Water Resources Center
Annual Technical Report
FY 2014

Introduction

During FY 2013 the Rhode Island Water Resources Center has supported two research grants and one information transfer project. The research project entitled, “Carbon-Based Renewable Hydrogel Nanocomposites for Water Purification,” by Samantha Meenach, involved developing and measuring an adsorption process for removing both anionic and cationic contaminants from wastewater. The second research grant, “Water Security, sustainability and Climate Impacts in Urban Regions,” by Ali Akanda investigated the impacts of climate on water quality and quantity. The information transfer project supported a Clean Water Conference and a summer Water Academy for middle and high school students. In addition to these activities, the Rhode Island Water Resources Center continued to partially support graduate and undergraduate students in research. This year, the Center added content to the revised the website (www.wrc.uri.edu) to include a video of the complete Clean Water Conference.

Research Program Introduction

The project, "Water Security, Sustainability, and Climate Impacts in Urban Regions," by Dr. Ali Akanda was funded by the RI Water Resources Center. In the developed world, many old cities are going through major urban renewal projects aimed at revitalizing aging infrastructure to meet the needs of changing demographics. A major problem in all of these urban regions of the world is to manage stormwater. Stormwater causes widespread damage to infrastructure, especially in lowlands and economically poor areas. This project consisted of the following tasks:

1. Compilation of a database of urban water quality and quantity indices in Providence, Lagos, and Dhaka with urban land use, water usage, climate, and socio-economic characteristics.

2. Identification of the impacts of climatic phenomena [Indian Ocean Dipole (IOD), Pacific North American (PNA), El Nino–Southern Oscillation (ENSO) Oscillations] on urban hydrology.

3. Development of a framework to understand and quantify population vulnerability in the focus regions due to climatic and anthropogenic change.

The second research project that was funded was, "Carbon-Based Renewable Hydrogel Nanocomposites for Water Purification," by Dr. Samantha Meenach. Water pollution is one of the most pervasive problems affecting people throughout the world. In particular, water contamination due to the indiscriminate disposal of industrial wastewater is a global environmental concern. This project focused on the use of a polymeric material, hydrogel nanocomposites, for the enhanced removal of heavy metal ions and organic contaminants from contaminated wastewater. Hydrogels are crosslinked polymeric systems capable of absorbing large quantities of water. Nano-sized materials can be entrapped in these networks to produce hydrogel composites with improved properties such as greater mechanical strength and specific adsorption of chemicals.

Carbon-Based Renewable Hydrogel Nanocomposites for Water Purification

Basic Information

Title:	Carbon-Based Renewable Hydrogel Nanocomposites for Water Purification
Project Number:	2014RI117B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	RI-002
Research Category:	Water Quality
Focus Category:	Wastewater, Treatment, Toxic Substances
Descriptors:	None
Principal Investigators:	Samantha Ann Meenach

Publications

1. E. Hurley, Z. Wang, S. Kennedy, S.A. Meenach, Integration of Graphene Oxide in Poly(ethylene glycol) Hydrogels for Wastewater Treatment, 2015 AIChE Northeast Regional Conference,, Boston, MA, March 7, 2015.
2. E. Hurley, Z. Wang, S.A. Meenach, renewable Graphene Oxide and Multiwalled Carbon Nanotube Hydrogel Nanocomposites for Waste Water Purification, 2014 Annual Student AIChE Meeting, Atlanta, GA, November 14-17, 2014..
3. E. Hurley, Z. Wang, S.A. Meenach, Renewable Graphene Oxide and Multiwalled Carbon Nanotube Hydrogel Nanocomposites for Waste Water Purification, 2014 INBRE SURF Poster Conference, Kingston, RI, August 1, 2014.

Final Report

Carbon-Based Renewable Hydrogel Nanocomposites for Water Purification

Overview

There are a large number of companies that have the potential to impact the quality of water that goes into the various wastewater treatment facilities throughout Rhode Island. Many cities throughout the state have strict limitations for the type and amount of pollutants and contaminants that can be discharged into their wastewater treatment facilities resulting in several Industrial Pretreatment Programs. These programs often have limitations on the discharge of heavy metal ions, organics, metals, solvents, and oil/grease that can be discharged into wastewater that is currently treated in the state. As a result, there is the need for companies to have the ability to effectively pretreat their wastewater for the removal of these contaminants. This research presents a solution to the limitations in the removal of industrial contaminants through a newly developed nanotechnology-based system capable of removing pollutants from wastewater. The polymer system will utilize nano-sized graphene oxide and carbon nanotubes, which have been explored for water purification applications but are often difficult to use in their free state. This system will incorporate these materials in a polymer system. This type of material could be used by companies for the removal of harmful compounds prior to the release of this pretreated wastewater into public treatment facilities. The material would offer an option that would result in a reusable material capable of adsorbing a high content of contaminants.

Detailed Project Abstract

Since the dawn of the industrial revolution indiscriminate dumping of wastewater from textile mills, metallurgical factories, and other manufacturing facilities have contaminated our waterways with toxic dyes and heavy metal ions. The removal of contaminants from wastewater has been successfully achieved using carbon-based materials such as C_{18} silica and activated carbon but these materials often suffer from low adsorption capacities and lack of reusability. Graphene oxide (GO) has recently been investigated as a solution to these problems. GO is a single atom thick nanomaterial with functionalized oxygen groups on its basal plane. Since GO is a flat sheet, there is tremendous surface area for interaction with other particles. The issue with GO is it tends to aggregate, however, incorporating GO into a hydrogel matrix can overcome this limitation. In this study, the hydrogel matrix was comprised of poly(ethylene glycol) (PEG) and the gels were made at room and cryogenic temperatures resulting in hydrogels and cryogels, respectively. The difference in polymerization temperatures caused a variation in pore size where cryogenic hydrogels (cryogels) formed a macroporous structure due to the freezing of water molecules and formation of ice crystals during polymerization. GO was added to the hydrogels and cryogels and swelling and adsorption tests were conducted. For the adsorption experiments, three model contaminates were tested; methylene blue (MB), eosin Y (EY), and 4-nitrophenol (4NP). The compounds were chosen to represent cationic, anionic, and organic molecules respectively, and thus cover a large range of potential contaminants. Adsorption experiments were conducted where gel samples were placed into a solution of each contaminant. The greatest adsorption potential for MB was seen by the PEG cryogel loaded with GO and little adsorption for 4NP was seen across all of the gels. For eosin Y, the greatest adsorption was by the PEG hydrogel loaded with GO. Overall, the integration of GO into polymeric networks has shown great adsorption potential for model wastewater contaminates.

Hydrogel Nanocomposite Synthesis and Swelling (Goal #1)

Materials and Methods. Poly(ethylene glycol) (PEG) was used as the polymers in the hydrogel systems owing to its temperature responsiveness characteristic. Nanosized graphene oxide (nGO) was added to the hydrogels because its large surface area and chemical nature allow for the attraction of metal ions and positively charged organic compounds that are potential wastewater contaminants. The hydrogel nanocomposites (HNC) were chemically crosslinked using ammonium persulfate (APS, free radical initiator) and tetramethylethylenediamine (TEMED, initiator) into the 1mm thick sheets between glass plates. Details of the hydrogel systems are as follows:

- PEG hydrogel components: 95 mole% PEG200 methylmethacrylate (PEG200MA), 5% PEG400 dimethacrylate (PEG400DMA), 0.125 weight % APS, 0.75 weight % TEMED, 50 weight % water, and 0 or 0.75 weight % GO.
- Cryogel formation: these systems were created by immediately placing any of the hydrogel systems in the freezer immediately following the addition of APS and TEMED but before hydrogel polymerization to allow for the formation of crystals in the systems.

Following hydrogel formation, 1cm circles were cut from the hydrogel sheets for the evaluation of hydrogel swelling. Hydrated gels were weighed (M_{wet}) after equilibrating in water at different temperatures and the freeze-dried then reweighed (M_{dry}) and their mass swelling ratio was calculated using:

$$Swelling\ Ratio\ (SR) = \frac{M_{wet}}{M_{dry}}$$

Results:

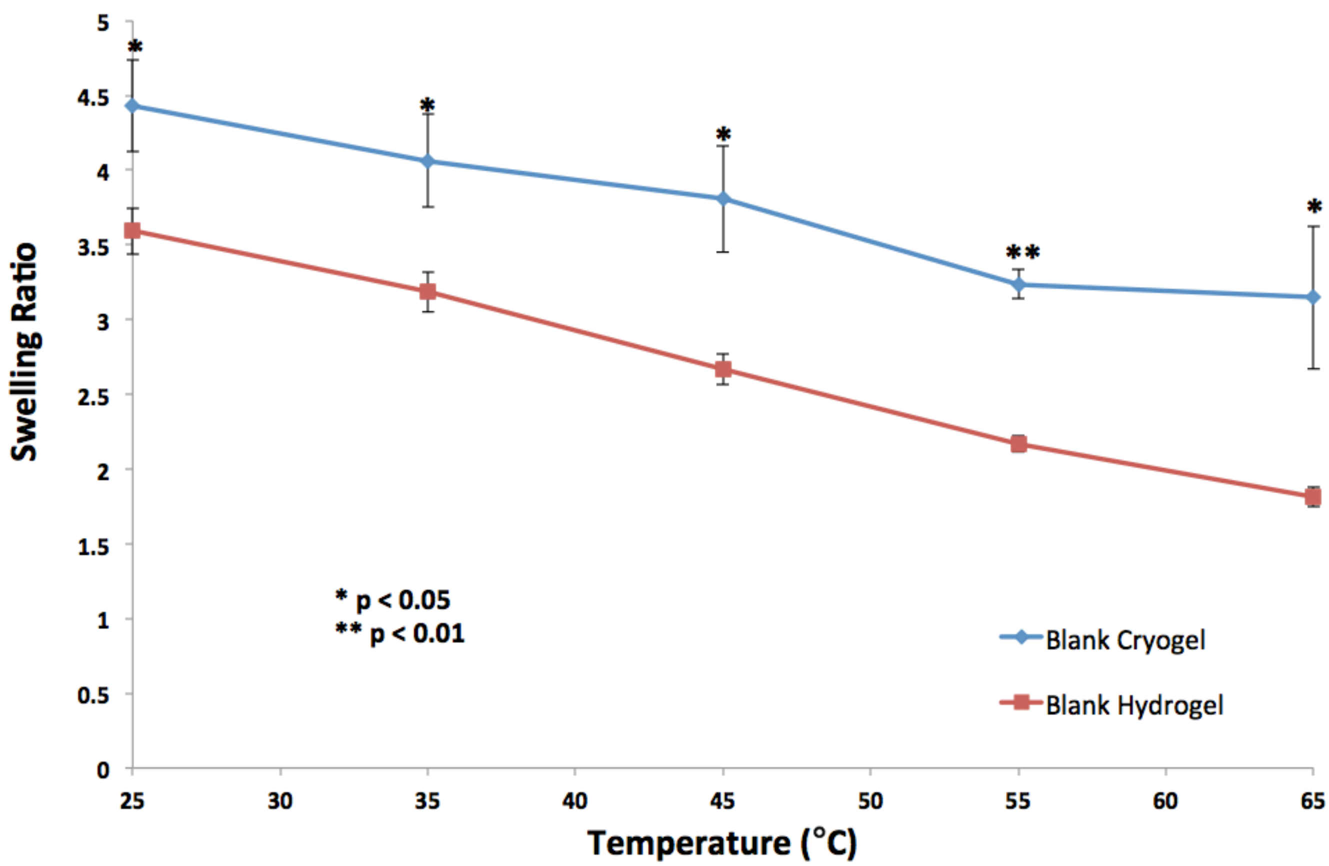


Figure 1. Swelling ratios of 0% GO (blank) PEG hydrogels and cryogels at different temperatures.

As seen in Figure 1, for PEG hydrogels without GO (blank gels), the swelling ratios decreased with increasing temperature, demonstrating that these systems are temperature responsive. In addition, the swelling of the hydrogels was significantly lower than the cryogels, indicating a structural difference between the to gel systems. This structural difference is likely due to the formation of crystals during the freezing of the cryogels, which causes large "gaps" or pore sizing within the hydrogel mesh. This difference in size could affect the ability of the systems to adsorb more or less contaminant owing to the availability of GO in the gel.

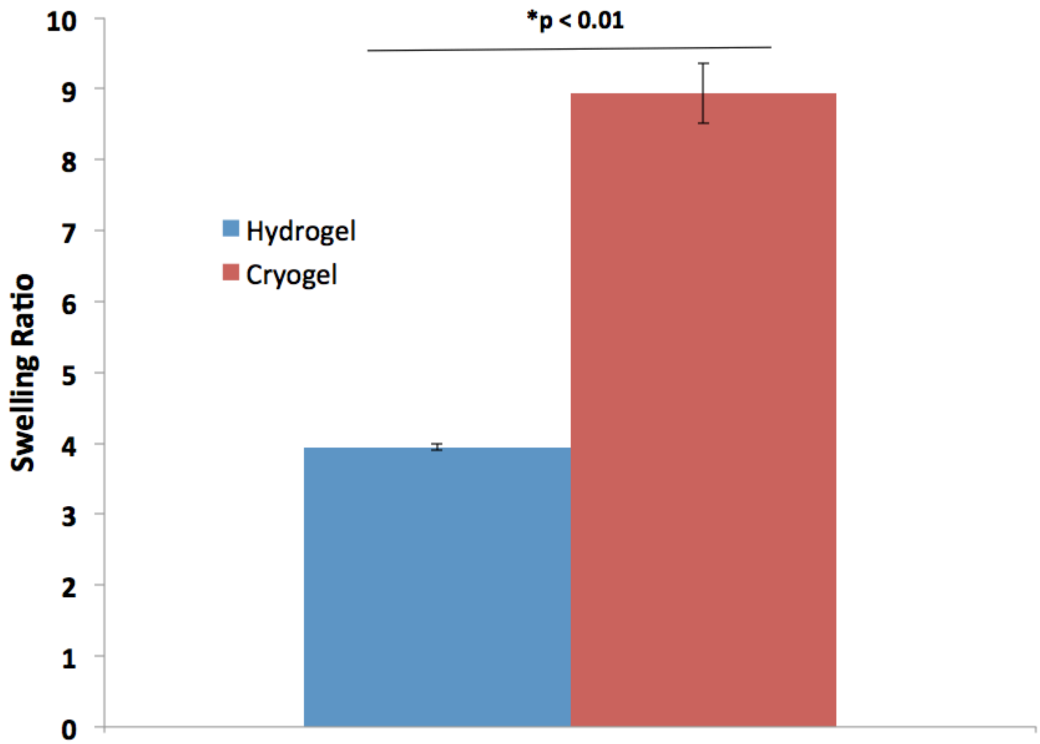


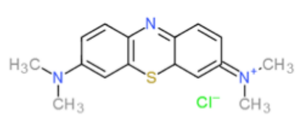
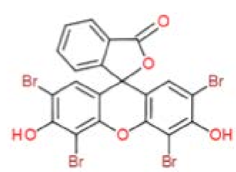
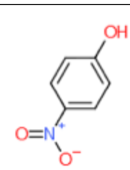
Figure 2. Swelling ratio of 0.75 weight% loaded PEG hydrogels and cryogels at 25°C.

Figure 2 indicates that the swelling ratios of GO-loaded PEG hydrogels and cryogels are statistically different and as in the blank gels, this is likely due to the difference in structure of the gels due to the presence of ice crystals during gel formation.

<u>Adsorption Experiments (Goal #2)</u>

Materials and Methods: The adsorption of model contaminants was evaluated using three contaminants with differing structures and characteristics as seen in Table 1.

Table 1. Model contaminants used in adsorption studies.

Model Contaminant	Structure	Characteristic(s)
Methylene blue (MB)		Cationic dye
Eosin Y (EY)		Anionic dye
4-Nitrophenol (4NP)		Neutral dye

The adsorption studies were completed by taking a swollen (wet) hydrogel or cryogel and placing it into a 0.1 mg/ml solution of the model contaminant. At given times (12, 24 and 26 hours), the absorbance value of the contaminant was measured to evaluate the amount of contaminant taken up into the hydrogel system. Calibration curves of known contaminant concentration versus absorption were used to evaluate the concentration of the solution at a given time. For calculations, the theoretical loading of the gel was found by:

$$L_{GO} = \frac{M_{GO}}{M_{Wet}} = \frac{M_{GO}}{M_{PEG200} + M_{PEG400} + M_{GO}}$$

where L_{GO} is the theoretical GO loading, M_{GO} is the mass of GO, M_{Wet} is the total mass of the swollen/wet gel, M_{PEG200} is the mass PEG200MA, and M_{PEG400} is the mass of PEG400DMA added during the gelation process. It is assumed that all of the GO is retained in the gel after gelation and that nearly 100% conversion of PEG200MA and PEG400DMA is achieved during this process. Using the swelling ratio data and the mass of the swollen hydrogel used from the sample, the theoretical dry mass of the gel and theoretical GO loading in the gel can be calculated:

$$M_{GO} = L_{GO} M_{Dry} = L_{GO}\left(\frac{M_{Wet}}{SR}\right)$$

Finally, the adsorption (q) of the contaminant was calculated from:

$$Adsorption, q\ (mg\ contaminant * g^{-1} GO) = \frac{(C_0 - C_t) * V}{M_{GO}}$$

where C_0 is the initial contaminant concentration, C_t is the contaminant concentration at time t, and V is the volume of the solution.

Results:

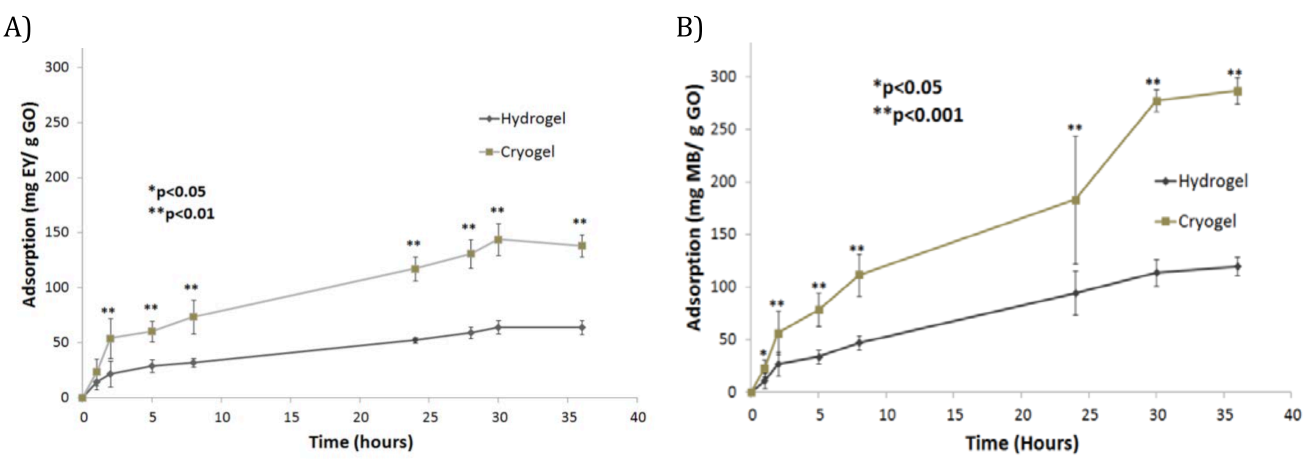


Figure 3. Adsorption of model contaminants (A) eosin Y (EY) and (B) methylene blue (MB) in GO-loaded PEG hydrogel and cryogel systems with respect to time.

Both EY and MB were adsorbed by the cryogels systems much greater than by hydrogel systems at all times points during the adsorption experiments with time (Figure 3). Overall, this demonstrates the capacity of the GO-loaded gels to adsorb both anionic and cationic dyes. Studies with 4NP are currently ongoing.

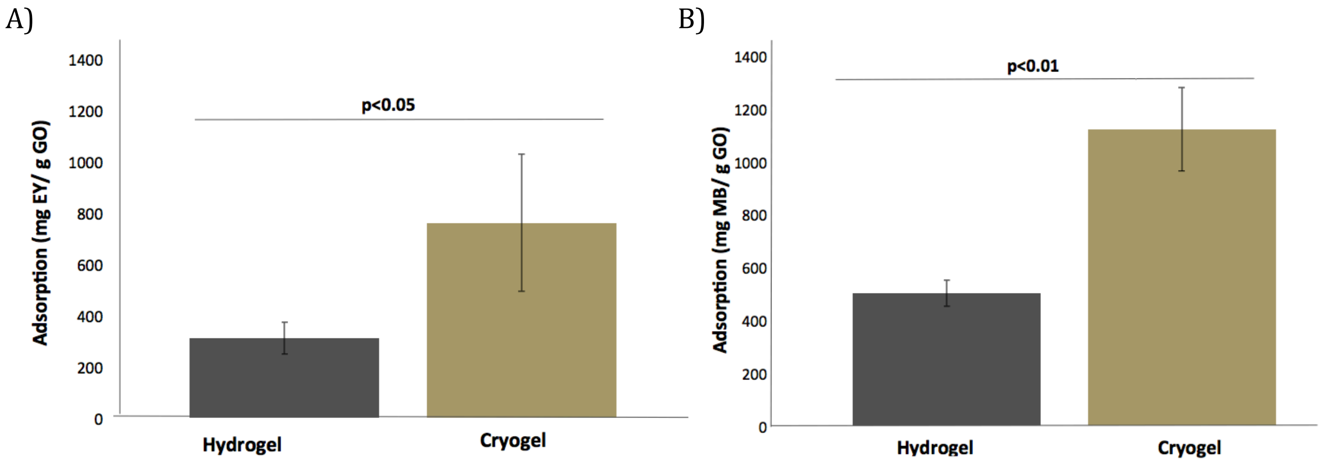


Figure 4. Maximum adsorption of model contaminants (A) eosin Y (EY) and (B) methylene blue (MB) in GO-loaded PEG hydrogel and cryogel systems.

The maximum adsorption capacity for EY and MB for GO-loaded hydrogels and cryogels can be seen in Figure 4. As expected, the cryogels resulted in a high adsorption for both dyes in comparison to hydrogels. For EY, the measured adsorption value of 760 mg EY/g GO is higher than any known values reported in literature. This was an unexpected result since both EY and GO are anionic, which should have repulsive interactions, so that the mechanism for adsorption is not fully known. For MB, the highest adsorption value for the cryogel was 1120 mg MB/g GO. As expected, the adsorption of MB was much higher than for EY since MB is cationic and should interact to a greater extent with GO.

Summary

Overall, we have successfully loaded GO into temperature-responsive PEG-based hydrogels and cryogels and this is the first time this has been done using these particular compounds. The PEG cryogel systems exhibited excellent adsorption toward both cationic and anionic dyes acting as model wastewater contaminants. The adsorption values reported here are much greater (up to 3x) that previously reported values. These hydrogels systems show great promise to be used in the design of adsorbents for the removal of unwanted contaminants in water systems.

Additional Comments (Project Limitations)

Lack of use of CNT: In the proposal, carbon nanotubes (CNT) were to be used in addition to graphene oxide (GO), however, it was determined that it was physically very challenging to disperse CNT evenly in the hydrogel systems. In addition, the CNT did not result in additional adsorption of model contaminants in comparison to pure hydrogel systems (data not shown).

Lack of physicochemical characterization: nanoparticulate loading and physicochemical characterization of the gels was not completed because of limitations with the analysis systems or data produced. For example, scanning electron microscopy (SEM) did not capture the mesh or pore structure of the gels as expected and all samples looked the same (like smooth sheets). Also, the thermal gravimetric analysis (TGA) and Fourier transform infrared spectroscopy (FTIR) equipment are currently unavailable to use.

Future Work

Studies that will be need to be complete for this project include:

- Adsorption of 4PL in GO-PEG gels
- Desorption of the contaminants from the hydrogels to allow for reuse of the systems

- Evaluation of adsorption of compounds released during explosive testing
- Design of a flow through filtration apparatus to include the hydrogels as adsorbants
- Evaluation of poly(acrylic acid) (PAA) as a hydrogel matrix component with GO

Student Impact

Both a graduate students (Zimeng Wang) and undergraduate student (Erik Hurley) in chemical engineering oversaw the described project and benefited from the work undertaken. Erik presented his work at several conferences and research symposiums including the national American Institute of Chemical Engineers (AIChE) conference in Atlanta, Georgia in November 2014, the regional student Northeastern AIChE conference in Boston, MA in March 2015, and the URI Chemical Engineering Research Symposium in April 2015. Erik was awarded 3rd Place for his poster presentation at AIChE in Atlanta in the Environmental Division of the competition.

Water Security, Sustainability, and Climate Impacts in Urban Regions

Basic Information

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Project Number:	2014RI119B
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Research Category:	Climate and Hydrologic Processes
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Descriptors:	None
Principal Investigators:	Ali S Akanda

Publications

There are no publications.

Research Report

May 2015

Water Security, Sustainability, and Climate Impacts in Urban Regions

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Abstract

In the developed world, many old cities are going through major urban renewal projects. These projects aim to revitalize aging infrastructure and meet the needs of the changing demographics, and carefully plan to merge new design processes and technology among the old infrastructure. On the other hand, in emerging urban regions of the developing world, most new development is taking place without adequate urban or regional planning, and a majority population is crowded into densely populated settlements without basic infrastructure, also known as slums. In both developed and developing countries, such development projects have huge impacts on the urban hydrology – both quality and quantity – and in an issue that requires rigorous planning and analyses. The factor that consistently stands out among different cities in transition from both worlds is that the urban poor are typically left to be the most vulnerable to climatic threats, such as water scarcity and quality issues in drought conditions, or water and sanitation breakdown and stormwater contamination problems. In this proposal, we focus on three major cities from three different income groups of countries: Providence, RI, USA from the developed world (or the OECD group), Lagos, Nigeria from Middle-Income Countries (MICs), and Dhaka, Bangladesh from the Least Developed Countries (LDCs). We propose to perform the following: (1) Compile a database of urban water quality and quantity indices in **Providence**, **Lagos**, and **Dhaka** with distinct urban land use, water usage, climate, and socio-economic characteristics; (2) Identify the impacts of climatic phenomena [Indian Ocean Dipole (IOD), Pacific North American (PNA), El Nino–Southern Oscillation (ENSO)] on urban hydrology; and (3) Develop a framework to understand and quantify understand population vulnerability of the urban poor in the focus regions due to climatic and anthropogenic change.

Table of Contents

Section	Title	Page
1	Introduction and Background	4
2	Literature on Urban Water Quality and Quantity	7
3	Impacts of Large Scale Climate Variability and Change	14
4	Framework to Assess and Quantify Population Vulnerability	20
5	Pilot Effort on Dengue in Puerto Rico	26
6	Poster Presented at AGU 2014 Fall Meeting	31
7	References	32

1. Introduction and Background:

A major problem in all urban regions of the world is to manage stormwater. Stormwater is huge in volume and difficult to route within urban regions with limited space. Stormwater causes widespread damage to infrastructure, especially in lowland and economically poor and slum areas. Stormwater is contaminated due to runoff from paved surfaces, waste disposals, and sanitation infrastructure and spreads the contamination around, and in turn, affect public health in urban regions. Also, stormwater is rarely used for groundwater recharge in a systematic way despite having high volumes that are typically flown out of the system.

A number of recent studies have focused on urban water systems and problems, such as water scarcity, drought, and access issues in urban regions, hurricanes, flooding and climate-compliant infrastructure in major cities, modern water and wastewater treatment and distribution systems, and stormwater contamination and routing problems. However, very few studies have focused on the urban poor. More specifically, how changes in climatic and anthropogenic factors affect the vulnerability of the economically poor areas (e.g., old neighborhoods, lowland settlements, and slums) to water and climatic threats, remain understudied. In addition, there is limited knowledge on how rapid urbanization and global environmental change have affected urban quality and quantity indicators.

In Providence, Rhode Island (RI) - stormwater pollution remains the biggest water quality problem, according to the Environmental Protection Agency (EPA, 2012). RI is the smallest member of the United States, yet, like many other larger states, it has a big stormwater pollution problem. Stormwater runoff is the leading cause of pollution in Providence and other watersheds in Rhode Island. Over the past 30 years, the state invested millions of dollars to upgrade municipal wastewater treatment facilities, pre-treat industrial wastes, and eliminate combined sewer overflows. Despite great progress in dealing with these pollution sources, changing climatic and anthropogenic influences on the environment make stormwater pollution a more serious problem for the local and regional rivers and coastal waters than previously thought.

In Dhaka, Bangladesh slums have a population density that is 200 times greater than the nationwide average density (CUS, 2006). About 70% of slum dwellers have no access to safe waste disposal and latrines and about 90% live below the poverty line ($2 a day). Most of these slum areas are located in low elevation areas around the city periphery near water bodies. People living in these areas typically suffer increased water stress and thus reduced access to sanitation and hygiene during the dry season. Fewer safe water sources and cohabitation with contaminated water bodies increase the risk of pathogen exposure and disease transmission. Almost half of Dhaka slums also get inundated fully or partially during heavy Monsoon rains and only 10% have sufficient drainage to avoid water logging, exposing water bodies to pathogens due to flooding (Streatfield and Karar, 2008). Diarrheal diseases, such as cholera, dysentery and rotavirus, show distinct seasonal and spatial patterns in Dhaka City peripheries and the congested slum areas remain vulnerable to waterborne disease outbreaks due to lack of planning, and access to safe water, and sanitation (Alam and Rabbani, 2007).

In Lagos, Nigeria, the largest and fastest growing mega city in Africa's most populous nation, two out of three people live in slums with no reliable access to safe drinking water, sanitation, or electricity (IRIN Africa, 2006). While the climatic forcings are not as seasonal here as in Dhaka, the lack of planning, the socio-economic conditions of the slums, the coastal ecology, and the ubiquitous dependence on water in places like the Makoko slums (Figure 1d) expose the inhabitants to harmful water-related diseases. Malaria is a serious public health problem in Nigeria (about 70% of outpatient hospital visits in the Lagos city area are due to Malaria) (Oyewole et al., 2011). Rapid urban growth and unplanned development in Lagos have greatly altered ecosystems around the city and consequently, mosquito species have moved to municipal water reservoirs, turning them into larval habitats for malaria. Nigeria also experienced one of its worst disease outbreaks in 2010, infecting almost forty thousand people and killing over 1500 (Enserink, 2010), although the capital city of Lagos was spared during this epidemic. Coastal proximity of the area's lagoons and the seasonal increase in salinity in these water bodies (Emmanuel and Salawu, 2009) during drier months make Lagos especially vulnerable to future outbreaks by providing breeding grounds for *V. cholerae*.

Research Objectives

In this proposal, we focus on three major cities from three different income groups of countries: Providence, RI, USA from the developed world (or the OECD group), Lagos, Nigeria from Middle-Income Countries (MICs), and Dhaka, Bangladesh from the Least Developed Countries (LDCs) (World Bank, 2012). Providence, RI has one of the highest proportions of urban poor in the USA (population under poverty there is twice the US national average of approximately 15%). The other two cities (Lagos and Dhaka) both have high growth rates of poor urban settlements or slums (4.0% and 4.7% annually, respectively). As part of this research project, we proposed and performed the objectives:

- Compile literature on urban water quality and quantity indices in **Providence**, **Lagos**, and **Dhaka** with distinct landuse, water usage, climate, and socio-economics.
- Identify impacts of climatic phenomena [Indian Ocean Dipole (IOD), Pacific North American (PNA), El Nino–Southern Oscillation (ENSO)] on these urban regions.
- Develop a framework to understand and quantify understand population vulnerability of in the focus regions due to above mentioned climatic and anthropogenic drivers.

Structure of the Document

Section 2 of this report focuses on literature review, data collection, analysis and compilation of water and health related assessment of Providence, RI and some of the world's emerging megacities based on a large body of published research work. A research poster based on this work, prepared and presented for the American Geophysical Union Annual Fall Meeting in December 2014, has also been attached in this section. Section 3 focuses on the large-scale climate phenomena that affect water and health related drivers in the study regions. Section 4 of the report details the work on developing a vulnerability framework to understand the role of these climatic and anthropogenic drivers. To gain a better understanding of water and health conditions in emerging urban regions in tropical climates that may enable Dengue transmission, Section 5 details a pilot effort using Observed ground and Remote Sensing datasets in San Juan, Puerto Rico and surrounding regions where Dengue is a major problem.

2. Literature on Urban Water Quality and Quantity

A major problem in all urban regions of the world is to manage stormwater. Stormwater is huge in volume and difficult to route in urban regions with limited space. Stormwater causes widespread damage to infrastructure, especially in lowland and economically poor and slum areas. Stormwater is contaminated due to runoff from paved surfaces, waste disposals, and sanitation infrastructure and spreads the contamination around, and in turn, affect public health in urban regions. Also, stormwater is rarely used for groundwater recharge in a systematic way despite having high volumes that are typically flown out.

Contaminated stormwater brings harmful sediments to water bodies, and destroys aquatic habitats for fish and plants. It also contributes excess nutrients (for example, phosphorus and nitrogen) to water bodies, causing unwanted algal blooms that remove oxygen from the water and kill fish and other aquatic life. It contributes bacteria and other pathogens to water bodies, which can flow into swimming areas and create health hazards. It contributes debris or litter to water bodies that wash into lakes, streams, rivers, and the ocean, and can choke or suffocate aquatic life such as ducks, fish, turtles, and birds. It contributes household hazardous wastes such as insecticides, pesticides, paint, solvents, used motor oil, and other auto fluids to our water bodies. The contamination can also affect drinking water sources, affect human health, and increase treatment costs.

Providence, Rhode Island

In Providence, stormwater pollution remains the biggest water quality problem, according to the Environmental Protection Agency (EPA, 2012). RI is the smallest member of the United States, yet, like many other larger states, it has a big stormwater pollution problem. Stormwater runoff is the leading cause of pollution in Providence and other watersheds in Rhode Island. Over the past 30 years, the state invested millions of dollars to upgrade municipal wastewater treatment facilities, pre-treat industrial wastes, and eliminate combined sewer overflows. Despite great progress in dealing with these pollution sources, changing climatic and anthropogenic influences on the environment make stormwater pollution a more serious problem for the local and regional rivers and coastal waters than previously thought. Rhode Island weather is already being impacted by climate change for the past 80 years, as seen in trends of increasing temperature, precipitation and the frequency of intense rainfall events and storms. Since 1991, the Northeast has seen an 8% increase in overall precipitation and, since 1958, a 71% rise in heavy rain events. Since 2010, four major coastal storms hit Rhode Island prompting federal emergency procedures (Figure 1).

The health effects of these natural disasters extend beyond the immediate injuries and trauma of a disaster, affecting communities long after the event with issues associated with disease outbreaks, public health problems, water damages and population displacement. These public health implications vary depending on the nature of the event and the characteristics of the affected population. Certain populations are affected more acutely by health risks that arise during and after a hurricane, such as low income neighborhoods and people who live in mobile homes. Also, children, the elderly, and the disabled are usually more affected, as they are dependent on others for evacuation and emergency help. Additionally, certain communities are more vulnerable geographically. A recent Brown University report notes that low-income individuals are more likely to reside on property that lies on a floodplain. Because they are more vulnerable geographically, the impact of the storm or disaster may be greater in these communities (Rhode Island Department of Health, 2013).

Additionally, storms and flooding can disrupt sewage and sanitation systems, increasing the risk of infectious disease transmission. The extensive water damage caused by a hurricane can also pose serious health risks with mold in damaged structures, and skin irritation and respiratory problems. Displacement after a disaster may also cause crowding of displaced people in shelters and increased probability of disease transmission. A 2010 report on vulnerability in Rhode Island found that the additional hurricane risk associated with the climate change resulting from a high-emissions pathway could increase hurricane damages by $2 to $6 billion.

Figure 1: A flooded street in Cranston, RI during the March 2010 tropical cyclone.

Lagos, Nigeria

The city of Lagos is a growing megacity located in the low lying coastal region of Nigeria with 71%, of the commercial capital of the country, being comprised of wetlands and lagoons (Obiefuna, et al 2013, Stimson 2012). Lagos began to grow during the 1970's oil boom and has continued to rapidly expand since then (Stimson 2012). In 2012, Stimson cited that the population was about 10 million people, however according to the Lagos State Government website that figure is currently about 21 million. The city is very densely populated and about two thirds of inhabitants live in slums whose structures are built on wetlands or on stilts over open water (Figure 2; Stimson 2012). Figure 3 shows the distribution of sanitation facilities in urban Nigeria.

Figure 2: The Makoko slum in Lagos, Nigeria

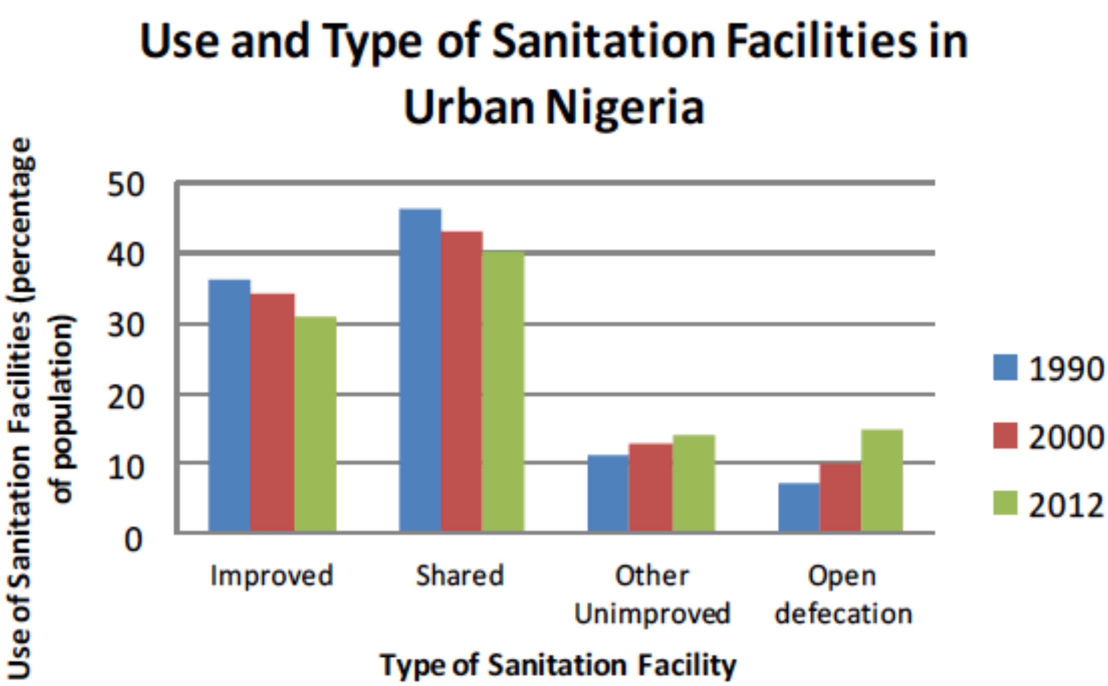


Figure 3: Distribution of sanitation facilities in urban Nigeria

In Lagos there are several health concerns stemming from lack of infrastructure. For example, "by the end of 2008, vigorous efforts by the state water authority achieved a water delivery capacity of 200 million gallons per day (mgd) against a demand of 600 mgd, a gap of about 66%" (Stimson 2012). In addition, the Lagos Water Corporation struggles to collect payment for the water it is able to deliver, which has a serious impact on budgets for capital and maintenance (Stimson 2012). Because they have no access to piped water, residents get their water from private wells and from street vendors (Stimson 2012). The water sold from these vendors is commercially purified and sold in plastic pouches called "water satchels" which are often contaminated with bacteria and heavy metals (Stimson 2012). The plastic satchels the water is distributed in have become an environmental hazard all their own, clogging waterways and drainage systems (Stimson 2012). People with access to private wells will soon see their water contaminated as well, if they haven't already, because of the way the city is urbanizing. Obiefuna et al detailed the change in land use showing a significant decrease in swamps (344.75km2 to 165.37 km2) and mangroves (88.51km2 to 19.95 km2), with a huge increase in built-up areas (48.97km2 to 282.78 km2) between 1984-2006. This has impacted quality and quantity of water that is recharging aquifers, as increased impervious surfaces means decreased infiltration, and less vegetation to filter runoff (Obiefuna, et al 2013).

Wastewater, solid waste, and air pollution are all major problems in Lagos as well. Air particulate concentrations are 500% higher than WHO standards, and Lagos alone accounts for 40% of newly registered vehicles in the entire country (Stimson 2012). As for wastewater and solid waste, we once again see a major lack of infrastructure, as less than 1% of households are tied into closed sewage systems (Stimson 2012). There are several more staggering statistics about waste in Lagos including this one from Stimson stating, "More than 10% of estimated 4000-6000 tons of solid wastes generated each day in Lagos are dumped directly into open spaces or municipal drainage systems, blocking drainage during heavy rains". The water satchels people rely on for lack of water infrastructure are a major contributor to this solid waste catastrophe. All of these issues, but especially flooding, will only continue to get worse as the world faces heavier rainfalls and rising sea levels due to climate change.

Lagos is facing several very serious issues resulting from urbanization so rapid that infrastructure and government policy can't keep up. In the past few years, millions of dollars have been invested on health initiatives in this city, however, these efforts cannot be effective unless the overall conditions of the city are improved. As outlined by Obiefuna et al the first step will be to curb unplanned urban growth and to increase green engineering efforts. Another very important part of this process will be establishing water, wastewater, and solid waste infrastructure. With what we know about climate change and its effects on cholera and other water borne illnesses, in addition to widespread urban flooding, rising number of cholera and dysentery cases are rising.

Dhaka, Bangladesh

In Dhaka, Bangladesh the slum population doubled between 1995 and 2005, and the number of slums communities also increased (Akanda and Hossain, 2012). People in slums are in general more vulnerable to natural hazards such as droughts and floods when it comes to access to clean drinking water but, in this area specifically, both the expected changes in the dry and the monsoon seasons will be of major concern (Akanda and Hossain 2012). Also, floods are not the only contributor to this disease burden- droughts allow for greater salt water intrusion in coastal areas, creating a better environment for the bacteria. Almost half of Dhaka slums are flooded to some extent (partially or fully) during monsoon rains, and only 10% have drainage sufficient enough to avoid flooding, meaning populations in these slums are regularly exposed to flood waters contaminated with pathogens (Figure 4; Streatfield and Karar 2008). Diarrheal diseases such as cholera, dysentery, and rotavirus show distinct seasonal and spatial patterns in Dhaka communities. These densely populated slum areas remain vulnerable to waterborne disease outbreaks due to lack of planning and access to safe water and sanitation (Alam and Rabbani 2007). Work has already been attempted to develop an early warning system for floods and consequential cholera outbreaks in Dhaka due to extreme weather events, but not using remote sensing (Akanda et al. 2011; Reiner Jr. et al 2012). Remote sensing could help create real-time monitoring of slum growth in emerging megacities (Figure 5) and issues such as disease prevention and disaster management response.

Figure 4: The Korail slum in Dhaka, Bangladesh

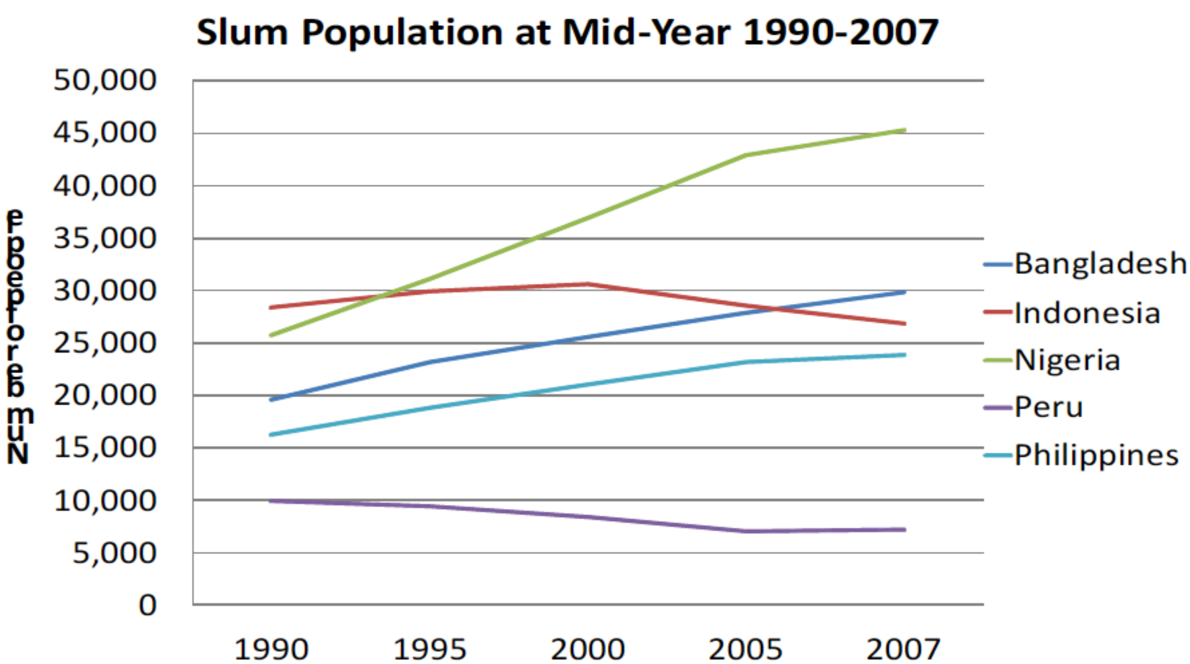


Figure 5: Rate of change of slum population in emerging megacities

3. Impacts of Large Scale Climate Variability and Change

The El Nino-Southern Oscillation (ENSO) phenomenon is considered a primary modulator of global climatic events (Rasmusson and Wallace, 1986). Ropelewski and Halpert (1987) have carefully examined and identified various regions of the world where consistent ENSO-related large scale precipitation patterns are observed. For example, studies have investigated the relationships between ENSO and streamflow for large tropical rivers such as the Nile and the Congo (Amarasekera et al. 1997; Molinier et al. 2009) and the Ganges (Whitaker et al. 2001). Precipitation in the Pacific coast of South America (Rossel and Cadier, 2009; Takahashi, 2004) and the Amazon and Parana drainage basins (Molinier et al. 2009; Pasquini and Depetris, 2010) on the eastern coast are strongly influenced by the ENSO. ENSO related variability has been used to forecast streamflow (Piechota et al. 1999; Hamlet et al. 1999; Whitekar et al. 2001) and precipitation patterns in the Asian Monsoon (Lim and Kim, 2007).

The ENSO is also known to influence the occurrences of various infectious diseases in many parts of the world (Patz et al. 2002; Harvell et al. 2002). Studies have suggested relationships between disease epidemics in Peru (Salazar-Lindo et al. 2008; Martinez-Urtaza et al. 2008) and Bangladesh (Koelle et al. 2005; Pascual et al. 2000; Rodo et al. 2002) and the ENSO cycle. Given that the influences of the ENSO phenomenon on hydrologic and climatic signals are different in various areas of the world, it is important to investigate the climatological, microbiological and epidemiological evidences of the effects of ENSO on disease dynamics in different regions. Studies of large scale climate effects on disease so far have primarily focused on the effects of ENSO. However, these studies mostly attempted to explain the variability of dual cholera peaks with the assumption of a single underlying environmental process; none of these studies tried to explain the impacts of these large-scale climatic processes on individual seasons.

The ENSO phenomenon is known to have a varied influence on the precipitation characteristics of the GBM basin region. While the Ganges basin part of the region has shown increased flow with the La-Nina phase (Whitekar et al. 2001), the higher share of discharge seen in the Brahmaputra basin has no known influence due to the phenomenon (Jian et al. 2009). As the rivers are known to have a strong contrasting affect on regional hydrology in the dry and wet seasons in this region (Akanda et al. 2011), the role of ENSO needs to be interpreted in the context of the seasonal role of individual rivers, not as a teleconnection having a unified affect. Also, Koelle et al (2005) and Pascual et al (2008) reported an 11-month lag relationship between ENSO indices and waterborne disease dynamics in Bangladesh; as well as a 14-month lag between rainfall in northeastern India and subsequent outbreaks in downstream Bangladesh. However, these studies failed to identify the impacts on the individual biannual peaks or provide any meaningful hydroclimatological explanation of these linkages. The ENSO influences hypothesized in the studies by Pascual et al. (2000; 2008), Rodo et al. (2002), Koelle et al. (2005) thus lack a physical mechanism related to the teleconnections. More specifically, how the warm (El-Nino) and the cold (La-Nina) phase of the same phenomenon may affect the discharge characteristics of the major rivers in this region differently, and how such a large scale phenomena would impact water related hazards in Bangladesh in two different seasons, have been overlooked.

In contrast, the goal of this section is to understand how the water-climate relationship in the Bengal Delta region explicitly manifests itself in each outbreak season during such large-scale events. Climate phenomena such as the ENSO and associated extreme hydroclimatic events may cause large water related hazards such as droughts and floods. Also, other climatic phenomena such as the Indian Ocean Dipole (IOD) (Saji et al. 1999) and the Pacific North American (PNA) oscillation (Wallace and Guztler, 1981), two well known atmospheric circulation patterns in the Indian Ocean and the northern Pacific Ocean, respectively, have been found to have significant influences on the precipitation patterns in the Indian Subcontinent region (Peings et al. 2009; Izumo et al. 2010). We shall build on the existing understanding of the role of regional hydroclimatology on droughts and floods in the Bengal region. In addition to ENSO, global climatic phenomena such as the Indian Ocean Dipole Mode Index (DMI) and the PNA Index will be studied to identify the impacts on the dry and wet season hydroclimatology in the region and the changes in climatic variables relevant for disease.

Observational records of regional precipitation, streamflow, and SST patterns with be analyzed to identify plausible relationships with major ENSO, IOD, and PNA events. For example, the Ganges and the Brahmaputra rivers have been found to be important contributors in seasonal cholera infection (Akanda et al. 2012). Shahid (2007) found significant negative correlation between pre-monsoon droughts in the region, especially in the Ganges basin area of Bangladesh, and ENSO indices. In addition, the occurrence of floods in these two rivers have been found to be modulated by indivdual mechanisms; leading to devastating floods when streamflow peaks coincide (Mirza, 2003). Thus, instead of analyzing the teleconnections as unified influences on the hydroclimatology of this region, the effects on streamflow and precipitation characteristics in each river basin during the dry and wet seasons should be investigated separately.

Figure 6 shows that a moderately strong El-Nino condition has been developing in the Nino 3.4 region since Fall 2014 and is likely to affect the weather patterns and water and health conditions in North America. Especially, as Figure 7 shows, the impact on the New England region was felt through a colder and wetter winter due to Polar Jet streams.

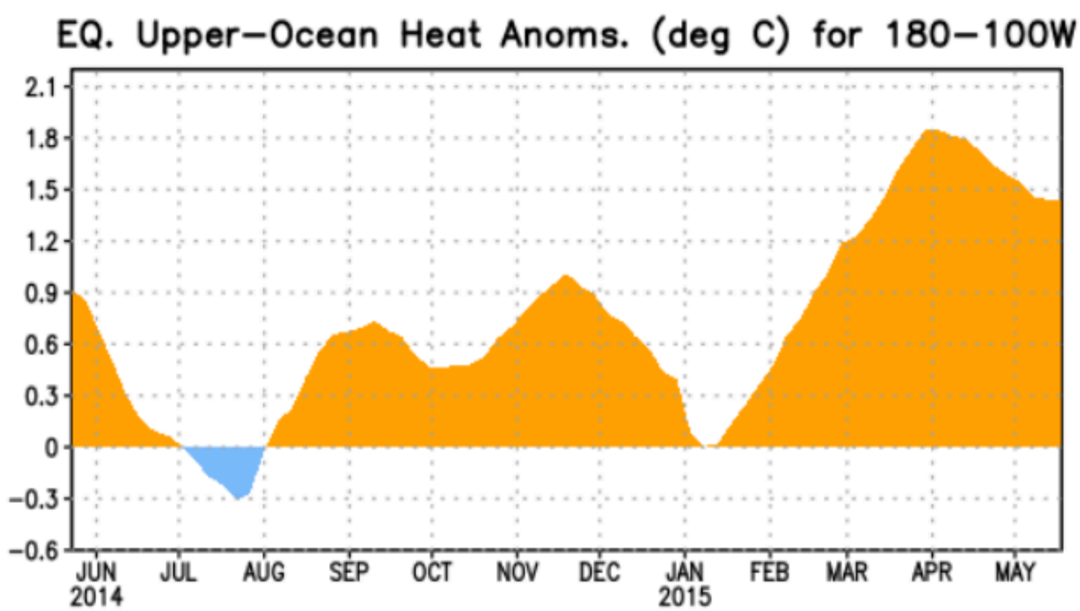


Figure 6: Current state of ENSO related temperatures in the Nino 3.4 region

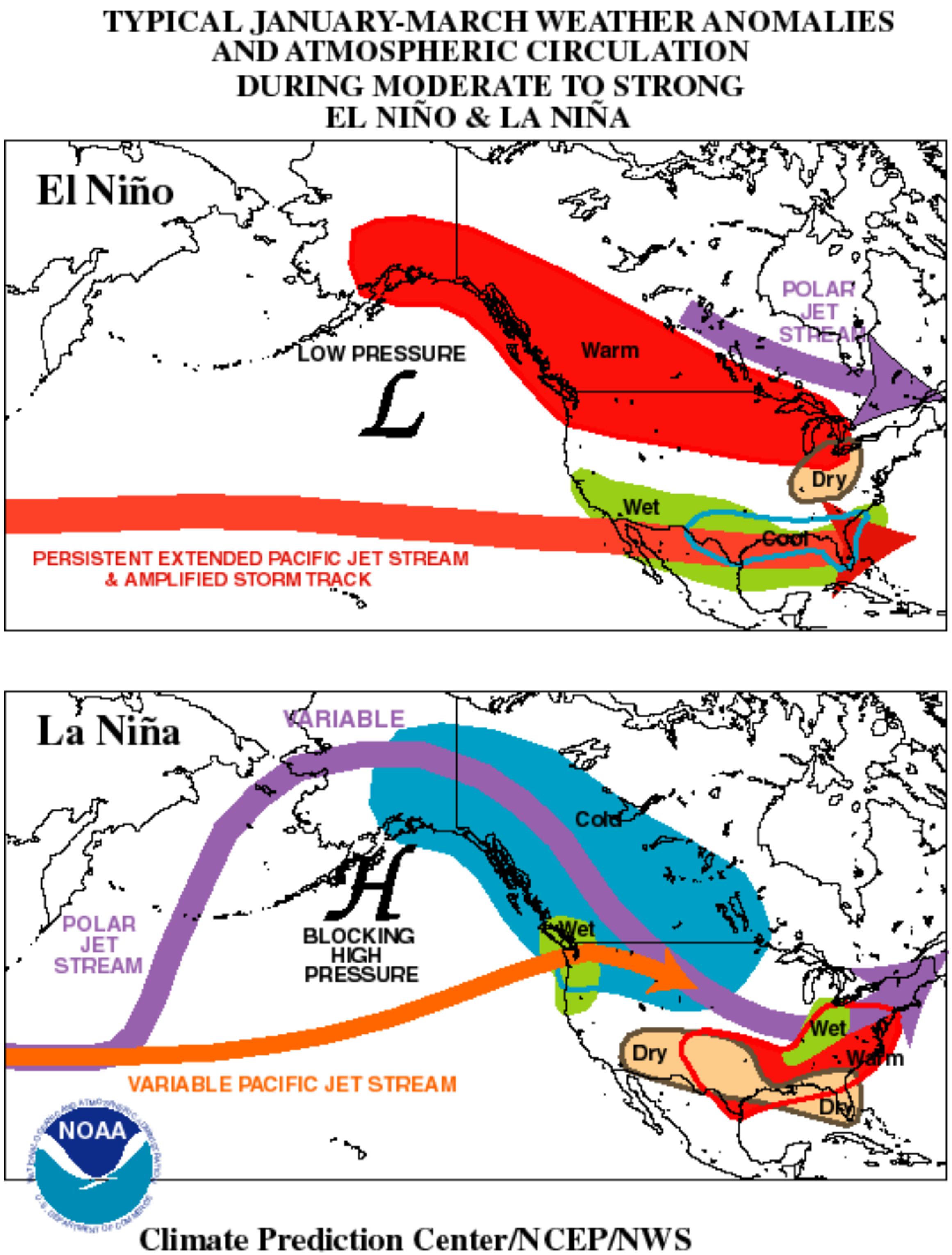


Figure 7: Schematic showing the long term average impact of ENSO phenomena on meteorological conditions in the Pacific Ocean and North America (Source: NOAA)

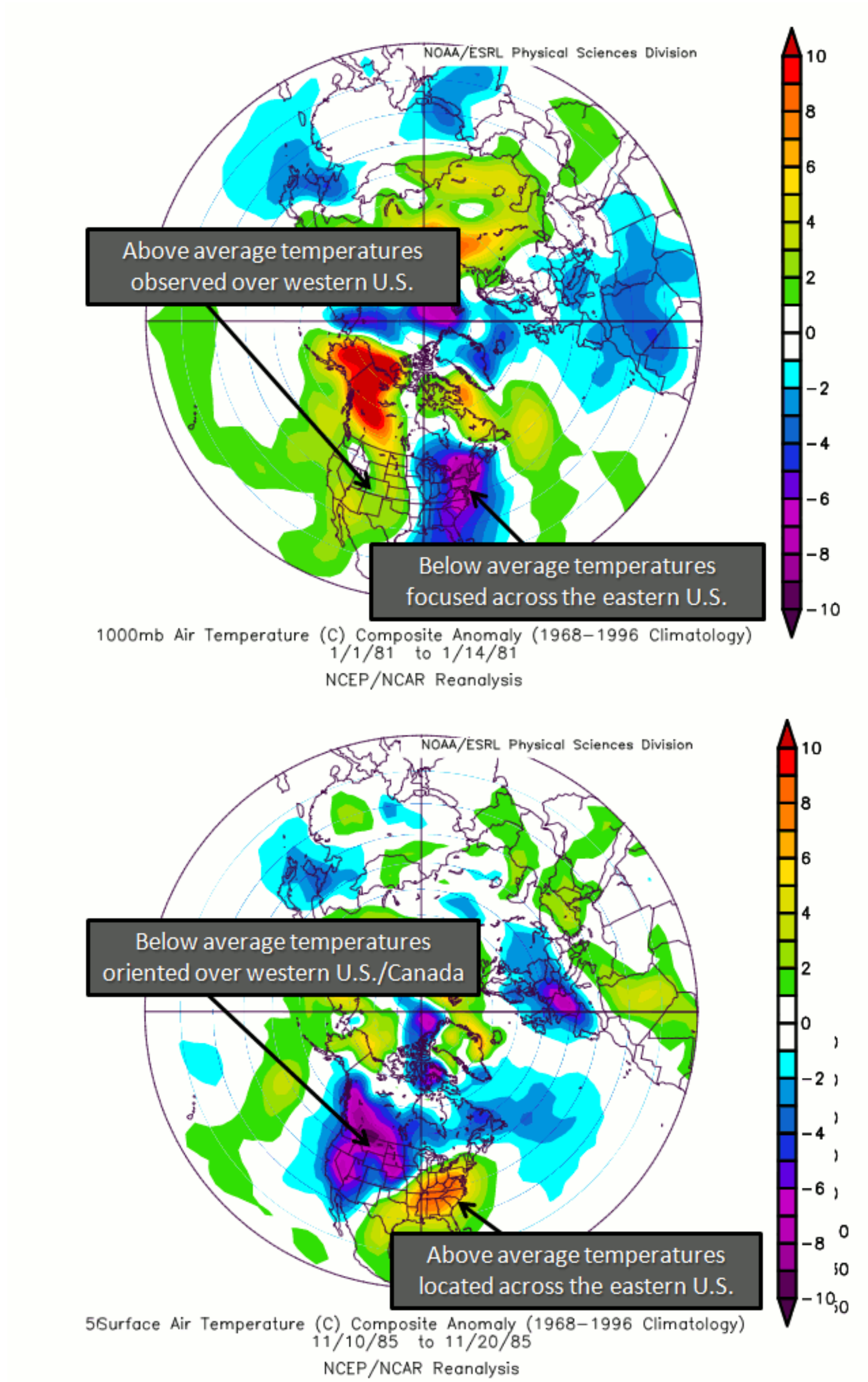


Figure 8: Long-term climatology of (a) Positive and (b) Negative PNA Impacts on Eastern US (Source: NCEP/NCAR Reanalysis Project)

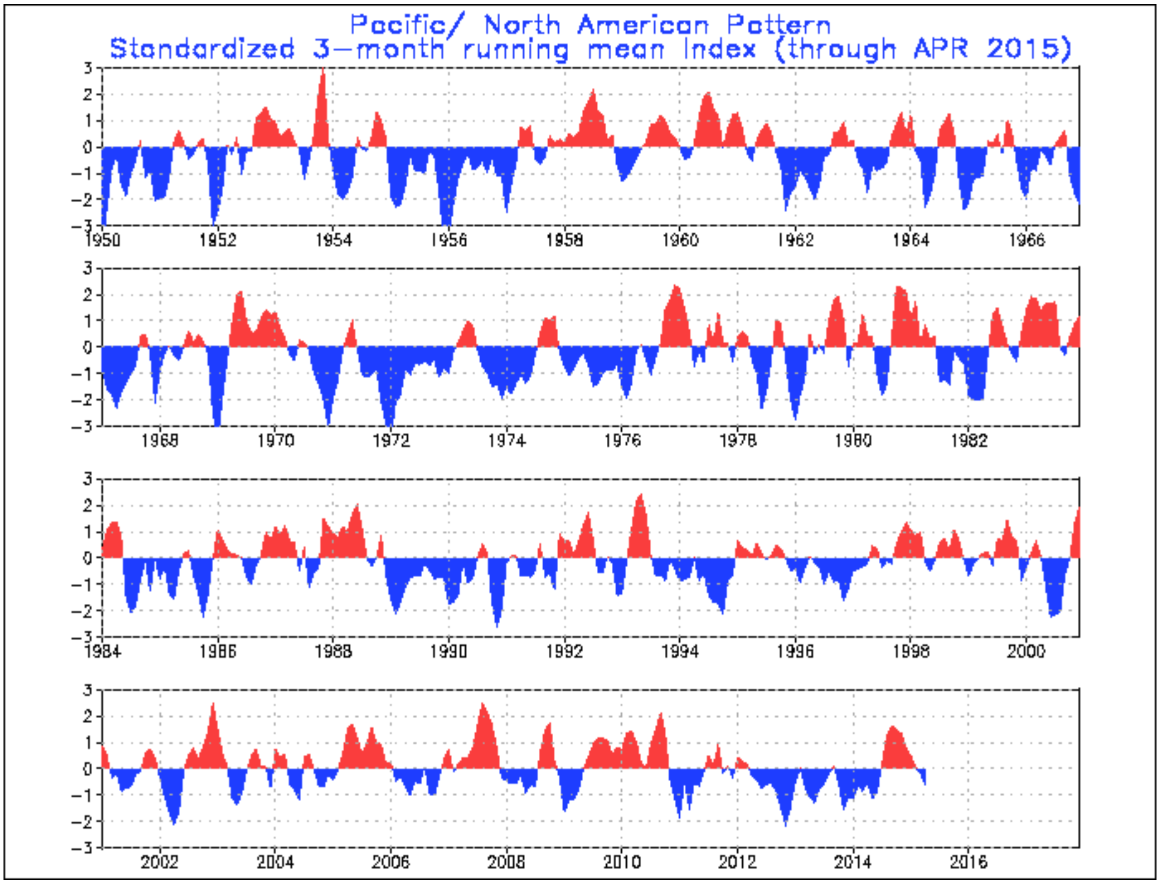


Figure 9: Time series of PNA index conditions (Source: NOAA)

As shown in Figure 8, the Pacific-North-Atlantic oceanic conditions have a strong impact on weather in the North American region. A dipole effect is seen during positive or negative PNA conditions that bring in lower than average temperatures in eastern US or above average temperatures across the eastern seaboard. Figure 9 shows that a negative to positive trend in PNA index has been developing since 2013 and a strong positive anomaly is seen during the end of 2014, which brought in a record cold winter across the eastern US. Thus PNA can be a major force that contributes to local and regional hydrological and meteorological conditions in New England and cause increased number of storm events, flooding, as well as lack of rainfall and scarcity of freshwater.

4. Framework to Understand and Quantify Population Vulnerability

Region-specific climatic variability and location-specific socio-economic conditions interact to influence vulnerability to water-related diseases in emerging megacities. Thus, this vulnerability, or its corollary, resilience is highly contextual, and different megacities can demonstrate completely different levels of resilience despite being in similar climates. Impact of natural and anthropogenic changes on water cycle is well established from the point of view of land-use, weather and mesoscale climate, surface hydrology and stress on infrastructure (Shepherd, 2005; Degu et al., 2011). Research should focus on 'stretching' this understanding to what meso-climate modification means for vulnerability to health in megacities, and how climate adaptation measures can incorporate and prepare for these changes in coming decades. While a rigorous scientific study utilizing Global Circulation Models (GCMs) can give a 'top-down' picture of potential impacts, a distributed 'bottom-up' approach involving stakeholders is likely to produce a more effective adaptation strategy (Braun and Aßheuer, 2011).

Although monthly climatology looks somewhat similar for Dhaka and Lagos, one key difference is the amount of surface water passing through the regions. The hydroclimatology of the Ganges-Brahmaputra-Meghna (GBM) basin region in South Asia is highly seasonal and the asymmetric availability of water affects vast areas of Bangladesh differently in space and time. Over 80% of the annual precipitation occurs during four monsoon months of June through September. Water quality degradation and scarcity reduces water and sanitation access during the prolonged dry season, and increased salinity in coastal areas contributes to pathogen growth and exposure, and contamination of water bodies (Akanda et al., 2011). Convergence of people on few available water sources exposes them to high risks of infection; making the cities vulnerable to health impacts of drought conditions and water distribution problems. The situation reverses in the monsoon, when the GBM drains a huge amount of water from upstream regions (Nishat and Rahman, 2010) and the effect of local precipitation gets amplified when most parts of the country is rapidly flooded in July or August. Open mixing of water reservoirs and networks around Dhaka leads to a breakdown in sanitation and reservoirs, which are unprotected, become rapidly contaminated with harmful pathogens (Islam et al, 2006). Such vulnerability to water-related hazards is expected to worsen in Dhaka due to changes in Indian monsoon patterns and as runoff in the Brahmaputra basin is expected to rise up to 40% (Milly et al., 2005).

For Lagos, population vulnerability to water-related disease outbreaks arises largely from the lack of urban planning, as well as lack of public health infrastructure around population centers (Stimson, 2010). The explosive growth rate of this megacity has lead to unplanned development of water, sanitation, and waste management facilities, and local authorities are unable to meet rising water demands, both in terms of quantity and quality. Microbial contamination and growth of disease vectors in water distribution systems or natural reservoirs around city slums can lead to epidemic outbreaks that the public health response system will be ill equipped to handle. The nutrient-rich water bodies around slum areas can be ideal breeding grounds of mosquito larvae and diarrheal pathogens and expose the surrounding populace to the risk of malaria, cholera and other water-related disease outbreaks (Emmanuel and Salawu, 2009). In addition, for Lagos and its coastal enclaves, the frequency of flood events is likely to intensify due to sea-level rise, which would also affect salinity patterns of the inland water reservoirs around city slums and increase vulnerability to water-related hazards and disease outbreaks.

To combine the above issues in an effective framework to assess vulnerability to climatic and anthropogenic drivers of natural hazards and water related health disasters, we have developed a Geographic Information Systems (GIS) and Remote Sensing (RS) based tool to assess population vulnerability due to climatic and anthropogenic change and sea-level rise and related changes in water and health conditions of Warwick, RI – a suburb just south of Providence, RI situated on the ocean. Warwick is the second largest city of Rhode Island with a population of around 82 thousand. As Warwick is beside a Bay, it will experience devastating loss in future years due to sea level rise and associated storm surge. Sea level rise and associated storm surge can be highly devastating to coastal community. Future sea level rise could lead to destruction of coastal houses, recreational facilities and also government and public utilities.

In this study, an attempt has been made to identify vulnerable zones to sea level rise and storm surge in the town of Warwick. The vulnerability map has been developed with combination of several risk maps. Initially a map has been developed to find topographic information of the study area (Town of Warwick). Inundation area of 0ft, 4ft, 5ft and 6ft from current Mean Higher High Water level (MHHW) are identified with topographic information. House density of town has been calculated and categorized in to five vulnerable classes. Similarly, Road Density also calculated and risk are classified based on different water depth. Proximity of important structures like school, hospital, airport, and cemetery are identified to find the risk of inundation. Recreational and natural sites are provided great importance as they are mostly situated around coastline of Warwick and posses great values to local population. Residential, Commercial and Industrial zones are categorized and provide economic values to understand potential damage of sea level rise. Finally, a vulnerable zone map with combined criteria is established around the coastal area of Warwick. Information about city of Warwick are collected from secondary literatures. From the Rhode Island geographic Information (RIGIS) website, following data were collected:

- Town boundary
- Digital elevation model (DEM)
- Bathometry
- Road information
- Local Building information
- Public structures
- Land-use
- Soil information
- Wetlands information
- Lake information

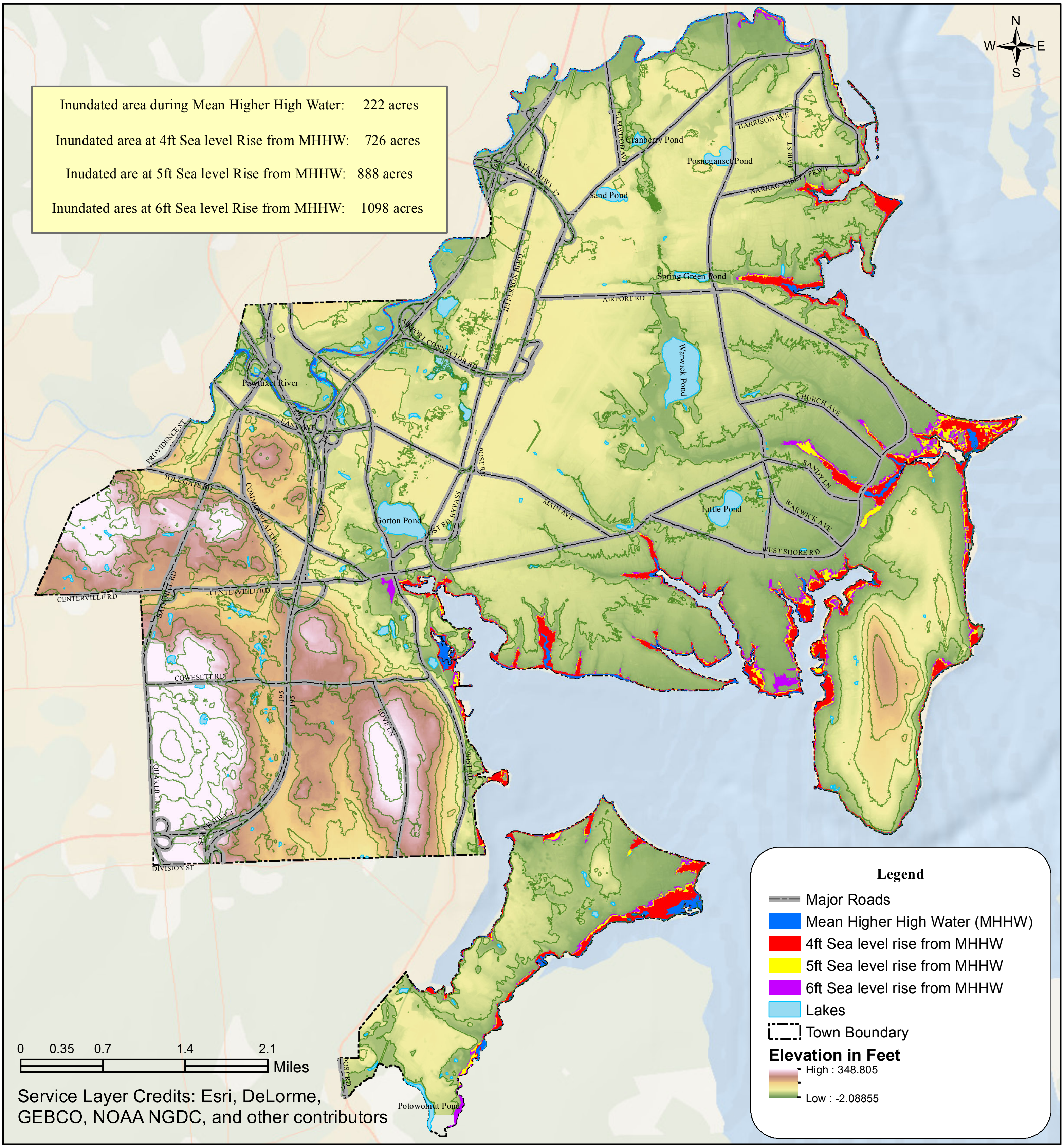
The following types of vulnerability maps have been produced as part of the study:

Map A: Inundation Map with topographic information.

Map B: Indicator maps for anthropogenic vulnerability

Map C: Combined water-climate vulnerability index

Map A : Inundation map of the town of Warwick



Map provides the information about the inundation areas by Mean Higher High Water level, 4ft sea level rise from MHHW, 5ft sea level rise from MHHW and 6ft sea level rise from MHHW at the Town of Warwick. It also contains the information of elevation of the Town and topography. It was estimated that 4ft, 5ft and 6ft inundation will cause 504 acres, 666 acres and 876

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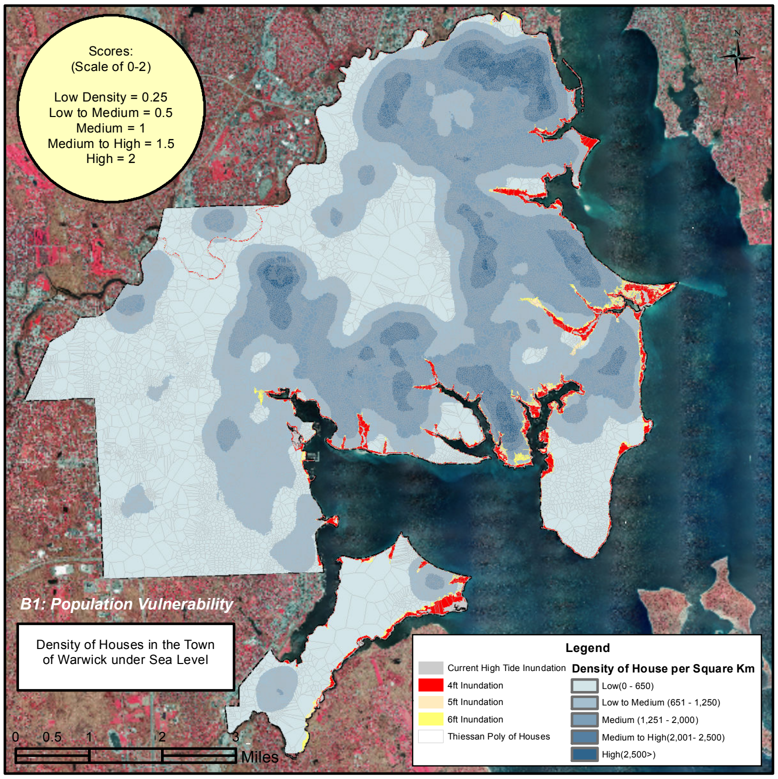
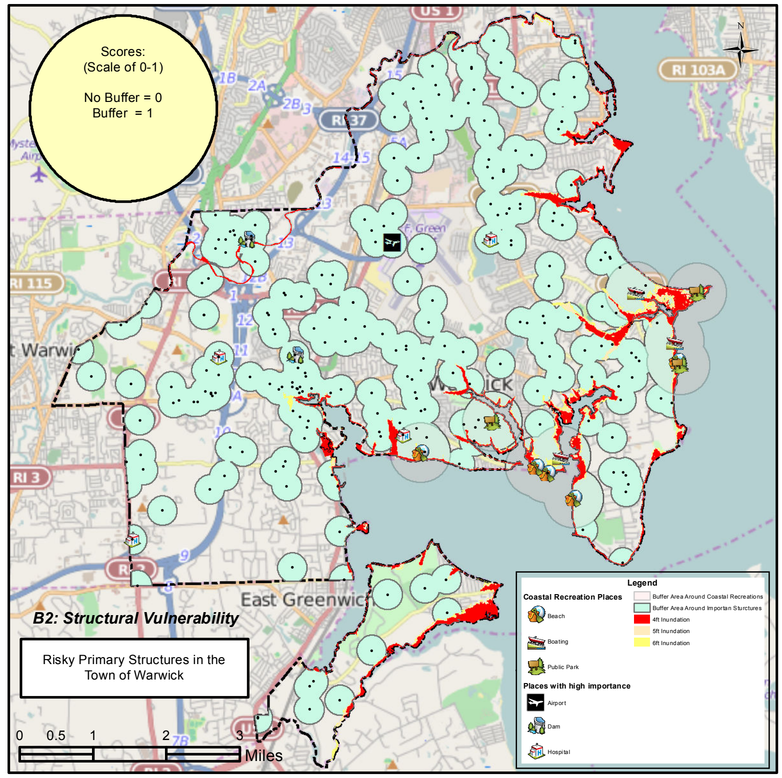
Data Sources

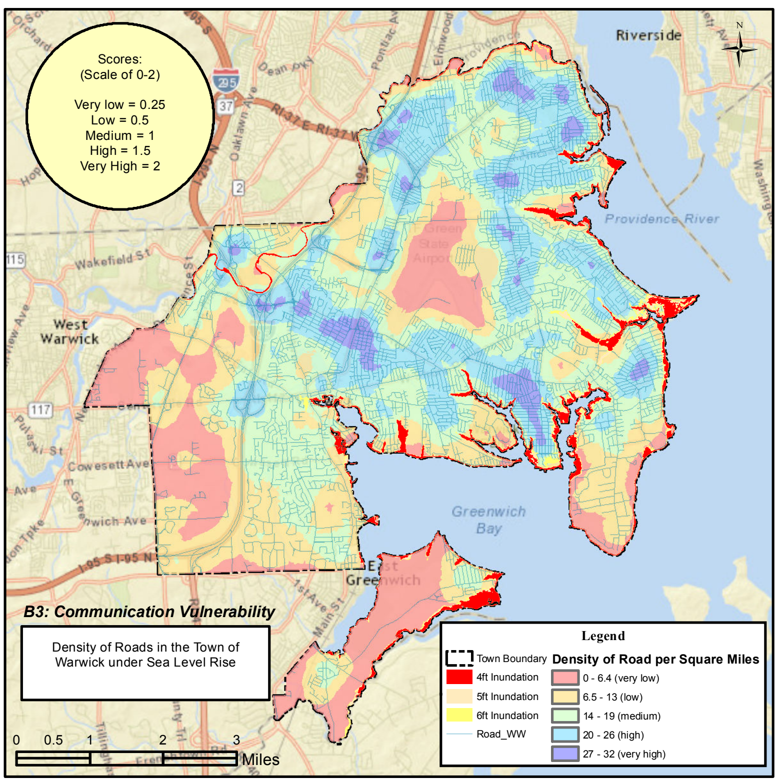
RIGIS, URIEDC,
Rhode Island Department of Transportation

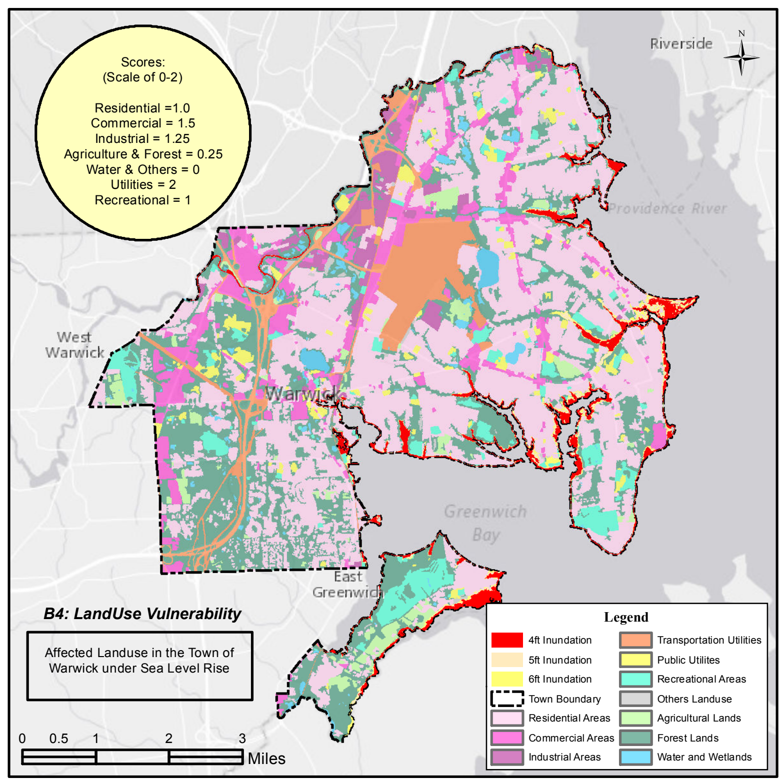
May, 2015

Map B : Indicator maps for vulnerability index









Four criteria has been considered to evaluate vulnerability zoning. The criteria's are, Population, Communication, Structures and Land Use. For each criteria a maps has been made shown in Map B. Each maps results a vulnerability index which represents each criteria of vulnerability. Population vulnerability has been developed using density information of houses. Structural vulnerability developed based on public utilities and recreational structures proximity. Communication vulnerability developed based on road density. Finally land use vulnerability developed based land use classes.

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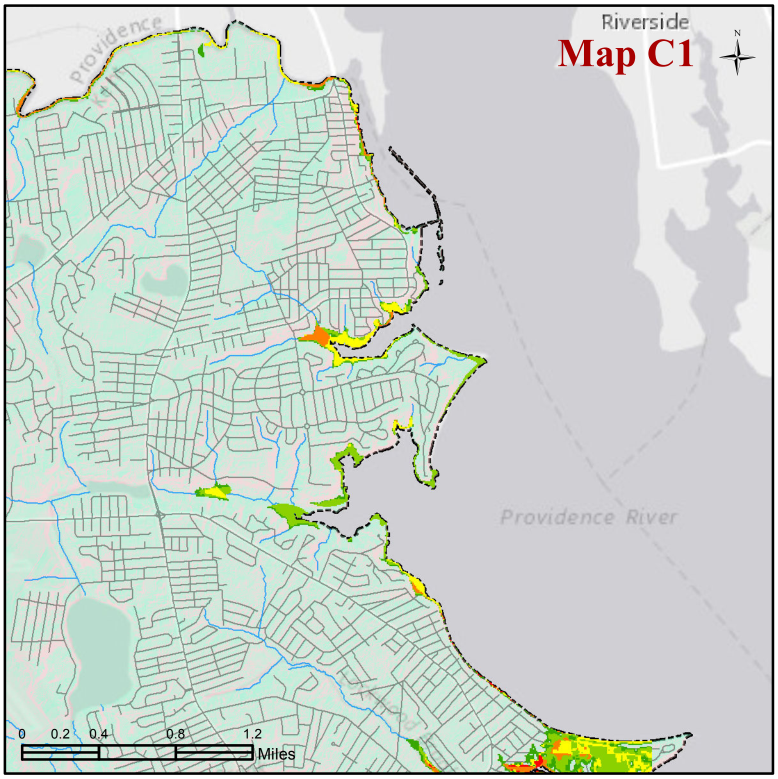
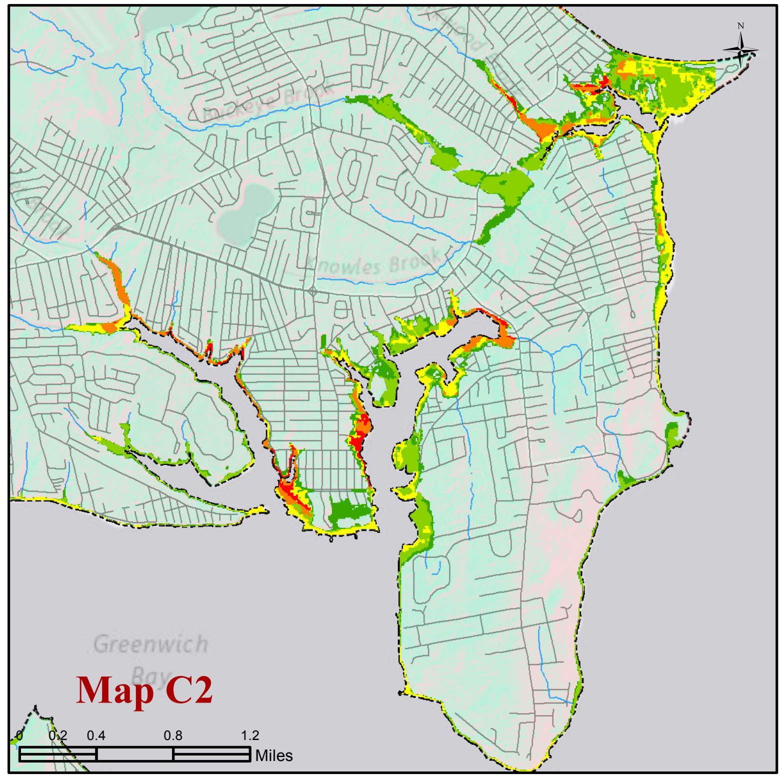
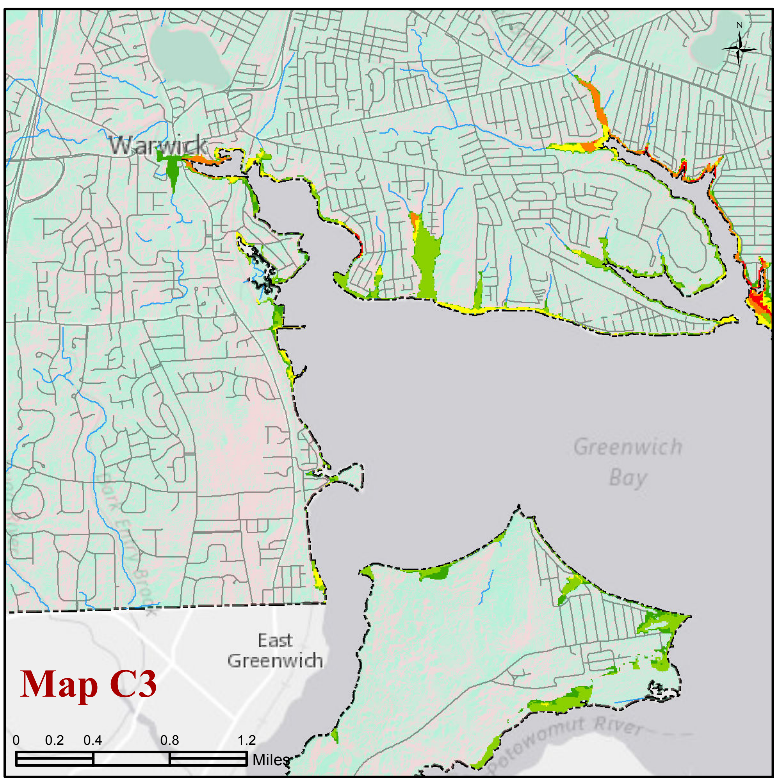
Map C : Combined vulnerability index

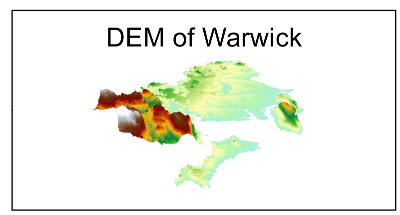






Risk Factor	Qualitative Attribute	Area (Square Miles)
1 to 5	Very Low	0.31
6 to 10	Low	0.53
10 to 15	Medium	0.27
16 to 20	High	0.11
20 to 25	Very High	0.03

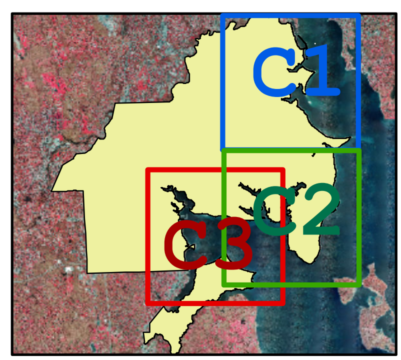
Scenarioes	Weight of Inundation Area
MHHW	0.25
4ft	3
5ft	2
6ft	1



Legend

Sea Level Rise Vulnerbility

- Very Low
- Low Risk
- Medium Risk
- High Risk
- Very High Risk
- Rivers
- Roads
- Town Boundary



The map shows vulnerable zones due to sea level rise in the Town of Warwick. From the criteria indicators that are found from Map B are combined according to some weight. The population, communication and land use each provided a weight of 2 and structural provide one. Later all this values are combined and formulated a combined weight map values ranging from 1 to 7. Then, inundation area of 0ft, 4ft, 5ft and 6ft are provided some specific weight and multiplied with combined weight map. In this way final risk map of the town of Warwick has been generated.

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Data Sources

RIGIS, URIEDC, NOAA
Rhode Island Department of Transportation

May, 2015

5. Pilot Effort on Dengue in Puerto Rico

Dengue fever is a virus transmitted primarily by *Aedes aegypti* mosquitoes (CDC 2014, Eisen and Lozano-Fuentes 2009, Gubler 2002, Little et al 2011) . There are an estimated 50-100 million cases a year worldwide, a number which, at present, is 30 times the amount of cases 50 years ago (Little et al 2011, WHO 2014). Because of the complexity of the disease, a vaccine has not yet been successfully manufactured. Dengue fever has 4 serotypes which people can build immunity to; however, if they contract more than one of the serotypes they are more likely to develop Dengue Haemorrhagic Fever (DHF) or Dengue Shock Syndrome (DSS) (Little et al 2011, CDC 2014). In addition to the cases of dengue fever, each year there are also about 500,000 cases of DHF and 22,000 deaths from DF/DHF most of whom are children (WHO 2014).

Dengue fever has emerged in the last 60 years as a major problem, but it has existed for hundreds of years. Dengue was present in the 18th and 19th centuries, but because of how slowly people and goods were able to move around the globe at that time, outbreaks were infrequent (Gubler 2002). That all changed during WWII when war impacted ecology, and hastened the movement of supplies and people (Gubler 2002). The first case of DHF was in Manila, Philippines, in 1953-1954 and it marked the beginning of the spread of dengue throughout Southeast Asia during the 1970's (Gubler 2002). At the time, the Americas were spared, mostly, because of the eradication of *Ae. aegypti* to stop the spread of yellow fever, however, once that program ended *Ae. aegypti* re-emerged and are currently a major threat (Gubler 2002). Increased global travel and trade aided in the spread of dengue fever to new areas (WHO 2014).

Aedes aegypti mosquitoes prefer humans for their blood meals and live in close proximity to humans (Little et al 2011). It has even been shown that the number of DF/DHF cases increases with population (Gubler 2002). In fact, several anthropogenic factors have created an ideal situation for *Ae. aegypti* mosquitoes including: *"rapid population growth, rural-urban migration, inadequate basic urban infrastructure (eg. unreliable water supply leading to householders to store water in containers close to homes) and* *increase in volume of solid waste , such as discarded plastic containers and other abandoned items which provide larval habitats in urban areas."* (WHO 2014). Discarded trash makes good larval habitat because the female *Ae. aegypti* will lay her eggs along the sides and when it rains, the water pools in the container, covers the eggs, and they hatch (CDC 2014, Little et al 2011).

Because there is no vaccine, the only way to prevent dengue is to manage mosquito populations (Little et al 2011). Early prevention/mosquito control methods included pesticide application and inspection of homes for breeding suitability, however, these methods were deemed "unsustainable" (CDC 2015). The United States Center for Disease Control (CDC) has a special "Dengue Branch" located in San Juan, Puerto Rico, where they publish weekly reports on cases for the island, and are testing innovative mosquito control techniques (CDC 2015). Ae. aegypti are also incredibly resilient and their eggs can survive long periods of desiccation, which is part of the reason they have spread so efficiently around the globe (CDC 2014).

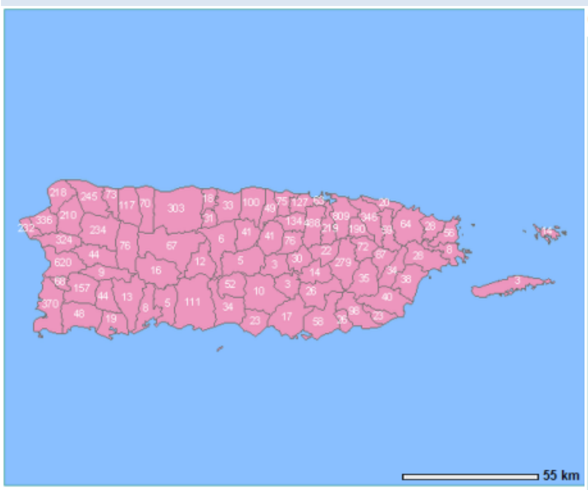
Puerto Rico has experienced epidemic dengue activity since 1963, and the disease is currently endemic (CDC 2015). Since 1990 there have been 4 large epidemics, the most recent in 2010 where there were nearly 27,000 cases reported – almost 1% of the island's total population (CDC 2015). In Puerto Rico, citizens are urged to play an active role in dengue management by wearing repellant, seeking medical care and fixing potential "breeding sites" for mosquitoes (CDC 2015). One example of these breeding sites are uncovered or broken septic tanks as, "…it was recently found that *Ae. aegypti* is able to undergo immature development in broken or open septic tanks… resulting in the production of hundreds or thousands of *Ae.aegypti* adults per day" (CDC 2015).

The following three pages shows a compilation of preliminary research data on Dengue spread in space and time across Puerto Rico and associated climatic and anthropogenic factors under study to assess the linkages between urban development, climatic factors, and impact on dengue transmission.

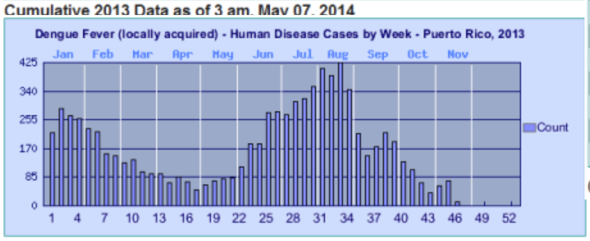
Background Information

Puerto Rico	Dengue
• Population: 3,620,897 • Slightly less than 3 times the size of Rhode Island • Capital city: San Juan – Population ≈ 390,000 • Tropical marine climate, little temperature variation between seasons	• Transmitted by *Aedes aegypti* and *Aedes albopictus* • 50-100 million cases world wide each year (WHO) • Periodic epidemics in P.R. since 1963 • Most recent epidemic, 2010 with nearly 27,000 cases (nearly 1% of the island's population)

https://www.cia.gov/library/publications/the-world-factbook/geos/rq.html, http://www.cdc.gov/Dengue/epidemiology/index.html, http://www.cdc.gov/dengue/about/inPuerto.html, http://www.cdc.gov/Dengue/entomologyEcology/index.html



Cumulative 2013 Data as of 3 am, May 07, 2014



Cumulative Human Disease Cases by Local Jurisdiction - Puerto Rico, 2013

Adjuntas Municipality	16	Fajardo Municipality	56	Naguabo Municipality	28
Aguada Municipality	336	Florida Municipality	31	Naranjito Municipality	76
Aguadilla Municipality	218	Guanica Municipality	19	Orocovis Municipality	5
Aguas Buenas Municipality	22	Guayama Municipality	58	Patillas Municipality	98
Aibonito Municipality	3	Guayanilla Municipality	8	Penuelas Municipality	5
Anasco Municipality	324	Guaynabo Municipality	219	Ponce Municipality	111
Arecibo Municipality	303	Gurabo Municipality	72	Quebradillas Municipality	73
Arroyo Municipality	26	Hatillo Municipality	70	Rincon Municipality	232
Barceloneta Municipality	18	Hormigueros Municipality	68	Rio Grande Municipality	64
Barranquitas Municipality	3	Humacao Municipality	38	Sabana Grande Municipality	44
Bayamon Municipality	488	Isabela Municipality	245	Salinas Municipality	17
Cabo Rojo Municipality	370	Jayuya Municipality	12	San German Municipality	157
Caguas Municipality	279	Juana Diaz Municipality	34	San Juan Municipality	809
Camuy Municipality	117	Juncos Municipality	87	San Lorenzo Municipality	35
Canovanas Municipality	59	Lajas Municipality	48	San Sebastian Municipality	234
Carolina Municipality	346	Lares Municipality	76	Santa Isabel Municipality	23
Catano Municipality	63	Las Marias Municipality	44	Toa Alta Municipality	134
Cayey Municipality	26	Las Piedras Municipality	34	Toa Baja Municipality	127
Ceiba Municipality	8	Loiza Municipality	20	Trujillo Alto Municipality	190
Ciales Municipality	6	Luquillo Municipality	28	Utuado Municipality	67
Cidra Municipality	14	Manati Municipality	33	Vega Alta Municipality	49
Coamo Municipality	10	Maricao Municipality	9	Vega Baja Municipality	100
Comerio Municipality	30	Maunabo Municipality	23	Vieques Municipality	3
Corozal Municipality	41	Mayaguez Municipality	620	Villalba Municipality	52
Culebra Municipality	14	Moca Municipality	210	Yabucoa Municipality	40
Dorado Municipality	75	Morovis Municipality	41	Yauco Municipality	13

Cumulative Total Entire State: 8,204

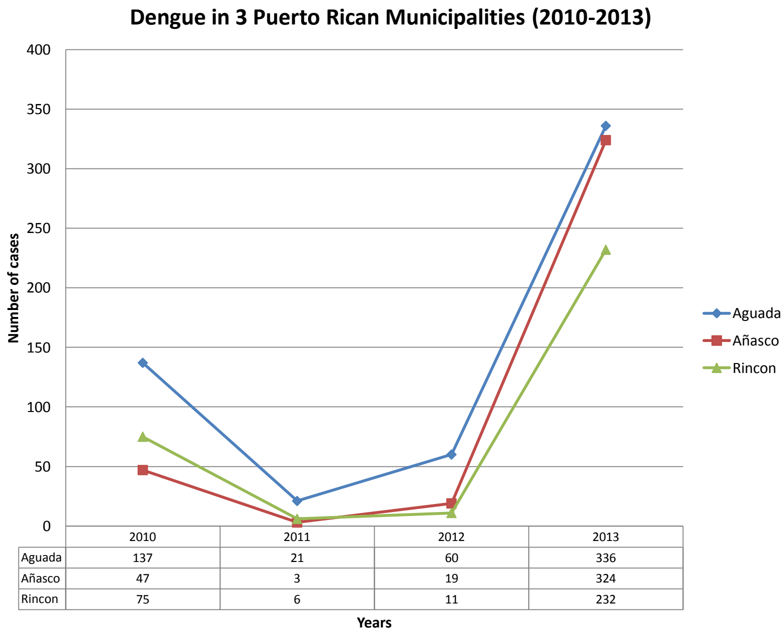
http://diseasemaps.usgs.gov/2013/del_pr_human.html

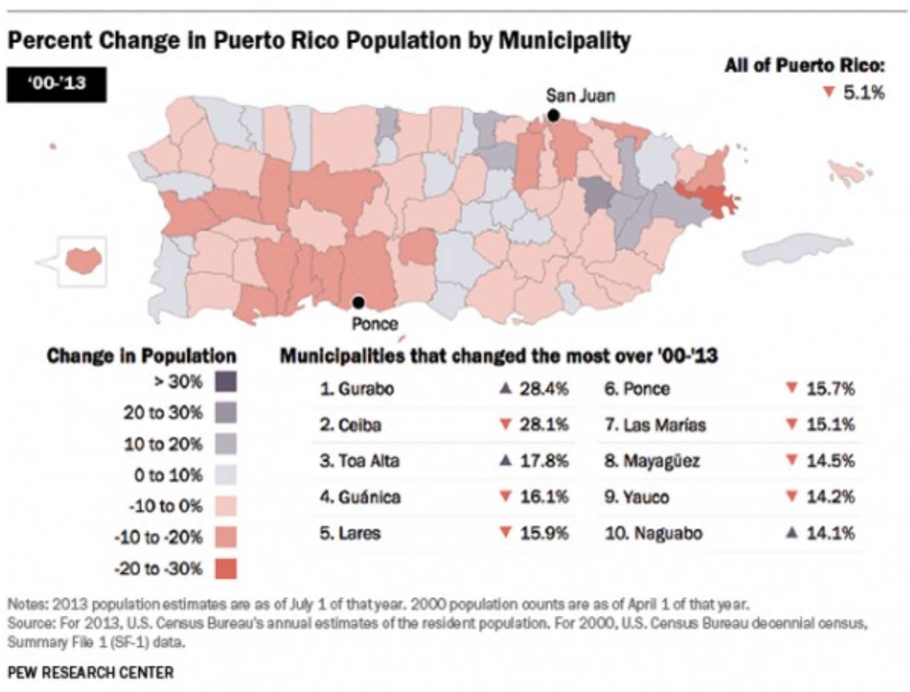
Slides Page 1

Municipalities with an Increase in Dengue Cases

Municipality	# of Dengue Cases 2010	2011	2012	2013	Population Census 4/1/2010	Estimate 7/1/2014
Aguada	137	21	60	336	41,959	40,329
Aguas Buenas	16	7	11	22	28,659	27,473
Añasco	47	3	19	324	29,261	28,403
Cabo Rojo	74	1	81	370	50,917	50,349
Caguas	248	42	141	279	142,917	137,032
Carolina	266	124	627	346	176,762	165,820
Comerio	13	2	9	30	20,778	20,253
Culebra	2	0	2	14	1,818	1,818
Hormigueros	18	0	35	68	17,250	16,746
Mayaguez	226	7	182	620	89,080	81,915
Rincon	75	6	11	232	15,200	14,782
San German	58	0	61	157	35,691	33,725

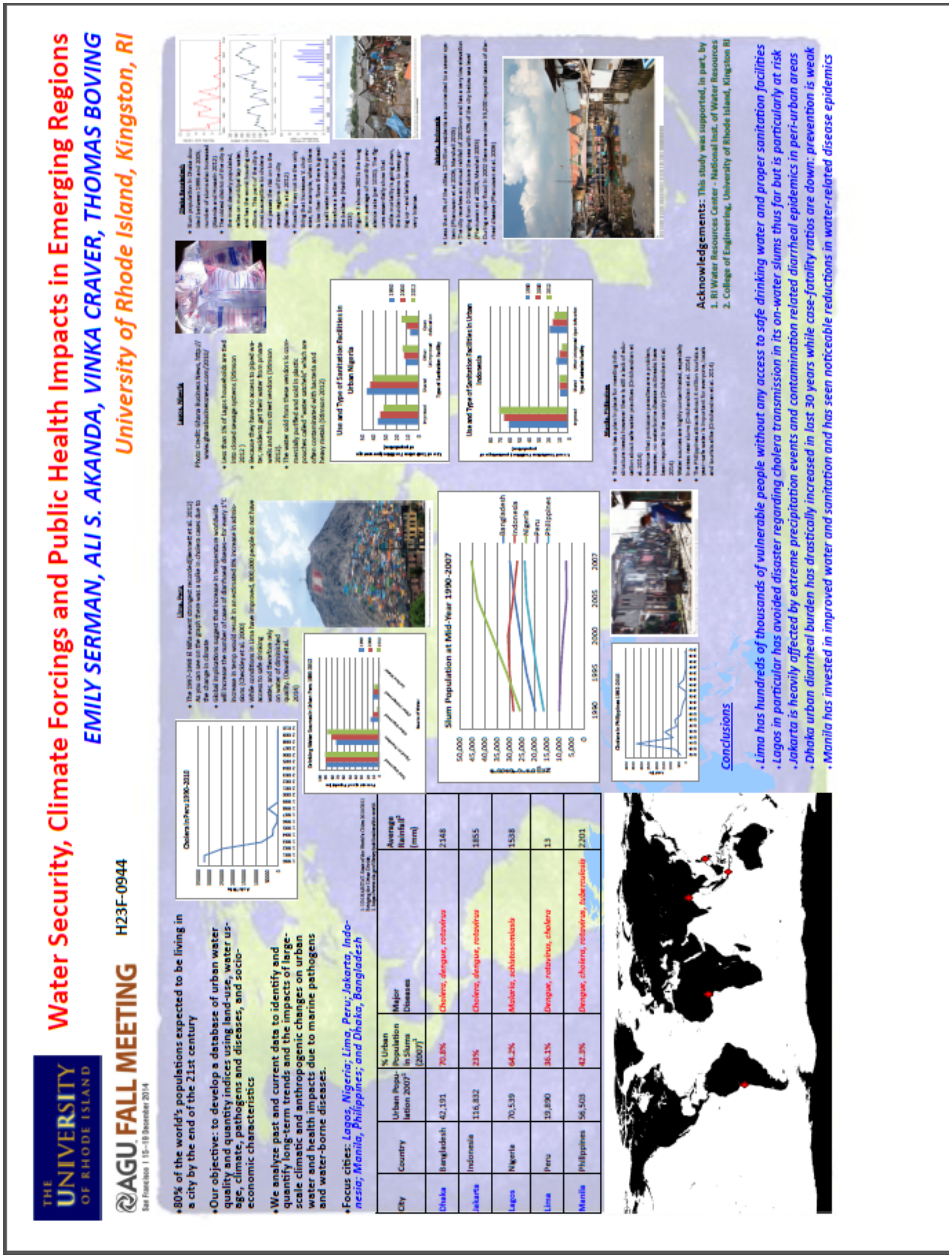
Slides Page 2





<u>Slides Page 3</u>

6. Poster Presented at AGU 2014 Fall Meeting



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Information Transfer Program Introduction

The two main focuses of this project deal with outreach to the Rhode Island community. The first focus deals with the continuation of the already successful Clean Water Conference that is held each year at the University of Rhode Island. This ongoing conference series covers both the policy and technical aspects associated with providing clean water in the state of Rhode Island. The conferences reach out to professionals and students alike. It allows professionals to take away a knowledge of current projects around the state and region and it gives students a chance to network with the professionals in attendance. The second focus is a summer workshop for middle and high school students. This summer workshop would promote interest in clean water concepts using lectures, laboratories, and field trips. The goal of the workshop is to encourage students to pursue STEM related careers.

Outreach for the Promotion of Clean Drinking Water in Rhode Island

Basic Information

Title:	Outreach for the Promotion of Clean Drinking Water in Rhode Island
Project Number:	2014RI118B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	RI 2
Research Category:	Not Applicable
Focus Category:	Education, Surface Water, Floods
Descriptors:	None
Principal Investigators:	Harold Knickle, Geoffrey Bothun

Publications

There are no publications.

Final Report

Drinking Water Outreach in Rhode Island

Harold N. Knickle
Professor Emeritus of Chemical Engineering
University of Rhode Island

Abstract

There were two thrusts to this project. The first was to create a conference to provide background and knowledge for working professionals in the clean water fields and to educate graduate and undergraduate students in the scope of the clean water field. This ongoing Rhode Island conference series on clean water was promoted and held at the University of Rhode Island. This ninth annual conference focused on Water Planning for the Future with a keynote presentation by Alisa Richardson, Principal Engineer, Office of Water Resources, RI Department of Environmental Management. This focus provided water professionals in Rhode Island with an overall view of problems associated with water in Rhode Island by inviting them to participate in the conference.

The second focus was to promote interests in professions associated with water resources by students. This major activity involved the hosting of a summer workshop (camp) at the University of Rhode Island for middle and high school students to introduce them to clean water concepts using lectures, laboratories, and field trips to promote interest in clean water careers.

INTRODUCTION

The project focused on information technology and education by two major outreach activities, a comprehensive conference for the clean water community and a summer camp for high school students to promote interest in clean water related careers.

OBJECTIVES

Two major objectives have been set for this project.

1. The first is to advance the awareness and knowledge of the importance of clean water in Rhode Island and provide insight into the various factors affecting the

ability to obtain clean water for multiple uses in Rhode Island by hosting a major Clean Water Conference. The creation of the conference provided background and knowledge of the work of professionals in the clean water fields. The conference has become an annual event. Graduate students will be encouraged to take courses in environmental areas and undergraduates will be encouraged to consider pursuing degrees related to the clean water profession.

2. The second major activity was the hosting of a summer camp at the University of Rhode Island for high and middle school students to introduce students to clean water concepts with a goal of promoting interest in clean water careers.

KNOWLEDGE TRANSFER

Dissemination was an important part of this project. Results of this project will be shared with all participants. A WEB page was added to the Rhode Island Water Resources web site on Clean Water. The WEB page contains important information on the conference and information presented at the conference. The WEB page will also contain a description of the summer camp. The Audiences included clean water professional, graduate, undergraduate, and high school students, faculty and administrators. The WEB page is www.wrc.uri.edu

LEADERSHIP

The conference effort was guided by a steering committee. The steering committee provided guidance in choosing key speakers and presenters and hosting special break-out sessions. The steering committee consisted of students, faculty and administrators at the University of Rhode Island and representation from government and industry. Specific representation on the committee will include a representative from the Providence Water Board, Dr. Rose, on the board of the Kingston Water Supply, Dr. Thiem, Director of the RI Water Resources Center, Dr. Barnett, leader of the RI Pollution Prevention Center, Dr. Gray, with research interests of replacing solvents for cleaning, Dr. Bothun with interests in student learning and Dr. Knickle with research interests in Clean Water.

TIMELINE

June 23, 2014 to June 27, 2014: Ran the Clean Water Summer Camp for High School Students.

November 13, 2014: Held the Clean Water Conference

SUMMER CAMP FOR HIGH SCHOOL STUDENTS ON CLEAN WATER

High school students were recruited from high schools in Providence, Rhode Island to participate in the 2014 summer camp. Recruitment took place by visiting the schools and meeting the science teachers. With their help students were recruited that have an interest in this clean water program. The schedule for the camp was from Monday to Friday and from June 23 to June 27. Students started the day at 9:00 am and completed the day at 3:30 pm. Lunch was provided by the Dean of the College of engineering. There were no fees for this summer camp and both lunch and buses were provided to the students.

Activities included presentations of the water cycle, chemistry of water, water quality and treatment, sewage treatment and biological technology, runoff and storm water, industrial water pollution, pollution prevention, and investigation of macro-invertebrate in the URI pond and health effects. Laboratory exercises and experiments included surface tension, settling measurements, turbidity measurements, water quality sampling and testing, pH and dissolved oxygen measurement, bacteria pollution testing, conductivity testing, acid rain testing, aeration, adsorption, filtration and settling, oil spill spreading, and macro invertebrate identification. and health effects. Field work included the collection of samples from various locations and water bodies. Field trips were made to a fresh water treatment facility and a sewage treatment plant as well as to the well water source and distribution on the URI campus.

Success of the summer camp was determined by two surveys one at the beginning and one at the end of the camp. Each student also wrote a brief laboratory report for some of the laboratory exercise and an essay indicating the activities of most interest to each individual student.

Excellent laboratory facilities were used at the University of Rhode Island for the summer camp high school students and in a chemistry laboratory at a Providence high school. Facilities at the University of Rhode Island included Bliss Hall, where the environmental laboratories reside, and in Crawford Hall which houses the chemical engineering laboratories. Glassware, scales pH and conductivity meters, chemicals and other equipment was available in these laboratories for use in the summer camp activities. Classrooms and computer labs were available in both building with appropriate audio-visual devices. The computer lab was used to access the web to identify bacteria in water and to use EXCEL to calculate oil spill spread on calm water. The Flyer is attached..

Training Potential.

Summer Camp on Clean water

The number of high school students attending was 24, 9th, 10th and 11th grade students. These students were screened for having potential interest in being in clean water professions and interested in the STEM disciplines.

CONFERENCE ON CLEAN WATER

The Clean Water conference of 2013 was held at the University of Rhode Island in Cherry Auditorium of the Kirk building. (See below) Invited speakers provided focus on the role of wastewater in Rhode Island. The program is included on the next page. The presentations are on the RI Water Resources WEB site: www.wrc.uri.edu

About 32 graduate students attended and 56 undergraduates. These students were primarily from Civil and Environmental Engineering and from Chemical Engineering.

About 20 other water professionals attended.   Most of the undergraduates were juniors or seniors. This attendance exceeded expectations.

The Cherry Auditorium was used for the conference along with the attached gallery for displays and exhibits. Coffee breaks were held the hallways surrounding the auditorium.

Cherry Auditorium – The Engineering Conference Center-Part of the Kirk Building

Final program 2013

Clean Drinking water CONFERENCE

FINAL PROGRAM 2013

EIGHTH ANNUAL CLEAN WATER CONFERENCE

12:45 to 1:00pm Registration

1:00 Welcome Remarks
Dean Wright,
Dr. Thiem, Dr. Knickle

Session 1: 1:10pm to 2:00 pm
Follow the Water in Rhode Island: Planning for the Future.

Alisha Richardson, Principal Engineer, RI DEM, Office of Water Resources

COFFEE BREAK

Session 2: 2:15 to 3:00 pm

Current Status of Real-Time data on Streamflow, Groundwater, Water Quality, Precipitation and Lakes and Reservoirs in Rhode Island

Gardner Bent, Senior Hydrologist, NE USGS Water Sciences Center

Session 3: 3:00 to 3:40pm

Roadway Runoff Treatment Including Activated Carbon

Hui Chen Ph.D., URI Post-doc student

4:00 pm ADJOURN

East Greenwich Wastewater Treatment Plant

Warwick Sewage Treatment Plant

Planning Committee Members
From the College of Engineering
Dr. Stanley Barnett, Dr. Donald Gray, Dr. Harold Knickle, Dr. Vincent Rose, Dr. Leon Thiem, Dr. Geoff Bothun

Sponsored by

RI Water Resources Center

www.wrc.uri.edu

Department of Chemical Engineering

www.egr.uri.edu/che

Department of Civil and Environmental Engineering

www.egr.uri.edu/cve

Conference is Free All Welcome

Refreshments Courtesy of Amgen, W Greenwich RI

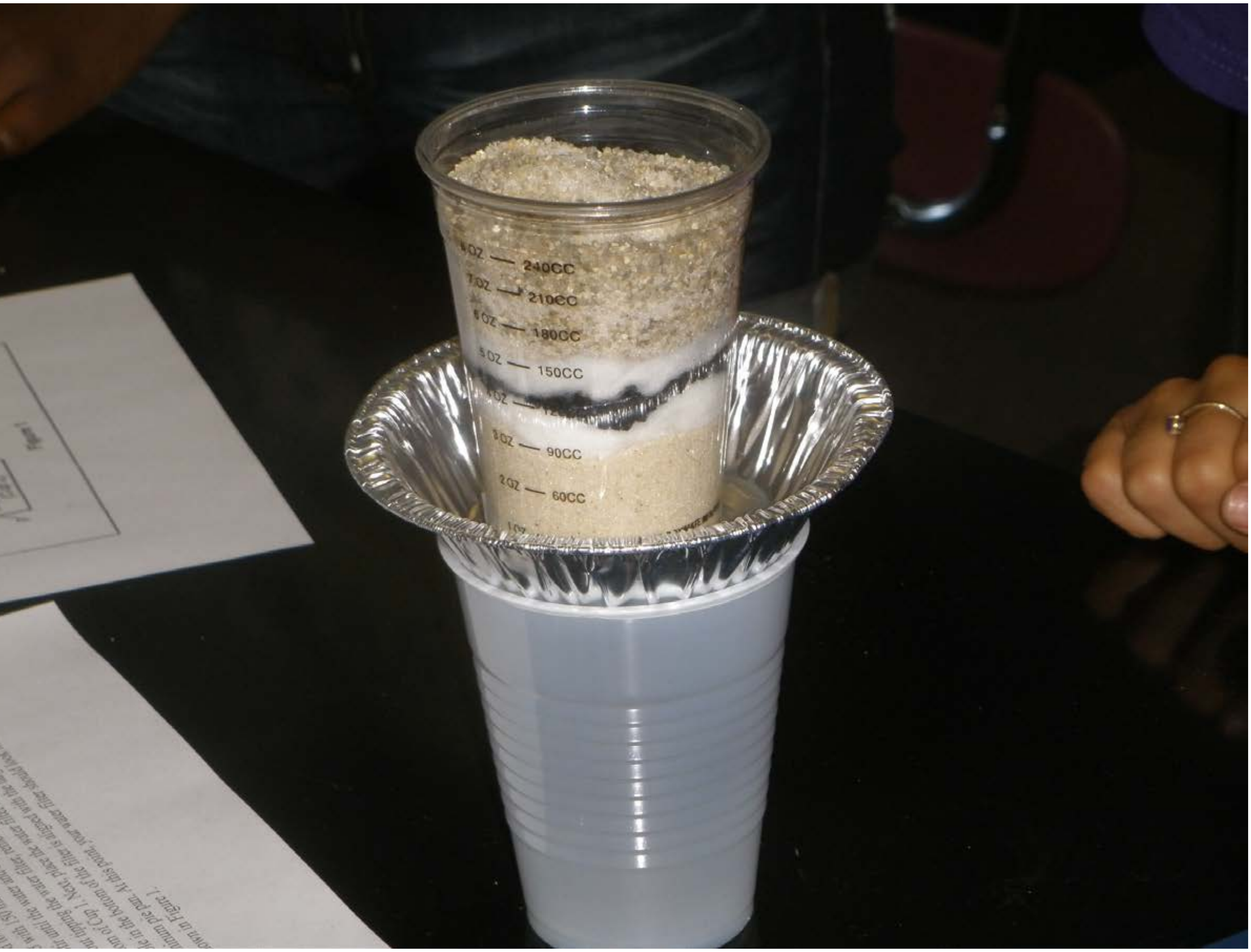
RESULTS AND BENEFITS.

The conference provided insight into the various factors affecting the ability to obtain clean water for multiple uses in Rhode Island. The breadth and depth in this project on water quality provided both awareness and knowledge to the clean water community in Rhode Island and to graduate and undergraduate students. This conference raised awareness of conservation and a broad planned approach to water supply in Rhode Island..

The hosting of a summer camp at the University of Rhode Island for high school students brought 20 students to the URI campus and provided lectures and labs on to clean water concepts with a goal of promoting interest in clean water careers.

Preparing for Water Filtration Experiment.

Pouring the "dirty" water to be filtered.



Close-up of filter.

Inspecting the filter.

Filtration is complete.

Laboratory setup.

Warwick, Rhode Island Wastewater Treatment Facility.

Warwick treatment facility clarifier.

Pawtucket, Rhode Island Water Treatment Plant Filters

High School Teacher, Dr. Fontaine, Receiving a Certificate for Helping with the Summer Camp Presented by Harold Knickle

Water quality sampling on 30-Acre Pond.

Finding Macro-invertebrate in 30 Acre Pond

Gathering Macro-invertebrate in 30 Acre Pond.

Collecting Macro-Invertebrates in 30 Acre Pond

Writing up lab reports.

Students with their diplomas.

Program/Flyer for the Summer Camp on Clean Water June 2013

Clean water ACTIVITIES

ALL SESSIONS 9:00 TO 3:30

Breakfast Snack and Lunch Included

Sponsored by LSAMP & URI Water Resources Center Leon Thiem, Director

College of Engineering **No person shall be denied membership because of race, color, sex, handicap, nationality, religious affiliation or belief**

URI

Summer 2014

Clean Water Engineering & Science Academy

June 23 June 27

9:00 AM to 3:30 PM

CLEAN WATER ACTIVITIES

ALL SESSIONS 9:00 TO 3:30

Breakfast Snack and Lunch Included

Session 1: Monday June 23 URI

- Introductions and Survey
- Surface Tension: Drops on a Penny
- Water Cycle Introduction
- Settling Measurements
- Turbidity Measurements
- Intro to Water Chemistry and the Periodic Table
- Water Sample Collection
- Drinking Water Testing
- Laboratory Report

Session 2: Tuesday June 24

- **Reaction Time & Temperature**
- Sewage Treatment Flow Sheet
- Biology Technology
- Nitrogen and Phosphorous
- Introduction to COD,BOD
- Bacteria check 4 microbes www.google.com
- Warwick Sewage Treatment Plant Field Trip. J. Burke

Session 3: Wednesday Jun 25

- Dissolved Oxygen and pH
- Common Materials and their pH
- Water Hardness Testing
- Theory of Adsorption
- Adsorption Measurement
- Filtration and Settling
- Filtration Laboratory
- Laboratory Report
- Water Runoff and Storm Water-Hydrology
- Pollution Prevention.
- Oil Spills Lab and graphs
- Alternate Lab
- Video: Ponds & Rivers
- Laboratory and Report

Session 4: Thursday June 26 T2

- Health Effects Associated With Water Quality
- Filtration and Settling

- Filtration Laboratory
- Laboratory Report
- Pawtucket Water Supply Field Trip

Field Trip Chris Collins

- **Friday June 27 URI**
- 30 Acre Pond Sampling
- Macro Invertebrates
- Introduction and Identification
- Post Assessment Survey
- Certificates and Awards

Application to Clean Water Academy 2014

June 23 to June 27

CIRCLE YOUR INTEREST

Math Science Engineering

Name: ___________________________

Address: __________________________

Telephone: ________________________

Email: ___________________________

School Name:_____________________

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Grade: ___________________________

PARENTS' APPROVAL SIGNATURE

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Return to: Dr H. Knickle, College of Engineering 874-2678, knickle@egr.uri.edu

122 Crawford Hall, Kingston, RI 02881

Clean Water Academy Summer 2013
June 23-June 27

Sponsored by URI Water Resources Center and the College of Engineering

Are you a high school student interested in math and science?

Are you interested in understanding how math and science are a key part of being an engineer?

Do you want to experience some of the fun of doing experiments?

If you answered yes, then you should participate in our own Clean Water Academy.

The Academy Coordinators want to help you to see just how exciting your future can be.

These **hands on** sessions will show you how interesting science and engineering can be, while you explore the options in engineering and learn valuable tools for success.

The University of Rhode Island's College of Engineering has eight undergraduate programs. There are also many physical, chemical, and biological science programs at URI.

If you decide to participate, other students will join you in the following activities:

- *Interactive workshops.*
- *Participate in real hands-on experimental activities.*
- *Interact with teachers and students from the University of Rhode Island.*

H. Knickle, PI

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	2	0	0	0	2
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Aaron Bradshaw, a RI water Resources Center PI, had an article written about his research on the impact of an earthquake on the Gainer Dam in Scituate, RI in Rhode Island's major newspaper, The Providence Journal. He also appeared on several local television stations to discuss his findings. After reviewing Aaron's report, the owner of the dam (Providence Water Supply Board) provided funding to conduct a soil boring analysis on a part of the dam to verify his results.