Flooding & Inundation Mapping

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Jerry Kauffman

Lewes DE, Oct. 30, 2017

University of Delaware

Flooding and Inundation

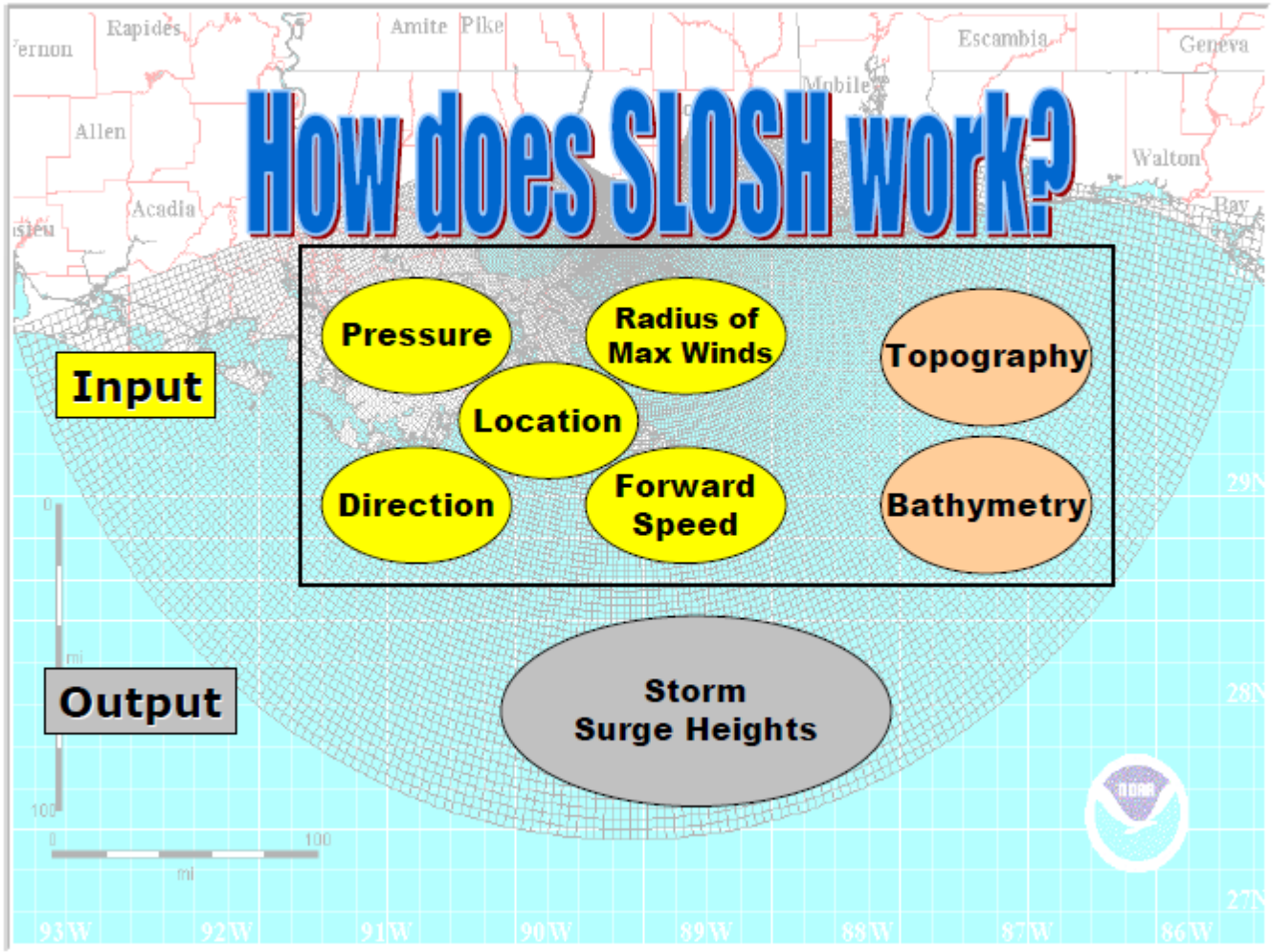
- Hurricane inundation
- Fluvial flooding
- Sea level rise
- How will this affect DelDOT's assets?
- Sandy and a hypothetical "worst-case" Sandy-like storm

Other inundation scenario studies

- This effort aims to complement other major studies on flooding and SLR:
  - DNREC
  - DGS
- Here, the focus is on DelDOT infrastructure

Inundation -- SLOSH

- Sea, Lake, and Overland Surge from Hurricanes
- “A computerized model developed by the National Weather Service (NWS) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.”

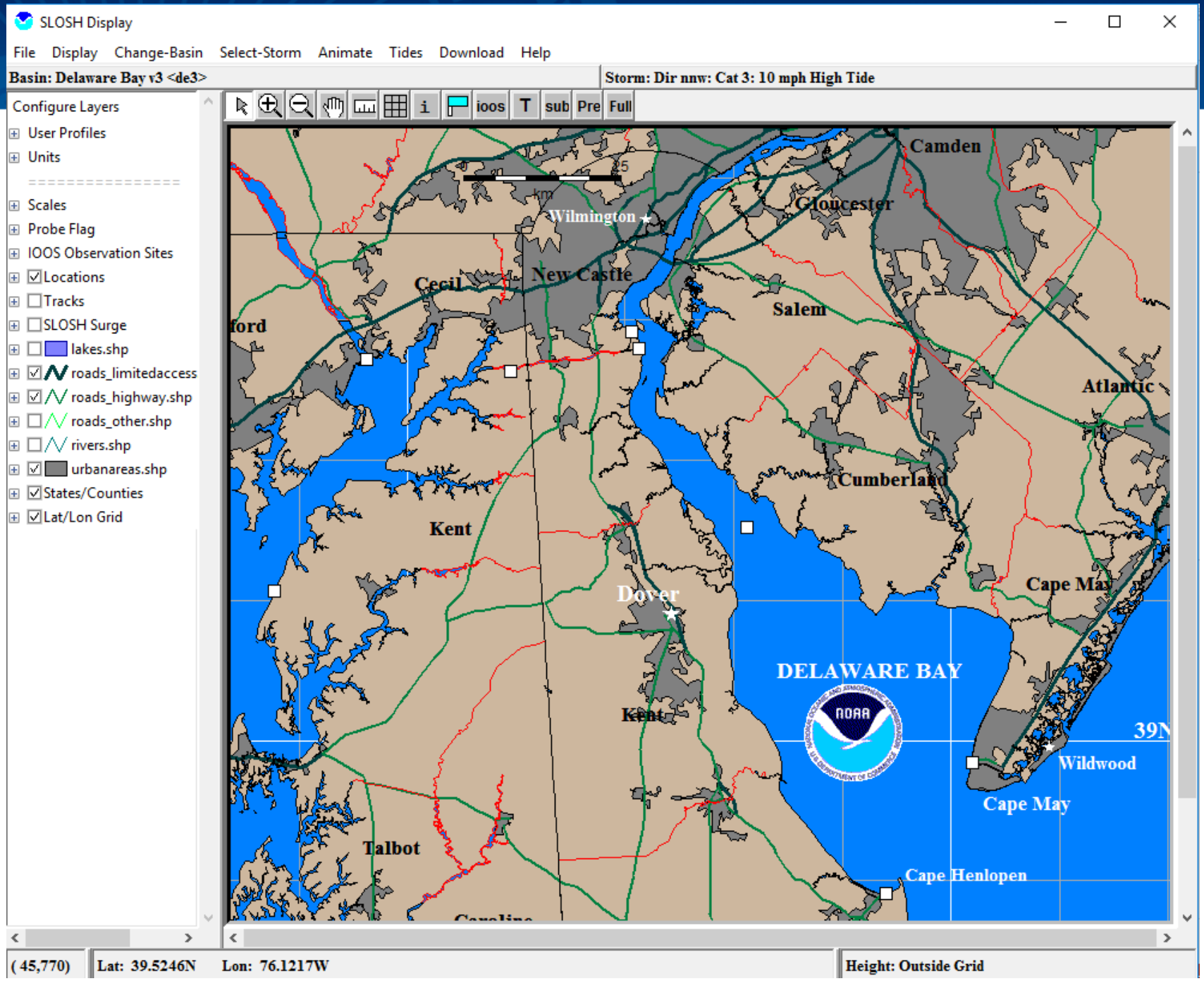

How does SLOSH work?
Input
Pressure
Radius of Max Winds
Location
Direction
Forward Speed
Topography
Bathymetry
Output
Storm Surge Heights
Rapides
Amite
Pike
Escambia
Geneva
Mobile
Allen
Acadia
Walton
Bay
29N
28N
27N
93W
92W
91W
90W
89W
88W
87W
86W
0
100
mi

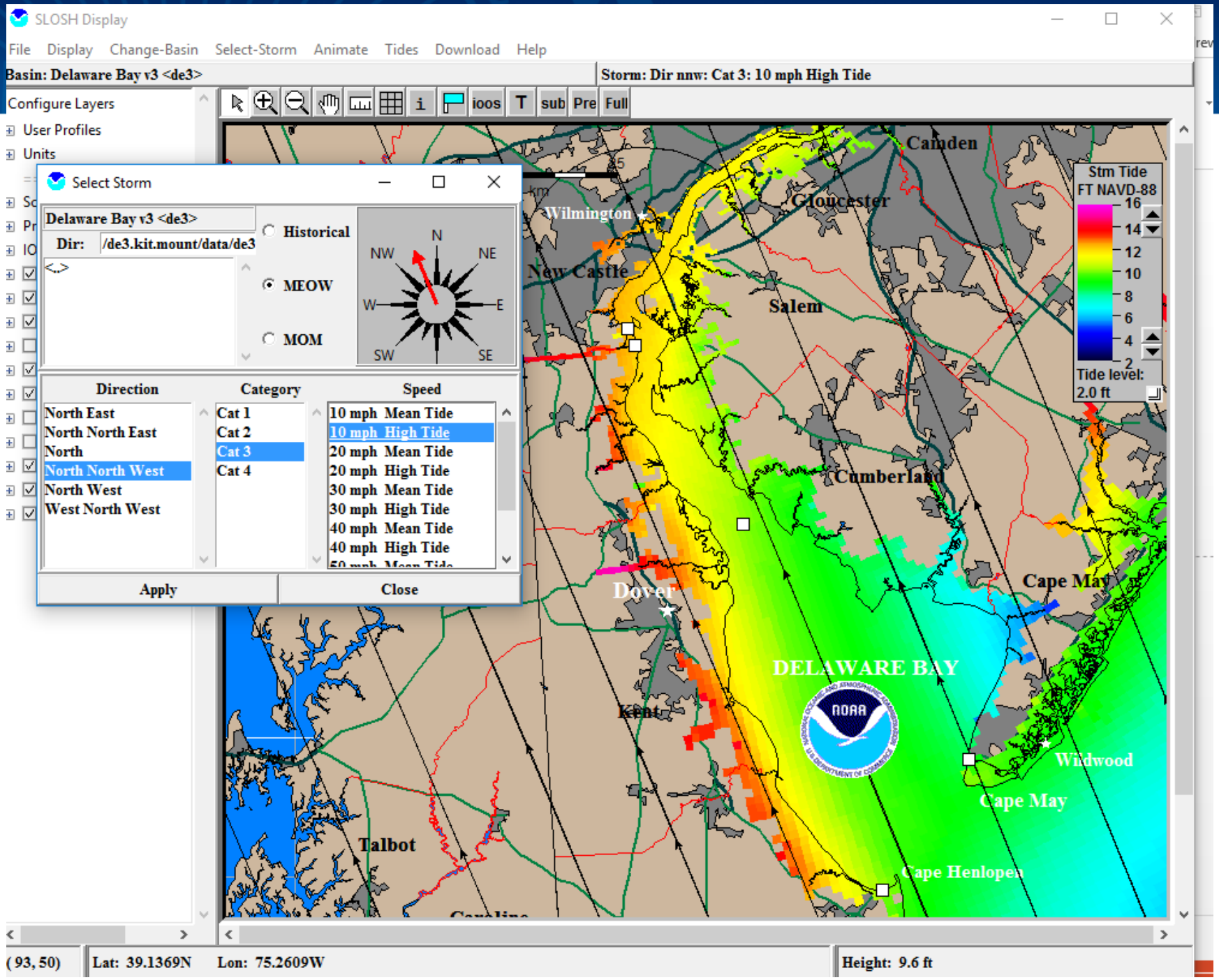
SLOSH

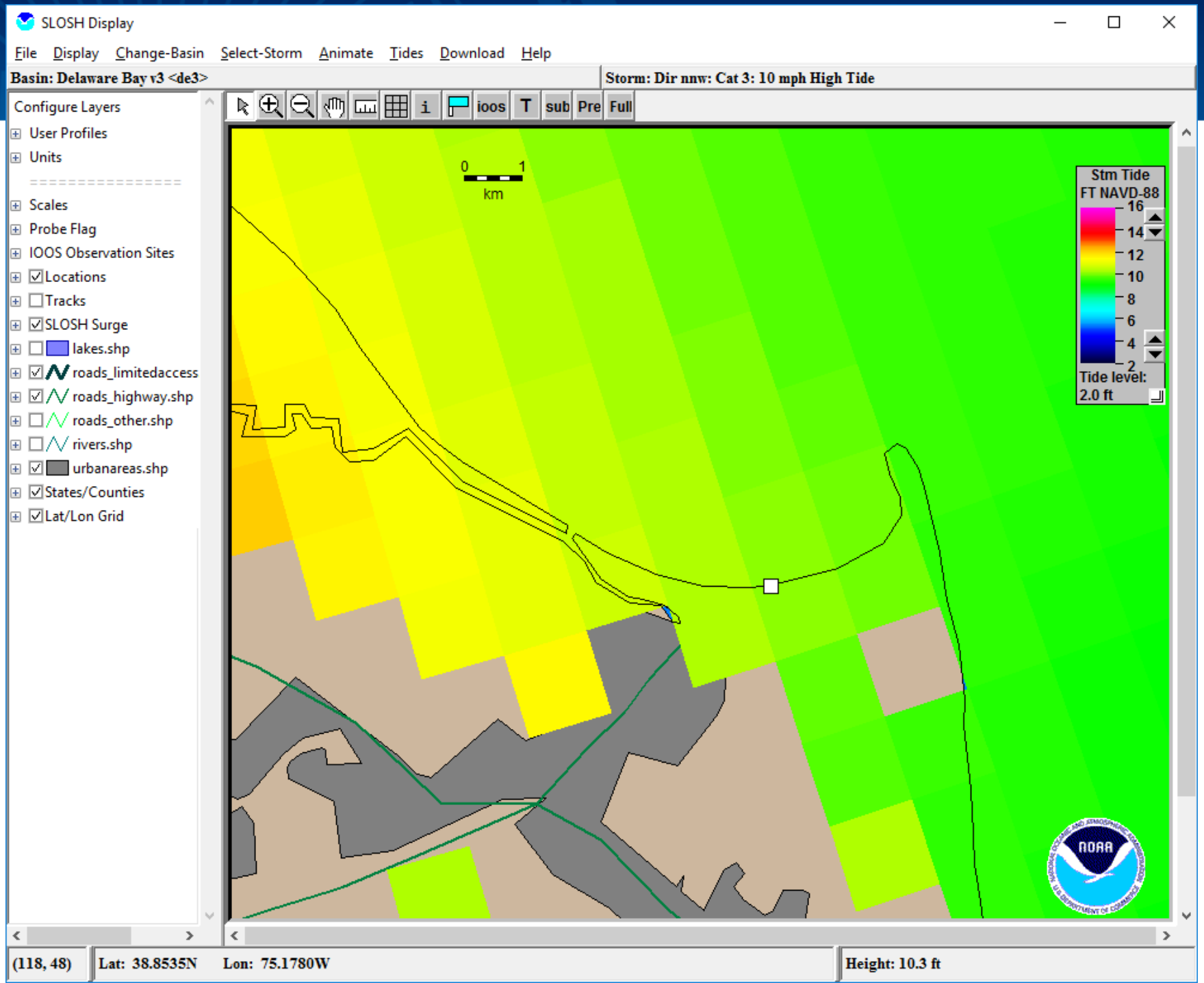
- Does not include rainfall, riverine flow, or wind driven waves.
- Does include tide information.
- Accuracy has been found to be within ±20%.

SLOSH

- Dynamic model
- For our use we focused on the static MOMs
  - MEOW: Maximum Envelope of Water
    - Summarizes max inundation for given storm intensity, speed, and direction.
  - MOM: Maximum of MEOWs
    - Worst effects of all potential storms


SLOSH Display
File
Display
Change-Basin
Select-Storm
Animate
Tides
Download
Help
Basin: Delaware Bay v3 <de3>
Storm: Dir nnw: Cat 3: 10 mph High Tide
Configure Layers
User Profiles
Units
Scales
Probe Flag
IOOS Observation Sites
Locations
Tracks
SLOSH Surge
lakes.shp
roads_limitedaccess
roads_highway.shp
roads_other.shp
rivers.shp
urbanareas.shp
States/Counties
Lat/Lon Grid
ioos
T
sub
Pre
Full
Camden
Gloucester
Wilmington
Cecil
New Castle
Salem
Atlantic
Cumberland
Kent
Dover
Cape May
DELAWARE BAY
NOAA
Wildwood
Cape May
Talbot
Cape Henlopen
(45,770)
Lat: 39.5246N
Lon: 76.1217W
Height: Outside Grid


SLOSH Display
File Display Change-Basin Select-Storm Animate Tides Download Help
Basin: Delaware Bay v3 <de3>
Storm: Dir nnw: Cat 3: 10 mph High Tide
Configure Layers
User Profiles
Units
ioos T sub Pre Full
Select Storm
Delaware Bay v3 <de3>
Dir: /de3.kit.mount/data/de3
<->
Historical
MEOW
MOM
N NW NE W E SW SE
Direction
North East
North North East
North
North North West
North West
West North West
Category
Cat 1
Cat 2
Cat 3
Cat 4
Speed
10 mph Mean Tide
10 mph High Tide
20 mph Mean Tide
20 mph High Tide
30 mph Mean Tide
30 mph High Tide
40 mph Mean Tide
40 mph High Tide
Apply
Close
Stm Tide
FT NAVD-88
16
14
12
10
8
6
4
2
Tide level:
2.0 ft
Camden
Gloucester
Wilmington
New Castle
Salem
Cumberland
Cape May
Dover
DELAWARE BAY
NOAA
Kent
Widwood
Cape May
Talbot
Cape Henlopen
(93, 50)
Lat: 39.1369N
Lon: 75.2609W
Height: 9.6 ft


SLOSH Display
File
Display
Change-Basin
Select-Storm
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Download
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Basin: Delaware Bay v3 <de3>
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Configure Layers
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IOOS Observation Sites
Locations
Tracks
SLOSH Surge
lakes.shp
roads_limitedaccess
roads_highway.shp
roads_other.shp
rivers.shp
urbanareas.shp
States/Counties
Lat/Lon Grid
ioos
T
sub
Pre
Full
0
1
km
Stm Tide
FT NAVD-88
16
14
12
10
8
6
4
2
Tide level:
2.0 ft
NOAA
(118, 48)
Lat: 38.8535N
Lon: 75.1780W
Height: 10.3 ft

NOAA's National Hurricane Center

- Used SLOSH to generate inundation scenarios (MOMs).
  - Maximum of MEOWs--composite "worst case"
- Up-scaled the coarse data using LiDAR data.
- Provided series of inundation scenarios for storm categories.

Storm Surge Inundation Map

Creating Resilient Water Utilities

EPA

Introduction | Hurricane Frequency | Storm Surge Flooding | FEMA Flood Zones | Details

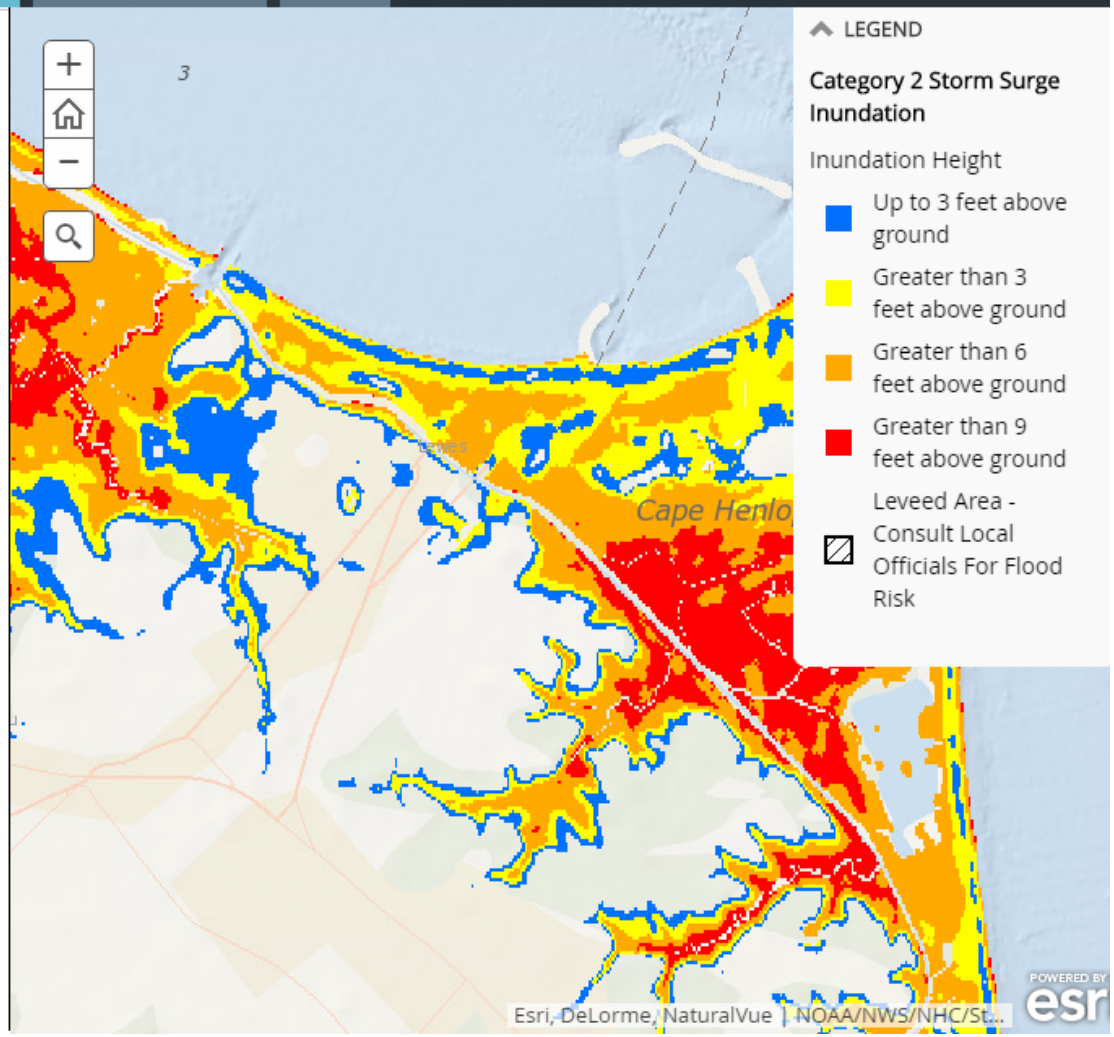
Overland surges from hurricanes) model. SLOSH is a numerical model used by NWS (National Weather Service) to compute storm surge. Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Flooding from storm surge depends on many factors, such as the track, intensity, size, and forward speed of the hurricane and the characteristics of the coastline where it comes ashore or passes nearby.

Click on a button to see inundation depth for each hurricane storm category on the map.

Category 1 | Category 2 | Category 3 | Category 4 | Category 5

Once you have selected a category of interest, use the search or zoom into your location to review potential inundation depth.

This product displays a seamless national map of storm surge hazard scenarios developed by the NHC (National Hurricane Center) Storm Surge Unit. This map merges the Maximum of Maximums (MOM) product from 27 of the operational SLOSH grids. Each grid for the Category 1-5 SLOSH MOMs was merged into one national grid. The national grid was then resampled, interpolated, and processed with a DEM (Digital Elevation Model, i.e. topography) to compute the storm surge hazard above ground for each hurricane category. This means when NHC forecasts storm surge of 20 ft that means 20 ft above ground. SLOSH products do not include Category 5 storms north of the NC/VA border.



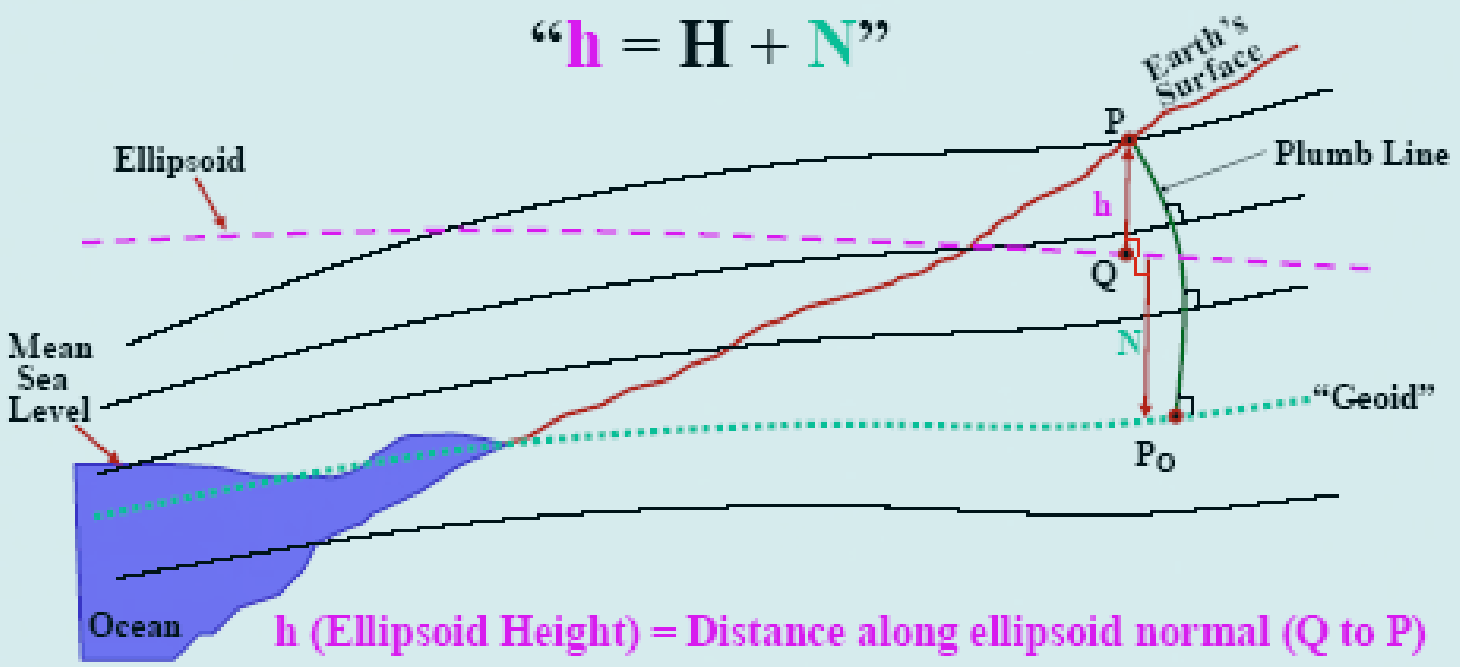
A word on datums

- Important to pin down what you're measuring against.
  - Inundation predictions,
  - Tide gauge info,
  - DEM heights,
  - etc.
- Tide stage adds/subtracts.

A word on datums

- Tidal heights—from long term tidal data (MSL, MHHW, MLLW)
- Ellipsoidal heights—From the mathematical figure of the earth (GPS)
- Geoidal heights—From the actual (modeled) earth (NAVD 27, NAVD 88)
- When water rises, we care about topographic heights—depth relative to ground surface.

Ellipsoid, Geoid, and Orthometric Heights



https://vdatum.noaa.gov/docs/datums.html

Riverine Flooding

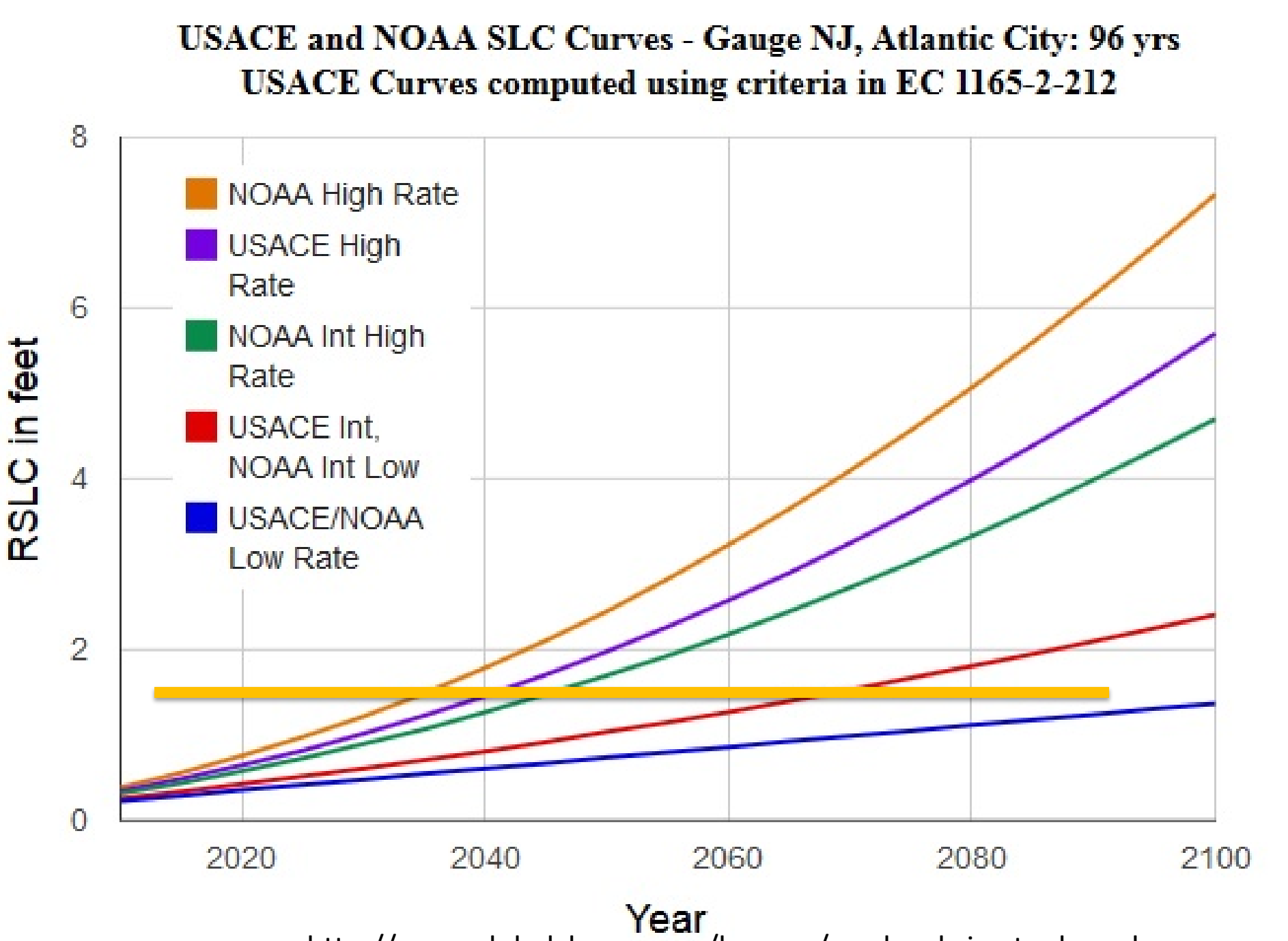
- Use FEMA “100” and “500” year flood zone data.
- Overlay on hurricane inundation results.
- These effects can be independent, or they could be additive.

Mapping Procedures

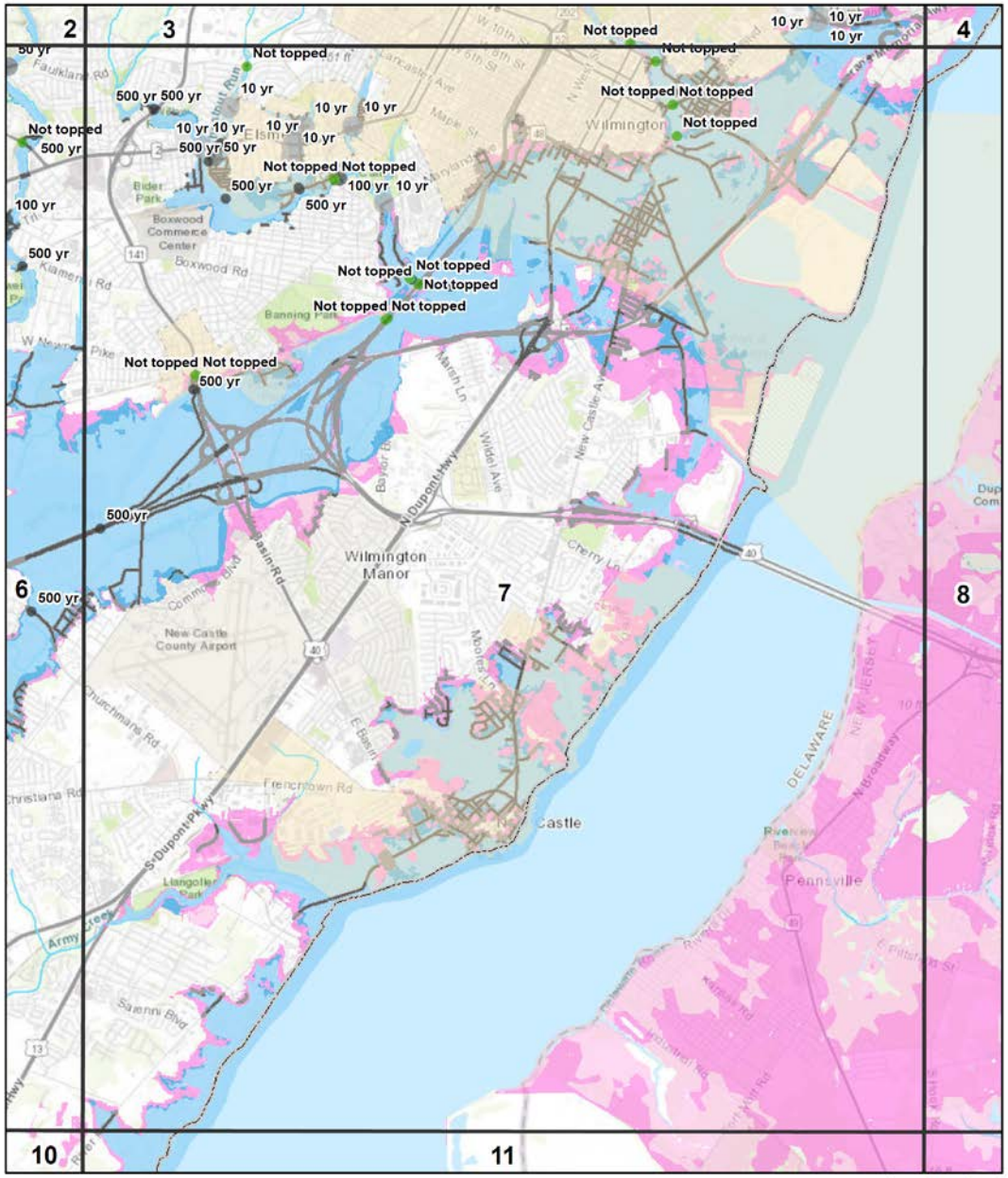
- Create a statewide map series.
- Use NOAA's coastal inundation data.
  - Focus on Category 1 and Category 3 storms.
- Estimate the effect of storm inundation with 0.5m, 1.0m, and 1.5m SLR.
- Combine with FEMA flood zones.

Mapping Procedures

- Maps include
  - Cat 1 and Cat 3 storms inundation zones
  - Fluvial flood zones
  - Roads flooded by scenario
  - Effects on bridges (overtopping).



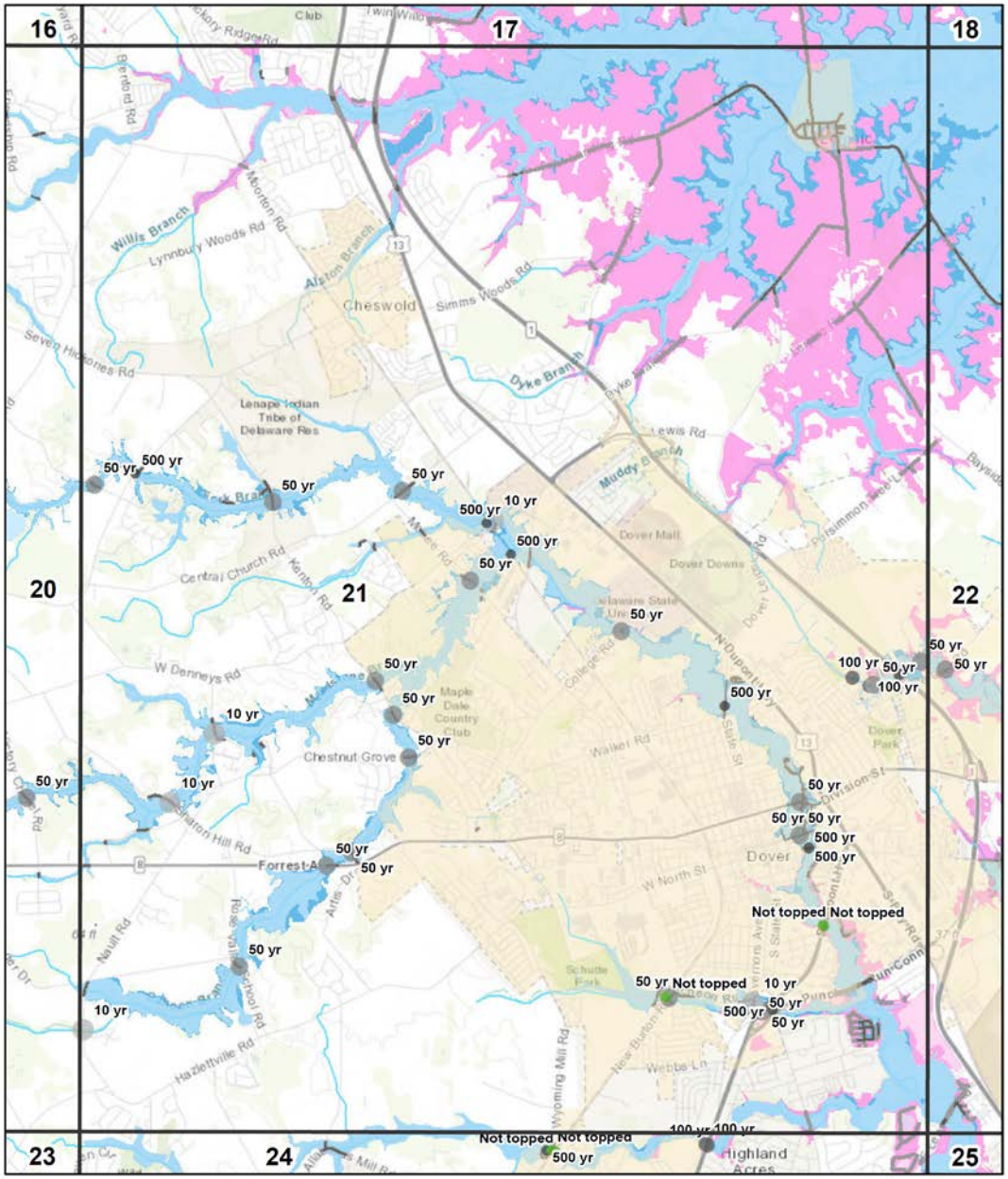
http://www.globalchange.gov/browse/sea-level-rise-tool-sandy-recovery



7

Wilmington South

2	3	4
6		8
10	11	



Flood/Surge zone

- 100 Year
- 500 Year
- Cat 1
- Cat 3

Road in

- Floodplain
- Surge zone

Bridge topped

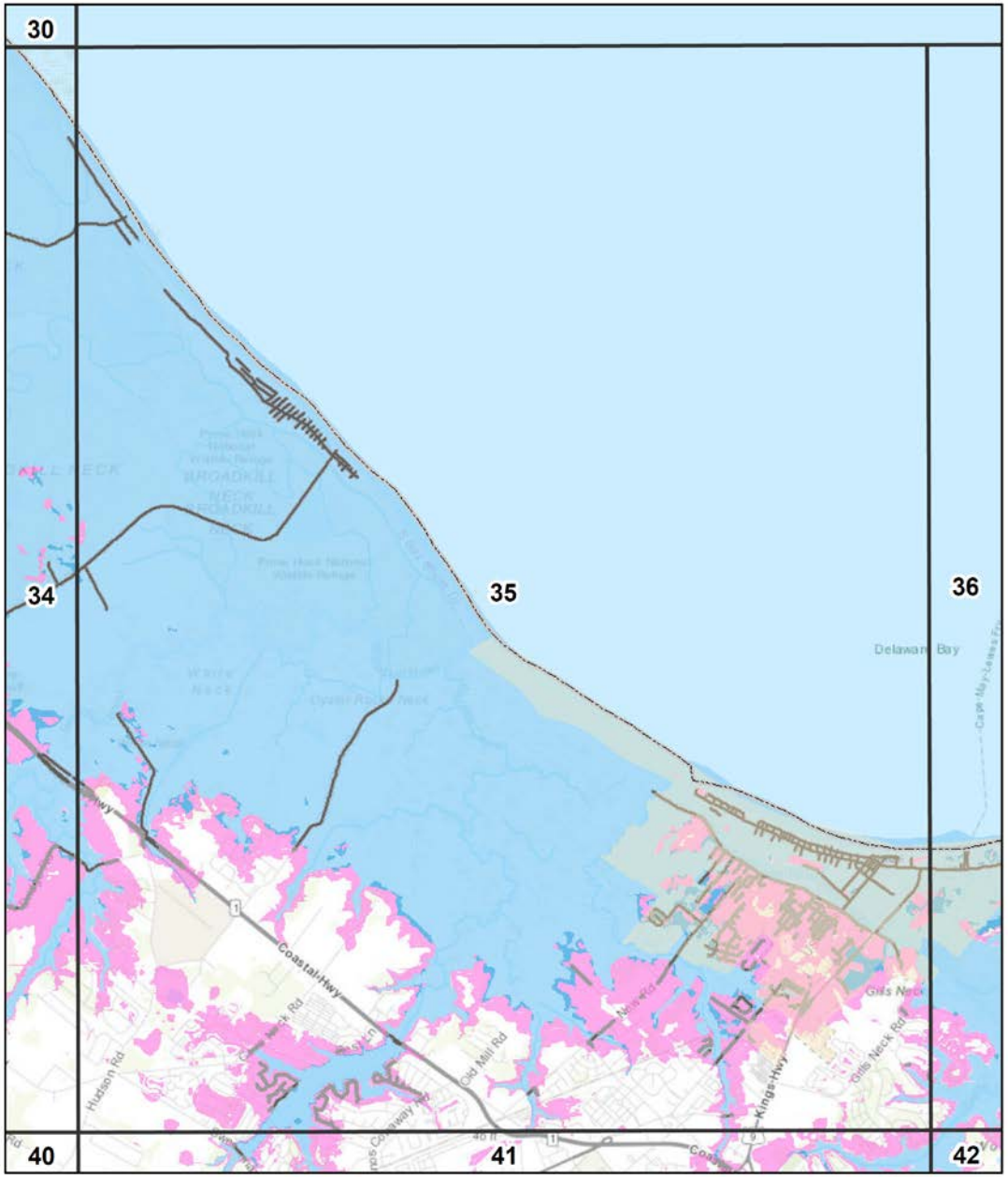
- 10 Year
- 50 Year
- 100 Year
- 500 Year
- Not Topped

21

Dover

0 0.25 0.5 1 1.5 2 Miles

16	17	18
20		22
23	24	25



Flood/Surge zone

- 100 Year
- 500 Year
- Cat 1
- Cat 3

Road in

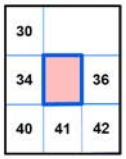
- Floodplain
- Surge zone

Bridge topped

- 10 Year
- 50 Year
- 100 Year
- 500 Year
- Not Topped

35
Lewes

0 0.25 0.5 1 1.5 2 Miles



Effects on DelDOT infrastructure

- Cat 1 and Cat 3 storms
- 100 and 500 year floods
- Road miles, major routes
- Road miles, all roads
- Bridges (riverine flooding only)

Bridge Vulnerability

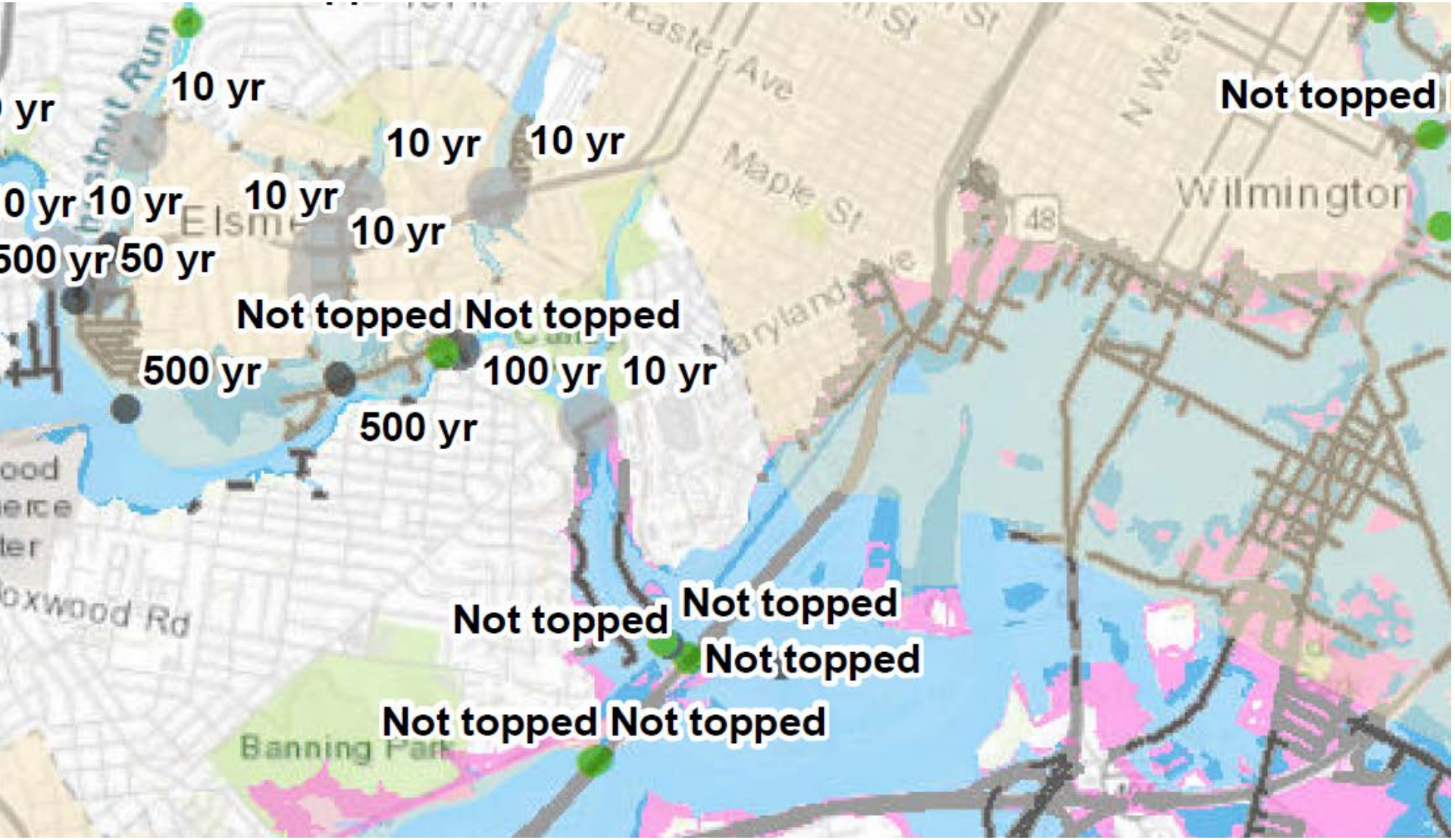
County	Local	Major	Minor	Railroad	Other	Total
Kent	79	31	30	12	18	**170**
New Castle	59	45	75	40	41	**260**
Sussex	44	26	10	10	8	**98**
Total	**182**	**102**	**115**	**62**	**67**	**528**

By type

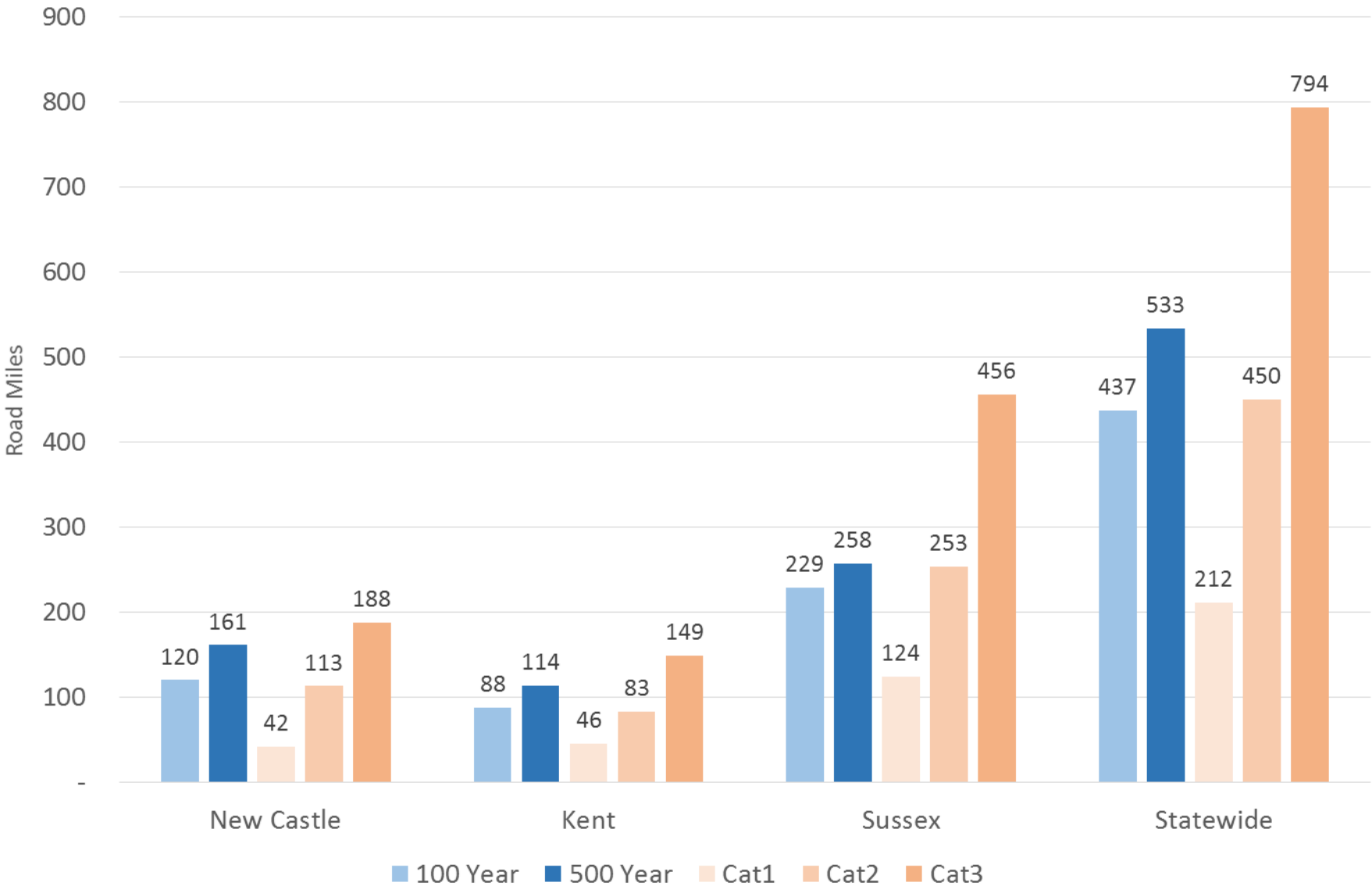
Bridge Vulnerability

County	Municipal	Railroad	State	Other	Total
Kent	0	12	129	29	**170**
New Castle	2	40	161	60	**263**
Sussex	1	10	77	10	**98**
Total	**3**	**62**	**367**	**99**	**531**

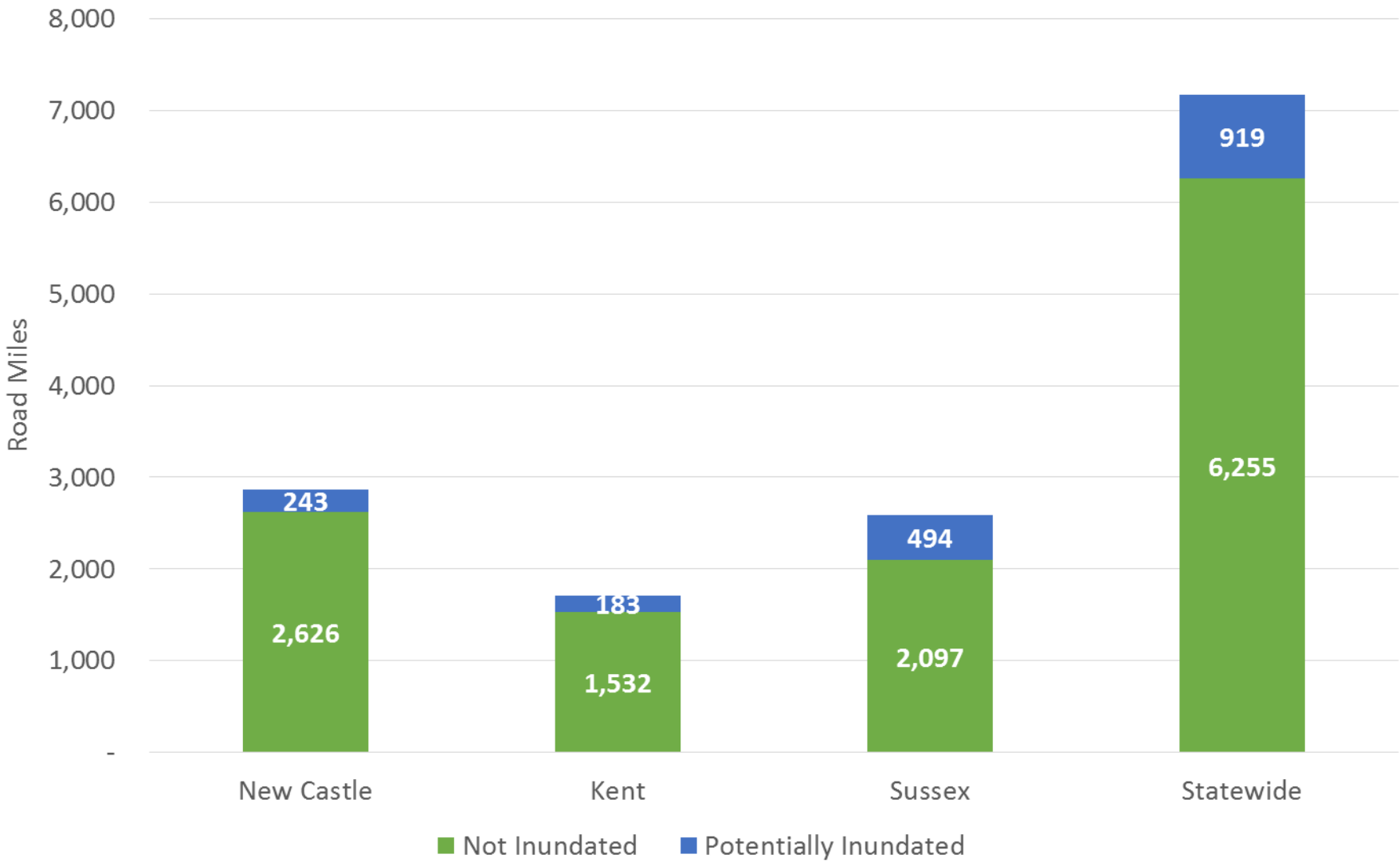
By ownership

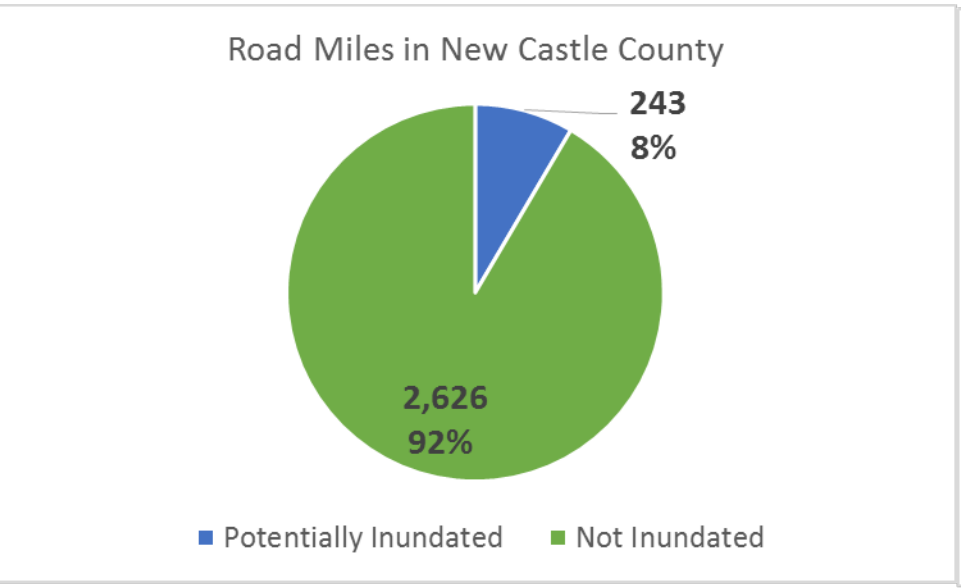

10 yr
10 yr
10 yr
10 yr
10 yr
10 yr
50 yr
Not topped
Not topped
500 yr
100 yr
10 yr
500 yr
Not topped
Not topped
Not topped
Not topped
Not topped
Not topped
Wilmington
Elsmere
Banning Park
Maple St
Maryland Ave
Foxwood Rd
48

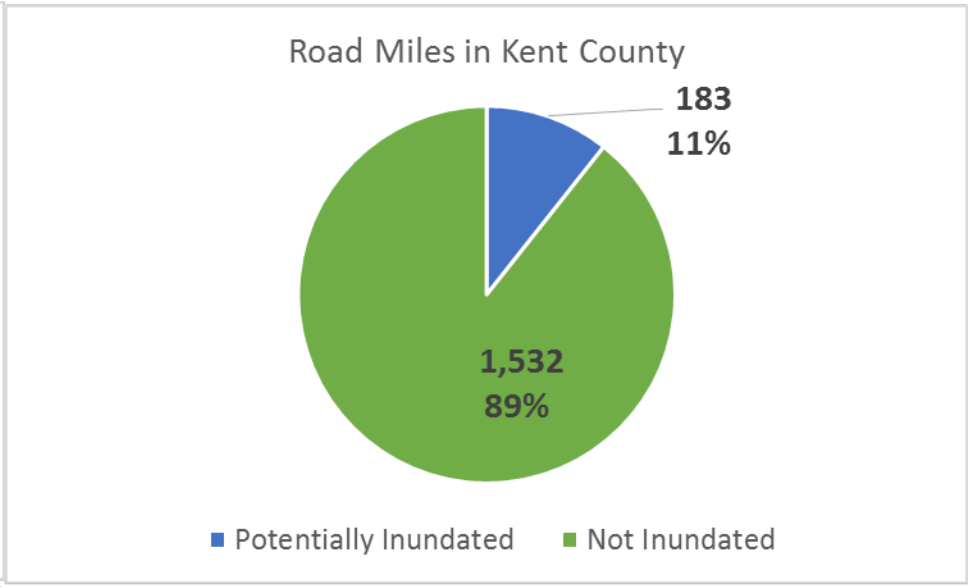
Road Miles in Flood Zones (100 Year, 500 Year) and Potential Hurricane Storm Surge (Category 1 - 3) Inundation Areas

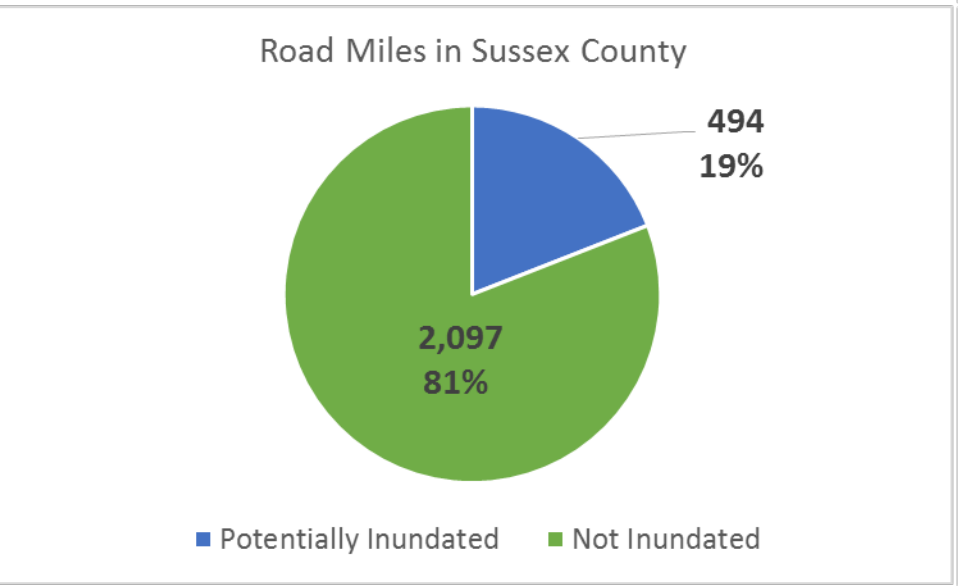


Road Miles in Potential Inundation Zones (100 Year, 500 Year Flood Zones Plus Category 3 Hurricane Storm Surge Inundation Areas) v. All Road Miles




Road Miles in New Castle County
243
8%
2,626
92%
Potentially Inundated
Not Inundated


Road Miles in Kent County
183
11%
1,532
89%
Potentially Inundated
Not Inundated


Road Miles in Sussex County
494
19%
2,097
81%
Potentially Inundated
Not Inundated

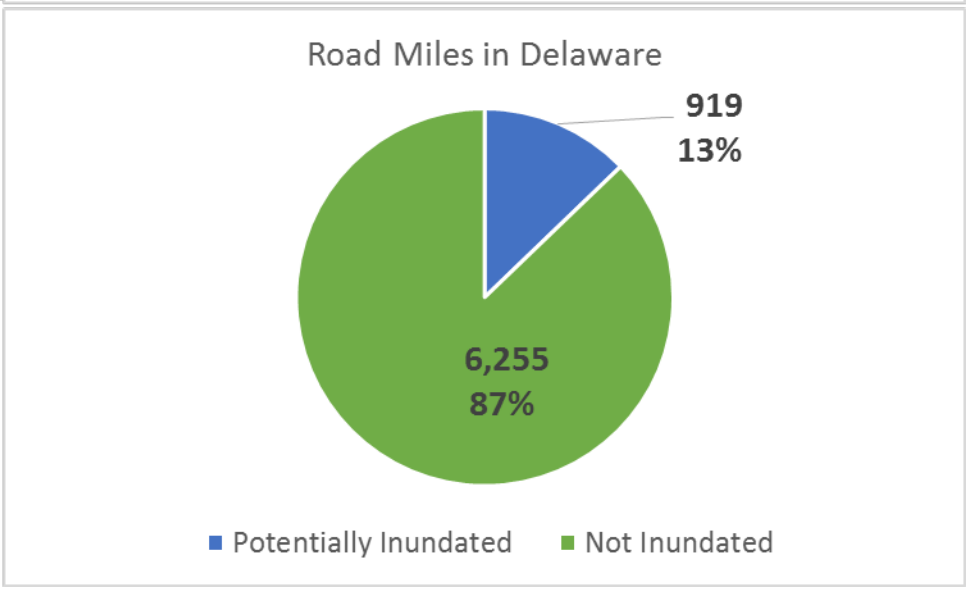
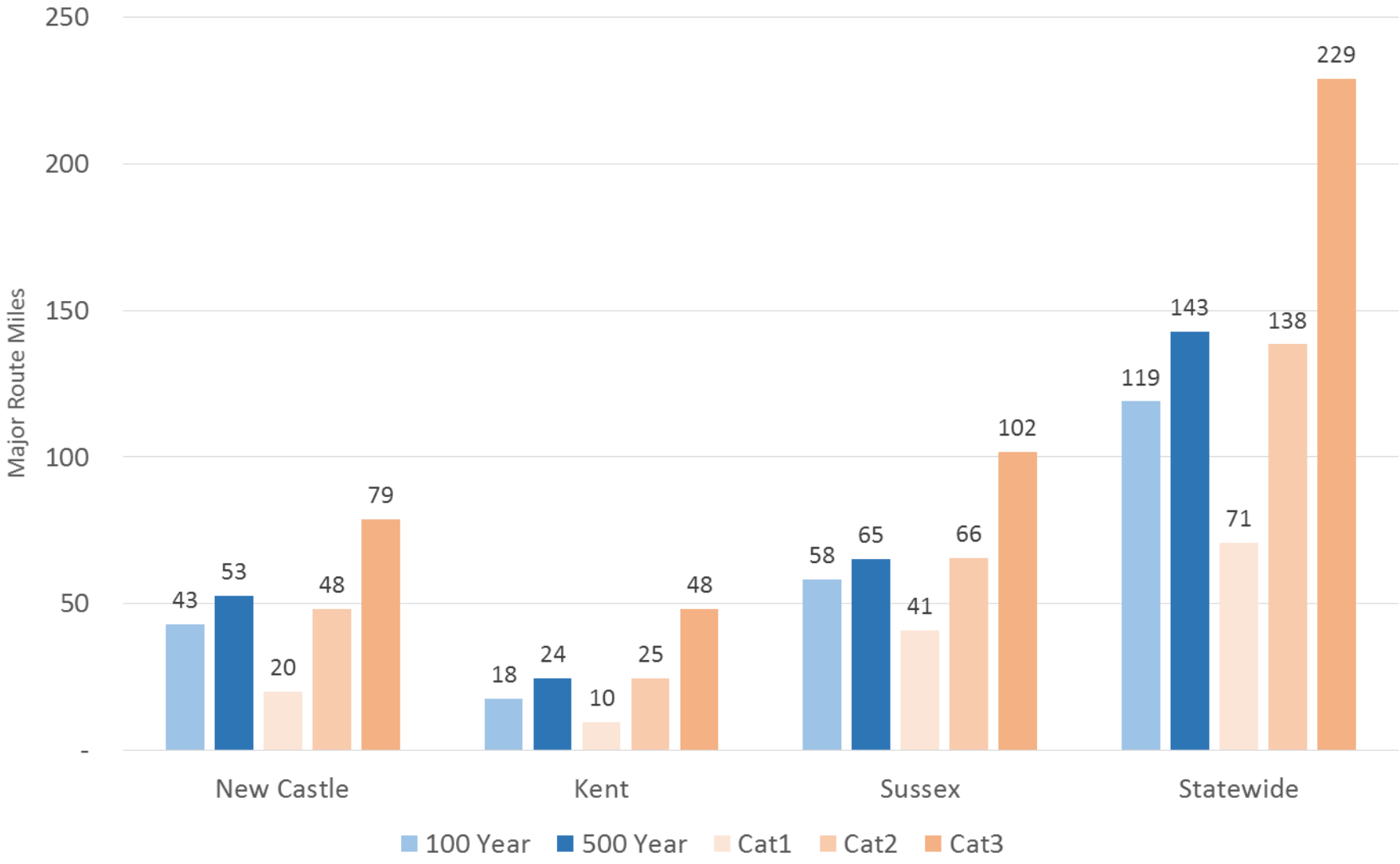

Road Miles in Delaware
919
13%
6,255
87%
Potentially Inundated
Not Inundated

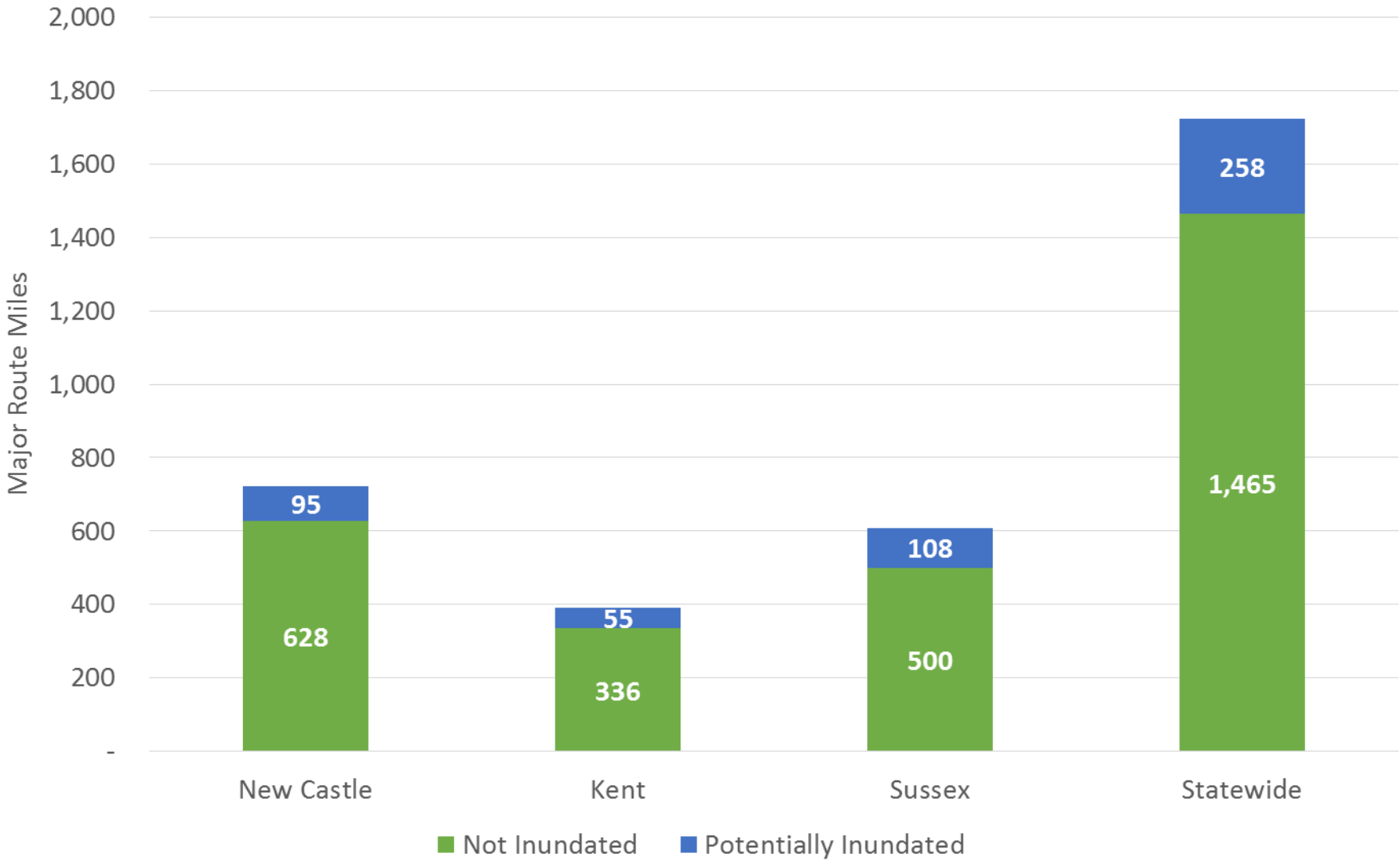
Table 5.2 Total road miles potentially inundated by flooding in Delaware

	New Castle	Kent	Sussex	Statewide
Miles inundated by				
100-year Flood	120	88	229	437
500-year Flood	161	114	258	533
Cat. 1 Storm	42	46	124	212
Cat. 2 Storm	113	83	253	450
Cat. 3 Storm	188	149	456	794
500-year Flood plus Cat 3 Storm	243	183	494	919
% of total miles				
100-year Flood	4%	5%	9%	6%
500-year Flood	6%	7%	10%	7%
Cat. 1 Storm	2%	3%	5%	3%
Cat. 2 Storm	4%	5%	10%	6%
Cat. 3 Storm	7%	9%	18%	11%
500-year Flood plus Cat 3 Storm	9%	11%	19%	13%

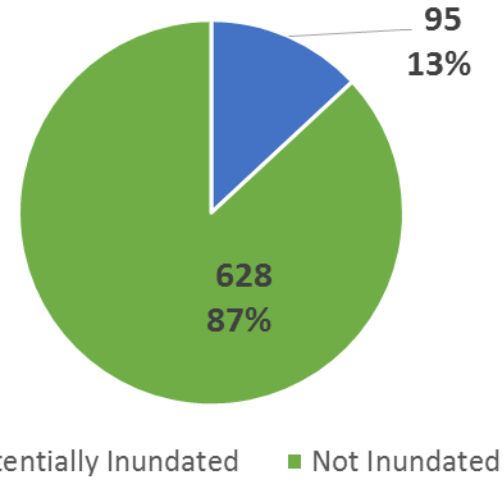
Major Route Miles (Federal and State Roads) in Flood Zones (100 Year, 500 Year) and Potential Hurricane Storm Surge (Category 1 - 3) Inundation Areas



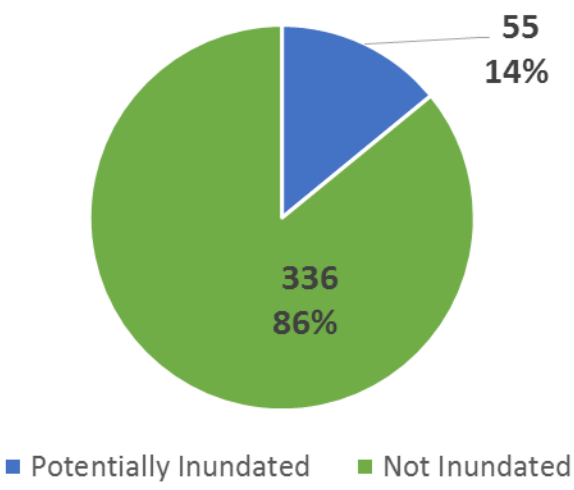
Major Route Miles (Federal and State Roads) in Potential Inundation Zones (100 Year, 500 Year Flood Zones Plus Category 3 Hurricane Storm Surge Inundation Areas) v. All Major Route Miles



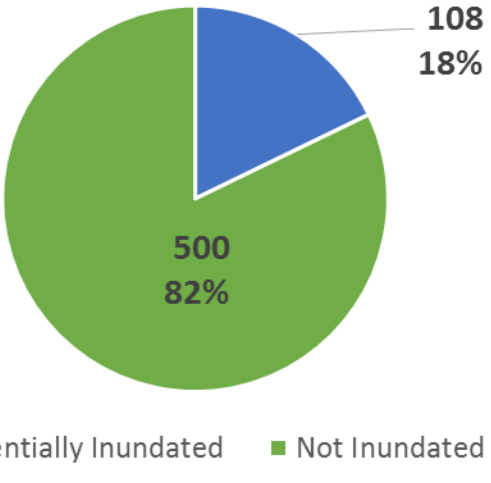
Major Route Miles in New Castle County



Major Route Miles in Kent County



Major Route Miles in Sussex County



Major Route Miles in Delaware

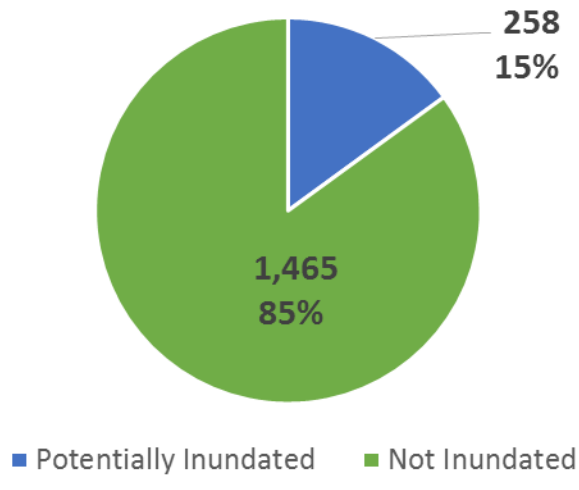


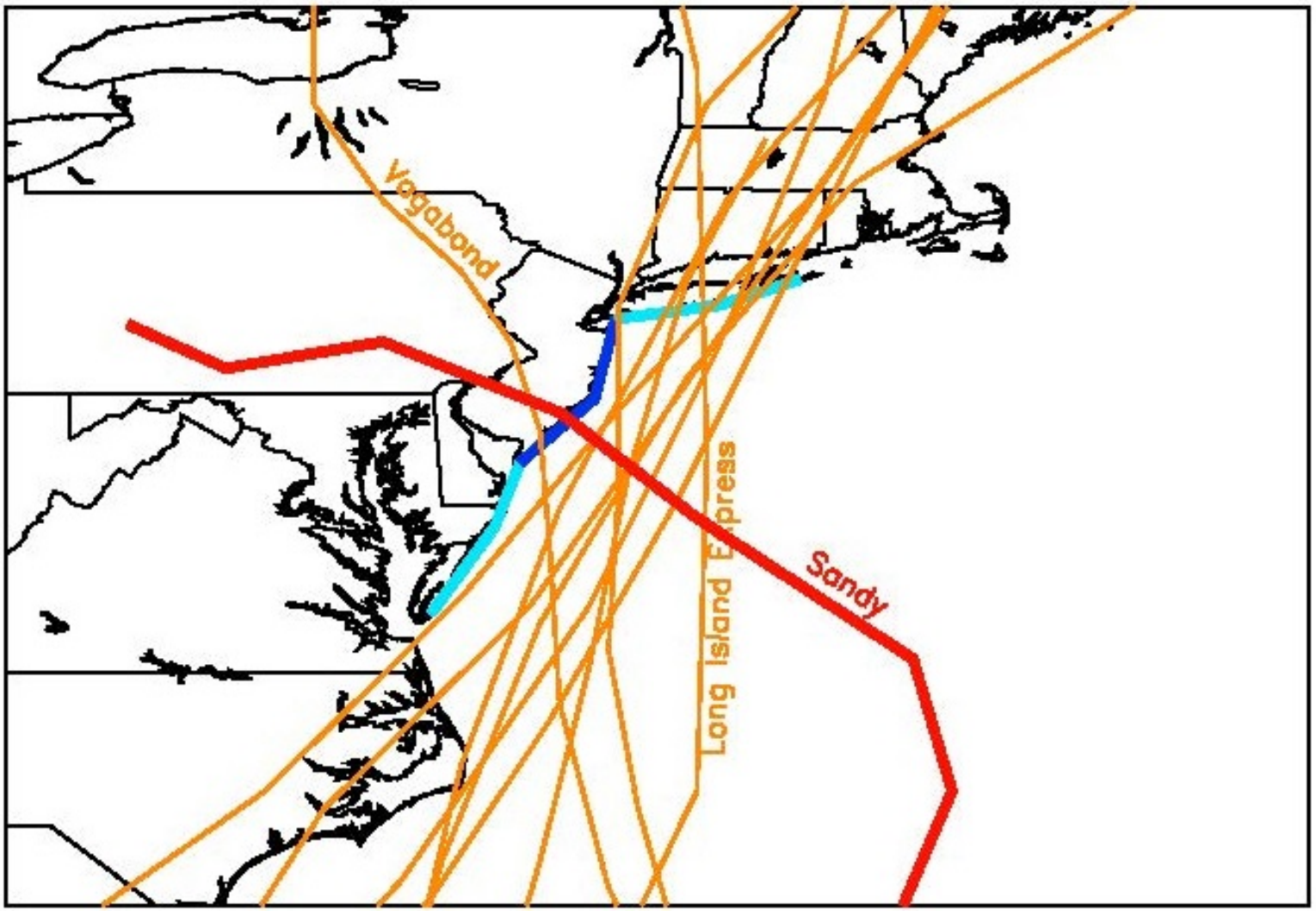
Table 5.3 Major route miles potentially inundated by flooding in Delaware

	New Castle	Kent	Sussex	State
Miles inundated by				
100-year Flood	43	18	58	119
500-year Flood	53	24	65	143
Cat. 1 Storm	20	10	41	71
Cat. 2 Storm	48	25	66	138
Cat. 3 Storm	79	48	102	229
500-year Flood plus Cat 3 Storm	95	55	108	258
% of major roads				
100-year Flood	6%	5%	10%	7%
500-year Flood	7%	6%	11%	8%
Cat. 1 Storm	3%	3%	7%	4%
Cat. 2 Storm	7%	6%	11%	8%
Cat. 3 Storm	11%	12%	17%	13%
500-year Flood plus Cat 3 Storm	13%	14%	18%	15%

Sandy, Oct. 30, 2012

Sandy was Super

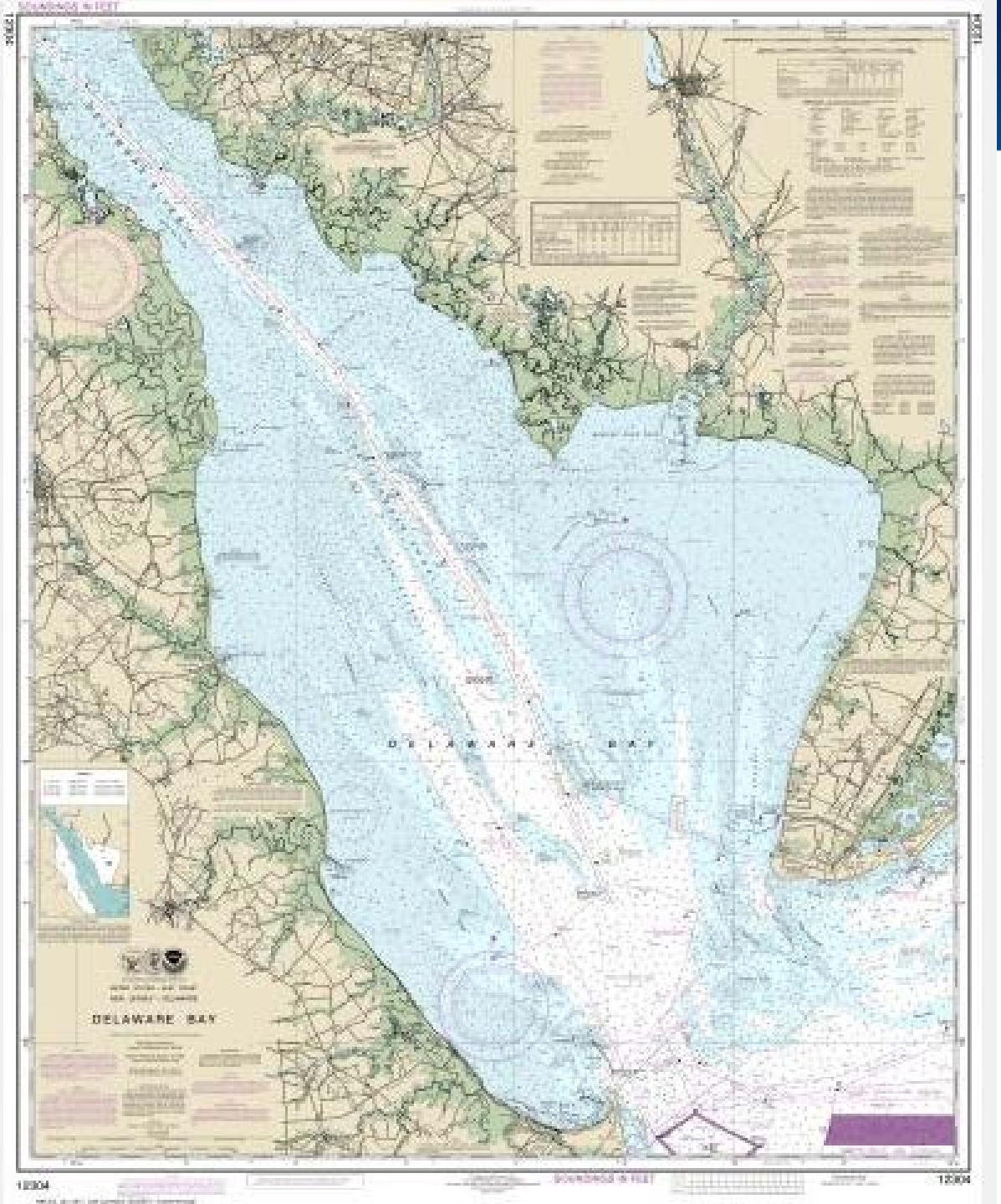
- Weak Jetstream caused rare westerly path
- Warm water increased energy
- Large size was anomalous
- Winter storm inland slowed progress
- Struck highly populated region at full moon
  - Battery Park, Manhattan: 2.79m surge, 4.28m height with peak tide

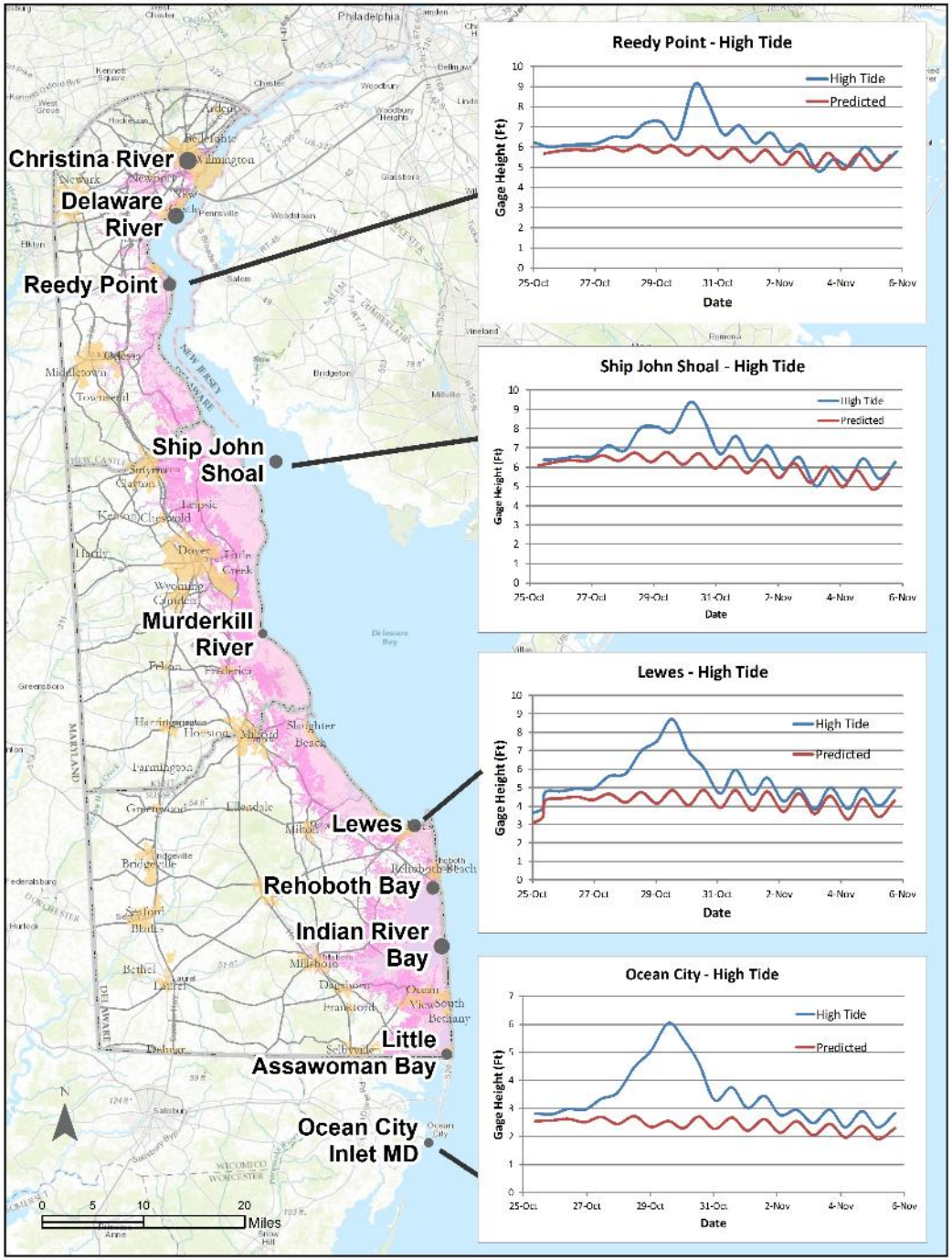


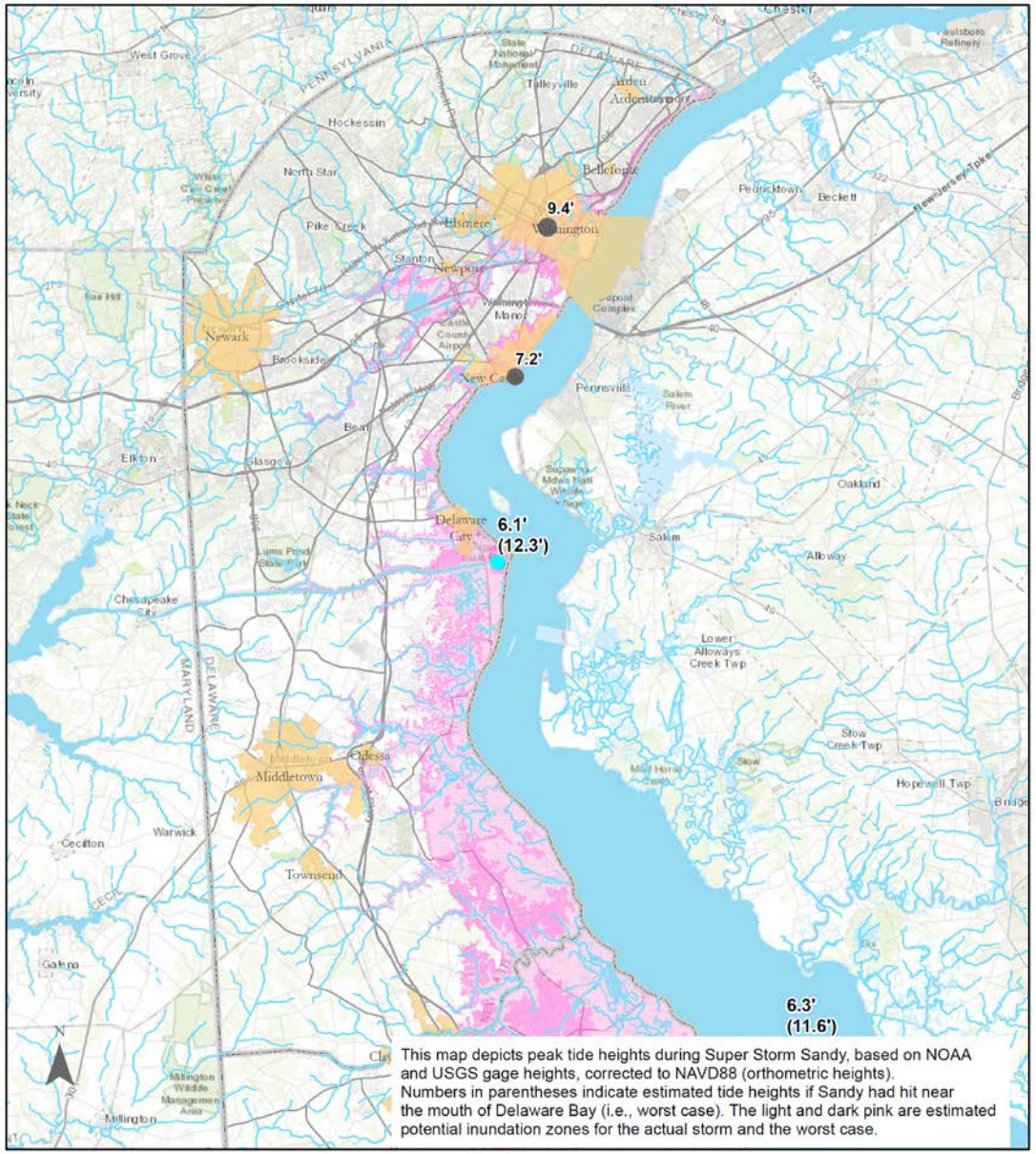
Hall, T. M., and A. H. Sobel (2013), On the impact angle of Hurricane Sandy's New Jersey landfall, Geophys. Res. Lett., 40, 2312–2315, doi:10.1002/grl.50395.

Sandy Scenarios

- Use existing tide gage information to derive peak surge surface.
- Merge DEM data with peak surge to estimate “actual” Sandy flood effects.
- Based on peak surge in NYC, estimate worst case for DE.
- Map effects of “worst-case”, Sandy-like strike on DE Bay.


SOUNDINGS IN FEET
12304
DELAWARE BAY
DELAWARE BAY
12304
SOUNDINGS IN FEET
12304


Christina River
Delaware River
Reedy Point
Ship John Shoal
Murderkill River
Lewes
Rehoboth Bay
Indian River Bay
Little Assawoman Bay
Ocean City Inlet MD
Philadelphia
Wilmington
Dover
0 5 10 20 Miles
Reedy Point - High Tide
Ship John Shoal - High Tide
Lewes - High Tide
Ocean City - High Tide
High Tide
Predicted
Gage Height (Ft)
Date
25-Oct
27-Oct
29-Oct
31-Oct
2-Nov
4-Nov
6-Nov



Super Storm Sandy (Oct.-Nov. 2012)
Estimated Actual and Potential
Wost Case Inundation Scenarios

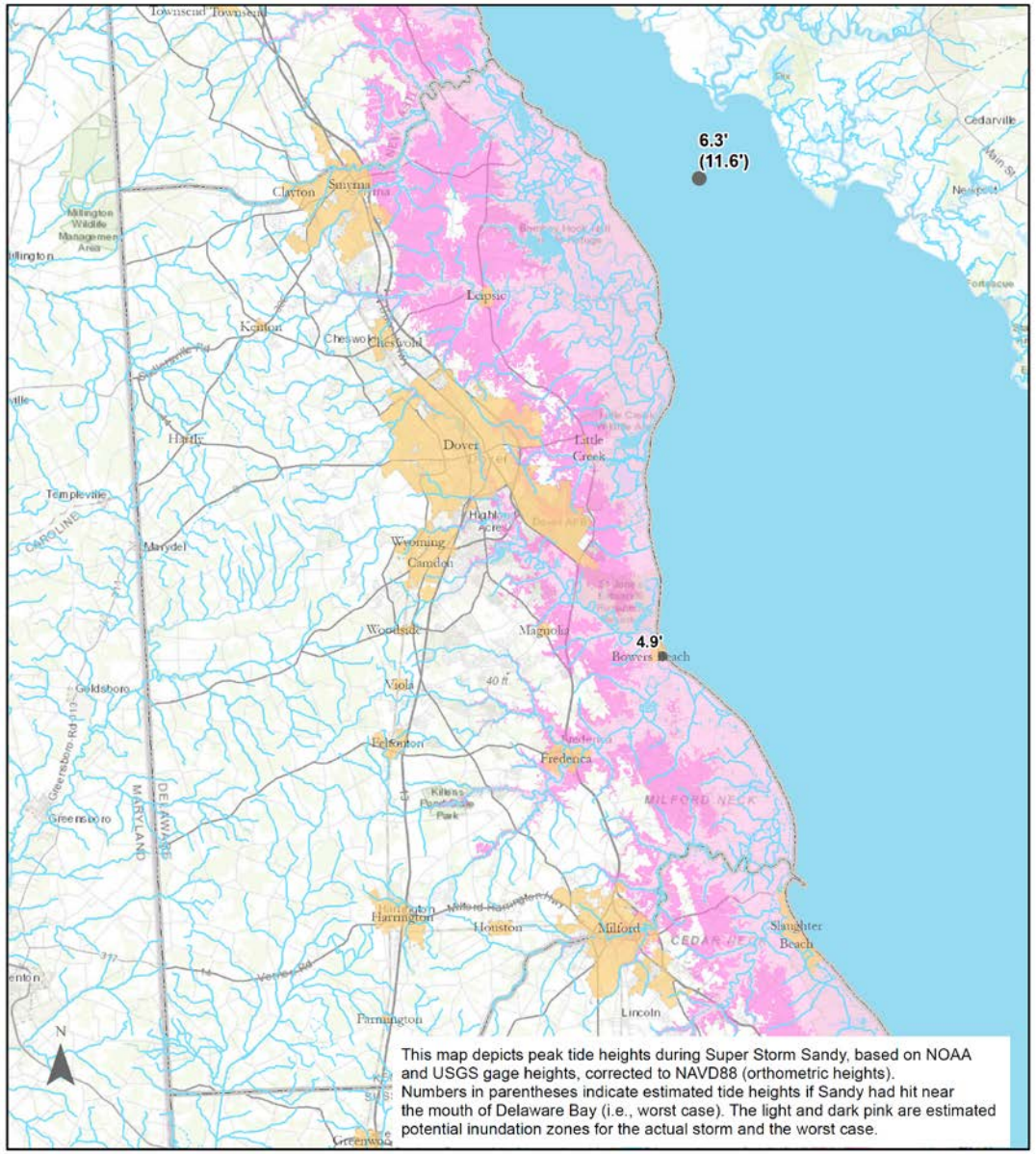
New Castle County

0 3 6 12 Miles

Tide gage height, ft.

- < 5 feet
- 5 - 6 feet
- 6 - 7 feet
- 7 - 8 feet
- > 8 feet

- Estimated inundation
- Pot. max. inundation
- Major route
- Town



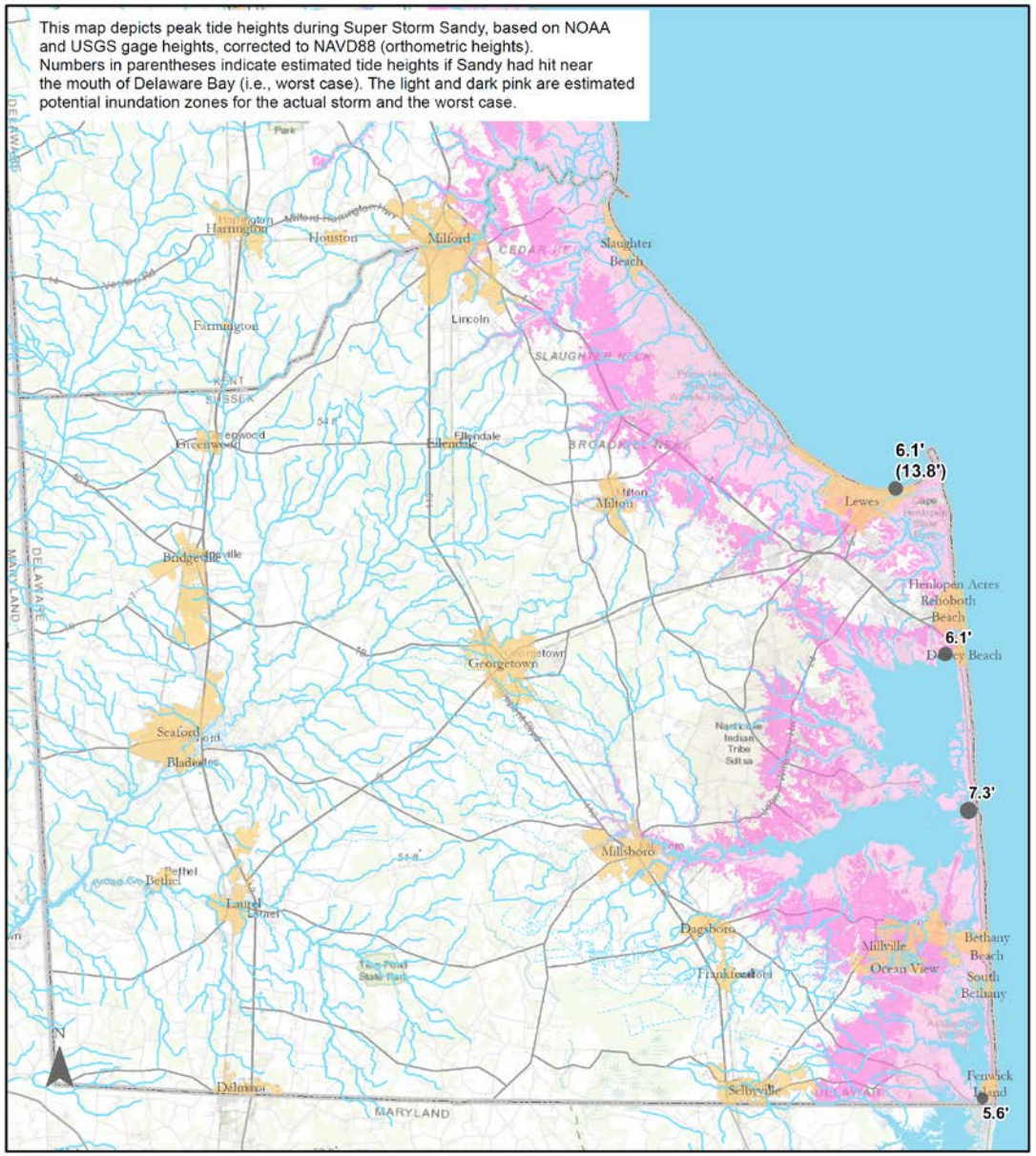
Super Storm Sandy (Oct.-Nov. 2012)
Estimated Actual and Potential
Wost Case Inundation Scenarios
Kent County

0 3 6 12 Miles

Tide gage height, ft.

- < 5 feet
- 5 - 6 feet
- 6 - 7 feet
- 7 - 8 feet
- > 8 feet

Estimated inundation
Pot. max. inundation
Major route
Town



Super Storm Sandy (Oct.-Nov. 2012)
Estimated Actual and Potential
Wost Case Inundation Scenarios

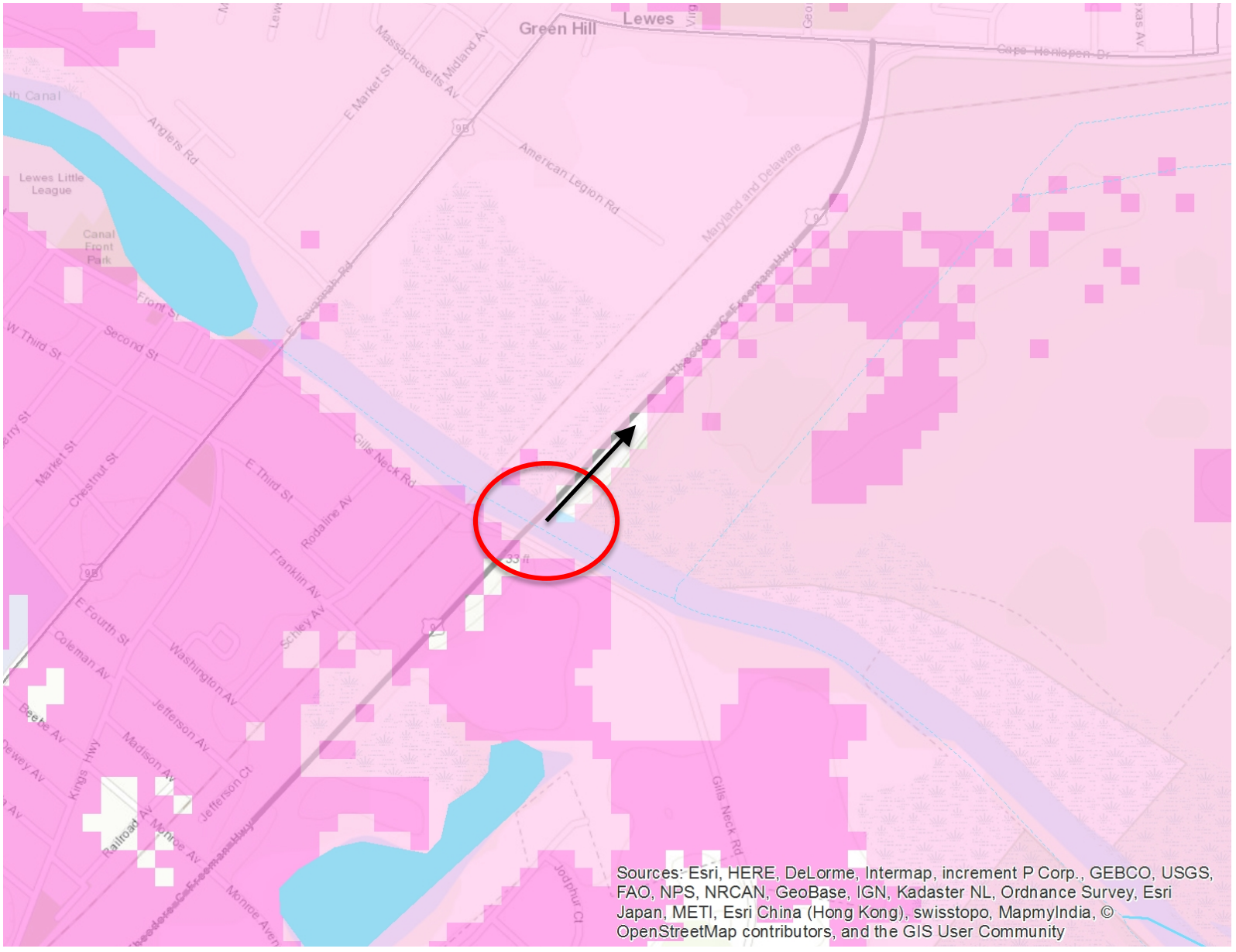
Sussex County

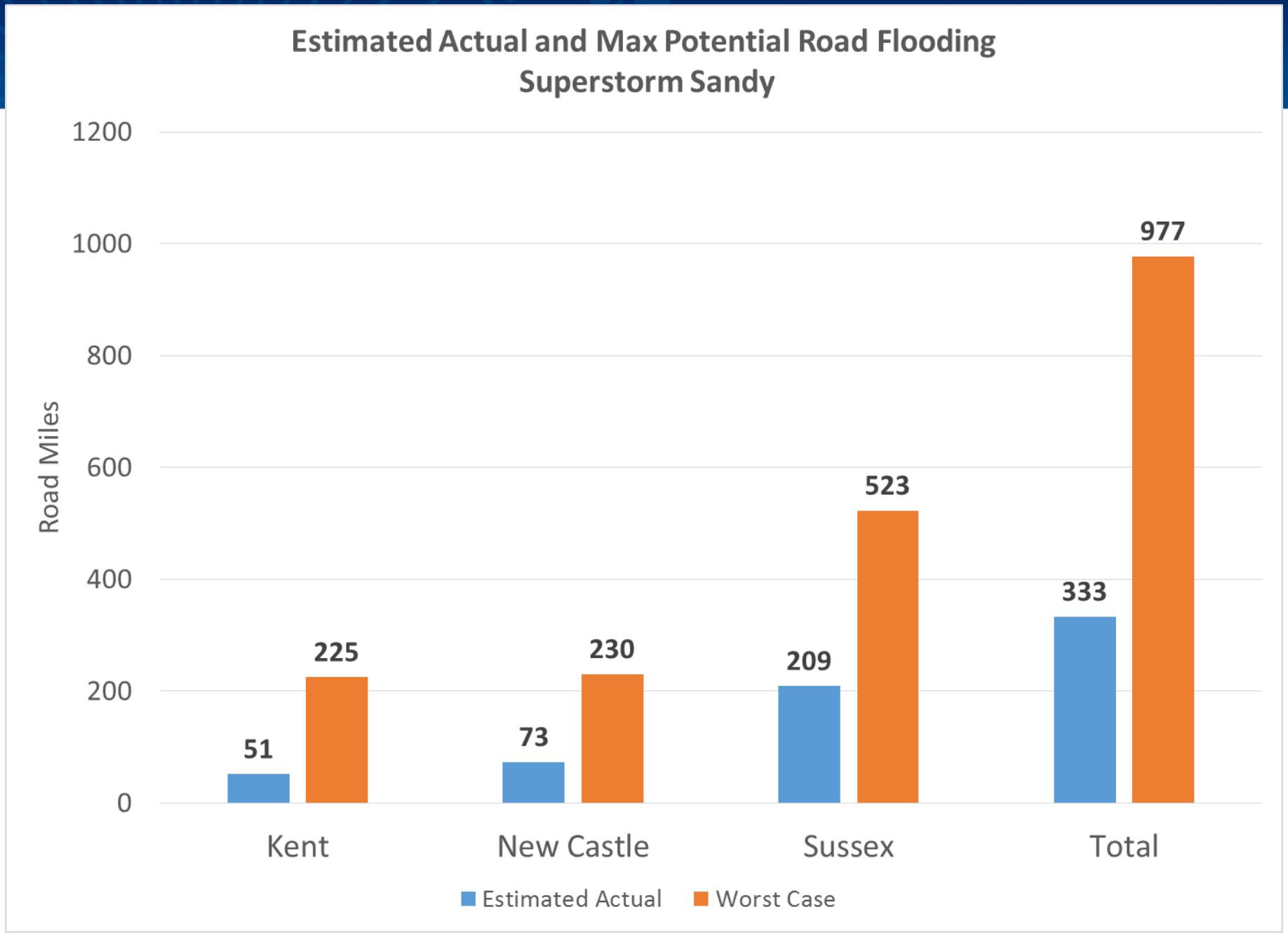
0 3 6 12 Miles

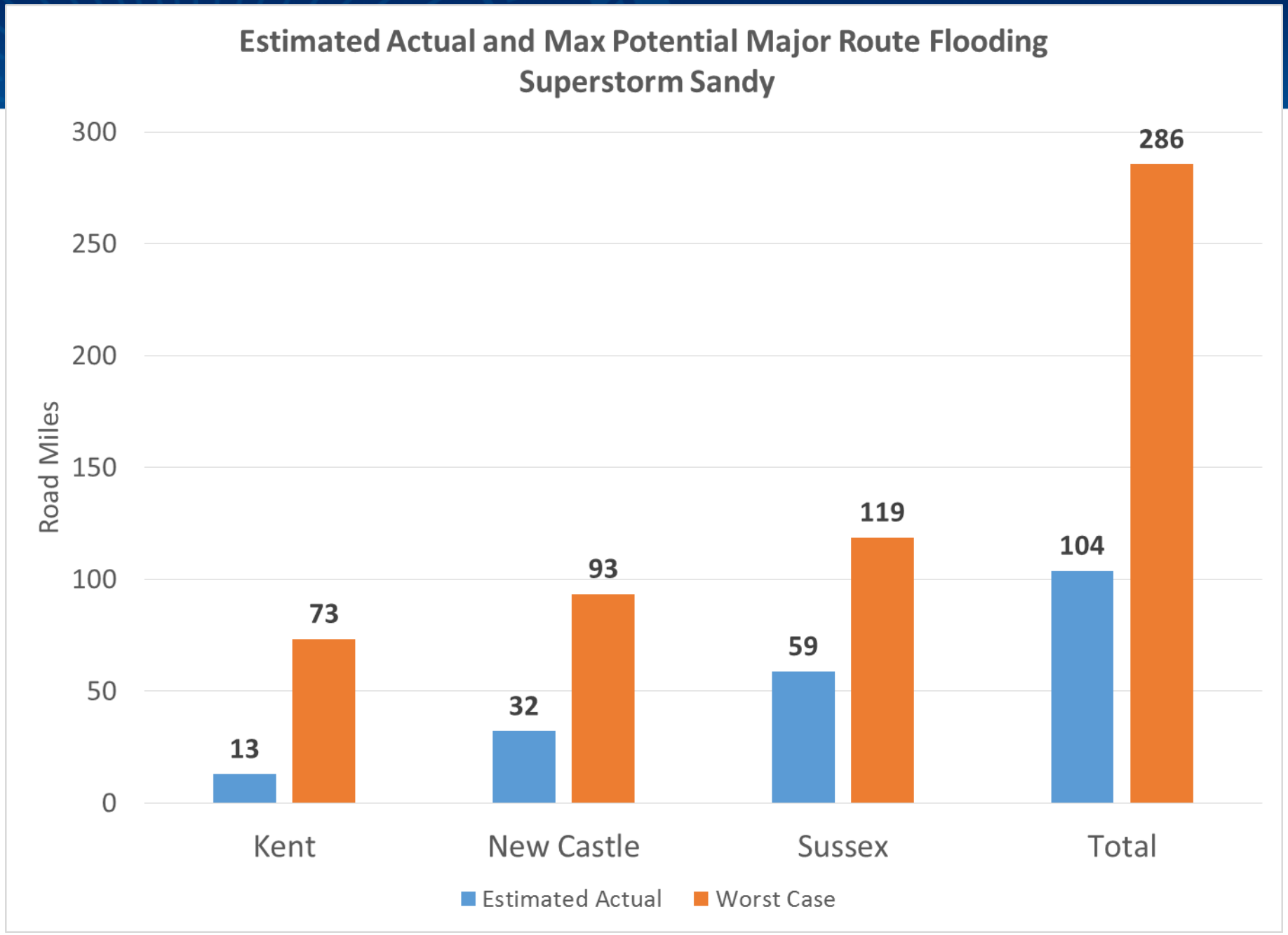
Tide gage height, ft.

- < 5 feet
- 5 - 6 feet
- 6 - 7 feet
- 7 - 8 feet
- > 8 feet

- Estimated inundation
- Pot. max. inundation
- Major route
- Town


Green Hill
Lewes
Lewes Little League
Canal Front Park
Front St
Second St
W Third St
Market St
Chestnut St
E Third St
Rodaline Av
Franklin Av
Schley Av
E Fourth St
Coleman Av
Washington Av
Jefferson Av
Madison Av
Bebee Av
Dewey Av
Kings Hwy
Railroad Av
Monroe Av
Jefferson Ct
E Market St
Massachusetts Midland Av
Arglers Rd
American Legion Rd
Maryland and Delaware
E Savannah Rd
Gills Neck Rd
Cape Henlopen Dr
Gills Neck Rd
Josphur Ct
33 ft
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community


Estimated Actual and Max Potential Road Flooding
Superstorm Sandy
Road Miles
1200
1000
800
600
400
200
0
51
225
73
230
209
523
333
977
Kent
New Castle
Sussex
Total
Estimated Actual
Worst Case


Estimated Actual and Max Potential Major Route Flooding
Superstorm Sandy
Road Miles
300
250
200
150
100
50
0
13
73
32
93
59
119
104
286
Kent
New Castle
Sussex
Total
Estimated Actual
Worst Case

Conclusions

- Flood and inundation scenarios indicate a significant impact on Delaware roads and other infrastructure.
- Will affect response times and evacuations.
- Climate change may well exacerbate rainfall and storm frequency and power.
- Sea level rise will potentially be a factor, but smaller than storm intensity.

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- NOAA NHC—Arthur Taylor, Jamie Rhome