The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure

Phase 1 - Final Report: the District of Columbia, Maryland, North Carolina and Virginia

(Phase 2: New York, New Jersey, Pennsylvania, Delaware, South Carolina, Georgia, Atlantic Coast of Florida)

Study Goals and Methodologies

Introduction

This study was designed to produce rough estimates of how future climate change, specifically sea level rise and storm surge, could affect transportation infrastructure on the East Coast of the United States. It is important, for the stability of commerce and the safety of the population, to have a broad picture of the land and infrastructure that may be affected by the change in coastline and resulting periodic flooding.. An estimate of the impact must be quantified in order to create a plan to address the potential impacts of sea level rise. This study's major purpose is to aid policy makers, specifically at the U.S. Department of Transportation, by providing estimates of these effects as they relate to roads, rails, airports and ports. The resulting maps and statistics demonstrate the location and quantity of infrastructure that could be affected under the climate scenarios.

This study was not intended to create new estimates of future eustatic[1] sea levels, or to provide a detailed view of a particular area at a given point in time. Instead, this study explored how the predictions of future global sea level elevations from the United Nations Intergovernmental Panel on Climate Change (IPCC) may affect transportation infrastructure. The study's inherent value is its broad view of the subject and the overall estimates identified. However, given the uncertainty of the sea level rise data, it should not be used to predict sea levels at a particular location or point in time.

The study is broken into two phases. The first phase focuses on North Carolina, Virginia, Washington D.C. and Maryland. This report focuses on the progress made in the first year. The next phase will explore New York, New Jersey, Pennsylvania, Delaware, South Carolina, Georgia, and the Atlantic coast of Florida and is expected to be completed in mid-2008.

1 Background

Sea level may continue to rise at an accelerated rate

The majority of the scientific community is in agreement that increasing atmospheric concentrations of carbon dioxide and other greenhouse gases are expected to cause a global warming that will potentially raise the sea level several feet in the next century. The United Nations Intergovernmental Panel on Climate Change (IPCC) estimated in their Third Assessment Report (TAR) that sea level will rise 9 to 88 cm by the year 2100. A U. S. Environmental Protection Agency (EPA) study estimated that there is a 50 percent chance that global sea level will rise 45 cm, and a 1 percent chance of a 112 cm rise by the year 2100.[2] Other studies by EPA have estimated that along the Gulf and Atlantic coasts, a 30 cm rise in sea level is likely by 2050.[3]

[1] Eustatic sea level rise refers to the change in sea level created by any volumetric increase in the oceans worldwide, primarily due to thermal expansion and ice melt.
[2] EPA. 1996. "The Risk of Sea Level Rise", Titus and Narayanan http://epa.gov/climatechange/effects/coastal/Risk_of_rise.html
[3] EPA. 1995. "The Probability of Sea Level Rise," Titus www.epa.gov/globalwarming/sealevelrise

It is further expected that by 2100 a 60 cm rise is most likely with some models predicting as much as a 120 cm rise. Along the coast of New York, which typifies the United States, sea level is likely to rise 26 cm by 2050 and 55 cm by 2100. There is also a 1 percent chance of a 55 cm rise by 2050 and a 120 cm rise by 2100.[4]

Sea level rise could have an important impact on transportation infrastructure

More than half of the world's population lives within 60 km of the shoreline. With current and predicted demographic trends, this could rise to three quarters by the year 2020. In the United States, coastal counties are home to about 53 percent of the U.S. population.[5]

The rising sea level, combined with the possibility of an increase in the number of hurricanes and other severe weather related incidents could cause increased inundation, and more frequent flooding of roads, railroads, and airports, and could have major consequences for port facilities and coastal shipping.

A large percentage of the shoreline of the United States is currently eroding at a rate between 1 and 4 feet per year. The rising sea levels would inevitably accelerate this erosion. In a report released in June 2000, the Federal Emergency Management Agency (FEMA) estimated that about a quarter of homes and other structures within 500 feet of the U.S. coastline and Great Lakes shorelines will be overtaken by erosion during the next 60 years[6].

Many of the low-lying railroads, tunnels, ports, runways, and roads are already vulnerable to flooding. A rising sea level will only exacerbate the situation by causing more frequent and more serious problems as well as introducing problems to infrastructure not previously affected by these factors. Examples include the tunnels connecting New Jersey and Manhattan Island, the port facilities in New York, Boston, Charleston, Miami, New Orleans, Texas City, San José, and Long Beach, and the airports in New York, Boston, and Washington, D.C. Some of these low-lying transportation lines, if not protected, may be permanently flooded.

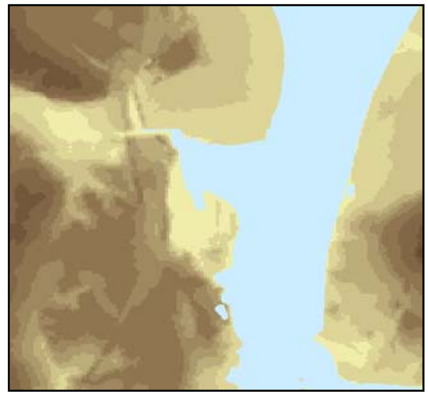
[4] EPA. 1995. "The Probability of Sea Level Rise," Titus www.epa.gov/globalwarming/sealevelrise
[5] U.S. Census Bureau, U.S. Department of Commerce, "Population Change and Distribution, 1990 to 2000" http://www.census.gov/prod/2001pubs/c2kbr01-2.pdf
[6] Federal Emergency Management Agency, Shoreline Change Conference II: A Workshop on Managing Shoreline Change May 3 to 5, 2006 Charleston, SC PROCEEDINGS. http://www.csc.noaa.gov/shoreconf/ShorelineChangeConferenceII_proceedings_final.pdf

2 Summary of Study Process

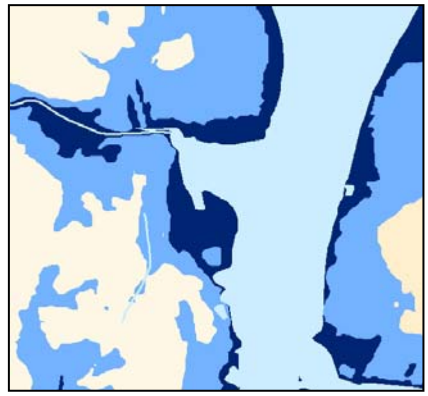
Listed below is a brief summary of the process used in this study. Beginning with section 3, we explain the study methodology in greater detail.

This study:

- *Using digital elevation models (DEMs) evaluated the elevation in the coastal areas and created tidal surfaces to describe the current and future predicted sea water levels.* This spatial information helped identify areas that are, without proper protection, expected to be ***regularly inundated*** or that are ***at-risk*** of periodic inundation due to storm surge.



- *Identified land that, without protection, will regularly be inundated by the ocean or is at-risk of periodic inundation due to storm surge at the given temporal intervals.* From this spatial information it is possible to plan for the protection of current infrastructure and to prevent the building of infrastructure in areas that are, without proper protection, expected to be ***regularly inundated*** or that are ***at-risk*** of periodic inundation due to storm surge.



- *Identified the transportation infrastructure that, without protection, will regularly be inundated by the ocean or at-risk of periodic inundation due to storm surge at the given temporal intervals.* The maps and GIS data produced by this study detail the infrastructure that is expected to be ***regularly inundated*** or that is ***at-risk*** so that measures may be taken to protect, reroute, or remove the infrastructure as the ocean encroaches upon them.

- *Provided statistics to demonstrate the potential amount of inundated and at-risk land surge at the given temporal intervals.* The statistics calculated describe both the total amount of inundated and at-risk land and the total length of roads, railroads and other infrastructure that may be ***regularly inundated*** or that is ***at-risk*** of periodic inundation.

Potentially Impacted Transportation Network		
Type	**Inundated**	**At-Risk**
Roads (km)		
Interstate Highways	0.9	11.2
Principal Arterials	7.2	38.3
Minor Arterials	0.0	0.0
National Highway System Features	6.4	41.7
Other Transportation Types (km)		
Railroads	36.1	64.5
Seaport	0	0
Potentially Impacted Land Area (acres)		
Total Impacted Area	2261	4853
Airport Property Area	0	0
Airport Runway Area	0	0

3 Study Methodologies

The intended uses of this study and its uncertainties must be clear, in order to understand the methodologies employed. This study was designed to produce high level estimates of the net effect of sea level rise and storm surge on the national transportation network. It was designed primarily to aid policy makers at the U.S. Department of Transportation by providing estimates of these effects as they relate to roads, rails, airports and ports.

The study was not intended to create a new estimate of future sea levels, or to provide a detailed view of a particular area under a given scenario. Instead, the study explored existing predictions of global sea level elevations from the United Nations Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) and examined large areas for study. The inherent value of this study is the broad view of the subject and the overall estimates identified.

This study was meant to provide a broad first look at potential sea level changes on the Atlantic coast, and the results should not be viewed as defining specific changes in water levels at specific points in time. Due to the overview aspect of this study, and systematic and value uncertainties in the involved models, this analysis appropriately considered sea level rise estimates from the IPCC TAR as eustatic occurrences. The confidence stated by IPCC in the regional distribution of sea level change is *low* due to significant variations in the included models; thus it would be inappropriate to use the IPCC model series to estimate local changes. Local variations, whether caused by erosion, subsidence or uplift, local steric[7] factors or even coastline protection, were not considered in this study.[8] The unpredictability of anthropogenic mitigation was also not taken into consideration. Some studies are underway that may, in the future, allow for this to be considered, but are not currently publicly available.

As this study was initiated well before the IPCC released results of its fourth assessment in 2007, the estimates of sea level rise used in this study are taken from the IPCC Third Assessment Report (TAR) released in 2001. However, the estimates used in this study are in line with the results of the Fourth Assessment Report (AR4). As discussed below, the range of increase in global eustatic sea level rise by 2100 used in this report is based on the range of the average of the model results for all 35 SRES scenarios, about 31 to 50 cm.[9] This is much narrower than the range of results for the complete set of models and scenarios of 9 to 88 cm from 1990 to 2100, which includes uncertainties in land-ice changes, permafrost changes and sediment deposition. The 4th and most recent IPCC report, AR4, gives a range of 18 to 59 cm for the six illustrative scenarios.[10]

While methods for estimating changes have significantly improved, the overall picture of the predicted changes relevant to this study remains relatively unchanged. The results of the two reports are in fact not all that different, if differences in the analysis are considered. The IPCC notes that if two differences in the analysis are taken into account, the TAR model means would be within 10% of the central estimates of the AR4 results. These two

[7] Steric - this study uses this term to refer to the volumetric increase in water due to thermal expansion.

[8] It is recognized that protection such as bulkheads, seawalls or other protective measures may exist or be built that could protect specific land areas but, due to the overview nature of this study they were not included in the analysis.

[9] IPCC3, WG1, c.11, pp. 671-72. http://www.grida.no/climate/ipcc_tar/wg1/pdf/TAR-11.PDF

[10] IPCC4, WG1, summary for policy makers, p. 13. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_SPM-v2.pdf

differences are: 1) while the TAR gives projections for 2100, the AR4 gives projections for 2090-2099, and 2) the TAR analysis includes some small constant additional contributions, which are not included in the AR4 analysis. Furthermore, the IPCC notes that the ranges in the TAR and AR4 would have been similar if uncertainties had been treated the same.[11]

It is also noteworthy to consider that this study, like the TAR and the AR4, does not include the effects of full melting of either the Greenland or West Antarctic Ice Shelf. Combined or individually, melting of these ice features would add significant additional water to the global ocean and raise the level beyond any estimates in this study.

This study compares current conditions (2000) to estimates of future effects for the years 2025, 2050, 2075 and 2100 (given temporal intervals). The estimates of eustatic sea level rise used in this study are based upon the *range of averages* of the Atmosphere-Ocean General Circulation Models (AOGCMs) for all 35 SRES (Special Report on Emission Scenarios) as reported in figure 11.12[12] from the United Nation's Intergovernmental Panel on Climate Change (IPCC) third assessment report (2001). This estimate of eustatic sea level rise, the dark shaded region in Figure 3-2 below, is hereafter referred to as the e*stimate range*. For each temporal interval four areas of concern were established. These are:

- ***regularly inundated*** – *low estimate and high estimate*
- ***at-risk*** – *low estimate and high estimate*

The *regularly inundated* areas are described as all the areas falling between NOAA's mean higher high water (MHHW), the study definition of sea level, in 2000 and the projected sea level for the given temporal interval. For each temporal interval, projected sea level rise based on either the upper-limit or lower-limit of the e*stimate range* for that interval will be added to the MHHW to create the *regularly inundated* areas.

The *at-risk* areas are the areas falling between MHHW and NOAA's highest observed water level (HOWL), the study definition of storm surge, for the temporal interval. For each temporal interval, projected sea level rise based on the upper and lower limit of the e*stimate range* is added to the HOWL to create the *at-risk* areas.

Figure 3-1 provides a description of how *regularly inundated* and *at-risk* areas are defined for each interval. The projected sea level for each temporal interval is based on the range of averages (the dark shaded areas) from Figure 3-2.

[11] IPCC4, WG1, c.10, pp. 820-822. http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_Ch10.pdf
[12] IPCC3, WG1, c.11, page 671. http://www.grida.no/climate/ipcc_tar/wg1/pdf/TAR-11.PDF

	2000	2025	2050	2075	2100
regularly inundated (Low)	Below MHHW	MHHW to MHHW + 6 cm	MHHW to MHHW + 13 cm	MHHW to MHHW + 21 cm	MHHW to MHHW + 30 cm
regularly inundated (High)	Below MHHW	MHHW to MHHW + 6.5 cm	MHHW to MHHW + 17.5 cm	MHHW to MHHW + 31 cm	MHHW to MHHW + 48.5 cm
at-risk (Low)	MHHW to HOWL	MHHW + 6 cm to HOWL + 6 cm	MHHW + 13 cm to HOWL + 13 cm	MHHW + 21 cm to HOWL + 21 cm	MHHW + 30 cm to HOWL + 30 cm
at-risk (High)	MHHW to HOWL	MHHW + 6.5 cm to HOWL + 6.5 cm	MHHW + 17.5 cm to HOWL + 17.5 cm	MHHW + 31 cm to HOWL + 31 cm	MHHW + 48.5 cm to HOWL + 48.5 cm

Figure 3-1: definition of *regularly inundated* and *at-risk* areas at given temporal intervals for the *low* and *high* ranges of possible inundation. These figures are based on the range of averages of the Atmosphere-Ocean General Circulation Models (AOGCMs) for all 35 SRES Scenarios as reported figure 11.12 from the TAR (2001).

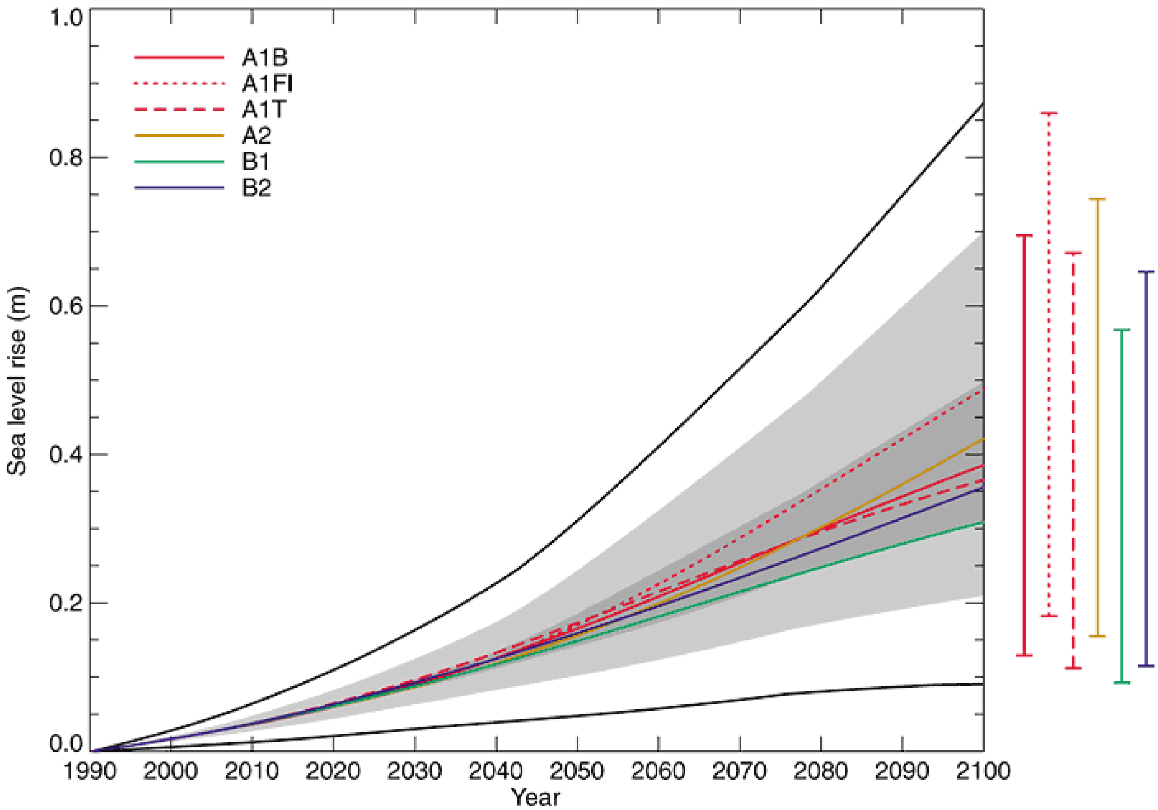


Figure 3-2: Global average sea level rise 1990 to 2100 for the SRES scenarios. ICF used the upper and lower limits of the dark shaded area in this study as the basis for the changes in sea level. These figures are based on the range of averages of the Atmosphere-Ocean General Circulation Models (AOGCMs) for all 35 SRES Scenarios as reported figure 11.12 from the IPCC's third assessment report (2001).

3.1 Creating Current Sea Level Surface Models

Given that sea level is not a flat and easily defined surface, a surface model that suits the study needs was required. NOAA's National Ocean Service (NOS)[13] maintains numerous *tidal stations* along the coast of the United States that are used to measure the daily variances of sea level. These tidal station data are maintained as a matter of public record[14] mainly as a service to ensure commercial and private maritime safety. While it is important for sea going vessels to understand how low the low tides may be, so they do not run aground, they also need to know how high the high tides (Mean Higher High Water) are expected to be so that they do not collide with the underside of structures such as bridges. This latter measurement is useful to this study to determine areas that are *regularly inundated* and is therefore the basis for our current (or base year 2000) sea level model. This area defines the highest areas that are wet on a regular basis and would therefore be of concern to those who plan and maintain transportation infrastructure.

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Station ID: 8594900                 PUBLICATION DATE:   09/05/2003
Name:       WASHINGTON, POTOMAC RIVER
            DISTRICT OF COLUMBIA
NOAA Chart: 12289                   Latitude:          38° 52.4' N
USGS Quad:  WASHINGTON WEST         Longitude:         77°  1.3' W


                          T I D A L   D A T U M S


Tidal datums at WASHINGTON, POTOMAC RIVER based on:

     LENGTH OF SERIES:        228 MONTHS
     TIME PERIOD:             January 1983 - December 2001
     TIDAL EPOCH:             1983-2001
     CONTROL TIDE STATION:


Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

     HIGHEST OBSERVED WATER LEVEL (10/17/1942)     =  3.368
     MEAN HIGHER HIGH WATER (MHHW)                 =  0.965
     MEAN HIGH WATER (MHW)                         =  0.896
     MEAN SEA LEVEL (MSL)                          =  0.472
     MEAN TIDE LEVEL (MTL)                         =  0.471
     NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)     =  0.425
     MEAN LOW WATER (MLW)                          =  0.047
     MEAN LOWER LOW WATER (MLLW)                   =  0.000
     LOWEST OBSERVED WATER LEVEL (02/26/1967)      = -1.539
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Figure 3-3: An example of the tidal station data collected from the NOS showing the location of the facility, and all of the National Tidal Datum Epoch (NTDE) datums for the tidal epoch of 1983-2001 are shown above. The NOS defines a tidal epoch as "the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years. Tidal datums in certain regions with anomalous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch."[15]

[13] The National Ocean Service http://oceanservice.noaa.gov/
[14] See http://www.tidesandcurrents.noaa.gov for further details on Tidal Station data
[15] See http://tidesandcurrents.noaa.gov/datum_options.html for definitions

Figure 3-4: an exaggerated 3D view of the MHHW sea level surface within the Chesapeake Bay area.

There are 368 stations from New York to the Atlantic coast of Florida that include the data needed (MHHW and NAVD) to produce a surface model of the sea[16]. To use these measurements across the broad area of the Atlantic coast, a surface was needed to approximate the elevation of the ocean at MHHW. Given the sparse population of discreet data from the tidal stations, this interpolation does not account for all local variations in the real world environment. This sparseness also introduces some value uncertainty. However, for the prescribed broad usage of this study, it does provide enough information to estimate the shape of the surface of sea level. In order to model this, the actual ground elevation (MHHW less NAVD) of the MHHW from the tidal stations was entered into a Geographic Information System (GIS) and a Triangulated Irregular Network (TIN) surface was interpolated. In the table above from the Washington, Potomac River tidal station, MHHW is 0.965 meters above MLLW and MLLW is 0.425 meters below NAVD, the benchmark ground elevation. By subtracting the NAVD from the MHHW the actual ground elevation of the MHHW can be found, in this case 0.965 (MHHW) – 0.425 (NAVD) = 0.54 meters. This process was performed on each tidal station and the TIN was interpolated from these points. The TIN created by this process was used to represent base year (2000) sea level. An example of the surfaces created by this process is found in Figure 3-4: **an exaggerated 3D view of the MHHW sea level surface within the Chesapeake Bay area**.

[16] This model estimates all elevations by using the North American Vertical Datum of 1988

3.2 Creating Future Sea Level Surface Models

Working with the base year MHHW data from the tidal stations, additional TINs were created for each scenario by adding that scenario's estimated increase in sea level to the base year tidal station data. For example, in the table above from the Washington, Potomac River tidal station, the actual ground elevation of MHHW is 0.54 meters (see section 3.1 for further explanation of process) and the estimated increase in sea level for the 2100 high scenario for *regular inundation* is 48.5 cm (0.485 m). The addition of the estimated increase to the base year provides a sum of 1.024 meters. This process was repeated for each tidal station and scenario and a new surface model TIN created.

3.3 Creating the Highest Observed Water Levels (Storm Surge) Surface Models

The Highest Observed Water Level (HOWL) data was extracted from the same tidal station data source (NOAA's National Ocean Service) used to create the current sea level models. The HOWL represents the highest recorded water level at that station and the date on which that observation was made. Therefore the HOWL data is completely dependent upon the length of time that the tidal station has been in existence. The oldest HOWL was recorded in 1898.

This data was used to model the base year (2000) surface representing areas *at-risk* of periodic inundation (storm surge). Of the 368 Atlantic coast tidal stations with full tidal data, 173 maintain data on HOWL, resulting in some value uncertainty in the base year surface.

The same process was used to create the HOWL surface as was used in creating future sea level surface models. For example, in the table above from the Washington, Potomac River tidal station, the actual ground elevation of HOWL is 2.943 meters (see section 3.1 for further explanation of process) and the estimated increase in sea level for the 2100 high scenario for *regular inundation* is 48.5 cm (0.485 m). The addition of the estimated increase to the base year provides a sum of 3.428 meters. This process was repeated for each tidal station and scenario and a new surface model TIN created for each scenario for a total of 8 HOWL surface models.

3.4 Identifying Areas of Concern

The areas of concern are the areas that will be *regularly inundated* - areas falling between the current MHHW and the projected sea level for the given temporal interval – and that are *at-risk* of periodic inundation - areas that fall between projected sea level and the projected HOWL for the temporal interval.

These areas were produced by using a 3D geographic information system tool that compared the surfaces created in the previous steps to Digital Elevation Models (DEMs) produced by USGS for the National Elevation Dataset (NED). These primarily have a horizontal grid size of 30 meters but in some areas 10 meter resolution is available (containing 9 times more data). The highest precision data available for each DEM was used in this study.

These DEMs were then resampled to a 5 meter resolution using a bilinear interpolation to prevent "terracing" that occurs at such coarse scales as the 30 meter resolution.[17] This function smoothes out the DEM and provides interpolated elevation data between the cells.

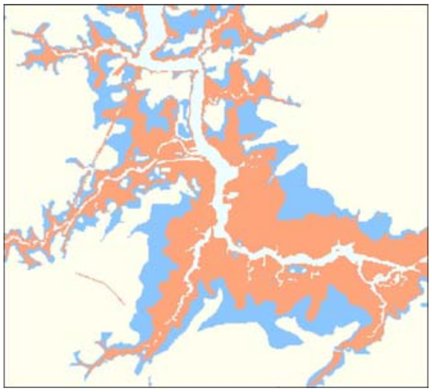

Figure 3-5: Areas of Concern

The surface models for all scenarios were then compared to the DEMs to determine where the surface models were above the elevation of the DEMs. This comparison found areas that are now considered to be *regularly inundated* or *at-risk* of periodic inundation due to storm surge. The results are created as polygon features.

[17] The term "terracing" refers to the effect produced when a continuous surface (land elevation in this case) is represented by discrete data at large intervals. In this case, the DEMs used take an elevation reading every 30 meters and assign that elevation to the entire grid cell, thus making unnatural cliffs and flat areas where cells converge.

3.5 Identifying Potentially Affected Transportation

Once the areas of concern polygons were created, they were overlaid upon the transportation network data to identify potentially affected transportation infrastructure. The data used in this analysis include:

- 1:100K scale Road data from the National Highway Planning Network (NHPN)[18] including:
    - Interstate Highways
    - Non-Interstate Principal Arterials (hereafter refereed to as Principal Arterials)
    - Minor Arterials
    - National Highway System (NHS)[19]
- 1:100K scale Rail data from the Federal Railroad Administration
- 1:100K scale Airport boundaries and runway areas from TeleAtlas[20]
- 1:100K scale Port boundaries digitized from DOQQs[21] for the land boundaries and the MHW line for the water boundaries. Ports included in Phase I include:
    - Baltimore, MD
    - Norfolk Harbor, VA
    - Wilmington, NC

The roads and rails were overlaid with the areas of concern to identify the linear distance in kilometers affected within each scenario. The airports, runways and port areas were also intersected with the areas of concern to identify the area in acres affected within each scenario.

Since the elevations from the DEMs represent the actual ground elevation, this study did not account for situations where infrastructure is artificially elevated. However, the results in this study are still relevant in those areas. For example, a highway with a high bed is indicated as inundated in this study. While the road itself may not be underwater, the bed, which is inundated, was not likely designed to be permanently underwater and thus must still be considered for mitigation.

[18] The NHPN is a product of the U.S. Department of Transportation's Federal Highway Administration.
[19] There are other roads identified on the lower functional systems to include the remainder of the National Highway System (NHS). There may be other roads identified which are Non-NHS/Non Arterial, but these systems are not complete in the NHPN.
[20] This data was extracted from ESRI's StreetMap Pro dataset which uses TeleAtlas North America data.
[21] A digital orthophoto quadrangle (DOQ) is a computer-generated image of an aerial photograph in which image displacement caused by terrain relief and camera tilts has been removed. For more information see: http://www.usgsquads.com/prod_doqq.htm.

3.6 Statistic Calculations

From the analysis in the previous steps, statistics at the county and state level were created for each scenario. For each scenario the statistics include:

- Kilometers of ***Interstate Highways*** potentially impacted
- Kilometers of Non-Interstate ***Principal Arterial*** roads potentially impacted
- Kilometers of ***Minor Arterial*** roads potentially impacted
- Kilometers of ***National Highway System*** facilities potentially impacted
- Kilometers of ***Railroads*** potentially impacted
- Total acres of ***Land*** potentially impacted
- Acres of ***Airport Property*** potentially impacted
- Acres of ***Airport Runways*** potentially impacted
- Acres of ***Port Property*** potentially impacted

The statistics tables include both regularly inundated and at-risk land areas. These are mutually exclusive, meaning the areas at-risk do not also include regularly inundated areas. The sum of these two fields equals the total land area impacted. For example, in the table below, the total area for the 6 cm scenario is the sum of the regularly inundated (RI) area, 243,799 acres, and the at-risk (AR) area, 579,277 acres, for the total 823,075 acres impacted by either regular inundation or at-risk.

MD State Statistics	6 cm (2025 Low)					
Increase in Eustatic SLR	Regular Inundation		At-Risk		Total	
Length	Km	% Affected	Km	% Affected	Km	% Affected
Interstates	0.2	0%	20.6	3%	20.8	3%
Non-Interstate Principal Arterials	13.0	5%	122.6	16%	135.6	18%
NHS Minor Arterials	8.5	1%	133.1	9%	141.6	9%
National Highway System (NHS)	11.2	0%	113.8	5%	125.0	5%
Rails	9.0	0%	273.9	10%	282.9	11%
Area	Acres	% Affected	Acres	% Affected	Acres	% Affected
Ports	0	0%	0	0%	0	0%
Airport Property	86	1%	1,000	8%	1,086	9%
Airport Runways	1	0%	39	6%	40	6%
Total Land Area Affected	243,799	4%	579,277	9%	823,075	13%

Figure 3-6: An example of the output statistics showing one temporal interval

3.7 Map Creation

To visualize the data created in the previous steps, maps were created. For each state an overview map for each scenario was created. Similarly, for each county that was affected a map of each scenario was created. The maps contain both regular inundation and at-risk areas for each scenario for a total of eight maps per county. Note that since Washington D.C. is not a state, it's "State" and "County" maps are one and the same. In Figure 3-7 below, the map depicts Washington D.C. and is representative of the other maps created under this study.

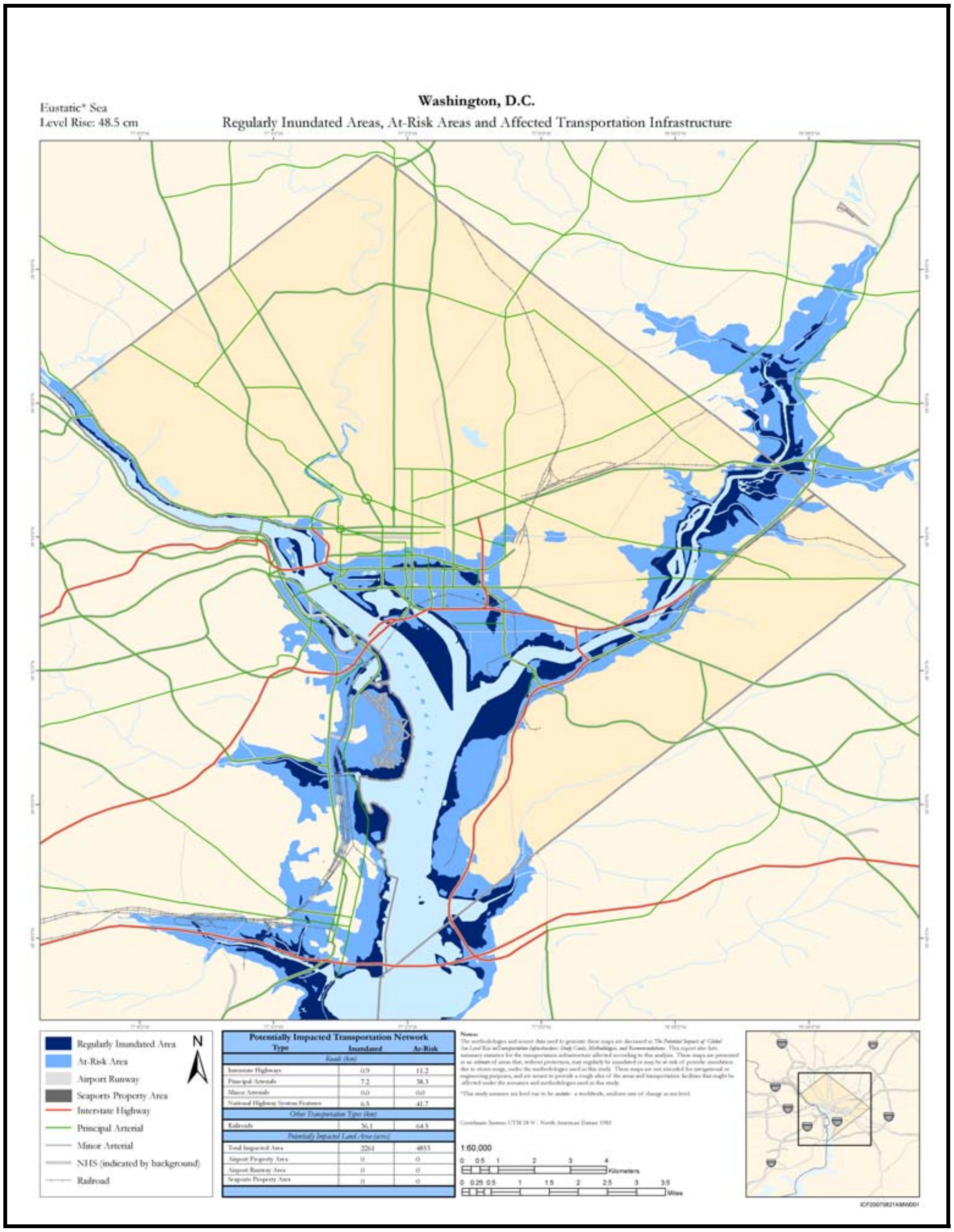

Figure 3-7: a representative output map from this study showing regular and at-risk areas at the 48.5 cm (2100 high) scenario.

4 Appendix

4.1 *Tables accompanying this report:*

- Washington D.C
  - DC State Statistics.xls
- Maryland
  - MD State Statistics.xls
- Virginia
  - VA State Statistics.xls
- North Carolina
  - NC State Statistics.xls

4.2 *Maps accompanying this report:*

All statewide maps created are available publicly and county maps will be available upon request.

- Washington D.C
  - Washington DC - Eustatic Sea Level Rise 6cm.pdf
  - Washington DC - Eustatic Sea Level Rise 6.5cm.pdf
  - Washington DC - Eustatic Sea Level Rise 13cm.pdf
  - Washington DC - Eustatic Sea Level Rise 17.5cm.pdf
  - Washington DC - Eustatic Sea Level Rise 21cm.pdf
  - Washington DC - Eustatic Sea Level Rise 30cm.pdf
  - Washington DC - Eustatic Sea Level Rise 31cm.pdf
  - Washington DC - Eustatic Sea Level Rise 48.5cm.pdf
- Maryland
  - Maryland - Eustatic Sea Level Rise 6cm.pdf
  - Maryland - Eustatic Sea Level Rise 6.5cm.pdf
  - Maryland - Eustatic Sea Level Rise 13cm.pdf
  - Maryland - Eustatic Sea Level Rise 17.5cm.pdf
  - Maryland - Eustatic Sea Level Rise 21cm.pdf
  - Maryland - Eustatic Sea Level Rise 30cm.pdf
  - Maryland - Eustatic Sea Level Rise 31cm.pdf
  - Maryland - Eustatic Sea Level Rise 48.5cm.pdf
- Virginia
  - Virginia - Eustatic Sea Level Rise 6cm.pdf
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- North Carolina
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