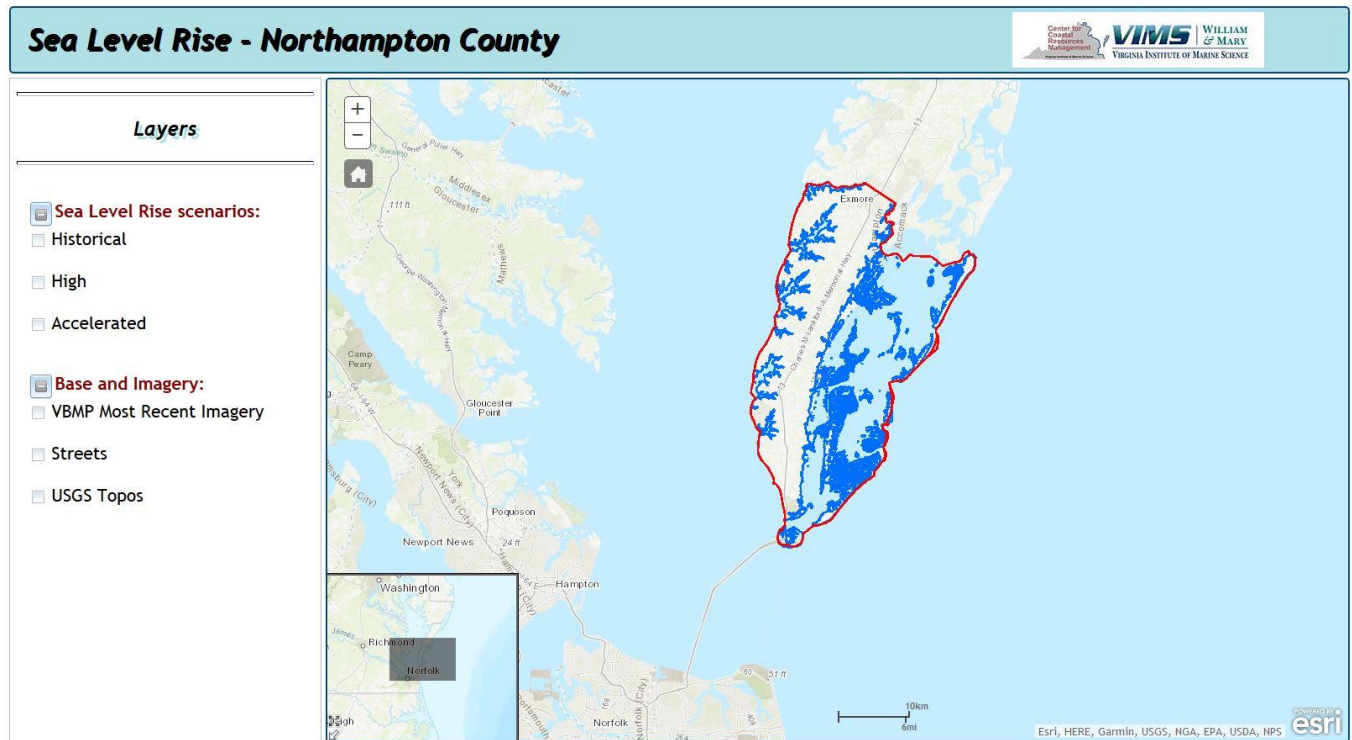


The Sea Level Rise Inundation Tool – User Guide



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Introduction

A number of different techniques have been developed to model sea level rise and communicate the output of those modeling efforts to the broad audience of stakeholders (NOAA, 2012; USACOE, 2013). These tools vary in content, complexity and delivery format. Nearly all applications require a highly accurate 3-D topographic surface to map and compute inundation areas, and most deliver data through some type of 2-D map service.

The Sea Level Rise Inundation Tool, developed by the Center for Coastal Resources Management (CCRM) at the Virginia Institute of Marine Science (VIMS), is one of several tools generated to support a new era of coastal resource management planning in Virginia which promotes resiliency of coastal resources through strategic planning and shoreline best management practices. Information pertaining to sea level rise and shoreline best management practices is locality specific and under development. This document focuses on the methods and use of the Sea Level Rise Inundation Tool. More information about the guidance being prepared for local governments as the Commonwealth moves forward with its 2011 environmental policy pertaining to coastal resource management planning can be found at this website: <http://ccrm.vims.edu/ccrmp/index.html>. The remainder of this document pertains to the Sea Level Rise Inundation Tool; one of several applications developed by CCRM to support coastal resource management in Virginia.

Methodology

The data used for generating 3-D surfaces for this analysis came from multiple sources, and only the best available data were used. ESRI software (ArcGIS Desktop 10, ArcGIS Server 10, Image Server) was used to process data, generate sea level rise flood rasters, create the visual interface and other visible data layers, and serve them in a GIS web mapping applications. ESRI's Javascript API (Application Programming Interface) was used to develop the web visualization tool for desktop viewing.

Creating the topographic surface

First, LIDAR (Light Detecting and Ranging) data was acquired from the Virginia Geographic Information Network (VGIN) and individual localities. LIDAR is the most accurate source for elevation data.

After processing the source data into consistent projections, datums, and units, the data were merged into seamless elevation surfaces for larger regions, and then clipped to the boundary of individual localities. All data were projected, when necessary, to Virginia State Plane HARN with units of feet. Either Virginia State Plane North or Virginia State Plane South was chosen depending on the locality's geographic location. Vertical units were converted, when necessary, from meters to feet. The use of English rather than metric units was a decision based on the preferred system elected by the majority of the end users; in this case local government personnel. A shoreline digitized from the VBMP imagery (2006-2007, 2009, or 2013) was used as the shoreline boundary of the localities.

The elevation values on these surfaces were initially referenced to the widely used NAVD88 vertical datum, which is referenced to a fixed benchmark based on land. However, due primarily to tidal influence, sea level at a given time will vary by location when referenced to the NAVD88 datum. In practice, this means that a water level value that is constant in the NAVD88 datum applied across a large coastal area will generate inaccurate land inundation zones.

When modeling coastal inundation with sea level rise, it is more accurate to reference the coastal land elevations to tidal datums (i.e. mean sea level, mean high water, etc.) since water level variation is primarily dependent on the tidal cycle. Tidal datums are local (i.e. vary along the coast) and take this tidal variation into account. Therefore, for this application, it is useful to convert the land elevation surfaces from the NAVD88 datum reference to a tidal datum reference. We chose to use the mean high water (MHW) reference, and all flood zones in the sea level rise tool are at MHW. NOAA's Coastal Services Center provided the necessary adjustment data to convert land elevation surfaces from the NAVD88 reference to the MHW reference. This adjustment data were generated using a tool developed by NOAA called VDatum, which is used to convert between different vertical reference systems.

When generating the inundation areas, we were concerned only with the flood area caused by sea level rise. In general, a surface will contain "sinks", or sunken depressions, in the topography which will be susceptible to flooding through rain or runoff. Flooding in these sinks is not associated with the sea level rise of interest here, and is hydrologically isolated from the flooding caused by sea level rise. Before running the model to extract the inundation zones, a GIS operation known as "filling" was executed on the elevation surfaces. This operation will fill

in all of these isolated sinks on the surface so they do not appear as part of the inundation zones due to sea level rise.

Selecting the sea level rise scenarios

The next stage of the process was to generate the sea level rise flood areas. The sea level rise scenarios used in this analysis were based on the 2014 National Climate Assessment. This study produced four scenarios which represent plausible trajectories for local sea level based on a combination of factors. These scenarios were modified by incorporating an estimation of land subsidence in southeastern Virginia (Figure 1).

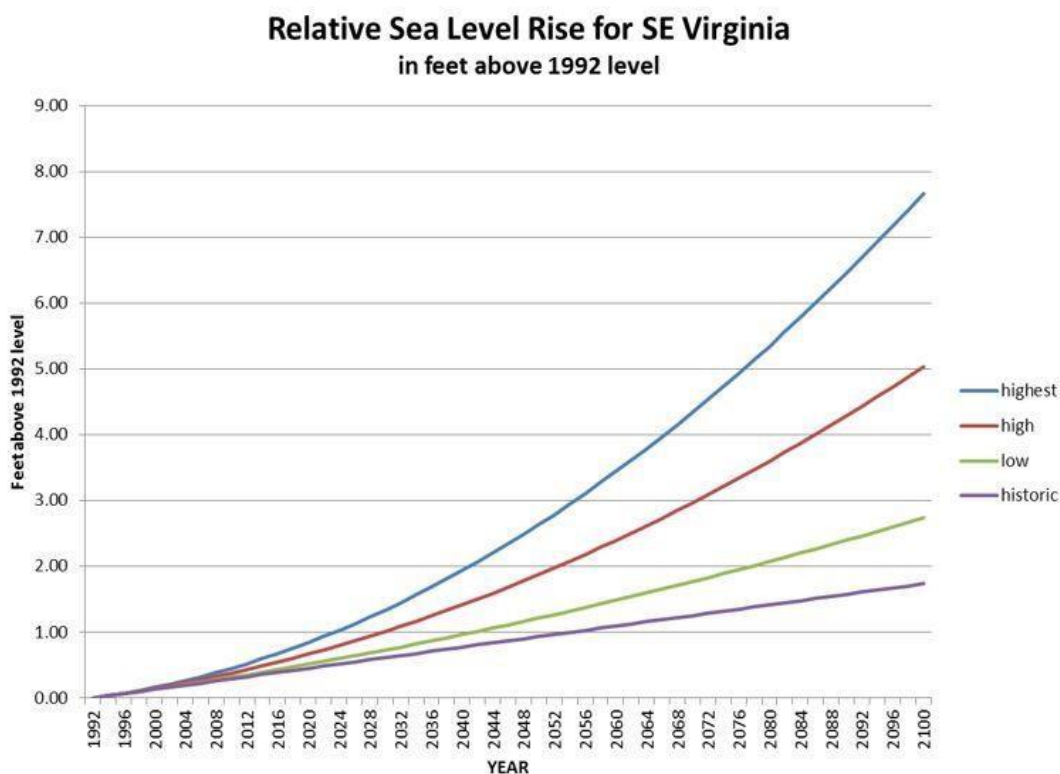


Figure 1. National Climate Assessment Sea Level Rise Scenarios

The lowest or “historic” scenario is simply a projection of observed long-term rates of sea level rise going back a century or more, and contains no acceleration. The “highest” scenario is based on estimated consequences from global warming combined with the maximum possible contribution from ice sheet loss and glacial melting (a practical worst case scenario based on current understandings). The “high” scenario is based on the upper end of projections from semi-empirical models using statistical relationships in global observations of sea level and air temperature. The “low” scenario is based on the IPCC fourth Assessment model using conservative assumptions about future greenhouse gas emission.

The original National Climate Assessment scenarios are for global sea level rise only. To incorporate subsidence in southeast Virginia into the analysis, we added a constant 2.7mm/yr (0.11 in/yr) to the projections. This is the value one gets from the Seawells Point tide record which has a long term average rate of rise of 4.44mm/yr (0.17 in/yr), and then subtracting the average global sea level rise rate of 1.7mm/yr (0.07in/yr). We are now displaying the historic and highest scenarios in our web applications for all posted localities, as “Historical” and

“Accelerated” scenarios, respectively. Some localities also include an intermediate rate which is extracted from values that fall between the green and the yellow curve illustrated in Figure 1.

The precise values we used for projected sea level rise are shown in Table 1:

| Year | Historical (ft) | High (ft) | Accelerated (ft) |
|------|-----------------|-----------|------------------|
| 2020 | 0.45 | 0.66 | 0.84 |
| 2040 | 0.77 | 1.41 | 1.94 |
| 2060 | 1.09 | 2.39 | 3.44 |
| 2080 | 1.41 | 3.60 | 5.35 |
| 2100 | 1.74 | 5.03 | 7.67 |

Table 1. Inundation rates used in the sea level rise tool

Generating the flood levels

Following the procedure carried out above, the surface model is already referenced to MHW. Therefore, when the sea level rise inundation values for the different years are applied to the surface the result represents the change in flood level of MHW over time. The Raster Calculator tool in ArcGIS Spatial Analyst was used to extract all raster cells below the flood level for the “Historical”, “High”, and “Accelerated” scenarios and for all years. The resulting rasters were used as the flood zones visible in the web application.

After generating all the flood rasters for a given locality, a raster collection called a mosaic dataset was created for each scenario and for each locality. The appropriate flood rasters for the three scenarios were then added to the respective mosaic datasets (i.e. each locality has a mosaic dataset for each scenario, and each of those mosaic datasets contains flood rasters for years 2020, 2040, 2060, 2080, 2100). The mosaic dataset format allows for the creation of a time slider tool, as seen in the web application. The time slider is a GIS visualization tool provided by ESRI, which allows for easy visualization of a time series of rasters.

The various flood levels represent the inland intrusion of MHW over time. The increase in flood levels is associated with sea level rise and subsidence using values reported in Table 1. At this time, flooding does not consider storm surge.

Creating the visualization tool

To create a time slider, an image service must first be created from the mosaic dataset. The image service is a GIS dataset which allows one to serve raster data efficiently in a web

mapping application. The image service is served with Image Server, an ESRI product which, in this application, was used as an extension of ArcGIS Server. A time slider was created from each image service which allows visualization, as a time series, of the flood rasters populating the image service. Other data layers visible in the web applications come from ESRI's own online image services or standard map services we created from our own data for use with ArcGIS Server.

The web applications were developed in the Javascript API developed by ESRI. ESRI provides a series of development tools for GIS functionality that are integrated into this API; these tools allow development of GIS web mapping applications that run on all major web browsers.

Using the Tool

When the tool opens the user has the opportunity to select a base map under the “Base and Imagery” layer group. The default view is a general map with manmade features such as towns and roads, and shading that emphasizes the land topography. The three layers available are the most recent publicly available, Virginia Base Mapping Program’s (VBMP) high resolution imagery, a street map, and USGS topo quads. All three layers can be selected, and the adjacent slide bars can be used to control the transparency of the layer (Figure 2).

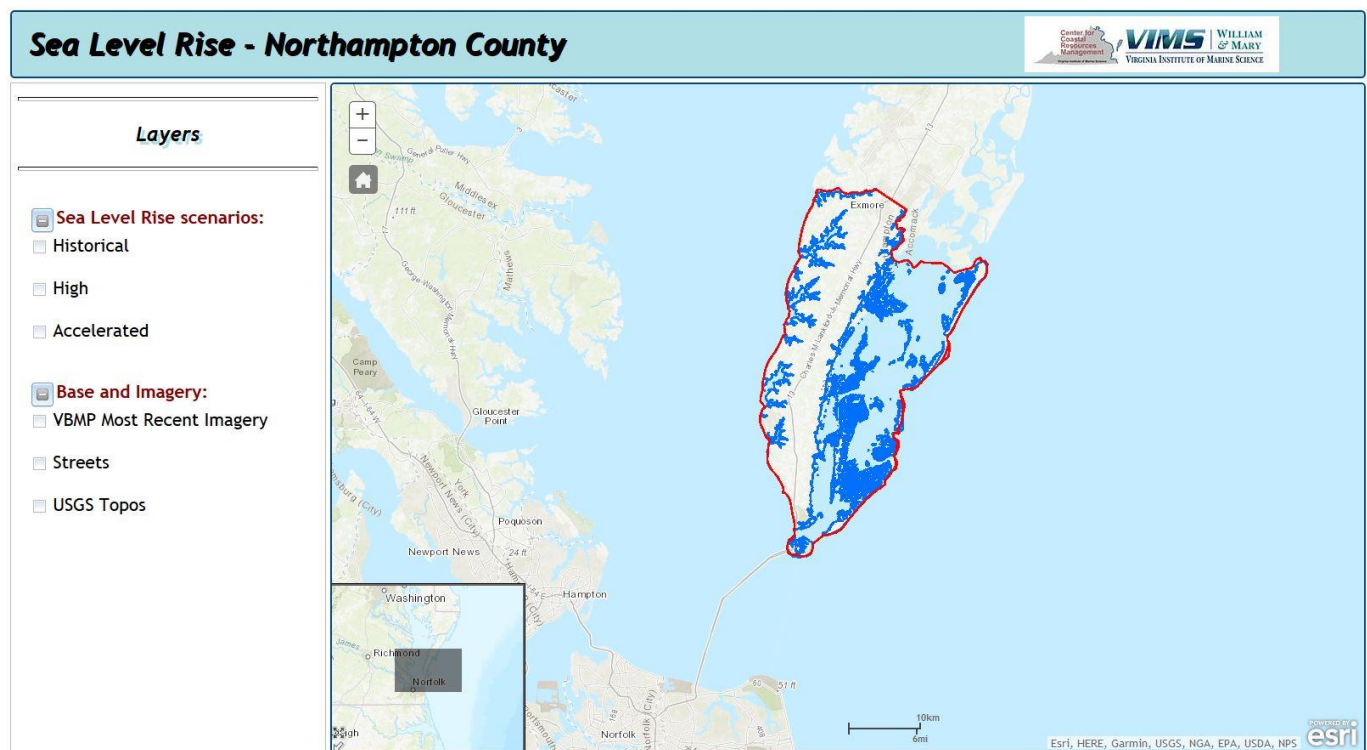


Figure 2. Base maps are selected in the Base and Imagery layer group in the Layers pane to the left of the map display.

Next, the user must select the sea level rise (SLR) scenario he/she wishes to view. This is seen in Figure 2 in the “Sea Level Rise scenarios” layer group. Three choices are available: “Historical”, “High”, and “Accelerated”. When the box for a given scenario is clicked, a time slider bar will display (seen in Figure 4) and that scenario will be accessible and visible on the map display.

Multiple scenarios can be viewed simultaneously, and their shading on the map display can be adjusted using the slide bars below the respective scenario check boxes in the layer list.

Shown in the upper left of the map display in Figure 2 is the tool to zoom and pan your map within the map viewer. The tool includes “+” and “-” buttons to zoom in and out (Figure 3), and a “Home” button just below to send you back to the original map extent. Use these buttons to zoom to your area of interest.



Figure 3. Zoom buttons.

The Sea Level Rise tool is developed to observe inundation over time under a user defined rate of sea level rise. After the user has zoomed to the area of interest, and selected his/her sea level rise scenario, the time slider bar (Figure 4) is used to step through time and observe the land area inundated as the MHW mark shifts inland due to sea level rise. The arrow on the left of the slide bar allows for a continuous automated animation through time. The pair of arrows on the right side of the bar allows the user to manually step forward and back in time at 20 year intervals to observe the inundation.

The time slider bar begins in 2012, when the model was developed. The map window displays MHW water levels at the year indicated on the time slider. The projected scenario flood levels are generated at 20 year increments beginning with the year 2020 and ending with the year 2100.

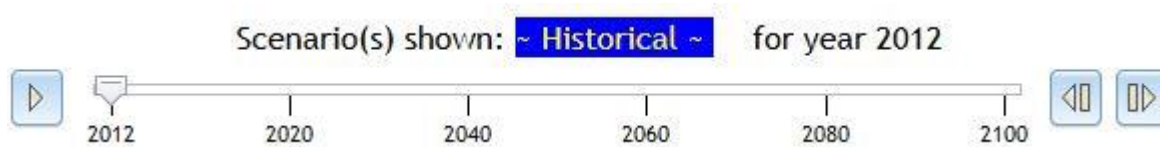


Figure 4. Time slider.

The modeling that is described above does not account for any changes in the land surface or the submerged bottom due to shifting sediments, erosion, or accretion. Like in a bathtub, the model simply raises water in the basins over a fixed surface and uses the MHW line as the starting point. The output of the model is expressed as a zone of inundation illustrated in blue. As stated above, the user can control the level of shading. Figure 5 is an example of a time series of inundation using the “Accelerated” rate of sea level rise (Table 1) for an area in Northampton County, Virginia. The years 2012, 2080, and 2100 are shown.

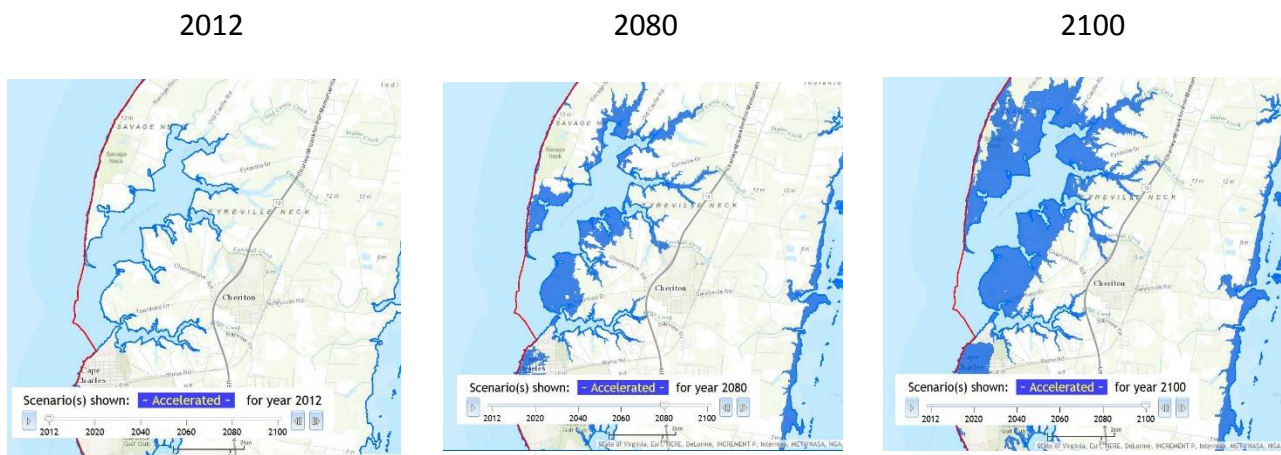


Figure 5. An inundation time series.

More information about sea level rise and flooding in Virginia can be found in this 2012 study prepared by CCRM:

http://ccrm.vims.edu/recurrent_flooding/Recurrent_Flooding_Study_web.pdf.

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