Preparing for Tomorrow's High Tide

A Mapping Appendix to the Delaware Sea Level Rise Vulnerability Assessment

July 2012

Other Documents in the Preparing for Tomorrow's High Tide Series

A Progress Report of the
Delaware Sea Level Rise Advisory Committee
(November 2011)

Delaware Sea Level Rise Vulnerability Assessment
for the State of Delaware
(July 2012)

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A Mapping Appendix to the Delaware Sea Level Rise Vulnerability Assessment

Prepared for the Delaware Sea Level Rise Advisory Committee
by the Delaware Coastal Programs
of the Department of Natural Resources
and Environmental Control

About This Document

This Map Appendix was developed and produced by the DNREC Delaware Coastal Programs for use by the Delaware Sea Level Rise Advisory Committee. It contains background information about sea level rise, the sea level rise vulnerability assessment, and maps depicting the exposure of thirty-nine resources to sea level rise under three scenarios. This Appendix is intended to be used in concert with the Delaware Sea Level Rise Vulnerability Assessment Document, which contains detailed descriptions of each mapped resource and their vulnerability to sea level rise.

Users of this document should carefully read the introductory materials included to understand the assumptions and trade-offs that were made in order to depict this information at a statewide scale.

These maps are a representation of inundation based on local Mean Higher High Water (MHHW). Inundation is assumed to occur at a constant elevation (Bathtub Model) and no other factors other than tidal elevation are used to determine water levels.

The land surface elevations are based on data with an average accuracy of 15 cm (6 inches); however areas of heavy vegetation may have errors exceeding that amount.

The Delaware Coastal Programs makes no warranty and promotes no other use of these maps other than as a preliminary planning tool.

This project was funded by the Delaware Department of Natural Resources and Environmental Control, in part, through a grant from the Delaware Coastal Programs with funding from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administrations, under award number NA10NOS4190202.

Further information about this document and the Delaware Sea Level Rise Advisory Committee can be found online at **http://de.gov/slradvisorycommittee** and at the address below:

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Delaware is a Coastal State

Its economy and quality of life have historically been linked to its shores, its vast expanses of protected tidal wetlands and its fertile farm fields. Because of its location and dependence on the coast, Delaware is particularly vulnerable to the effects of rising sea levels.

The line between land and sea along Delaware's coast is constantly on the move. It is obvious to those who live near or spend time on the water that the high tide line along Delaware's shorelines fluctuates daily depending on local weather and the cycle of the moon. Less obvious is that fact that the high tide line is slowly and steadily moving landward and upward[1].

Tide data has been collected at Lewes for ninety years and at Reedy Point (located near the C&D Canal) for fifty years. These data sets have given scientists consistent long-term tidal records to track tidal fluctuation and sea level changes in the ocean and bays. The tide data show that the mean sea level in Delaware has risen about a foot over the last century. Other long-term tide stations within the Mid-Atlantic region show similar trends[2].

Globally, sea level rises for two main reasons: warming water and loss of ice on land. As the ocean absorbs solar radiation, the water warms. When water warms, it expands and causes the mean level of the water to rise. In addition, as the Earth becomes warmer, land-based glaciers and icecaps melt. This meltwater empties into oceans and increases mean sea levels worldwide. The worldwide average rate of sea level rise during the twentieth century, as determined by tide gauge measurements, was about 0.07 inches per year (or about 7 inches over 100 years).[3]

Tide gauges indicate that Delaware's local sea level is rising faster than the worldwide average. The rate of sea level rise recorded at the tide gauge in Lewes is 0.13 inches per year (or 13 inches over 100 years)[4], as compared to the worldwide average rate of 0.07 inches per year. The difference between the local rate and the global rate is due to the vertical movement of the Earth's crust, which is causing the land in Delaware to slowly sink. Tide gauges used to track sea level record the combined motion of the land and the sea.

[1]CCSP, 2009. Sea Level Rise and its effects on the coast. In: Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus et al. U.S. Environmental Protection Agency, Washington D.C., USA, pp 11-24. Available online: http://www.climatescience.gov/Library/sap/sap4-1/final-report/

[2]Tide gauge information is available from the National Oceanic and Atmospheric Administration: http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml

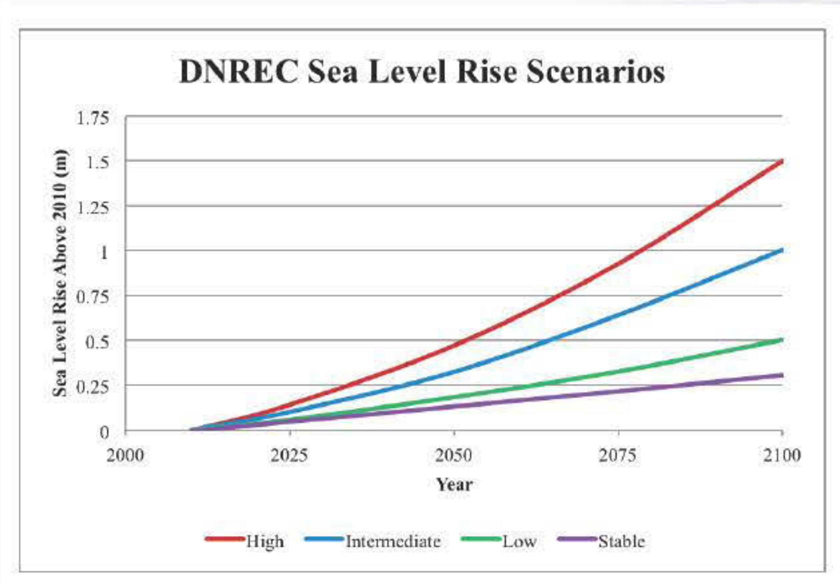
[3]IPCC (Intergovernmental Panel on Climate Change), 2001. Observations: Oceanic Climate Change and Sea Level. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC [S. Solomon et al (eds)]. Cambridge University Press, Cambridge, UK, and New York, pp. 387 – 432. Available online: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

[4]Tide gauge information is available from the National Oceanic and Atmospheric Administration: http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

Future Sea Levels

While it cannot be proven with certainty, climatologists have predicted that the rate of sea level rise occurring today will likely become greater in the decades to come[5]. If this occurs, it will affect homes, businesses, roads, natural areas and other important resources. Many federal, state and local officials have decided that it is prudent to begin planning now for the effects of rising sea levels[6].

In 2009, the Delaware Department of Natural Resources and Environmental Control (DNREC) formed a Sea Level Rise Technical Workgroup to provide planning scenarios for sea level rise up to the year 2100. This workgroup, composed of scientists from the University of Delaware, Delaware Geological Survey, Center for the Inland Bays, Partnership for the Delaware Estuary and DNREC, reviewed historical data for local sea level rise and reviewed the findings of international and national expert panels. Based on this information, the Sea Level Rise Technical Workgroup recommended three planning scenarios. The conclusions of the workgroup were then reviewed by several national experts. The Committee chose to recommend a range of scenarios because it is not possible to precisely predict future rates of sea level rise[7]. These scenarios can be used for understanding and planning for sea level rise.



The Technical Workgroup's lowest scenario was a sea level rise of 1.6 feet (0.5 meters) between now and the year 2100. This scenario is slightly higher than the current rate of sea level rise in Delaware and is partially based on low estimates for future global warming. The highest scenario was a sea level rise of 4.9 feet (1.5 meters) between now and the year 2100. This scenario is based on higher estimates of future global warming. The middle scenario was 3.3 feet (1.0 meter) between now and the year 2100, and is based on moderate estimates of future global warming.

From these planning scenarios, a series of maps was developed using very accurate elevation data. These maps show the areas that could be flooded (or inundated) for each planning scenario. The inundation maps were used by the Sea Level Rise Advisory Committee to complete this Vulnerability Assessment. The inundation maps are available through an online viewer at: http://de.gov/slrmap

[5]IPCC (Intergovernmental Panel on Climate Change), 2001. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC [S. Solomon et al (eds)]. Cambridge University Press, Cambridge, UK, and New York, pp 749 - 845. Available online: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

[6]DNREC Sea Level Rise Technical Workgroup, 2009. Recommended Sea Level Rise Scenarios for Delaware. Available online: http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/Final%20and%20Signed%20DNREC%20SLR%20scenarios.pdf

[7]DNREC Sea Level Rise Technical Workgroup, 2009. Recommended Sea Level Rise Scenarios for Delaware. Available online: http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/Final%20and%20Signed%20DNREC%20SLR%20scenarios.pdf

Future Sea Level

DETAILED METHODOLOGY

The sea level rise vulnerability assessment maps were designed to provide at-a-glance information on extent and density of inundation impacts for Sea Level Rise Advisory Committee members and interested citizens. For interested readers, the following provides an in-depth, technical explanation of the steps and methods used

CREATION OF BATHTUB INUNDATION MODEL

A statewide bathtub inundation model was created by the Delaware Coastal Programs in support of DNREC's internal sea level rise policy. This bathtub model uses only two variables, the inundation level (in this case, the sea level rise scenarios) and the ground elevation, derived from a lidar-based digital elevation model (DEM). The land surface elevations derived from lidar data have a statewide average root mean square error (RMSE) of 18 cm (6 inches) however; areas of heavy vegetation may have elevation errors exceeding that amount.

In the bathtub model, we assume that the tidal range will remain constant with SLR, thus the MHHW levels will increase at the same rate as sea level rise. This is a simplification. Increasing water depth and fetch length may increase the amplitude of MHHW.

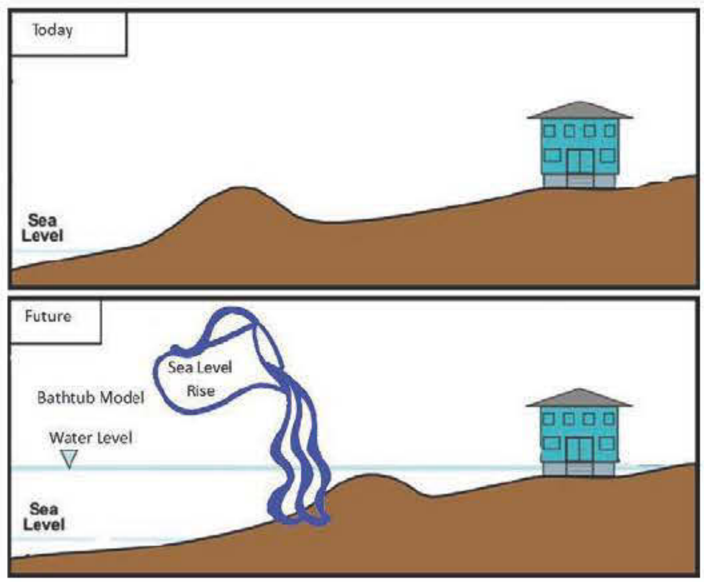


Figure 1 - Bathtub model of sea level rise

In simple terms, any land with an elevation lower than the sea level rise scenario is assumed to be inundated (Figure 1). However, impoundments and other areas protected by dikes or dams are assumed to protect the inland areas from tidal inundation until the water level exceeds the lowest dike elevation, at which time all land area behind the dike is assumed to become inundated. Bridges are shown at true elevation; if the bridge is shown as inundated on the bathtub map, the water level has exceeded the road surface of the bridge.

Bathtub models are limited in that they do not account for the complex natural and human processes (erosion, tidal forcing, sediment accretion and shoreline protection structures) that may accompany rising sea levels, but do provide a readily available and understandable planning tool capable of estimating the magnitude of potential impacts. Figure 2 compares bathtub models to hydrodynamic models.

	Modeled Water Surface	Single Value Water Surface
Data Readily Available	sometimes	✓
Quickly Create Multiple Scenarios	✗	✓
Accounts for Hydrodynamics of Water Rise	✓	✗

Figure 2 - Comparison of bathtub (Single Value) model vs. a modeled water surface.

Watershed	MHHW
Naamans Creek	0.9666
Shellpot Creek	0.9858
Brandywine River	0.9684 (mouth of Christina @ Delaware River)
Christina River	0.9684
City of New Castle	0.9336
Army Creek	0.9194
Red Lion Creek	0.9180
Dragon's Run	0.9169
C&D Canal	0.9259
Appoquinimink River	0.9712
Blackbird Creek	0.9711
Cedar Swamp	0.9624
Smyrna River	0.9588
Leipsic River	0.9033
Little Creek	0.8694
St Jones	0.8394
Murderkill River	0.8367
Mispillion River	0.7468
Cedar Creek	0.7472
Broadkill River	0.6479
Lewes & Rehoboth Canal	0.4029 (average of Broadkill and Rehoboth Bay)
Rehoboth Bay	0.1579 (inside Rehoboth Bay)
Indian River Bay	0.2466 (inside Indian River Bay)
Indian River	0.2710 (@ junction of IRB and IR watersheds)
Assawoman Bay	0.0995
Atlantic Ocean	0.5511
Nanticoke River	0.3578 (Seaford)

Table 1 - MHHW, by watershed, as calculated by VDatum.

PROCEDURE FOR DEVELOPING INUNDATION MAPS

1. Lidar data was converted to a more usable format using raster math to convert meters to centimeters.

2. Target watershed boundaries were extended into receiving water body and lidar data was extracted for the target watershed.

3. Mean Higher High Water (MHHW) elevations were determined for each watershed in the state using NOAA VDatum software[8]. (Table 1)

[The watershed reference location for MHHW is at the confluence of the selected watershed's river and the Delaware Bay/River, except for the Inland Bays, Nanticoke River, and Atlantic Ocean. In the Inland Bays, the location of MHHW is the center of the selected bay. In the Nanticoke River, the location of MHHW is the city of Seaford, and in the developed Atlantic Coast, the location is offshore in the Atlantic Ocean near Indian River Inlet.]

4. To create the scenario layers the elevation data was reclassified into the number of target elevations (i.e scenarios) plus 1.

Example: Lowest number in data to MHHW = 0, MHHW+1 to first target number = 2, last target number +1 to highest number in data = No Data. (Spatial Analyst/Reclass/Reclassify)

5. Data was converted to polygons for each of the target elevations.

6. County-based layers were created by first splitting watersheds that border counties. Then all the watersheds for each county were combined into one layer.

[8]NOAA's VDatum software is also used to link elevations with differing datums. This allows the MHHW references to be tied to the lidar land elevations based on NAVD88.

Future Sea Level

IDENTIFYING AND COLLECTING RESOURCE DATA

The Sea Level Rise Advisory Committee Society & Economy, Natural Resources and Public Safety & Infrastructure workgroups identified 140 resources they wished to analyze for the Vulnerability Assessment. Due to the large number of resources of concern, the best available existing data was used for the assessment as time and staff resources would not permit the creation or enhancement of any new datasets. These existing datasets were used "as-is". Staff involved in the assessment attempted to ensure that the datasets were reasonably accurate; however the Delaware Coastal Programs and the Delaware Sea Level Rise Committee make no guarantees as to the accuracy of the data utilized in this assessment.

Summary Info[9]	
Total Data Layers	140
Data Layers Collected and Analyzed	79
Data Layers Pending	8
Data Layers Not Collected	28
Larger Research Needed	25

Table 2 - Summary of GIS layers used in the vulnerability assessment

Of the 140 resource data layers requested, 75 were analyzed during the course of the vulnerability assessment. Thirty-six layers did not exist, were not reasonable accurate, were never received from the source or were classified and unable to be utilized in a public document. Twenty-five of the data requests required more study or research to develop and use.

Table 2 shows the number of data layers identified and used as part of the vulnerability assessment.

Data availability for a statewide assessment was a significant challenge for this initiative. While some data layers were easily identified and located, others were much more difficult to find, in large part because there is no centralized data location system for the state or its executive branch departments. Once found, most of this data lacked information regarding the methods used to collect it and date of last update. The largest hurdles for data collection included:

- No central, statewide listing or searchable index of data layers
- No one person/agency to contact for data information
- Agency data residing in only in hardcopy reports
- Private sector or proprietary data not available for public use
- Privacy concerns
- Homeland security restrictions

Privacy concerns and homeland security restrictions were able to be addressed so the data could be utilized. Census and housing data was summarized to the Block Group level to avoid singling out individuals that could potentially be identified through mapping community data. Other sensitive data, such as individual residential wells, were summarized on a square mile grid or displayed at a scale that would eliminate singling out one location. In some cases (i.e. pipeline data) the data simply was not mapped due to homeland security restrictions and vulnerability data is provided in table form only.

[9]Workgroup Vulnerability Data Lists.xlsx

PROCESSING VULNERABILITY DATA IN GIS

Analysis of each data layer followed a similar process, outlined below. As much as possible, tools available in ArcGIS were used to automate analysis and provide consistency among the five analysts performing the work.

1. Aggregate or split data by county
2. Create county-level impacts for each scenario – see Model Builder diagram below.
3. Summarize into Excel spreadsheet – lots of cutting and pasting

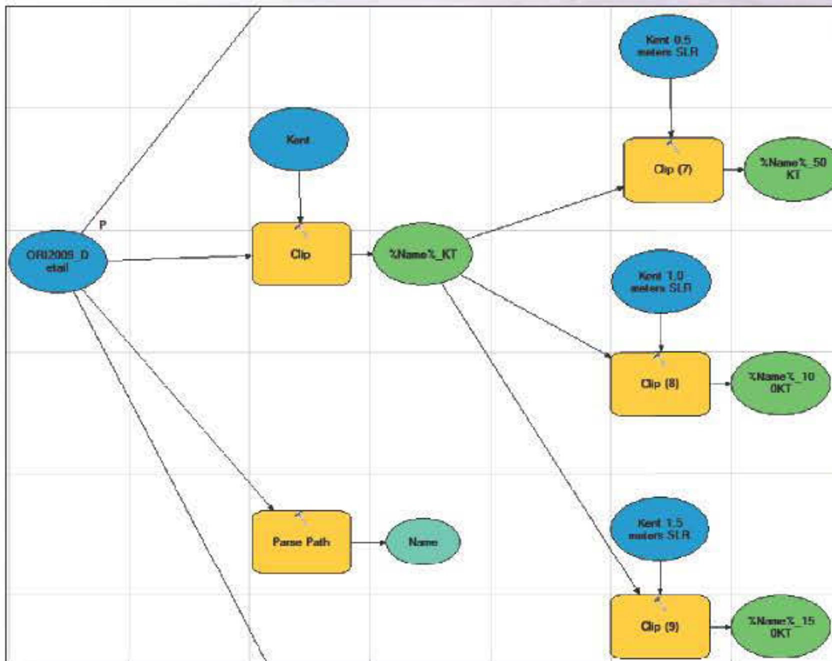


Figure 3 - Example segment from ArcGIS ModelBuilder, clipping data to scenarios in Kent County

Unfortunately, there was no automated way to transfer the data summarized from the attribute table of the data layer into an Excel Spreadsheet. As such, there were lots of manual copy and paste operations. The result, however, was a very useful, condensed data table for each resource analyzed. These data tables are available in the main body of the Sea Level Rise Vulnerability Assessment.

Figure 4 - Example data table.

Protected Lands (2009)							
County	Total Acres	Acres Inundated			Percent of Total Inundated		
		0.5 m	1.0 m	1.5 m	0.5 m	1.0 m	1.5 m
State	168,384	61,989	70,003	74,653	37%	42%	44%
New Castle	45,553	11,407	12,681	13,428	25%	28%	29%
Kent	54,399	30,289	34,336	36,388	56%	63%	67%
Sussex	68,433	20,294	22,986	24,837	30%	34%	36%

Source: DNREC - Parks and Recreation, Outdoor Recreation Inventory (2009), unpublished

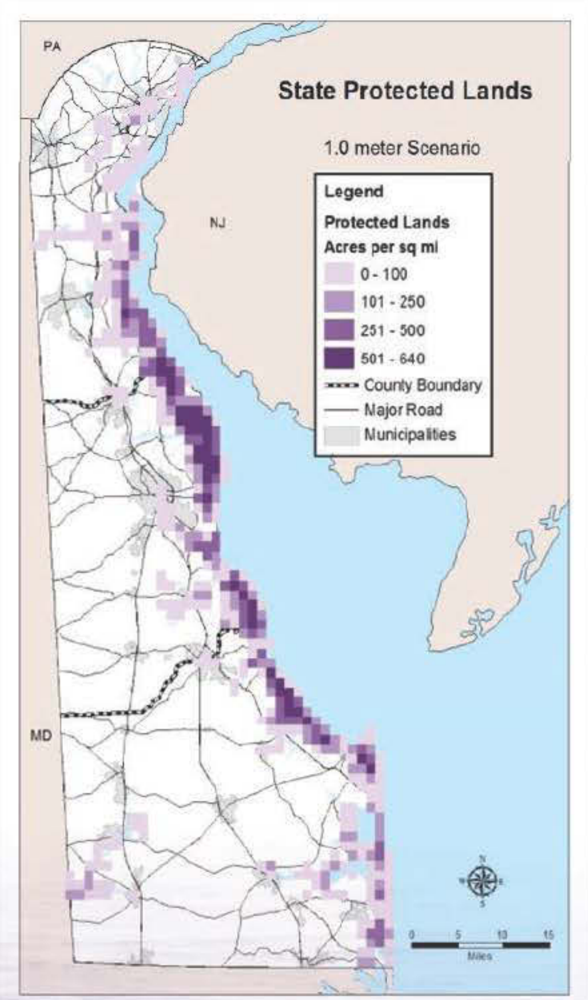
Scaling Data: Displaying Information for Different Uses

Some datasets developed for the Sea Level Rise Advisory Committee contain hundreds or thousands of individual point locations for a resource; others may contain numerous tracts of land. In order to display this volume of information at a statewide scale, the data is converted into "grid" maps where 1 grid = 1 mi^2. Using a color coded scale, the grids display either the total number of locations or acres affected within that square mile. At a glance, this allows viewers to see the degree to which a particular resource is affected by sea level rise in relation to other areas within the State.

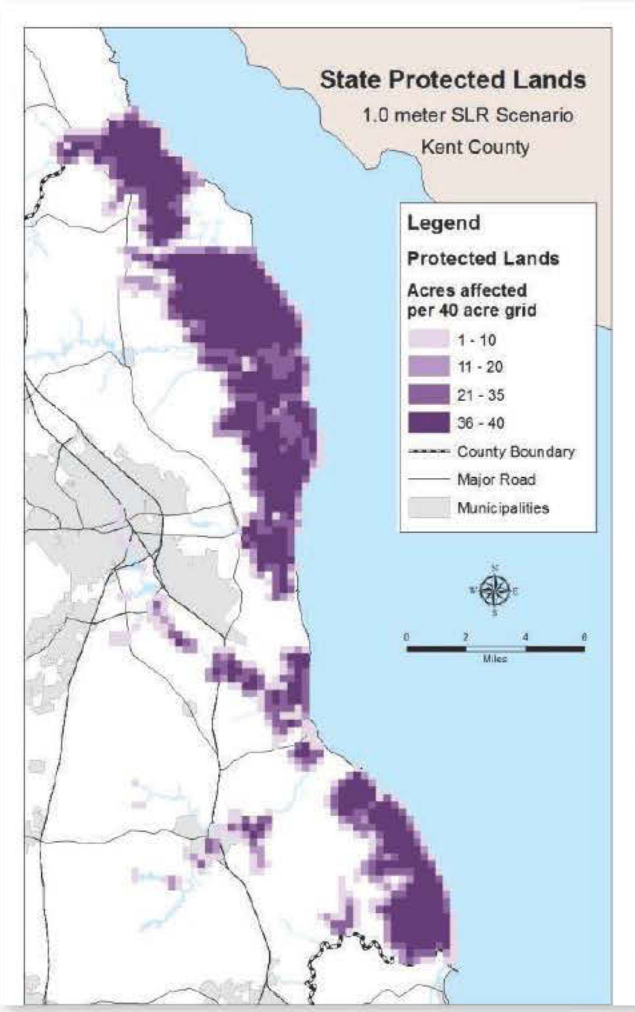
State

1 grid = 1 square mile

Statewide maps allow for the identification of regions of concern and areas where more detailed study would be required. These maps also show the overall impact of sea level rise on the State's resources.



For smaller areas of interest, decreasing the grid size will more precisely show the areas affected by sea level rise.

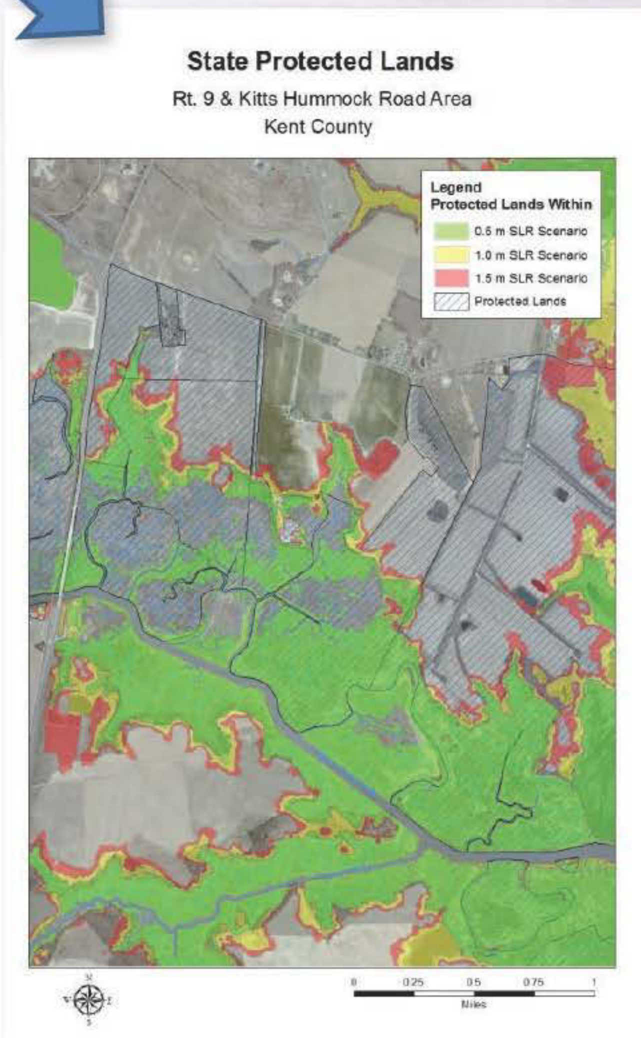


County

1 grid = 1/16th square mile

County maps could be used by those needing more specific information, but not necessarily exact locations. Acreages or total numbers of points in the area can still be easily determined.

At the local level, the area of interest is usually small enough that the actual locations or tracts of land can be displayed.



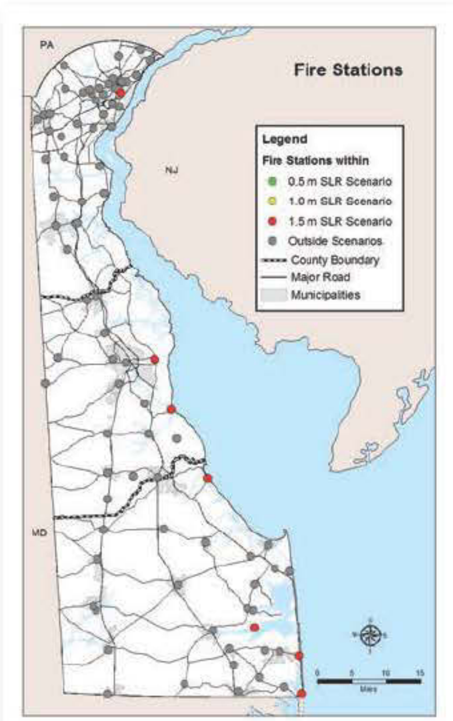
Local

Non-gidded Data

Local maps may include aerial photography to precisely show locations. These maps are used to identify individual points or tracts of land to determine how much of a certain tract might be affected.

Data Types Used in Vulnerability Mapping

Maps were developed to visually show where resources could be inundated by sea level rise. Each map contains data shown as one of three types: point, line, and polygon. Geographic data is almost always depicted in one of these forms.

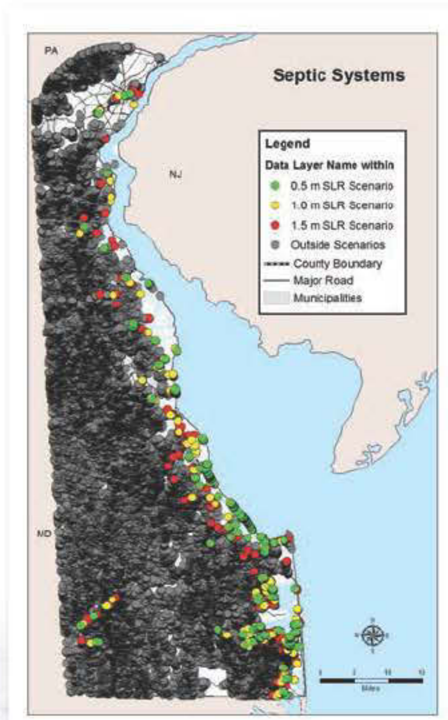


POINT

A point is an object that has a specific location on a map.
Examples: Historic Sites, Septic Systems, Fire Stations

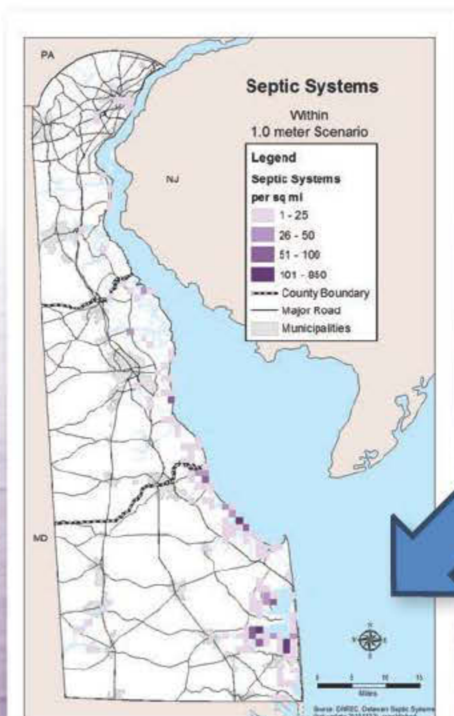
145 points

Can be easily viewed at the state level



78,109 points

Cannot be easily viewed at the state level



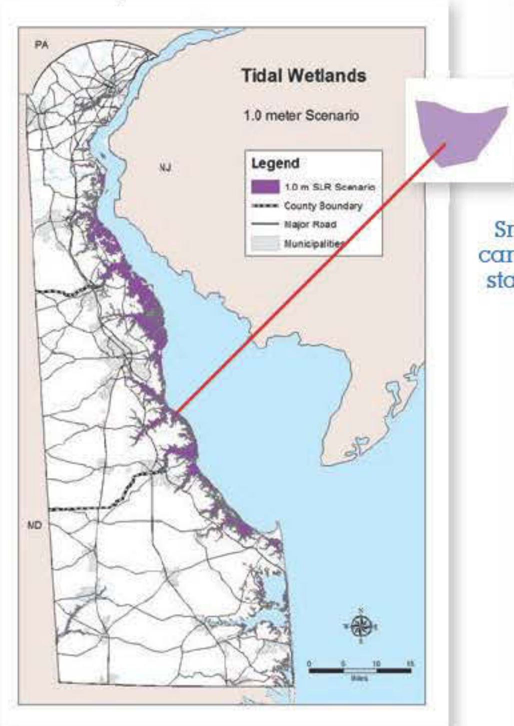
Convert to Grid

A grid map, which counts points within a square mile, is a better way to visualize inundation impacts for resources at the state level with a large number of points.

POLYGON

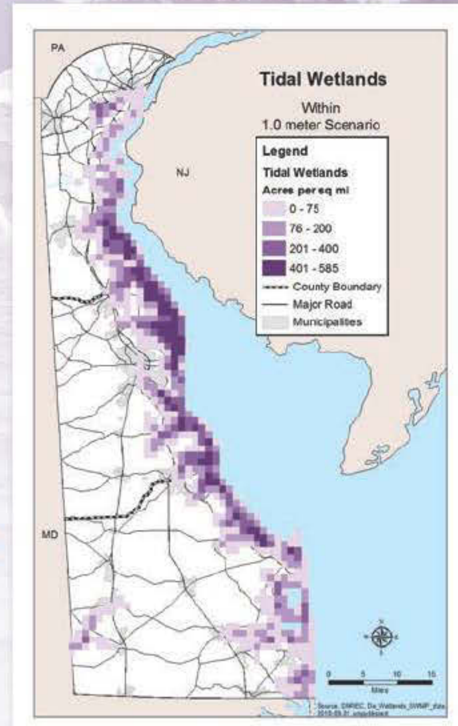
A polygon is an enclosed feature with at least three sides.

Examples: Wetlands and Parcels of Land.



Small polygons cannot be seen on state-wide maps.

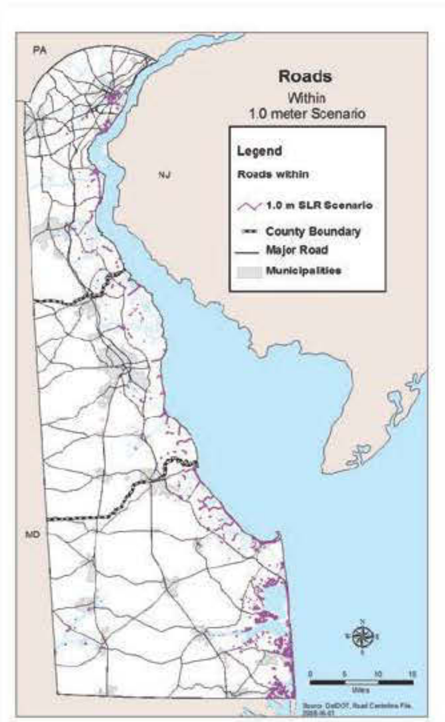
A grid map allows small polygons to be summed, which makes impacts visible.



LINE

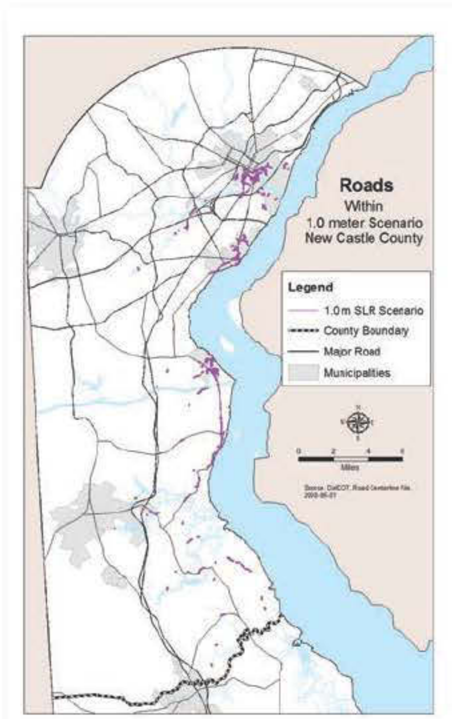
A line is a feature which only has length and no width. The feature has a beginning and an end.

Examples: Roads, Evacuation Routes, Railroads.



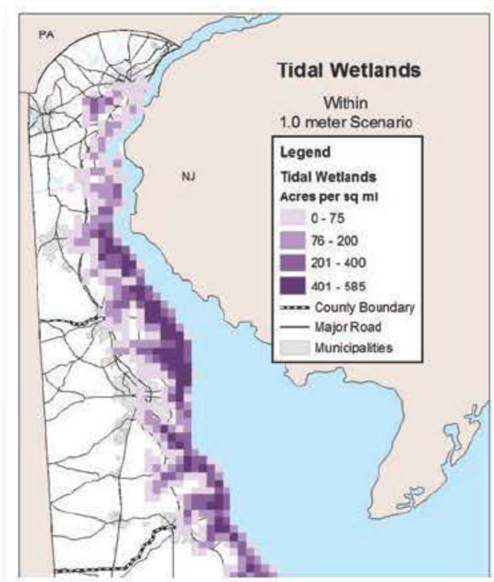
At the state level, small impacted line segments cannot be easily seen.

Impacts to line segments become more detailed and easier to see as the map area becomes more localized.



How Maps are Presented in this Document

GRIDS

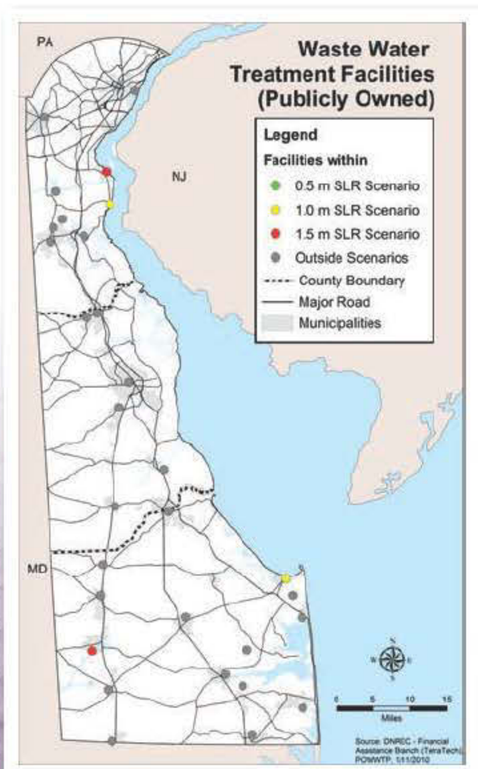


Point and polygon data, as shown on the previous page, may be difficult to see if there are many points or there are many small or thinly shaped polygons. To make the information easier to see, maps here are shown with this type of data as a grid.

In the example to the right, is a Grid Map of Tidal Wetlands impacted by the 1.0 meter Scenario. Because the impacts form thin, narrow bands as polygons. The data was converted to a 1 square mile grid system.

Through GIS analysis, the wetland polygons within each 1 mile square are counted and summed together. This illustrates acres of impacted wetlands per square mile. Similarly, for maps with many points that will be affected, GIS is used to count the number of points inside each box. The boxes are then color coded to indicate how many points are inside.

The legend breaks the data into four groups using the Natural Breaks (see ESRI ArcGIS documentation). Data for each resource is classified starting with the 1.5 meter scenario. This forms the upper bound and the legend is then applied to the other scenarios. Applying the legend this way allows the reader to see the trend of the impact as the scenarios progress. Exposure is shown in shades of purple; the darker the color, the greater the impact in that square mile box. Creation of the legend classifications is repeated for each resource so while the number values are comparable between scenarios for a given resource, only the magnitude of impact is comparable between resources.



POINTS

For some point data layers, there are only a few points in the entire State (e.g. Sewage treatment plants). In these cases the individual points are shown on the map and the points are color coded to show which SLR scenario affects them first.

Green – point is first affected by the 0.5 meter SLR Scenario
Yellow – point is first affected by the 1.0 meter SLR Scenario
Red – point is first affected by the 1.5 meter SLR Scenario
Grey – these points are not impacted by any of the 3 Scenarios

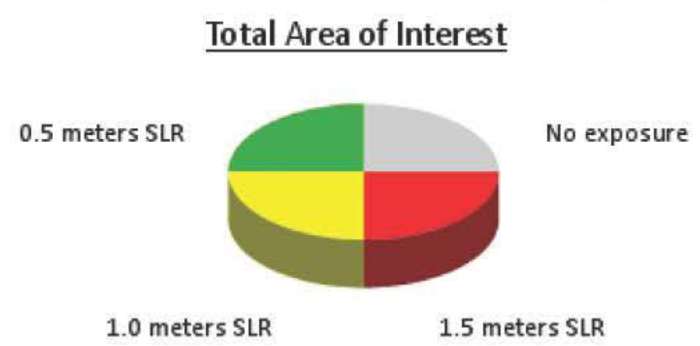
So, a green point will be inundated during the 0.5; 1.0; and 1.5 meter scenarios. A red point is only inundated at the 1.5 meter scenario.

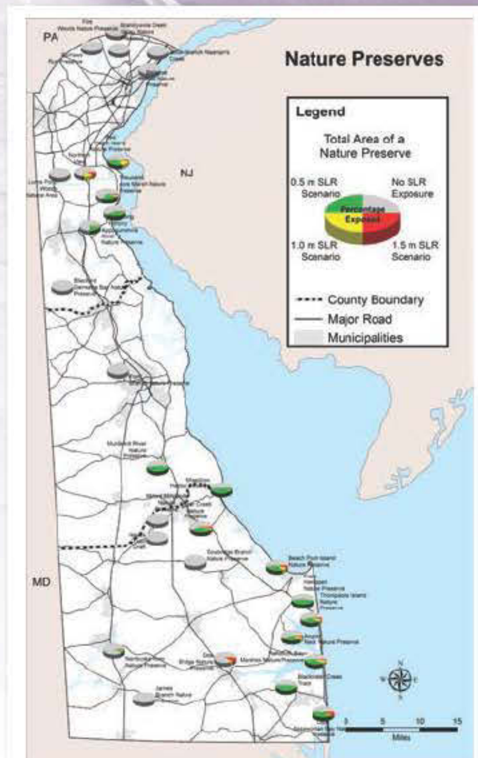
INDIVIDUAL AREAS

Some data layers are based on polygons, but there are only a few polygons throughout the state. In these cases, there are not enough to create the grids, as above. However, we still want to show how each of those polygons, individually, is affected by sea level rise. This is the case for resources like State Parks or Nature Preserves where we want to know how much of a specific area is affected under each of the scenarios.

Pie Chart symbols are used to illustrate percentage of impact.

Pie charts are useful for illustrating how individual parts contribute to an overall whole set. For clarity, it is best if there are only a few categories to display. 4 categories are used for this application.





Each pie represents the total area of interest, say a Nature Preserve. Each colored slice of the pie is that portion of the whole affected with each scenario. The remaining grey portion is that portion not exposed to impacts from sea level rise.