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Report No. 477

COASTAL GROUNDWATER WATCH: A CITIZEN SCIENCE PROJECT

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COASTAL GROUNDWATER WATCH: A CITIZEN SCIENCE PROJECT

ABSTRACT

The goals of this study were to utilize citizen scientists in groundwater research in a coastal community where groundwater plays a large role in sustainable water resources management, and assess the extent of groundwater and marine inundation in response to future sea-level rise scenarios. A total of 7 citizen scientists participated in the study by measuring water levels from 15 groundwater monitoring wells using water level meters once a week over a 10-week period. Automated water level loggers were deployed in three of the same wells to assess the quality of the data collected by the citizen scientists. Additional water level loggers were deployed in other groundwater monitoring wells to increase the amount of water level data collected across the island. Several methods were used to assess agreement (i.e., validity) between water level measurements collected by citizen scientists and automated water level loggers. Scatter plots showed that data did not significantly deviate from the line of linearity, suggesting that the data collected by the citizen scientists were comparable to the data collected by automated water level loggers. The Pearson correlation coefficient was greater than 0.9 for all plots that revealed a linear correlation between measurements from different methods. The Bland-Altman method was also used to evaluate the validity of measurements by assessing agreement between measurements from citizen scientists and automated water level loggers. The intraclass correlation coefficient (ICC) and the concordance correlation coefficient (CCC) were used to assess reliability of measurements of water levels from citizen scientists. The values for the ICC and CCC were greater than 0.95 indicating excellent agreement. These values demonstrate that environmental data collected by citizen scientists can be trustworthy. A pretest-posttest survey design and a focus group were used to examine how participants perceived the citizen science project, and how participation as a citizen scientist influenced the participants' knowledge about water resources and stormwater flooding. Qualitative data suggest that citizen scientists improved their knowledge about groundwater systems on the island. Additionally, the citizen scientists found the project to be enriching and beneficial to their understanding of issues facing the island (e.g., storm water flooding). The groundwater data from both the citizen scientists and automated water level loggers were used to calibrate a numerical groundwater model that characterized the baseline conditions of the water table on the island. Impacts of projected sea-level rise ranging from 0.2 m to 1.4 m on the baseline water table were then simulated under steady state conditions. Finally, geospatial techniques were used to estimate the proportion of land that would be lost to marine inundation and groundwater inundation under identical sea-level rise scenarios. Results indicate that marine and groundwater inundation would have comparable effects on the island, with between 7 and 22% of the land being lost under sea-level rise scenarios of 0.2 to 1.2 m. At extreme sea-level rise scenarios (1.4 m), the effects of groundwater inundation are far much greater than those of marine inundation (with losses of 28% for marine inundation and 40% for groundwater inundation). As a consequence, groundwater inundation may therefore play an important role in future discussions about how climate change and sea-level rise may impact groundwater resources in coastal communities. Involving community residents in scientific research such as the project described in this report may therefore be an effective way for positively engaging with residents about important environmental issues such as climate change, sea-level rise and groundwater resources.

ACKNOWLEDGMENTS
The North Carolina Coastal Federation, town of Atlantic Beach, town of Emerald Isle, town of Pine Knoll Shores, and the Trinity Center are thanked for providing access to sites where groundwater monitoring wells were installed on Bogue Banks. We would like to express our gratitude to Robert Howard at the Center for GIScience at East Carolina University for designing and developing a prototype portal ((e.g., https://www.nccoastalatlas.org/cgww) that citizen scientists can use to submit groundwater level data to project personnel. This project would not have possible had it not been for the dedication of the citizen scientists that participated in the project. This research project was supported with funds from the North Carolina Water Resources Research Institute (Project No. 14-09-W) and the North Carolina Sea Grant (Project No. R/14-NCSG-02).

1. INTRODUCTION

Citizen science, which is the public participation of non-scientists in scientific research (Johnson et al., 2014), is a tool that is useful for connecting the public to the scientific community with the goal of expanding scientific knowledge and literacy (Bonney et al., 2009). Citizen scientists are therefore increasingly being sought to collect environmental data across various temporal and spatial scales in many parts of the world to meet various needs (e.g., Hidalgo-Ruz et al., 2013; Newson at al., 2015; Dennhardt et al., 2015; Hollow et al., 2015; Jackson et al., 2015; De Coster et al., 2015). Although citizen scientists may provide an opportunity to collect various types and quantities of data, questions remain about the quality of the collected data (e.g., Tregidgo et al., 2013).

To counter the notion that the threat of a progressively shallow water-table that is induced by rising sea-level is generally an unrecognized risk by coastal residents, we involved citizen scientists in this research project to characterize the water table on Bogue Banks. The citizen scientists were to collect groundwater level data, and provide feedback about their perceptions of the groundwater monitoring project. Researchers involved citizen scientists in the project because the literature suggests that collaborations with the citizen scientists are more likely to have sustained impacts on local communities than solutions generated by outsiders (e.g., Robinson, 2013).

Current research suggests that climate change and sea-level rise will have a significant effect on water resources in coastal communities around the world (Green *et al*., 2011; Nicholls and Cazenave, 2010; Taylor *et al*., 2013). As the earth warms, it is expected that glacial melting and ocean water expansion will lead to increased volumes of water in the oceans. Such an increase will lead to sea-level rises of 0.2 m to 1.4 m by 2100 (Jevrejeva *et al*., 2012; NRC, 2012; Rahmstorf *et al*., 2012; Horton *et al*., 2014). In many coastal regions, sea-level rise may cause marine inundation (where previously dry land is occupied by sea water), saline water intrusion (where saltwater replaces freshwater in aquifers) (Cooper *et al*., 2013) and/or groundwater inundation (where groundwater tables reach the land surface leading to localized flooding) (Manda et al., 2014; Mastersen *et al*., 2013; Rotzoll and Fletcher, 2013) (Fig. 1). Whereas marine inundation and saltwater intrusion are well-documented in the literature, groundwater inundation has not received great interest from researchers in the field of water resources. Groundwater inundation may pose threats to local communities. These threats include loss of available dry land, chronic coastal flooding, changes to surface drainage patterns, creation or expansion of wetlands, and increased vulnerability to storms (Nicholls, 1995).

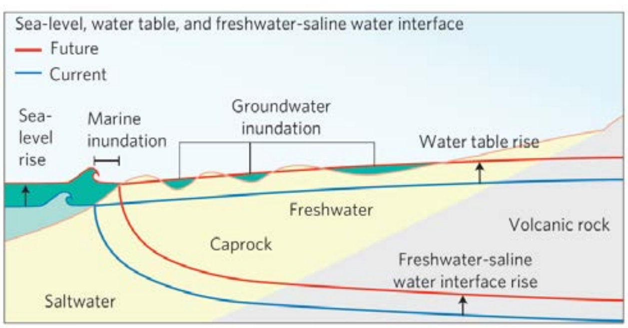

Figure 1 Sketch illustrating marine inundation and groundwater inundation resulting from sea-level rise (from Rotzoll and Fletcher, 2013).

This project addresses the two issues highlighted above by (a) enlisting community members in a scientific project to characterize the water table in coastal communities where groundwater plays a large role in sustainable water resources management, and (b) assessing the extent of groundwater and marine inundation in response to future sea-level rise scenarios. Specific objectives of the study are to (a) recruit, train, educate and engage citizen scientists in a groundwater monitoring project, (b) monitor and record groundwater levels using citizen scientists and automated water level loggers, (c) determine the validity and reliability of hydrologic data collected by citizen scientists, (d) evaluate the perceptions of citizen scientists participating in the project, and (e) apply groundwater modeling and geospatial techniques to assess the proportion of land impacted by groundwater and marine inundation in response to future sea-level rise scenarios.

1. STUDY SITE AND HYDROGEOLOGIC SETTING

The study was conducted on Bogue Banks, a ~28 km^2 barrier island off the coast of North Carolina (Fig. 2). In many communities on Bogue Banks (e.g., the towns of Emerald Isle, Pine Knoll Shores and Atlantic Beach), stormwater flooding events are of great concern to residents. Town managers on the island are therefore intent on employing engineering solutions to alleviate the effects of the stormwater flooding events. However, any engineering solutions may be inadequate if the drivers of the flooding are not entirely understood. Since the island is dominated by dunes and swales, the low lying areas may be prone to flooding where the water table rises above the ground surface during certain storm events, thereby contributing to stormwater flooding.

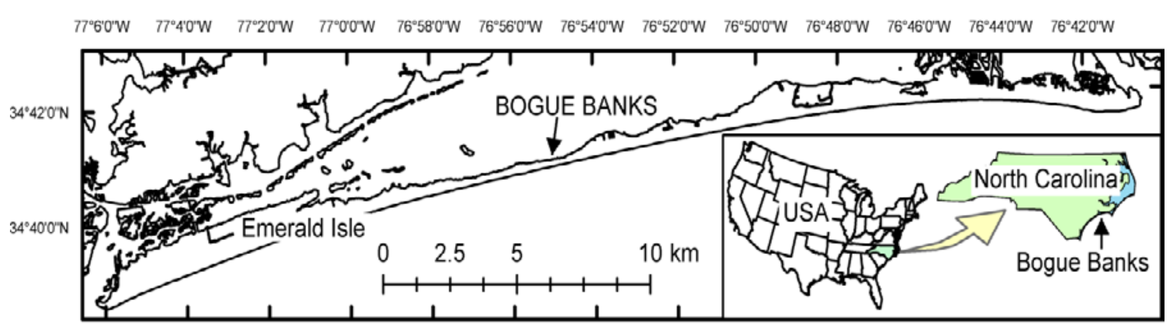

Figure 2 Location of Bogue Banks off the coast of North Carolina.

The topography on Bogue Banks is characterized by a series of shoreline parallel dunes and swales (Fig. 3). The elevation ranges from approximately 1 m below sea-level to 17 m above sea-level. The largest dunes on Bogue Banks are observed in the south eastern part of the island, whereas the ground surface in northern portion of the island generally slopes gently into Bogue Sound.

Lautier (2001) characterizes the hydrogeologic framework of the North Carolina Coastal Plain aquifer system as a wedge of formations that dip and thicken to the east. The resulting sediment wedge varies from 30 meters thick in the western coastal plain to more than 2400 meters thick under Cape Hatteras on top of Paleozoic basement rock (Winner and Coble, 1996). The surficial aquifer or water table aquifer, (which is the focus of this study) is an unconfined, Quaternary aquifer composed mainly of sandy material with some beds of mud and clay that is present throughout the North Carolina Coastal Plain (Lautier, 2001). The predominant source of recharge for the surficial aquifer is precipitation. The average precipitation for a 10-year period from 1990 to 1999 in the North Carolina Coastal Plain was ~130 centimeters, but 52 to 92 % of annual precipitation is lost to runoff and evapotranspiration depending on soil infiltration capacity, land surface slope, and local evapotranspiration rates (Lautier, 2001). The water table is typically close to the ground surface in the surficial aquifer. On Bogue Banks, the water table may vary from being above the ground surface in depressional areas, to several meters below the surface on top of large dunes.

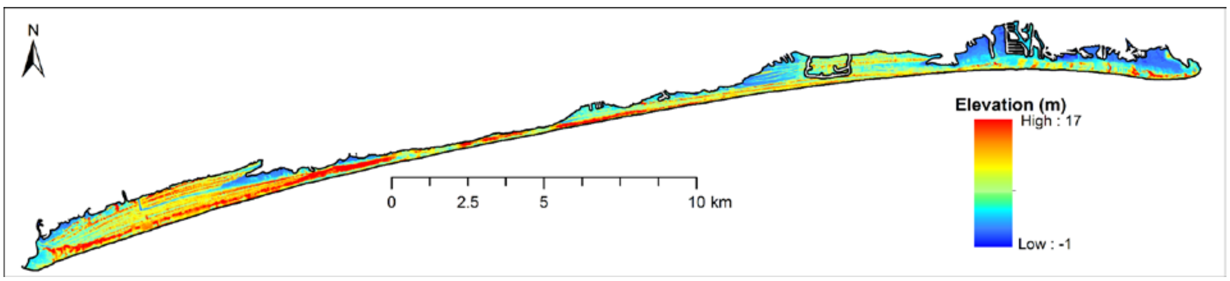

Figure 3 High resolution (~1.5 x 1.5 m) digital elevation model of Bogue Banks.

2. METHODOLOGY

3.1 Well Installation

A total of 29 shallow groundwater monitoring wells and two stilling wells were installed in the surficial aquifer and surface water bodies (i.e., Bogue sound and a canal) on Bogue Banks (Fig. 4). The wells were installed in different environments to account for differences in geology, topography and hydrology. In addition, the wells were installed in areas that were easily accessible and relatively safe for researchers and citizen scientists.

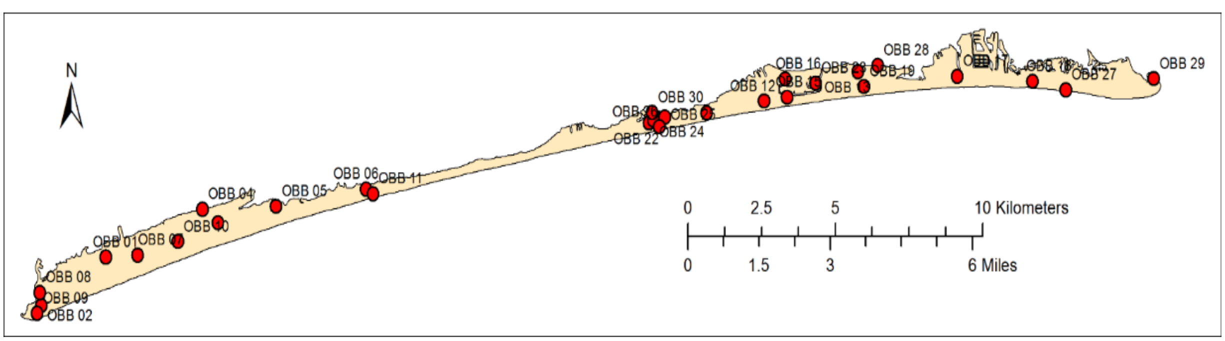

Figure 4 Location of wells installed by the investigators on Bogue Banks.

The wells were installed using a 'geoprobe' direct push drilling rig (Fig. 5) following North Carolina State standards for constructing groundwater monitoring wells. The wells were installed to depths ranging from 2 to 8 m below ground (Table 1). Each well was made of 1-inch diameter

Table 1. Characteristics for shallow groundwater monitoring wells on Bogue Banks.

Well ID	Well Latitude	Well Longitude	Elevation of Top of Casing (m)	Elevation of Ground Surface (m)	Well Depth (m)	Depth to Top of Screen (m)	Depth to bottom of Screen (m)	Distance from Shoreline* (m)
OBB 01	34.659720	-77.068570	4.42	3.51	5.49	0.91	5.49	294.30
OBB 02	34.647723	-77.092704	1.85	1.24	2.44	0.91	2.44	218.70
OBB 03	34.667750	-77.026800	1.82	0.86	5.13	0.61	5.13	485.90
OBB 04	34.671383	-77.032450	2.81	1.90	3.66	0.61	3.66	9.00
OBB 05	34.671674	-77.005220	2.31	1.39	2.13	0.61	2.13	45.07
OBB 06	34.675495	-76.971694	3.64	2.67	3.61	0.61	3.61	85.27
OBB 07	34.660096	-77.056705	4.92	4.00	5.18	0.61	5.18	572.28
OBB 08	34.651107	-77.093083	3.73	2.76	3.61	0.61	3.61	148.77
OBB 09	34.645851	-77.094319	3.90	2.98	3.66	0.61	3.66	283.98
OBB 10	34.663241	-77.041730	4.84	4.00	5.26	0.61	5.26	572.27
OBB 11	34.674247	-76.969175	3.01	1.95	3.51	0.61	3.51	136.28
OBB 12	34.695300	-76.823740	5.35	4.66	7.24	0.61	7.24	246.66
OBB 13	34.702230	-76.788720	2.94	2.02	3.66	0.61	3.66	143.80
OBB 14	34.692740	-76.845080	5.27	4.35	5.18	0.61	5.18	195.71
OBB 15	34.696149	-76.815219	4.29	3.38	5.18	0.61	5.18	249.12
OBB 16	34.700780	-76.815807	4.12	3.20	5.18	0.61	5.18	278.08
OBB 17	34.700340	-76.751950	2.88	1.96	3.66	0.61	3.66	333.14
OBB 18	34.698528	-76.724139	2.95	2.04	3.66	0.61	3.66	150.23
OBB 19	34.698342	-76.786602	3.31	2.39	3.66	0.61	3.66	246.65
OBB 20	34.691750	-76.863220	2.14	1.23	3.66	0.61	3.66	135.07
OBB 21	34.691600	-76.864200	3.72	2.80	3.66	0.61	3.66	110.76
OBB 22	34.690490	-76.866420	4.61	3.80	5.27	0.61	5.27	211.06
OBB 23	34.699540	-76.804530	3.91	2.99	3.66	0.61	3.66	442.93
OBB 24	34.691200	-76.864850	3.57	2.66	3.66	0.61	3.66	149.43
OBB 25	34.691900	-76.860680	2.52	1.60	3.66	0.61	3.66	161.14
OBB 26	34.689430	-76.862720	7.66	6.52	8.00	0.61	8.00	75.03
OBB 27	34.696124	-76.711815	4.31	3.40	3.66	0.61	3.66	121.01
OBB 28	34.703639	-76.781306	2.61	1.70	3.66	0.61	3.66	49.28
OBB 29	34.698280	-76.679170	2.99	2.08	3.66	0.61	3.66	134.84

slotted PVC pipes. The slotted section was attached to a solid pipe section that projected about a meter above the ground surface and extended down to ~0.9 m below the ground surface. The wells were completed by first filling the annulus between the walls of the borehole and the PVC pipe with a sand filter pack. Bentonite clay was then placed on top of the filter pack to prevent the migration of surface water along the sides of the well casing. The wells were finally completed by grouting a metal cover over the well casing. The well covers, which extended about a meter above the ground surface, were all secured with a lock. A Trimble GPS unit was used to determine the geographic coordinates of the completed wells. Upon completion, a Solinst water level meter was then used to measure the water level in the well (Fig. 5). A sediment core was extracted from each bore hole in order to analyze the sediment in the subsurface.

Figure 5 Well installation using a ‘geoprobe’ drilling rig and recording the depth to the groundwater level in a monitoring well using a water level meter.

3.2 Recruitment of Citizen Scientists

In this study, the researchers interacted with primary and secondary stakeholders to meet the objectives of the study. Primary stakeholders (e.g., municipalities, non-profit organizations, etc.) are entities that facilitated access to citizen scientists, whereas the citizen scientists are the secondary stakeholders. The researchers engaged with both types of stakeholders through telephone and email communications, in-person discussions, recruitment sessions, training workshops, and educational activities. The researchers used already established relationships with primary stakeholders in a coastal community to recruit citizen scientists to collect groundwater level data.

A total of 10 citizen scientists were initially targeted to record water levels in 20 groundwater wells. However, only eight citizen scientists volunteered to measure water levels in 15 groundwater wells. Of these, only one volunteer did not follow through with recording water levels during the research project. Thus, a total of 7 citizen scientists recorded water levels in 12 groundwater wells. These numbers represented 70% of citizen scientists and 60% of monitoring wells that were initially targeted by the researchers. Each citizen scientist was assigned to monitor groundwater levels in at least one shallow groundwater monitoring well over the duration of the study.

The Trinity Center in Pine Knoll Shores, the North Carolina Coastal Federation in Newport, and major municipalities on the island (i.e., the Towns of Emerald Isle, Pine Knoll Shores and Atlantic Beach) were used as avenues through which to recruit citizen scientists for the project and/or to provide access to sites for installing groundwater wells. The Trinity Center provided access to install five groundwater wells on their property and one stilling well in Bogue Sound. The North Carolina Coastal Federation, which is a 501(c)(3) non-profit corporation that works to protect and restore the coast through environmental education, restoration, preservation and advocacy, provided avenues to recruit and engage with participants. Recruitment of citizen scientists from the membership of the North Carolina Coastal Federation was done in person at organized events and by emailing members of the organization. Town managers and/or mayors in the major towns on the island were supportive of and committed to the project by providing access to public sites where groundwater monitoring wells were installed. The North Carolina Coastal Federation and the Town of Pine Knoll Shores provided meeting rooms where engagement (for training, demonstrations of groundwater concepts, focus groups) with citizen scientists took place.

Once recruited, the citizen scientists attended a 3-hour workshop to learn about groundwater systems and how to collect data using water level meters. Prior to presenting any material to the citizen scientists, a pretest survey was administered by the workshop facilitators to determine the demographics, perceptions, and content knowledge of the citizen scientists before commencing with the project. A posttest was administered after the groundwater monitoring phase of the project to determine whether the citizen scientists' perceptions and environmental literacy changed over the course of the project.

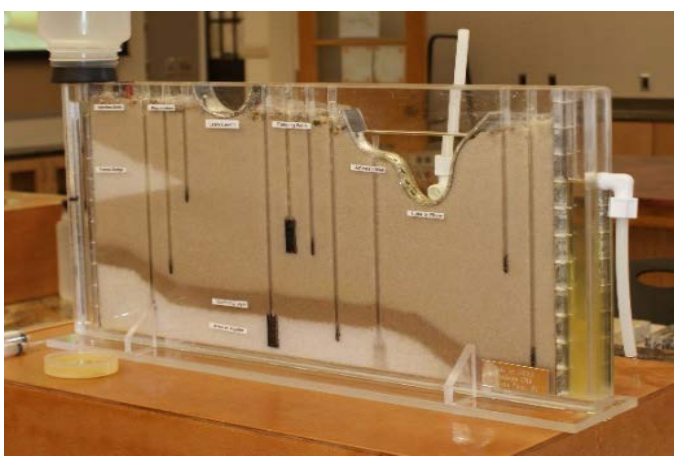

Figure 6 Example of a physical groundwater model that will be used to promote active learning.

During the workshop, physical groundwater models (Fig. 6) were utilized to educate citizen scientists about groundwater concepts in an active learning type of environment. A demonstration of how water level data from groundwater is collected was then conducted to allow the citizen scientists to practice the protocol for measuring water levels. The citizen scientists were then provided with maps, data sheets and water level meters to aid in measuring and recording water levels during the project.

3.3 Monitoring Groundwater Levels

A total of 7 citizen scientists were recruited to manually measure depths to the watertable using water level meters once a week over a 10-week period. The citizen scientists were to collect data synchronously, with each citizen scientist collecting data once every Friday at 10AM. In addition to recording manual groundwater levels, automated groundwater levels were also recorded using water level loggers to (a) augment the data from the citizen scientists, and (b) assess whether the data collected by the citizen scientists were reasonable. The automated groundwater levels were recorded in some of the same wells that the manual water levels were recorded. The automated water levels were also recorded in groundwater monitoring wells where no manual water levels were recorded by the citizen scientists. The automated water levels were recorded at 10-minute intervals. A pressure transducer that recorded barometric pressure was also deployed in the study area in order to assist with correcting the water level data. The researchers also manually collected groundwater level data whenever they were in the field area. These periodic measurements were used to confirm the quality of readings recorded by the automated water level loggers and citizen scientists. The water level data collected by the citizen scientists were compared to independently collected water level data to assess reliability and validity of measurements collected by citizen scientists.

During the course of the project, the investigators periodically communicated with the stakeholders to discuss preliminary results, revise strategies for accomplishing tasks, gather data sheets, and get feedback from the stakeholders. This approach ensured that (a) the citizen scientists were continuously reminded of the importance of their monitoring efforts, and (b) the project activities continued to pique the interests of the citizen scientists.

3.4 Groundwater and Geospatial Modeling

The commercially available groundwater flow simulation software, Visual MODFLOW was used to model the groundwater flow system beneath Bogue Banks. Visual MODFLOW utilizes the three-dimensional modular finite-difference groundwater flow code MODFLOW (McDonald and Harbaugh, 1988; Harbaugh, 2005) to simulate flow in steady or transient state. Water level data collected by citizen scientists and automated water level loggers were used to calibrate the groundwater model.

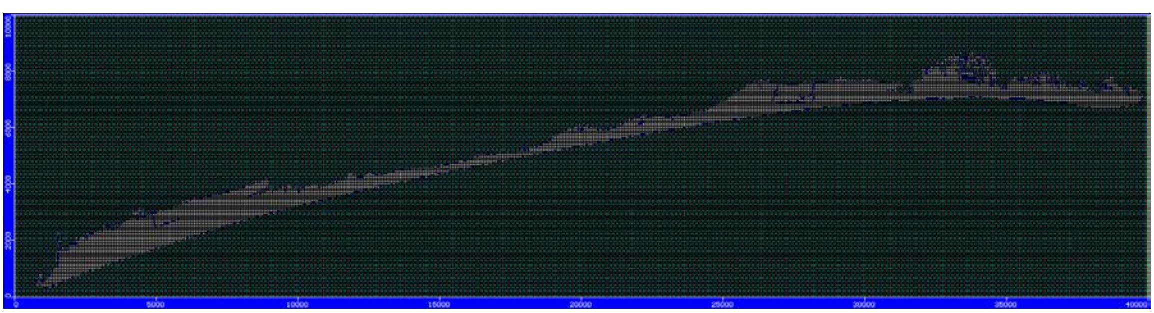

Figure 7 Model showing how the model grid over the study area.

The model, which is 40,000 m (in the E-W direction) by 10,000 m (in the N-S direction), was discretized into 500 rows and 250 columns for a grid size of 80 m by 40 m (Fig. 7). The average depth of the surficial aquifer on Bogue Banks was determined using well logs from the NC Department of Environmental Quality. The bottom of the model was therefore set at -18.5 meters whereas a digital elevation model (Fig. 3) was used to define the topography. A geospatial layer representing the outline of Bogue Banks was designated as a constant head boundary (sea-level at an elevation of 0 meters). The top of the model designated a recharge boundary. The Surficial aquifer was assigned recharge rates ranging from 0 to 121 cm/year in order to account for spatially varying soil types (Mew 2003).

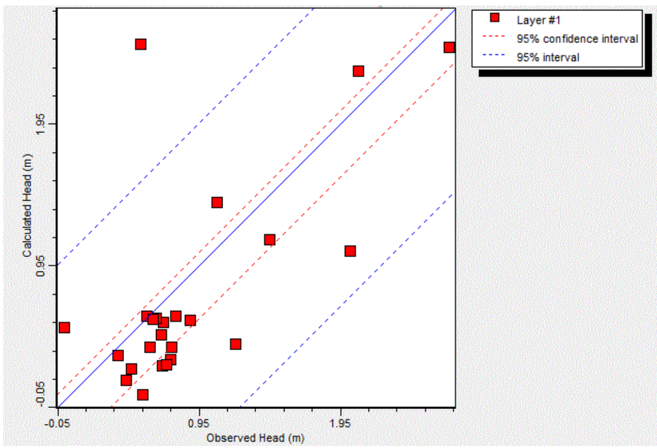

Figure 8 Scatter plot showing results from calibrated model.

Water level data that were collected from the groundwater monitoring wells were used to calibrate a groundwater numerical model. Since the water level data were collected from point locations at specific time intervals and locations, a groundwater model had to be used to characterize the water table under various sea-level rise scenarios. The groundwater model was calibrated under steady state conditions by adjusting values for hydraulic conductivity for the surficial aquifer. A trial and error approach was first used to calibrate the model. During the calibration process, water level data collected in the field were compare to water level data derived from the model to determine how well the model was calibrated (Fig. 8). Initial estimated ranges for hydraulic conductivity were acquired from Heath (1983) based on descriptions of types of sediment observed in the recovered core. After the trial and error process, an automated calibration process using the PEST function in Visual Modflow was used to fine tune the calibration results. The calibration target was a normalized root mean squared error (NRMSE) of 10 percent (Anderson et al., 2015). However, the lowest value for NRMSE achieved was 14.6 percent with a hydraulic conductivity of 0.3 m/day.

Water table contours from the calibrated groundwater model were used as baseline conditions (Fig. 9) for simulating changes under sea-level rise scenarios of 0.2 m to 1.4 m above present day levels. The water table map for baseline conditions shows that there are several areas with high water levels on the island. These regions are located on the western and eastern parts of the island.

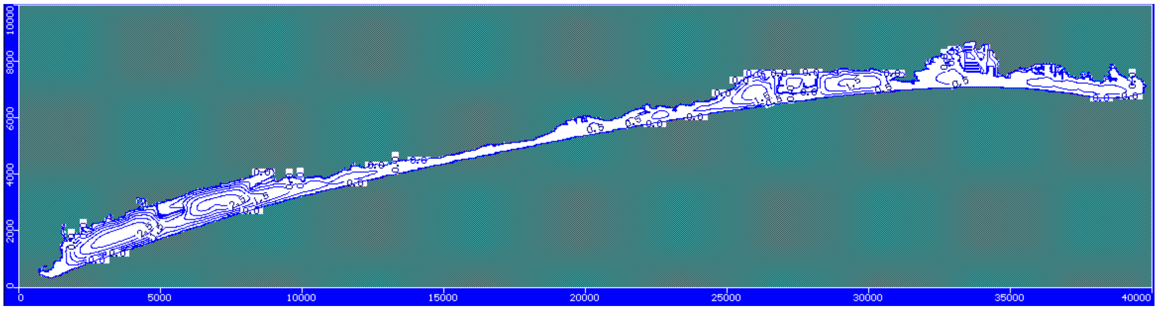

Figure 9 Water table contours of baseline conditions from calibrated groundwater numerical model.

Sea-level was simulated by adjusting the values of the constant head boundary condition from 0 m (baseline current day conditions) to 1.4 m in 0.2 m increments. An xyz ASCII file representing water level elevations that were simulated from each of these scenarios was then exported from Visual Modflow to a Geographic Information System to determine the proportion of land that was impacted by marine and groundwater inundation.

The ArcGIS 10.3 software program was used to determine areas impacted by groundwater and marine inundation. Determining the proportion of land impacted by groundwater inundation involved converting the xyz vector files of water table elevations to raster formatted files with a cell size of 1.524 m. The raster files representing each scenario were then subtracted from the digital elevation model of the island (Fig. 3) with the same resolution as the rasters for the water table. Positive values represented areas where the water table was below the ground surface whereas negative values represented areas where the water table was above the ground surface. The raster was then reclassified into two classes where all positive values were reclassified to a value of 0 and the negative values were reclassified to a value of 1. Pixels with a value of 0 represent unimpaired areas, whereas pixels with a value of 1 represent areas impaired by groundwater inundation. This process was then repeated to determine the proportion of land on the island that was under groundwater inundation for all the different sea-level rise scenarios.

The ‘bath tub’ model was used to determine areas impacted by marine inundation (Cooper *et al*., 2013; Manda et al., 2014). The process involved using a high resolution digital elevation model with a resolution of 1.524 m (Fig. 3). For the digital elevation model, the elevation values of 0 m represent sea-level and positive values represent the ground surface. Determining the area occupied by ocean water under various scenarios of sea-level rise involved reclassifying the raster of the digital elevation model by assigning all elevation values equal to and below the specified sea-level scenario (e.g., 0.6 m) equal to 0. The values above the specified sea-level rise scenario were then assigned a new value of 2. All the pixels in the final reclassified raster therefore had a value of 2 that represented the area inundated by the ocean due to sea-level rise or a value of 0 that represents land unimpaired by sea-level rise. This process was then repeated to determine the proportion of land on the island that was under marine inundation for all the different sea-level rise scenarios.

3.5 Validity and Reliability

Several methods were used to assess agreement (i.e., validity) between water level measurements collected by citizen scientists and other techniques. Scatter plots were used to show how data deviated from the line of linearity. The Pearson correlation coefficient was used to measure the linear correlation between measurements from different methods. The ICC and the CCC were used to assess *reliability* of measurements of water levels collected by citizen scientists.

ICC and CCC values of >0.74 were considered 'excellent' (where 0 = no agreement at all and 1= perfect agreement) (Cicchetti 1994; Landis and Koch 1977). Since the use of correlation may sometimes be misleading, the Bland-Altman method was also used to evaluate the *validity* of measurements by assessing agreement between measurements collected by citizen scientists and the automated water level loggers (Bland and Altman, 1986). The Bland-Altman method is a graphical technique that calculates the mean difference between two methods of measurement and 95% limits of agreement as the mean difference.

3.6 Collection and Analysis of Survey Data

In addition to assessing the reliability, validity, and trustworthiness of data collected by citizen scientists, this study used a pretest-posttest survey design to examine how participation as a citizen scientist influenced participants' knowledge about groundwater resources.

At the start of the study, citizen scientists were administered the pretest survey. The first part was a short questionnaire that collected demographic information about participants (e.g., age, gender, education level) and participants' perceptions regarding flood risk awareness (e.g., To what extent does stormwater flooding pose a serious threat to your community?) (refer to Appendix). The second part of the pretest survey was a series of questions designed to assess participants' level of knowledge regarding water resources and causes of flooding. This survey was a five-point Likert-type survey with a total of 22 questions (refer to Appendix).

To acquire more information from the citizen scientists, a focus group was convened at the offices of the North Carolina Coastal Federation at the conclusion of the groundwater monitoring phase of the project. Prior to commencing with the focus group session, the second part of the pretest survey (i.e., participants' level of knowledge regarding water resources and causes of flooding) was administered again to determine any changes in knowledge after participating the project. The pretest and posttest data were then compared to get a better understanding of how participation in the study impacted participants' knowledge of water resources and stormwater flooding.

The focus group was attended by four citizen scientists and two other individuals representing primary stakeholders. The session, which was facilitated by a PhD candidate from the Coastal Resources Management Program at East Carolina University, lasted approximately 2 hours. The facilitator was provided a script to jump start the discussion but was allowed to explore other issues that were raised by the participants. Comments and contributions from the focus group participants were recorded on paper. The focus group session, and the survey questions for both the pre- and posttest yielded a mix of quantitative and qualitative data for analysis. The results from the focus group sought to shed more light on the citizen scientists' perceptions of the project.

4. RESULTS AND DISCUSSION

4.1 Participant Characteristics

According to the data in the pretest survey, 10 individuals originally signed up for the study. The individuals were equally divided between men and women. Seven of the 10 participants were older than 50 years and only four of the citizen scientists were currently employed, the rest of the participants were retired. One participant had an associate's degree, five had bachelor's degrees, two had Master's degrees, and two others had doctorate degrees. Although all the participants were residents of Bogue Banks at the time of the study, only one individual was not a full time resident on the island. Of the ten participants, only three had lived on the island for five years or less. The rest of the participants had lived on the island for more than 5 years, with two participants having lived on the island for more than 20 years.

On a question about the significance of flooding on Bogue Banks, eight of the participants indicated that storm water flooding was either a significant or very significant concern on the island. The survey respondents listed several areas that they thought experienced the most significant storm water flooding problems on the island. These areas were identical to the areas that town managers listed as problem areas. The respondents were also knowledgeable about the different causes of flooding on the island. The causes listed by respondents included heavy rains, high water table, limited runoff, low elevation, storm surge, soil makeup, increases in impervious surfaces etc.

4.2 Water Level Measurements

A total of 13 groundwater monitoring wells were monitored by citizen scientists over a 10-week period. An example of water level measurements recorded by citizen scientists over the 10-week period is shown in Figure 10. Additional time series of water level measurements collected by citizen scientists are provided in the Appendix. The plots show the relative position of the water table to the ground surface. The plots generally reveal that the water table was at the highest levels in October, with a few wells revealing that the water table came close to the ground surface (e.g., Wells OBB03 and OBB13).

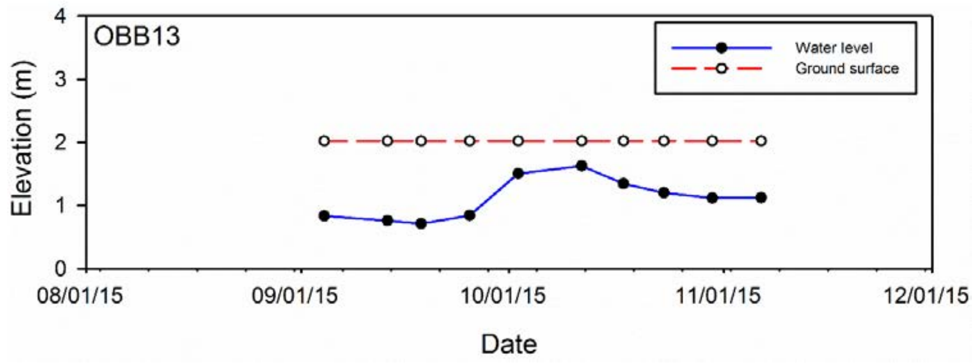

Figure 10 Example of time series of water level data collected by a citizen scientist.

Automated water level loggers were used to collect data in 20 groundwater monitoring wells. An example of water level measurements recorded by the automated water level loggers is shown in Figure 11. Additional time series of water level measurements recorded by the automated loggers are provided in the Appendix. The time series plots created with data from the automated water level loggers span a much longer time period than the measurements from the citizen scientists (Fig. 10 vs Fig. 11). Figure 11 also reveals that over the 10-week period that citizen scientist collected their data, the water levels recorded by some of the automated water level loggers rose to elevations above the ground surface. In such situations, the water table was contributing to storm water runoff at those locations.

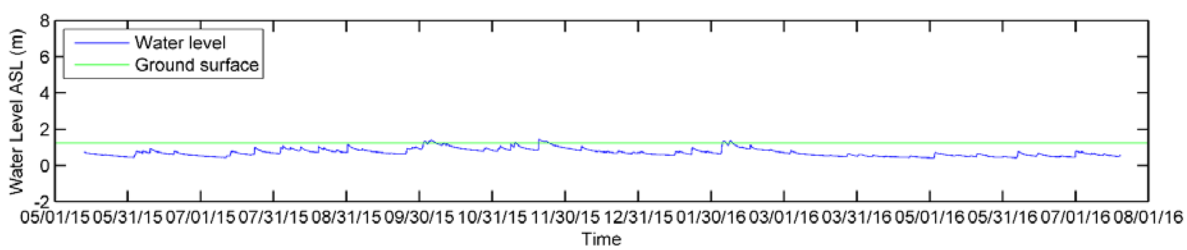

Figure 11 Example of time series of water level data collected by automated water level loggers (Well OBB02).

Note that not all the time series data recorded by the automated water level loggers indicate water levels above the ground surface. This is because of the diversity in the nature of the locations where the groundwater monitoring wells were installed. Some of the wells were installed in low lying areas, others on top of dunes, and others still on steeply sloping land. Some of the time series plots clearly show that not only was the water table close to the ground surface during the monitoring period, but that on occasion, the water level in certain wells (e.g., OBB02 and OBB03) rose above the ground surface. The driver of the rises in the water table was precipitation (Fig. 12). When there was high precipitation, water levels rose in response. The slopes of the rising and falling limbs in the time series plots are a function of rainfall intensity, depth to the water table and the nature of the material properties.

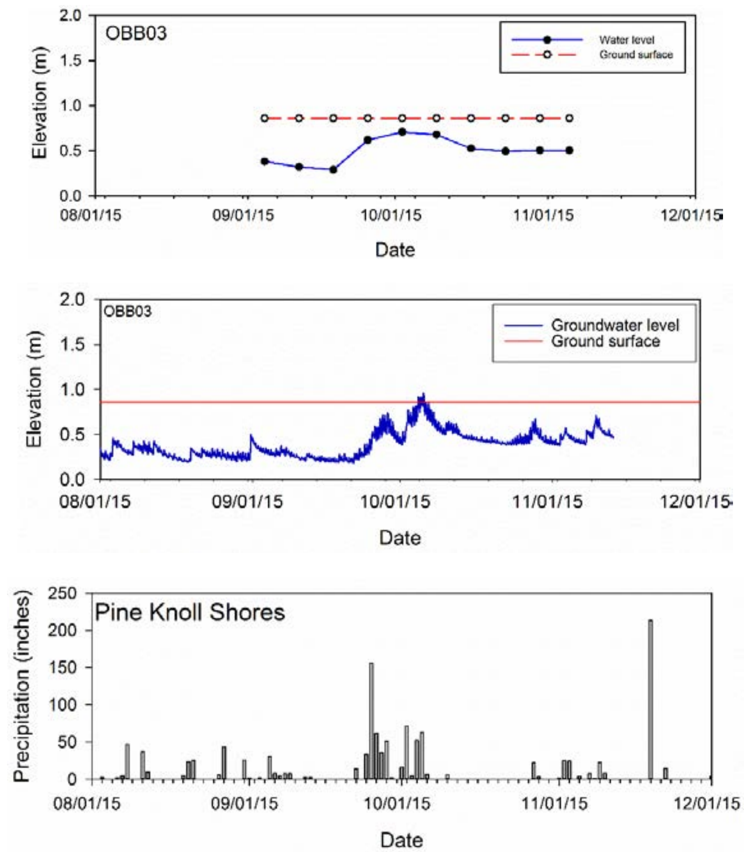

Figure 12. Time series plots from OBB03 showing how groundwater levels in the monitoring well responded to precipitation. Top panel represents water levels collected by citizen scientists, middle panel is from automated water level loggers, whereas bottom panel is precipitation.

4.3 Trustworthiness of Data

The validity and reliability of results was assessed by comparing water level measurements collected by citizen scientists and water level measurements recorded by automated water level loggers in three of the same groundwater monitoring wells. Visual inspection of time series plots of water levels indicates that there was little difference in the measurements from citizen scientists and automated water level loggers (Fig. 13).

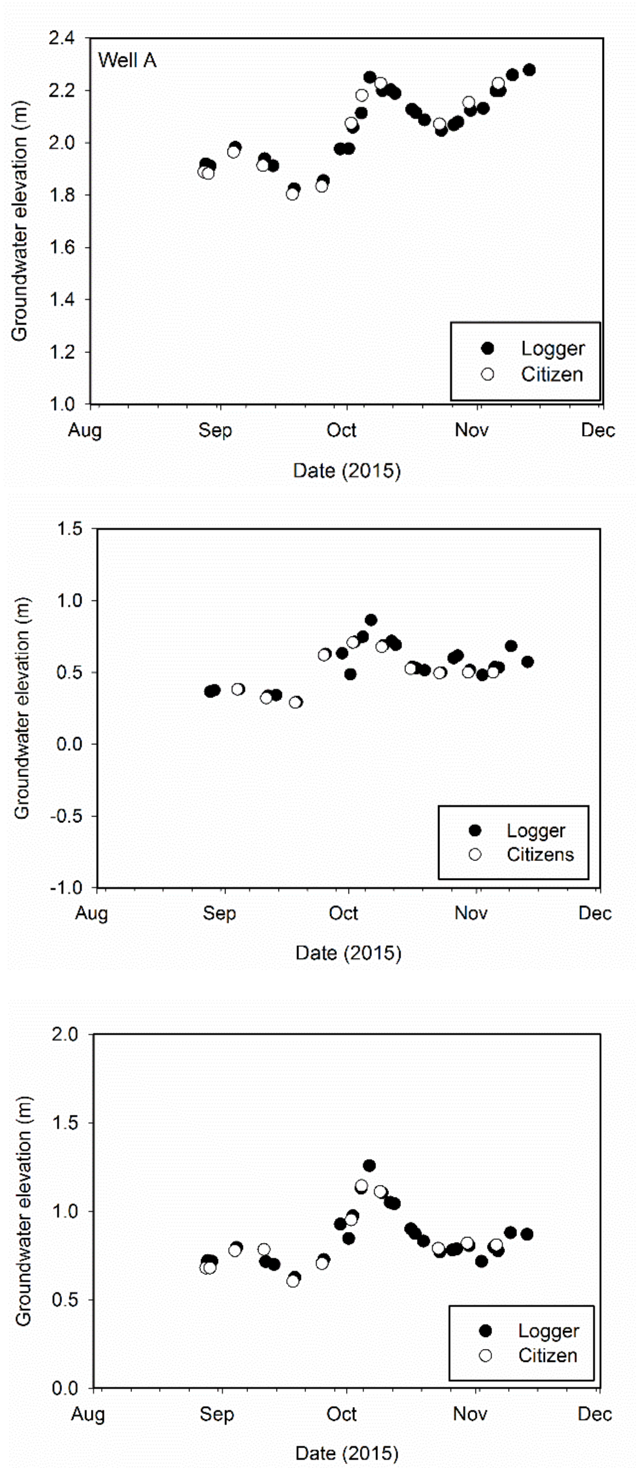

Figure 13. Water levels collected by citizen scientists versus water level loggers from automated water levels loggers.

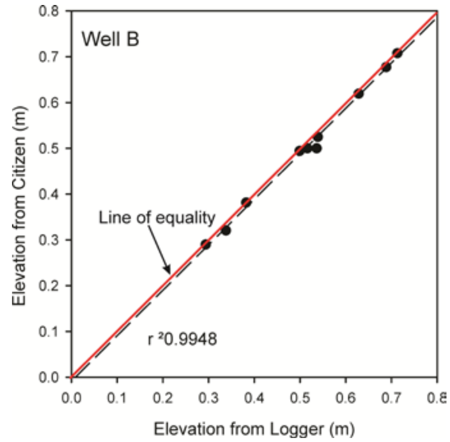

Figure 14. Scatter plot showing an excellent match between water level data collected by citizen scientists and automated loggers for well OBB03.

Although there were slight discrepancies between the times and water levels recorded by the citizen scientists and automated water level loggers (Fig. 13), the data from the citizen scientists track the data from the automated water levels very well. To quantify how well the data align, scatter plots of data from citizen scientist versus water level loggers was created. The plots indicate that the data points lie close to the 1:1 line (Fig. 14). The Pearson Correlation Coefficients were greater than 0.9 indicating a strong correlation between variables. Bland-Altman (Bland and Altman, 1986) plots were used to evaluate the validity of measurements by assessing agreement between measurements from three citizen scientists and automated water level loggers (e.g., Fig. 15).

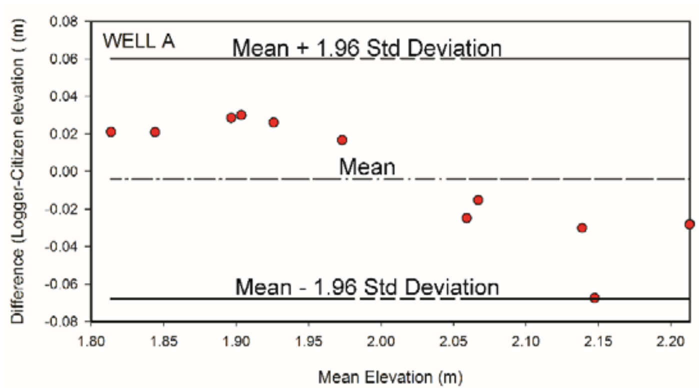

Figure 15 Example of a Bland-Altman plot for OBB03 showing that the majority of the measurements were within 2 standard deviations of the mean difference.

Mean differences, range of differences and limits of agreement between measurements from citizen scientists and automated water level loggers were used to construct the Bland-Altman plots. Most of the data in the plots were located in a narrow band, signifying good agreement between measurements (e.g., Fig. 15 and Appendix). The ICC and CCC were used to assess reliability of measurements of water levels collected by citizen scientists. The ICC and CCC were higher than 0.95 for each statistic indicating excellent agreement between methods (Table 2). Tables that were used to compute the ICC are presented in the Appendix. The results from the Bland Altman, and the values for the ICC and CCC indicate that water level data collected by citizen scientists were reliable and valid when compared to water level measurements collected by automated water level loggers.

Table 2. Results for ICC and CCC from three citizen scientists and automated water level measurements.

Well ID	ICC	CCC
OBB01	0.98	0.97
OBB03	0.99	1.00
OBB08	0.98	0.98

4.4 Perceptions and Knowledge

Pretest surveys of knowledge of the 10 citizen scientists that originally signed up for the study reveal that three of ten citizen scientists scored a median score of 5, whereas the rest scored a median score of 4 on the pretest survey (refer to Appendix). Unfortunately, only three of the original ten participants completed the posttest survey. When the pre and posttest survey results for the three participants are compared, the results reveal that none of the three participants scored a median score of 5 on the prestest, but one participant scored a median score of 5 on the posttest (Table 3). The changes in the three participants' median scores between pre and posttest surveys for each question reveal that there were no differences in median scores for 41% of the questions. Improvements were observed for 45% of the questions, whereas the median score dropped for only 14% of the questions. The pre and posttest results indicate that the citizen scientists had a high level of knowledge before they took part in the study. The posttest results suggest that even though the citizen scientists had a high level of knowledge before participating in the study, there were modest improvements in their knowledge as a consequence of taking part in the citizen science project.

During focus group sessions that were conducted after all water level data were collected, the citizen scientists revealed that prior to participating in the project, they had never thought about percolation, groundwater levels and groundwater flooding. The citizen scientists indicated that they were more aware about their environment particularly how stormwater flooding is impacted by development, runoff, and groundwater. Further, they indicated that if the current stormwater flooding issues are controlled in part by groundwater, then sea-level rise may mean greater flooding events in the future. Some of the participants shared that participating in the groundwater monitoring program has armed them with the knowledge to effectively describe the role that groundwater plays on stormwater flooding to their neighbors.

One of citizen scientist was so motivated to take part in the study that they not only collected data at a higher frequency, but they went on to write an article about their experience in a local newsletter on their own initiative. The citizen scientist contacted the researchers to request feedback on the analyses that they conducted on the data as well as additional feedback on the interpretation of the data. The perceptions and actions described above suggest that the environmental literacy of the citizen scientists had improved over the course of the project.

Table 3. Changes between the median scores of pretest and posttest results for each question on the surveys.

STATISTIC	QUESTION NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Median pretest (n=10)	4	4	3	4	4	4	3	4	4	4	4	4	4	4	4	3	4	5	5	4	4	5
Median pretest (n=3)	3	4	3	2	4	4	3	4	4	4	4	4	4	4	4	3	4	5	4	4	4	4
Median posttest (n=3)	4	4	4	4	5	4	4	3	4	4	4	5	5	4	5	3	5	4	5	4	3	4
*Change (n =3)	1	0	1	2	1	0	1	-1	0	0	0	1	1	0	1	0	1	-1	1	0	-1	0

*Where change is the difference between median scores for the pretest (n=3), and median scores for posttest (n=3).

The citizen scientists also identified several barriers and challenges that they encountered during the project. They indicated that while the water level data and maps that were processed by the research team were in SI units (meters), the data that they collected were in imperial units (feet). Additionally, the graduations on the water level meters were in decimal feet rather than feet and inches, thus some of the citizen scientists incorrectly recorded water level measurements. Note that this issue was not fatal to the project because the researchers identified the discrepancy on the data sheets and corrected any erroneous records as needed.

Another concern that the citizen scientists raised had to do with variables used to characterize the water level on time series plots and water level maps. In the field, the citizen scientists were tasked with measuring the depth to the water table from a reference point on well casing. However, the time series plots and water table maps that were processed by the researchers did not use *depth* to water level as a variable, rather researchers used *elevation* of the water level above a reference datum (sea-level) to create the plots and maps. Furthermore, the citizen scientists expressed that the water level measurements that they collected appeared to be counter intuitive to what they expected for rising water tables. Specifically, they indicated that rising water tables were represented by declining depth to water level values, and vice versa (this was one of the reasons why the researchers had to convert the depth to water level values to elevations). The relationship between the depth to the water level and elevation of the water level was not entirely clear to a segment of the citizen scientists.

The focus group session also revealed that the citizen scientists encountered difficulties with accessing the groundwater monitoring wells because some of the locks got stuck in the locked position. Another difficulty that was raised had to do with the data collection sheet that was initially provided to the citizen scientist. The original data sheet had additional columns that appeared to be redundant to the citizen scientists. The citizen scientists that encountered these problems used their own initiative to remove the broken locks from the wells and create their own data sheets.

4.5 Sea level-rise scenarios

Examples of water table maps that were created for each sea-level rise scenario above baseline conditions are shown in Figure 16. The water table maps show that the patterns created by the contours for each of the future scenarios are identical. However, with an increase in sea-level, the elevation of the water table in each of the maps also increases. Thus, since the topography is considered stationary over the simulation period, the water level progressively gets closer to the land surface with each passing scenario. When the water table rises above the ground surface, groundwater inundation is said to occur in these areas. This situation may exacerbate problems related to a thinning of the freshwater lens in surficial aquifer under sea-level rise scenarios (Masterson et al., 2013).

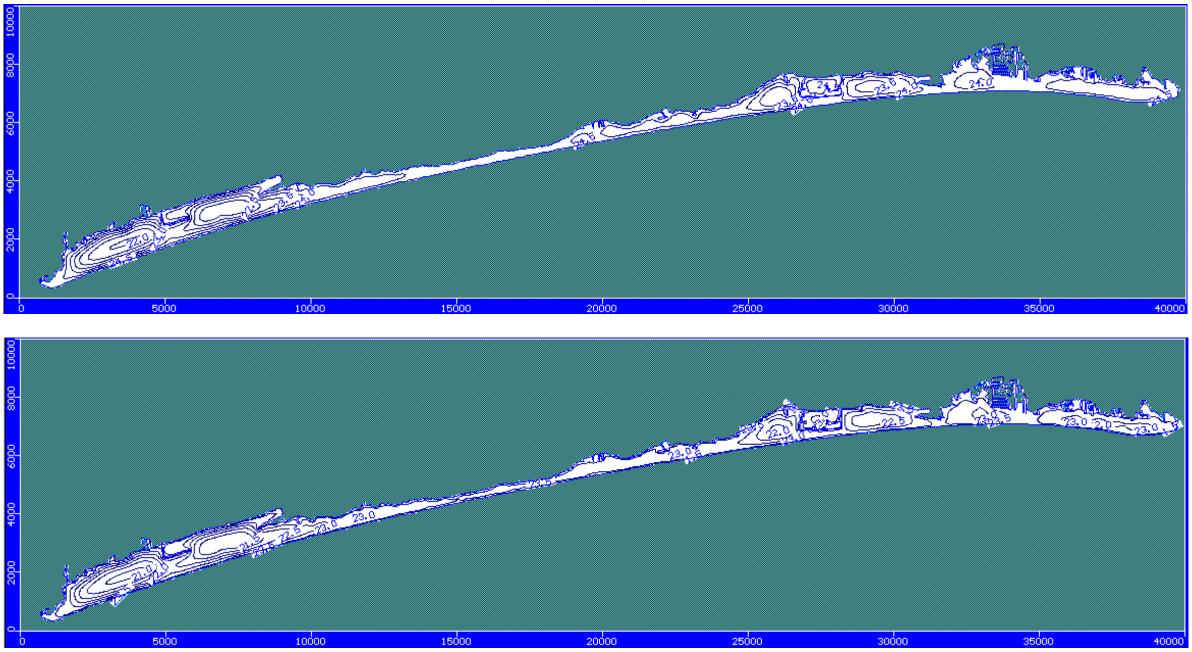

Figure 16 Water table contour maps for scenarios with sea-level rises of 0.2 m (top), and 1.4 m (bottom).

When sea-level rises, groundwater inundation starts to occur in the hinterland where land elevations are generally low. The western part of Bogue Banks sees the most impact from groundwater inundation owing to the dune and swale topography prevalent in that region (Figs. 17-23). In contrast, marine inundation is mostly prevalent on the northern part of the island which is characterized by gently sloping land that grades into Bogue Sound. However, the southern part of the island is generally unimpaired because this region is characterized by high land elevations where the largest dunes on the island are located (Fig. 3).

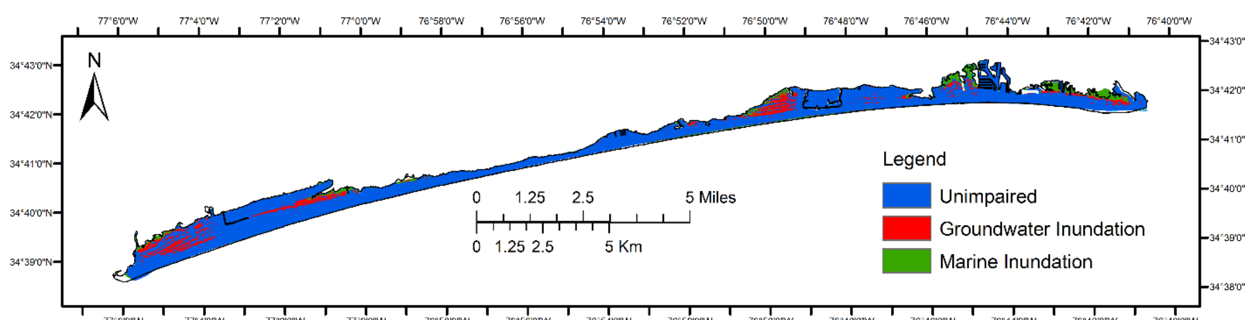

Fig. 17 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 0.2 m above present levels.

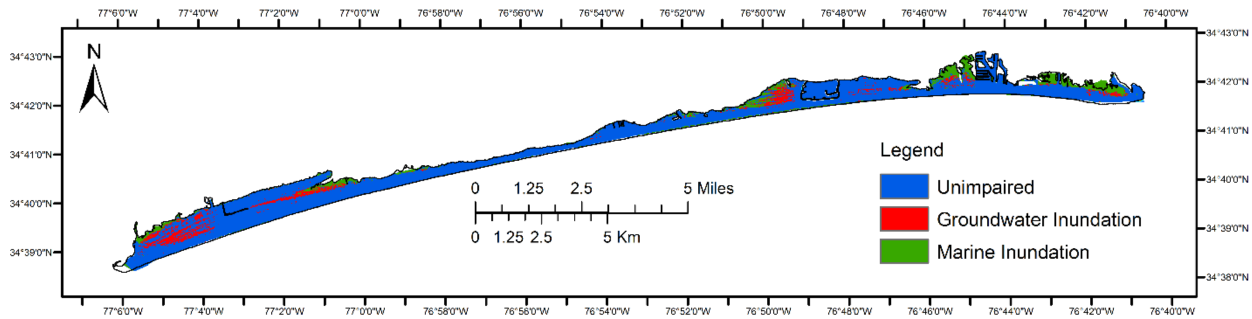

Fig. 18 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 0.4 m above present levels.

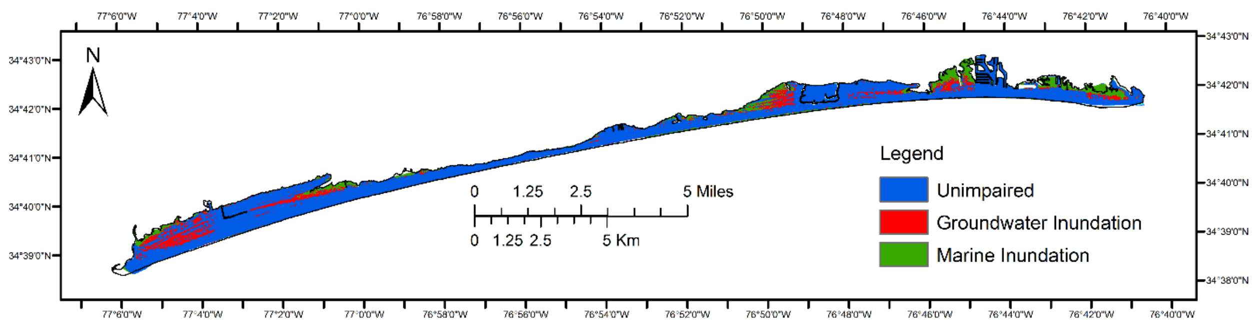

Fig. 19 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 0.6 m above present levels.

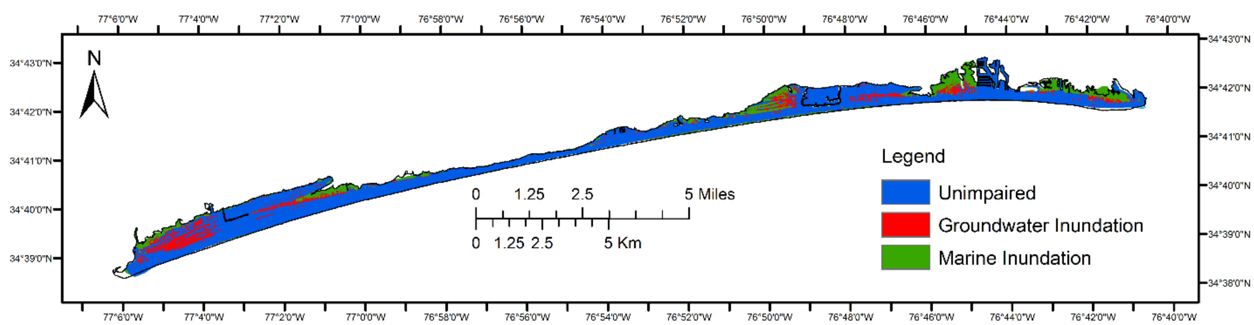

Fig. 20 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 0.8 m above present levels.

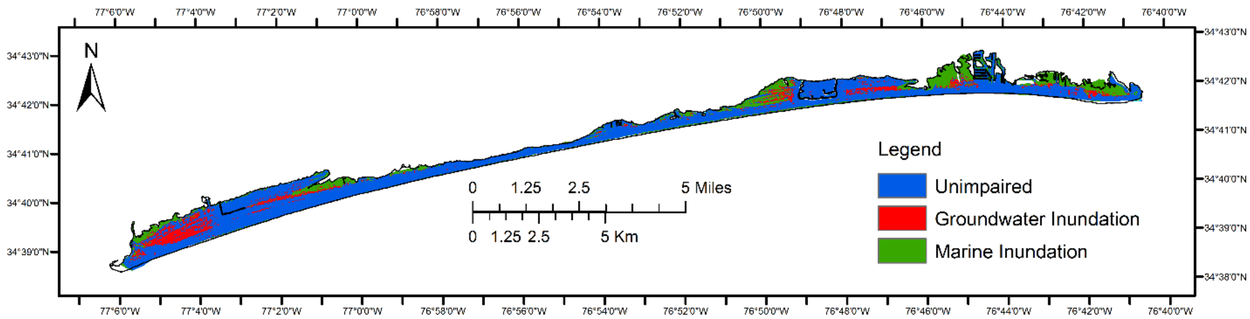

Fig. 21 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 1.0 m above present levels.

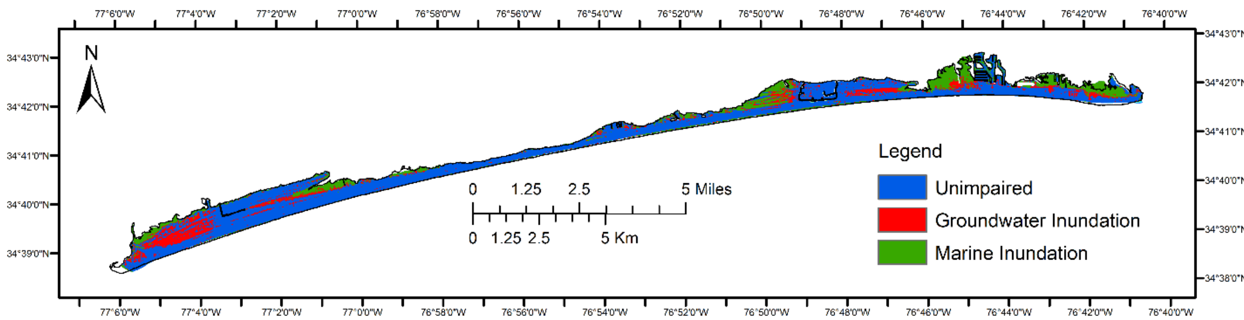

Fig. 22 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 1.2 m above present levels.

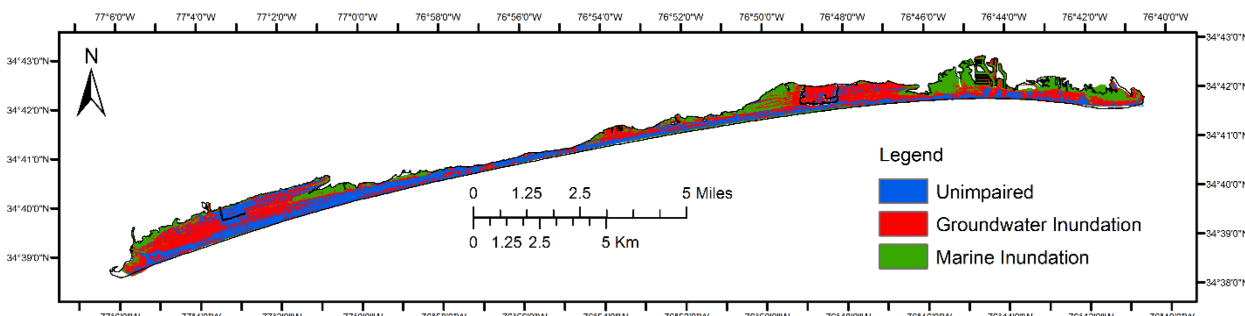

Figure 23 Proportion of land inundated by roundwater and sawater under a sea level rise scenario of 1.4 m above present levels.

The proportion of land impacted by both groundwater and marine inundation under sea-level rise scenarios of 0.2 m to 1.4 m ranges from ~17 to 68%, representing regions with areas ranging from 4.8 km^2 to 19.2 km^2 (Table 4). On average, the change in the amount of land occupied by both groundwater and marine inundation is about 1.1 km^2 for every 0.2 m increase for sea-level rise scenarios of between 0.2 m and 1.2 m. However, the change in land areas occupied by groundwater and sea water increases to 9 km^2 when sea-level rises from 1.2 m to 1.4 m. The proportion of land impacted by marine inundation is comparable to the proportion of land impacted by groundwater inundation for sea-level scenarios of 0.2 to 1.2 m (Tables 5 and 6). For the most extreme sea-level rise scenario (1.4. m rise), groundwater inundation occupies 40% of the land surface on Bogue Banks whereas marine inundation only occupies 28% of the land. For this scenario, impairment is only restricted to groundwater inundation owing to high elevations exposed to this phenomenon. The results from this research are similar to those conducted by Manda et al., (2014) on the western part of Bogue Banks. Manda et al. (2014) showed that groundwater inundation may be as significant as, if not more significant than marine inundation under similar sea-level rise scenarios.

Table 4. Proportion of land on Bogue Banks impacted by both groundwater and marine inundation under different sea-level rise scenarios.

Seal level-rise scenario	Impaired Area (km^2)	Unimpaired Area (km^2)	Proportion of impaired area (%)	Proportion of unimpaired area (%)
0.2 m	4.8	23.4	16.9	83.1
0.4 m	5.9	22.3	20.9	79.1
0.6 m	6.8	21.4	24.1	75.9
0.8 m	7.7	20.5	27.4	72.6
1.0 m	9.1	19.2	32.1	67.9
1.2 m	10.1	18.1	35.8	64.2
1.4 m	19.2	9.1	67.9	32.1

Table 5. Proportion of land on Bogue Banks impacted by marine inundation only under different sea-level rise scenarios.

Seal level-rise scenario	Impaired Area (km^2)	Proportion of impaired area (%)
0.2 m	2.2	7.8
0.4 m	3.6	12.7
0.6 m	3.6	12.7
0.8 m	4.8	16.9
1.0 m	6.1	21.7
1.2 m	6.1	21.7
1.4 m	7.9	27.8

Table 6. Proportion of land on Bogue Banks impacted by groundwater inundation only under different sea-level rise scenarios.

Seal level-rise scenario	Impaired Area (km^2)	Proportion of impaired area (%)
0.2 m	2.6	9.1
0.4 m	2.3	8.3
0.6 m	3.2	11.4
0.8 m	3	10.6
1.0 m	2.9	10.4
1.2 m	4	14.1
1.4 m	11.3	40.1

Results from the numerical groundwater and spatial models show that increases in sea-level can lead to progressively larger percentages of land on Bogue Banks being impaired from both groundwater and marine inundation. Simulations show that low-lying swales become impaired by groundwater inundation even under the most optimistic predictions of sea-level rise. Therefore, town managers must prepare mitigation strategies for the inevitable degradation of infrastructure throughout the island.

5. LIMITATIONS

This study suffers from several limitations. First, the number of citizen scientists that participated in the study was small (n = 7). Furthermore, the number of citizen scientists that participated in both the pretest and posttest surveys was even smaller (n = 3). The results from the small sample size may not be representative of the larger population. To overcome the small sample size, various avenues were used to elicit opinions from the citizen scientists (e.g., focus group, workshop sessions, training sessions etc.).

The numerical groundwater model that was built was based on the assumption that the aquifer properties on the island were homogenous and isotropic. Additionally, the outline of the island was assumed to be at sea level at the start of the simulations. Other assumptions that were made are that the island does not move laterally and vertically during the 100-year simulation period, the topography does not change over the same period, and the rate of sea level rise will be linear.

6. CONCLUSIONS AND RECOMMENDATIONS

Citizen scientists participated in the project by collecting groundwater level data from shallow groundwater monitoring wells. These data were augmented with water level data from automated water level loggers to calibrate a groundwater numerical model that represented baseline conditions of the water table on the island.

Citizen scientists that participated in the project were provided with opportunities to only increase their scientific and environmental awareness through training sessions and workshops, but also to engage in active learning opportunities. The citizen scientists displayed evidence that they were ambassadors of science by communicating their findings to fellow citizen scientists and the community at large. In so doing, the citizen scientists raised awareness about relationships among stormwater flooding, climate change, sea-level rise and groundwater resources to coastal communities.

The results of this study demonstrate that environmental data collected by citizen scientists can be trustworthy if certain protocols are followed when interacting with citizen scientists. Citizen scientists should be provided with clear and simplified instructions on how to perform tasks pertinent to the successful completion of an environmental project. Furthermore, there should be open lines of communication during the entire period so that citizen scientists can engage with research scientists. This could be achieved by encouraging the citizen scientists to email or call the research scientists when they have problems, or the research scientists could schedule periodic meetings to check in with the citizen scientists. Researchers should expect that the number of people participating in a project should decline over time. With this expectation, research scientists should have a mechanism to address attrition. This could include a process for letting the researchers know quickly whether a citizen scientist has decided to no longer take art in the project. The research scientists could then make attempts to recruit another citizen scientist to continue with the project.

This coastal groundwater project provided a dataset of groundwater levels from the surficial aquifer across Bogue Banks and information about the proportion of land that could be lost to groundwater and marine inundation under sea-level rise scenarios of 0.2 to 1.4 m above current conditions by 2100. Results from groundwater and geospatial modeling indicate that the land that could be lost to groundwater inundation may be as large as, if not larger, than the land that could be lost to marine inundation under projected sea-level rise scenarios of 0.2 – 1.4 m over the next 100 years. The effects of groundwater inundation may therefore be far much greater than those of marine inundation (with losses of 28% for marine inundation and 40% for groundwater inundation). As a consequence, groundwater inundation may therefore play an important role in future discussions about how climate change and sea-level rise may impact groundwater resources in coastal communities. Involving community residents in scientific research such as the project described in this report may therefore be an effective way for positively engaging with residents about important environmental issues such as climate change, sea-level rise, and groundwater resources.

In an age where financial resources may be unavailable to maintain large-scale groundwater monitoring stations with automated/telemetric water level recording capabilities, citizen scientists may therefore be a viable option for measuring and recording water levels from these groundwater monitoring stations. A similar blueprint to the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS - http://cocorahs.org/) may be developed for monitoring groundwater levels in areas where groundwater monitoring wells currently exist. As with CoCoRaHS, community members would be recruited, trained and provided with low-cost measurement tools to measure and map groundwater levels in their communities. These data may then be uploaded to a website (e.g., https://www.nccoastalatlas.org/cgww) where time series data can be plotted and synchronous water levels from different monitoring wells can be mapped. The broader community is likely to benefit from these activities by having access to high-quality, long-term, and widely distributed groundwater level data that may be available to researchers and other end users (e.g., water managers). The citizen scientists may benefit by making an important contribution to science, improving their scientific literacy, and having meaningful interactions with scientists and other volunteers (through training sessions, workshops, field trips etc.).

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APPENDICES

APPENDIX 1

LIST OF ABBREVIATIONS AND SYMBOLS

ASCII - **American Standard Code for Information Interchange**

CCC - Concordance correlation coefficient

DEM **–** Digital elevation model

ICC - Intraclass correlation coefficient

NRMSE - Normalized root mean squared error

SI- International System of Units

APPENDIX 2

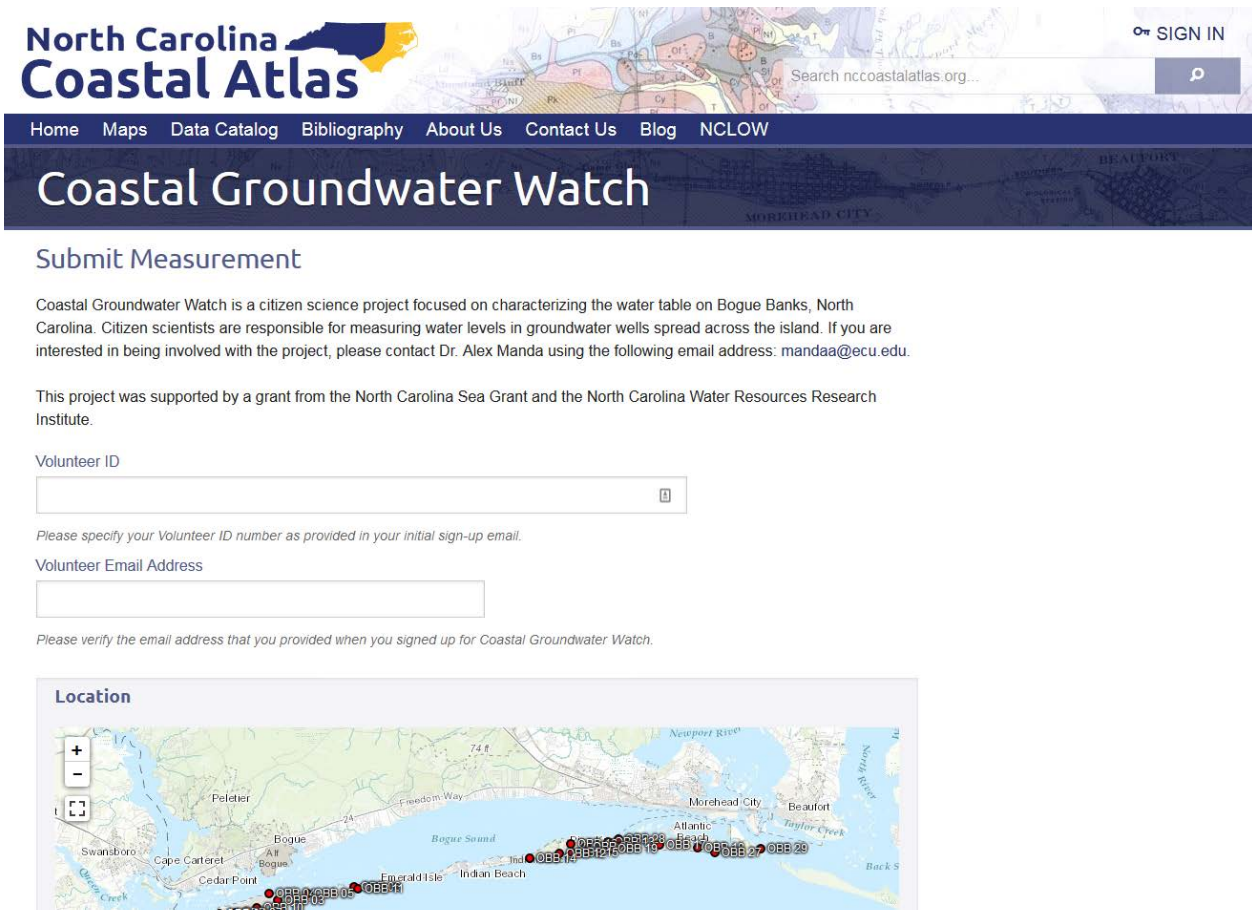
PRESENTATIONS

Title	Presenter/Author	Event	Location	Date
Using citizen scientists to investigate the influence of a shallow watertable on storm water flooding in coastal communities	Alex K Manda, Lauren Kolodij, Wendy Klein and James Owers	Citizen Science Symposium	Duke University, Durham, NC	16-Apr-16
Coastal Groundwater Watch: A citizen science project to monitor groundwater levels	Alex K Manda	Geology Seminar Series	East Carolina University, Greenville NC	12-Feb-16
Coastal Groundwater Watch: a citizen science project to monitor groundwater levels in the surficial aquifer of the North Carolina coastal plain	Alex K Manda, Lauren Kolodij, Wendy Klein and James Owers	Southeast Section of Geological Society of America	Columbia SC	1-Apr-16
Coastal Groundwater Watch: A citizen science project to monitor groundwater levels	Alex K Manda	North Carolina National Estuarine Research Reserve Coastal Training Program	Beaufort, NC	3-Feb-16
Coastal Groundwater Watch: A citizen science project to monitor groundwater levels	Alex K Manda	Invited Talk	Pitt Community College, Winterville NC	23-Feb-16
Coastal Groundwater Watch	Alex K Manda	Community Engagement	Town of Pine Knoll Shores	19-Feb-16
Using GIS to assess impacts to infrastructure in coastal communities that are threatened by rising groundwater		NCArcUser Group conference	East Carolina University, Greenville NC	26-May-16

WEBSITES DEVELOPED

COASTAL GROUNDWATER WATCH

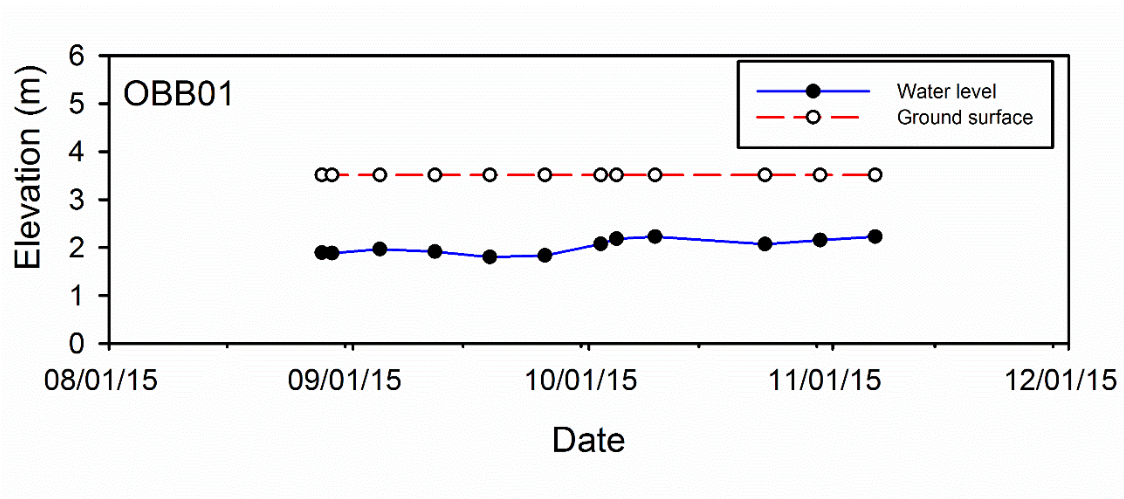
Website developed on the North Carolina Coastal Atlas Portal-
https://www.nccoastalatlas.org/cgww



APPENDIX 3

TIME SERIES OF GROUNDWATER LEVEL DATA COLLECTED BY CITIZEN SCIENTISTS

OBB01



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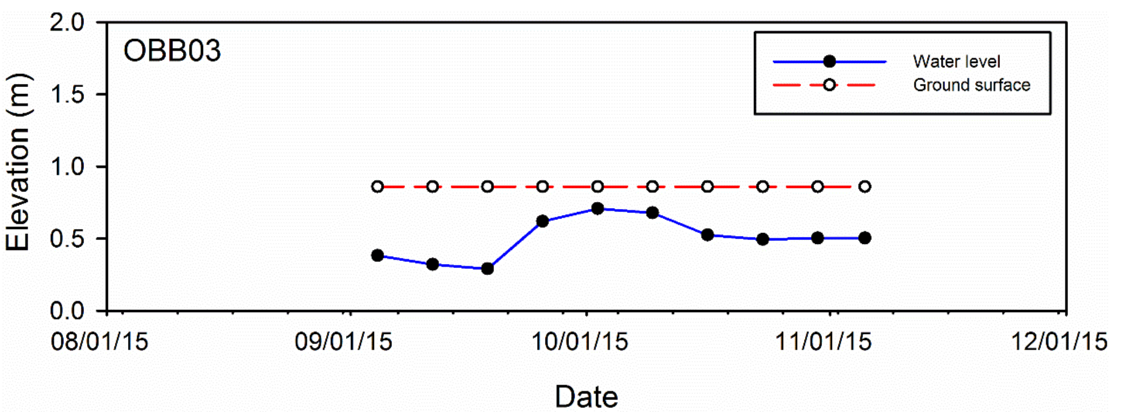

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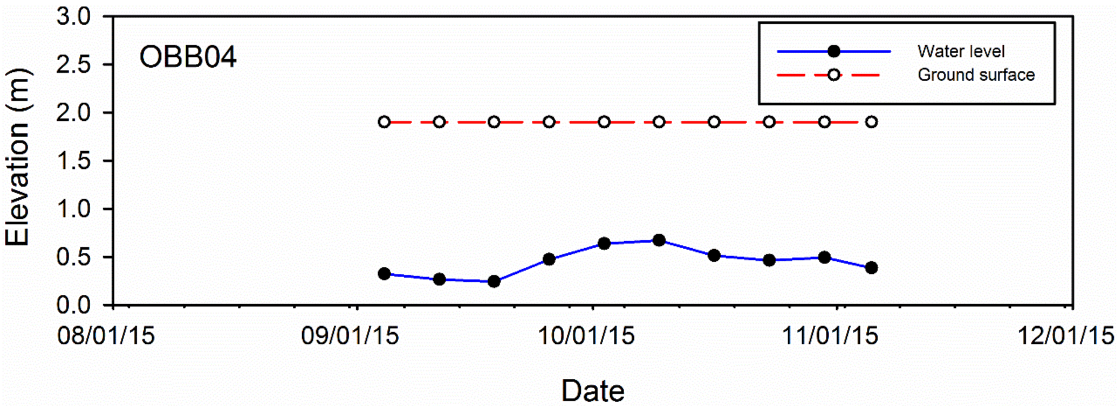

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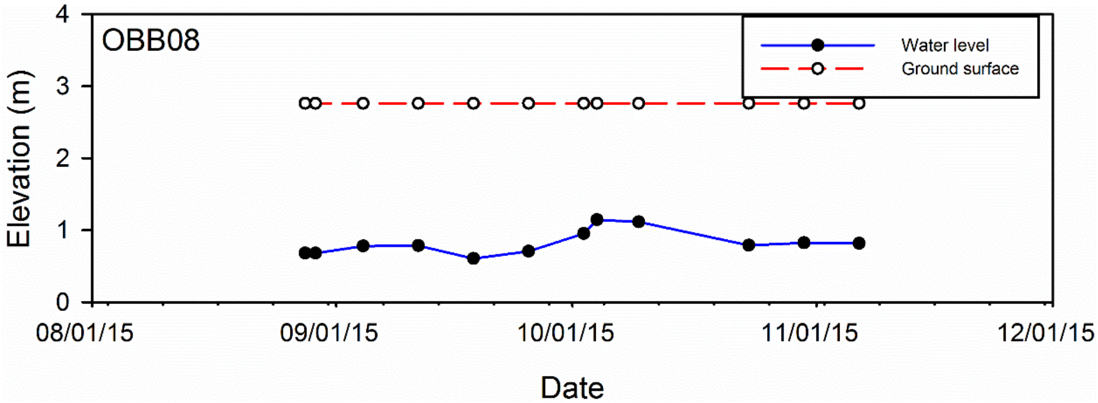

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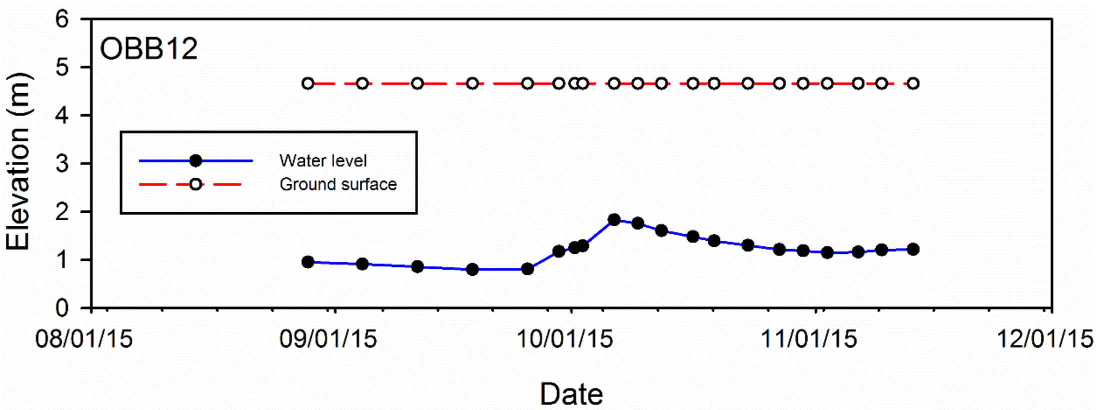

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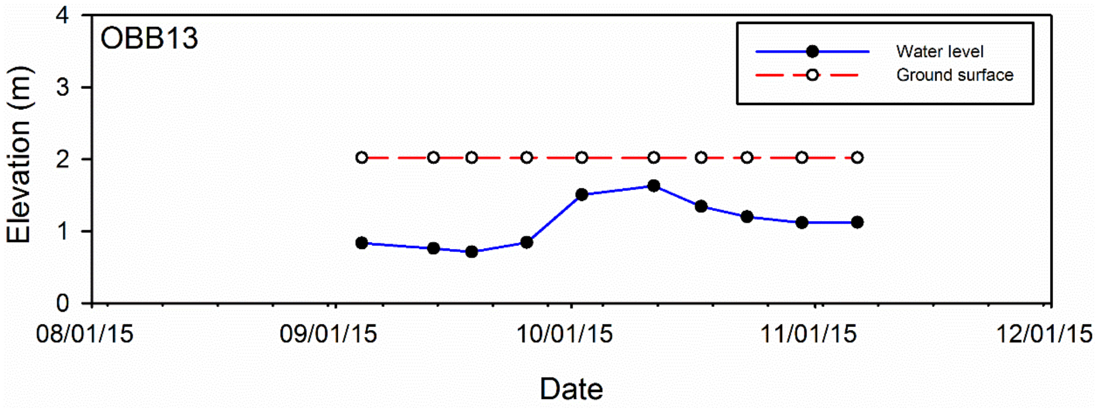

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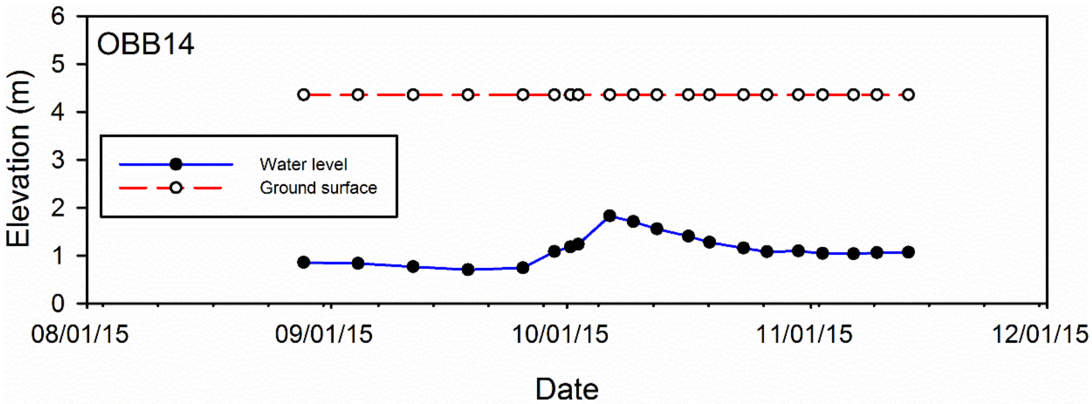

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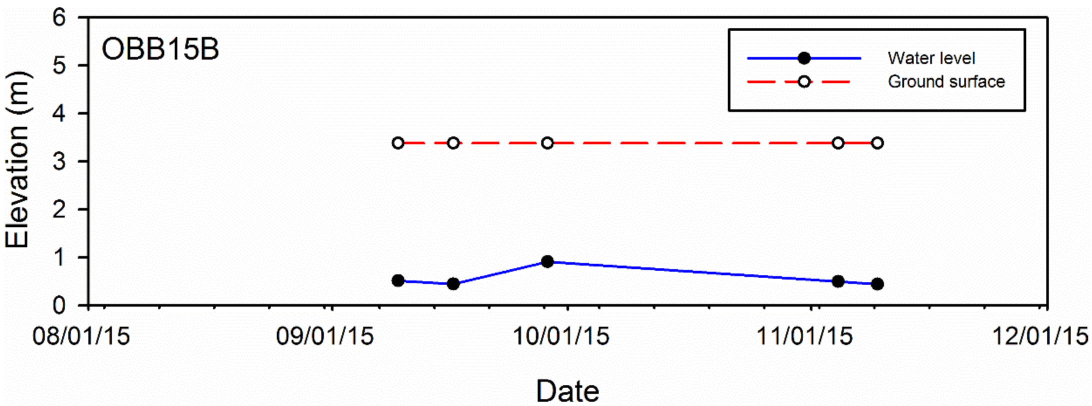

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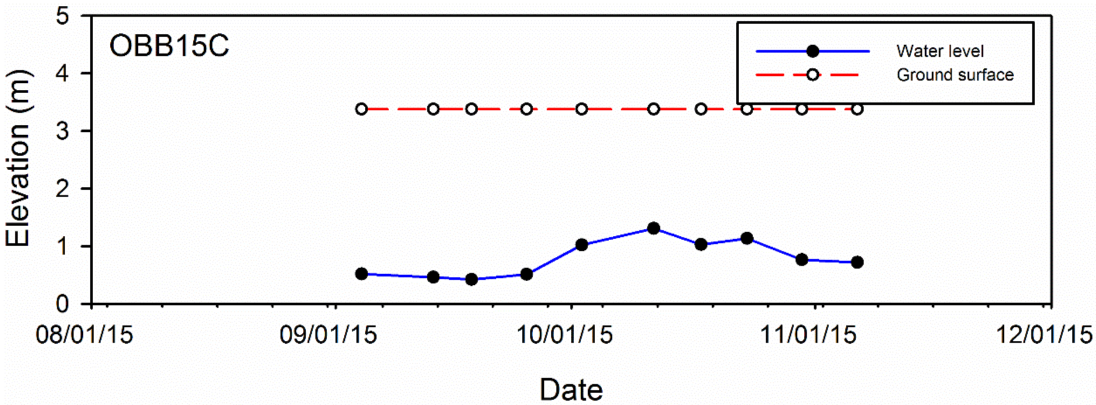

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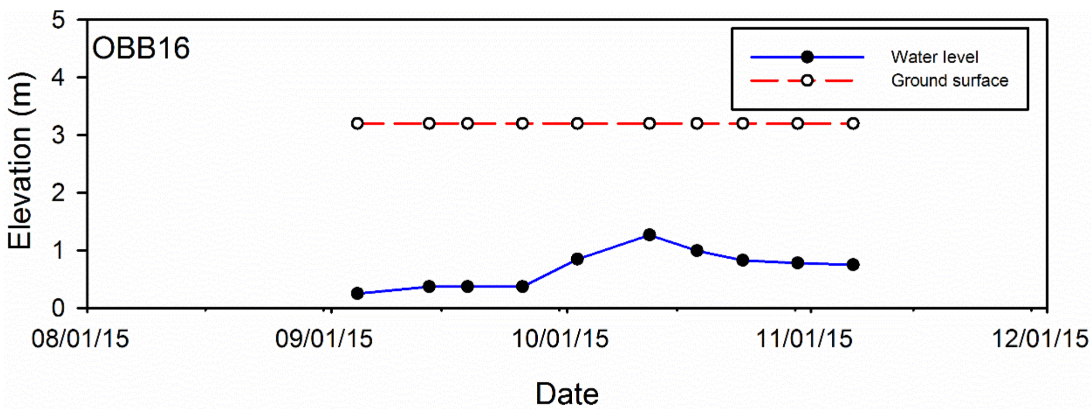

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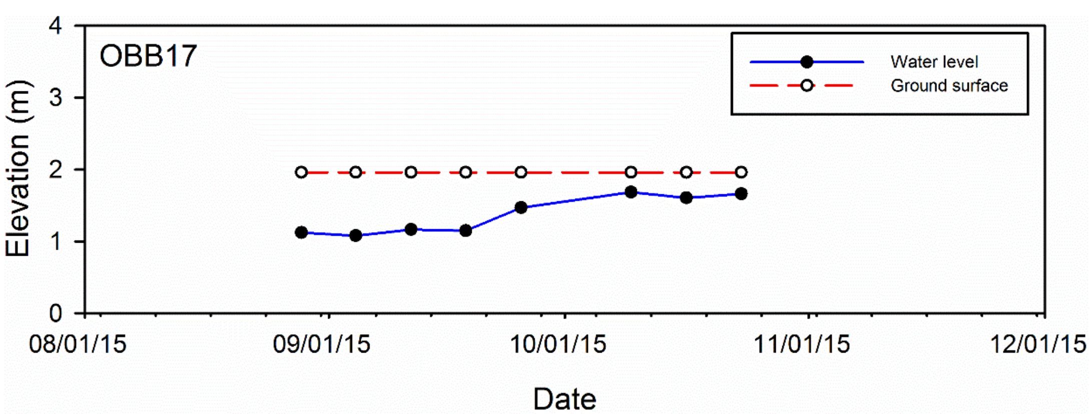

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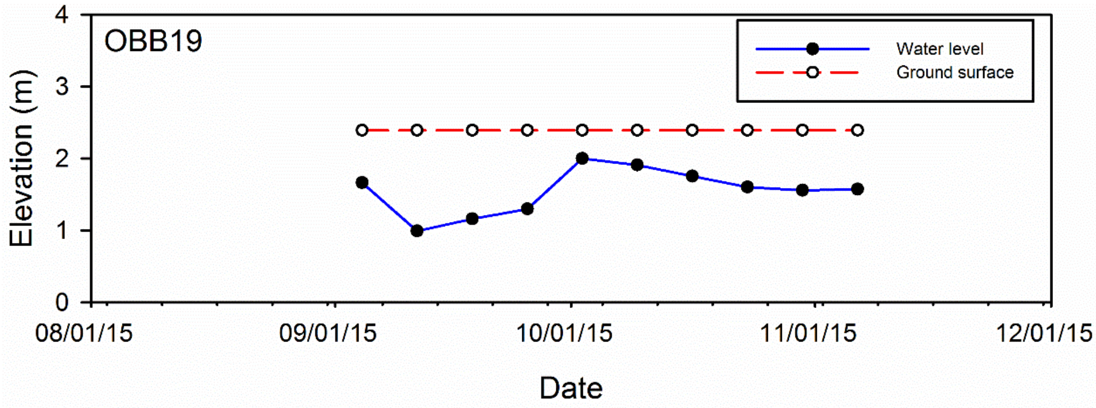
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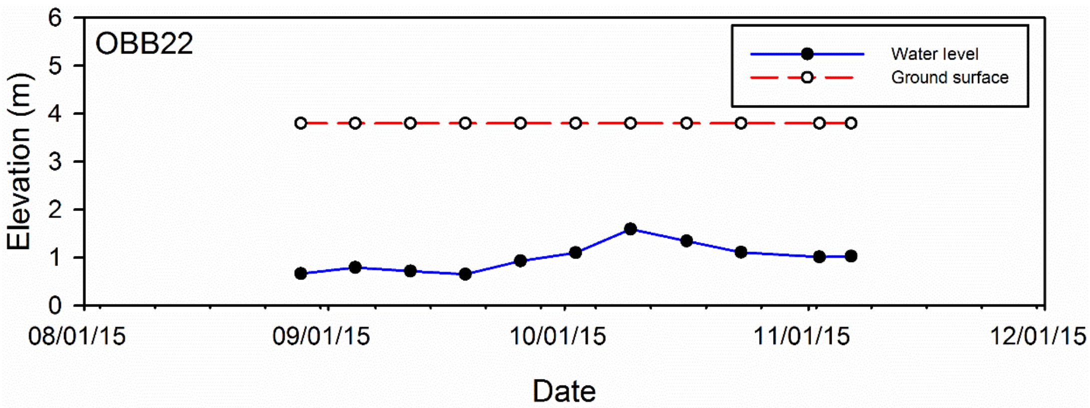
Water level
Ground surface
Elevation (m)
4
3
2
1
0
08/01/15
09/01/15
10/01/15
11/01/15
12/01/15
Date

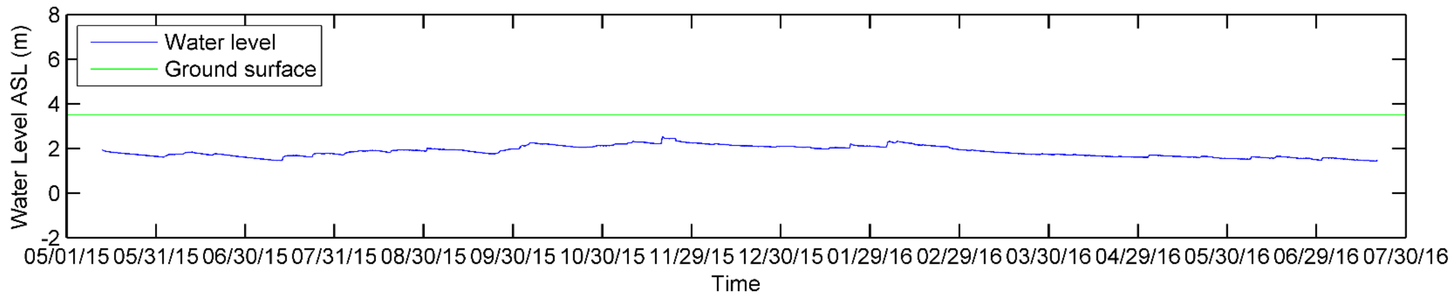
OBB22


OBB22
Water level
Ground surface
Elevation (m)
6
5
4
3
2
1
0
08/01/15
09/01/15
10/01/15
11/01/15
12/01/15
Date

APPENDIX 4

Time series of groundwater levels from Bogue Banks.

OBB01



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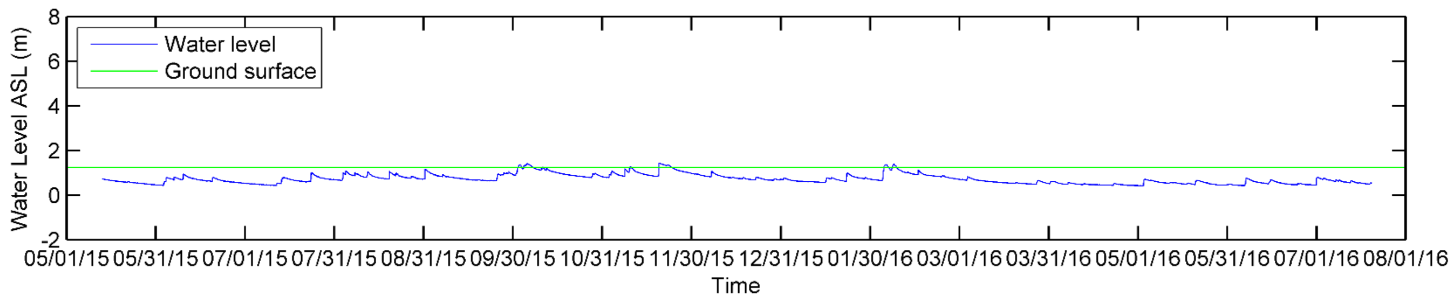

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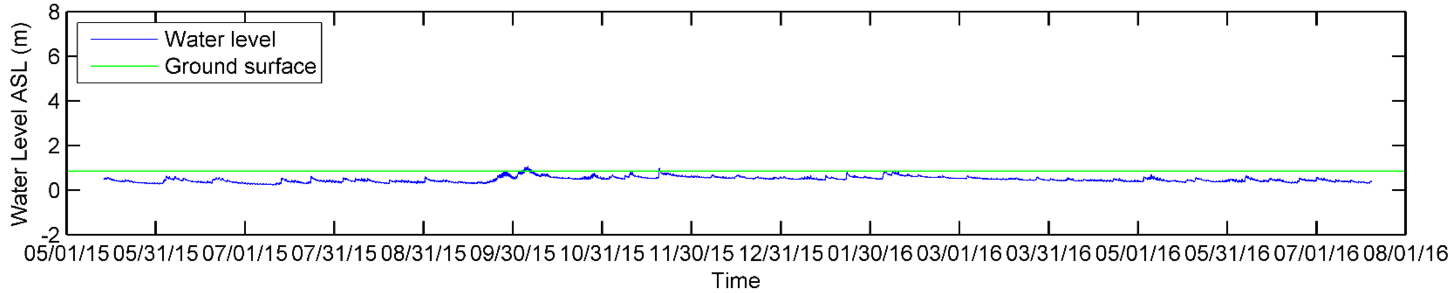

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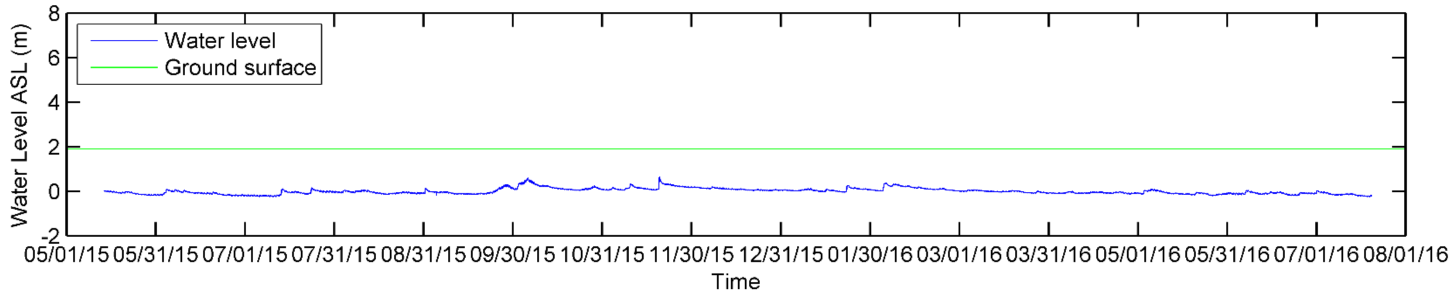

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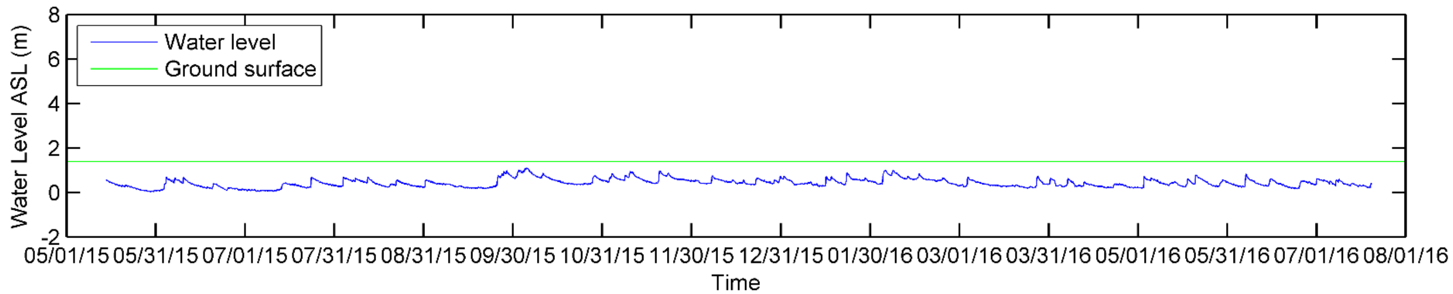

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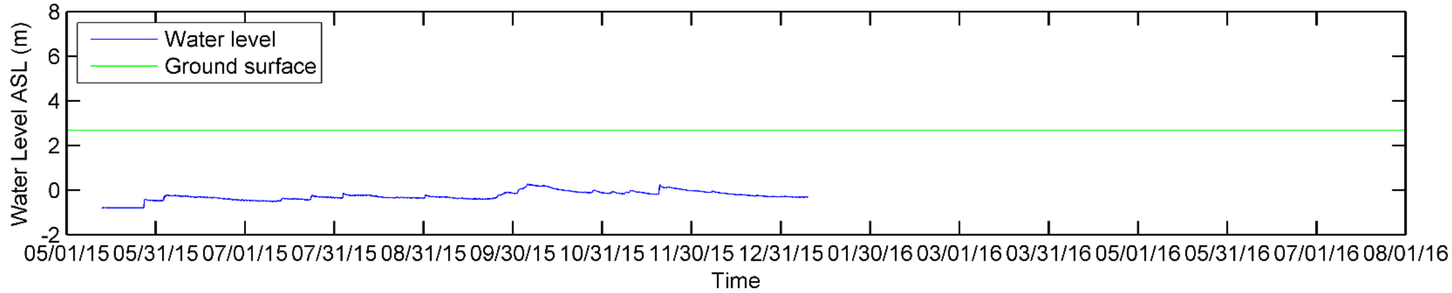
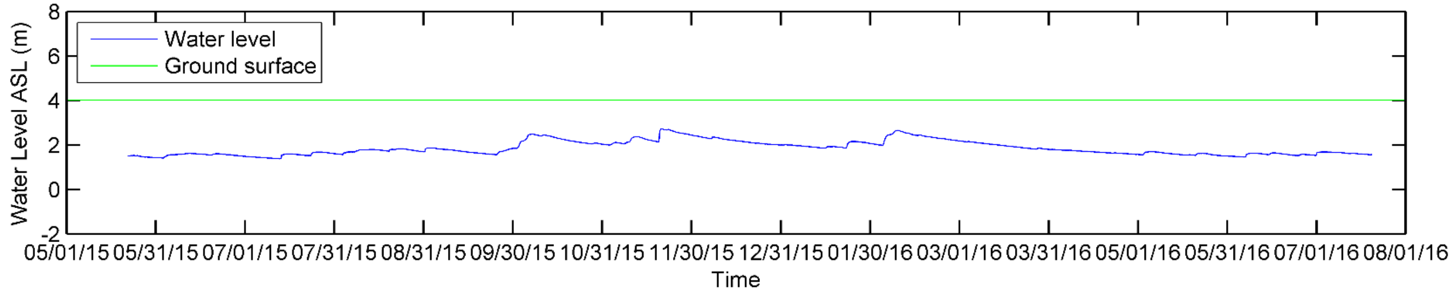

Water level
Ground surface
Water Level ASL (m)
8
6
4
2
0
-2
05/01/15
05/31/15
07/01/15
07/31/15
08/31/15
09/30/15
10/31/15
11/30/15
12/31/15
01/30/16
03/01/16
03/31/16
05/01/16
05/31/16
07/01/16
08/01/16
Time

OBB07


Water level
Ground surface
Water Level ASL (m)
8
6
4
2
0
-2
05/01/15
05/31/15
07/01/15
07/31/15
08/31/15
09/30/15
10/31/15
11/30/15
12/31/15
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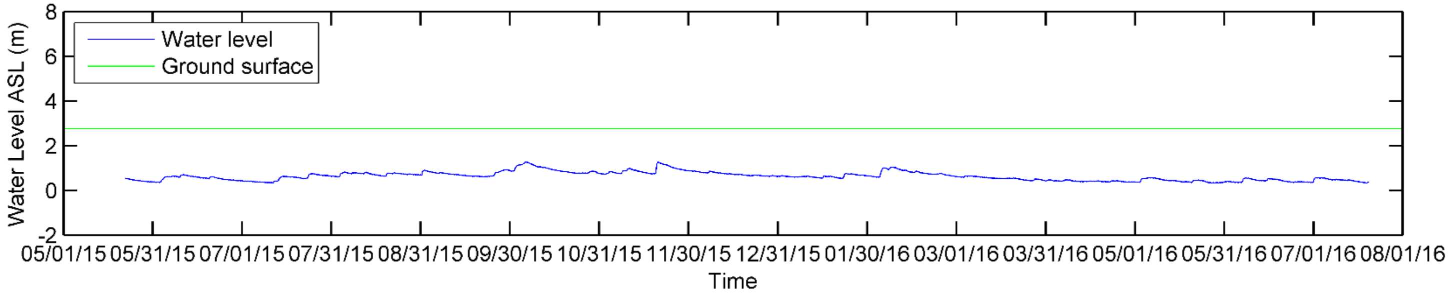
08/01/16
Time

OBB08



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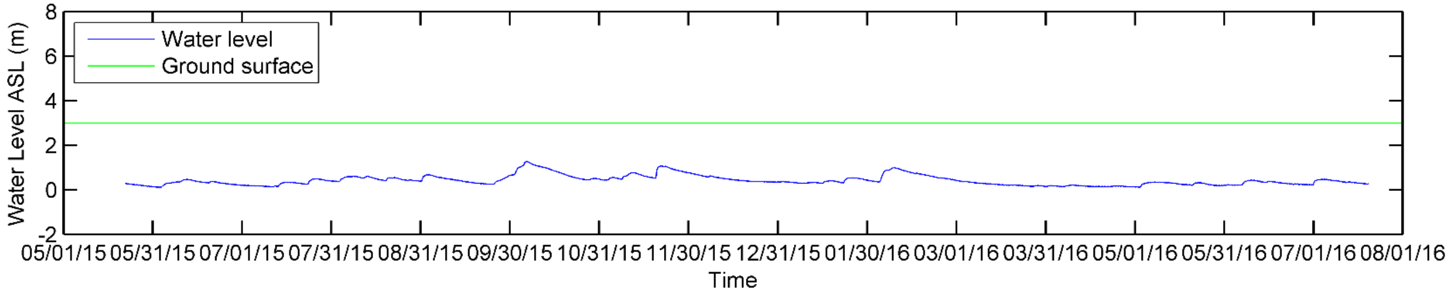

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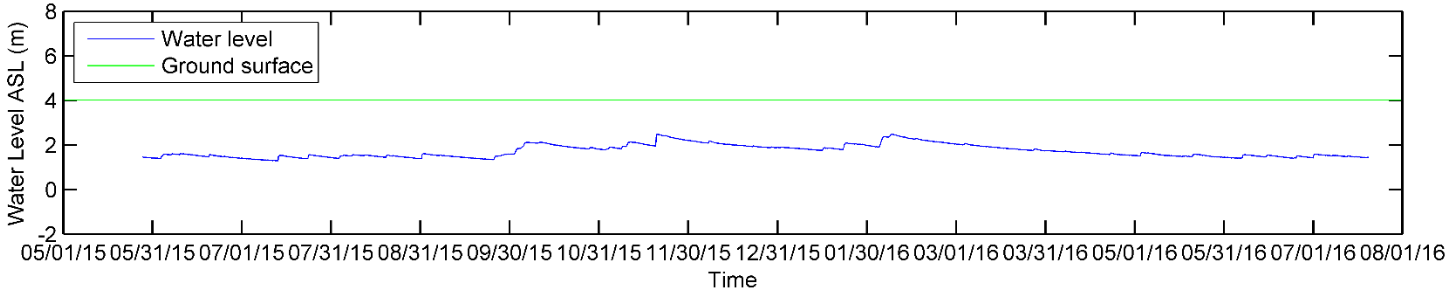

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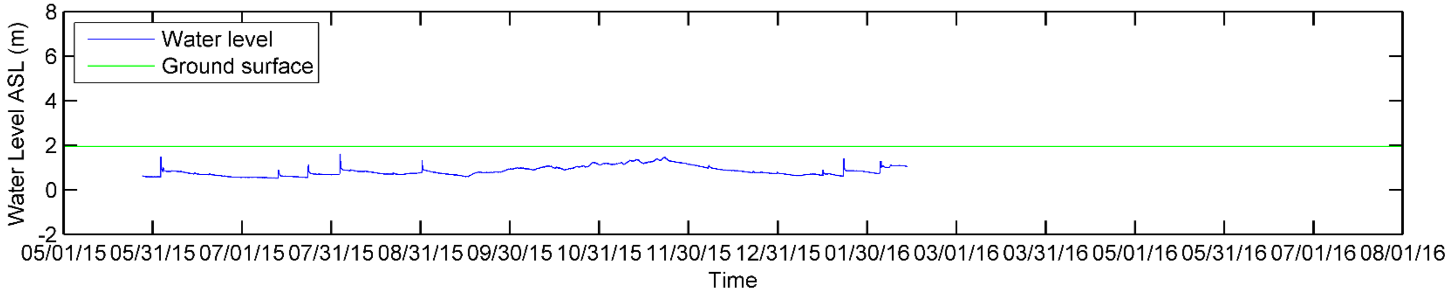

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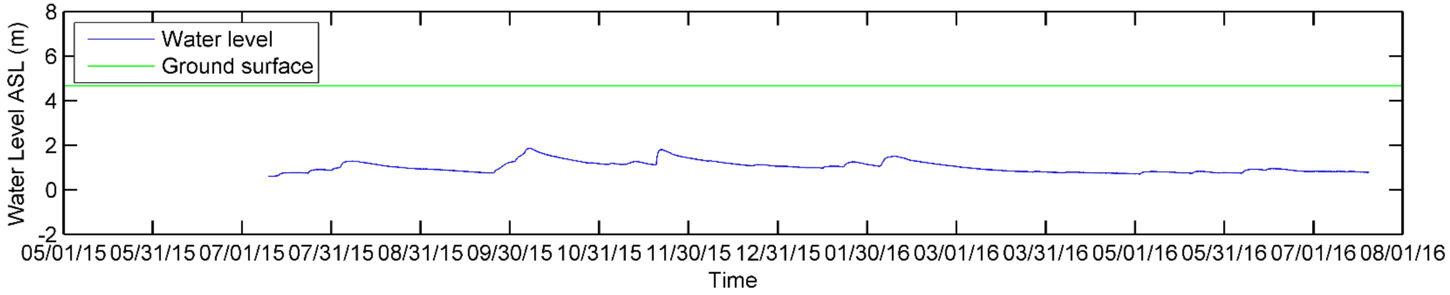

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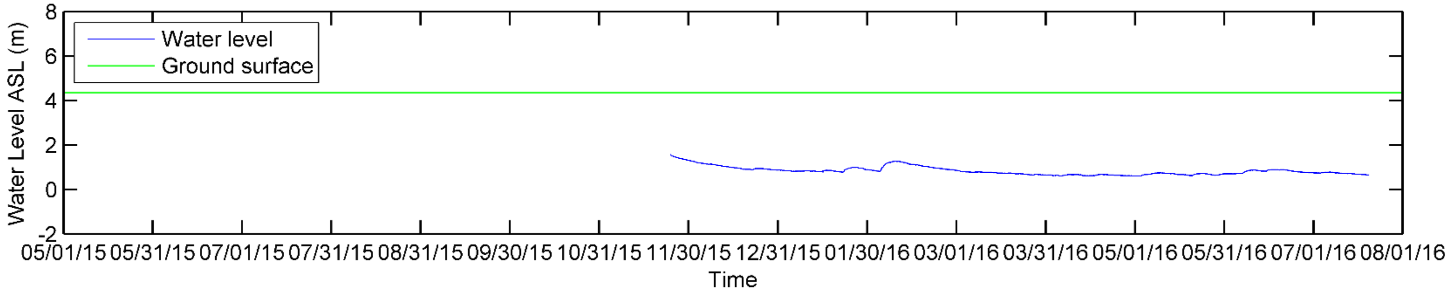

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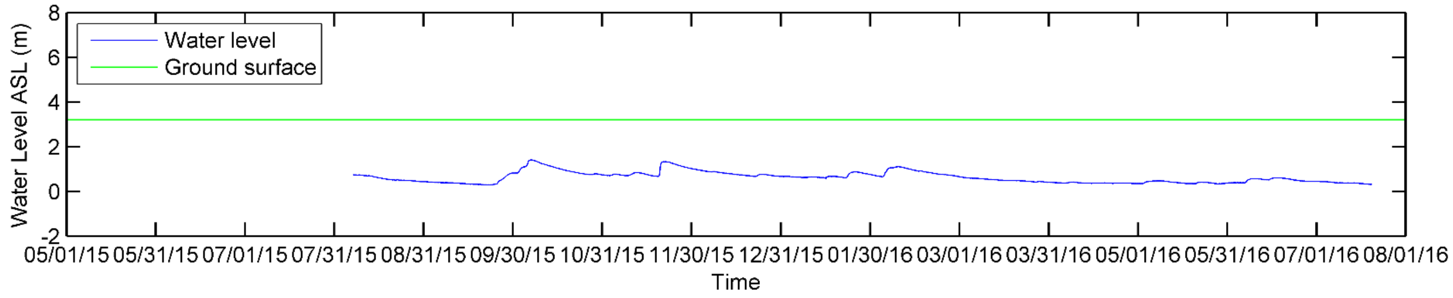

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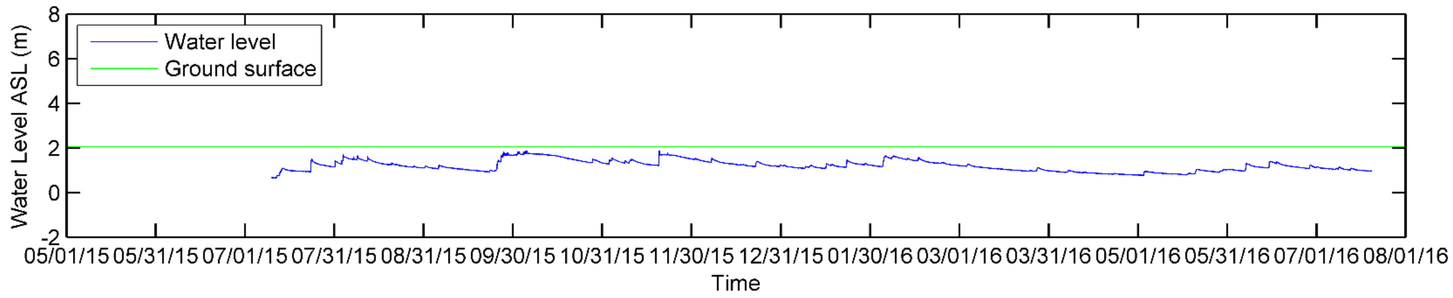

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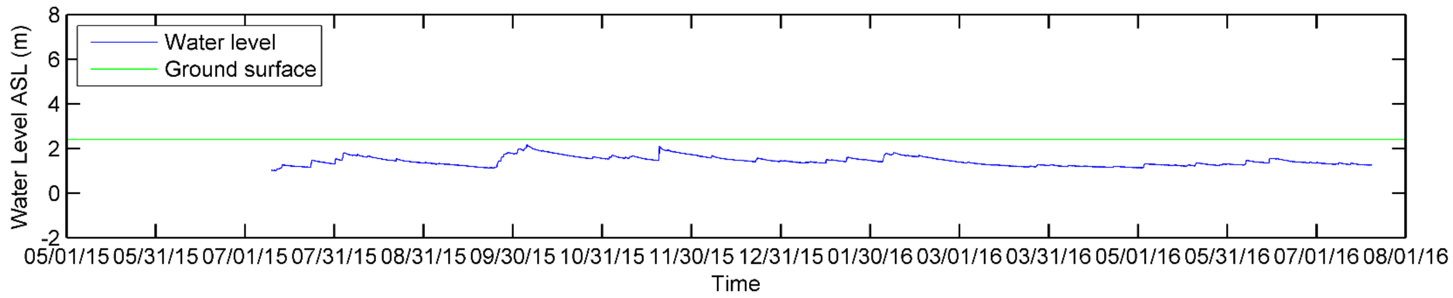

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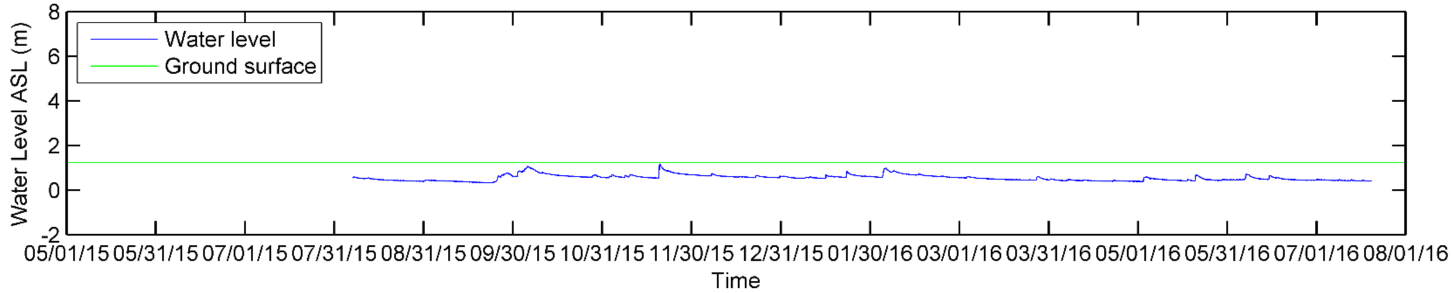

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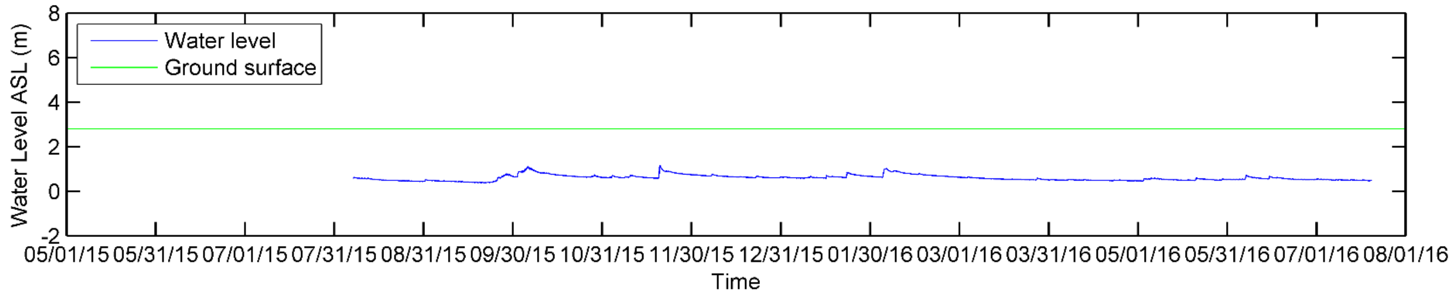

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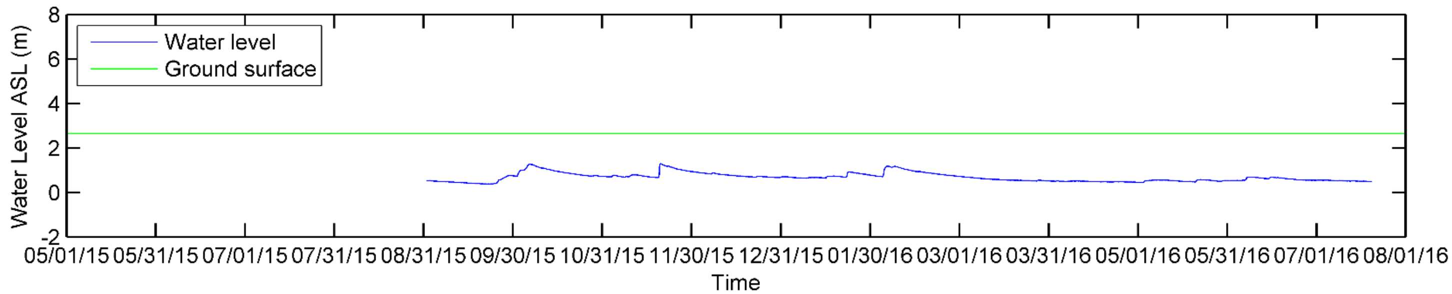

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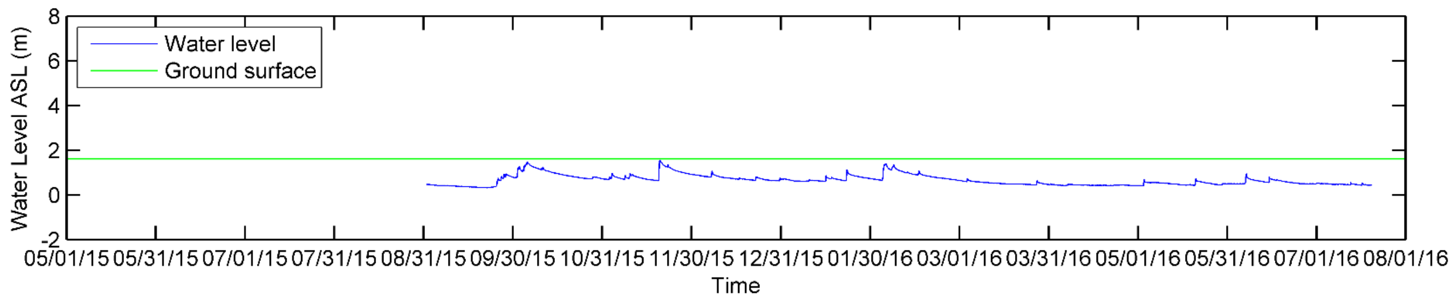
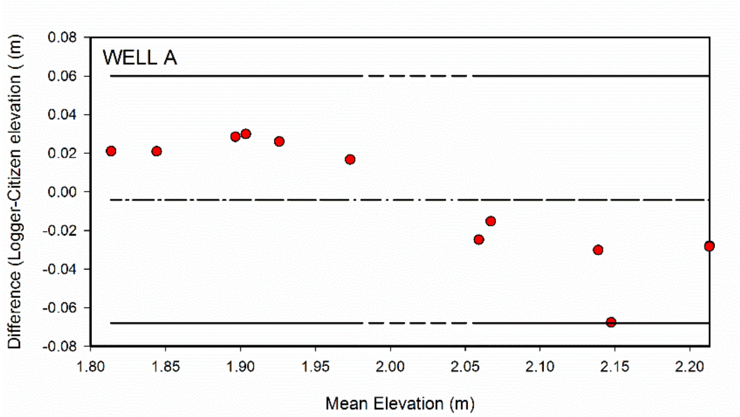


Water level
Ground surface
Water Level ASL (m)
8
6
4
2
0
-2
05/01/15 05/31/15 07/01/15 07/31/15 08/31/15 09/30/15 10/31/15 11/30/15 12/31/15 01/30/16 03/01/16 03/31/16 05/01/16 05/31/16 07/01/16 08/01/16
Time

APPENDIX 5

BLAND ALTMAN PLOTS

OBB01



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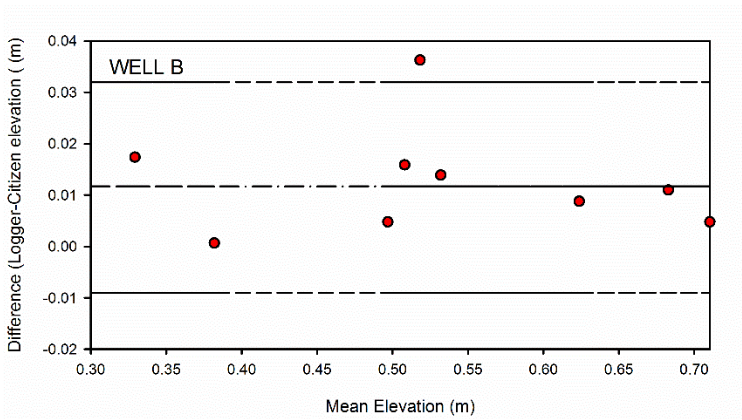

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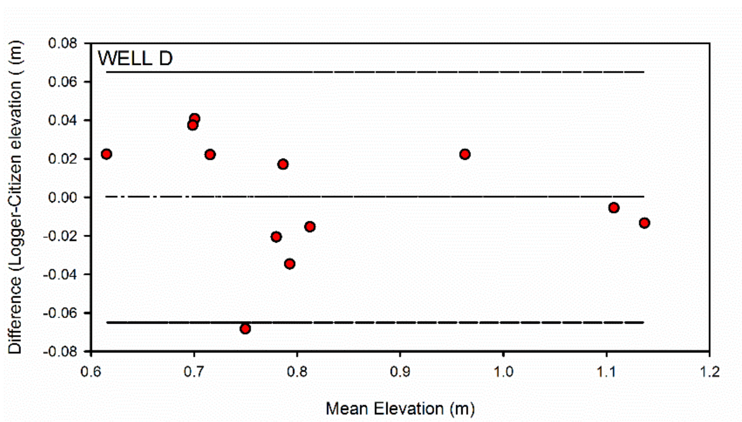


APPENDIX 6

RESULTS FROM ANOVA

OBB01

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.44369	11	0.040335	78.91099	7.88E-09	2.81793
Columns	0.000106	1	0.000106	0.207884	0.6573	4.844336
Error	0.005623	11	0.000511			
Total	0.449419	23				

OBB03

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.36069	9	0.040077	758.6638	7.19E-12	3.178893
Columns	0.000687	1	0.000687	13.00119	0.005697	5.117355
Error	0.000475	9	5.28E-05			
Total	0.361852	19				

OBB08

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.585452	9	0.06505	118.9039	2.86E-08	3.178893
Columns	0.000147	1	0.000147	0.269474	0.616207	5.117355
Error	0.004924	9	0.000547			
Total	0.590523	19				

APPENDIX 7

PERCEPTIONS QUESTIONNAIRE

COASTAL GROUNDWATER WATCH: PRE-PARTICIPATION PERCEPTIONS SURVEY

This survey is conducted by East Carolina University researchers pursuant to a project funded by East Carolina University, North Carolina Sea Grant, and the North Carolina Water Resources Research Institute

***Instructions*: Please write your full name in the upper left corner of each page. Your name will be used solely to match your pre- and post-participation surveys. YOUR RESPONSES WILL BE KEPT CONFIDENTIAL.**

Read each question carefully and respond as best you can. There are no wrong answers, and no "best" answers. Choose the answer which best describes you.

THANK YOU!

Background

The objectives of this research are to:

- Assess how aware citizen scientists are of flood risk
- Determine whether citizen scientists possess the knowledge of specific ways to mitigate flood risk
- Evaluate the perception of citizen scientists of barriers to mitigation activities
- Determine whether citizen scientists are aware of steps taken to reduce flood risks in the study region

PART I. FLOOD RISK AWARENESS

A. Residency

Please circle the answer which best describes you.

1. Do you live on Bogue Banks? Yes No
2. If yes, are you a Part-time resident Full-time resident
3. If you live on the island, how long have you lived on the island? 1-5 years 6-10 years 11-20 years > 20years

4. If not a resident, how frequently do you visit Bogue Banks in a year? 1-2 times 3-5 times
   6-10 times >10 times

5. Do you, or someone in your household, rent or own the house in which you live?

   Own or buying to live in   Own or buying for as a vacation home
   Rent to live in   Rent as a vacation home
   Other (please specify) ____

6. Were you informed about flood risk before buying or renting your house? Yes No

7. How important would it have been to you to have been informed about flood risk before you moved into your house? Very Important Somewhat Important Not Important

B. Impacts

8. How significant is flooding on Bogue Banks?

   Not significant Significant Very Significant Don't Know

9. Which areas on Bogue Banks do you think experience the most significant storm water flooding problems?
   ____
   ____
   ___

10. How have past flood events had any direct ongoing positive or negative effects on you and or your family?

    No effects I can think of   Don't know   Positive (Give details)__________________
    ____
    ____

    Negative (Give details)
____
    ____
____

11. Would information about flood risk have impacted your decision to purchase your home?

Yes No

12. Have past flood events had any ongoing positive or negative effects on your community (e.g. social networks, parks and reserves, amenities)?

No effects I can think of Don’t know Positive (Give details)

____

____

____

____

____Negative (Give details)____

____

____

13. Have past flood events had any ongoing positive or negative economic effects on your community?

No effects I can think of Don’t know Positive (Give details)

____

____

____

____

____Negative (Give details)____

____

____

C. Risks

14. In your opinion, what is the cause of flooding on Bogue Banks?-

____

____

____

15. In the next 50-100 years, how do you think flood risk will change?

Get worse (Give details why) ____

Stay the same (Give details why)____

Get better (Give details why)____

16. Have you looked at a flood risk map for Bogue Banks before?

    Yes No Not sure

17. If you have seen flood risk maps, how useful do you think they are to inform residents about their flood risk?

    Very useful Somewhat useful Not useful

18. How many times have you looked at the flood risk map for Bogue Banks in the last 5 years?

    0 1-5 6-10 >10

19. What have you done to minimize the risk from flooding on Bogue Banks? ____________________
    ____
    ______

20. What have local authorities done to address the risk of flooding on the island? _______________
    ____
    ______

21. Name several features that can be used/installed to address flooding. ______________________
    ____
    ____

D. Communication of Risk

22. How many times in the last year have you heard about flooding on Bogue Banks from local authorities?

0 1-5 6-10 >10

23. How have you heard about flooding on Bogue Banks?

Newspaper Internet Brochure Town meeting
Other___________________

24. How frequently would you like to hear about flood risk from local authority in a year?

0 1-5 6-10 >10

25. How do you want to hear about flood risk in your community?

Newspaper Internet Brochure Town meeting
Other________________

PART II. ADAPTATION AND MITIGATION MEASURES

The following table lists a number of potential adaptation measures. Please indicate (with an x) which of these are planned or have been implemented in your area as a response to flooding concerns, and which you deem necessary and/or effective in addressing flooding-related problems. Please add additional measures, if necessary.

Adaptation measure	**Implemented**	**Planned**	**Effective/ necessary (but not planned yet)**	**Not relevant/ necessary**
Flood protection				
Technical flood protection (e.g., upgrade drainage systems)				
Restriction of settlement/building development in risk areas				

Adaptation measure	Implemented	Planned	Effective/ necessary (but not planned yet)	Not relevant/ necessary
New standards for building development (e.g. permeable surfaces, greening roofs)				
Regulations for flood management				
Improving flood forecasting, monitoring, information, and early warning systems				
Improving flood insurance programs				
Ad hoc post-event environmental monitoring program (e.g. to identify new areas of flooding)				
Awareness-raising and involvement of the public				
Institutional measures: policies, plans, regulations, economic incentives and financial mechanisms				
Integrated risk management and information campaign in cooperation with public health authorities				
Others, please specify:				

PART III. DEMOGRAPHIC INFORMATION

1. What is your age? 18-30 31-50 50-70 over 70

2. Gender: ____Male ____Female

3. What is the highest level of school you have completed? *If currently enrolled, highest degree received.* Some high school, no diploma High school graduate, diploma or the equivalent (for example: GED) Some college credit, no degree Trade/technical/vocational training Associate degree Bachelor's degree Master's degree Professional degree Doctorate degree

4. Employment status: Employed Unemployed Retired

5. Which of the following best matches your total household income before tax? $0 - $25,000 $25,001 – $45,000 $45,001 - $65,000 $65,001 - $85,000 >$85,000

7. Have you ever held public office? Yes No

8. Have you ever run for public office? Yes No

9. Have you ever attended or participated in public hearings regarding environmental issues?
Yes No

10. Have you ever been involved (in any capacity, including volunteer or financial donor, as well as member, officer or director) with any environmental advocacy group? Yes No

11. Have you ever volunteered to work on environmental preservation, restoration or monitoring projects? Yes No

Thank you for taking the time to provide your comments. Your completed questionnaire can be submitted as follows:

1. Go to the following link and submit your response online:

2. Send an email with responses to the questions to: garnerma10@students.ecu.edu. Please insert the following title into the subject line of your email: Coastal Groundwater Watch

3. Print a copy of the questionnaire, complete it and mail to:

   Margaret Garner
   East Carolina University
   Rivers West, RW-106
   Greenville, North Carolina 27858

If you have any questions please email them to: garnerma10@students.ecu.edu with Coastal Groundwater Watch in the subject line or call Margaret Garner at 252-737-1772.

APPENDIX 8

KNOWLEDGE QUESTIONNAIRE

COASTAL GROUNDWATER WATCH: PRE-PARTICIPATION KNOWLEDGE SURVEY

This survey is conducted by East Carolina University researchers pursuant to a project funded by East Carolina University, North Carolina Sea Grant, and the North Carolina Water Resources Research Institute.

The objective of this survey is to assess citizen scientists' basic knowledge of water resources and causes of flooding.

***Instructions*: Please write your full name in the upper left corner of each page. Your name will be used solely to match your pre- and post-participation surveys. YOUR RESPONSES WILL BE KEPT CONFIDENTIAL. Read each question carefully and respond as best you can. There are no wrong answers, and no "best" answers. Choose the answer which best describes you.**

THANK YOU!

To what extent do you agree or disagree with each of the following statements? *Circle the number under the answer that best describes you.*

Only about 2% of the world's water is fresh water.	1	2	3	4	5
Most of my household water comes from surface waters such as rivers, lakes, and reservoirs.	1	2	3	4	5
Groundwater accounts for about 12% of the world's freshwater resources.	1	2	3	4	5
Groundwater comes primarily from underground rivers.	1	2	3	4	5
"Aquifer" is the name given to underground soil or rock through which groundwater can easily move.	1	2	3	4	5
The top of the water in the soil, sand, or rocks is called the water table.	1	2	3	4	5

Coastal aquifers generally consist of a fresh water layer overlying a denser, saltwater layer.	1	2	3	4	5
Groundwater comes from water seeping into the ground.	1	2	3	4	5
Most of the world's freshwater is stored in frozen form, generally in glaciers, icefields, and snowfields.	1	2	3	4	5
Water quality can vary within an aquifer.	1	2	3	4	5
Groundwater is recharged by precipitation.	1	2	3	4	5
An artesian aquifer is a confined aquifer containing groundwater under positive pressure. This causes the water level in a well to rise.	1	2	3	4	5
Groundwater is contained in pore spaces and cracks.	1	2	3	4	5
Water moves in a continuous cycle above, on, and below the surface of the Earth.	1	2	3	4	5
Components of the hydrologic cycle include atmospheric, surface, vegetation, soil, and groundwater components.	1	2	3	4	5
The potentiometric surface is equivalent to the water table in an unconfined aquifer.	1	2	3	4	5
Springs and flowing wells may result from artesian aquifers.	1	2	3	4	5
Groundwater can be contaminated by human activities.	1	2	3	4	5
Shallow wells are less likely to be contaminated than deep wells.	1	2	3	4	5
Pollutants travel with groundwater.	1	2	3	4	5
With rising seas, the water table will be raised and saltwater will rise in the aquifer.	1	2	3	4	5
Rising water tables may result in increased flooding	1	2	3	4	5

Thank you for taking the time to provide your comments. Your completed questionnaire can be submitted as follows:

1. Go to the following link and submit your response online:

2. Send an email with responses to the questions to: garnerma10@students.ecu.edu. Please insert the following title into the subject line of your email: Coastal Groundwater Watch

3. Print a copy of the questionnaire, complete it and mail to:

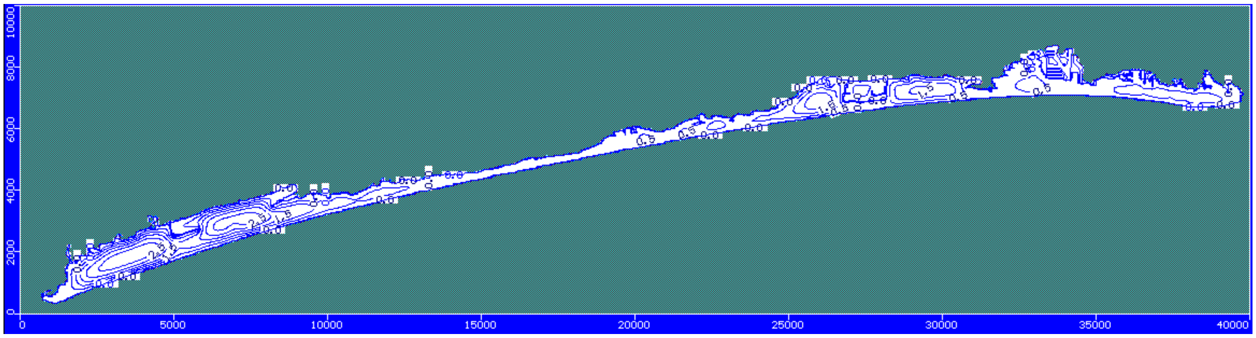
   Margaret Garner
   East Carolina University
   Rivers West, RW-106
   Greenville, North Carolina 27858

If you have any questions please email them to: garnerma10@students.ecu.edu with Coastal Groundwater Watch in the subject line or call Margaret Garner at 252-737-1772.

APPENDIX 9

WATER TABLE CONTOUR MAPS UNDER VARIOUS SEA-LEVEL RISE SCENARIOS

BASELINE



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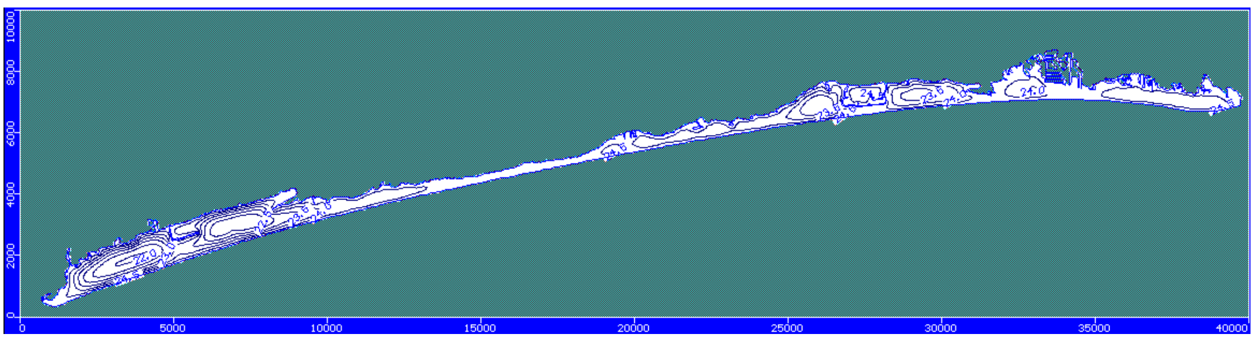

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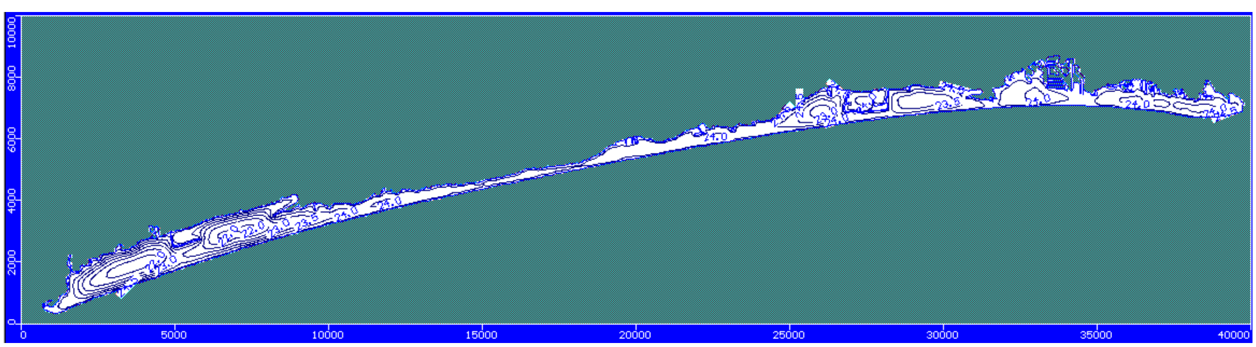

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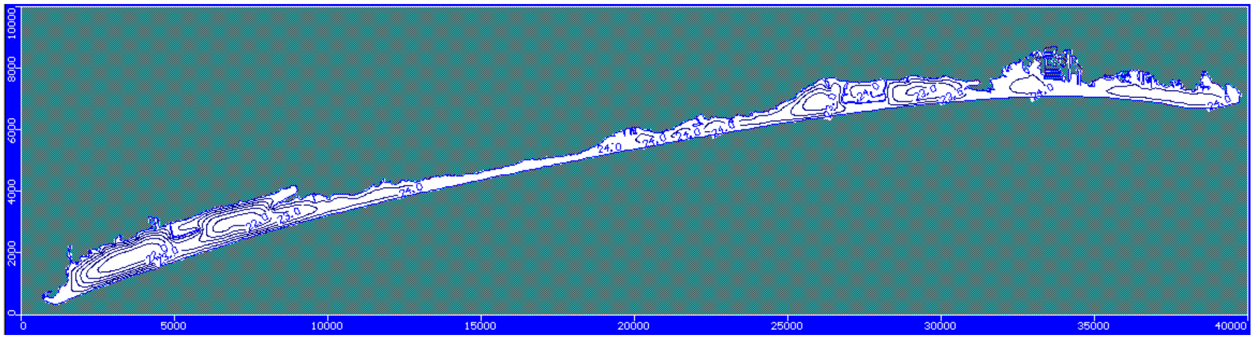

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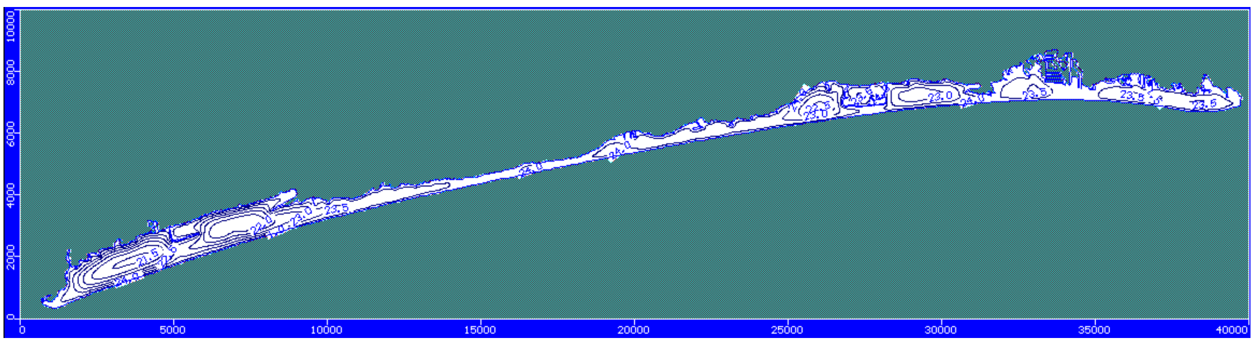

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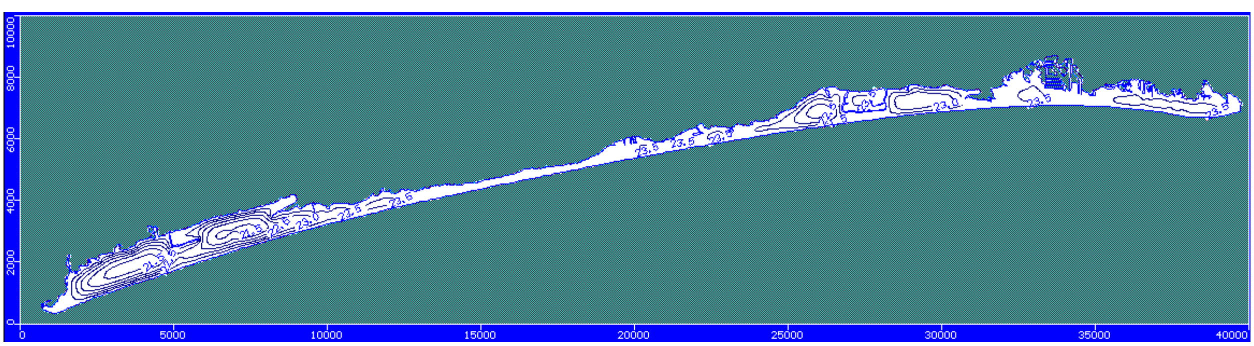

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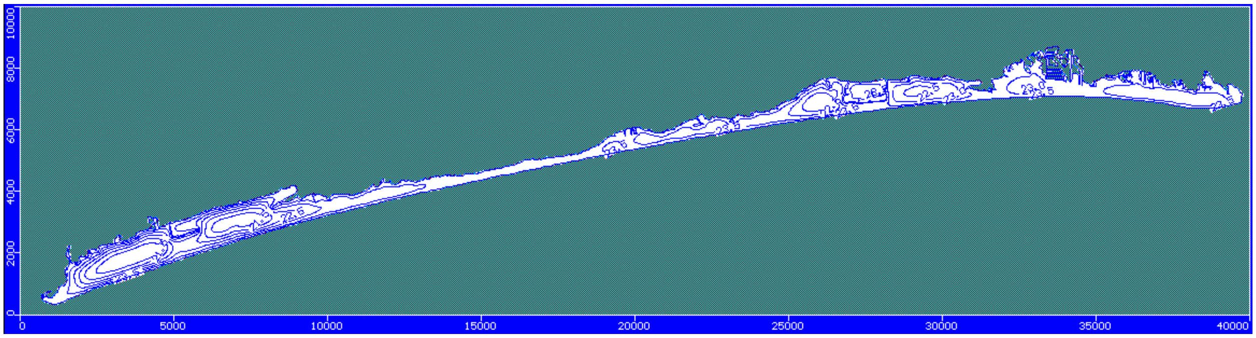
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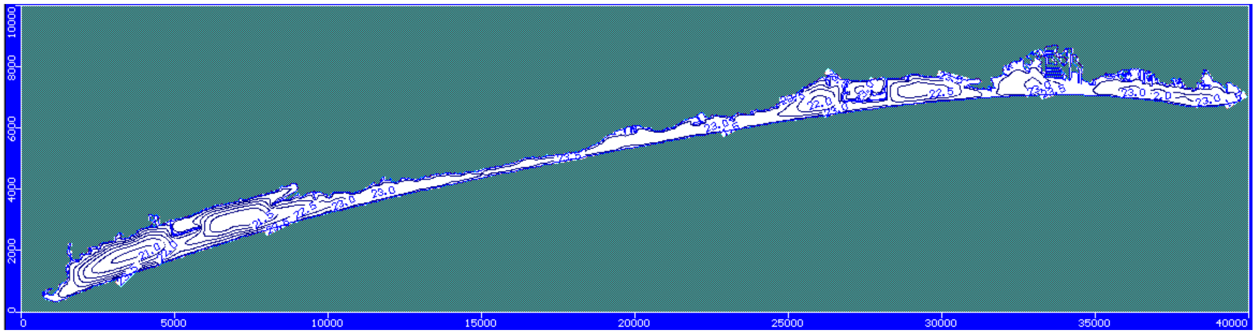
40000

1.4 m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APPENDIX 10

Students from East Carolina University that gained practical field experience from the completed project

Student	Status	Program	Experiences
James Owers	Graduate student	MS Geology	Well installation, surveying, data collection, community engagement, data analysis
James Pitt	Graduate student	MS Geology	Well installation, surveying, data collection, community engagement
Nick Kelley	Graduate student	MS Geology	Surveying
Beau Benfield	Graduate student	MS Geology	Well installation
Carolina Smith	Graduate student	MS Geology	Well installation, surveying
Bailey Donovan	Graduate student	MS Geology	Data Collection
Emily Harrison	Graduate student	MS Geology	Data Collection
Mark Akland	Graduate student	MS Geology	Well installation
Kim Urban	Graduate student	MS Anthropology	Surveying
Wendy Klein	Graduate student	PhD Coastal Resources Management	Well installation, surveying, data collection, community engagement
Elizabeth Brown-Pickren	Graduate student	PhD Coastal Resources Management	Well installation
Cale Galloway	Graduate student	PhD Coastal Resources Management	RTK GPS surveying
Crystal Fraley	Undergraduate student	BS Geology	Well installation
Nelson Padget	Undergraduate student	BS Geology	Well installation, surveying
Raymond Strand	Undergraduate student	BS Geology	Well installation, surveying