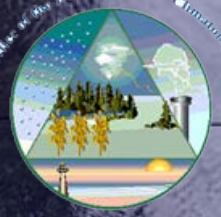
Please Note: The following presentation was given at the May 24, 2016 DRBC Flood Advisory Committee meeting. Contents should not be published or re-posted in whole or in part without the permission of DRBC.

The Delaware Coastal Flood Monitoring System

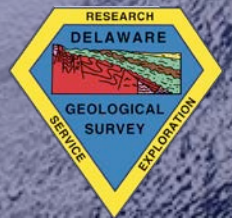
John A. Callahan
Delaware Geological Survey
College of Earth, Ocean, and Environment
University of Delaware

Delaware River Basin Commission
Flood Advisory Committee
May 24, 2016

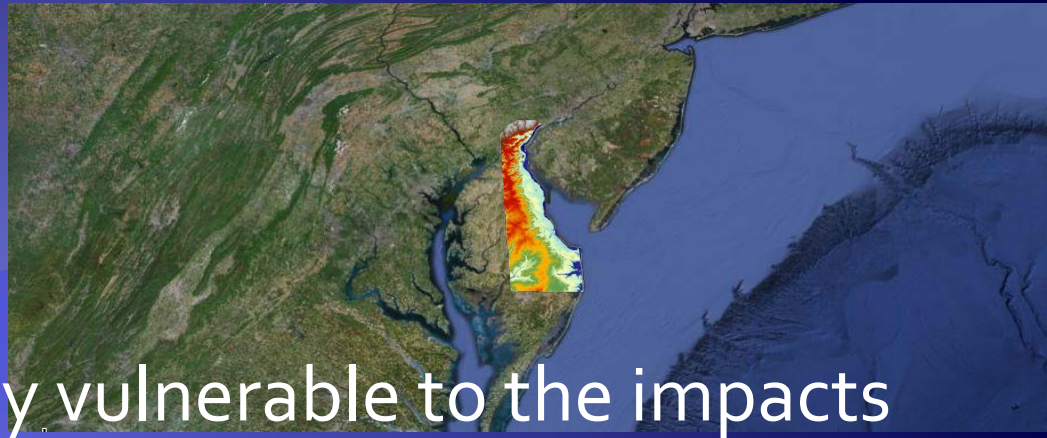


DEMAC

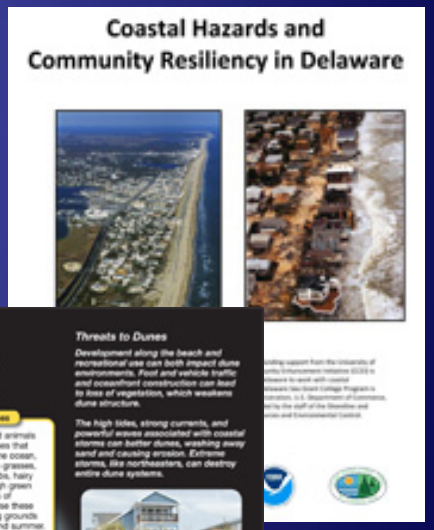
DELAWARE COASTAL PROGRAMS
DCMP

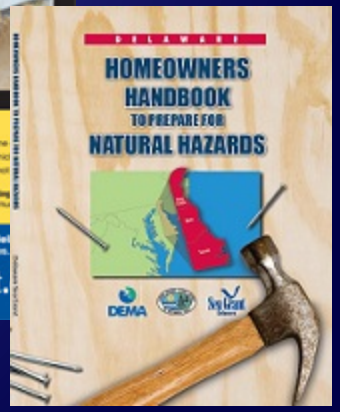


Delaware



- Delaware is extremely vulnerable to the impacts of coastal hazards.
  - Tropical systems and Nor'easters
    - Rain, surge, waves, inland flooding
  - Extreme Wind
  - Shoreline erosion
  - Sea-level rise
  - Tsunamis



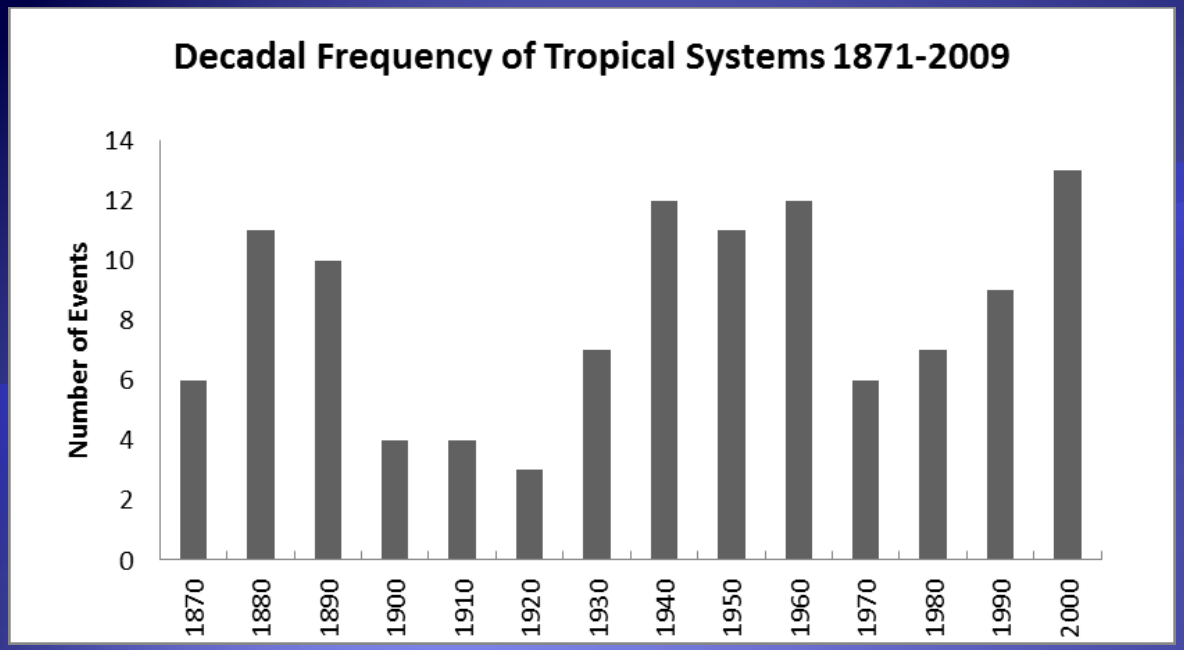


Hurricane Sandy
10/29/2012

Indian River Bay Inlet

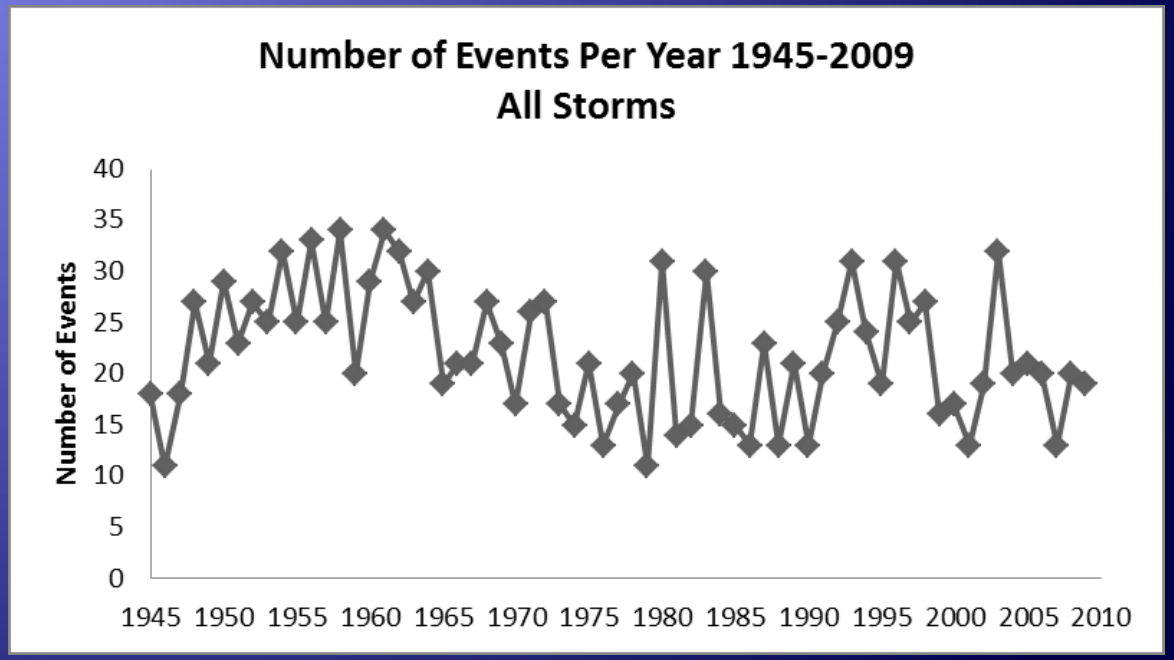
Fenwick Island

Delaware Coastal Storm Frequency



Tropical Systems

All events



Only about 10% of all coastal storms near Delaware are tropical!

http://climate.udel.edu/research/delaware-coastal-storm-climatology

Risk Ranking of Hazards in Delaware

Table 4.2-47
Overall Risk Ranking for the State of Delaware by County and Statewide

Hazard Ranking	New Castle County	Kent County	Sussex County	Statewide
1	Flood	Flood	Flood	Flood
2	Hurricane Wind	Drought	Drought	Winter Storm
3	Winter Storm	Winter Storm	Winter Storm	Thunderstorm
4	Earthquake	Thunderstorm	Thunderstorm	Hurricane Wind
5	Drought	Extreme Heat/Cold	Extreme Heat/Cold	Extreme Heat/Cold
6	Thunderstorm	Earthquake	Earthquake	Drought
7	Extreme Temperature	Tornado	Tornado	Tornado
8	Tornado	Hurricane Wind	Hurricane Wind	Hail
9	None	Hail	Hail	Wildfire
10	Hail	Wildfire	Wildfire	Tsunami
11	Wildfire	Coastal Erosion	Coastal Erosion	Earthquake
Unranked	Coastal Erosion	Dam/Levee Failure	Dam/Levee Failure	Coastal Erosion
Unranked	Dam/Levee Failure	Tsunami	Tsunami	Dam/Levee Failure
Unranked	Tsunami	Volcano	Volcano	Volcano
Unranked	Volcano	Terrorism	Terrorism	Terrorism
Unranked	Terrorism	HazMat Incident	HazMat Incident	HazMat Incident
Unranked	HazMat Incident	Pipeline Failure	Pipeline Failure	Pipeline Failure
Unranked	Pipeline Failure			

DEMAC Delaware Environmental Monitoring & Analysis Center

HOME | ABOUT DEMAC | PARTNERS | PROJECTS | RESOURCES | CONTACT

Delaware Environmental Monitoring Sites

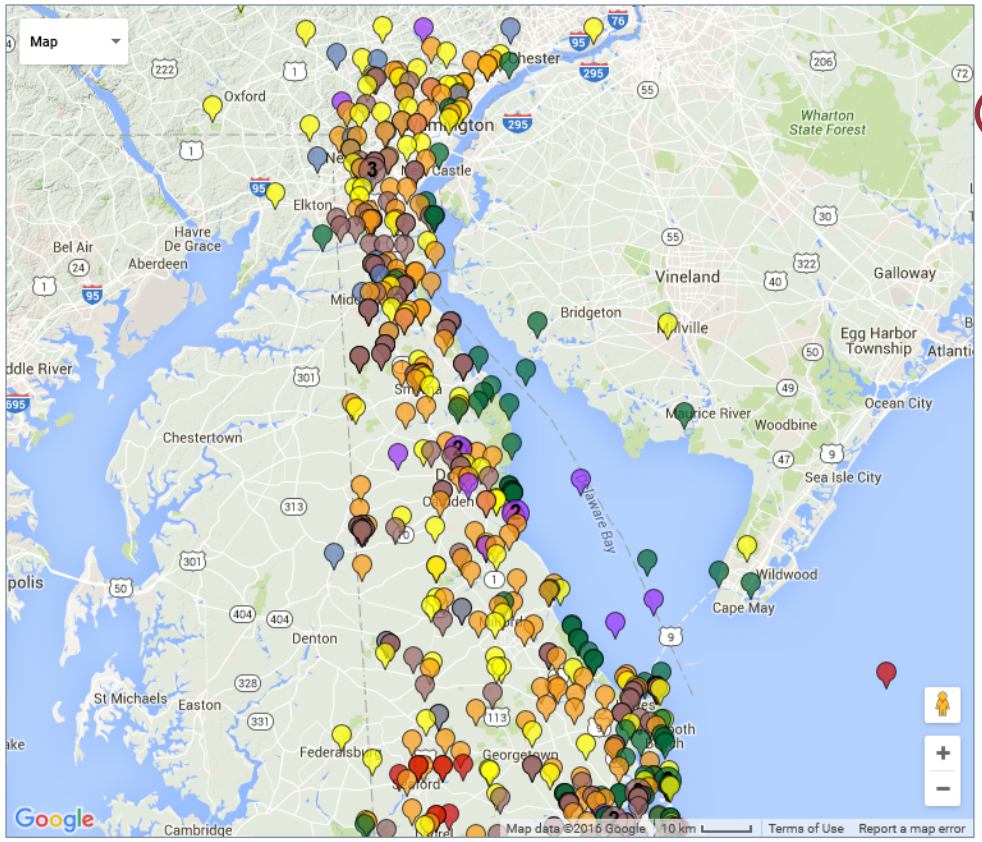
MAP • TABLE • LIST VIEW

564 Items

Type
- 2 Currents
- 185 Groundwater
- 113 Meteorological
- 6 Pond Monitoring
- 27 Streamflow

Source
- 24 COOP/NWS
- 17 DELDOT
- 88 DEOS
- 185 DGS
- 167 DNREC
- 23 NOAA
- 12 NWS
- 2 USACE
- 46 USGS

Project
- 4 Bombay Hook
- 6 CFMS
- 24 COOP/NWS
- 2 DCMP
- 17 DELDOT
- 2 DelDOT Monitoring



Groundwater | Meteorological | Streamflow | Tidal | Water Quality | Others | Multiple

Text Search

☐ Delaware Watersheds

Active?
- 190 N
- 374 Y

Realtime?
- 22 (missing this field)
- 385 N
- 157 Y

Variables
- 30 (missing this field)
- 120 air temperature
- 9 altimeter
- 133 bacteria
- 2 barometric pressure
- 1 CDOM
- 1 chlorophyll
- 2 current direction
- 2 current speed
- 86 dewpoint temperature
- 2 directional spreading sigma theta
- 28 discharge
- 154 dissolved oxygen
- 14 dissolved oxygen %sat
- 2 dominant wave period

Page is co-maintained by the Delaware Environmental Monitoring and Analysis Center and the Delaware Geological Survey.

Delaware is very well monitored!

College of Earth, Ocean, and Environment

UD SATELLITE RECEIVING STATION

polar orbiter receiving dish (Willard Hall, UD Main Campus)

Satellites:

- GOES - East
- MODIS Terra & Aqua
- NPP/JPSS
- NOAA – 16, 18, 19
- MetOP

Products:

- Channel data
- SST/LST
- NDVI
- Chlorophyll
- CO2
- Cloud Pressure
- Cloudtop Temp
- Water Vapor Pressure/Heights

geosynchronous receiving dish (Willard Hall, UD Main Campus)

Products vary in…

- Resolution: 250m – 4km
- Frequency: 15 min – 4x daily
- Holdings: past week - 2010

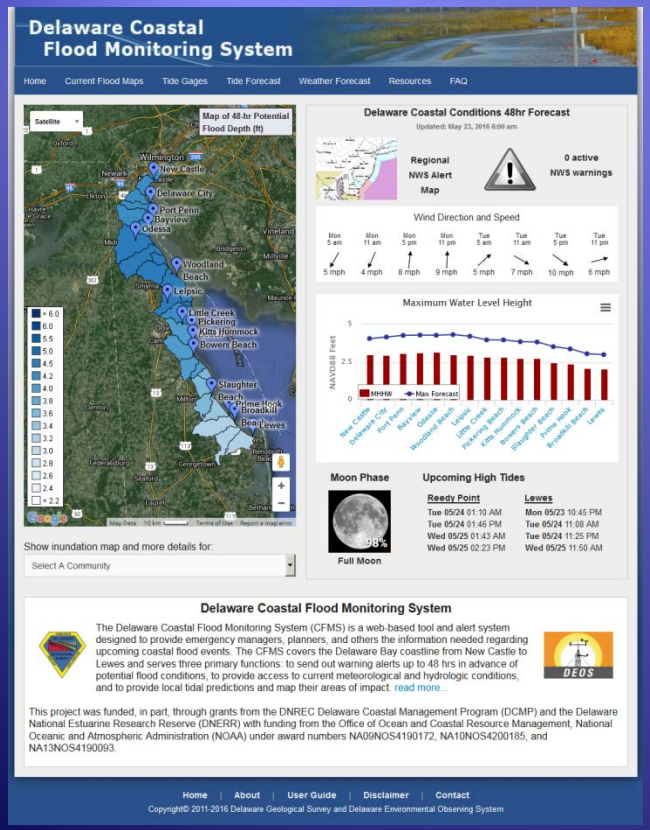
http://udsrs.udel.edu

DGS, DEOS/Office of State Climatologist staff serve in the DEMA EOC during extreme events.

- Tropical systems
- Nor'easters
- Wind, precip, ice/snow
- Stream flooding
- Storm surge
- Evacuations
- Road and bridge closures

Participate on Statewide "**bridge calls**" and provide briefings.

Development of the Delaware Coastal Flood Monitoring System…



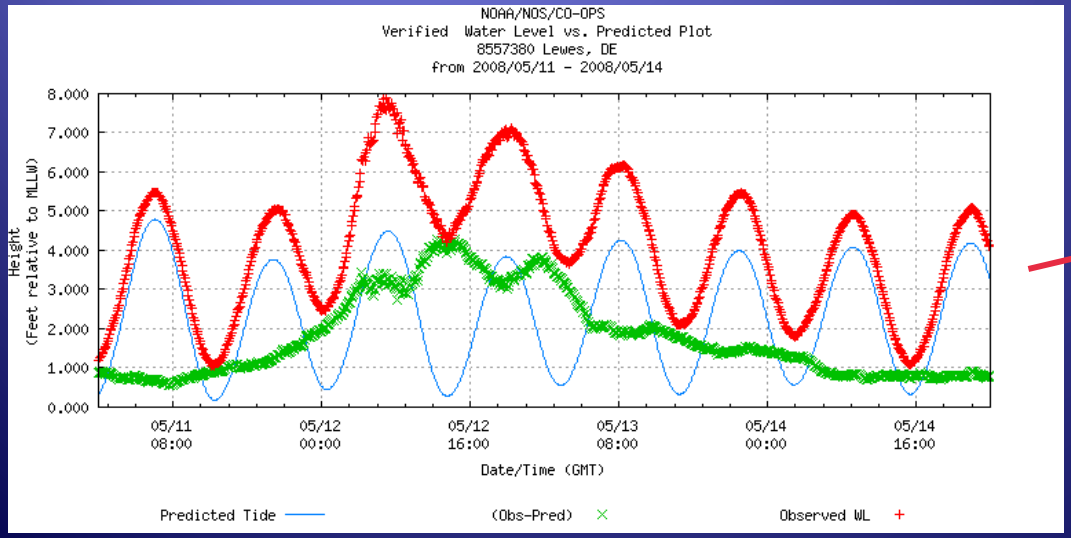
Delaware CFMS team:
John Callahan (DGS)

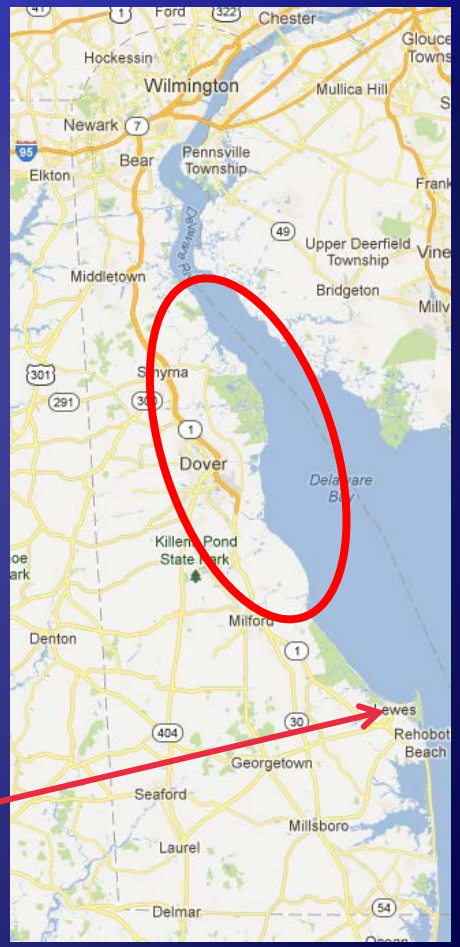
Kevin Brinson, Daniel Leathers (Delaware Environmental Observing System)

Tina Callahan (Delaware Environmental Monitoring and Analysis Center)

Mother's Day Storm

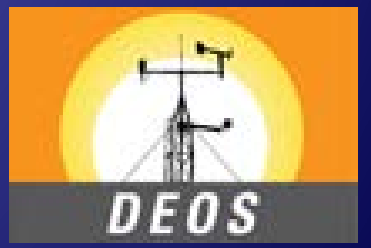
- May 12th, 2008 Nor'easter and astronomically high tides caused significant coastal flooding
- Evacuations at Slaughter Beach, Kitts Hummock, Bowers Beach, and Woodland Beach





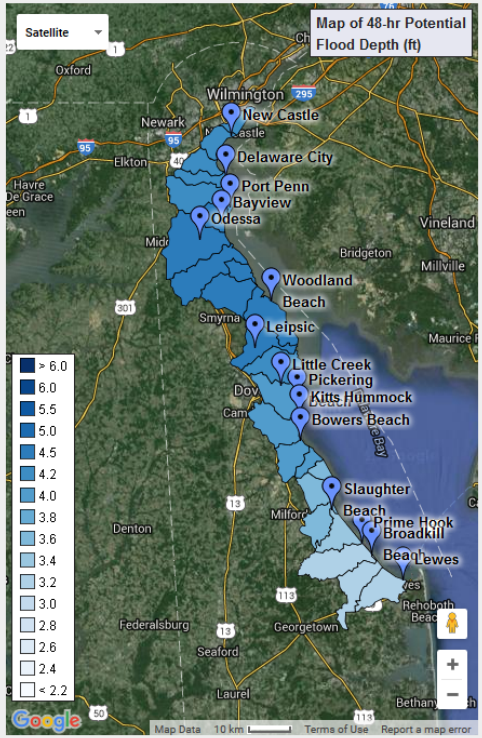
Can we give people more time?

Can we better predict and inform people on where the flooding might occur and how bad it might be?



Delaware Coastal Flood Monitoring System

Home | Current Flood Maps | Tide Gages | Tide Forecast | Weather Forecast | Resources | FAQ



Show inundation map and more details for:

Select A Community

Delaware Coastal Conditions 48hr Forecast

Updated: May 23, 2016 6:00 am

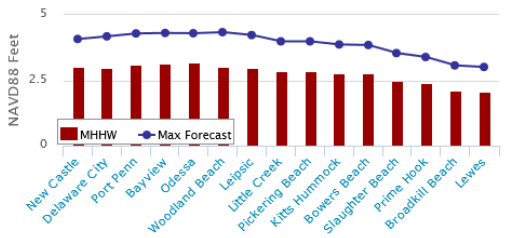
Regional NWS Alert Map

0 active NWS warnings

Wind Direction and Speed

Mon 5 am	Mon 11 am	Mon 5 pm	Mon 11 pm	Tue 5 am	Tue 11 am	Tue 5 pm	Tue 11 pm
5 mph	4 mph	8 mph	9 mph	5 mph	7 mph	10 mph	6 mph

Maximum Water Level Height



Moon Phase

Full Moon

Upcoming High Tides

Reedy Point	Lewes
Tue 05/24 01:10 AM	Mon 05/23 10:45 PM
Tue 05/24 01:46 PM	Tue 05/24 11:08 AM
Wed 05/25 01:43 AM	Tue 05/24 11:25 PM
Wed 05/25 02:23 PM	Wed 05/25 11:50 AM

Delaware Coastal Flood Monitoring System

The Delaware Coastal Flood Monitoring System (CFMS) is a web-based tool and alert system designed to provide emergency managers, planners, and others the information needed regarding upcoming coastal flood ev
Lewes and serves three p
potential flood conditions,
and to provide local tidal p

http://coastal-flood.udel.edu

This project was funded, in part, through grants from the DNREC Delaware Coastal Management Program (DCMP) and the Delaware National Estuarine Research Reserve (DNERR) with funding from the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration (NOAA) under award numbers NA09NOS4190172, NA10NOS4200185, and NA13NOS4190093.

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Delaware Coastal Flood Monitoring System

Home | Current Flood Maps | Tide Gages | Tide Forecast | Weather Forecast | Resources | FAQ

Bowers Beach

Water Depth (feet)

MLLW	NAVD88
9.64	7.0
8.64	6.0
7.64	5.0
6.64	4.0
5.64	3.0
4.64	2.0
3.64	1.0
2.64	0.0

Reset Map to: Current | Max

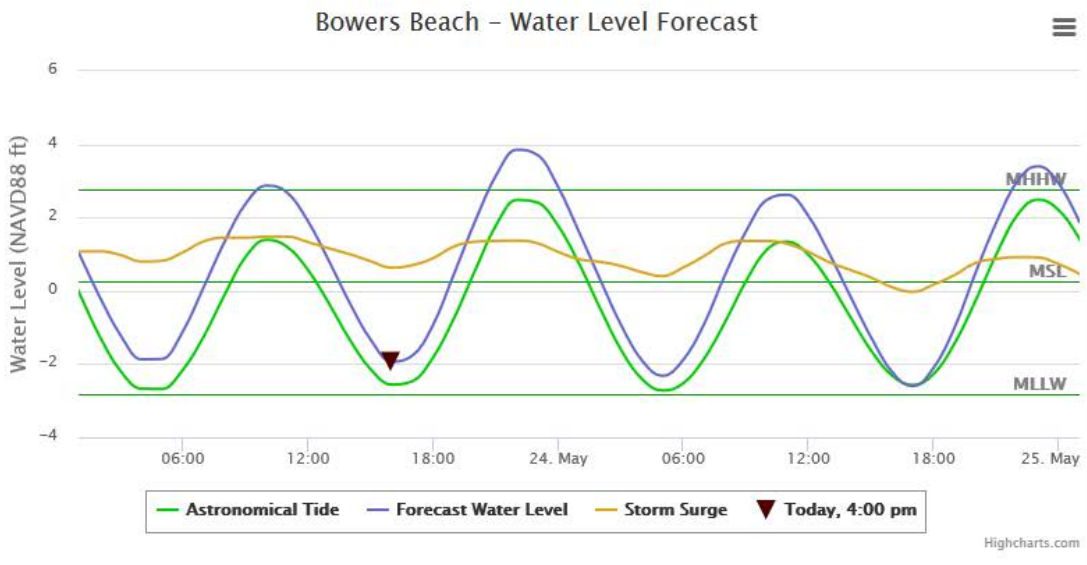
Current model data:
-1.93 ft* ▼
Today, 4:00 pm

Maximum forcasted water level:
3.85 ft*
05/23/2016 10:00 pm

MHHW: 2.75
MSL: 0.248
MLLW: -2.83

***All data relative to NAVD88**

Tides | Winds | Tidal/Wind Data | Bowers Beach Rd | South Bowers Rd



Delaware Coastal Flood Monitoring System

Bowers Beach

Water Depth (feet)

9.64	7.0
8.64	6.0
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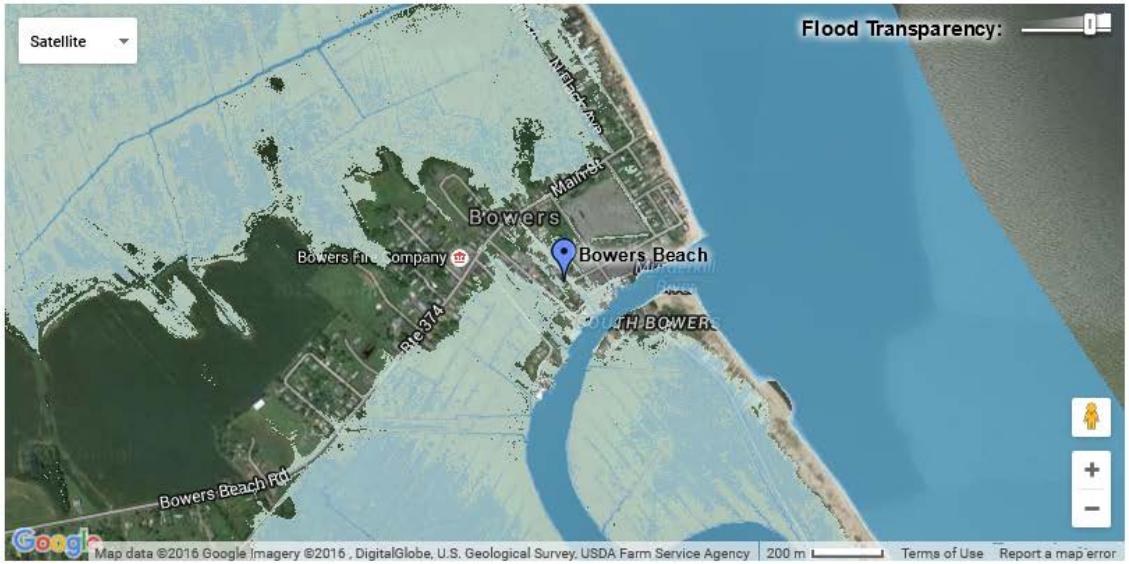
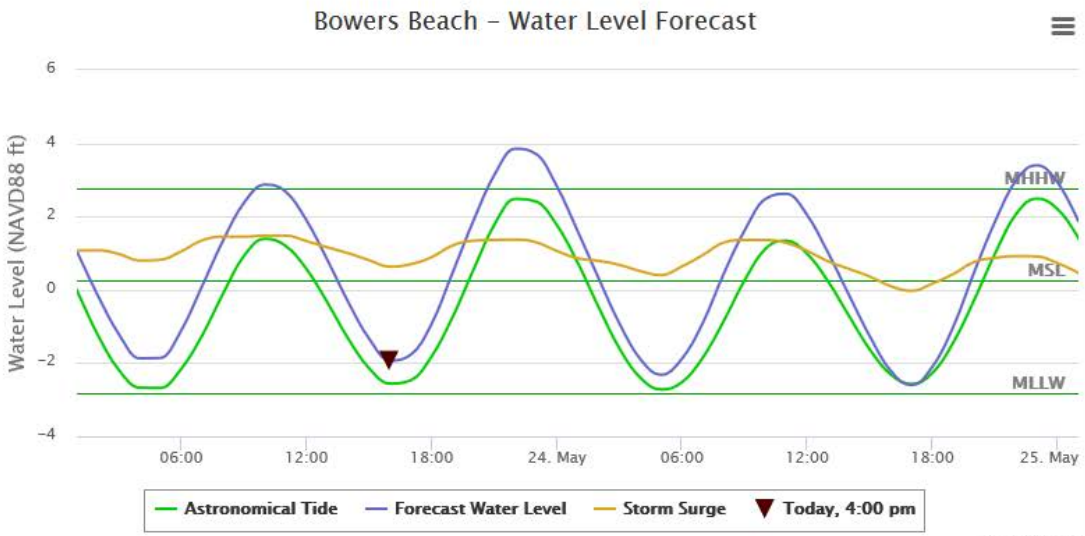


Tides | Winds | Tidal/Wind Data | Bowers Beach Rd | South Bowers Rd



Delaware Coastal Flood Monitoring System

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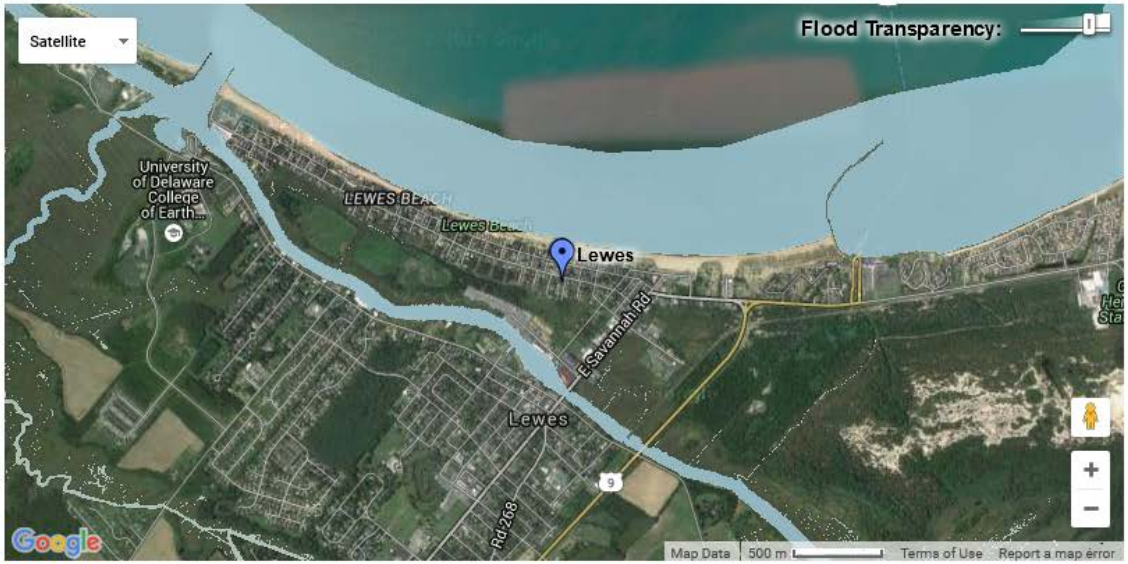
Lewes

Water Depth (feet)

MLLW	NAVD88
9.64	7.0
8.64	6.0
7.64	5.0
6.64	4.0
5.64	3.0
4.64	2.0
3.64	1.0
2.64	0.0



Reset Map to: Current | Max

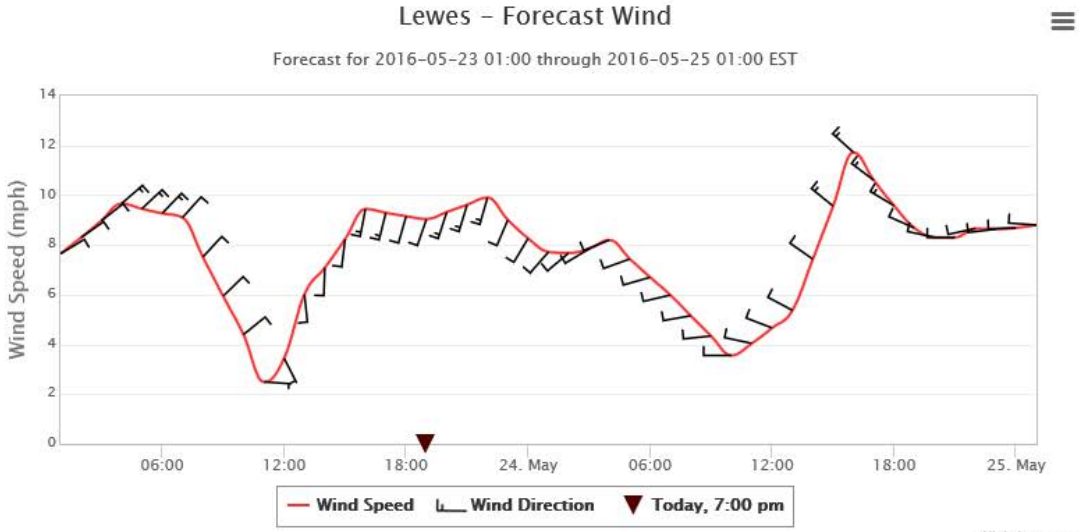
Current model data:
1.46 ft* ▼
Today, 7:00 pm

Maximum forcasted water level:
3.01 ft*
05/23/2016 09:00 pm

MHHW: 2.07
MSL: 0.386
MLLW: -2.46

***All data relative to NAVD88**

Tides | Winds | Tidal/Wind Data | Rt 9 | Cedar St



Delaware Coastal Flood Monitoring System

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Bowers Beach

Water Depth (feet)

9.64	7.0
8.64	6.0
7.64	5.0
6.64	4.0
5.64	3.0
4.64	2.0
3.64	1.0
2.64	0.0
MLLW	NAVD88

Reset Map to: Current | Max

Current model data:
-1.93 ft* ▼
Today, 4:00 pm

Maximum forcasted water level:
3.85 ft*
05/23/2016 10:00 pm

MHHW: 2.75
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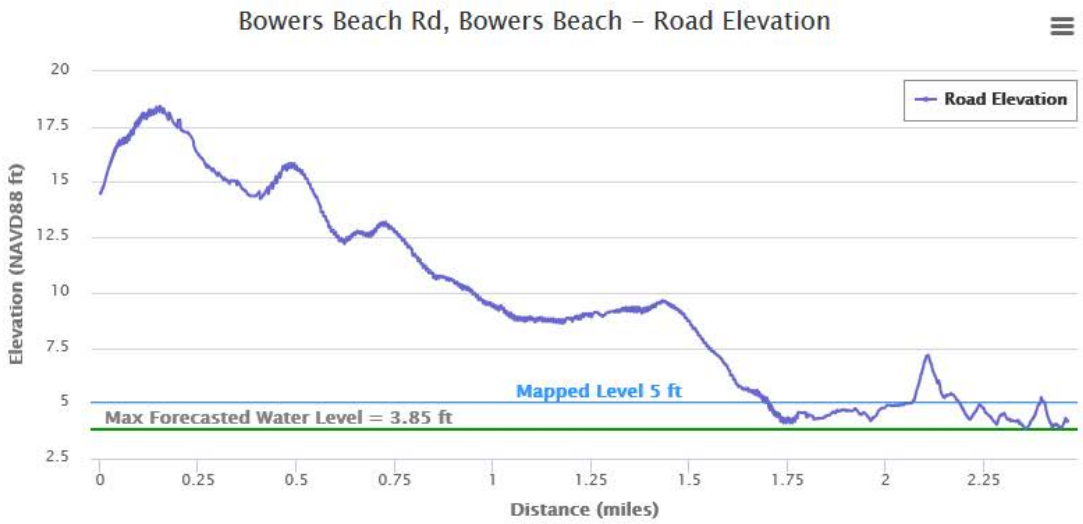
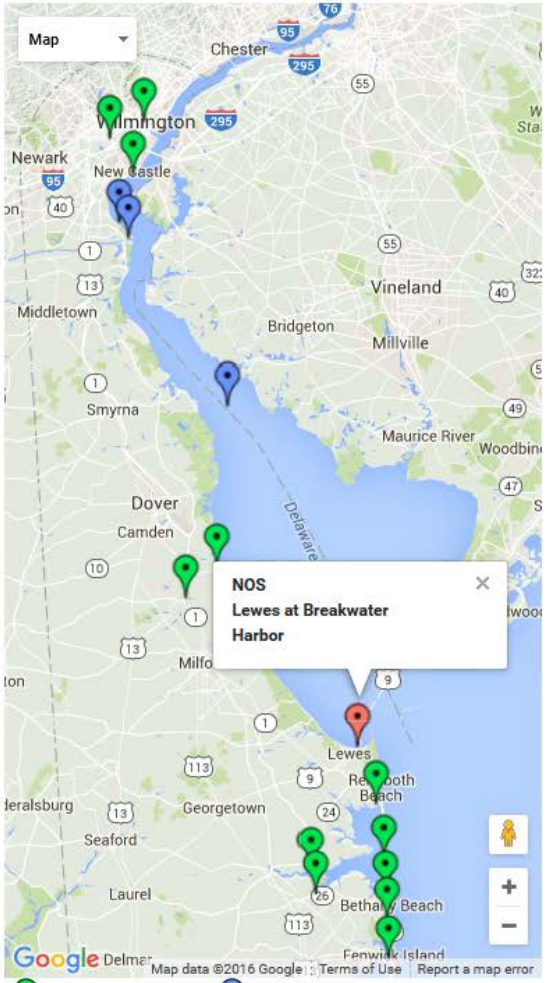
***All data relative to NAVD88**

Tides | Winds | Tidal/Wind Data | Bowers Beach Rd | South Bowers Rd



Delaware Coastal Flood Monitoring System

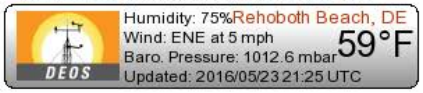
Below are real-time observation stations for the two primary networks for real-time monitoring of tides: United States Geological Survey (USGS) and NOAA's National Ocean Service (NOS). Click on a station map marker to display the latest weather and water level data.



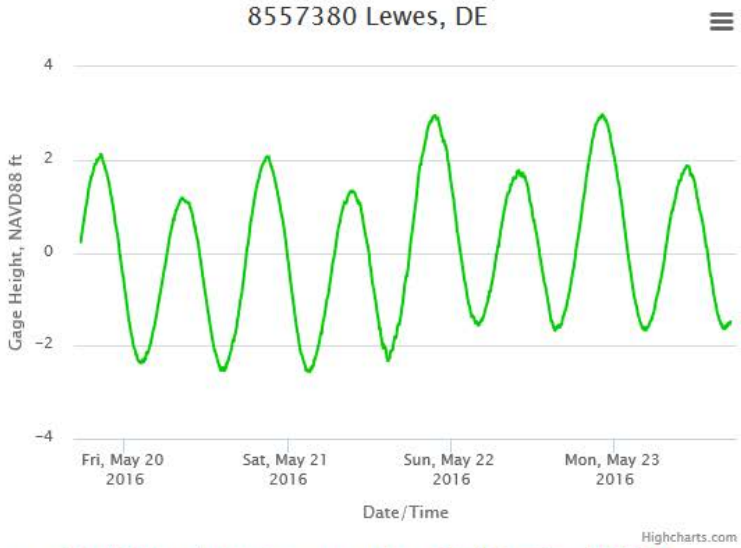
= USGS station = NOS station

NOS: Lewes at Breakwater Harbor

Nearest DEOS meteorological station:



Tidal station graph:



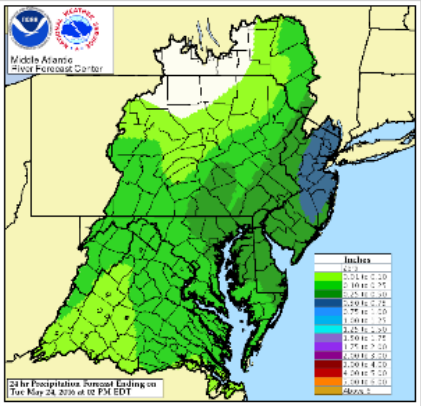
Source: http://tidesandcurrents.noaa.gov/geo.shtml?location=8557380

Delaware Coastal Flood Monitoring System

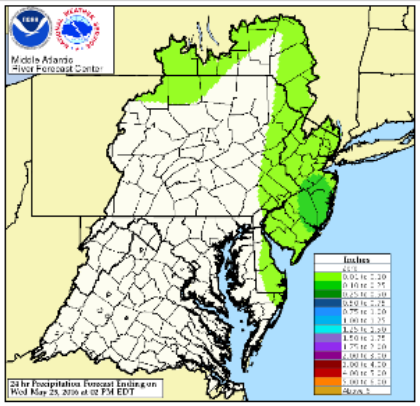
Precipitation Forecasts

The NWS Mid-Atlantic River Forecast Center (MARFC) makes forecasts on total rain accumulation over the next few days. Below are the latest model runs for the next 72 hours in the Delaware region.

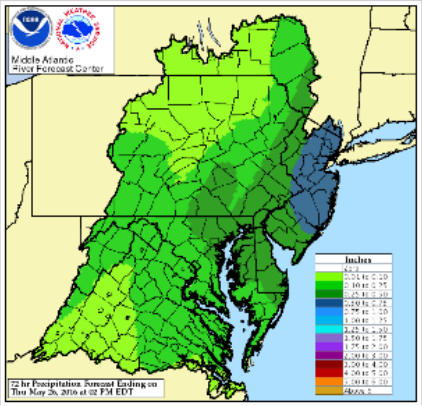
Day 1 Total



Day 2 Total



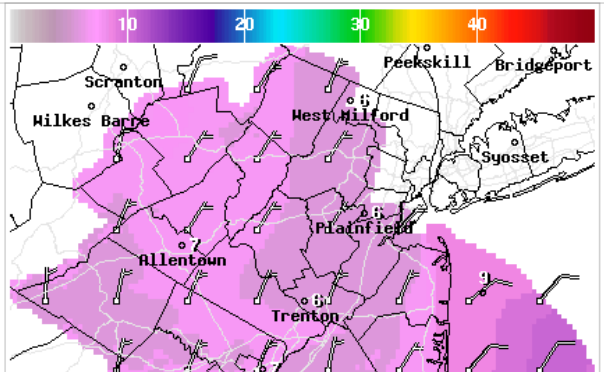
3 Day Total Accumulation

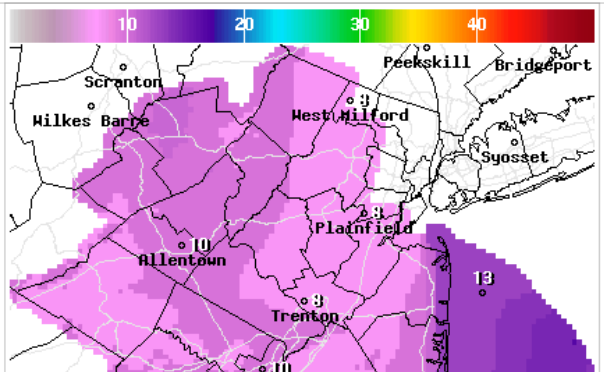


More information on NWS MARFC: http://www.weather.gov/marfc/Precipitation_Forecasts

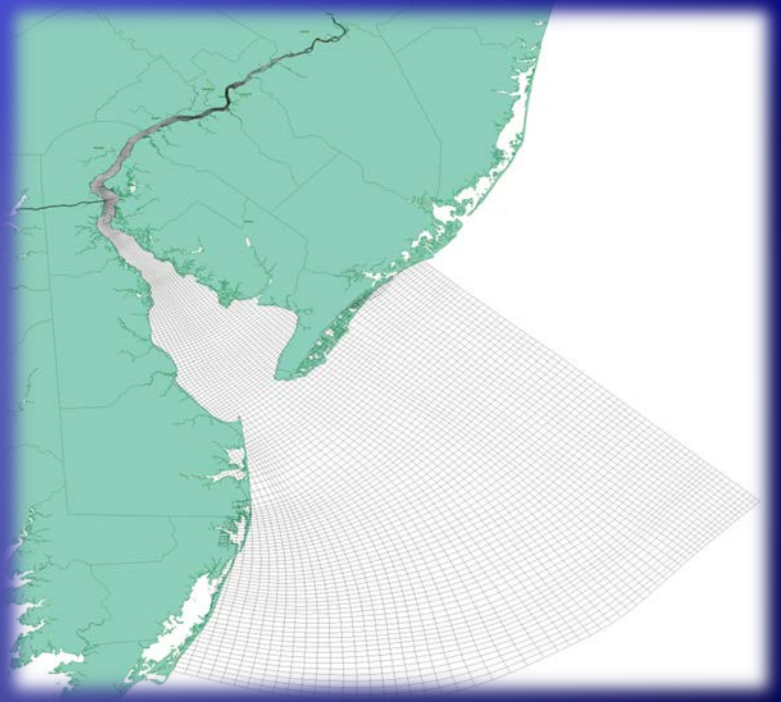
NWS Modeled Wind Forecasts

The NWS makes forecasts on winds and other meteorological variables available from the National Digital Forecast Database (NDFD). Below are the latest model runs for current wind gusts and sustained winds.





Input - DBOFS Forecast

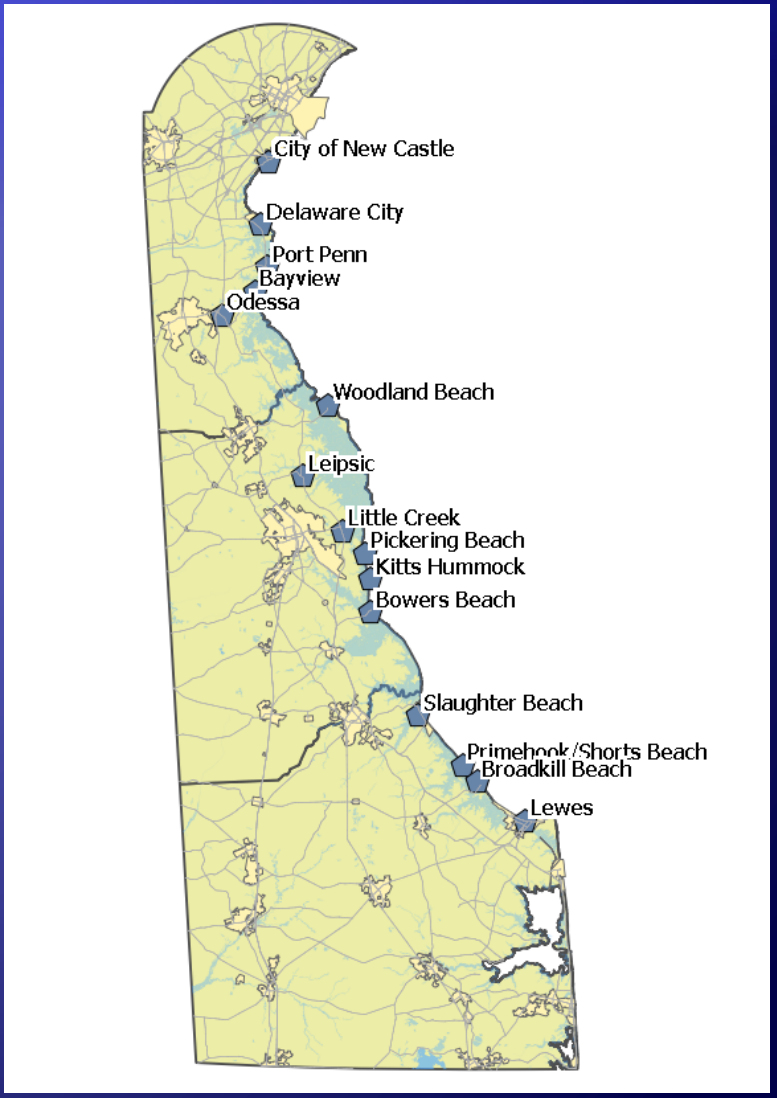


- 48-hour forecast
- 4xdaily, hourly output
- 100m – 3km grid cells
- 119 x 732 x 10
- ROMS hydro model
- Winds: NAM-12, then GFS
- Nowcast mode: CO-OPS and USGS observations
- Forecast mode: ET-Surge and Nowcast output for boundary/initial conditions

Coastal Community Coverage

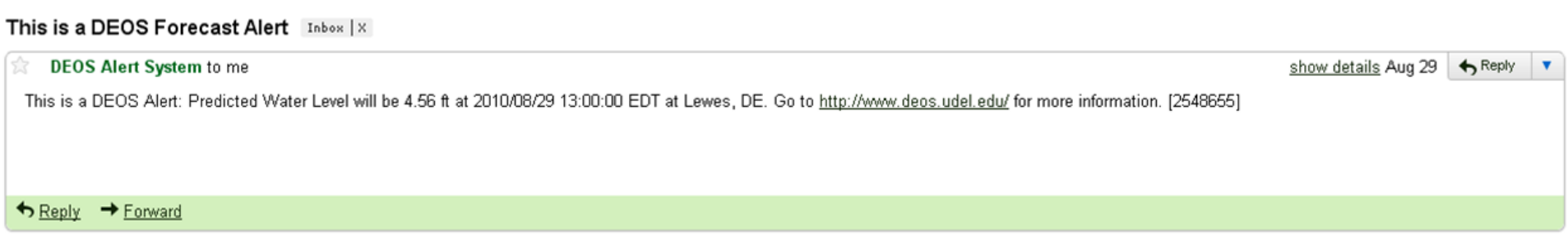
- 15 communities between cities of New Castle and Lewes

- Each community has:
  - Configurable alerts
  - Inundation maps
  - Road profiles
  - Tidal parameters



Forecast Alerts

- Each subscriber sets a critical level to be notified
- If that level is reached, at any time within the 48 hour forecast (adjustable), an alert is sent via text and email



- Intended use: Let emergency managers know they need to begin keeping an eye on tide gages and possibly begin preparations for any potential flooding.

Delaware CFMS

- Current site released in early 2013. Education and training workshops conducted as needed.
- Overall, very positive response from locals. In use during coastal events by numerous state and county agencies.
- Maps do well with highlighting problem areas and with magnitude.
  - Not so well in DE Inland Bays
- 48 hour lead time seems to be sufficient.

Demonstration

http://coastal-flood.udel.edu

Related Ongoing Work…

- Historical Analysis
  - Coastal Storm Climatology
  - Stream and Tide "Storm Books"
  - High Water Mark database and website
  - Changes in Nuisance and Extreme flooding

- Predictive (to be integrated into the CFMS)
  - Delaware Bay Model Validation Analysis
  - Inland Bays Tidal and Storm Surge Prediction
  - Coastal Storm Severity Index (CSSI)

Related Ongoing Work…

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  - Delaware Bay Model Validation Analysis
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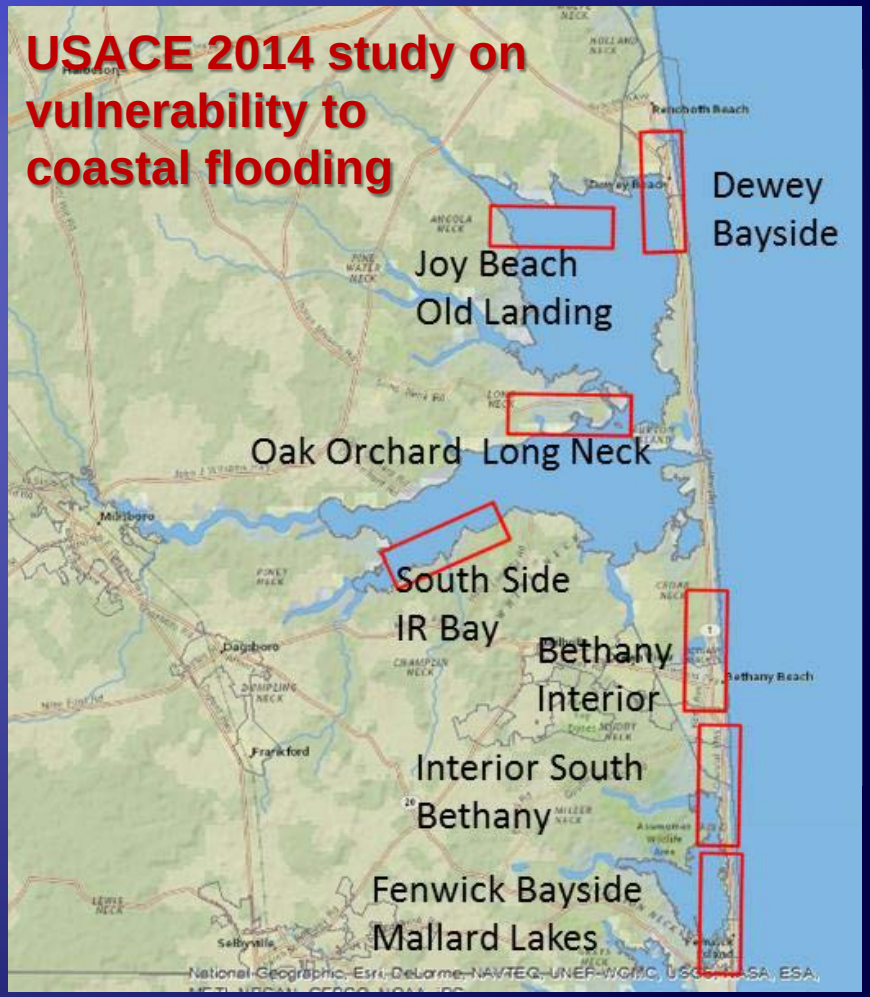
  - **Coastal Storm Severity Index (CSSI)**

1. Tidal and Storm Surge Relationships in Delaware Inland Bays

- Important to Delaware's economy (recreation, fishing, tourism), natural habitat (white cedar swamp, fish, waterfowl), migratory birds, ecosystem services (filtering nutrients)…
- However, they are poorly flushed (slight changes can upset the balance), heavily developed, extremely vulnerable to coastal flooding



NOAA National Ocean Service

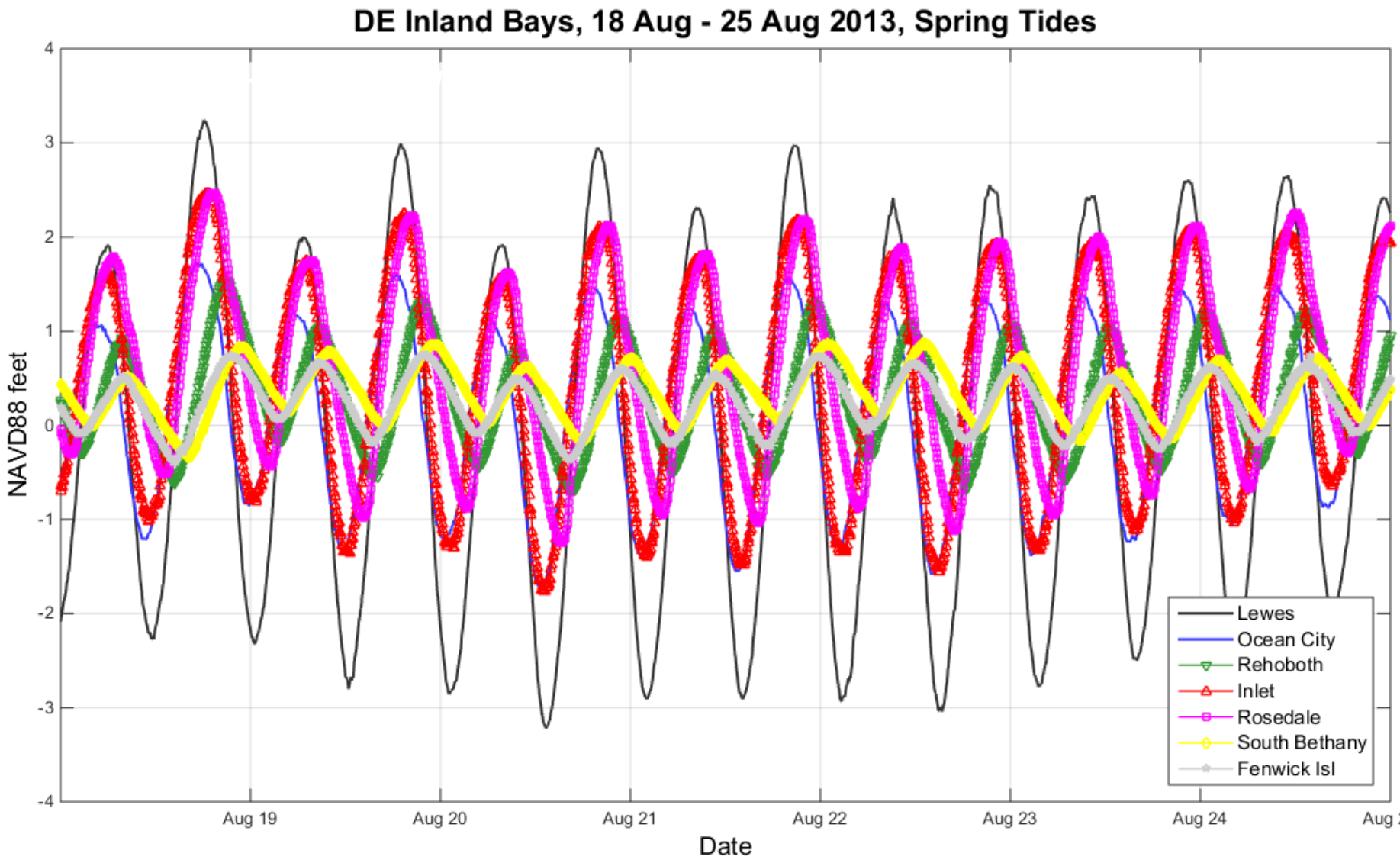
- Lewes Breakwater (1919)
- Ocean City Inlet (1997)

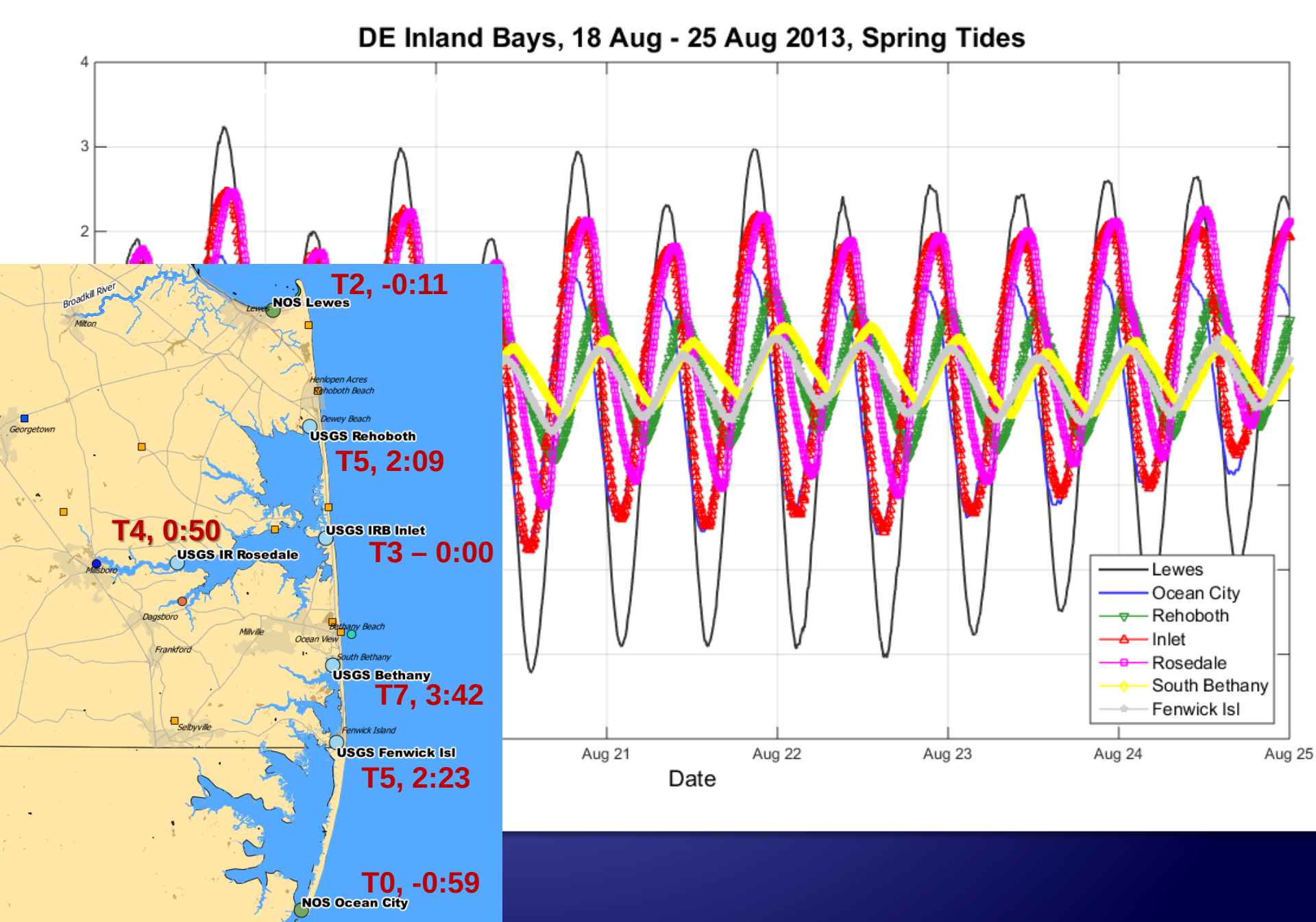
United States Geological Survey

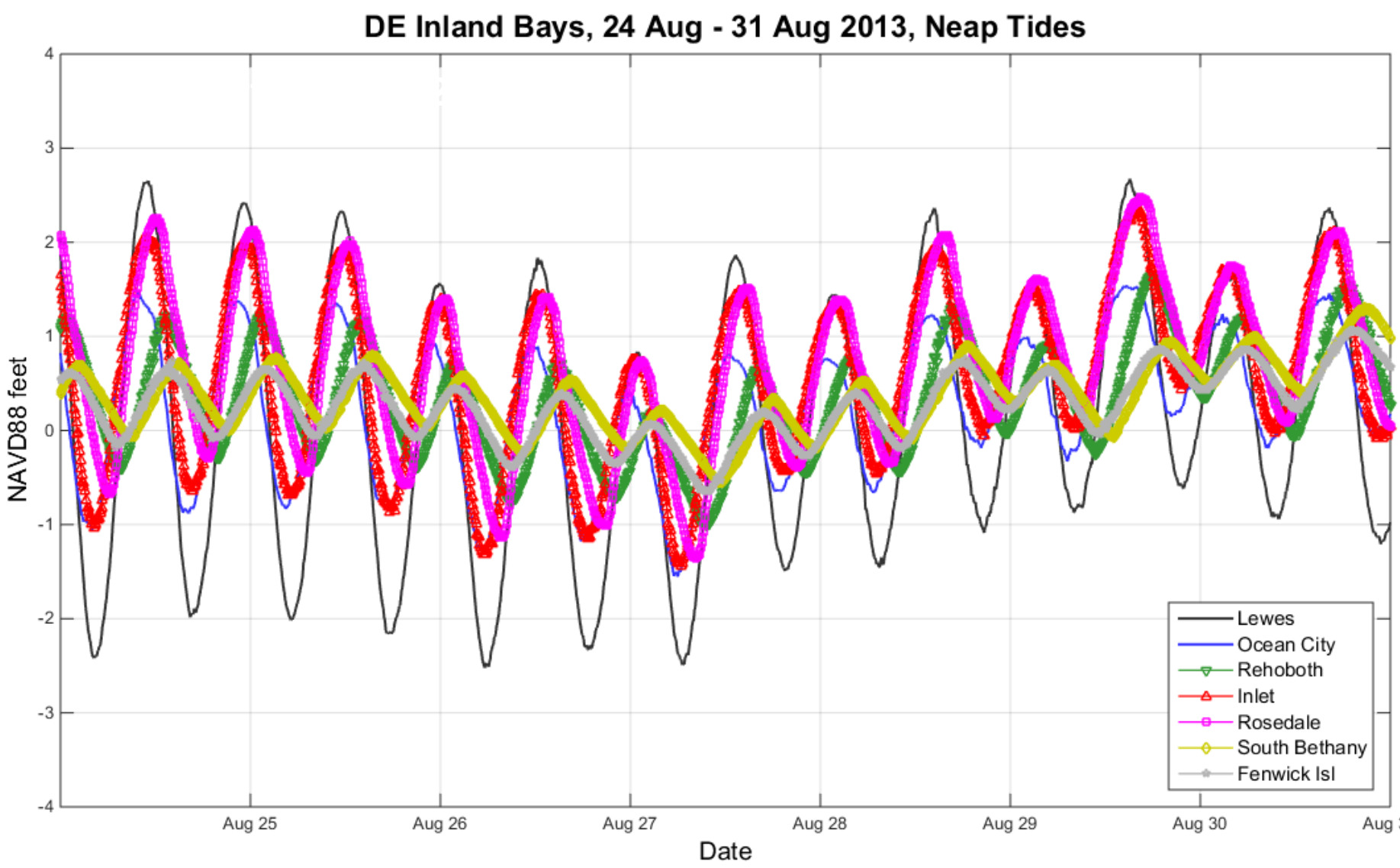
- Rehoboth Beach (1985)
- Indian River Bay Inlet (1989)
- IRB Rosedale (1992)
- South Bethany (1999)
- Fenwick Island (1999)

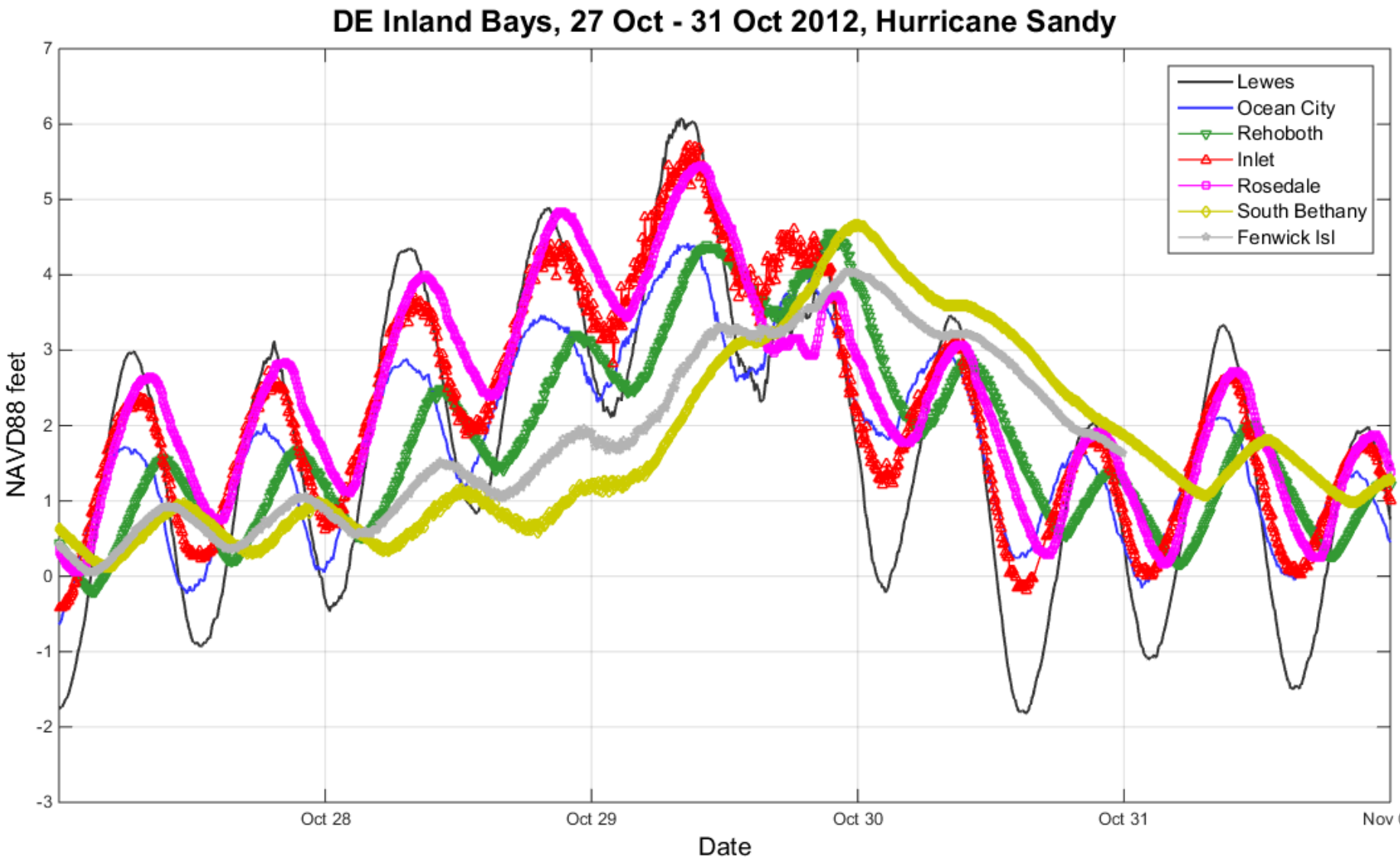
Delaware Environmental Observing System (DEOS)

- Research monitoring sites
- Meteorological stations


DE Inland Bays, 18 Aug - 25 Aug 2013, Spring Tides
NAVD88 feet
4
3
2
1
0
-1
-2
-3
-4
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
Aug 25
Date
Lewes
Ocean City
Rehoboth
Inlet
Rosedale
South Bethany
Fenwick Isl


DE Inland Bays, 18 Aug - 25 Aug 2013, Spring Tides
4
3
2
Aug 21
Aug 22
Aug 23
Aug 24
Aug 25
Date
Lewes
Ocean City
Rehoboth
Inlet
Rosedale
South Bethany
Fenwick Isl
T2, -0:11
NOS Lewes
USGS Rehoboth
T5, 2:09
T4, 0:50
USGS IRB Inlet
T3 – 0:00
USGS IR Rosedale
USGS Bethany
T7, 3:42
USGS Fenwick Isl
T5, 2:23
T0, -0:59
NOS Ocean City
Broadkill River
Milton
Georgetown
Millsboro
Dagsboro
Frankford
Millville
Ocean View
Bethany Beach
South Bethany
Selbyville
Fenwick Island
Dewey Beach


DE Inland Bays, 24 Aug - 31 Aug 2013, Neap Tides
NAVD88 feet
4
3
2
1
0
-1
-2
-3
-4
Aug 25
Aug 26
Aug 27
Aug 28
Aug 29
Aug 30
Aug 31
Date
Lewes
Ocean City
Rehoboth
Inlet
Rosedale
South Bethany
Fenwick Isl


DE Inland Bays, 27 Oct - 31 Oct 2012, Hurricane Sandy
NAVD88 feet
7
6
5
4
3
2
1
0
-1
-2
-3
Oct 28
Oct 29
Oct 30
Oct 31
Nov 01
Date
Lewes
Ocean City
Rehoboth
Inlet
Rosedale
South Bethany
Fenwick Isl

Top Observed Storm Tides - DE Inland Bays

Lewes	WL (ft)
3/6/1962	6.59
1/4/1992	6.12
10/29/2012	**6.06**
1/28/1998	5.99
2/5/1998	5.86

IRB Inlet	WL (ft)
10/29/2012	**5.72**
2/5/1998	5.07
11/13/2009	5.05
5/12/2008	5.00
1/25/2000	4.87

Rosedale	WL (ft)
2/5/1998	6.21
1/28/1998	5.77
10/29/2012	**5.45**
11/12/2009	5.26
3/6/2013	4.98

Notable Storms
10/29/2012 – Sandy
11/13/2009 – Nor'Ida
5/12/2008 – Mother'sDay
1/28/1998 – Nor'easter
2/5/1998 – Nor'easter
9/19/2003 - Isabel

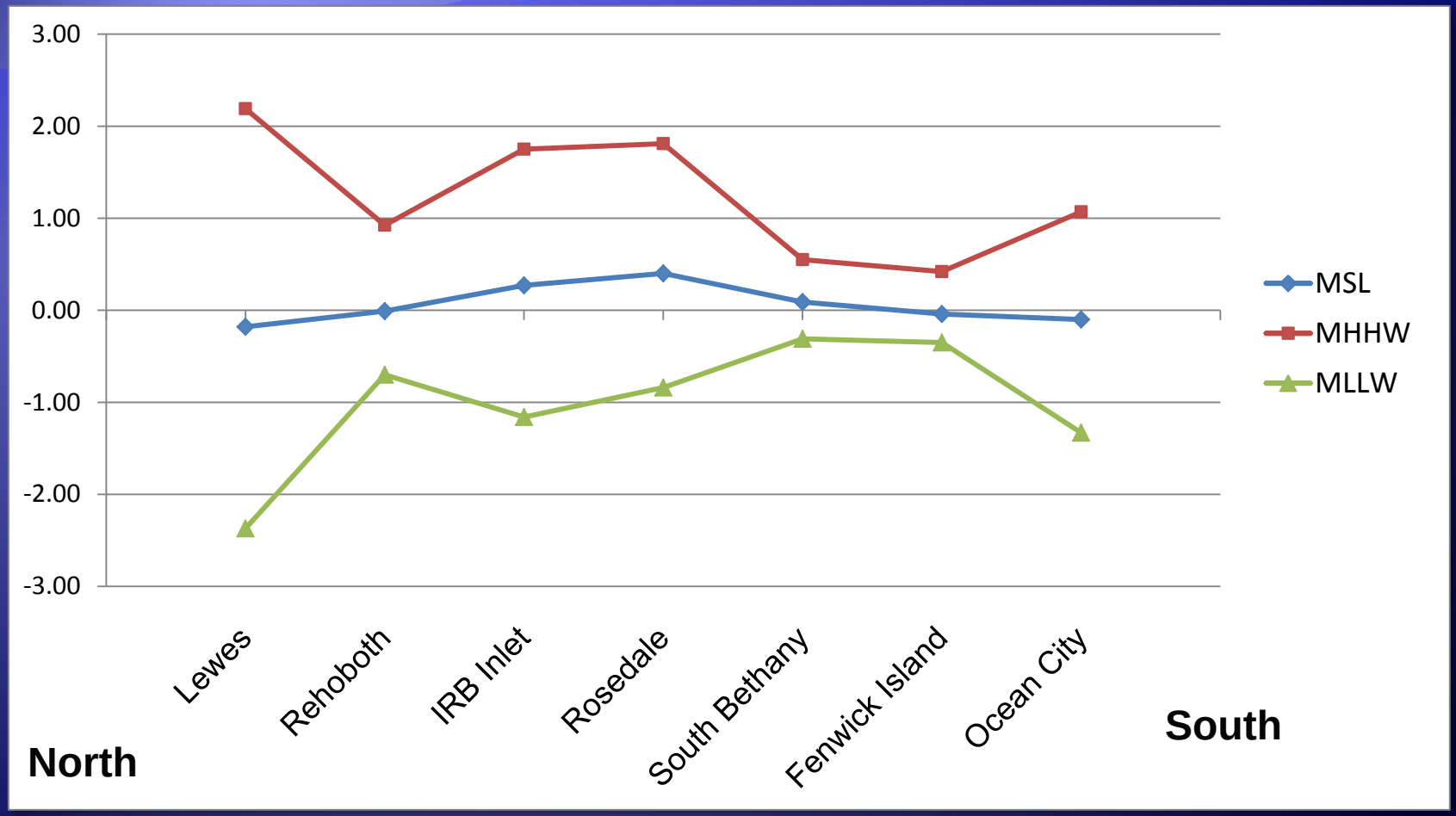
Rehoboth	WL (ft)
10/29/2012	**4.56**
10/31/1991	3.67
11/13/2009	3.62
5/12/2008	3.4
10/25/2005	3.28

S.Bethany	WL (ft)
10/29/2012	**4.66**
9/19/2003	2.74
10/25/2005	2.59
9/2/2006	2.38
11/8/2012	2.35

FenwickIsl	WL (ft)
10/29/2012	**4.04**
10/25/2005	2.35
9/19/2003	2.23
11/8/2012	2.22
11/13/2009	2.21

OceanCity	WL (ft)
10/29/2012	**4.41**
11/22/2006	3.88
11/13/2009	3.84
3/6/2013	3.21
10/18/2009	3.13

Inland Bays Tidal Datums (NAVD88)



Based over 14 year period, 5/1/2000 - 4/30/2014 (John Callahan, DGS/UD, unpublished)

Storm Tide Prediction

- Prediction (using multiple regression) at four inland USGS gauges (as pilot project)
- High tides only for 2013
- Statistical relationship of ocean-side tides/surge to Inland Bays coastal regions
  - Input: WL at Inlet, Lewes, and Ocean City
  - Input: Precip (1, 3, 6, 12 hrs) and Wind (1, 3, 6 hrs)
- Correlations: R2 from ~ 0.83 - 0.98
- 3-9 predictors, different for each wind direction and tide gauge

Tidal and Storm Surge Relationships in Delaware Inland Bays

- Installed new water level sensors, each sensor near a flood-prone community
- Analysis of storm tides and storm surge (i.e., non-tidal residuals) ongoing
- Real-time application of early warning system (integrated into CFMS) in near future

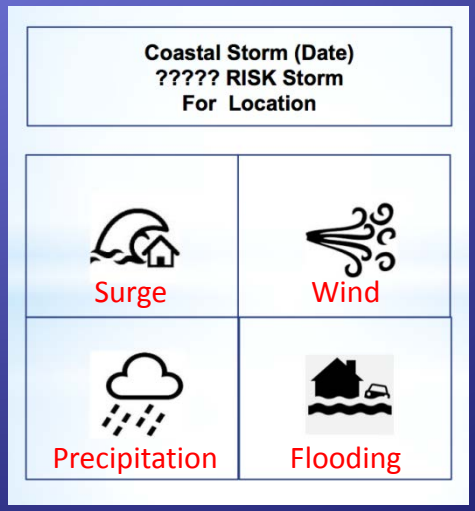
2. Coastal Storm Severity Index (CSSI)

- Storm severity is usually classified based on a storm-centric view
  - Saffir-Simpson Hurricane Scale, 1-5
  - Enhanced Fujita Tornado Scale, 0-5
  - Numeric values of peak wind, precip, surge, etc…
- However, how about we take an impact-centric or community-centric approach?

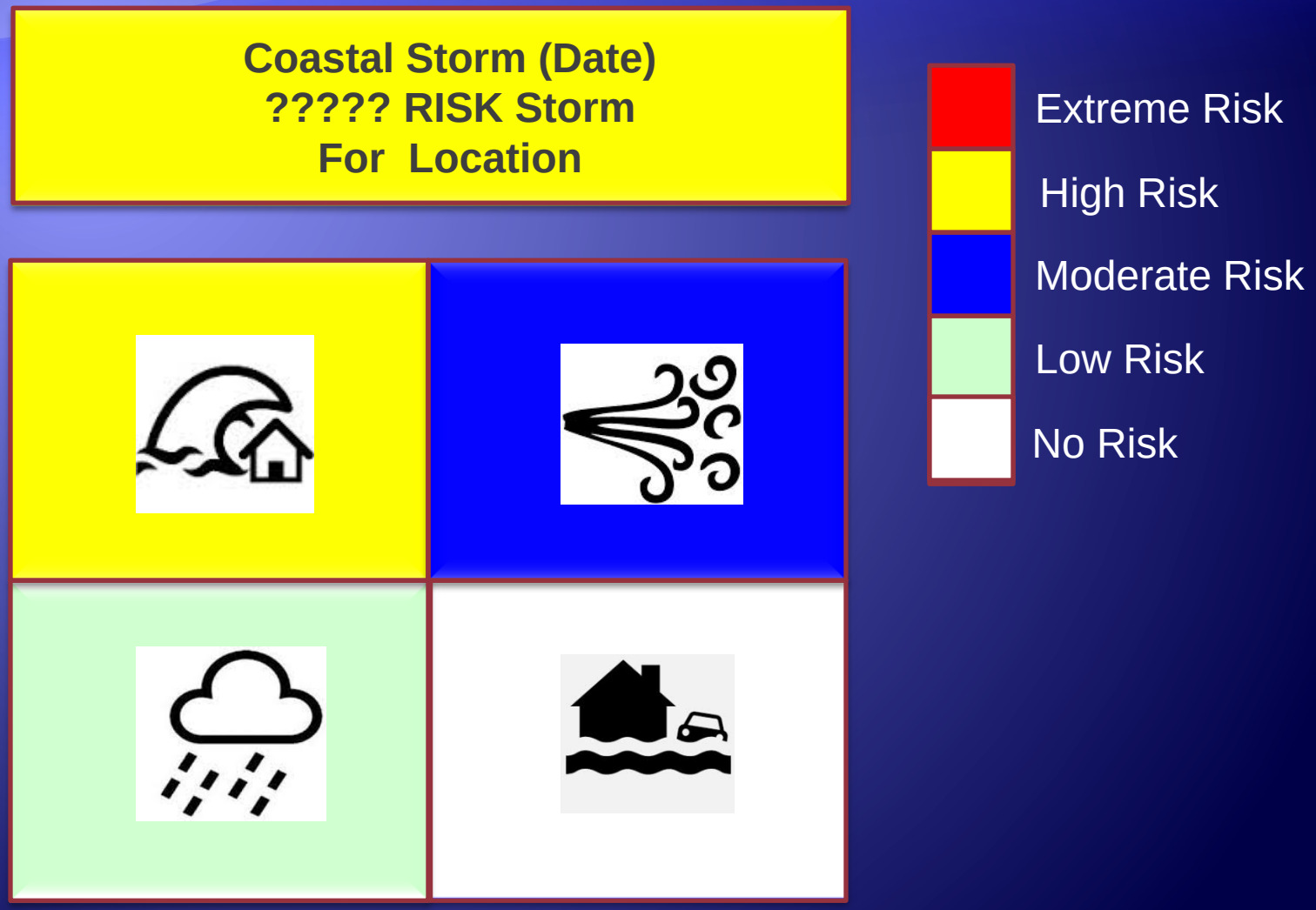
Forecasts of meteorological parameters, combined with high resolution GIS data to determine local impact ratings for at least four storm effects…

Model forecasts of precipitation, winds, surge, and stream flow.

Hi-res GIS data… land-use, elevation, population, distance to waterway

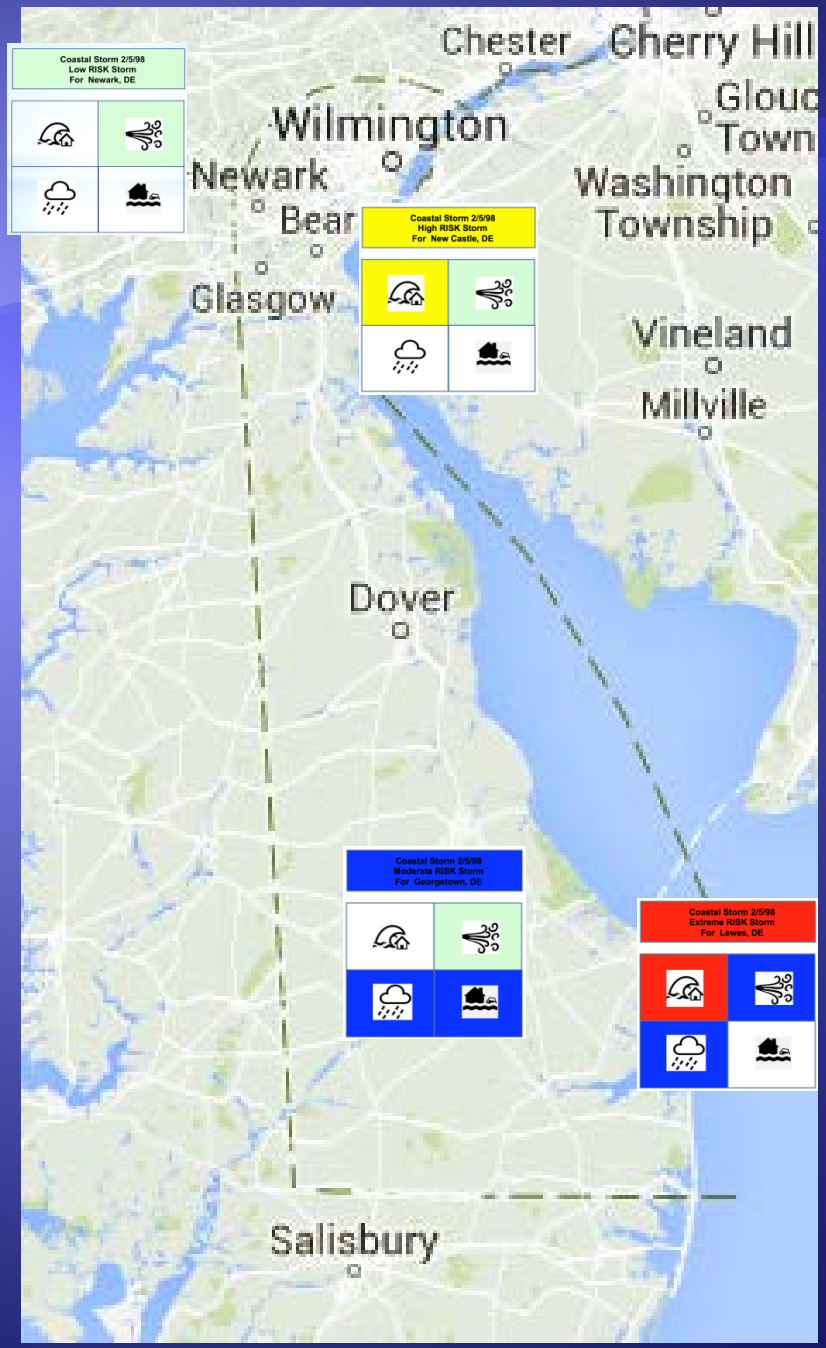


Example: Consider a coastal location, no streams, sub-urban with a coastal storm with moderate winds, large surge and moderate precipitation.



Nor’easter

Feb 4-6, 1998



Extreme Risk

High Risk

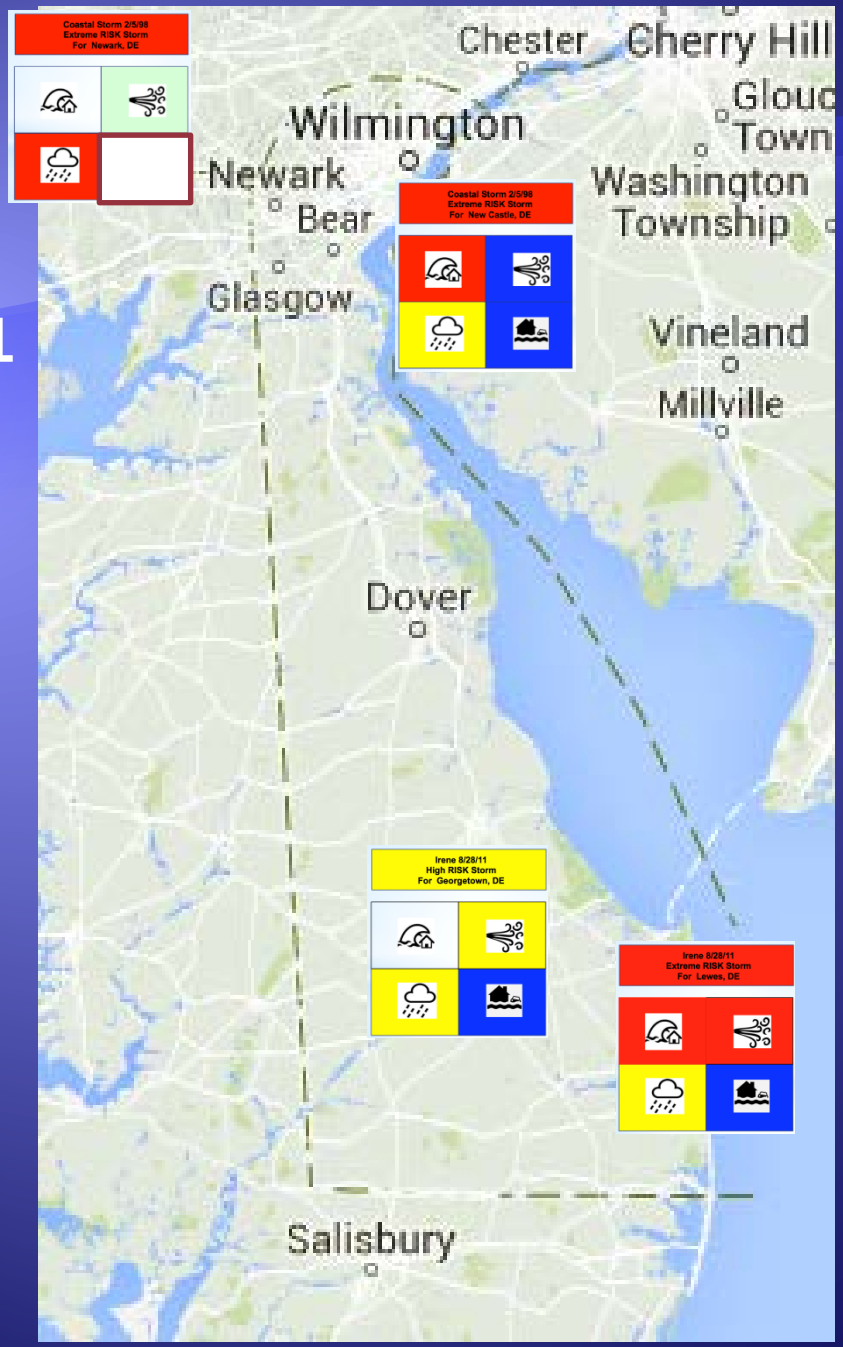
Moderate Risk

Low Risk

No Risk

Hurricane Irene

Aug 24-30, 2011



Extreme Risk

High Risk

Moderate Risk

Low Risk

No Risk

Status of CSSI

- State of Delaware (DNREC), Office of Delaware State Climatologist partnership. Workshop held in 2015.
- Working with Office of New Jersey State Climatologist
- Development of the CSSI is ongoing. Currently investigating intensity measures/ranking systems for each category
- Ultimately to be integrated into Delaware CFMS

Thank You!

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DEOS/DEMAC/ODSC

http://coastal-flood.udel.edu

DELAWARE COASTAL PROGRAMS
DCMP

Special Thanks!