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IMPACT ASSESSMENT OF EXTREME STORM EVENTS ON SOUTHERN NEW JERSEY COASTAL COMMUNITIES

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Abstract: Extreme weather events, such as hurricanes and flooding, impact our society in numerous ways. This has never been more evident than when Hurricane Sandy devastated the eastern seaboard of the United States. Hurricane Sandy was one of the largest and costliest recorded storms to hit the U.S. Northeast. The hurricane made landfall in southern New Jersey and caused billions of dollars in damages to the region. The majority of this damage was associated with the infrastructure of the state. This includes transportation, water retaining structures, and water treatment systems. This devastation uncovered the desperate need for appropriate response strategies in the face of extreme weather events in the state of New Jersey. This response needs to be in the form of better preparation and coordination among all government levels. This paper details an analysis that was conducted on the effects of extreme storm events on the infrastructure of southern New Jersey under various scenarios. Using several hydrodynamic models including Hazus (Hazards U.S. - Multi Hazards) and SLOSH (Sea, Lake, and Overland Surges from Hurricanes), a more accurate portrayal of the potential risk to the region's infrastructure including resulting flood depth from storm events was highlighted. Analysis show Hazus and SLOSH models could be used in conjunction, however, storm scenarios need to be properly matched, for example a 500-year Hazus storm is comparable to flood depths of a category 2 hurricane from SLOSH. The results of this work can be used to prepare much needed resiliency plans for coastal regions.

***Keywords**:* SLOSH; HAZUS; Hydrodynamic Modeling; Resiliency

1. INTRODUCTION

The past century has seen an overwhelming growth in both the magnitude and frequency of extreme weather events [2]. This growth can be attributed to accelerating sea level rise (Spanger-Siegfried, [15]), increased coastal flooding, and other natural and human-induced factors (Dasgupta, [3]). Hurricanes and flash floods can devastate infrastructures and create billions of dollars in damage (Melillo, [11]). This has been continuously apparent throughout the entire United States following disasters such as Hurricanes Ivan (2004), Katrina (2005), Ike (2008), etc. An increase in devastating storms can be especially seen in the coastal and riverine areas of southern New Jersey. A graphical representation of the most fundamental parameters involved in the analysis of coastal flooding is shown below in Figure 1. More recently, hurricanes such as Irene (2011) and superstorm Sandy (2012) have caused substantial damage to homes, businesses, and numerous forms of infrastructure. Notably, the state's wastewater and drinking water treatment infrastructure has suffered significant losses (Van Abs *et al.*, [20]). In addition, these storms have damaged or destroyed hundreds of acres of farmland and wetlands in the southern regions of New Jersey that, without proper protection plans for the future, will be nearly impossible to reclaim (New Jersey Future, [12]).

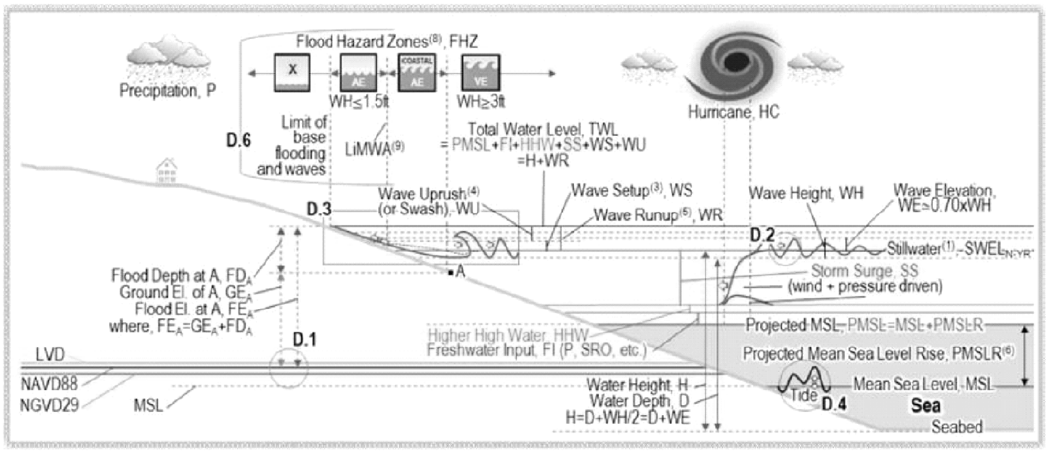

Figure 1: Graphical Representation of all Fundamental Parameters Involved in Coastal Flooding

Cumberland and Salem are two specific counties in southern New Jersey that can be highlighted as high-risk areas that would be greatly benefitted by better resiliency planning. Cumberland County is at a great risk from extreme weather events because of its geographical location and the potential for its infrastructure to experience major damage (Kenward, [10]). Four wastewater treatment plants are located within Cumberland County and all are in critical areas that leave them vulnerable to massive damages from extreme flooding. In Salem County various regions have already witnessed the damages resulting from extreme storm events. In Elsinboro Township, Hurricane Sandy has severely deteriorated and nearly breached two dikes that are responsible for ensuring the Delaware River does not claim hundreds of acres of valuable farmland, wetlands, homes and even historical properties. When examining these particular situations, it has become readily apparent that coordination and planning of resiliency measures in southern New Jersey is necessary to overcome the challenges that climate change [5] and its resulting storms will surely continue to impose in the future (NYCPCC, [13]).

The purpose of this study was to determine the effects that extreme storm events will have on southern New Jersey communities. More specifically, the predicted effects on infrastructure in both Cumberland County and Salem County have been documented. These two counties provide two different but valuable perspectives when examining the devastating effects of major storms. Salem County, specifically Elsinboro Township, is an excellent example of how resiliency planning can be used to prevent loss of valuable land in the future. Cumberland County serves as an example of how such measures can be used to properly and effectively prepare specific infrastructural elements for storms that will continue to grow in both frequency and magnitude in the future.

1.1. Cumberland County Background

Cumberland County, New Jersey, with over forty miles of coastline, is situated along the Delaware Bay (Forstall, [6]). It is also a low-lying county with numerous saltwater marshes and rivers, most notably the Maurice River, contained within the county. Four wastewater treatment plants are located in Cumberland County, including Landis Sewerage Authority, the City of Millville, Bayside State Prison, and the Cohansey Utilities Authority. Due to county's low elevation and coastal characteristics, these four wastewater treatment plants are at risk for potential flooding from major storms.

Although these plants favored relatively well during Hurricane Sandy, New Jersey wastewater plants discharged nearly 5.2 billion gallons of sewage overflows (Kenward, [6]). There are obvious social and environmental impacts associated with these overflows that could be detrimental to the region. With stronger storms becoming more frequent, it is only a matter of time before the vulnerable wastewater treatment plants in Cumberland County are affected in the same manner.

Sandy's devastation of New Jersey wastewater plants highlighted the lack of coordination and resilience between all levels of government. In a much needed response to the damage sustained by Hurricane Sandy, the New Jersey Department of Environmental Protection has allocated over 2.6 billion dollars to water infrastructure throughout the state (EPA [18]). Of the 2.6 billion dollars, more than half will be used to build resilience. The next major storm will truly test the new resiliency of the state and the effectiveness of the government to mitigate the devastating effects that are presented in the future.

1.2. Elsinboro Township Background

Elsinboro, New Jersey is located in Salem County along the Delaware Bay. It is a small, 13.5 square mile township with a long history of farming (Census [19]). The land bordering the Delaware Bay is a marshy wetland with the Alloway Creek coursing through the coastal lands (DeLorme, [4]). Not only is this natural wildlife region the only remaining physical border preventing flooding, but it also encompasses a future connection route to a new nuclear reactor at Hope Creek, in Alloway Creek Township, New Jersey.

In the past, Alloway Creek has managed to resist the flooding of neighboring farmlands and other properties by means of sod dikes, commonly implemented for salt hay farmland. In recent years, the dikes have deteriorated with a complete breach at the Mason Point Dike, seen in Figure 2, and a quickly eroding breach at the Abbots Dike, seen in Figure 3.

Figure 2: Mason Point Dike Breach (top) and the ultimate failure of Abbot's Dike (bottom)

With these failures, flooding of the land has increased in frequency to an approximate rate of two storm surge breaches a year (U.S. Army Corps, [16]).

Despite attempts to receive aid for reparation of the dikes, significant progress has not been made. The NJDEP Division of Fish and Wildlife has taken ownership of the levees to preserve the environmentally rich region. State Senate office reached out to the U.S. Army Corp of Engineers [L] to seek remedy to the failed dikes but has yet to see action. The Division of Fish and Wildlife suggested a 2-3 foot dike made of either geotubes or dredged material to replace the failing levee system.

The land in Elsinboro is in danger of losing its diversity as well as its functionality. Continual storm surges will reduce the farmland from salt hay fields to un-farmable land. The wetlands of the region are characteristic of biodiversity, high in nutrients and animal life. Without reparation to levee system, the land is at risk of being lost without a likely chance at future retrieval.

Residents in the threatened areas have been asked to sell their residential land to the government and to relocate. The area, maintaining a long, family-generation oriented population, has faced resistance to government buyouts. As the deterioration continues, the water rescue totals and frequencies have increased for stranded residences. Below, a photograph of Elsinboro residential home shows the flooding extent of Hurricane Irene which reached New Jersey as a tropical storm on August 28, 2011 (NOAA, [17]).

Figure 3: Local rescue after Hurricane Irene Flooding

Without remediation of the levee system, Elsinboro is at risk. The land can be compromised and destroyed, and the residents will continue to face disaster and be forced to sell their land and move. Dike installation or reparation needs to be performed to preserve the region at its current condition. Other strategies such is floodwalls, movable barriers and berms could ensure long term resiliency for this region.

2. METHODOLOGY

To perform the analyses, two models are used: National Oceanic and Atmospheric Administration (NOAA) SLOSH and Federal Emergency Management Agency (FEMA) HAZUS. SLOSH (Sea, Lake, and Overland Surges from Hurricanes) provides a compilation of data gathered by the NWS (National Weather Service) in regards to the tidal surges resulting from hurricanes of increasing intensities (Jelesnianski, [9]). Within this model is the ability to input data regarding characteristics of the anticipated hurricane including atmospheric pressure, size, forward speed, track data, and landfall location. This allows for the computation and simulation of extremely specific storms. The ease of manipulation, however, can have detrimental impacts to the results of the simulation as small changes in any of these factors can have major impacts on the storm. It is for this reason that the Deterministic Approach of modeling storms is often replaced with a Probabilistic Approach or a Composite Approach [1].

A Probabilistic Approach incorporates the statistics of past forecast performances and historic hurricane data to generate a small series of model runs based on changes of the previously mentioned factors. The approach used in this analysis of South Jersey was of a Composite nature. For this method, the storm surges are predicted based on several thousands of runs of the model with hypothetical hurricanes under varying inputs of atmospheric pressure, size, forward speed, and track data. The data generated from this approach is in the form of Maximum Envelopes of Water (MEOWs) and the Maximum of MEOWs (MOMs) (Glahn, [8]). Though they are less specific to the expected storm, their generality causes them to overestimate the results slightly. Rather than hurting the data, this slight overestimation serves as a factor of safety during simulation. It also represents the reality of forecast uncertainty that is often present during hurricane tracking. These MEOWs and MOMs are regarded by the National Hurricane Center (NHC) as the best approach for determining storm surge vulnerability for an area and form the basis for the development of the nation's evacuation zones.

To synthesize and manipulate the data, ESRI ArcMap is used. An approach was used by the team in which the hurricane data provided was manipulated to reflect the flood levels at specific points of New Jersey. Using a digital elevation model (DEM) of NJ at a 10 foot resolution, the elevations at each point in the state can be subtracted from the pixel value of surge height above sea level for that area based on the intensity of the desired storm. An equation simplifying this concept can be seen below in Equation 1. When the surge height is greater than the land elevation, a positive value will be calculated, indicating that level of flooding in the area. When the land elevation is greater than the surge height, a negative value will be calculated, indicating that there is no flooding in the area.

$$\textit{Surge Height (SH)} - \textit{Land Elevation (LE)} = \textit{Flood Level (FL)} \tag{1}$$

HAZUS is a GIS-based modeling program used for estimating losses from flooding, hurricane, and earthquake scenarios (FEMA, [14]). HAZUS produces graphic illustrations of high-risk locations and areas affected by different disaster scenarios as well as economic loss estimates in thousands of dollars. Additionally, it uses internal data to estimate the functionality of infrastructural elements following earthquakes and storms of different return periods.

As stated above, one of the great advantages of HAZUS-MH 2.1 is that the flood model is able to calculate flooding damages to a region and assign the economic losses. It calculates economic losses due to depreciation values of the damaged building, as opposed to the hurricane scenario which estimates the cost to completely rebuild new structures [7].

When determining the depreciated value of homes/structures that were flooded, a great amount of consideration is given to the age of the structure. The structural age accounts for the type of construction material (e.g. masonry, wood, or steel) around which the structure was built. Steel structures are the best at maintaining value, followed by masonry, and then wood. Along with the structural age, a chronological age is also considered. The older buildings will have higher depreciated values. When computing the possible damage to buildings and infrastructure, HAZUS estimates flood depth with depth-damage functions. The two inputs to the damage module are the building occupancy type with the first floor elevation, and the depth of flooding at the area weighted throughout the census block. Although every building type may not be known, it can be estimated due to the relationship between building types and occupancy.

HAZUS uses depth-damage functions, which are plots of floodwater depth versus percent damage, plotted for a variety of building types and occupancies. The HAZUS model uses Federal Insurance Administration's (FIA) "credibility weighted" depth-damage curves and selected curves developed by the U.S. Army Corps of Engineers (USACE) for estimations to damages to the general building stock. Damage to transportation and utility lifeline systems are estimated based on vulnerabilities of various parameters such as scour/erosion, and debris/ hydraulic loading. Damage to vehicles can be calculated from functions based on flood depth to percent loss from vehicles. Crop damage on the other hand is calculated by the date and the duration of flooding with consideration to the total area that was flooded.

The direct economic losses due to flooding are computed by algorithms considering relocation expenses, capital related income losses, wage losses, and rental income losses. Even indirect economic losses can be calculated in HAZUS by considering factors such as tourism. With these type of losses, HAZUS uses an Indirect Economic Loss Model to determine the loss of revenues from tourism with respect to Hotel revenues, and tax incomes.

3. RESULTS

3.1. Elsinboro, NJ

Using both storm models, the flooding depths were overlain over Salem County as raster data. The pixelated points are accurate to a 10 foot by 10 foot area on the land. Using the latitude and longitude of the locations of the failed dikes, the Mason Point and Abbots Dikes can be identified on the flood maps. With this ability, it is possible to predict the flood depths at the locations. Expected flood depths from the models are shown below in Table 1. This is an essential piece of knowledge when considering the height of the levees when they are rebuilt. The Division of Fish and Wildlife determined 2-3 feet would suffice, but the output of the SLOSH and Hazus concludes that higher berms may be necessary depending on the resiliency level chosen.

Table 1
Flood Depth Outputs at Dike Locations

Hazus-MH Return Period	*Mason Point Dike (ft.)*	*Abbots Dike (ft.)*	*SLOSH Hurricane Category*	*Mason Point Dike (ft.)*	*Abbots Dike (ft.)*
10 year	2.2	2.4	1	5.3	7.0
25 year	4.9	3.5	2	11.1	11.6
50 year	5.3	6.0	3	15.2	16.3
100 year	7.2	7.6	4	20.8	20.9
500 year	9.9	11.7	-	-	-

The flood maps of Salem County output from the two models can be viewed below in Figure 5, depicting the location of the breached dikes.

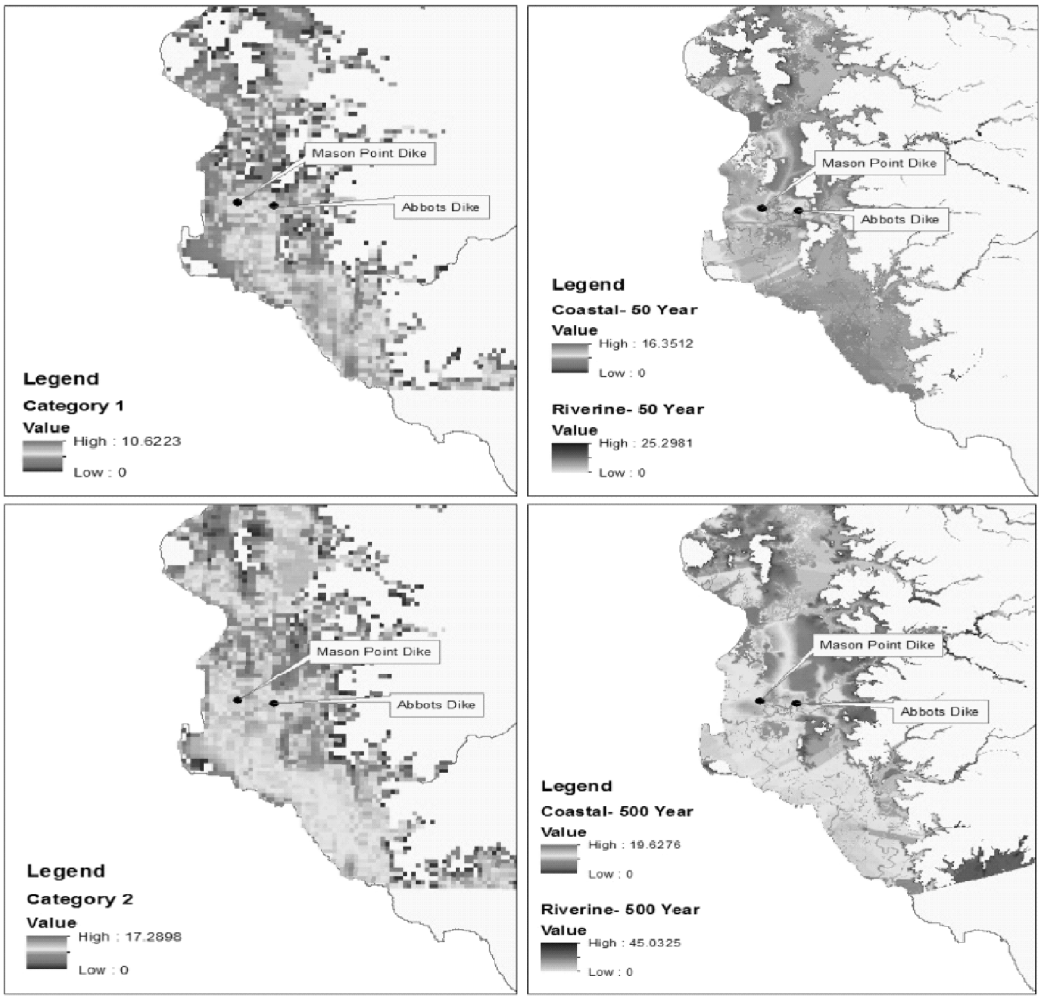

Figure 4: Salem County SLOSH (left) and HAZUS (right) Scenarios

3.2. Cumberland County Wastewater Plants

Using NOAA SLOSH, an analysis was conducted to determine not only the predicted flooding levels in the county under each hurricane scenario, but also when and how each plant will be affected. The Landis Sewerage Authority plant was not included in the analysis because its location in the northern part of the county helps it to be mostly unaffected by hurricane flooding. Shown below, Figure 5 presents a graphic map of the flooding effects under Category 1 through 4 hurricanes. Under a Category 1 hurricane, the City of Millville wastewater plant will be affected by flooding with levels between zero and ten feet. Landis and Bayside State Prison are virtually unaffected. During a Category 2 hurricane, the effects are the same only with the City of Millville receiving higher levels of flooding. During a Category 3 hurricane, the Bayside State Prison wastewater treatment plant also becomes affected while the Cohansey Plant remains unharmed. During a Category 4 hurricane Bayside State Prison and the City of Millville plants experience maximum estimated flooding while the Cohansey plant remains mostly unharmed.

Using Hazus, the analysis was run to determine the estimated damage in thousands of dollars and the functionality of the facility after each storm. For a storm with a return period of 100 years, Hazus estimated that the City of Millville wastewater treatment plant will experience 15.5 million dollars in damage and no longer be functional. For a storm

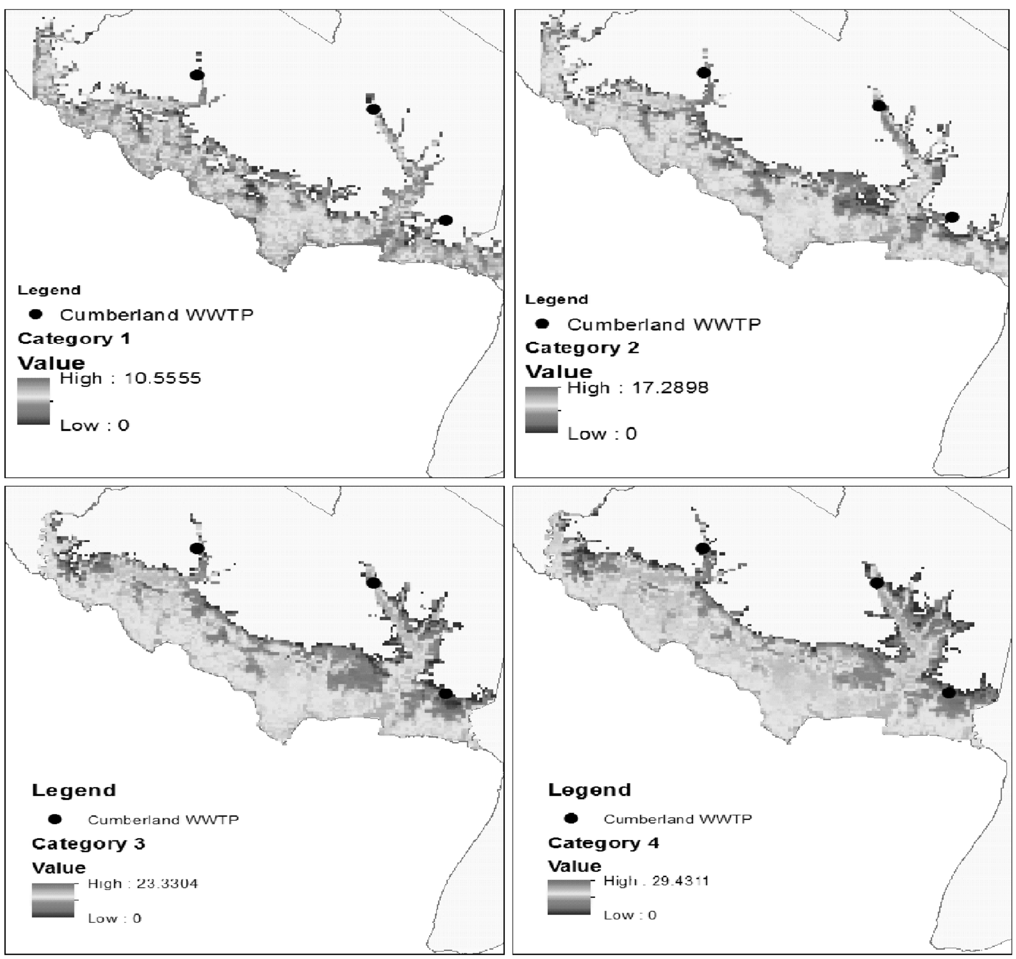

Figure 5: Flooding of Cumberland County Wastewater Treatment Plants under Hurricane Simulation (feet) Using SLOSH

with a 500 year return period, Hazus estimated that the City of Millville wastewater treatment plant will experience $23.8 million in damage and no longer be functional. Additionally, the Cohansey Utilities Authority plant will receive $6.8 million in damage but will still be functional. Landis Sewerage Authority and Bayside State Prison wastewater treatment plants were not included in the analysis because the Hazus model does not contain data for these plants. Adding the plant data would not be as simple as it would be in SLOSH because Hazus bases its estimates off of more detailed information about each facility including structural data, age of the facility, and things of that nature.

4. ANALYSIS

Hazus analyzes each storm based on return period for riverine and coastal flooding. As New Jersey is not prone to hurricane weather, Hazus will be the largest modelling influence.

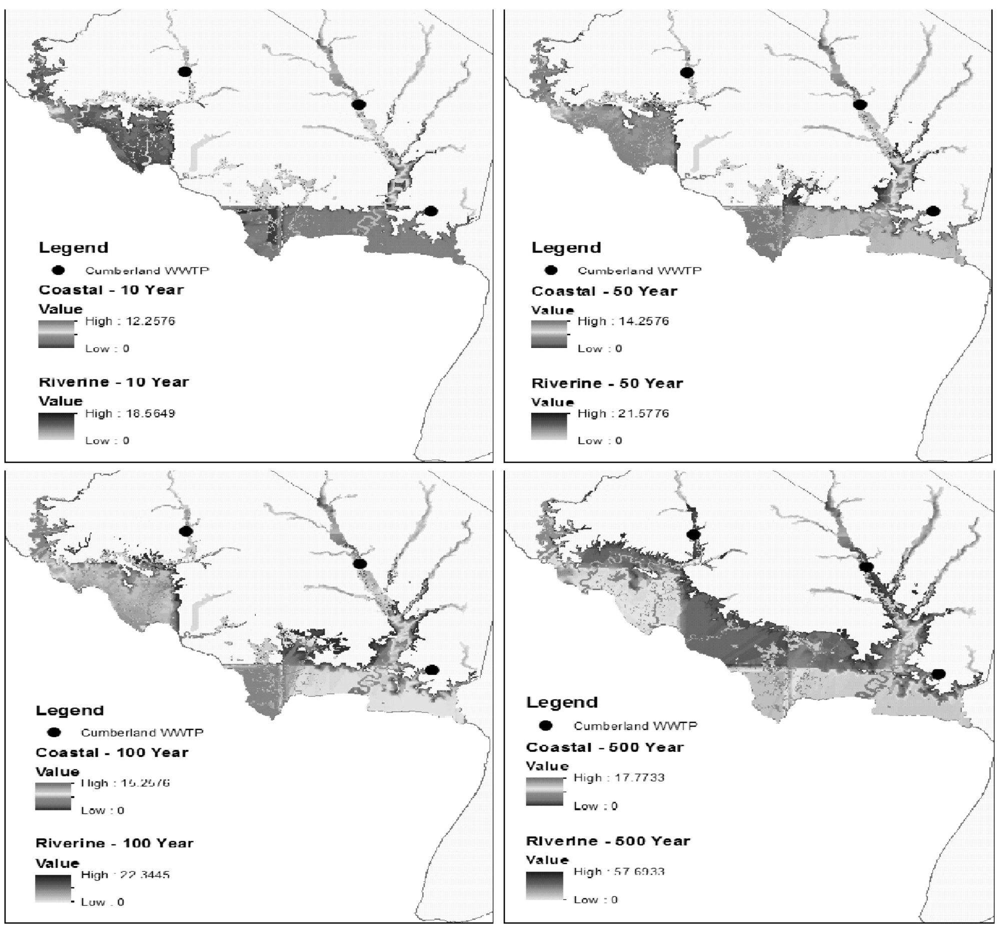

Figure 6: Flooding of Cumberland County Wastewater Treatment Plants under Hurricane Simulation (feet) Using SLOSH

The levee system design can be based on any return period of the Delaware Valley region by a 10, 25, 50, 100, or 500 year storm. As the current situation has it, Elsinboro currently sees breaches at an approximate 0.5 year return period. This is overwhelmingly often and can be avoided with better preparation and resiliency planning. When planning a defense against future storms, local engineers can use the data from Hazus to decide which return period is economically feasible and plan accordingly.

As seen in the previous figures, the different return periods of Hazus storms result in significantly different flood depths. With the coastal and riverine flooding, a more accurate representation of the expected flooding can be determined. Using the Hazus results, a berm can be designed to prevent flooding inland to the wetlands and farmland, as well as the residential areas.

SLOSH deals with strictly hurricane scenarios. The frequency of hurricane occurrences in New Jersey is relatively low, so the design of a berm to protect the land from hurricane surges may be extreme. With the addition of Hope Creek's new nuclear reactor, the new access road will course through the flood prone wetlands in Elsinboro. Protective measures must be taken for this access road even against extreme and infrequent events as loss of access to this facility could have devastating repercussions. Because SLOSH outputs the results relevant to hurricane surges likely to hit the region, the model can be used to design the access road based on the flooding data of the hurricane chosen by local engineers.

SLOSH can be compared to Hazus results roughly, but the comparison is strictly analytical. A 500 year Hazus storm has comparable flood depths to a category 2 hurricane from SLOSH. A category 1 hurricane is comparable to a 50 year storm from Hazus, which is pertinent to the design of the berm. As seen in the SLOSH maps, the coastal flooding intensities are similar to Hazus, but the surge moves further inland. This is a major concern as further inland flooding will reach more residential and commercial developments.

5. CONCLUSIONS

Utilization of these models can have monumental benefits if used properly. This not only includes proper operation of each model, but employment of their predictive capabilities before the onset of future extreme storm events. Committing the time and funds required to perform these analysis will not only soften the blow of extreme storm events but give the state an advantage when it comes to disaster response time. This data can provide the necessary framework to build widely-encompassing resiliency plans at both the state and municipal levels. Creating such plans would save the state millions, if not billions of dollars in recovery efforts. Having a plan of attack will eliminate the time required to orchestrate mitigation efforts which will ultimately lead to faster response times and shorter recovery times.

Though one umbrella plan would be a good start, this would not be sufficient to account for each community throughout the state as each extreme storm event delivers a mix impact to the state of New Jersey. The uniqueness of each community dictates how it will be affected. For example, coastal communities will be impacted differently than inland communities and urban communities in northern NJ differently than rural communities in southern NJ. The damage to New Jersey has already been done but proper preparations can prevent future occurrences of the same magnitude. Effective resiliency plans, tailored specifically to each community, will be essential to ensuring minimal damages, costs, and fast recovery times.

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