Worcester County
Sea Level Rise Inundation Model

Technical Report

Maryland Department of Natural Resources
&
U.S. Geological Survey

November, 2006

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Introduction

Maryland's diverse coastline is particularly vulnerable to rising sea level. In the Mid-Atlantic coastal region, sea level has risen approximately one foot in the last century and due to a combination of climate change and regional land subsidence, sea-level is predicted to rise another 2 to 3 feet by the year 2100 (Leatherman, 1992). The impact of such a rise in sea level, nearly twice global average, will undoubtedly exacerbate the frequency and extent of coastal flooding and storm surge, increase shoreline erosion and result in the slow but steady submergence of tidal wetlands and considerable areas of flat low-lying lands. The wetlands and marshes, tidal estuaries, sandy beaches, barrier islands and inhabited areas that comprise and surround Worcester County will be significantly impacted.

Over the past several years, the Maryland Department of Natural Resource's (DNR), Coastal Zone Management Division has directed substantial efforts towards analyzing and addressing the impact of rising sea levels along the State's coastline. Program activities have centered on the sea level rise planning and policy initiatives; technology, data and research support; and public outreach and engagement. DNR published a Sea Level Rise Response Strategy for the State of Maryland in October 2000 that set forth both short and long-term objectives, along with key activities, to address the primary impacts of sea level rise. DNR also staffed the legislatively chartered Shore Erosion Task Force (2000), which issued a broad suite of recommendations to improve the management of shore erosion. Included among those recommendations was the need to address sea level rise. DNR has also made great strides to obtain up-to-date sea level rise data and information. Recent data gathering efforts include the acquisition of LIght Detection and Ranging (LIDAR) high-resolution topography for Maryland's Eastern Shore, the completion of historic shoreline position maps, and the statewide calculation of historic erosion rates.

As part of DNR's concerted sea level rise research effort, the Agency proposed to the U.S. Geological Survey (USGS) in the Fall of 2003 an exchange of data for in-kind services to develop a sea level rise inundation model for one or more coastal counties in Maryland. USGS had recently developed a sea level rise inundation model using LIDAR for the Blackwater Wildlife Refuge in Dorchester County and DNR felt that the transference of the methodology on a county-wide scale would be an excellent research endeavor.

The selection of Worcester County as the study area was based on a number of factors. LIDAR data had been acquired for Worcester County had been completed in 2003 and 6-inch resolution orthoimagery was completed in 2004. Additionally, the Coastal Bays Comprehensive Conservation and Management Plan (1999) identified a specific need for enhanced sea level rise planning in the coastal bays region. A recommendation to continue sea level rise research and planning efforts was also contained in the Coastal Bays Hazards Initiative, Final Report (2004). Finally, an assessment of sea level rise impacts in Maryland's Atlantic Coastal Bays was conducted by Stephen Leatherman, et al., 1992. Both DNR and USGS felt that the development of a sea level rise model using base data, more accurate than what was available in 1992, as well as new technology, would advance our understanding of both sea level rise and sea level rise modeling capabilities.

DNR provided recently processed LIDAR and orthoimagery of Worcester County to the USGS, which the agency subsequently integrated, yielding a highly detailed LIDAR topographic elevation model of Worcester County. The model was then used to analyze the impact of rising sea level and storm flooding on the County's coastline and low-lying inland areas. USGS produced sea level rise inundation models depicting long-term and low magnitude changes in the position of Mean Sea Level (MSL) and Mean High Water (MHW) resulting from the ongoing rate of relative sea level rise for that area (ca. 3.0mm/yr) and increased rates of rise suggested by climate change projections. The models were ultimately adapted to predict storm surge inundation of the area from hurricanes, Category 1 – 4. The methodology and project deliverables for the modeling effort are outlined below and are followed by recommendations for the use of the model during future planning efforts.

Methodology

LIght Detection and Ranging (LIDAR) is a method of measurement using laser light to determine the elevation of ground surface in relation to a known elevation datum. A scanning laser is mounted on an aircraft, and as the aircraft flies along a line, the laser emits a continuous series of light pulses in a side-to-side motion. The time required for the pulse to return to the aircraft is recorded. Global Positioning System (GPS) position of the aircraft and its altitude is also recorded during the flight. The raw LIDAR data can then be processed to yield a Digital Elevation Model (DEM) or contours. LIDAR can be used to obtain ground surface elevations as well as elevations of vegetation or man-made structures along the flight line. Elevation data obtained by this method is very detailed and accurate. It is used for a variety of purposes including hydrology and floodplain studies, shoreline mapping, urban development and natural resources management.

Digital Elevation Model Development

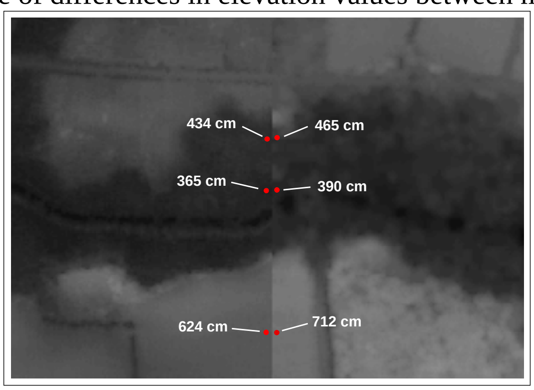
Worcester County LIDAR was acquired through cooperative agreements between the DNR, USGS and the Worcester County Department of Comprehensive Planning. Raw LIDAR data was collected by 3Di, Inc. in August - September 2002 and by Airborne 1 in April - July 2003 to fill in the gaps not covered by the 2002 mission. Flight operations were performed during low-tide cycle when possible. Raw data was referenced to Universal Transverse Mercator (UTM) coordinates. The first- and last-return data was processed by the Computational Consulting Services, LLC using proprietary software. Artifacts and features that did not reflect ground elevation were eliminated to create Bare Earth Mass Point files. Data was cast in the Maryland State Plane Coordinate System, NAD83, with elevations in meters referenced to the NAVD88 vertical datum. A gridded DEM was created from the Bare Earth Mass Point Files using 1,200 meter by 1,800 meter tiles. Cell size for the DEM grid was 2 by 2 meters. One-meter resolution unrectified aerial imagery was also generated by the Computational Consulting Services, LLC using the LIDAR return intensity data. The Bare Earth Mass Point files and gridded DEM files were independently checked for consistency and accuracy by Dewberry LLC using survey data provided by NXL Construction Services. The testing determined that final products met Federal Emergency Management Agency (FEMA) and DNR requirements for vertical accuracy.

Horizontal coordinates for each surveyed point meet the National Standard for Spatial Data Accuracy (NSSDA).

LIDAR data was delivered to USGS in the form of Bare Earth Mass Point files and as gridded DEM files. ESRI ArcGIS software was utilized for data manipulation and data display for the project. Gridded DEM files were used to create a DEM map of the Worcester County. Separate 1,200 meter by 1,800 meter tiles were merged together to form 15 rows, consisting of 29 to 78 tiles. Elevation (z) values of the LIDAR data was converted from meters to centimeters due to the file-size limits. Using the Arc/INFO Grid utility, meter-unit floating point grids representing each of the 15 rows were converted into a centimeter-unit integer grids.[1]

The 15 rows were then merged to create a composite LIDAR-derived DEM map of Worcester County. Visual inspection of the DEM revealed a 15 centimeter to >60 centimeter difference in elevations on the boundary between neighboring tiles/rows (Figure 1.). The vertical precision of LIDAR data is generally around 15 cm, therefore some areas in question were within the acceptable range. To correct bigger elevation differences between the adjacent tiles, the whole DEM grid was filtered using a 7-cell by 7-cell median filter. This was done by means of the ArcInfo GRID function, FOCALMEDIAN. For each cell in the input grid, FOCALMEDIAN finds the median elevation value within the specified 7-cell by 7-cell neighborhood and records that median value to the output grid in the corresponding cell location.

Figure 1. Example of differences in elevation values between merged DNR tiles.

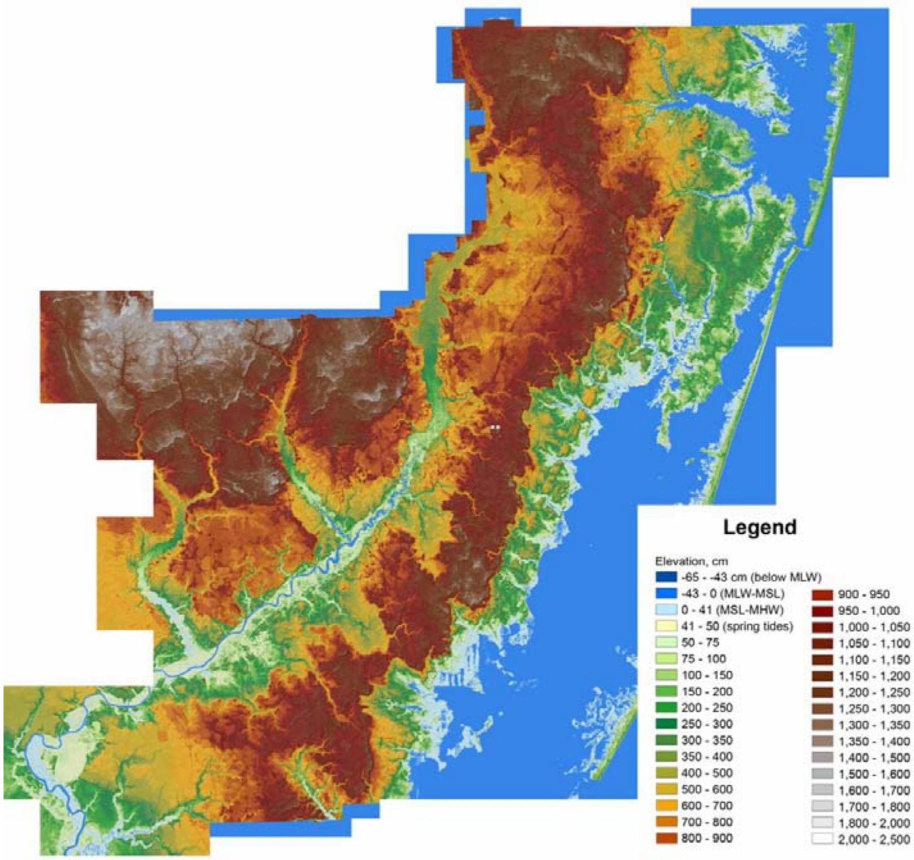


The resulting county-wide DEM map is a grey-scale map. It was color-coded according to the elevation values (See Figure 2.). The lowest elevation in the area is - 31 cm and the highest is 3,507 cm. The elevation range was divided into 32 intervals. First, three class breaks were chosen to correspond to the elevations of Mean Sea Level (MSL), Mean High Water (MHW) and Spring Tides characteristic for this area. Elevations for these water levels were based on the tidal

[1] During the conversion from a floating point grid to an integer grid, Arc/INFO Grid truncates decimal places instead of rounding to the nearest number. To ensure better accuracy of the integer grid a simple Arc/INFO routine was created as follows: (1) the original floating point and the resulting integer grids were compared, and (2) if the difference between the z-values for each cell was greater than 0.5 cm then this cell was assigned an elevation value of one centimeter higher (or lower in case of negative z-values) otherwise it was left the same. In the end, converting elevation raster dataset from floating point grid to an integer grid introduced an error of -0.5 cm to 0.5 cm, with 96% of error being between 0.00003 and 0.00001 cm.

datum and benchmark information from the Ocean City tide gages (Fishing Pier, Isle of Wight and Ocean City Inlet). Breaks in elevation classes for the rest of the data were chosen to be 50 cm and 100 cm, depending on the density of data in a particular elevation range. Elevation values between 1,800 cm to 2,000 cm and between 2,000 cm to 2,500 cm were arbitrarily combined. Elevations above 2,500 cm and up to the maximum 3,507 cm were omitted because they represented erroneous data and comprised less than 0.003% of all elevation values.

Figure 2. Worcester County Digital Elevation Model



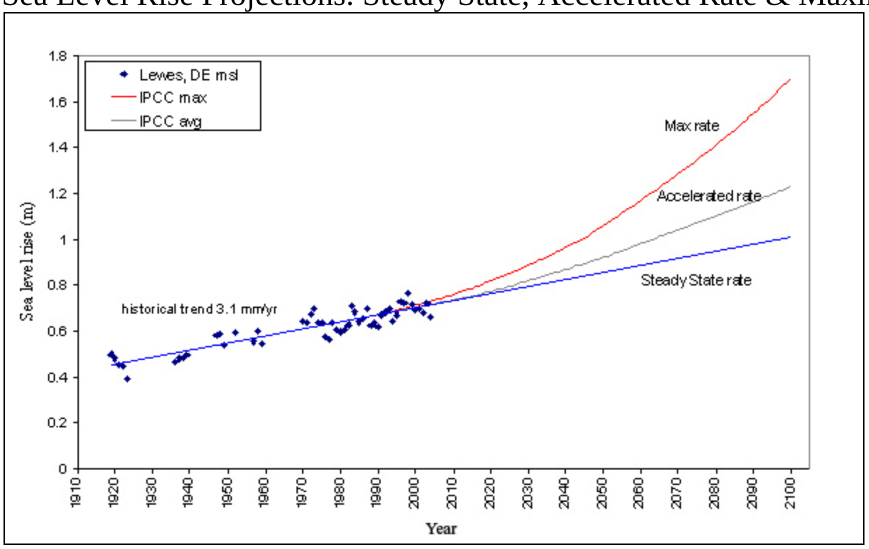
A hillshade grid of the area was generated from the County DEM using the ArcGIS Spatial Analyst extension. Hill shading provides a three-dimensional view of an area in two-dimensions by calculating illumination of each cell of an image based on the specified sun azimuth and altitude. A vertical exaggeration factor was applied to give more depth to a map surface. The following parameters were used for this project to create the shaded relief map: sun azimuth – 315 degrees; sun altitude – 45 degrees; vertical exaggeration – 15; cell size was left the same at 2 meters.

Additional layers of roads and railroads were acquired from Worcester County and were combined with the County DEM. The existing floodplain dataset for Worcester County was obtained from FEMA in the form of digital Q3 file. The Q3 Flood Data files are created by digitizing the hard-copy Flood Insurance Rate Maps (FIRMs) published by FEMA. [2] Worcester County Q3 file contained 100-year and 500-year flood plain boundaries, flood zone designations, Coastal Barrier Resources System (COBRA) areas, political boundaries, FIRM panel, USGS 7.5-minute quadrangle boundaries, and other features. Some of these features were eliminated using the ArcEdit extension for ArcInfo to leave only those pertinent to the project – flood plain boundaries, flood zone designations and COBRA areas. The geographic projection of Q3 file was changed from UTM coordinates to State Plane NAD83 coordinates to match the County DEM dataset.

Sea Level Rise Inundation Modeling

Three sea level rise scenarios were chosen for modeling sea level inundation of the Worcester County shoreline (See Figure 3.). The first scenario (Steady State model) is based on the long-term historic rate of sea level rise characteristic for this area. The rate was calculated from the water level records at two National Oceanographic and Atmospheric Administration (NOAA) tide gauges in Lewes, DE and Kiptopeke, VA. These two stations were chosen because of their relatively long period of water level observations (1919 – 2005 and 1951 – 2005, respectively) and their close location to the project area. Tide gauge stations on the coastline of Worcester County have short-term tidal records and thus are less reliable for calculating historic sea level trends. Water level records for Lewes, DE and Kiptopeke, VA were downloaded from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) website: http://tidesandcurrents.noaa.gov/.

Figure 3. Sea Level Rise Projections: Steady State, Accelerated Rate & Maximum Rate

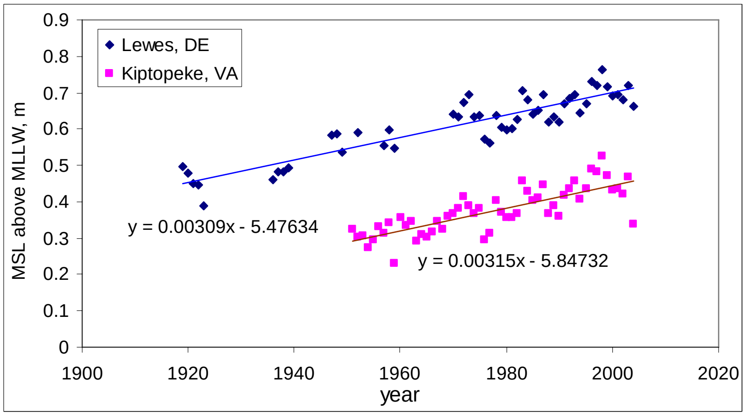


By running a linear regression through the data, USGS calculated the historic rate of sea level rise for the area to be approximately 3.1 mm/yr (Figure 4.). USGS applied this rate to the elevation values for MSL, MHW and Spring Tides, obtained from the tidal stations in Ocean

[2] For more information on the Q3 Flood Data files refer to FEMA web page: http://www.fema.gov/fhm/fq_q3.shtm.

City, MD, to model the sea level rise inundation of the study area for this century.[3] By applying historic rate of sea level rise (3.1 mm/yr) to those elevations, USGS modeled the positions of the tidal levels for three time periods: Year 2025, Year 2050 and Year 2100. The DEM map was color coded for each time period to show the advance of open water onto the shoreline.

Figure 4. Historic sea level rise trend for Worcester County, MD based on water level observations from Lewes, DE and Kiptopeke, VA tidal stations.



The second sea level rise inundation model for this project was based on the average accelerated rate of sea level rise estimated from the projections of the Intergovernmental Panel on Climate Change (IPCC). IPCC produced several scenarios for the sea level rise for this century based on the different contributions of greenhouse gases to the atmosphere, steric expansion of ocean water, melting of continental glaciers and other factors (IPCC, 2001). USGS calculated approximate rates of sea level rise for each decade by averaging the various IPCC projections. Using the present elevations of MSL, MHW and Spring Tides obtained from the Ocean City tide gauges and average accelerated rates of sea level rise, USGS estimated the inundation of the project area for the Years 2025, 2050 and 2100 for the second model. The DEM was then color-coded according to the USGS calculations.

The third sea level rise inundation model was dubbed the “Worst Case scenario.” It incorporates the acceleration in the rate of sea level rise based on the maximum range of all IPCC models and scenarios, including uncertainty in sediment deposition and changes in global permafrost and land-ice volume. The IPCC maximum projection for sea level rise is approximately 85 cm - 90 cm by the end of the century. As with the second of the models, the rates of sea level rise were calculated for each decade and applied to MSL, MHW, Spring Tides present-day elevations. The estimated positions of these tidal levels for Years 2025, 2050 and 2100 were incorporated into the Worcester County DEM. The DEM was then color-coded according to the elevation values.

[3] For the purposes of this project, the present position of MSL on the County DEM was assumed to be at 0 centimeters; present position of MHW was assumed to be at 41 cm; and present position of Spring Tides was assumed to be at 50 cm.

Storm Surge Inundation Modeling

The development of the storm surge inundation model for Worcester County was conducted in the second phase of the project. USGS proposed to predict the position of open water (MSL in this case) for storm surges resulting from Category 1 through 4 hurricanes in the project area and to combine these with the sea level rise inundation models. No allowance was made by USGS for water level fluctuations based on wind and tide variations during a storm event. The flood extent contours represent the average expected inundation based on storm severity. USGS used the Saffir-Simpson hurricane scale as the basis for the modeling efforts (See Table 1).

Table 1. The Saffir-Simpson Hurricane Scale.

Category	Wind speed, mph	Storm surge, ft	Storm surge, m	Storm surge, m, this project[4]
1	74 – 95	4 – 5	1.22 – 1.52	1.04
2	96 – 110	6 – 8	1.83 – 2.44	1.5
3	111 – 130	9 – 12	2.74 – 3.66	2.72
4	131 – 155	13 – 18	3.96 – 5.48	4.09

USGS derived flood extent contour lines corresponding to the elevations shown above from the DEM dataset for the County. The Spatial Analyst extension of ArcGIS was used for this purpose. As previously mentioned, the DEM contained a fair amount of erroneous data, with elevation values often representing not bare ground but elevation of vegetation or structures. Due to this fact, deriving contour lines from the DEM dataset resulted in many contours being drawn around vegetation clusters and buildings. To mitigate this problem the contour-line shapefile was converted to an Arc coverage and Arcs less than 125 meters long were deleted using ArcEdit algorithms in ArcInfo Workstation. Arcs were further simplified and smoothed and split arcs were joined together. Where the number of nodes in an arc exceeded 500, additional arcs were added, where necessary, to complete the contour line (Figure 5.).

USGS combined storm surge elevation estimates for Worcester County with the first two models of sea level rise inundation (Steady State model and Average Accelerated SLR model). For each of the models USGS added the projected MSL elevation for Years 2025, 2050 and 2100 to the elevation values of storm surge for Category 1 – 4 hurricanes. USGS derived contour lines corresponding to the calculated predicted water level elevations and processed them according to the method described above using an ArcInfo Workstation.

[4] USGS selected Hurricane Isabel as the starting point for calculating approximate storm surge values for the Worcester County. Isabel was reported as a category 2 hurricane, with storm surge at Ocean City 6.5 feet above MLLW. All estimates for storm surge values for the remaining three categories of hurricanes were adjusted as well to the MSL-MLLW difference.

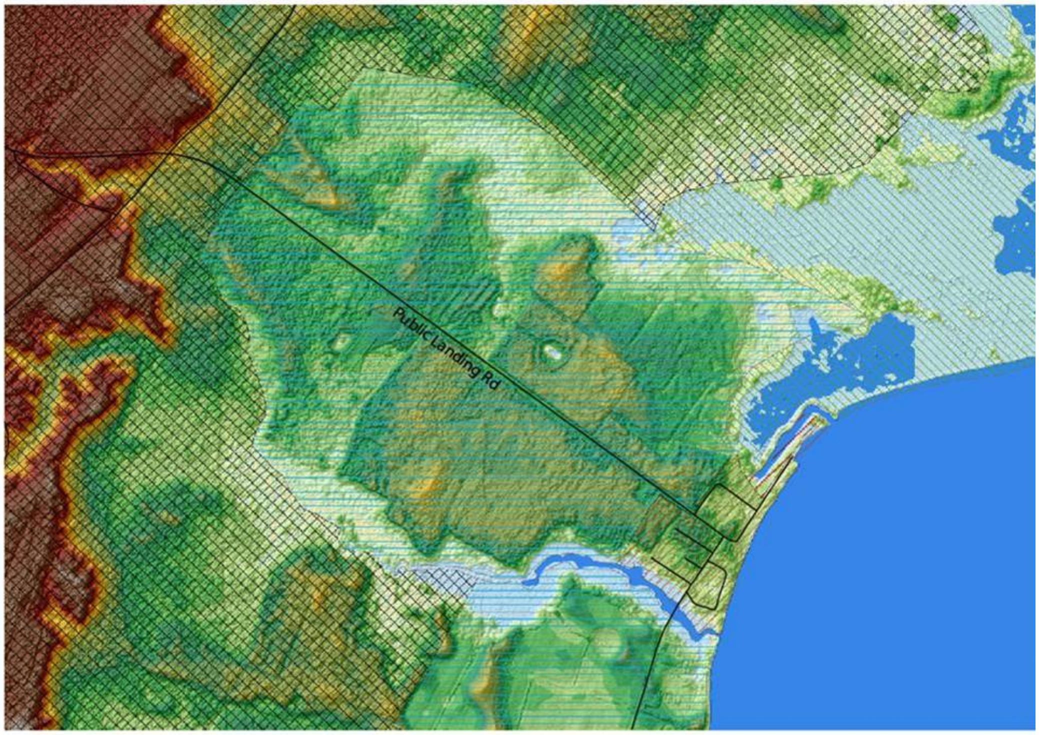
Figure 5. Storm Surge Contour Lines for Category 2 Hurricane

DEM derived original contour lines

ArcInfo processed contour lines

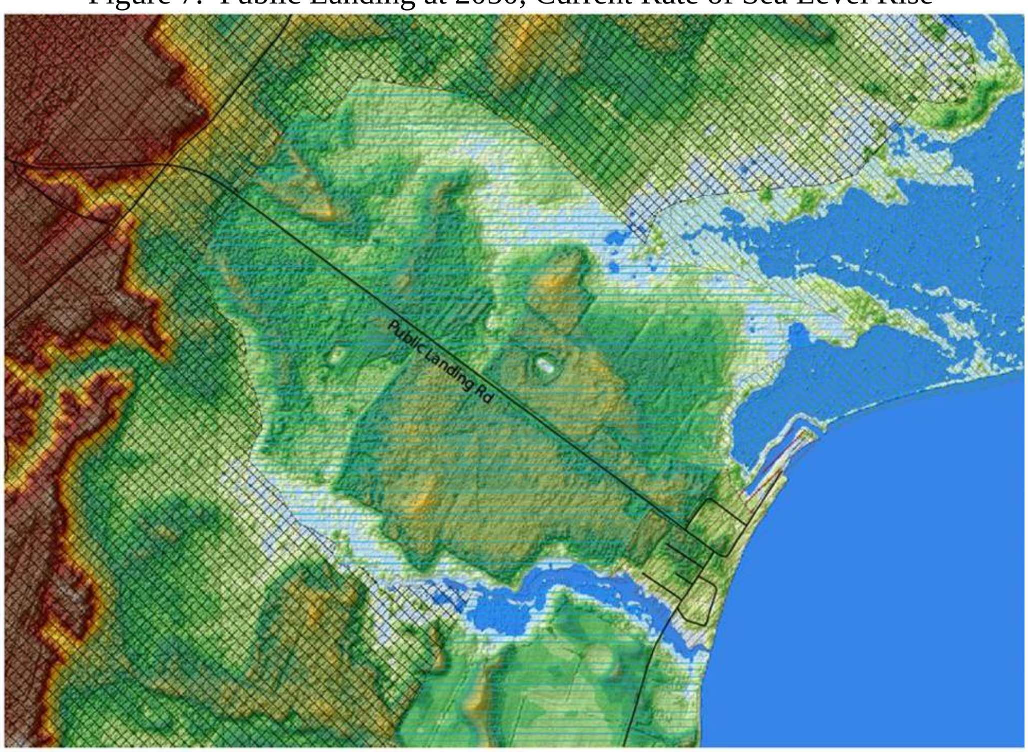
At the request of Worcester County, modeled sea level rise inundation datasets and storm surge inundation datasets were clipped to the extent of five small areas, along the east coast of the County, which presented areas of special interest. Figures 6-10 illustrate the select outputs for sea level rise inundation for the Public Landing and Figures 11 - 14 depict sea level rise inundation coupled with storm surge over time for the West Ocean City area. USGS was also provided with a georeferenced 12-digit watershed boundary file of the County. Five watersheds were chosen to illustrate the models of sea level rise and storm surge inundation.

Figure 6. Public Landing at Present



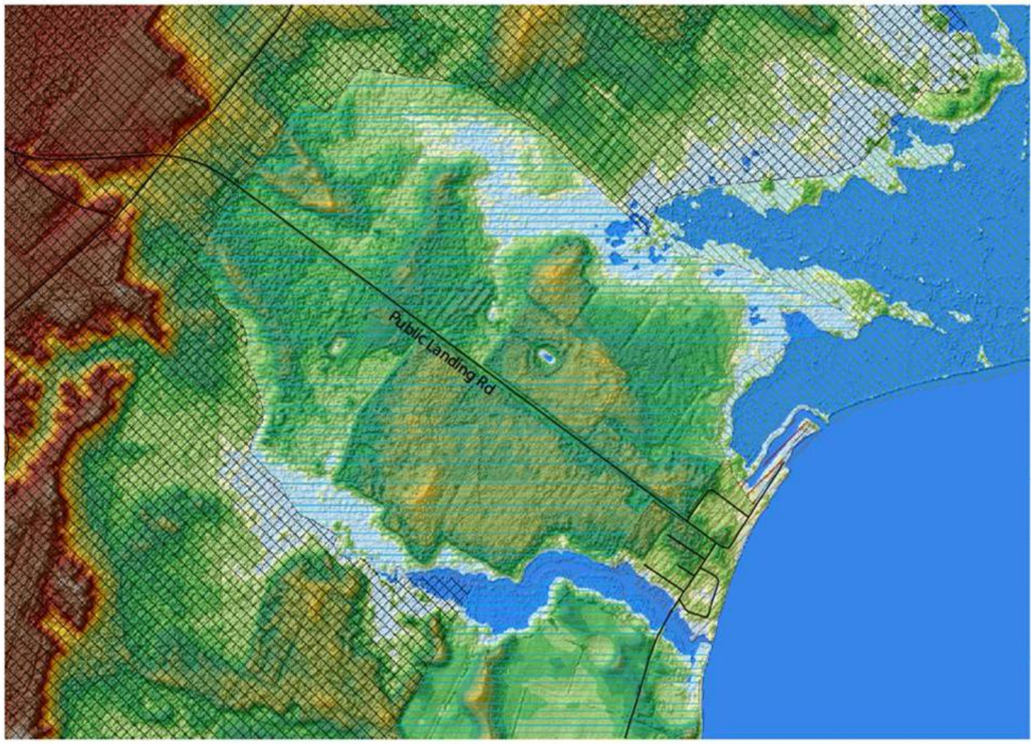
MLW - MSL   MSL - MHW   Spring Tides   Agricultural

Figure 7. Public Landing at 2050, Current Rate of Sea Level Rise



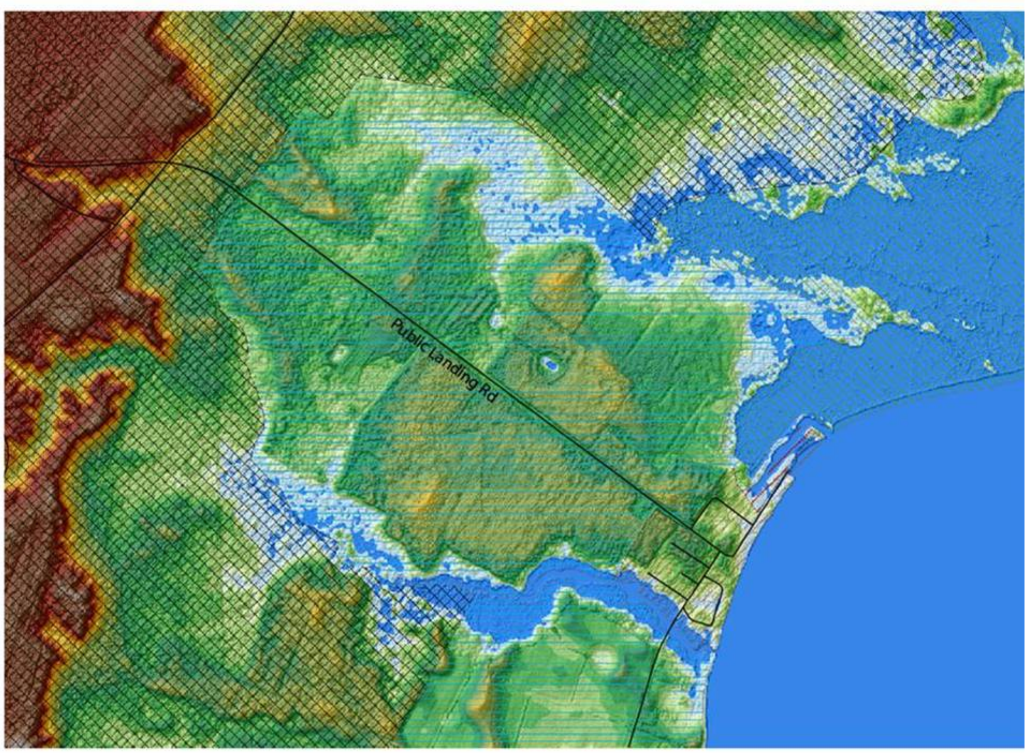
MLW - MSL   MSL - MHW   Spring Tides   Agricultural

Figure 8. Public Landing at 2100, Current Rate of Sea Level Rise



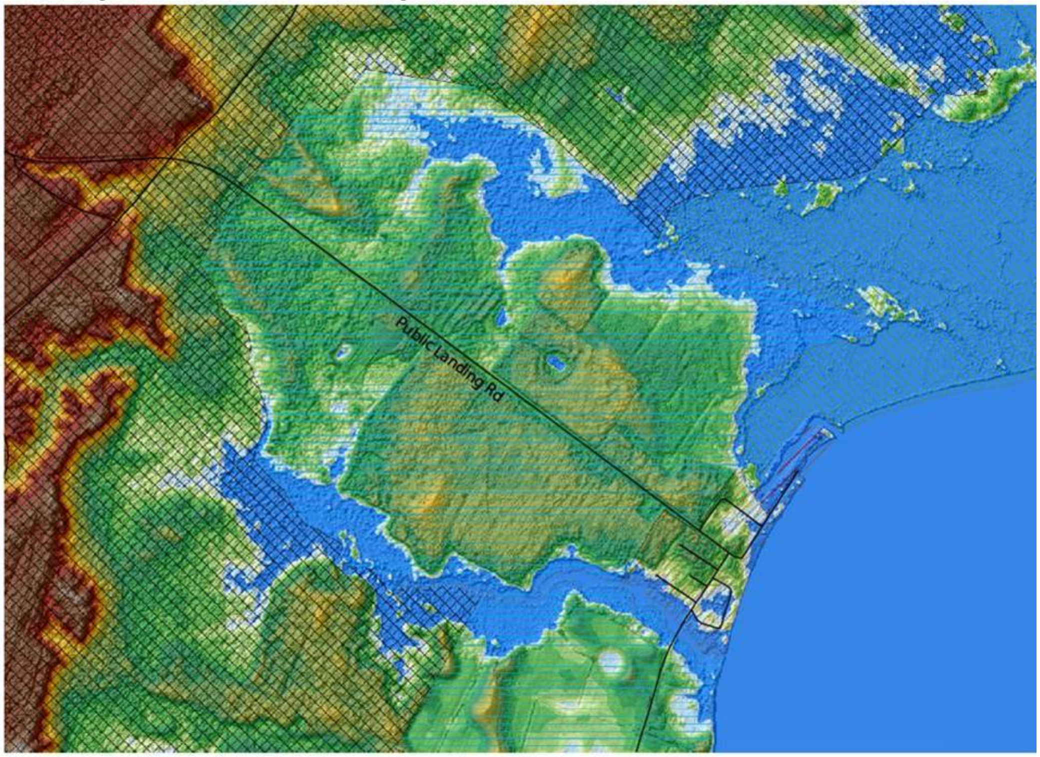
MLW - MSL   MSL - MHW   Spring Tides   Agricultural

Figure 9. Public Landing at 2100, Accelerated Rate of Sea Level Rise



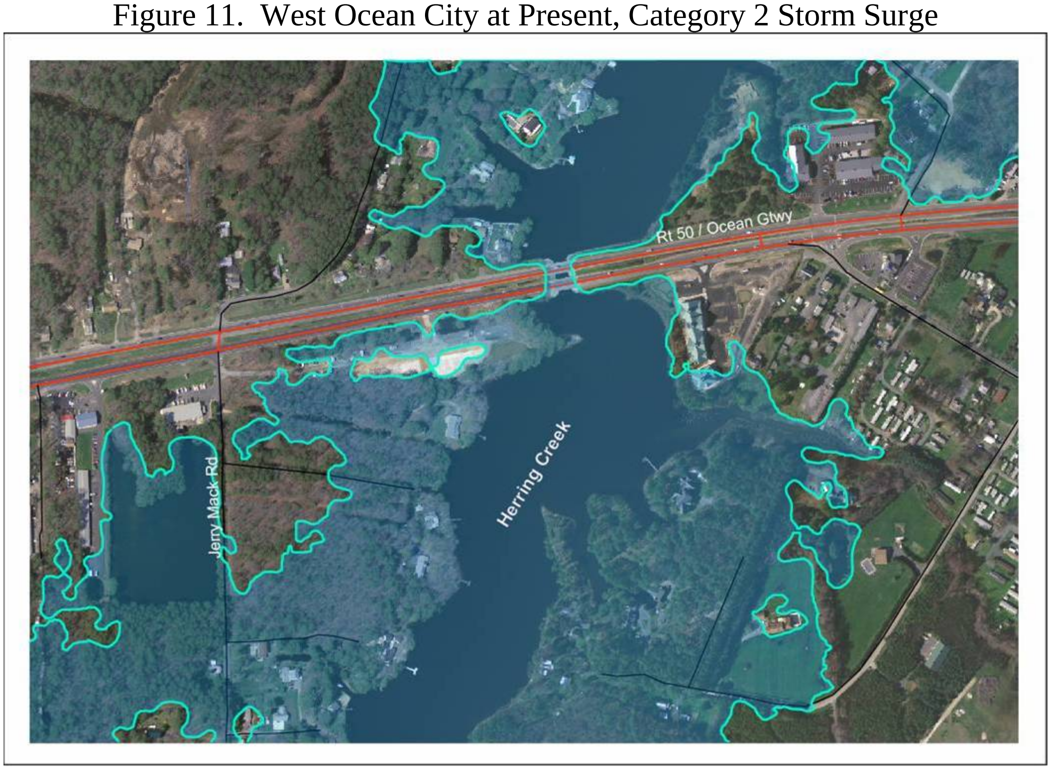
MLW - MSL   MSL - MHW   Spring Tides   Agricultural

Figure 10. Public Landing at 2100, Maximum Rate of Sea Level Rise



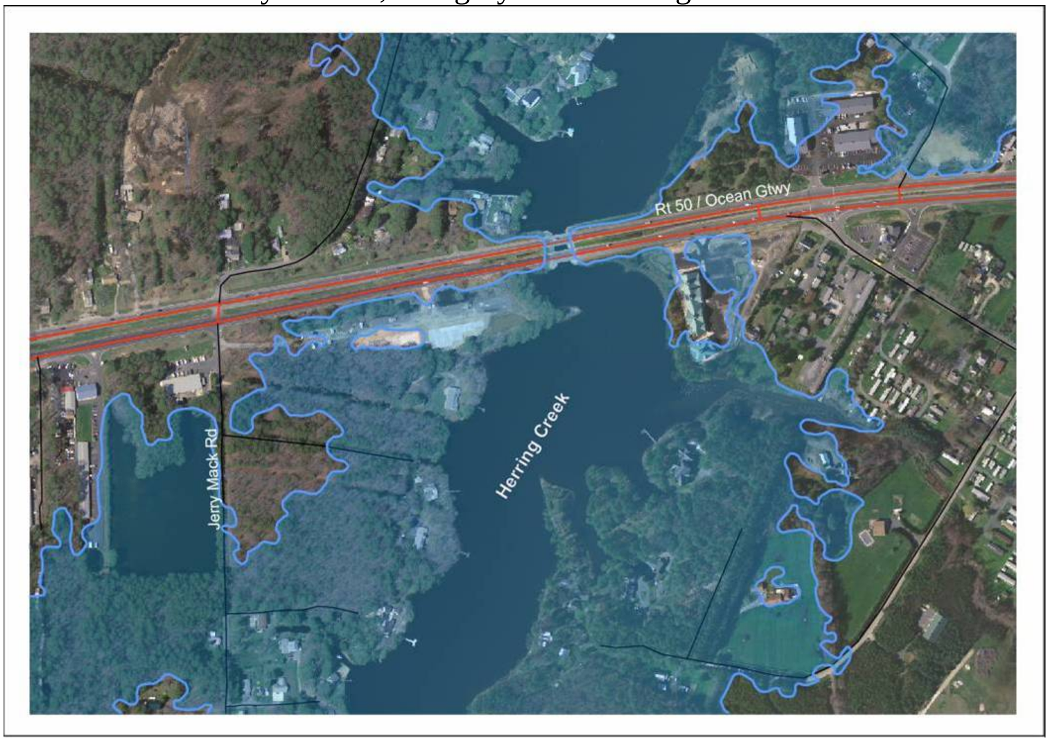
MLW - MSL | MSL - MHW | Spring Tides | Agricultural

Figure 11. West Ocean City at Present, Category 2 Storm Surge



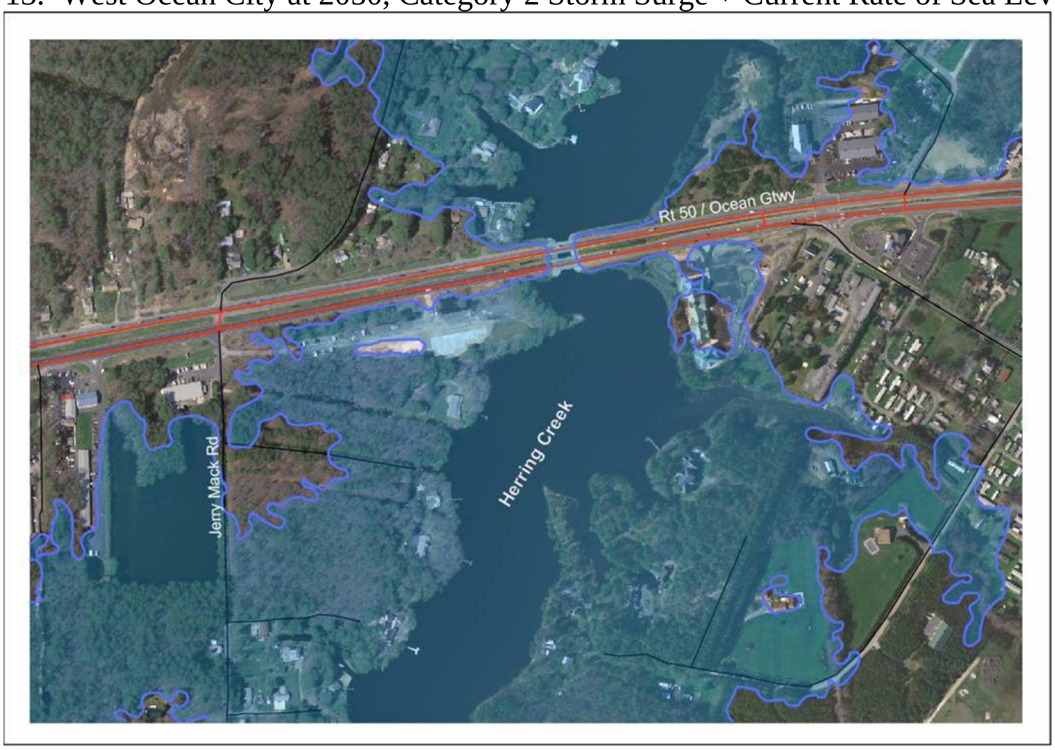
Storm Surge Boundary

Figure 12. West Ocean City at 2025, Category 2 Storm Surge + Current Rate of Sea Level Rise



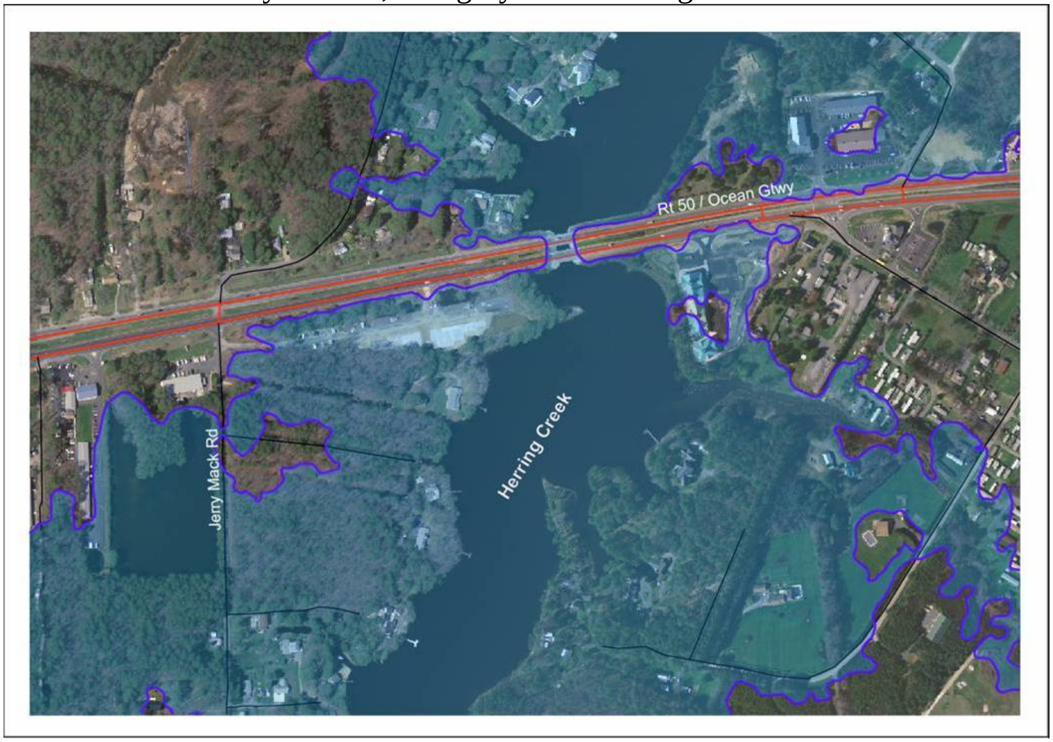
Storm Surge Boundary

Figure 13. West Ocean City at 2050, Category 2 Storm Surge + Current Rate of Sea Level Rise



Storm Surge Boundary

Figure 14. West Ocean City at 2100, Category 2 Storm Surge + Current Rate of Sea Level Rise



Storm Surge Boundary

Use of the Model

At this point in time, the primary product of the Worcester County Sea Level Rise Inundation Model has been the creation of a large-scale dataset that visually depicts sea level rise inundation coupled with storm surge over a 100-year time frame. The utility of the effort, however, will only be realized over time as the next phase of the project begins. This phase involves the project partners working together along with Worcester County and Ocean City Planning and Emergency Management staff, as well as the Coastal Bays Program, to identify opportunities for integrating use the model into future research efforts, as well as land-use decision-making processes. Opportunities worth pursuing are discussed below.

Sea Level Rise Response Strategy. The Comprehensive Plan for Worcester County, adopted by the County Commissioners on March 7, 2006, specifically addresses sea level rise by calling for the development of a sea level rise response strategy which should include a two-foot "free board" requirement for properties exposed to flooding and to discourage shoreline hardening. The Comprehensive Plan also directs future growth to areas outside of a Category 3 hurricane storm surge zone. During preparation of the Comprehensive Plan, Worcester County planners viewed and discussed model outputs with USGS scientists and Coastal Program staff. Discussion centered on using the model to gain an understanding of how existing structures and proposed growth areas could be affected by coastal storm events and future sea-level rise. The model will provide an invaluable tool to County planners as they begin to implement components of the Comprehensive Plan.

Linking Comprehensive and Emergency Response Planning. There is a general need among coastal communities throughout the State to link comprehensive and emergency response planning. There are several ways this can be done, but the concept is to guide growth and development away from areas vulnerable to the impacts of coastal hazards (i.e., coastal flooding, shore erosion, sea level rise inundation). Worcester County has taken the first step to accomplish this by directing future growth to areas outside of a Category 3 hurricane storm surge zone. The next step will be for emergency managers to use and analyze the model to conduct risk assessments for existing and proposed development. The 100-year flood boundary can be viewed with the orthoimagery and the LIDAR data, as can the predicted hurricane storm surge flood lines, and future sea-level rise inundation. Road closures and threats to public infrastructure (i.e., road, bridges) can be predicted, and evacuation plans can be better coordinated to save lives, and reduce the probability of first response personnel being put at risk. The final step is to update and/or modify County codes and ordinances to ensure future developments are not put "in harms way" and do not increase the need for public assistance in the event of an emergency. Additional "freeboard" standards are one way to do this; another, is to either update the standards for road elevations for new developments based on model outputs and/or require analysis of the model prior to granting a road elevation variance request.

Public Outreach. In general, the modeling effort has confirmed the findings of several other sea level rise inundation studies in the region (Michael, 2003) which demonstrate that that the zone of sea level rise inundation is dependent on a number of factors. Lower-lying lands with a gradual inland rise in slope will experience greater levels of inundation. Areas, which may not experience inundation within the steady state or average accelerated sea level rise scenarios, may still be subject to a great deal of impact due to episodic flooding due to storm surge. The component of timing is also demonstrated by sample outputs which show that storm surge resulting from a Category 3 hurricane, and such an event with a rise in sea level will cause flooding to areas much sooner than the area will see anticipated impacts due to inundation. Additionally, the model visually shows the impact of sea level rise coupled with storm surge and one can easily deduce the impact on existing and future population growth and development patterns. The sample model outputs have already proven quite successful for public outreach purposes related to advancing public and political support for the need for sea level rise response planning and should continue to be used for these purposes.

Future Research and Planning Efforts. An extensive amount of data and technology was utilized to conduct this modeling effort. Upon its release, the product will lend itself useful to a number of on-going and future research and planning efforts in the Coastal Bays. The model can be used to assist with wetland mitigation/restoration targeting and could also be incorporated into other tools, applications and data-sets currently under development by the Maryland Department of Natural Resources, such as the Comprehensive Shoreline Inventory, *Shoreline Changes Online*, and the Strategic Shore Erosion Assessment.[5]

Conclusion

[5] Information regarding these data products can be found online at http://shorelines.dnr.state.md.us/.

The Worcester County Sea Level Rise Model is a powerful tool, utilizing current, highly accurate datasets integrated using Geographic Information Systems (GIS). It is already proving useful and highly relevant in helping guide planning for a coastal region faced with a high likelihood of damaging coastal storms and a rising sea level. The partnership between DNR and USGS resulted in a tremendous amount of interdisciplinary work and resources used to complete the project and it is certain that many other areas in the State and Country, for that matter, have less access to such highly detailed integrated geospatial data. That said, the methodology, sample outputs from the model, and ideas for use of the product for comprehensive and emergency response planning purposes, can be of use to any area facing coastal hazards associated with sea level rise.

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