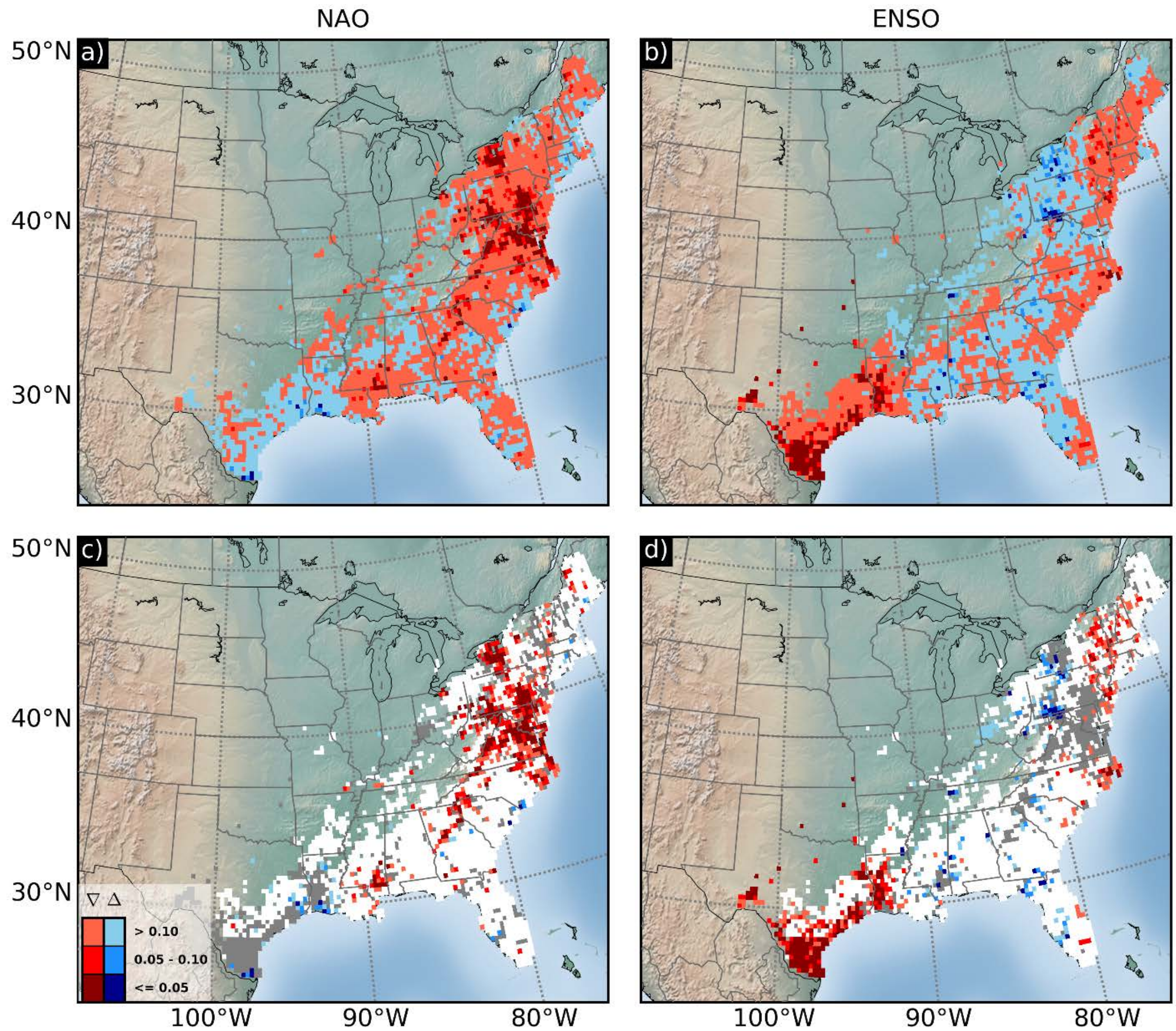

Figure 6: Similar to Figure 4 but for precipitation

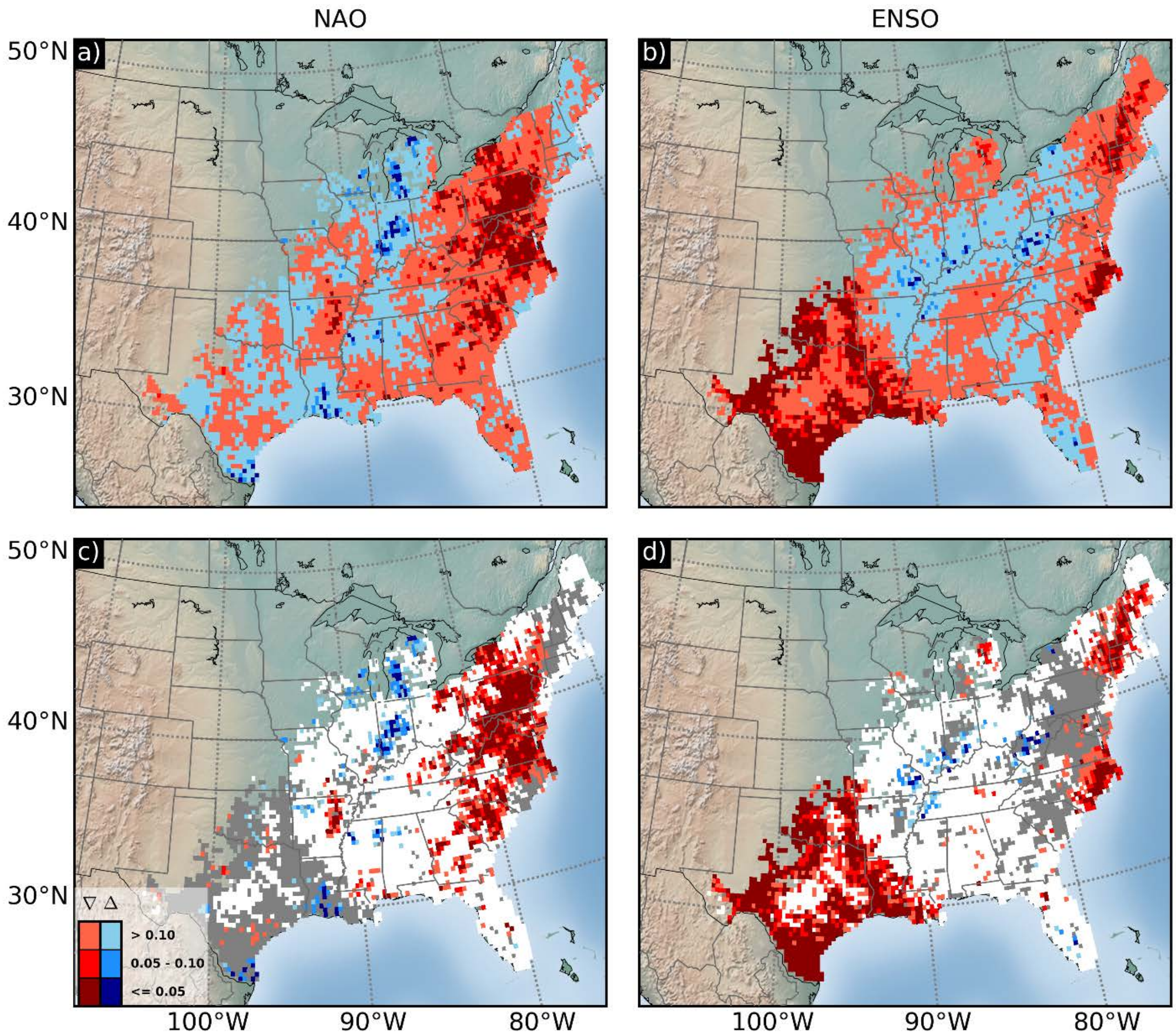

Figure 7: Similar to Figure 5 but for precipitation

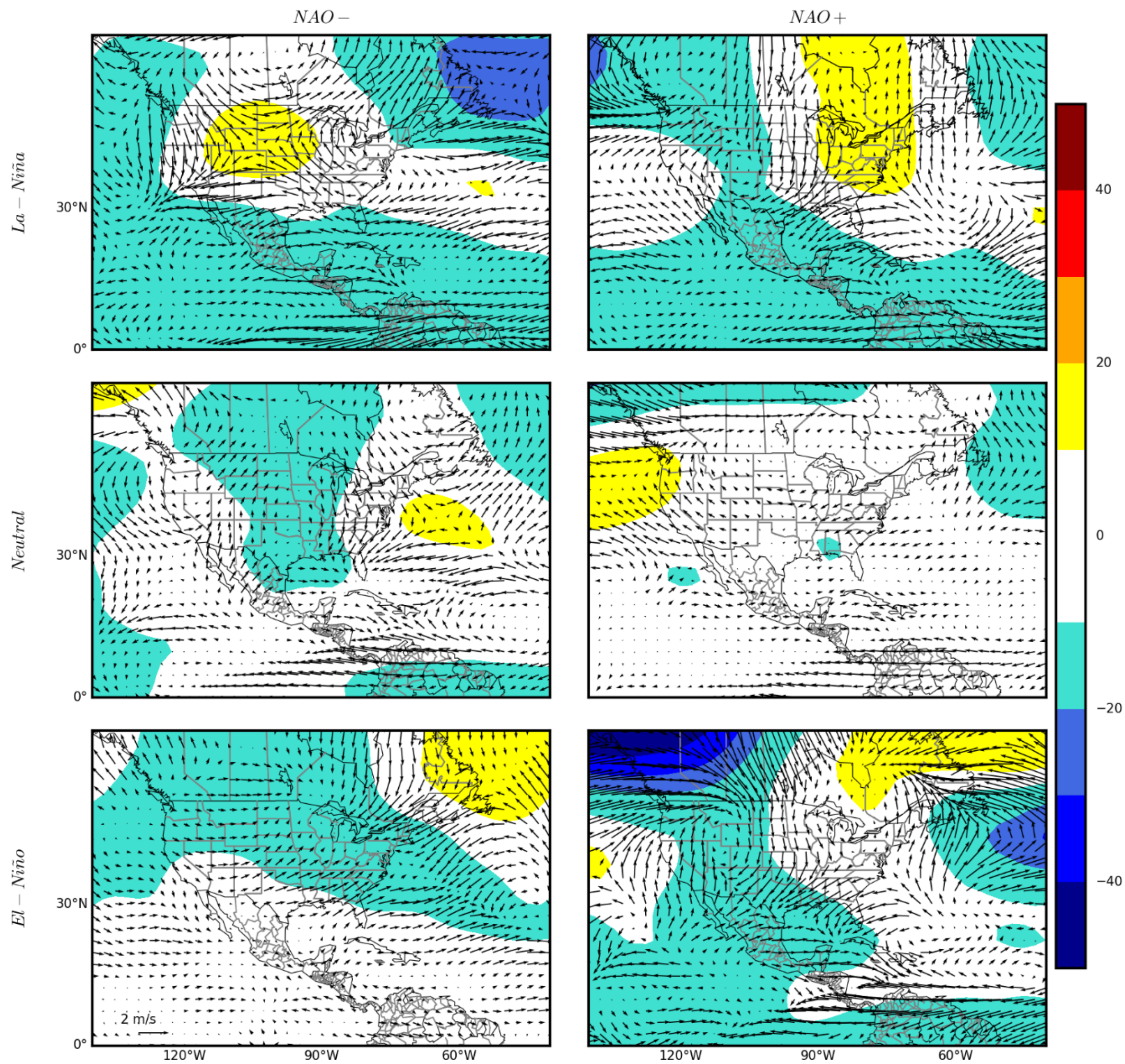

Figure 8: Maps of the 500 hPa geopotential height (unit: gpm) and wind fields (m/s) anomalies (August-October) during different ENSO and NAO phases. The anomalies of geopotential height and wind fields are based on 1981-2010 climatology

Student support

- Aryal, Yog Nath (Ph.D. student)
- Marilyn Montgomery (Post-doc)

Outcomes since the beginning of the project

Manuscripts:

- Czajkowski, J., G. Villarini, M. Montgomery, E. Michel-Kerjan, and R. Goska, Assessing current and future freshwater flood risk from North Atlantic tropical cyclones via insurance claims, Scientific Reports, 7, 1-10, 2017.
- Aryal, Y.N., G. Villarini, W. Zhang, and G.A. Vecchi, Long term changes in flooding and heavy rainfall associated with North Atlantic tropical cyclones, submitted to Journal of Hydrology, 2017.
- Barth, N.A., G. Villarini, and K. White, Flooding in the southwestern United States and tropical cyclones, 2017 (close to submission).

Prototype Multi-Jurisdictional Decision Making Web Platform for Integrated Water Resources Management: From Interagency Collaboration to Implementation in the Iowa-Cedar Watershed (Iowa)

Basic Information

Title:	Prototype Multi-Jurisdictional Decision Making Web Platform for Integrated Water Resources Management: From Interagency Collaboration to Implementation in the Iowa-Cedar Watershed (Iowa)
Project Number:	2015IA269S
USGS Grant Number:	
Sponsoring Agency:	U.S. Army Corps of Engineers
Start Date:	2/1/2015
End Date:	10/23/2016
Funding Source:	104S
Congressional District:	
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Marian V.I. Muste, Ibrahim Demir, Jason Thomas Smith, Toby Hunemuller

Publications

1. Xu, H., Hameed, H., Windsor, M., Muste, M., Demir, I., Smith, J., Hunemuller, T., Stevenson, M. B. (2017). Decision-support System for Underpinning Collaborative Planning for Multi-hazard Mitigation," Proceeding 37th IAHR World Congress, August 1318, 2017; Kuala Lumpur, Malaysia.
2. Xu, H., Hameed, H., Windsor, Smith, J., Hunemuller, T., M., Muste, M., Demir, I., Stevenson, M. B. (2017). "An Iowa Prototype for a Generic Watershed Decision Support System," 11th Annual Iowa Water Conference, March 22-23, 2017, Ames, IA
3. Xu, H., Hameed, H., Demir, I., Muste, M. (2016). Visualization Platform for Collaborative Modelling, 2016 AWRA Summer Specialty Conference - GIS and Water Resources IX, American Water Resources Association, July 11-13, 2016, Sacramento, CA. – Paper awarded with the Best Student Oral Presentation for Haowen Xu
4. Muste, M., Smith, J., Demir, I., Carson, A. (2017). "Serious Gaming for Community Engagement in Multi-Hazard Mitigation" Hydrolink, International Association of HydroEnvironment Engineering and Research, Madrid (IAHR), Spain

Iowa Water Center Report

1. **Project Number:** G15AP00041

2. **Project Title:** Prototype Multi-Jurisdictional Decision Making Web Platform for Integrated Water Resources Management: From Interagency Collaboration to Implementation in the Iowa-Cedar Watershed

3. **Project Start and End Dates:** 02/01/2015 – 2/28/2017

4. **Investigator Name(s):** Marian Muste (IIHR), Ibrahim Demir (IIHR), Jason T. Smith (USACE), Toby Hunemuller (USACE), Mary-Beth Stevenson (Iowa DNR)

5. **Congressional District:** Iowa 1st

6. **Research Category:** Data Science & Engineering

7. **Focus Categories:** climatological processes, floods, hydrology, water quality, management and planning, methods for integration of federal with state agencies, collaborative decision making, self-sustaining water resources management

8. **Keywords:** Decision Support Systems, Decision Making Process, Flood Mitigation, Flood Risk, Federal Government Interest, Multi Interagency Collaboration, Community Participation, Integrated Water Resources Management

9. **Problem and Research Objectives**

In many of the nation's watersheds countless dollars are spent at the local, state, and federal levels to address multi-faceted water resources issues. Solutions to these issues are typically formulated from a sectoral perspective (e.g., assuring water for various uses, mitigating flood, stream water quality or aquatic habitat) without coordination at the watershed scale. Often times, stakeholders are working to solve issues in isolation according to their personal interests or mission. This singular interest perspective poses difficult choices on assessing benefits and/or costs across jurisdictional boundaries (e.g., the upstream/downstream flood mitigation dilemma). Continuously increasing of watershed stresses due to land use and climate changes at a time when public funding for addressing water resources-related concerns is declining requires promotion of integrated and comprehensive planning. Such ambitious planning approach must include participation and actions of all individuals and groups with interests in the vitality of the watersheds. This in turn, demands that watershed stakeholders (from agencies to individuals) work together to align resources in a way that allows for entities to build on past efforts with confidence and consistency and to leverage and continuously integrate existing products in new studies with minimum effort and resource investments. While attempts to work collaboratively are increasing in the nation's watersheds, the "enabling technology" for formulating sound, cost-effective, and timely solutions to water issues has not been fully realized, limiting the efficiency of the multi-agency investments.

The increased stress on the natural landscape due to human impacts and climate change has triggered an increase in water-related hazards (e.g., floods, river pollution), which in turn, impose direct and immediate implications for the sustainability, resilience, and security of our watersheds. Because of their complexity, hazards are typically studied in isolation, as stand-alone processes. Moreover, the interconnections between different types of hazards are vast and not fully known. In most of the cases, however, the primary difficulty to simultaneously address hazards stems from our limited capabilities to integrate and handle the vast amount of data needed for solving the problem at the appropriate scale, i.e., the full size of the drainage area converging to the point of interest. The lack of the technological capability precludes not only the thorough the understanding of the feedback dynamics between the multiple hazards, but also accounts for the synergies and tradeoffs among the possible solutions used to address them.

Overcoming the status-quo requires the development of evidence-based decision support systems (DSS) that are focused on the end-user interests. A DSS typically provides users with interfaces that are easy to understand and use by all stakeholders using the DSS tools for problem-solving and decision-making.

The specific objective of the project are:

1. Bringing together data, information, and modeling results from a variety of disciplines to support effective management of competing environmental, economic, and social needs of the watershed through immediate or long-term interventions.
2. Filling gaps in information and knowledge, and facilitating the translation of research findings in concert with the participation of all stakeholders.
3. Establishing means for an effective dialogue between the watershed stakeholders (from federal, state and local agencies to communities) and data and information producers through widely accessible and transparent web-based tools.

10. Methodology

The prototype DSS developed through this project is referred herein as to: IoWaDSS, The computational environment, referred to as IoWaDSS, provides data insights for problem solving and supports decision-making for the mitigation of multiple hazards. The platform was developed using single-page application while implementing serious gaming concepts in order to enhance social learning. The platform was built with open source technologies that make the system light-weight, low-cost, and flexible. Conceptually, IoWaDSS is a domain specific web-based Problem Solving Environment (PSE). The PSE structure entails four modules: (1) the watershed characterization (offering a digital representation of the existing data about the watershed), (2) the watershed planning (new data and information created with multi-domain modeling), (3) the competitive gaming environment (enabling game-like competitions), and (4) the plan evaluation (entailing a metric for evaluation of the proposed alternatives and scoring of the competitors). Figure 1 illustrates the PSE modules and associated components.

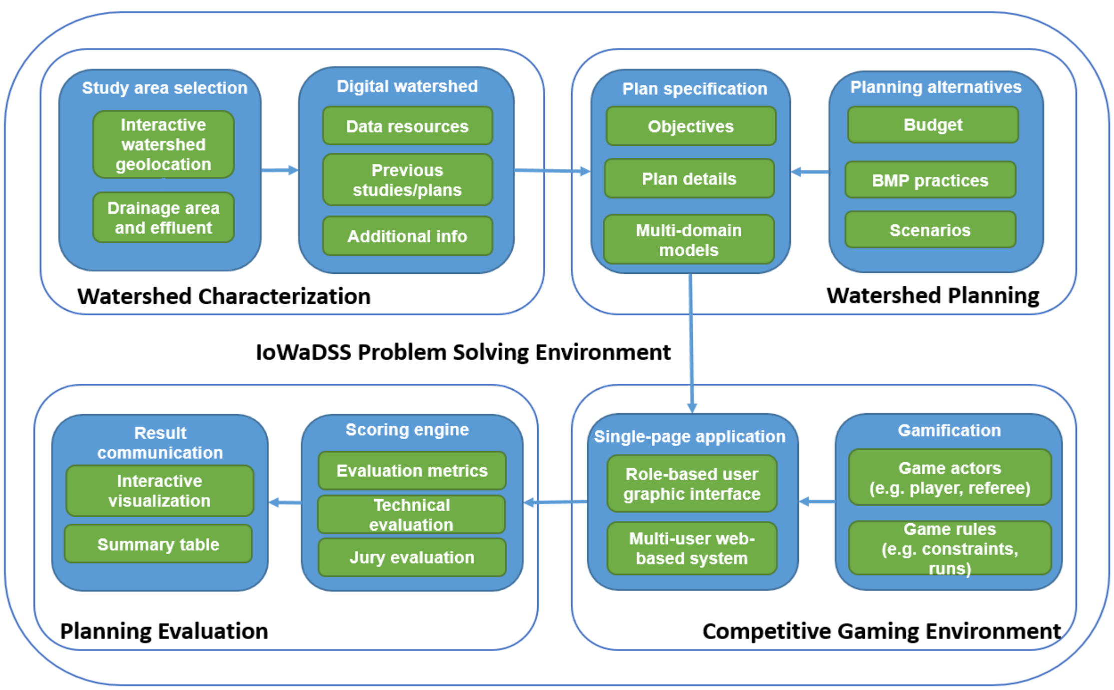

Figure 1. Problem Solving Environment structure for the IoWaDSS prototype

Following the modern web-application templates, the IoWaDSS, adopts a three-tier architecture that includes the following components: (1) presentation, (2) logic, and (3) data. To ensure the platform reliability, flexibility, extendibility, modularity, and maintainability, industrial design patterns and architecture patterns (e.g. MVC and MVVM) are applied in the system development. Figure 2 illustrates the overall architecture, along with the web, informatics, and GIS technologies that are associated with each tier.

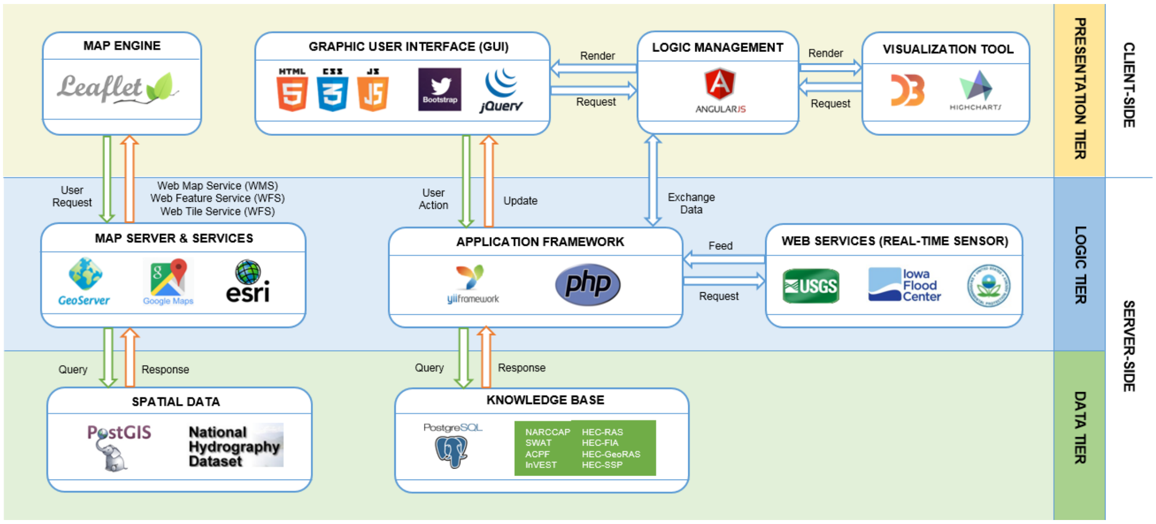

Figure 2. Overall architecture.

The presentation tier is primarily rendered at the front-end in user's web or mobile browser. It contains platform elements that a user can see and interact with. This tier provides users with Graphic User Interfaces (GUI), a map engine, and visualization tools to facilitate map operations, information retrieval, workflow control, watershed planning, and communication. The presentation tier in IoWaDSS entails four components: (1) the map engine, (2) the GUI, (3) logic management, and (4) the visualization tools. The map engine is the means to visualize geo-spatial information, such as basemaps, river networks, watershed boundaries, locations of BMPs, and modeling results (e.g. soil maps, inundation maps). For IoWaDSS, the presentation tier is developed with Leaflet JavaScript (JS) library and its extensions. The GUI provides a media for users to navigate through the platform, to manage and control tools, and to retrieve information. The GUI is developed using JQuery and Bootstrap JS library, which guarantees both the user interactivity and compatibility for multi-screen sizes.

The logic management component contains a front-end Model–view–controller (MVC), that improves fluid web page design and two-way data-binding. The main reason to have a logic management component is that our platform contains Single-Page Applications (SPAs), which make the front-end very heavy. The front-end MVC, a JavaScript library itself, helps structure and optimize the front-end developments with practical industrial conventions, which increases the maintainability and extendibility at the front-end. Visualization tools are primarily responsible for visual communication and representations (e.g. plots, chart). They are developed with D3.js and HighChart libraries, both of which are data-driven and user-responsive. The entire presentation tier is developed using common front-end technologies (e.g. JavaScript, HTML, and CSS). To perform multiple system operations (e.g. updating data & information, displaying spatial features on a map, user log-in, saving user-defined watershed plans), the presentation tier sends Asynchronous JavaScript and XML (AJAX) requests to exchange information with the server-side applications in the form of JSON, XML, and images.

Unlike the presentation tier, the logic tier and data tier are deployed on the server-side (i.e., "back-end" of the platform). The logic tier is responsible for organizing the data, assembling the services based on relationship between the user scenarios and the models, and for providing the necessary information requested by the presentation tier. The logic tier consists of three sub-components: (1) the map server and map services, (2) the application framework, and (3) the web services for real-time sensors. The map server and web services prepare and manage spatial information, as well as handle request from the presentation tier for the map visualization. The IoWaDSS uses GeoServer, an open-source map server application, to host spatial information that is stored locally on the server (e.g. river, watershed boundaries). The GeoServer complies with a number of open standards, such as Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS), which improve the interoperability of spatial data effectively. Third-party map services from Google and ESRI are also used to increase the diversity of the basemaps (e.g. satellite imagery, topo-maps, and NHD basemap) within the platform. The application framework components manage the overall back-end logic (e.g. scientific models, PSE design, and data integration) and user-scenarios (e.g. multi-user web-based system).

Many of the platform's tool and applications (e.g. watershed search engine) are hosted in the application module. This module hosts and is responsible for managing the local web services. The system design adopts a Service Oriented Architecture (SOA) to bring multiple web services in one place. There are two types of web services in the IoWaDSS: (1) local web services (that are developed within the application framework on the local server), and (2) external web services (that are hosted on third party servers). External web services in IoWaDSS are mainly third-party data providers (e.g. USGS, EPA). The web services are important components for the presentation tier as they facilitate the communication between the presentation and the logic tier. The backbone of the application framework module is Yii (a PHP framework that also follows the MVC pattern).

The data tier is located at the bottom of the architecture. This tier consists of databases and datasets. The spatial data are stored in the PostGreSQL database with its PostGIS library, which adds support for the use and management of spatial objects. The knowledge base is the customized database that stores results of simulations with the 8 multi-domain models and their relationship as entities. Details of model connection and information flow are illustrated in the Figure 3.

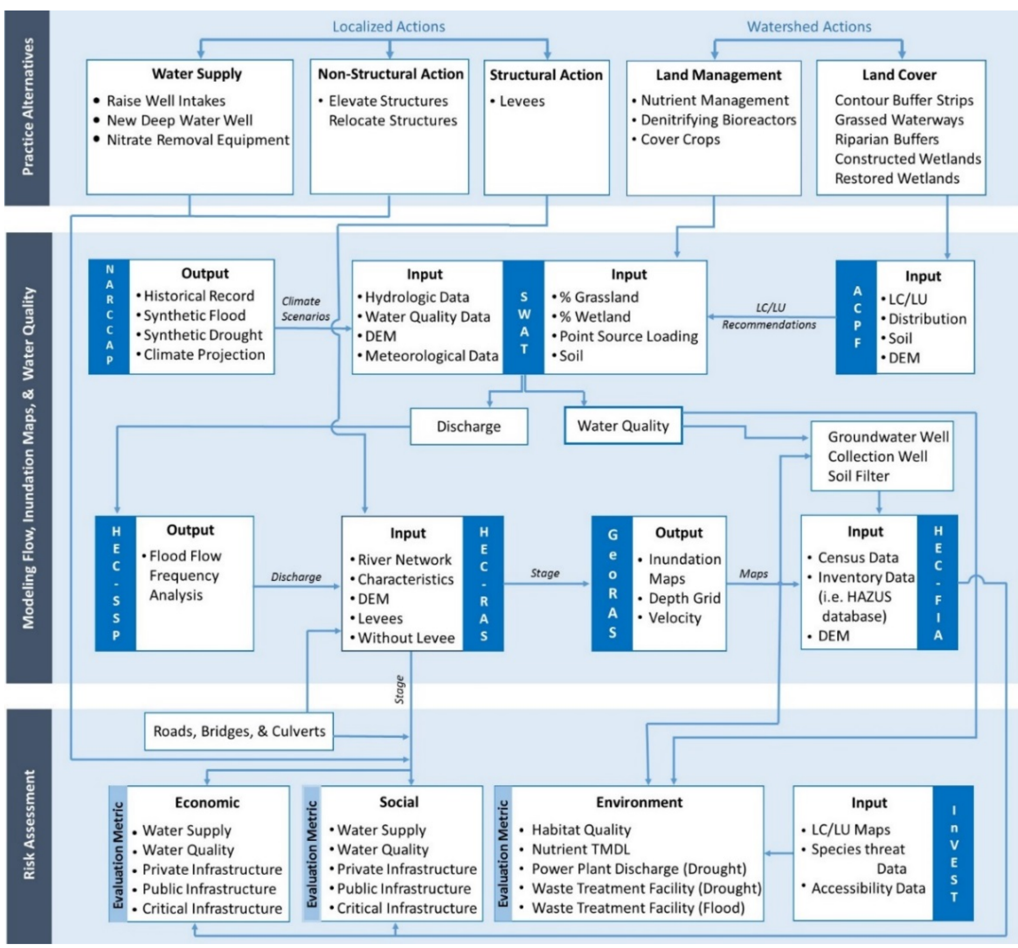

Figure 3. Flow of data and information between models used in the scenario analysis.

11. DSS web interfaces

The IoWaDSS was developed, and hosted at the "www.iowawatersheds.org" domain as a web-based platform for assisting the MHT delivery. The IoWaDSS is launched from a landing page that provided users guidance and tutorials pertaining to the platform, as well as the navigation to several platform features. The landing page entails an introduction, and a map of watershed management authorities in Iowa. The user can access the full introduction page, and the platform tutorial videos through home page. The navigation section includes four blocks: (1) decision support platform, (2) watershed infrastructure, (3) water resources management, and (4) communities & collaboration. The "decision support platform" section allows users to launch the actual PSE. The "water resource management" section presents the user with relevant management concepts, policies, and guidance in watershed management. While the "Communities & collaboration" section directs user to the webpage of Iowa-Cedar watershed interagency coordination team and several watershed organizations. Figure 4 shows the overview of the landing page.

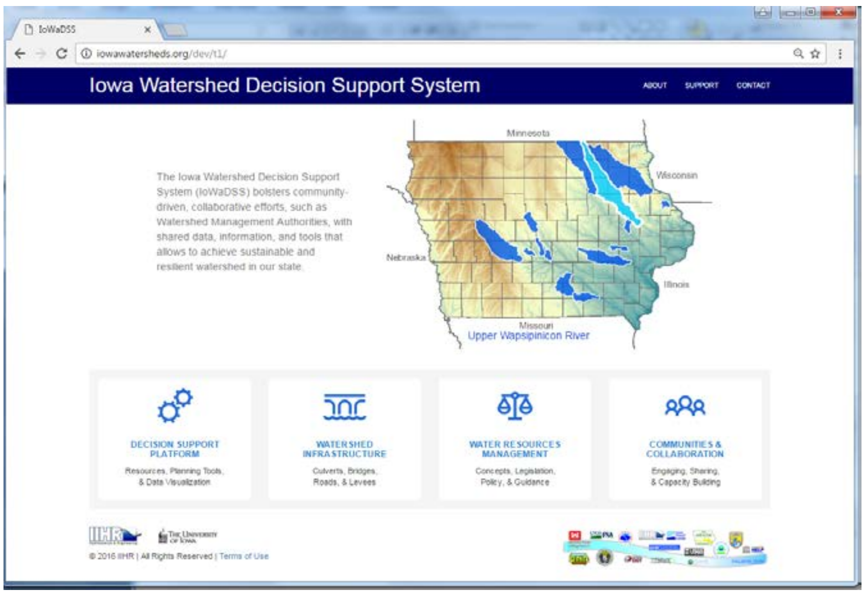

Figure 4. IoWaDSS landing page.

The "Decision-support platform" contains three workflows: (1) watershed-search, (2) watershed-info, and (3) watershed-planning. The Decision-support platform landing page is shown in Figure 5. The decision-support web page contains four functional blocks (1) the Menu bar, (2) the Workflow bar, (3) the functional panel, and (4) the web map, as illustrated in Figure 5. Similar to the landing page, the Decision-support platform carries the title of the platform and three tabs that lead user to the landing page, the DSS introduction page, and the tutorial page. The "Task bar" supports various aspects of the decision-making process by providing the user with the needed resources to carry out a watershed plan. For this purpose, four workflows have been designed: a) Search Watershed, b) Overview, C) Data resources, d) Planning. A "Help" button opens for the guidelines for using the platform.

The "Search Watershed" interface corresponds to the "Watershed characterization" module in the PSE design. The objective of this workflow is to define the study area on the map as well as the drainage area upstream (from where does the water come) and the main effluent leaving the watershed. Multiple search criteria are enabled: state level, HUC 8 watershed, HUC 12 watershed, city, county, and Point of Interest (POI) such as an address or a point on the map. Figure 6A presents the interface for the search criteria using as a point of interest the "Iowa state" (Figure 6A). Figure 6B shows the same for a HUC 8 watershed search. After the desired study area is identified, the user can access the DW by activating the "Load POI" button.

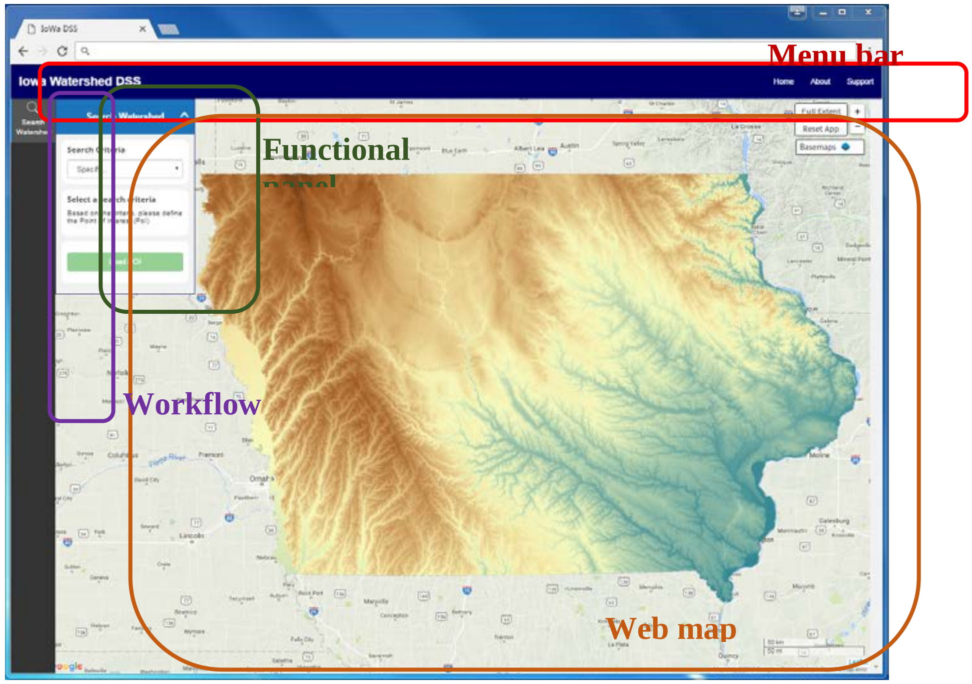

Figure 5. IoWaDSS customized interfaces

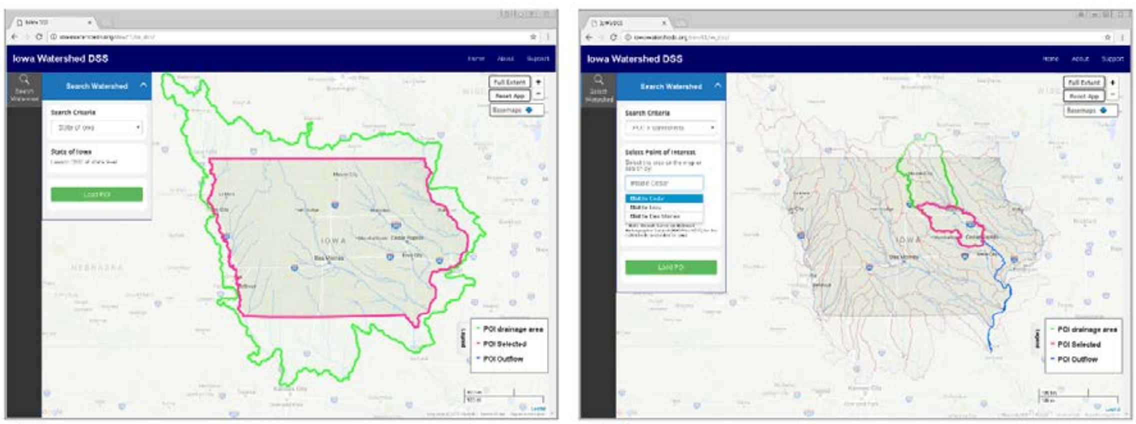

Figure 6. Search Watershed workflows using as criteria: a) the state of Iowa, and b) HUC 8 watershed.

Additional functions in the Workflow bar includes “Overview” and the “Data resources” options. These workflows assemble, synthesize and visualize important watershed data and information regarding the study area. The “Overview” workflow displays summary geographic information, displays dynamically the type of data available in the watershed including their providers (see Figure 7A), and lists the previous studies conducted in the watershed (see Figure 7B). The data resources tool displays the locations of different sensors grouped by their domain: hydrology, geomorphology, water quality, meteorology, land & water habitat, socio-economic. Each domain contains selected variables. For example, hydrology contains: stream discharges, stream stages, lake levels, runoff potential. The extension of the number of domains and variables for each domain can be increased if more on-line data is available. Uniformly-designed windows allow to view data for the variables acquired at various locations using two sub-interfaces. The first sub-interface shows the last recorded data and essential information about the source of the data that was selected for visualization (see Figure 7A). The second sub-interface shows the location of the sensor in an interactive map along with the time series for the variable plotted for a pre-established time window as illustrated in Figure 7D. Essential statistics of the visualized time series is also shown in this visualization sub-interface. This window is fitted with functions that allow to compare multiple time series acquired at other location and to download the data for further analysis.

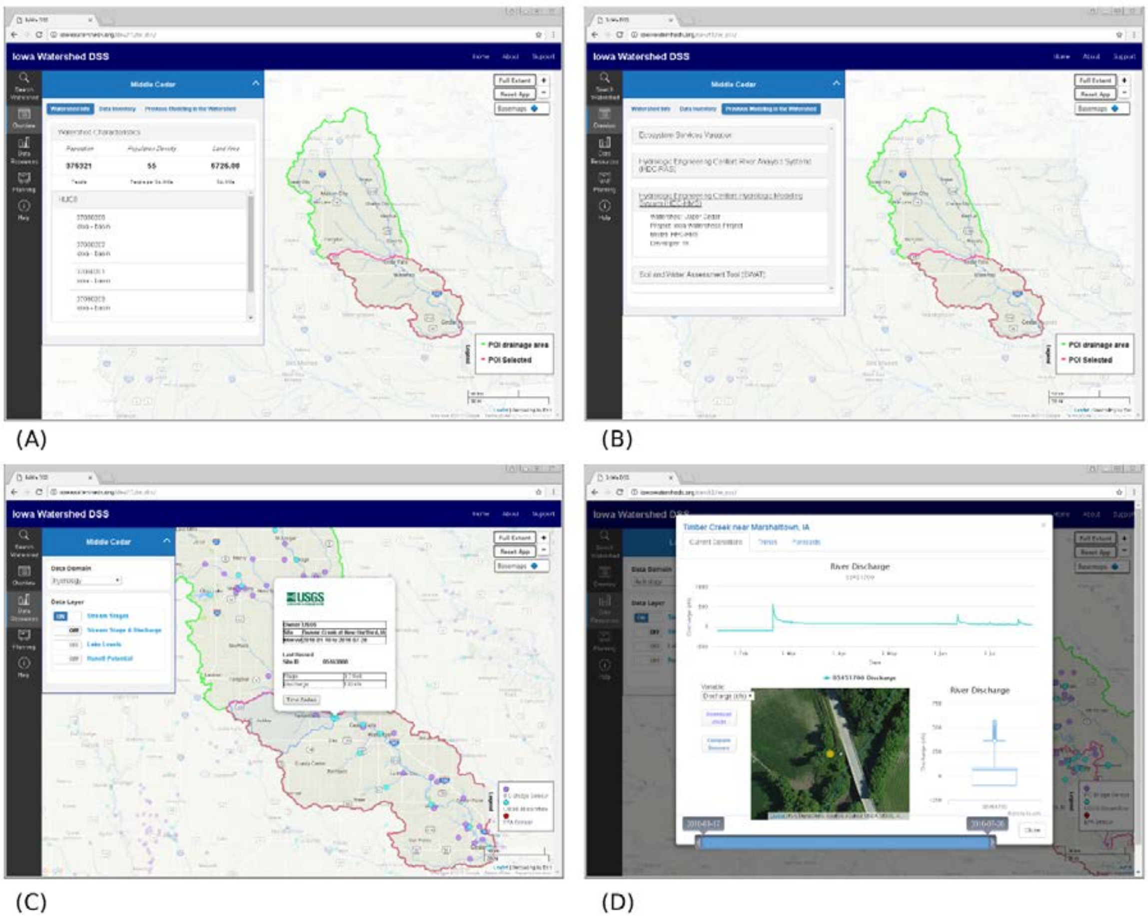

Figure 7. Interfaces for IoWaDSS workflows: A, B “Overview”; C) “Data resources”, and D) viewer for the discharge time series

The watershed-planning interfaces can be accessed from the “Planning” tab in the workflow bar (see Figure 8). This workflow is the most complex one in the platform and cannot be described in full in the present context. More details are provided in IWR (2016), Muste et al. (2017) and in the interactive tutorials published on the platform’s website (iowawatershed.org/iowadss/support.php). The workflow provides users with options to either manage previous watershed plans or to create new plans. The “Planning” workflow entails a phased sequence of seven steps: 1) Objectives, 2) Resources, 3) Alternatives, 4) Assessment, 5) Selection, 6) Implementation, and 7) Evaluation. The progress of the plan development is visually displayed as the work advances. Each of the planning steps has multiple sub-menus and interfaces that will be not described in this paper. The work on the plans can be interrupted and continued at the pace of the user’s availability. The Content Management System (CMS) developed behind the planning tool using PHP Yii framework allows simultaneous access of multiple contributors to the development of the plan. They all can store data and info, share, and manage the plans within the PSE.

Figure 9 illustrates the interface for the “Alternative” step (#4 in the upper part of the figure) of the “Planning” workflow. The choices of planning alternatives illustrated in this figure are those developed for the Multi-Hazard Tournament delivered in the Middle Cedar River watershed using the sequence of models shown in Figure 2 (IWR, 2016). The interactive interface allows the user to assemble an integrated hazard mitigation strategy using best management practices (BMP’s) deployed locally (“Localized Actions”) or within the watershed (“Watershed Actions”). The BMPs can be selected in multiple combinations to accommodate various hypothetical climate scenarios and budget limitations, which are the constraints in the game-like environment. The finalized plan is stored under user's account, and is submitted for evaluation in the "Assessment" step. The interface for the "Assessment" step is basically the front-end representation of the planning evaluation module (described in Section 2.2).

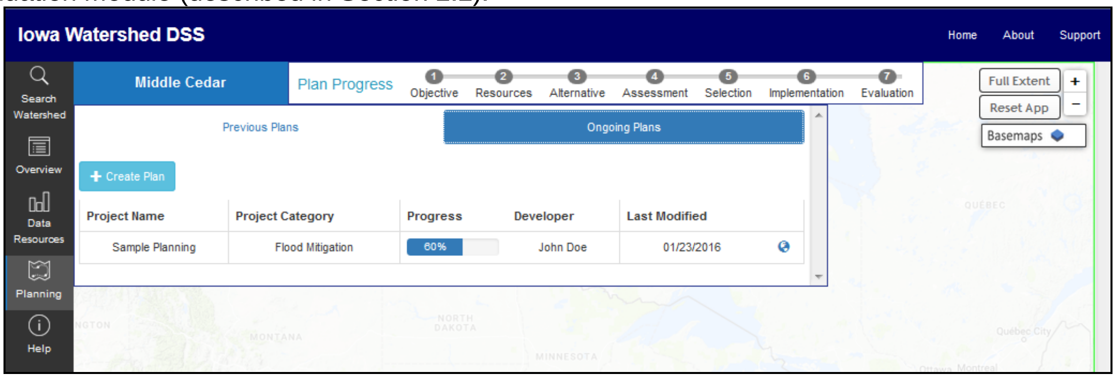

Figure 8. Watershed "Planning" initial interface

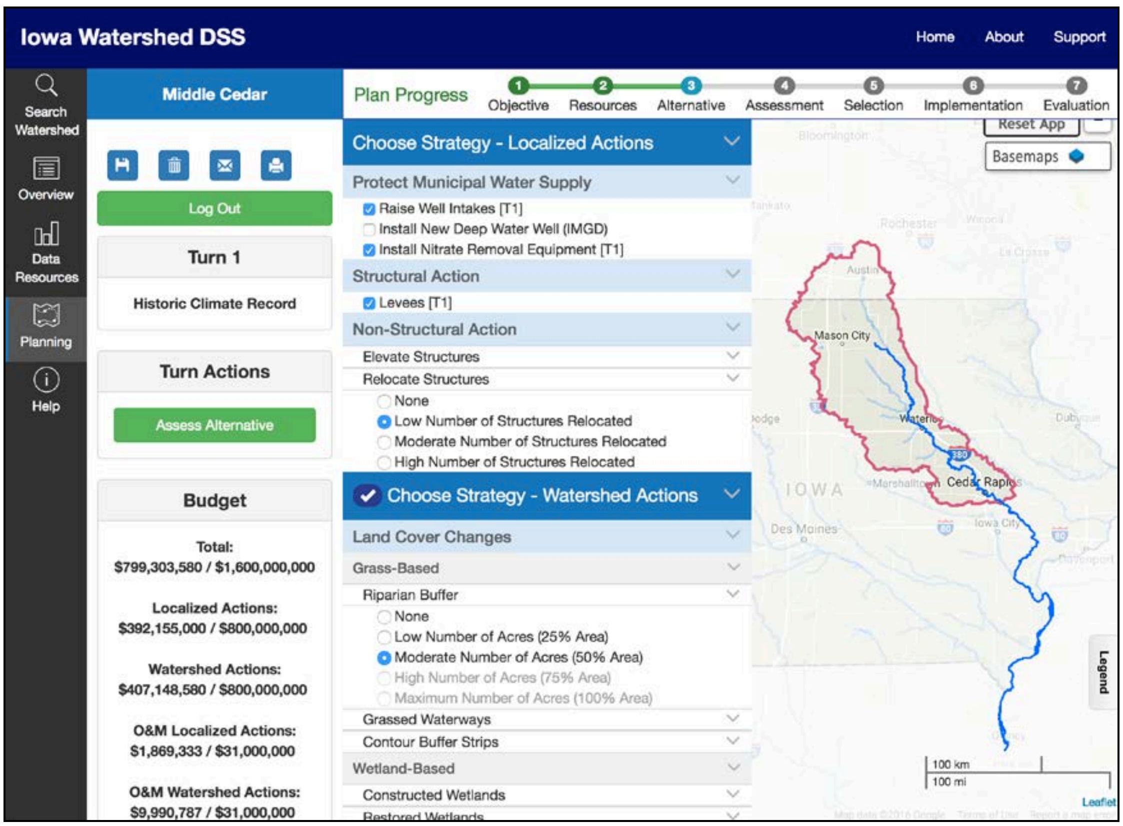

Figure 9. The interface for the "Alternative" step (#4) of the Planning workflow

12. IoWaDSS Prototype deployment.

The IoWaDSS protype was used for the delivery of a Multi-Hazard Tournament (MHT) organized by the US Army Corps of Engineers' Institute for Water Resources in the state of Iowa. The MHT was designed to be delivered in a game-like environment that promotes social learning through teams playing out potential adaptation strategies to reduce drought and flood risk while addressing water quality issues. The MHT was held on September 1, 2016, in Cedar Rapids, Iowa, with the support of the City of Cedar Rapids. The workshop participants entailed water resources management stakeholders from federal, state, and local agencies as players within teams (see Figure 10).

Figure 1. The Multi-Hazard Tournament participants are discussing watershed management strategies with their team members during the game in Cedar Rapids on September 1, 2016.

13. Principal Findings and Significance

The IoWaDSS user-friendly interfaces allowed the teams to consider holistic and systematic approaches to deal with water-related hazards by enabling players to share their knowledge and the local perspectives on the issues in a manner that they have not experienced before. According to a post-tournament survey, 71% of the participants were favorable to the idea of using the tournament results to inform future decisions. For this purpose, participants have been given permanent access to the decision support tool (http://iowawatersheds.org/dss/tournament) so they can go back and examine each team's choices, plans and outcomes to continue informing decisions going forward. The large team of federal and local agencies involved in developing and delivering the tournament will be checking back with participants in the upcoming months to see exactly how the tournament changed their approach to reducing risks from flood, drought and water quality.

14. Publications associated with the project

1. Xu, H., Hameed, H., Windsor, M., Muste, M., Demir, I., Smith, J., Hunemuller, T., Stevenson, M. B. (2017). Decision-support System for Underpinning Collaborative Planning for Multi-hazard Mitigation," Proceeding 37th IAHR World Congress, August 13-18, 2017; Kuala Lumpur, Malaysia.
2. Xu, H., Hameed, H., Windsor, Smith, J., Hunemuller, T., M., Muste, M., Demir, I., Stevenson, M. B. (2017). "An Iowa Prototype for a Generic Watershed Decision Support System," 11th Annual Iowa Water Conference, March 22-23, 2017, Ames, IA.
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4. Muste, M., Smith, J., Demir, I., Carson, A. (2017). "Serious Gaming for Community Engagement in Multi-Hazard Mitigation" Hydrolink, International Association of Hydro-Environment Engineering and Research, Madrid (IAHR), Spain
5. Three more journal papers are currently under preparation with two of them at the 80% completion degree.

15. Student Support

The number of students supported by this grant, their educational level (undergrad, masters, PhD, etc.), and their field of study

1 PhD student in Civil and Environmental Engineering: Haowen Xu

2 MS students in Computer Science: Haider Hameed and Mary Windsor

16. Achievements & Awards

A brief description of any especially notable achievements and awards resulting from work supported by this grant

1. As a direct follow up of the successful IoWaDSS prototype development and delivery, IWR contracted a new DSS for the Texas MHT to be organized in June 20-22, 2017.

2. Paper cited below was awarded with the Best Student Oral Presentation for Haowen Xu at the American Water Resources Association Conference:

   Xu, H., Hameed, H., Demir, I., Muste, M. (2016). Visualization Platform for Collaborative Modelling, 2016 AWRA Summer Specialty Conference - GIS and Water Resources IX, American Water Resources Association, July 11-13, 2016, Sacramento, CA.

Evaluation of subsurface drainage on P losses in the Black Hawk Lake Watershed, Iowa

Basic Information

Title:	Evaluation of subsurface drainage on P losses in the Black Hawk Lake Watershed, Iowa
Project Number:	2016IA266B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	IA-004
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Water Quality
Descriptors:	None
Principal Investigators:	Conrad brendel, Michelle Soupir

Publication

1. Brendel, Conrad E. Evaluation of Subsurface Drainage on Phosphorus Losses and Application of the SoilIceDB Model in the Black Hawk Lake Watershed, Iowa. Thesis. Iowa State University, 2017

3/1/16-2/28/17 Progress Report: Evaluation of subsurface drainage on P losses in the Black Hawk Lake Watershed, Iowa

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Abstract

Nutrient enrichment is a critical issue affecting Iowa surface water bodies. The Upper Midwestern United States is heavily drained and subsurface drainage provides a direct pathway for nutrients to enter surface waters. Nitrogen is typically the focus of research on nutrients in drainage; however, current research has shown that drainage can be a significant source of phosphorous loading as well. The goal of the project was to evaluate the impact of subsurface drainage on P concentrations in surface waters. Objectives of the study were (1) to determine intra-event contributions of different P pathways and (2) apply the SoilIceDB phosphorous model to Iowa agricultural watersheds. SoilIceDB is a system which runs the ICECREAMDB model on the SOIL model output. The SOIL model calculates one dimensional water and heat dynamics in the soil profile while ICECREAMDB is a graphical front-end for the ICECREAM model that also includes options to structure outputs. ICECREAMDB is a management oriented phosphorus loss model that quantifies runoff, erosion, and P losses at the field scale and has the capability to simulate phosphorus losses through drainage systems. Water quality monitoring and model simulations were conducted on the Black Hawk Lake watershed located in Carroll and Sac counties in Iowa. The Black Hawk Lake watershed was selected for this study because its three unique monitoring locations allow comparison of overland surface flow to tile flow water quality. Results of the project include an intra-event analysis of total phosphorus and dissolved reactive phosphorus concentrations in grass waterway, surface runoff, and tile flow and testing of a new model for predicting phosphorous in tiles, SoilIceDB, in the heavily drained Iowa landscape.

1. Problem and Research Objectives

Nutrient enrichment is a major water quality concern in Iowa. Of the 225 impairments in 118 lake/reservoir bodies listed on the 2014 Iowa 303(d) report 64 of the impairments are due to algae and 53 are due to turbidity, both of which can be indicators excessive phosphorus in a freshwater system. Subsurface drainage is one pathway in which nutrients enter surface waters. The focus of past research in nutrients in drainage has typically been on NO3-N; however, current research has shown that drainage can be a significant source of phosphorus loading as well. Based on the current research regarding phosphorus in tiles, there is a need for case studies to determine the pathways and contributions of P entering surface waters. In addition, there is a need to evaluate the performance of established best management practices (BMPs) on nutrient load reduction in agricultural areas. Finally, the use of predictive models could help for developing management plans and prioritizing areas where management practices are needed

The goal of this study was to evaluate the impact of subsurface drainage on P concentrations in surface waters. Objectives were:

1. Determine intra-event concentrations of different P pathways
2. Apply P model SoilIceDB to Iowa agricultural watersheds

2. Methodology

The Black Hawk Lake Watershed is located in Carroll and Sac Counties, Iowa. It has a drainage area of 13,156 acres (excluding the lake) and landuse distribution of 52.7% corn, 21.9% soybeans, 6.7% grass/hay/pasture, 5.8% water/wetland (excluding the lake), 1.9% timber, and 11% other. Monitoring occurred at three surface runoff sites (Subwatersheds 8, 11, & 12) and two tile outlet sites (Subwatersheds 8 &12) as shown in Figure 1. Intra-event samples were collected using ISCO 6700-Series automated samplers. In addition, flow, level, and velocity data were measured at all sites using ISCO 750 Area Velocity Flow Modules or ISCO 720 Pressure Transducer Modules. ISCO 674 Rain Gauges were installed at each subwatershed to obtain precipitation data.

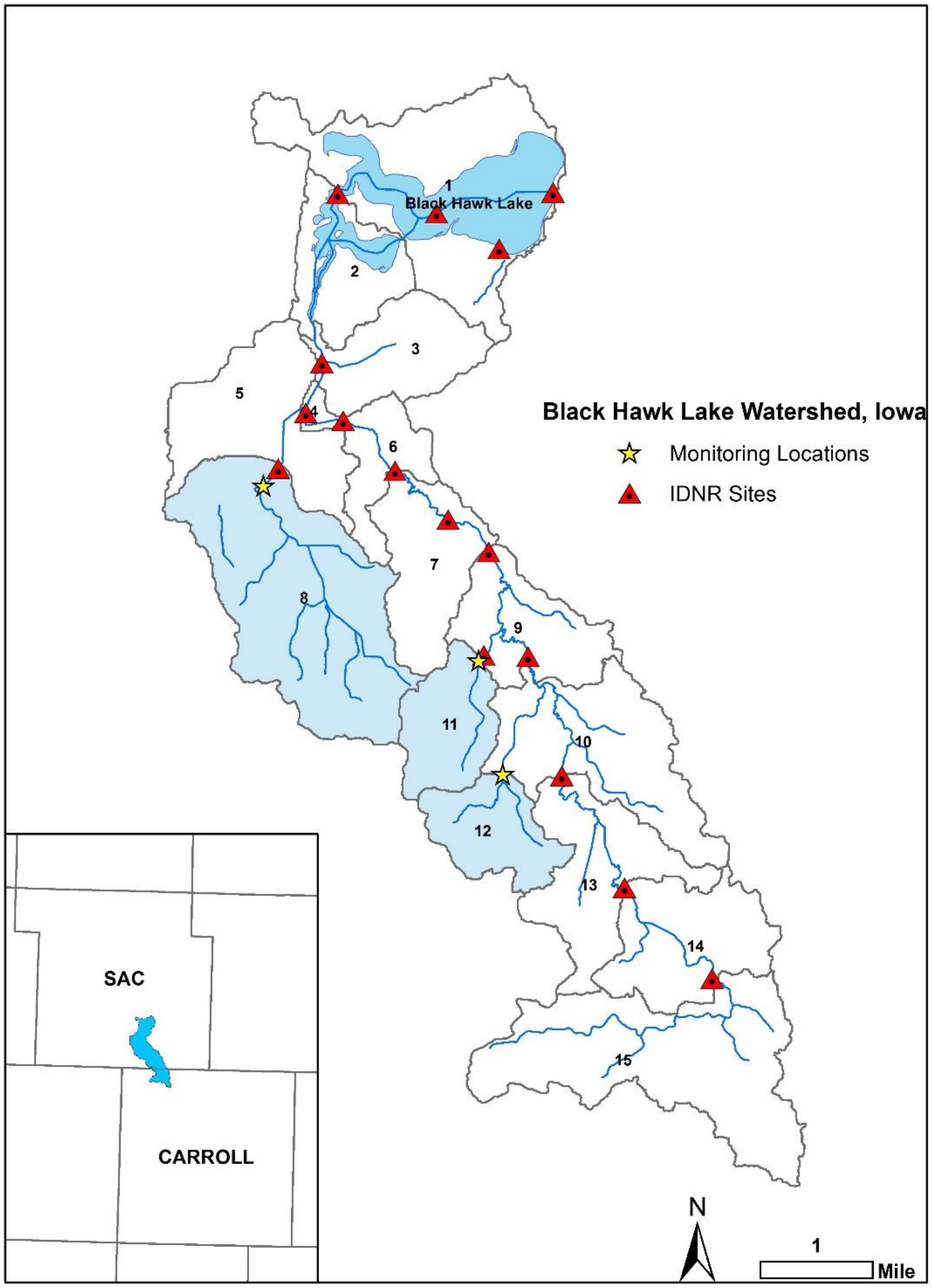

Figure 1: ISU and IDNR Monitoring Locations in Black Hawk Lake Subwatersheds

Subwatershed 8 has an area of 822.49 ha and is extensively tile drained. BMP implementation only occurs over 22.5% of the subwatershed and consists of terraces, grassed waterways, and nutrient management plans. Subwatersheds 11 and 12 are of similar size; subwatershed 11 is 229.44 ha versus 221.23 ha for subwatershed 12. However, fewer BMPs have been implemented in subwatershed 11; no till, nutrient management plans, cover crops, and terracing have been implemented in the western part of subwatershed 11 but only cover 30.0% of the subwatershed area. In subwatershed 12, terraces, CRP filters, no till, and nutrient management plans have been implemented over 87.5% of the subwatershed area. Subwatershed 12 also contains a segment of drainage district tile.

The three unique monitoring locations within the Black Hawk Lake Watershed were advantageous for evaluating the impact of drainage on P. The monitoring location at subwatershed 8 is a grass waterway adjacent to a tile outlet which enabled the comparison of overland surface flow to tile flow water quality. The monitoring location at subwatershed 12 is a stream adjacent to a tile outlet which enabled the comparison of stream flow to tile flow water quality. Since subwatersheds 11 and 12 are similar except for BMP implementation, a comparison of water quality and BMPs could be made. Finally, downstream IDNR monitoring data (locations marked in Figure 1) could be used to make upstream vs. downstream water quality comparisons.

Objective 1: Determine intra-event contributions of different P pathways

In 2016, intra-event samples were collected every four hours during precipitation events occurring on April 19th and April 27th and every three hours during events occurring on April 30th and June 14th. The intra-event samples from the four 2016 events were analyzed for total phosphorus (TP), total suspended solids (TSS), and Total Dissolved Phosphorus (TDP). Total Particulate Phosphorus (TPP) was calculated as the difference between the TP and TDP concentrations.

Linear regression analyses were performed between flow and intra-event TP, TDP, TPP, and TSS concentrations for all five BHL monitoring sites. Furthermore, an analysis of variance (ANOVA) was performed to identify any significant differences between the peak intra-event analyte concentrations at the five BHL monitoring sites or at the three surface sites (S8, S11, & S12) versus the two tile sites (T8 & T12). Differences were considered significant for *p*-values less than or equal to 0.05.

Objective 2: Apply P model SoilIceDB to Iowa agricultural watersheds

The SoilIceDB model was used to simulate flow and DRP, TP, and TSS losses from the tile outlets in subwatersheds 8 and 12. Simulations were run for 2008-2016 so there would be a 7-year spin-up period before the model was evaluated against the 2015 and 2016 observed data. Simulation results were summarized at the daily, monthly, and yearly timescales.

To evaluate the SoilIceDB model performance, Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS) analyses were conducted on the daily, monthly, and yearly simulated flow and DRP, TP, and TSS losses. Since BHL samples were not collected every day, the daily NSE and PBIAS analyses only compared the losses for each measured sample to the simulated losses for the day the sample was taken. The measured monthly losses were assumed to be the difference between the cumulative loss for the last sample collected during the month and the cumulative loss for the last sample collected during the previous month. Finally, the yearly simulated losses were calculated as the sum of the simulated losses for each of the months in the March-November monitoring period.

3. Objective 1 Principal Findings and Significance

Analyte concentrations were measured from each intra-event sample collected during the April 19th, April 27th, April 30th, and June 14th events in 2016. Time series of flow vs. analyte concentrations at each monitoring location were produced for each of the four events and similar trends were observed. Time series for the April 30th event are provided (Figures 2 & 3) because it was the only event in which an event response was observed at each of the five monitoring locations.

During the events, TP, TDP, and TPP concentrations typically followed the flow trends and peak analyte concentrations coincided with peaks in the hydrograph. At the grassed waterway (S8) and the two stream (S11 & S12) monitoring locations, strong, positive correlations were observed between analyte concentrations and flow; adjusted r^2 values ranged from 0.71-0.82 for TP, 0.59-0.87 for TDP, and 0.54-0.70 for TPP. During the events, flow did not decrease after peaking at both of the tile locations, indicating that the soil has reached its infiltration capacity. Peaks in the tile sample analyte concentrations coincided with peaks in the hydrograph. However, analyte concentrations decreased after peaking despite the elevated tile flow. Subsequently, correlations between analyte concentrations and flow at the tile locations (T8 & T12) were weaker than those observed at the surface sites; adjusted r^2 values ranged from 0.15-0.33 for TP, 0.24-0.28 for TDP, and 0.01-0.28 for TPP. From the ANOVA results, no significant differences were identified between intra-event peak TP or TPP concentrations at the five sites. However, the peak TDP concentrations at the grassed waterway were significantly higher (p=0.0313) than those at the other four sites. Overall, the intra-event time-series imply that flow is the driving force behind event analyte concentrations and that the analytes are flushed through the drainage system.

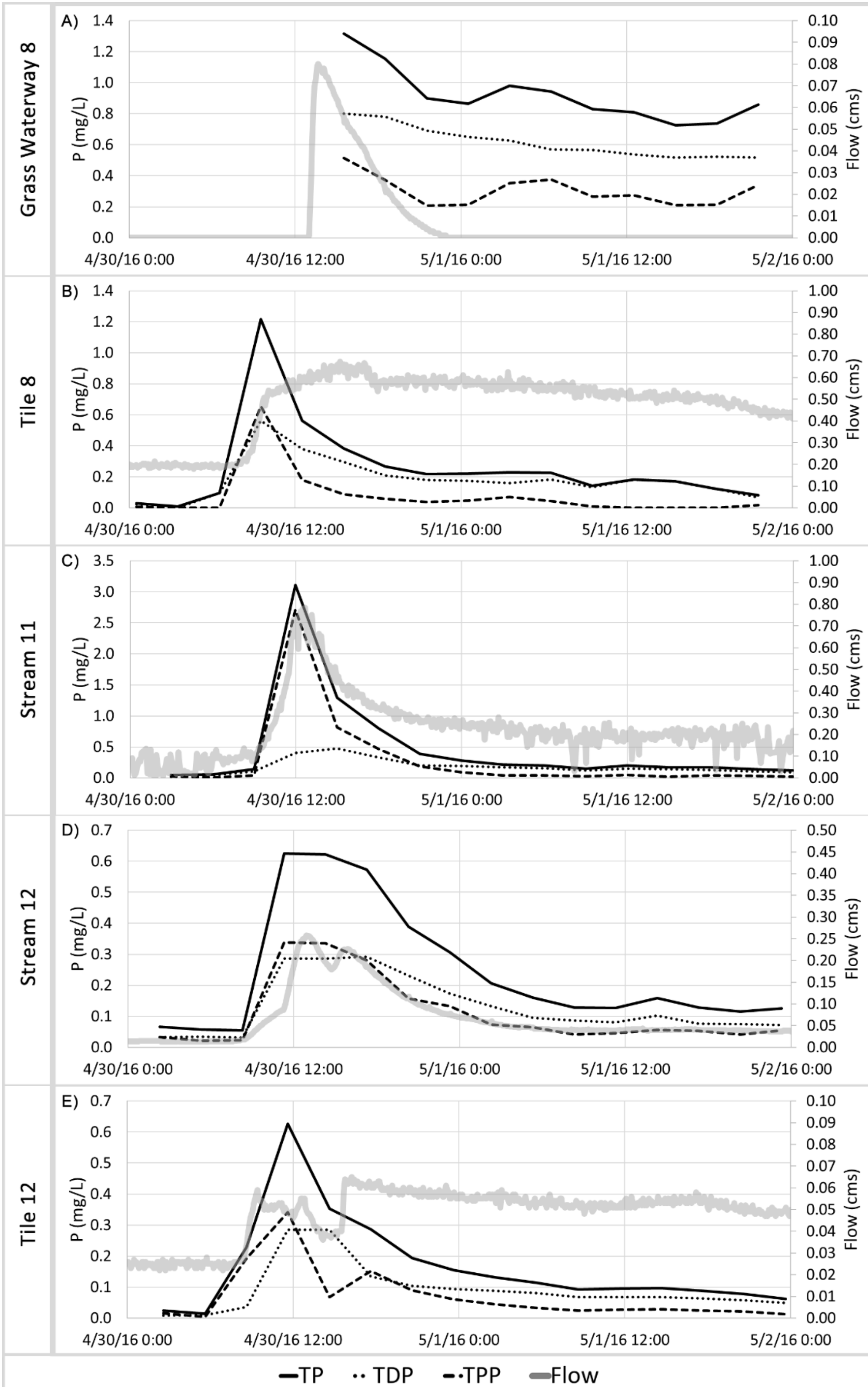

Figure 2: Flow and intra-event concentrations of total phosphorus (TP), total dissolved phosphorus (TDP), and total particulate phosphorus (TPP) during event on 4/30/16 at the (A) grassed waterway and (B) tile in subwatershed 8, (C) stream in subwatershed 11, and (D) stream and (E) tile in subwatershed 12.

The intra-event samples were also analyzed for TSS for each of the four events. At the two stream and the two tile monitoring locations, peaks in TSS concentrations coincided with peaks in the hydrograph. At the grassed waterway, however, TSS concentrations remained high at the end of the hydrograph. After peaking, tile TSS concentrations decreased despite continued elevated flow. Consequently, correlations between TSS concentration and flow were strong at the stream sites (adj. r^2=0.46-0.60) and weak at the tile outlets (adj. r^2=-0.05-0.18) and the grassed waterway (adj. r^2 = -0.07). No significant differences were identified between the peak TSS concentrations between the five sites (p=0.2245). Correlations between intra-event TPP and TSS concentrations were strong at the stream sites (adj. r^2=0.92-0.97) and the tile outlets (adj. r^2=0.89-0.97) but low at the grassed waterway (adj. r^2=0.02). During the April 27th, April 30th, and June 14th events, TPP concentrations exceeded those of TDP during the rising limb of the hydrograph but TPP concentrations were less than TDP concentrations during the falling limb of the hydrograph. These results indicate that initial P losses during events is particulate associated and that drainage is also an important pathway in suspended solids transport.

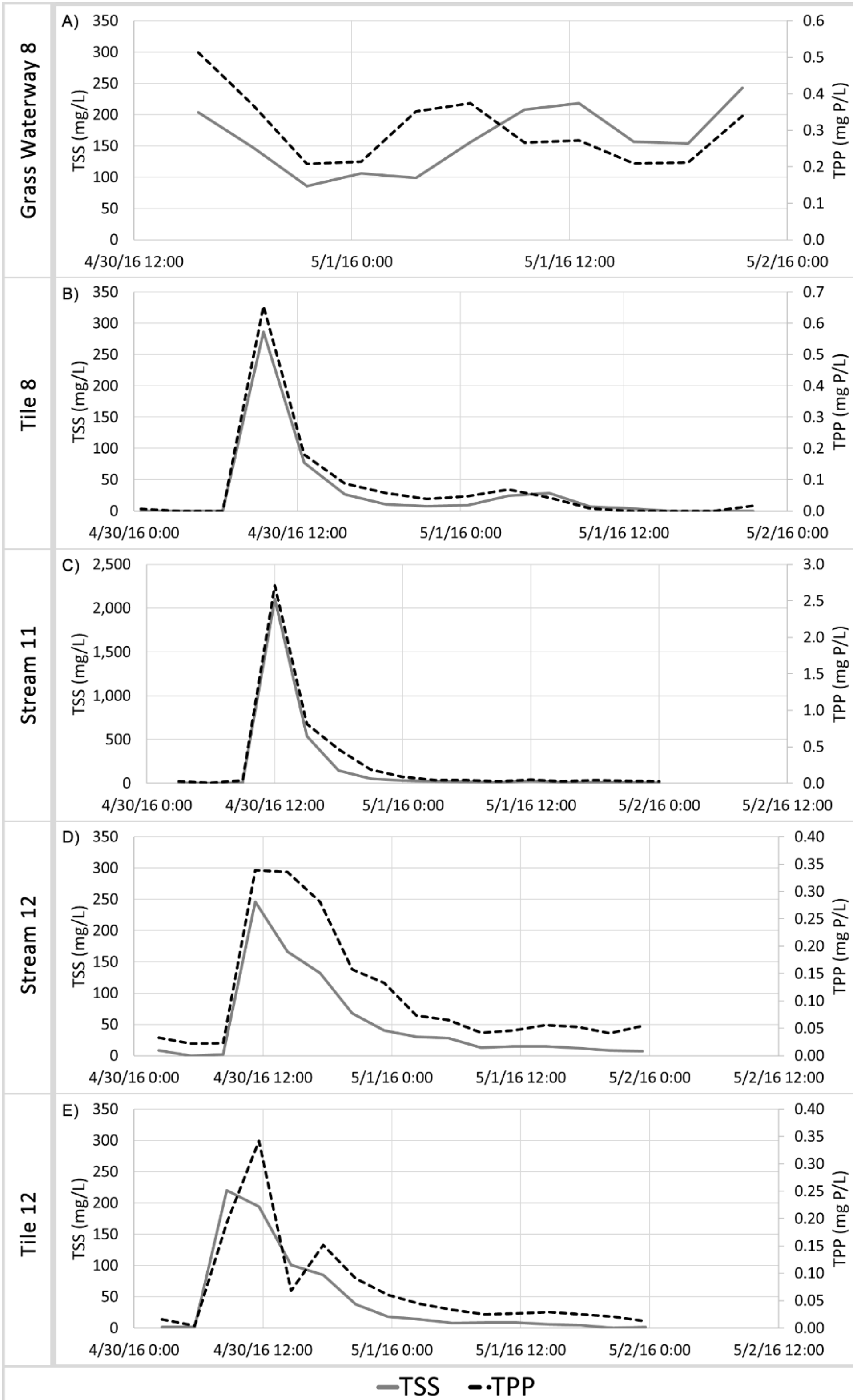

Figure 3: Intra-event concentrations of total suspended solids (TSS) and total particulate phosphorus (TPP) during event on 4/30/16 at the (A) grassed waterway and (B) tile in subwatershed 8, (C) stream in subwatershed 11, and (D) stream and (E) tile in subwatershed 12.

4. Objective 2 Principal Findings and Significance

In order to develop baseline results on the SoilIceDB model performance, the model was setup with Iowa input data but run with default parameters developed for Sweden. The model was used to simulate the flow and DRP, TP, and TSS losses at the two tile outlets and the model evaluation statistics are summarized in Table 1. Simulated flow was not analyzed at the daily timestep because the ISCO sampler software does not provide an option to summarize flow data at the daily timescale.

Table 1: SoilIceDB Model Evaluation Statistics

Flow						
Site	**T8**			**T12**		
Timescale	**Day**	**Month**	**Year**	**Day**	**Month**	**Year**
NSE	N/A	-1.0	-0.4	N/A	-1.9	-0.2
PBIAS	N/A	-105.3	-105.3	N/A	-128.9	-128.9
DRP						
Site	**T8**			**T12**		
Timescale	**Day**	**Month**	**Year**	**Day**	**Month**	**Year**
NSE	-0.2	-0.1	-1.9	-0.2	-8.7	-0.4
PBIAS	94.1	37.9	82.7	76.5	-206.9	11.3
TP						
Site	**T8**			**T12**		
Timescale	**Day**	**Month**	**Year**	**Day**	**Month**	**Year**
NSE	-1.1	-15.2	-706637.9	-26.3	-1296.2	-2.31E+10
PBIAS	69.5	-173.8	-36683.0	-57.8	-1715.8	-238102.5
TSS						
Site	**T8**			**T12**		
Timescale	**Day**	**Month**	**Year**	**Day**	**Month**	**Year**
NSE	-39.6	-3661.1	-458.7	-5.3	-59087.3	-29337.4
PBIAS	-101.2	-5619.9	-835.2	33.3	-11612.3	-2719.6

Based on the NSE and PBIAS analyses, the model failed to acceptably simulate flow, DRP, TP, or TSS at either site or timescale. The model typically overestimated the drainage flow and peaks in the measured and simulated flow did not always coincide. The model also overestimated the TP and TSS losses at the tile outlets. Overall, the model was best at simulating DRP losses. Peaks in the simulated DRP loss time series generally coincided with peaks in the observed time series, but the model underestimated the magnitude of the peaks.

Although neither of the SoilIceDB simulations produced acceptable results, the low magnitude of the NSE values for the flow and DRP simulations provide optimism that the model can be adapted to work on cropland outside of Scandinavia.

5. Notable Achievements/Awards

Brendel defended his Master's thesis entitled "Evaluation of subsurface drainage on phosphorus losses and application of the SoilIceDB model in the Black Hawk Lake Watershed, Iowa" on 4/11/17. Brendel's thesis included the intra-event P analysis as well as a preliminary evaluation of the SoilIceDB model from this project. Brendel was accepted to a PhD program in Civil Engineering at Virginia Tech and will continue his water quality research while focusing on urban BMPs.

6. Publication Citations

Brendel, Conrad E. *Evaluation of Subsurface Drainage on Phosphorus Losses and Application of the SoilIceDB Model in the Black Hawk Lake Watershed, Iowa*. Thesis. Iowa State University, 2017

Brendel and Soupir will reformat Brendel's thesis as a manuscript and will submit it for publication at a peer-reviewed journal during summer of 2017.

The role of iron mobility from anoxic sediments in stimulating harmful algal blooms

Basic Information

Title:	The role of iron mobility from anoxic sediments in stimulating harmful algal blooms
Project Number:	2016IA267B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	IA-004
Research Category:	Biological Sciences
Focus Category:	Geochemical Processes, Nutrients, Water Quality
Descriptors:	None
Principal Investigators:	Elizabeth Swanner

Publications

There are no publications.

1. **Problem and Research Objectives**
   a. Harmful Algal Blooms (HABs) at Iowa beaches caused a historic record number of beach closures (25 as of August 14, 2015) by the Iowa Department of Natural Resources (DNR). HABs in Iowa are primarily mediated by cyanobacteria (commonly referred to as "blue-green algae") that release toxins, such as microcystin, anatoxin, and saxotoxin, which can sicken or be deadly to people and animals. We will investigate the role of iron release by anoxic sediments in fueling HABs in Iowa's shallow and high-nutrient lakes. Our work will characterize the iron-releasing capacity of lake sediments, iron concentrations in lake water during blooms, and the evolving phytoplankton composition in waters that might receive iron inputs. This work will take place at Iowa's Great Lakes (West and East Lake Okoboji), utilizing the Iowa Lakeside Laboratory Regent's Resource Center (ILLRRC).
   Commonly accepted explanations for why HABs occur in lakes generally identify low nitrogen to phosphorus (N:P) ratios. The growth of cyanobacteria, which are the main mediators of HABs in lakes, are thought to be regulated by the availability of phosphorus. The availability of nitrogen in a biologically-usable form can also stimulate algal growth, but many cyanobacteria are capable of fixing their own atmospheric nitrogen. Therefore, low nitrogen but high phosphorus contents are thought to select for cyanobacteria relative to other algae. However, the occurrence of HABs does not necessarily correlate to the low N:P lakes (which would indicate that phosphorus controls HABs), but rather high total nitrogen and phosphorus.
   As the amount of organic carbon deposited to Iowa's lakes' sediments has increased in the past 150 years, and microbial breakdown of this organic carbon consumes oxygen, we are wonder whether the resulting anoxic bottom waters and sediments promote microbial reduction of iron. Reduction of iron releases mobile ferrous iron [Fe(II)], which can diffuse out of sediments into the water column. Cyanobacteria have a much higher requirement for iron relative to eukaryotic phytoplankton. Several studies have noted a linkage between the availability of iron in the water column and the growth of cyanobacteria. Therefore, we suggest iron availability could be a positive feedback, worsening HABs in already bloom-prone lakes.
   b. Our hypothesis is that Fe(II) fluxes will increase from the sediments throughout the summer, corresponding to the onset of HABs. We anticipate that shallow lakes and/or shallow sites will be most affected, because the sedimentary source of iron is proximal to the photic zone, where HABs form. We hypothesize that increasing anoxia through the summer will correspond to a shift from eukaryotic algae (e.g. diatoms, green algae, etc.) to cyanobacteria. East Lake Okoboji is relatively shallow (mean depth 10 feet) and has had HABs and beach closures in recent years. West Lake Okoboji, with a mean depth of 38 feet, has had less

severe HABs. These two lakes provide natural positive and negative controls for our investigation. As part of this, our objectives are:

i. Determine whether water column iron concentrations correlate with the presence and abundance of cyanobacteria and HABs and the absence of eukaryotic phytoplankton in a way that is distinct from the influence of P.
ii. Determine the potential of sediments to release iron, and quantify Fe fluxes.

2. Methodology

a. The first major method is track the composition of major algal taxa at our sites throughout the summer season using multi-wavelength fluorometry. This technique can separate fluorescence signals from cyanobacteria, green algae, diatoms/dinoflagellates, and phycoerythrin-containing algae, meaning that we can determine the amount of chlorophyll (which is related to biomass) of each of these types of algae in a sample. We propose that this rapid screening method will allow us to track the algal composition throughout the summer, and identify when potentially harmful cyanobacteria are becoming dominant (e.g. higher likelihood of HABs).
b. The second major method is to determine the aqueous iron concentrations in the porewater of sediment cores using voltammetric microelectrodes. For this, we collect sediment cores from sites of varying depths and severity of HABs in East and West Okoboji lakes. From the aqueous iron profiles we collect, we expect to calculate fluxes of iron from sediments. We will also measure dissolved iron in the water column at the different sites, to determine if iron reaches the photic zone. Nitrogen (ammonium, nitrate and phosphate) will also be measured, as well as dissolved oxygen and light penetration depth.

3. Principal Findings and Significance for the project year 3/1/16-2/28/17

a. We performed our first fieldwork in September 2016. Parameters collected for four different sampling localities (two in East and two in West Lake Okoboji) were Secchi disk depth and oxygen concentration-depth profiles. We noted that oxygen disappeared above sediments at shallow sites, including Site 2 (17 ft; *Fig. 1b*), which should promote iron reduction in these sediments. However we could not detect oxygen disappearance at our deep site (55 ft; data not shown), although we had only 50 ft of cable on our oxygen sensor.
b. We collected and analyzed surface water samples from the four sites for characterization of the phytoplankton community with traditional optical microscopy and multi-wavelength fluorometry (using a demo Phyto-PAM II). We identified major algal classes in samples from 3 of the 4 sites as part of our participation in the Phycological Research Symposium at ILLRRC in September 2016 (*Fig. 1a*), which do not match well to our uncalibrated fluorometry measurements (data not shown). However, we

are using our microscopic observations to identify which phytoplankton groups should be used to make reference measurements on the fluorometer. We are currently making these reference measurements, and can apply them to our existing data from September 2016.

c. We analyzed two sediment cores for porewater Fe(II). The first was collected from our deep (55 ft) site in West Lake Okoboji (*Fig.1*), where we did not detect anoxic bottom waters. We als did not detect Fe(II) within the sediment core, but did detect oxygen (data not shown). The second core was from a Site 2 in East Lake Okoboji (*Fig. 1*), with a water depth of 17 ft, where oxygen was absent in the bottom waters (*Fig. 1b*). The porewaters of this sediment were anoxic and we were able to detect Fe(II) with our voltammetric method (*Fig. 1c* and *1d*). We did not have a calibration to convert our detection of Fe(II) in units of nanoamps (nA) to molar values, but have now performed this calibration. This can then be applied to previously collected data to determine the Fe(II) concentrations in the core (see sec. 3g).
d. We analyzed several water samples from depths below each of the four sites for dissolved Fe. The dissolved Fe measurements were higher from Site 2 (*Fig. 1b*), where we detected Fe(II) in sedimentary porewaters, than at Site 4, where we did not detect Fe(II) in porewaters.
e. PhD student Tania Leung (see 5a) analyzed water samples for orthophosphate and total phosphate, as well as nitrate and ammonium. We realized the detection limits for many of these species were too high in our laboratory, so we submitted samples to ISU's Soil and Plant Analysis Laboratory, and made a plan for utilizing this laboratory for relevant samples in the future. We saw ammonium generally near the bottom of the lake at several sites, which is expected given that it is sourced from remineralization of nitrogen in decaying organic matter. We saw nitrate in shallow, near-shore samples, likely due to supply from runoff from nearby agricultural fields. We detected phosphate in all samples at ppb (for orthophosphate) or low ppm (for total phosphate) levels.
f. The Phyto-PAM II Instrument (Walz GmbH) was purchased and arrived in the lab in December 2017. Much time this winter has been devoted to familiarizing ourselves with the instrument and establishing a protocol for use in our Summer 2017 field campaign.
g. PhD student Tania Leung (see 5a) learned how to construct, polish and plate, and operate the microelectrodes. She completed a calibration for Fe(II) in the anoxic glovebox so that we can extract this data from past and future analyses of sediment cores.
h. PhD student Tania Leung (see 5a) performed microscopy on water samples collected in September 2016 to identify major algal taxa present, and received training in phycological identification from members of Prof. Beth Caissie's [GEAT] research group, and through an online course taken in identifying aquatic organisms in Spring 2017.

4. Any notable achievements or awards resulting from work on this project

a. PI Swanner developed a workshop on nutrients in surface waters with undergraduate Megan Greenlee in the Spring of 2016, as part of the First Year Honors Program at ISU. Megan presented this workshop over 2 days as part of ISU Extension's Iowa 4H Youth Conference in June 2016. Swanner presented part of this workshop to 8th grade Iowa girls visiting ISU as part of the Program for Women in Science in Engineering (WiSE) in October 2016.
b. We presented our work informally at the Phycological Research Symposium meeting in September 2016 at Lakeside Laboratory.
c. PI Swanner received a second year of IWC funding to extend this project one year, as part of the 2016 call on Harmful Algal Blooms.
d. PI Swanner submitted a collaborative proposal to the Freshwater Harmful Algal Blooms, EPA-G2017-STAR-A1 call in January 2017 in collaboration with Prof. Adina Howe [ABE], Prof. Kaoru Ikura [CCE E] and Dr. Jin Choi [ABE]. Swanner's part of the proposal follows up on techniques developed using the Phyto-PAM II within the IWC project for tracking algal composition of lakes prone to HABs.

5. **Student support provided by the project (please include student level (i.e. undergrad, masters, phd, or post-doc))**
   a. Tania Leung is a PhD student who started in the Geology Graduate Program at ISU in August 2017. Prof. Elizabeth Swanner is her primary advisor. Tania holds dual bachelor degrees in Biology and Geology from Florida Atlantic University, as well as a master's degree in Geology from Florida Atlantic University in 2016. Tania's salary is supported by the IWC grant for Spring and part of Summer 2017.
   b. We received match funding from ISU's College of Liberal Arts and Sciences to fund an undergraduate researcher for summer 2017 fieldwork.
6. **Publication citations associated with the project**
   a. None to date.

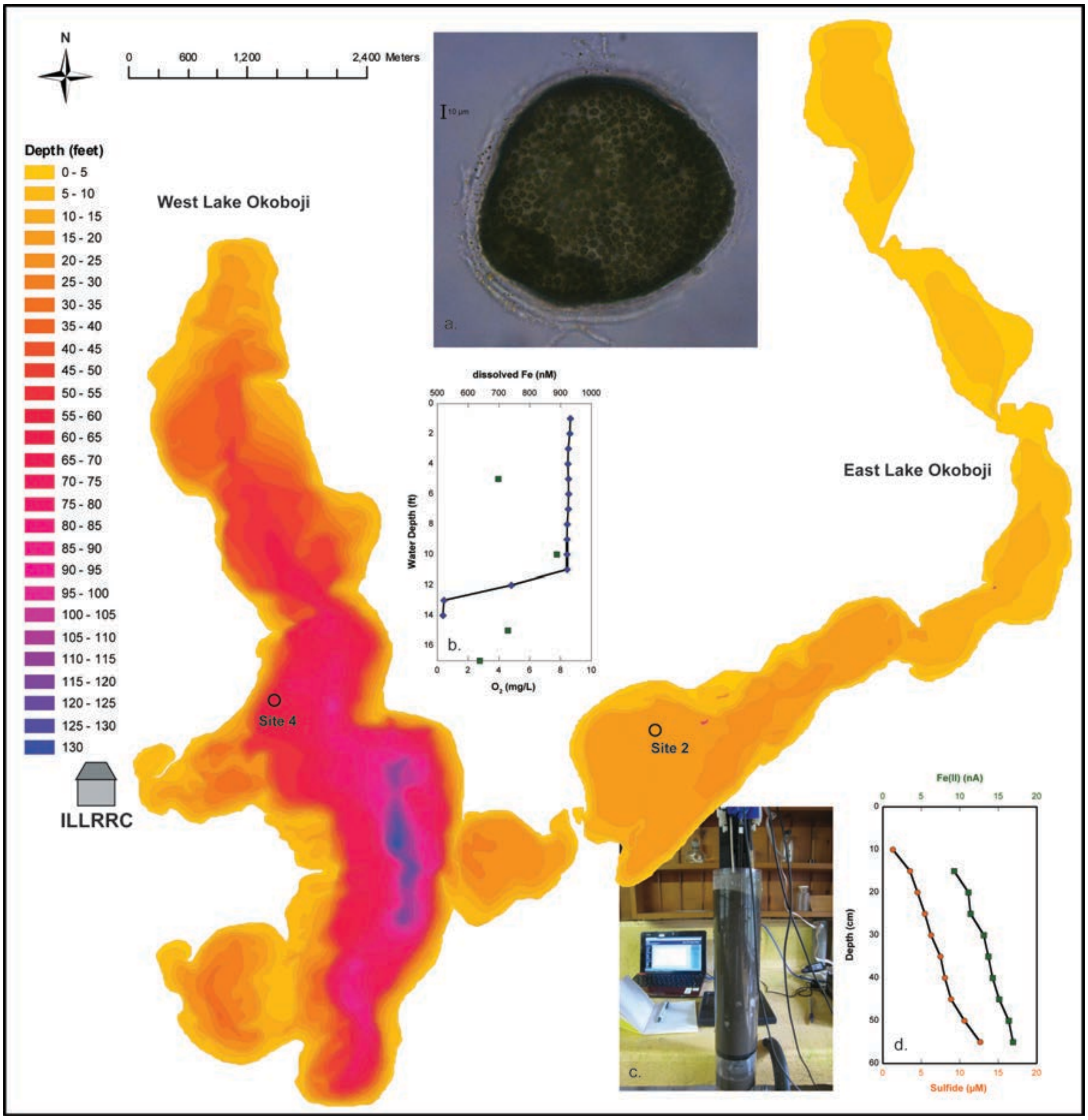

Figure 1. Bathymetric map of East and West Okoboji Lakes, showing the location of the ILLRRC. Sites 2 (17 ft water depth) and 4 (55 ft) were sampled in September 2016. a. Site 2 had abundant *Microsystis* sp., a toxin-producing cyanobacteria. b. Dissolved oxygen was depleted in the bottom waters of Site 2, which had >500 nM dissolved Fe in the water column. c. A sediment core from Site 2 was analyzed at ILLRRC with voltammetric microelectrodes. d. Results from this data document that Fe(II) is present in the porewaters of the Site 2 sediment core. Oxygen depletion was not detected in the water column of Site 4, nor was Fe(II) present in sediment porewaters (data not shown).

Information Transfer Program Introduction

Program Coordinator Melissa Miller began her fifth year at the Center, allowing for continued growth in the Information Transfer program. In August 2016, Hanna Bates was hired as the Program Assistant for the Center.

Information Transfer 2016

Basic Information

Title:	Information Transfer 2016
Project Number:	2016IA264B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	IA-004
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Richard Cruse, Melissa S Miller, Hanna Bates

Publications

There are no publications.

2016-2017 Iowa Water Center Information Transfer Project

The Iowa Water Center (IWC) places great importance on the Information Transfer aspect of its 104(b) program. Information Transfer activities achieve multiple goals for IWC: inform consumers about water related issues and research; connect researchers to complementing projects and facilitate collaboration; publicize IWC and its programs and products; and publicize and promote the Water Resources Research Institute Program and U.S. Geological Survey. IWC staff spends a significant portion of their time devoted to organizing, supporting and attending multiple education and outreach activities throughout the year. In addition to events, IWC staff prioritizes maintaining an effect web and social media presence.

Iowa Water Conference

The predominant Iowa Water Center information transfer product is the Iowa Water Conference, which was held March 23-24, 2016. The 2016 event was the 10th annual occurrence and had a theme of "AtTENtion - EnlighTEN- InTENsify: TEN years of the Iowa Water Conference." The conference has enjoyed stable participation rates the past several years, with 485 attendees, 20 attendees at the optional workshop, 40 exhibitors, and 42 poster displays. Evaluations received were positive.

The Art of Water 2016

On March 23, 2016, the Iowa Water Center hosted a community event commemorating the 10th anniversary of the Iowa Water Conference. The goal of the even was to bring together arts and sciences through dance, music, and video to illustrate the story of one watershed in Iowa. The performance examined the importance of water and the challenges community members face in the Dry Run Creek Watershed in Decorah, Iowa. The event was presented in partnership with Luther College and garnered over $5,000 in cash and in-kind support. The event included a pre-performance gallery exhibit by Ames High School Bluestem Institute. An estimated 300 people attended the event.

Getting into Soil and Water

The 2016 edition of the publication Getting into Soil and Water, produced with the Soil and Water Conservation Club at Iowa State University, was released at the Iowa Water Conference in 2016. This 35-page publication contains articles from 17 authors, including IWC Director Rick Cruse along with representatives from all aspects of water in Iowa ranging from private industry to public research. It is available for download from http://www.water.iastate.edu/content/getting-soil-water. The 2016 publication was distributed to approximately 2000 individuals, including Iowa Water Conference attendees, high school science and vocational agriculture teachers, attendees of the 2016 Iowa Environmental Council annual conference, potential students to the Agronomy program at Iowa State University, and handed out at various conferences where IWC was an exhibitor.

Speaking engagements

Iowa Water Center Director Rick Cruse was invited to give several presentations during this reporting period, including:

Cruse, Rick. February 16, 2017. Soil Erosion: Leading Cause for Damaging Soil and Water Quality. 2017 Soil Health Conference. Ames, IA.

Cruse, Rick. February 8, 2017. Cost of Soil Erosion. Rendez-vous végétal 2017. Brossard, Québec, Canada

Cruse, Rick, Brian Gelder, David James, and Daryl Herzmann. January 11, 2017. Soil erosion: How much is occurring, when and where? Wisconsin Agribusiness Classic.Madison, WI. ~300 people attending

Cruse, Rick. January 11, 2017. Why conserving Wisconsin's soil and water resources is a global necessity. Wisconsin Agribusiness Classic. Madison, WI. ~ 250 people attending.

Cruse, Rick. December 13, 2016. Why sustaining soil and water resources is critical. Land O'Lakes SUSTAIN® Grower Recognition Meeting. Ft. Lauderdale, FL.

Cruse, Rick. October 7, 2016. Impact of Changing Intense Rainstorms on Soil Erosion. The 4th Annual Iowa Climate Science Educators Forum. Des Moines, IA

Cruse, Rick. September 26, 2016. Daily Erosion Project: A Nebraska connection. Nebraska Resources Annual Conference. Kearney, NB.

Cruse, Rick. July 26, 2016. Water quality: Why such a challenge? Arkansas Annual Water Conference. Fayetteville, AR.

Cruse, Richard. May 26, 2016. Daily Erosion Project (DEP): Estimating soil erosion and water runoff in near real time. 7th International Symposium on Gully Erosion. West Lafayette, IN

Cruse, Rick, Brian Gelder, Daryl Herzmann, and David James. May 24, 2016. Daily Erosion Project (DEP): Estimating statewide soil erosion and water runoff in near real time. International Symposium on Gully Erosion. West Lafayette, IN.

Cruse, Rick. April 15, 2016. Soil erosion: how much and what does it cost? The True Cost of American Food. San Francisco, CA.

Cruse, Rick. April 7, 2016. Soil and Water: Resources with decreasing life expectancy? Southern Illinois University. Carbondale, Il.

Cruse, Rick. March 31, 2016. Are Current Soil Erosion Rates Sustainable? Huron County Soil and Crop Improvement Association. Holmesville, Ontario, Canada

Cruse, Rick. March 9, 2016. Why Soil Health? Archers Daniel Midland. Ankeny, IA.

Cruse, Rick. March 9, 2016. Why Soil Health? Archers Daniel Midland. Albia, IA.

Cruse, Rick. March 8, 2016. Why Soil Health? Archers Daniel Midland. Atlantic, IA.

Cruse, Rick. March 1, 2016. Threats to Water Quality: What does the future hold? Iowa Chapter of the American Fisheries Society. Honey Creek Resort. Moravia, IA.

Iowa Water Center Program Assistant Hanna Bates was invited to give one presentation during this reporting period:

Bates, Hanna, Jim Gillespie, Chris Jones, Tim Smith. 2016. "Plate of the Union" Campus Challenge Panel discussion on Water Quality. October 4, 2016. Iowa State University: Ames, Iowa.

Conference planning, exhibiting, and attendance

The Iowa Water Center and its staff assisted in planning and/or exhibiting at various events during the reporting year. At each event, staff identified themselves as Water Center representatives and shared information about IWC and its products. These events include:

-Conservation Districts of Iowa Annual Conference (exhibitor); August 29-30, 2016; Altoona, IA.

-Iowa Environmental Council Annual Conference: ECOnomics: Dollars, Sense & Sustainability (exhibitor); October 6, 2016; Des Moines, IA.

-Iowa Soybean Association Research Conference (attendee); February 7-8, 2017; Des Moines, IA

-Dubuque Watershed Management Symposium 2017 (attendee). February 8-9, 2017; Dubuque, Iowa.

-Soil Health Conference (exhibitor); February 16-17, 2017; Ames, IA.

-Prairie Lakes Conference (core planning committee member); held August 10-11, 2016; Okoboji, IA.

IWC staff also attended various meetings throughout the year, including those of watershed organizations and for research projects.

Web presence

The Iowa Water Center recognizes the importance of an effective web presence. To that end, IWC maintained an engaging website, bi-monthly electronic newsletters, and social media accounts on Twitter and Facebook.

<u>Website</u>: During the reporting period, IWC had 6,606 unique visitors to the website (water.iastate.edu), an increase of nearly 42% from 2015-2016. The average session duration was 2:34 with average 2.54 pages viewed per session

<u>Blog</u>: During the reporting period, IWC had 1,145 visitors with 1,1856 views of the website (iawatercenter.wordpress.com).

<u>Newsletter</u>: Newsletters were released the 2nd and 4th Thursday of each month during the reporting period for a total of 24 newsletters. At the beginning of the reporting period, the newsletter had 187 subscribers with a 41.7% open rate and 12% click-through rate. The last newsletter in the reporting period had 220 subscribers with a 41.1% open rate and an 8% click-through rate.

<u>Twitter</u>: At the end of the reporting period, IWC’s Twitter account had 814 followers, gaining 229 followers throughout the year.

<u>Facebook</u>: IWC started the reporting period with 244 likes on Facebook and gained 66 likes during the year, ending at 310.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	1	0	0	0	1
Masters	1	0	0	0	1
Ph.D.	1	1	0	0	2
Post-Doc.	0	1	0	0	1
Total	3	2	0	0	5

Notable Awards and Achievements

For Muste's project: As a direct follow up of the successful IoWaDSS prototype development and delivery, IWR contracted a new DSS for the Texas MHT to be organized in June 20-22, 2017

For Muste's project: Paper cited below was awarded with the Best Student Oral Presentation for Haowen Xu at the American Water Resources Association Conference: Xu, H., Hameed, H., Demir, I., Muste, M. (2016). Visualization Platform for Collaborative Modelling, 2016 AWRA Summer Specialty Conference - GIS and Water Resources IX, American Water Resources Association, July 1113, 2016, Sacramento, CA.

Brendel defended his Master’s thesis entitled “Evaluation of subsurface drainage on phosphorus losses and application of the SoilIceDB model in the Black Hawk Lake Watershed, Iowa” on 4/11/17. Brendel’s thesis included the intra-event P analysis as well as a preliminary evaluation of the SoilIceDB model from this project. Brendel was accepted to a PhD program in Civil Engineering at Virginia Tech and will continue his water quality research while focusing on urban BMPs.

PI Swanner developed a workshop on nutrients in surface waters with undergraduate Megan Greenlee in the Spring of 2016, as part of the First Year Honors Program at ISU. Megan presented this workshop over 2 days as part of ISU Extension’s Iowa 4H Youth Conference in June 2016. Swanner presented part of this workshop to 8th grade Iowa girls visiting ISU as part of the Program for Women in Science in Engineering (WiSE) in October 2016.

PI Swanner received a second year of IWC funding to extend this project