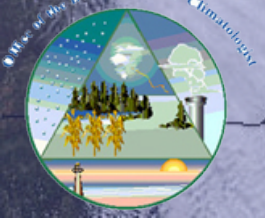
The Delaware Coastal Flood Monitoring System

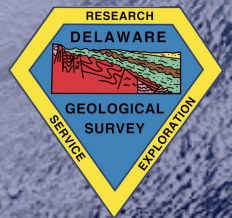
John A. Callahan
Delaware Geological Survey
College of Earth, Ocean, and Environment
University of Delaware

Mid-Atlantic Coastal Resiliency Institute (MACRI)
September 16, 2015
Clayton Hall Conference Center, Newark, DE

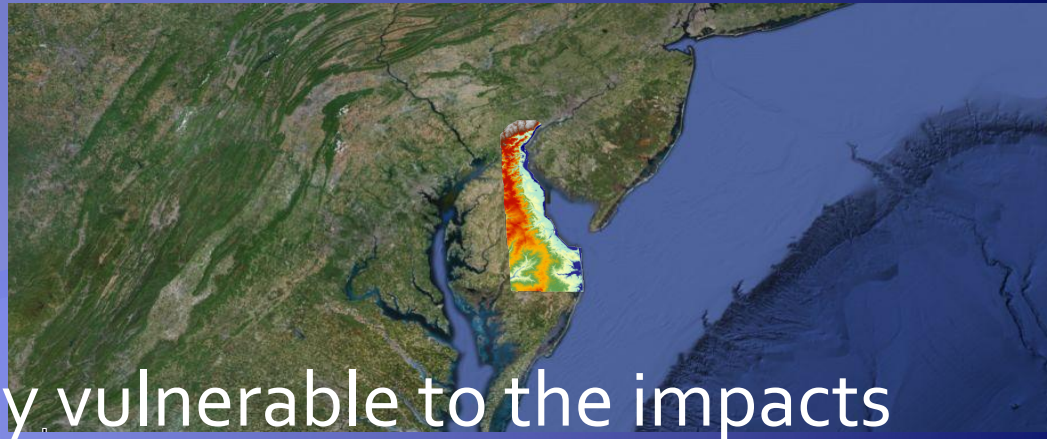


DEMAC

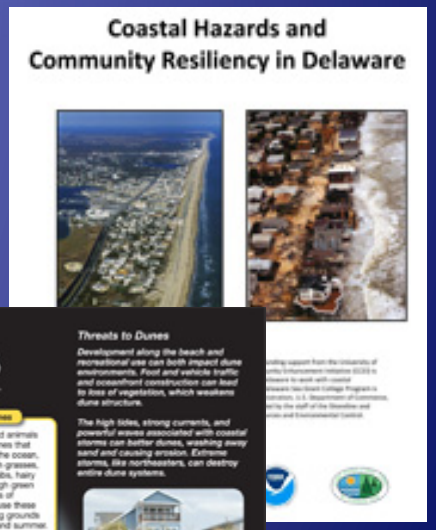
DELAWARE COASTAL PROGRAMS
DCMP

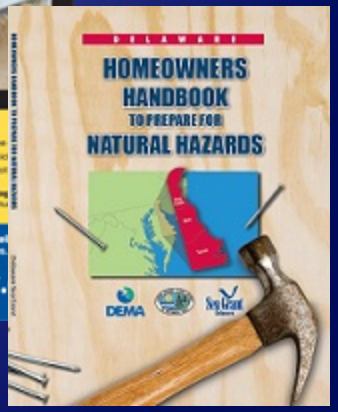


Delaware



- 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



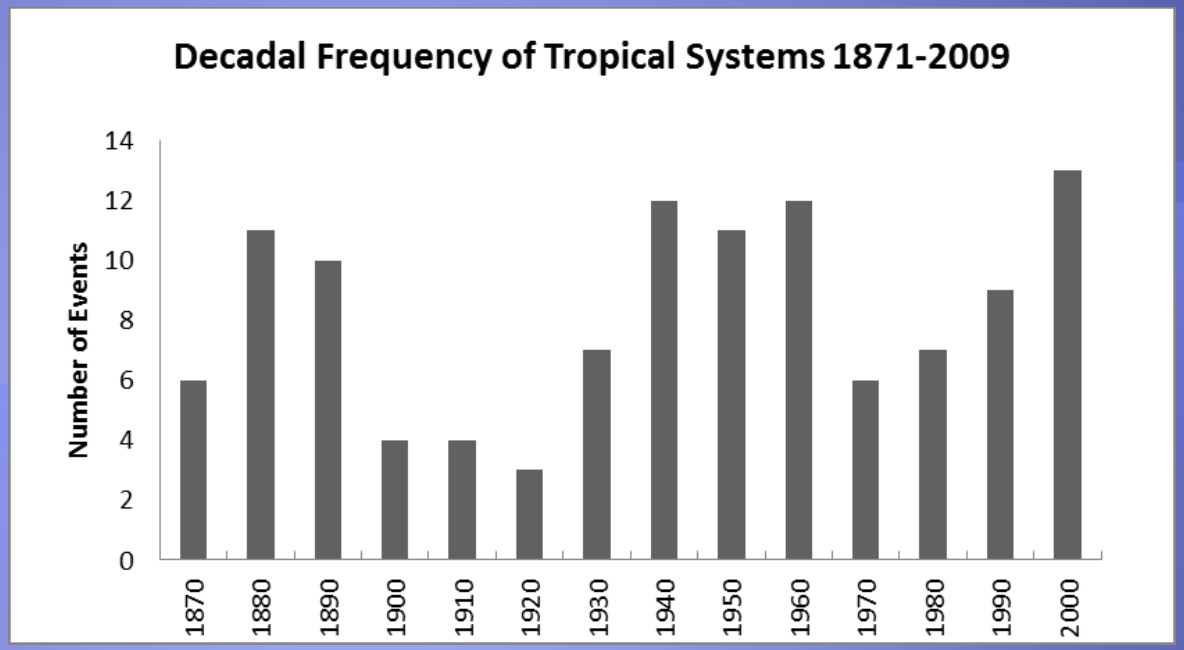


Hurricane Sandy
10/29/2012

Indian River Bay Inlet

Fenwick Island

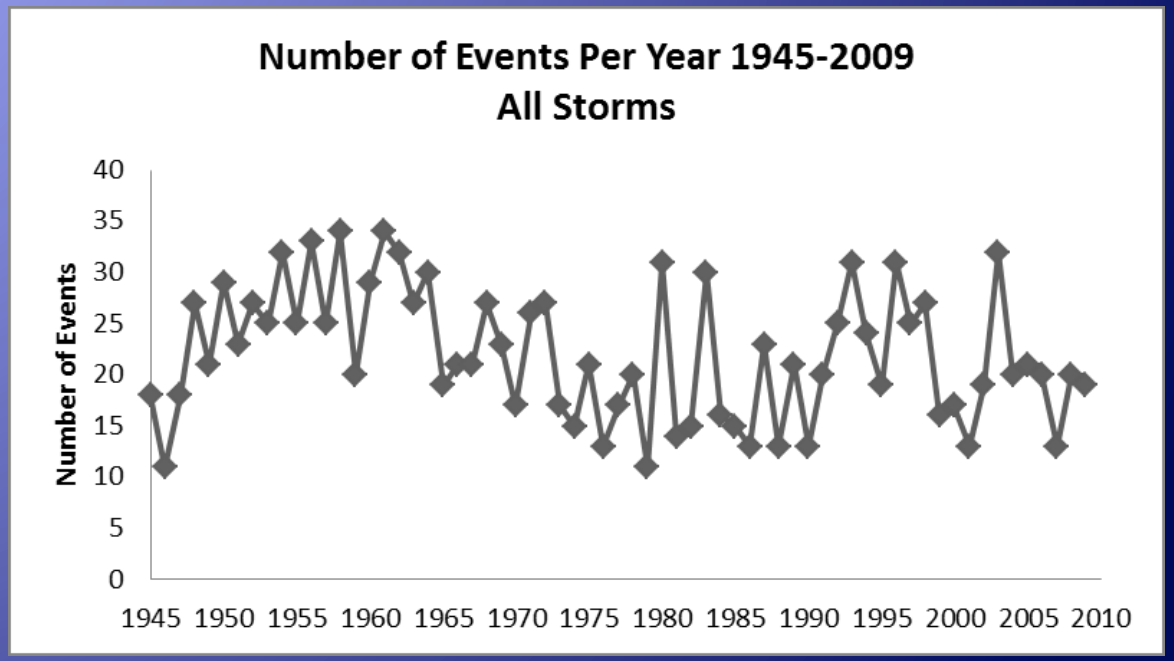
Delaware Coastal Storm Frequency



Tropical Systems

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

All events



http://www.deos.udel.edu/coastalstorm/index.html

Risk Ranking of Hazards in Delaware

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

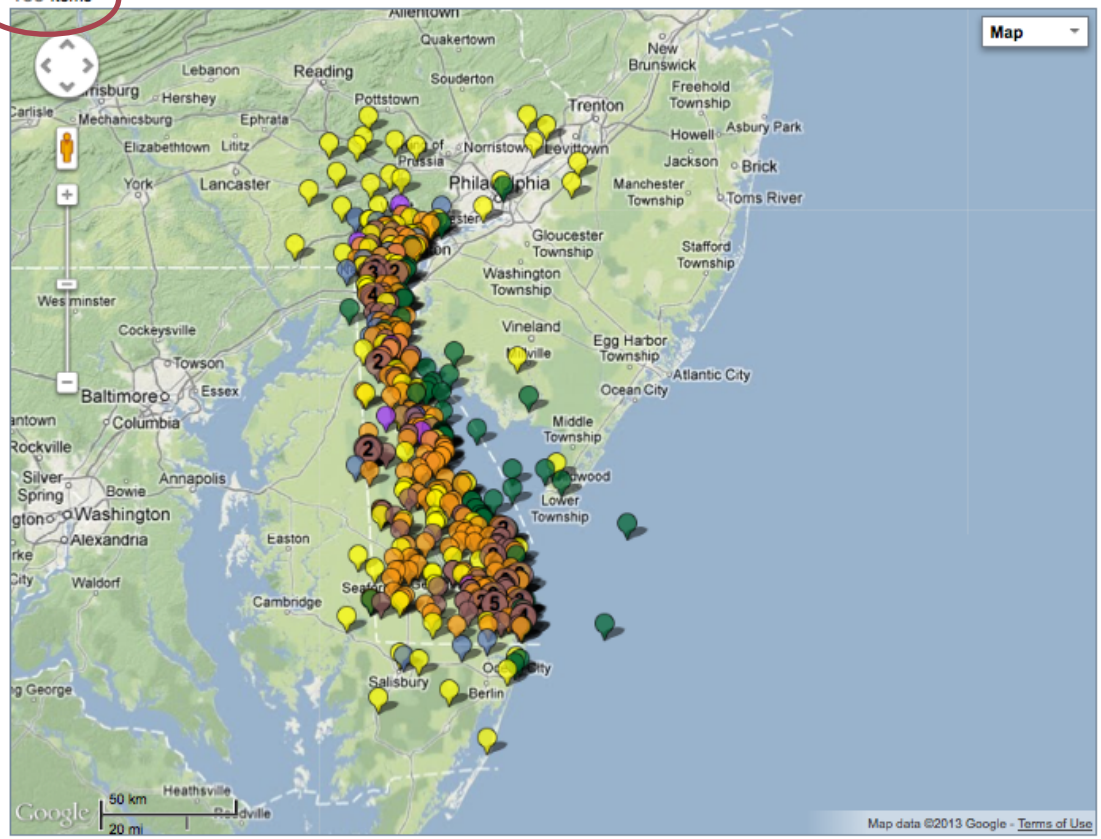
Hazard Ranking	New Castle County	Kent County	Sussex County	Statewide
1	Flood	Flood	Flood	Flood
2	Hurricane Wind	Drought	Drought	Winter Storm
3	Winter Storm	Winter Storm	Winter Storm	Thunderstorm
4	Earthquake	Thunderstorm	Thunderstorm	Hurricane Wind
5	Drought	Extreme Heat/Cold	Extreme Heat/Cold	Extreme 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			

Delaware is very well monitored!

Delaware Environmental Monitoring Sites

MAP • TABLE • LIST VIEW

469 Items



Type

- 137 Groundwater
- 96 Meteorological
- 27 Streamflow
- 66 Tidal
- 159 Water Quality

Source

- 24 COOP/NWS
- 9 DELDOT
- 58 DEOS
- 137 DGS
- 169 DNREC
- 12 FAA/NWS
- 14 NOAA
- 2 USACE
- 44 USGS

Project

- 4 Bombay Hook
- 6 CFMS
- 24 COOP/NWS
- 2 DCMP
- 9 DELDOT
- 50 DEOS

Text Search

Delaware Watersheds

Active?

- 71 N
- 398 Y

Realtime?

- 335 N
- 134 Y

Variables

- 108 air temperature
- 138 bacteria
- 1 cdom
- 1 ceiling height
- 1 chlorophyll
- 1 conductivity
- 1 current direction
- 1 current speed
- 74 dewpoint temperature
- 27 discharge
- 156 do
- 15 do %sat
- 4 dominant wave period
- 138 hardness
- 1 nitrate
- 146 nutrients

Groundwater · Meteorological · Streamflow · Tidal · Water Quality · Multiple

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Delaware Environmental Monitoring and Analysis Center (DEMAC)
University of Delaware • Newark, DE 19716 • USA
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Contact DEMAC

Dare to be first. UNIVERSITY OF DELAWARE

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

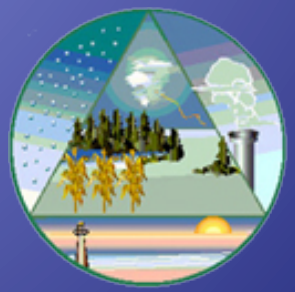
http://udsrs.udel.edu

DGS and ODSC staff serve in the Technical Assistance Center at the DEMA's EOC during extreme events.

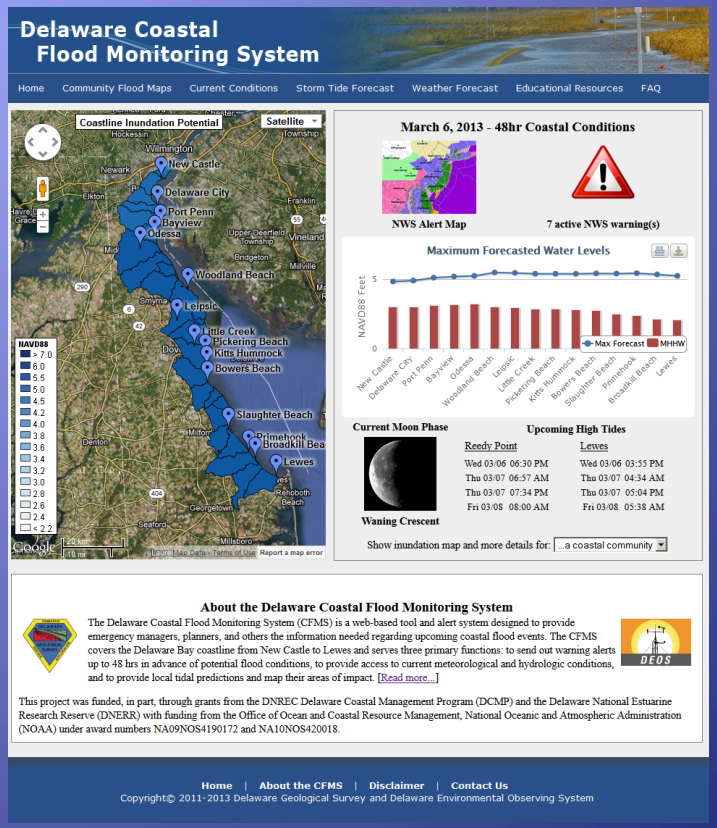
- Tropical systems
- Nor'easters
- Wind, precip, ice/snow
- Stream flooding
- Storm surge
- Evacuations
- Road and bridge closures

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

All of the groups mentioned thus far make up small part of UD and Delaware team!



Development of the Delaware Coastal Flood Monitoring System…



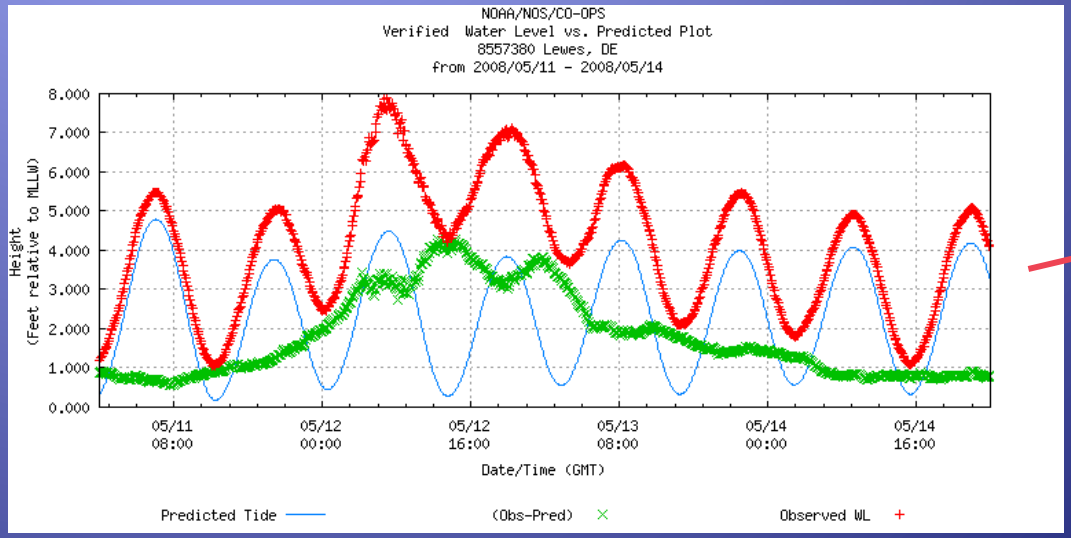
THE DELAWARE COASTAL FLOOD MONITORING SYSTEM

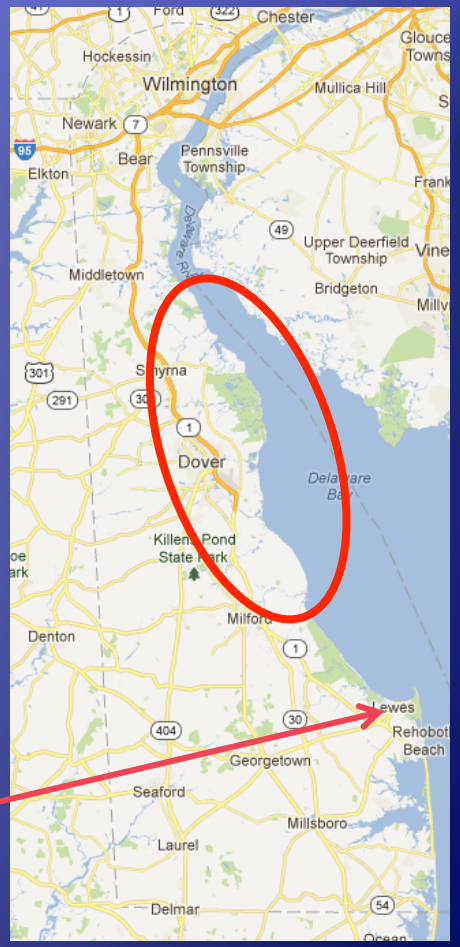
John Callahan (Delaware Geological Survey)
Kevin Brinson, Daniel Leathers (Delaware Environmental Observing System)
Tina Callahan (Delaware Environmental Monitoring and Analysis Center)

MACRI Inaugural Workshop
Aug 28, 2014

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



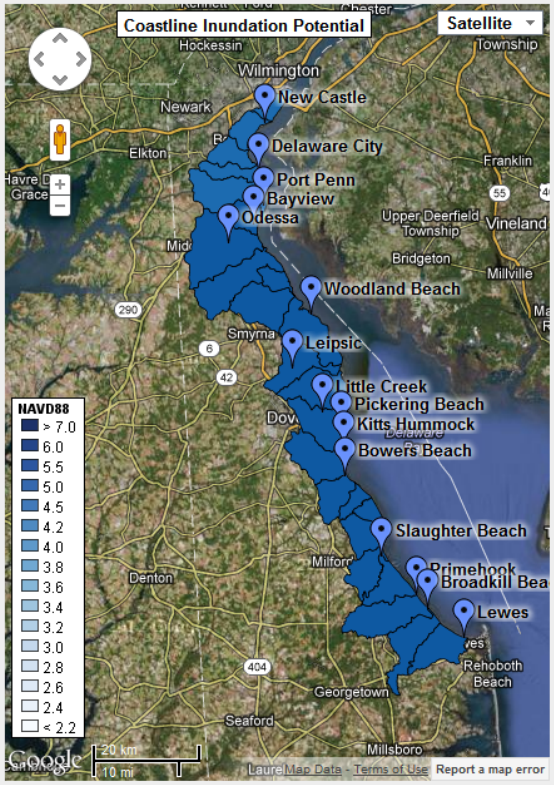


Can we give people more time?

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

Delaware Coastal Flood Monitoring System

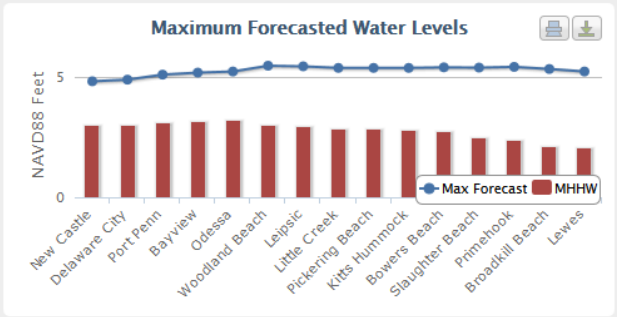
Home | Community Flood Maps | Current Conditions | Storm Tide Forecast | Weather Forecast | Educational Resources | FAQ



March 6, 2013 - 48hr Coastal Conditions

NWS Alert Map

7 active NWS warning(s)



Current Moon Phase

Waning Crescent

Upcoming High Tides

Reedy Point	Lewes
Wed 03/06 06:30 PM	Wed 03/06 03:55 PM
Thu 03/07 06:57 AM	Thu 03/07 04:34 AM
Thu 03/07 07:34 PM	Thu 03/07 05:04 PM
Fri 03/08 08:00 AM	Fri 03/08 05:38 AM

Show inundation map and more details for: ...a coastal community

About

The Delaware Coastal Flood Mor
emergency managers, planners, a
covers the Delaware Bay coastline from New Castle to Lewes and serves three primary functions: to send out warning alerts up to 48 hrs in advance of potential flood conditions, to provide access to current meteorological and hydrologic conditions, and to provide local tidal predictions and map their areas of impact. [Read more...]

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 and NA10NOS420018.

Delaware Coastal Flood Monitoring System

Bowers Beach

Flood Map Water Depth (Feet)

MLLW	NAVD88
9.83	7.0
8.83	6.0
7.83	5.0
6.83	4.0
5.83	3.0
4.83	2.0
3.83	1.0
2.83	0.0

Reset Map to: Current | Max

Current model data:
-3.1 ft* ▼
Today, 3:00 pm

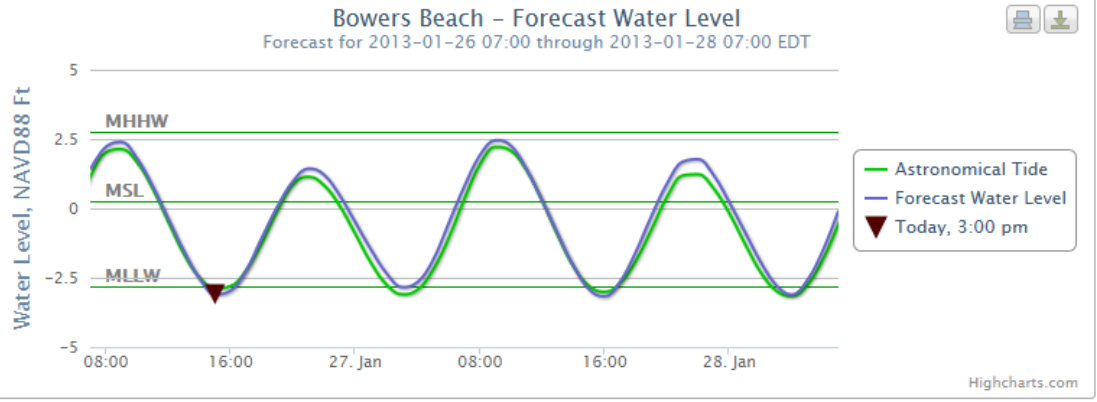
Maximum forcasted water level:
2.46 ft*
01/27/2013 09:00 am

MHHW: 2.75 ft
MSL: 0.248 ft
MLLW: -2.83 ft

***All data relative to NAVD88**

▼ = **Current time**

Tidal Graph | Tidal Data | Bowers Beach Rd | South Bowers Rd



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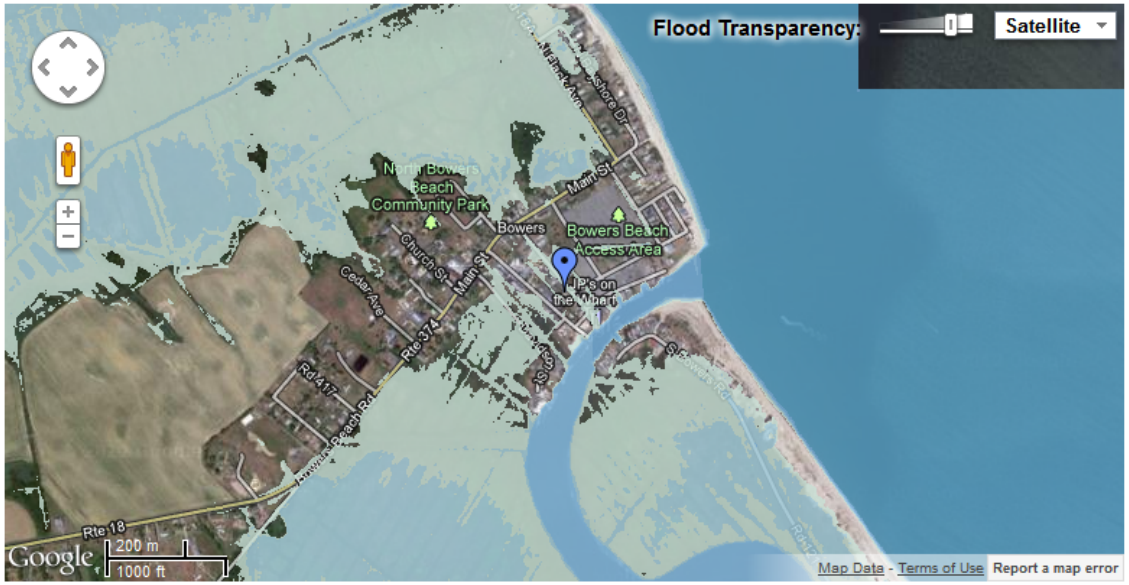

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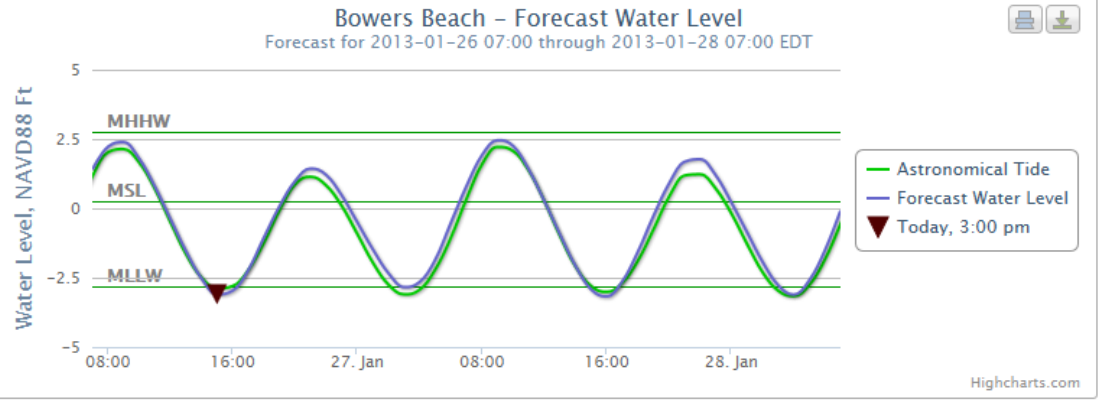

Delaware Coastal Flood Monitoring System

Home | Community Flood Maps | Current Conditions | Tide Models | Weather Forecast | Educational Resources | FAQ

Bowers Beach

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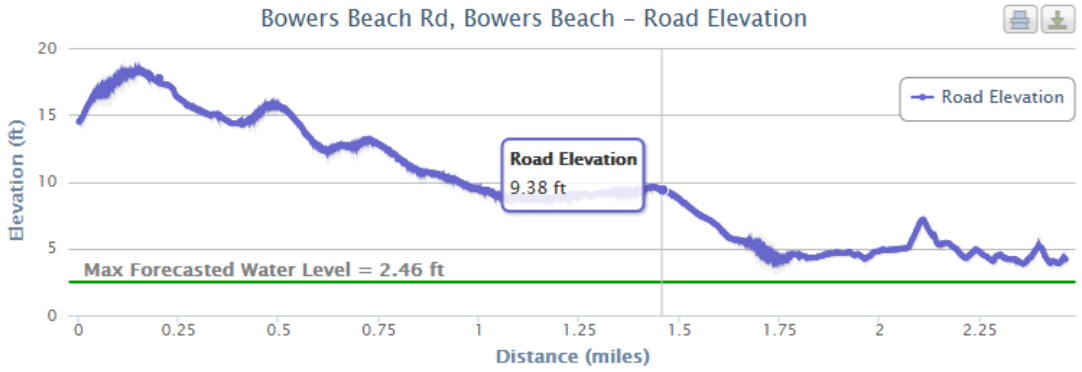
Tidal Graph | Tidal Data | Bowers Beach Rd | South Bowers Rd



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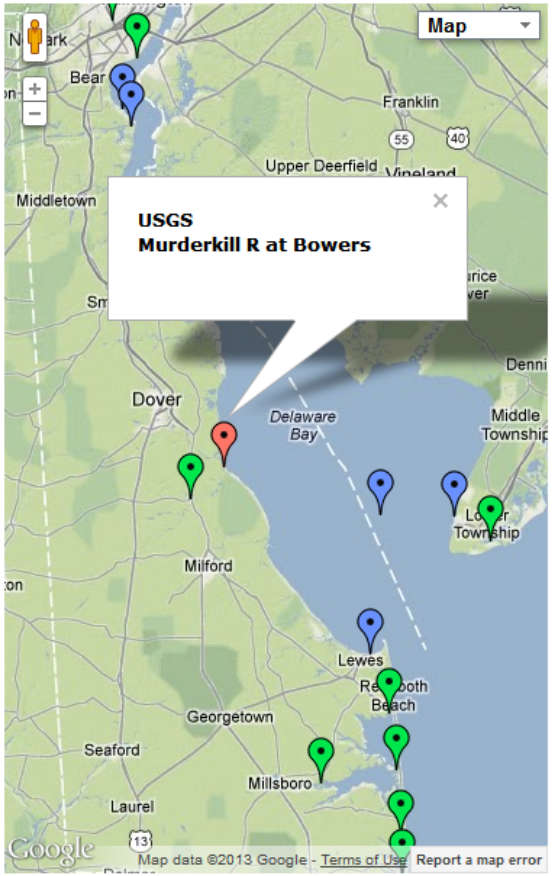
Delaware Coastal Flood Monitoring System

Current Meteorological and Tidal Conditions

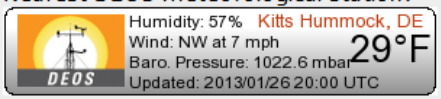
There are two primary networks for real-time monitoring of tides: United States Geological Survey (USGS) and NOAA's National Ocean Service (NOS). Both networks are displayed on the map below. Click on a map marker to display data.



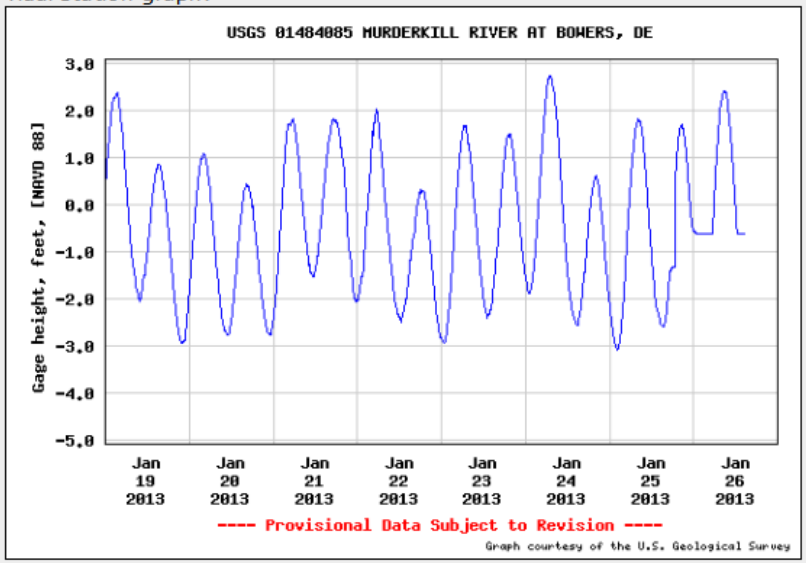
= USGS station = NOS station

USGS: Murderkill R at Bowers

Nearest DEOS meteorological station:



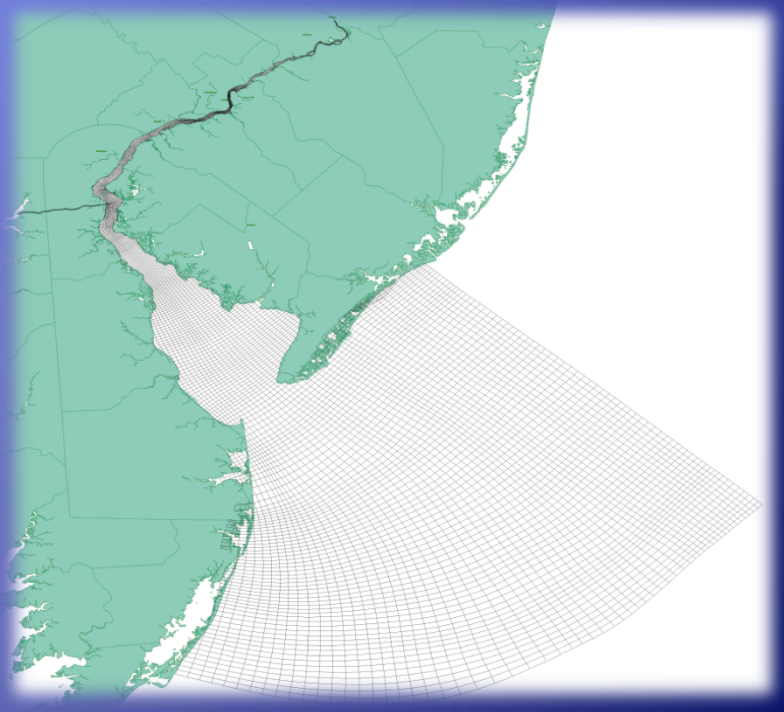
Tidal station graph:



Source: *http://waterdata.usgs.gov/usa/nwis/uv?01484085*

All tidal data graphs are MLLW feet, except for the USGS Bowers Beach gage, which is NAVD88 feet.

DBOFS Forecast

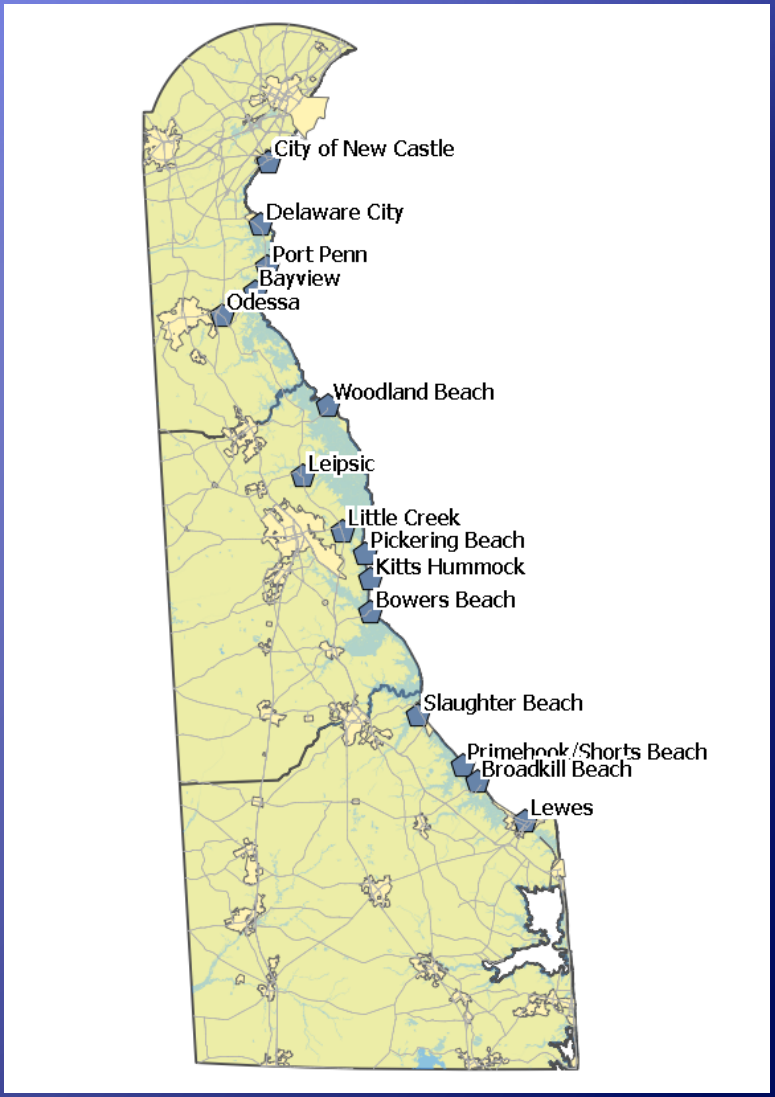


- 48-hour forecast
- 4xdaily, hourly output
- 100m – 3km grid cell
- 119 x 732 x 10
- ROMS hydro model
- Winds: NAM-12, then GFS
- Nowcast mode: CO-OPS and USGS obs
- Forecast mode: ET-Surge and Nowcast output for boundary/initial conditions

Coastal Communities

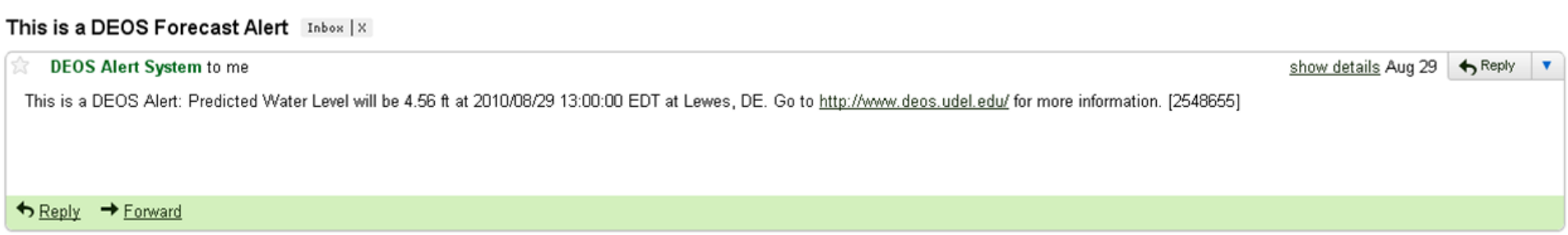
- 15 communities between cities of New Castle and Lewes

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



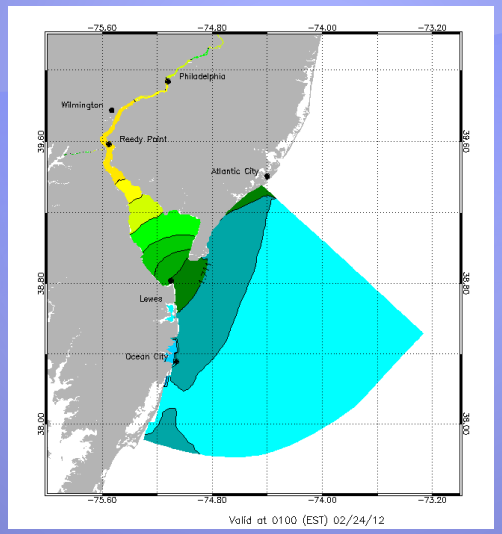
Forecast Alerts

- 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.

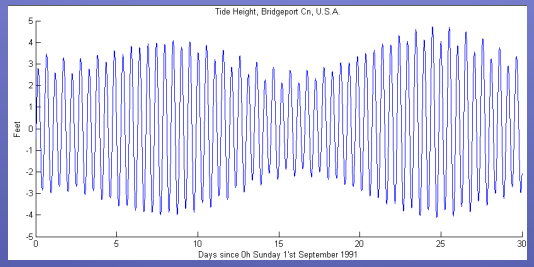
How It Works



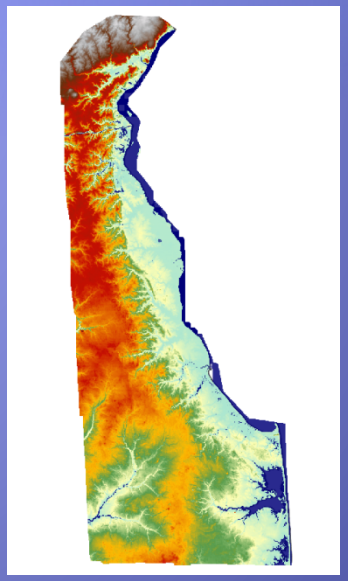
Delaware Bay Operational Forecast System (DBOFS)

+

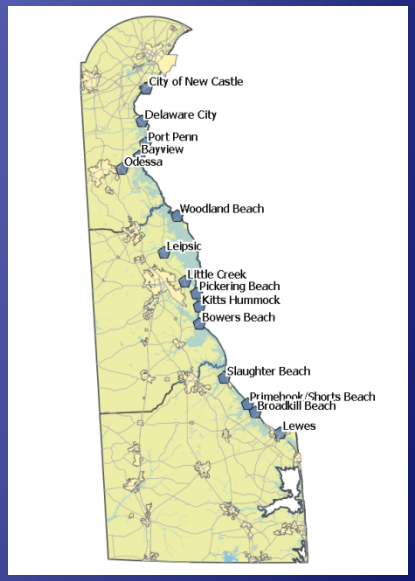
+



Astronomical Tides



Bathtub Model



Output
Community Maps
and Alerts

Demonstration

http://coastal-flood.udel.edu

CFMS thus far

- Current site released in early 2013. Education and training workshops as needed.
- Overall, very positive response. In use during coastal events by numerous state and county agencies.
- Maps do well with highlighting problem areas and with magnitude.
- 48 hour lead time seems to be sufficient.

Some ongoing work…

1. High Water Mark Database and Display System

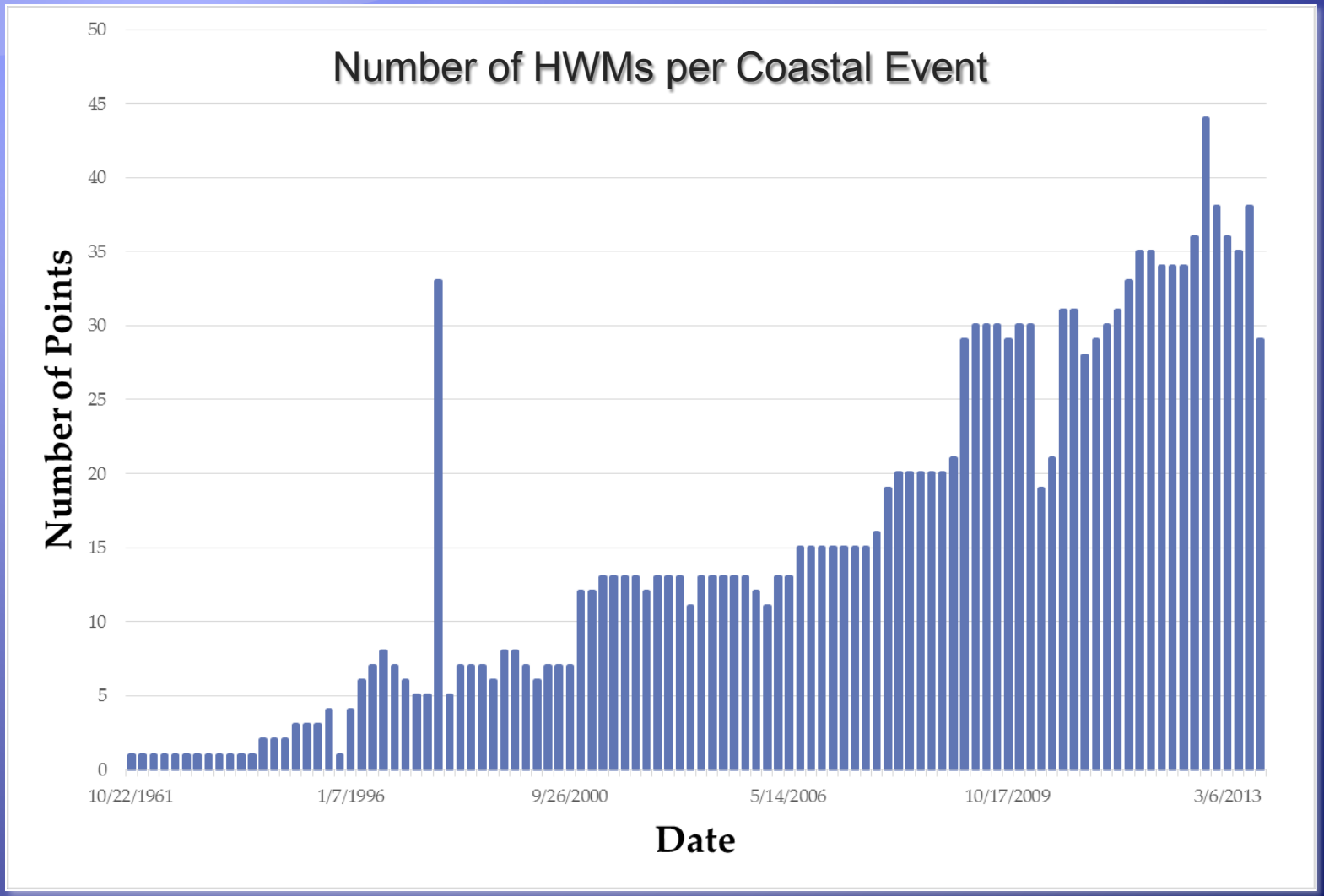
Delaware Sea Grant funded!

1. Technical infrastructure to store, display, and share HWMs for DE
2. Collaborative process for the pre- and post-event HWM collection
3. Test the feasibility of rapid deployment of low-cost water level sensors

High Water Mark Database and Display System – Data Collection

- 1960 – 2014, coastal focus
- Data sources: tide gages, reports and publications, other state agency records, etc…
- Reference tidal thresholds:
  - Reedy Point: 7.5 ft. MLLW (NOS)
  - Bowers Beach: 5.0 ft. NAVD88 (USGS)
  - Lewes: 7.0 ft. MLLW (NOS)
- Master HWM list of events includes (so far):
  - 114 event days
  - 19 days are associated with 9 multi-day events
  - 104 events with 1751 valid tidal readings

High Water Mark Database and Display System – Data Collection

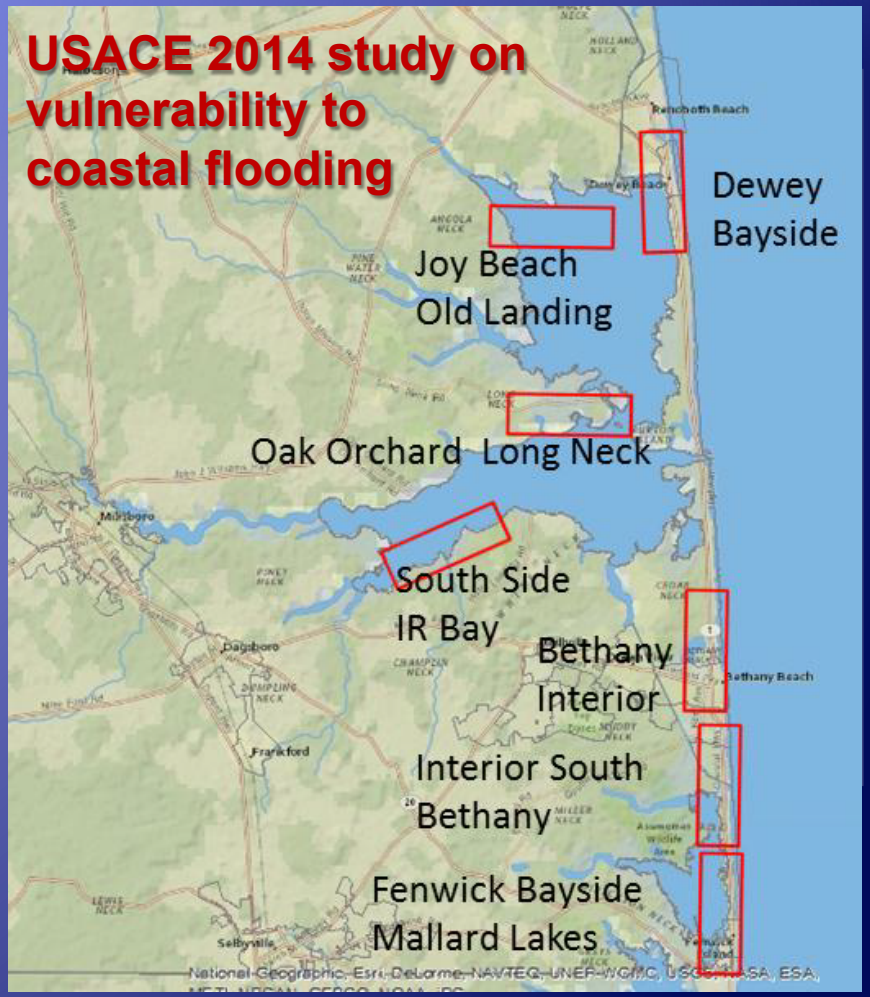


High Water Mark Database and Display System

- Website currently in development
  - Display water depth at all measured locations
  - Choose by storm or location
  - Update database using partners data
- Develop "storm tide books"
  - Listing of all top storms per gage
- Workshop held in Nov 2014

2. 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

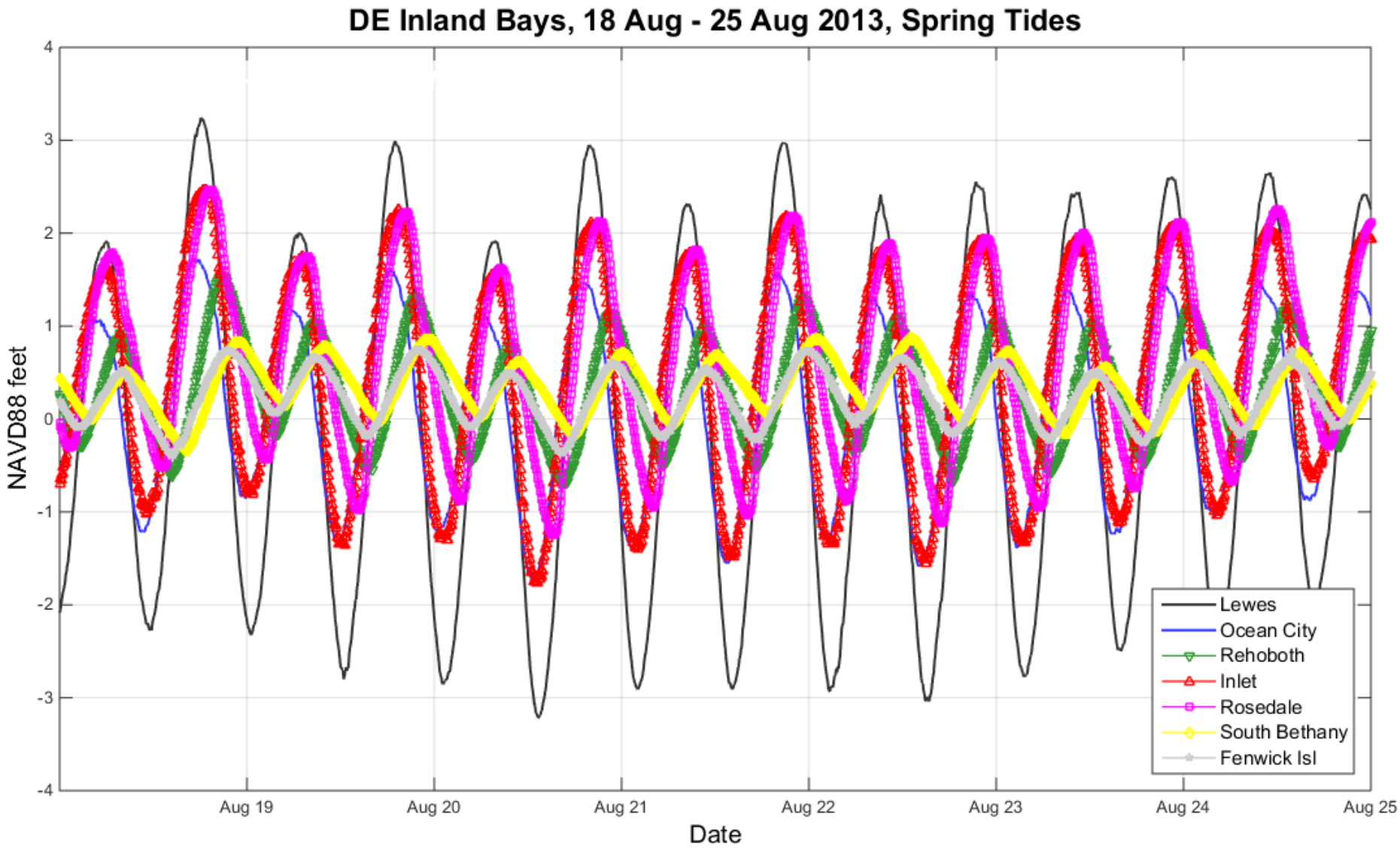
- Lewes Breakwater (1919)
- Ocean City Inlet (1997)

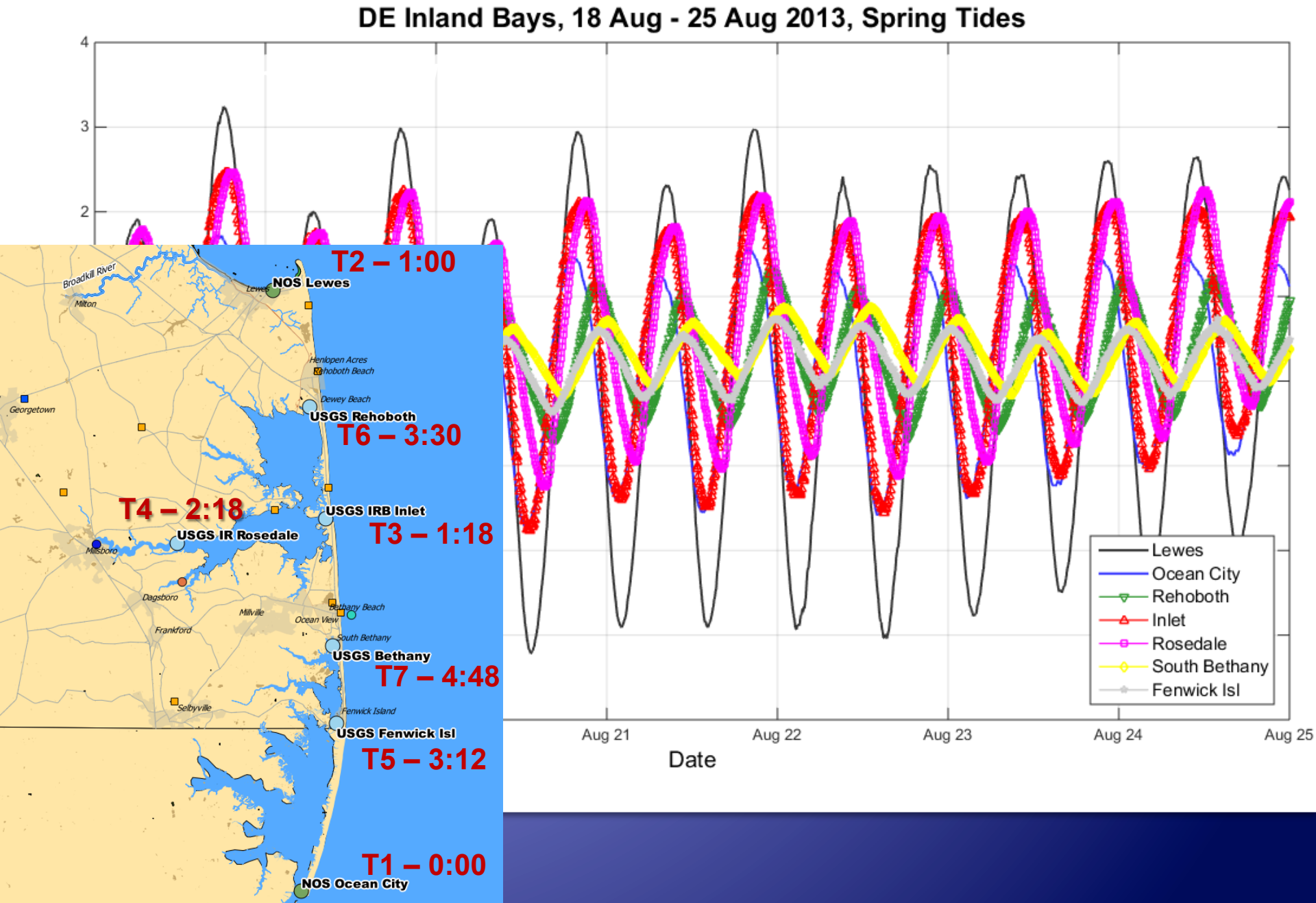
United States Geological Survey

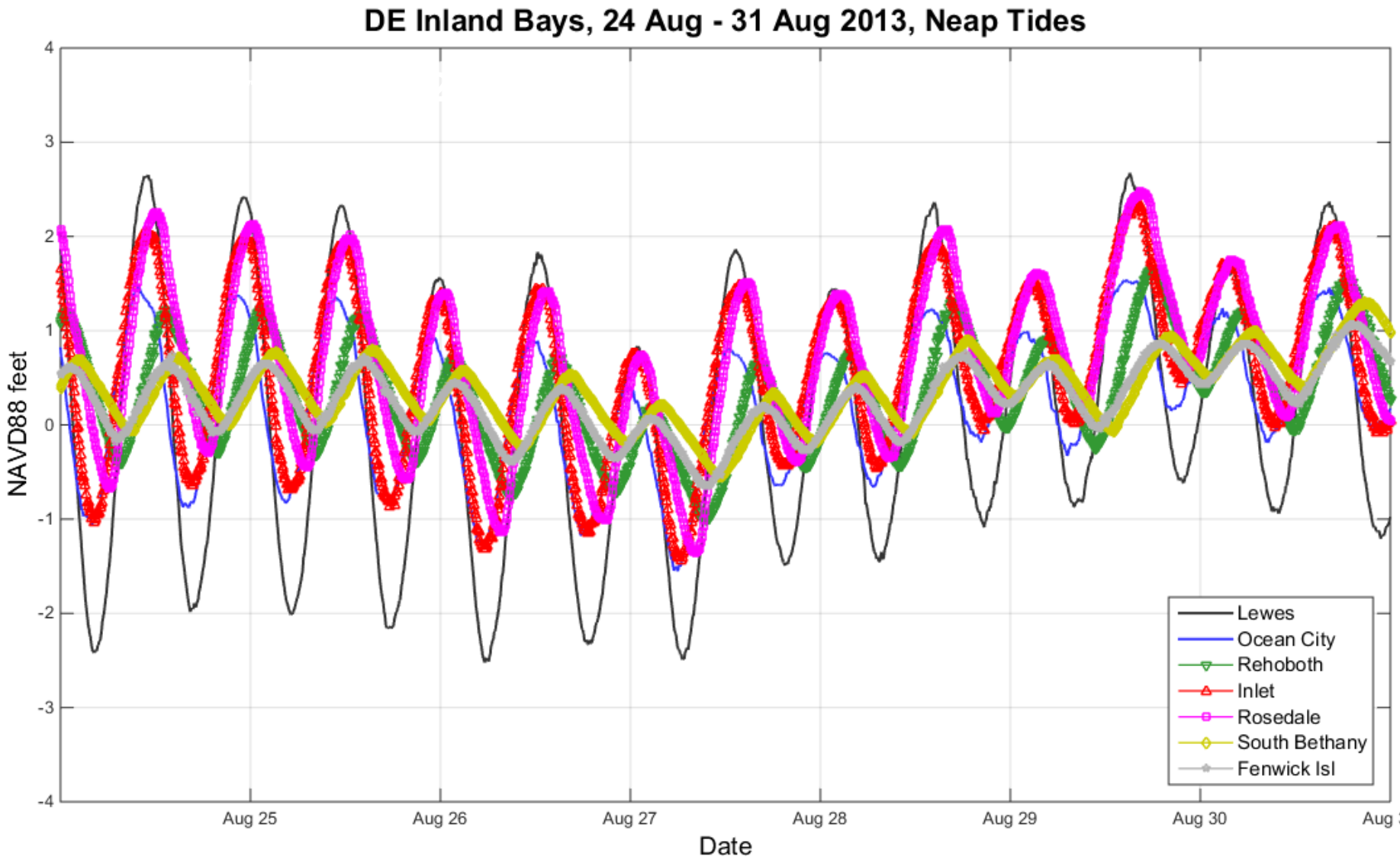
- Rehoboth Beach (1985)
- Indian River Bay Inlet (1989)
- IRB Rosedale (1992)
- South Bethany (1999)
- Fenwick Island (1999)

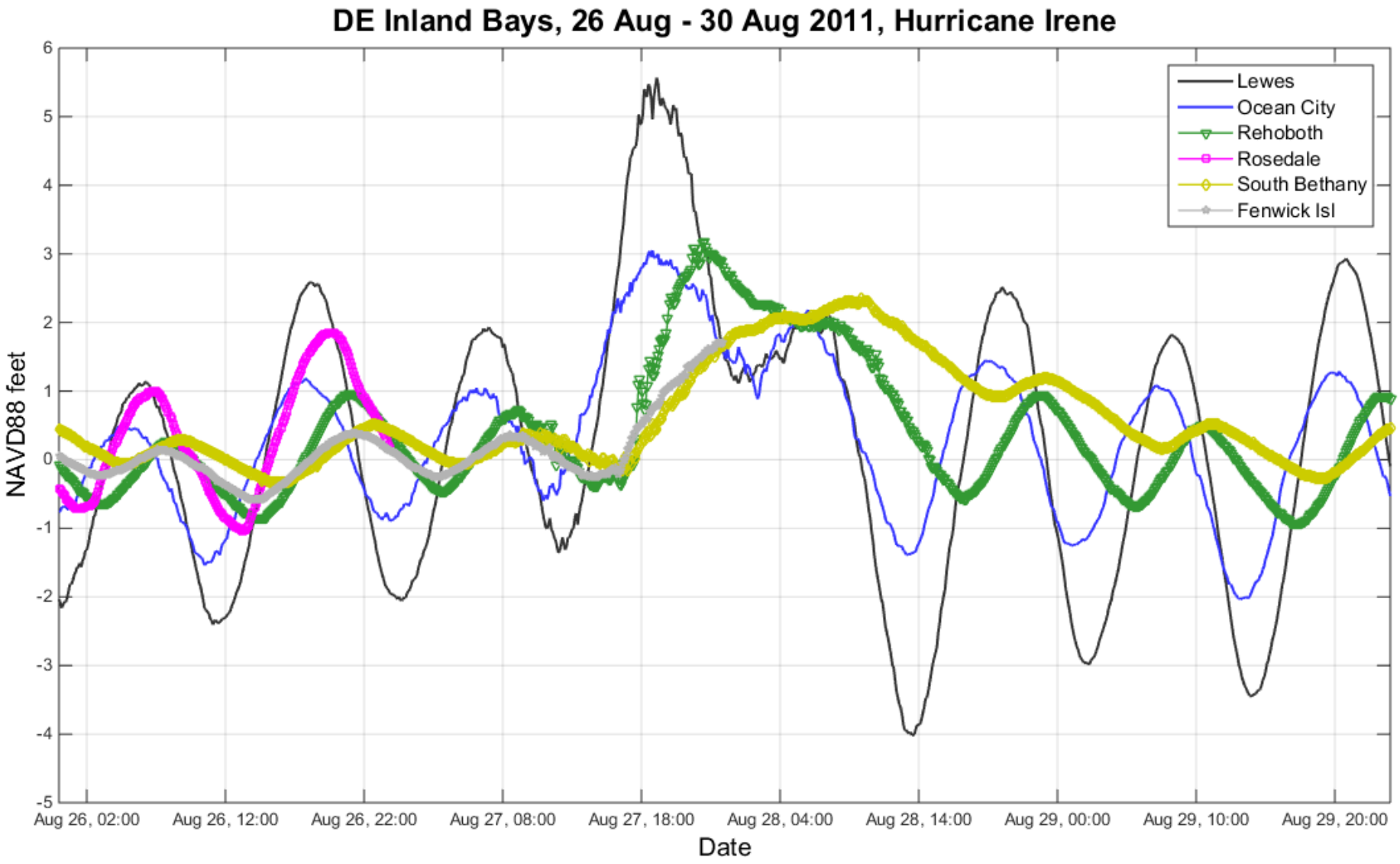
Delaware Environmental Observing System (DEOS)

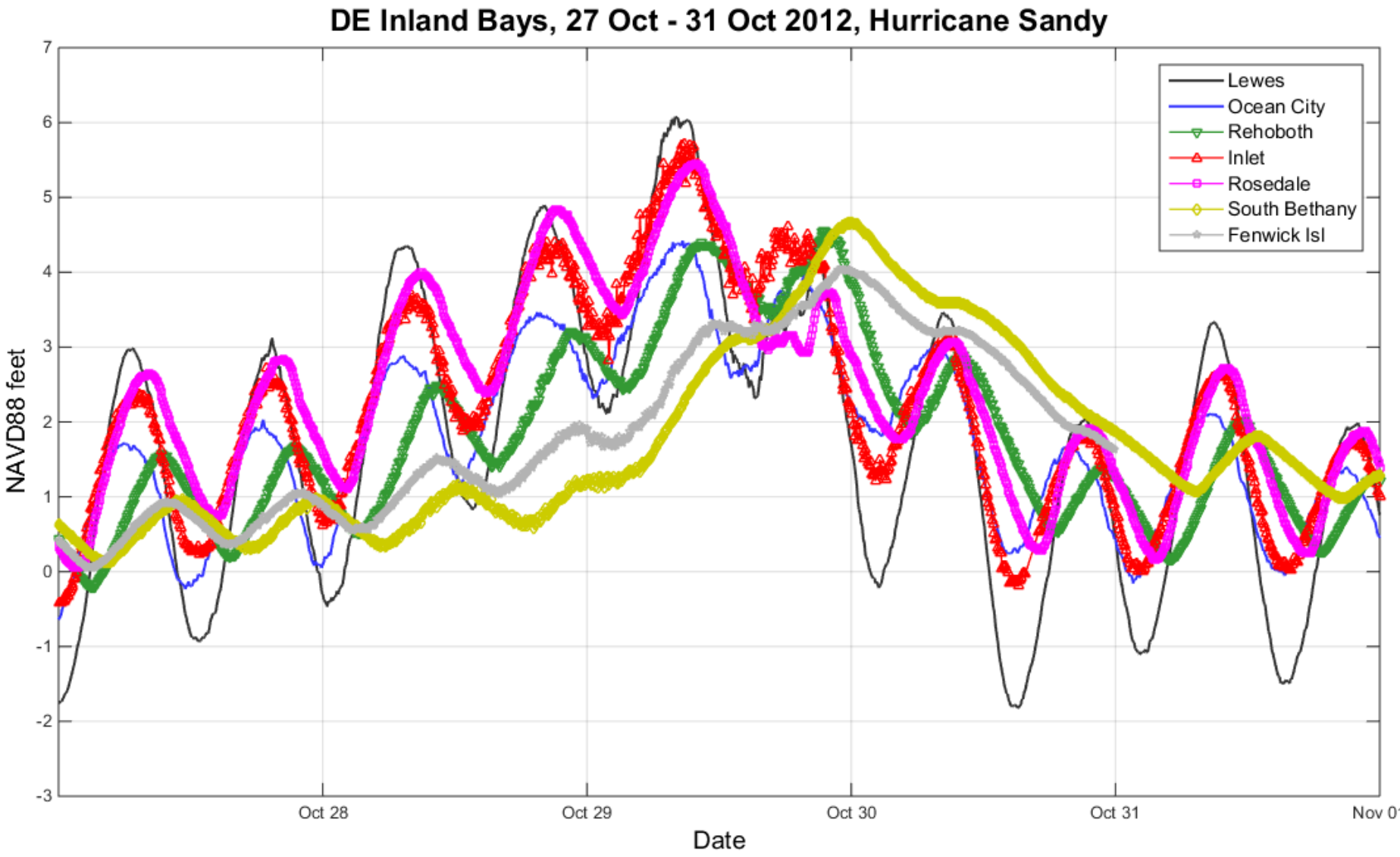
- Research monitoring sites
- Meteorological stations

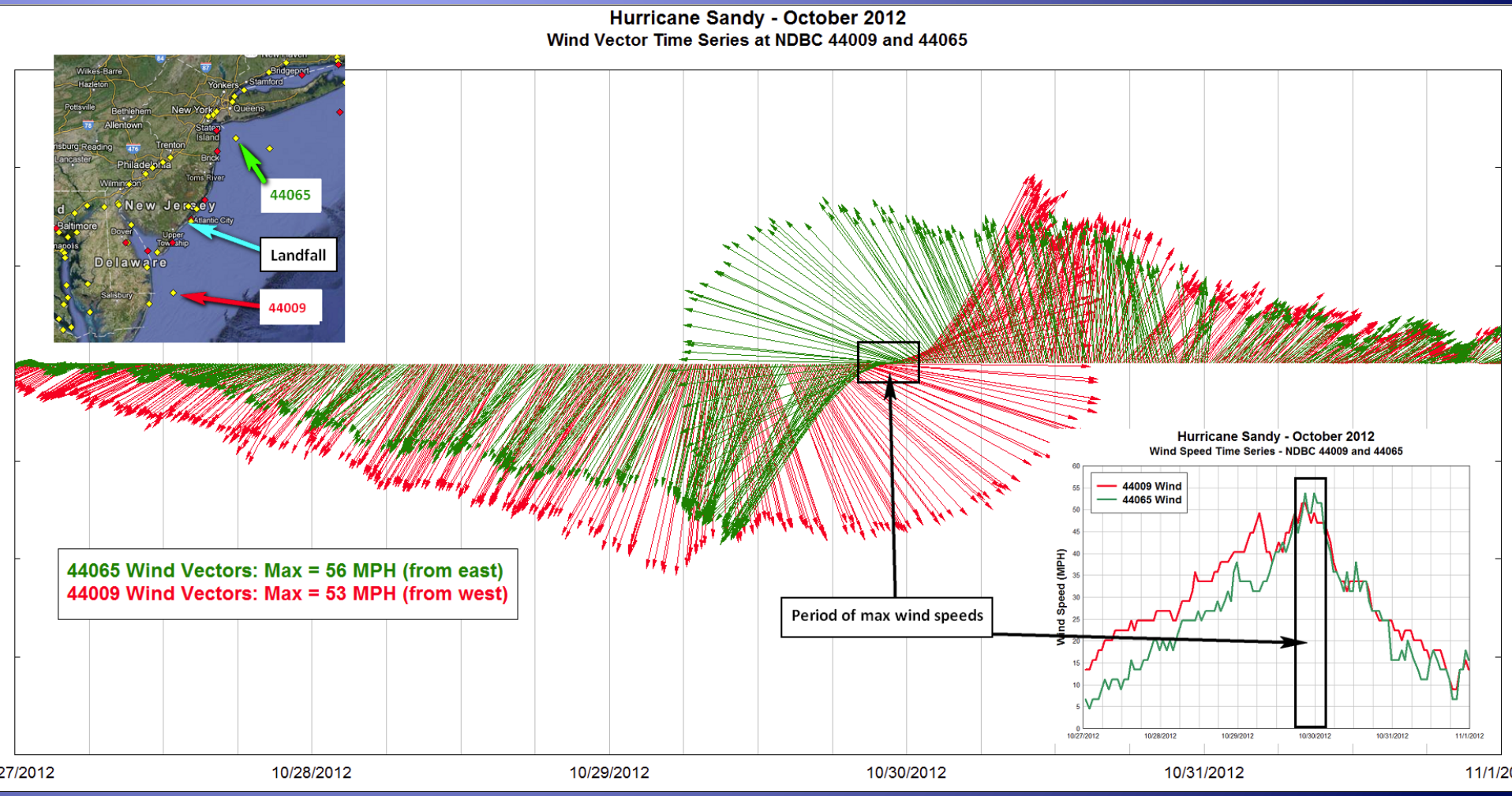

DE Inland Bays, 18 Aug - 25 Aug 2013, Spring Tides
NAVD88 feet
4
3
2
1
0
-1
-2
-3
-4
Aug 19
Aug 20
Aug 21
Aug 22
Aug 23
Aug 24
Aug 25
Date
Lewes
Ocean City
Rehoboth
Inlet
Rosedale
South Bethany
Fenwick Isl


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 – 1:00
NOS Lewes
USGS Rehoboth
T6 – 3:30
T4 – 2:18
USGS IRB Inlet
T3 – 1:18
USGS IR Rosedale
USGS Bethany
T7 – 4:48
USGS Fenwick Isl
T5 – 3:12
T1 – 0:00
NOS Ocean City
Broadkill River
Milton
Georgetown
Millsboro
Dagsboro
Frankford
Millville
Ocean View
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, 26 Aug - 30 Aug 2011, Hurricane Irene
NAVD88 feet
Date
Lewes
Ocean City
Rehoboth
Rosedale
South Bethany
Fenwick Isl
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
Aug 26, 02:00
Aug 26, 12:00
Aug 26, 22:00
Aug 27, 08:00
Aug 27, 18:00
Aug 28, 04:00
Aug 28, 14:00
Aug 29, 00:00
Aug 29, 10:00
Aug 29, 20:00


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



Source: Jeff Gebert, USACE Philadelphia District, 2013 presentatio

Top Observed Storm Tides

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

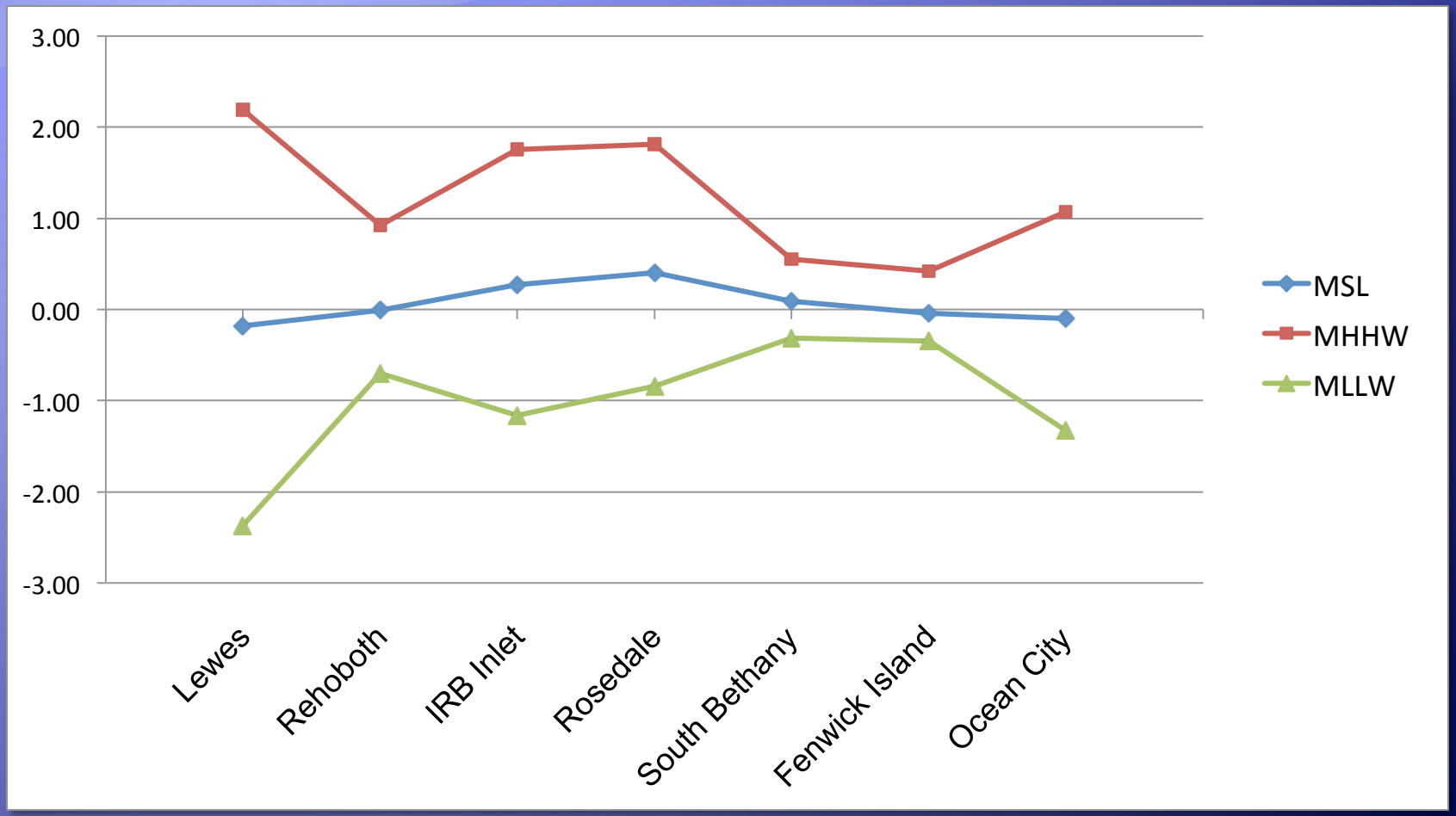
Rehoboth	WL (ft)
10/29/2012	4.56
10/31/1991	3.67
11/13/2009	3.62
5/12/2008	3.4
10/25/2005	3.28

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

Tidal and Storm Surge Relationships in Delaware Inland Bays

* 12 new water level sensors
* Statistical relationship of ocean-side tides/surge to Inland Bays coastal regions, based on wind/precip!
* Analysis of inundation frequency and severity
* Real-time application of early warning system

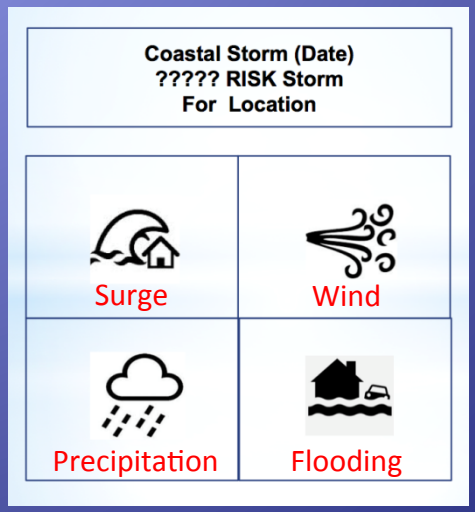
3. Coastal Storm Severity Index (CSSI)

- Storm severity is usually classified based on 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…

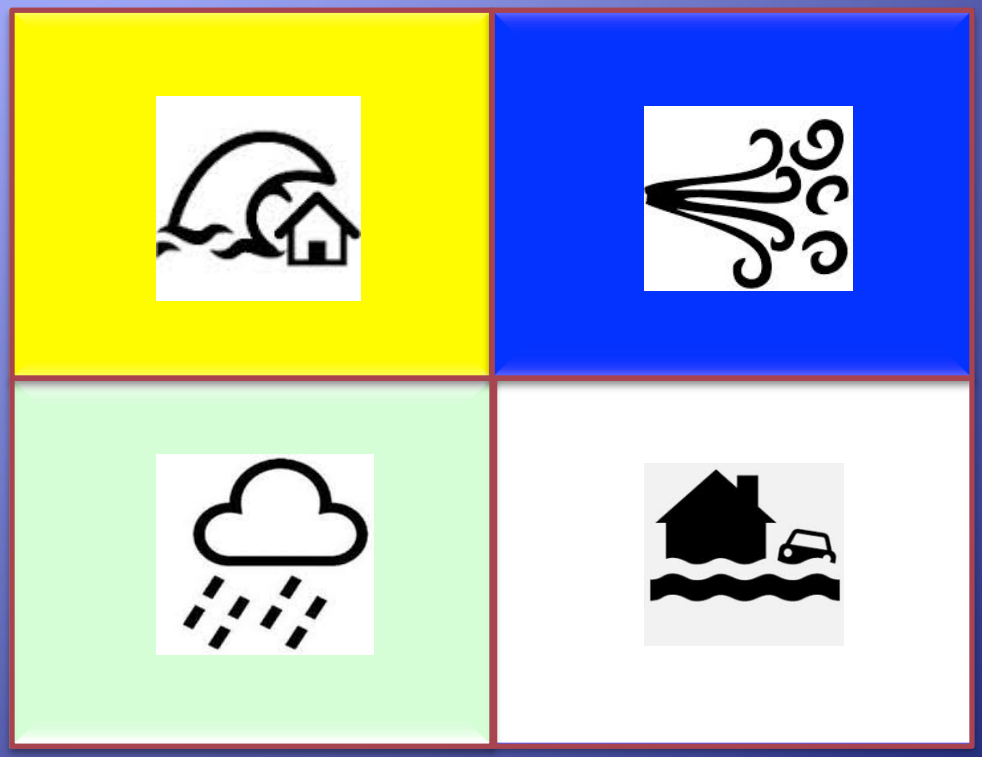
Model forecasts of precipitation, winds, surge, and stream flow.

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



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

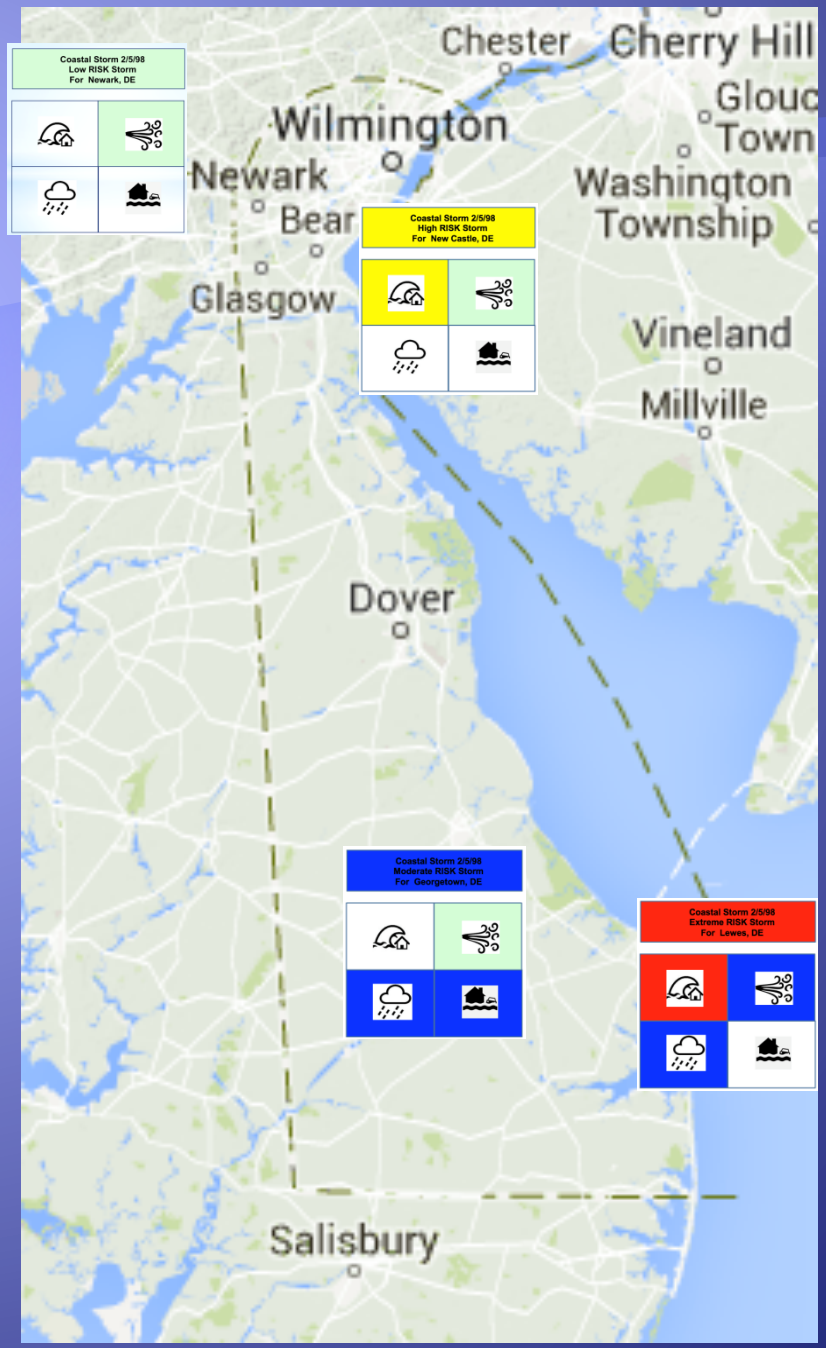
Coastal Storm (Date)
????? RISK Storm
For Location



Extreme Risk
High Risk
Moderate Risk
Low Risk
No Risk

Nor’easter

Feb 4-6, 1998



Extreme Risk

High Risk

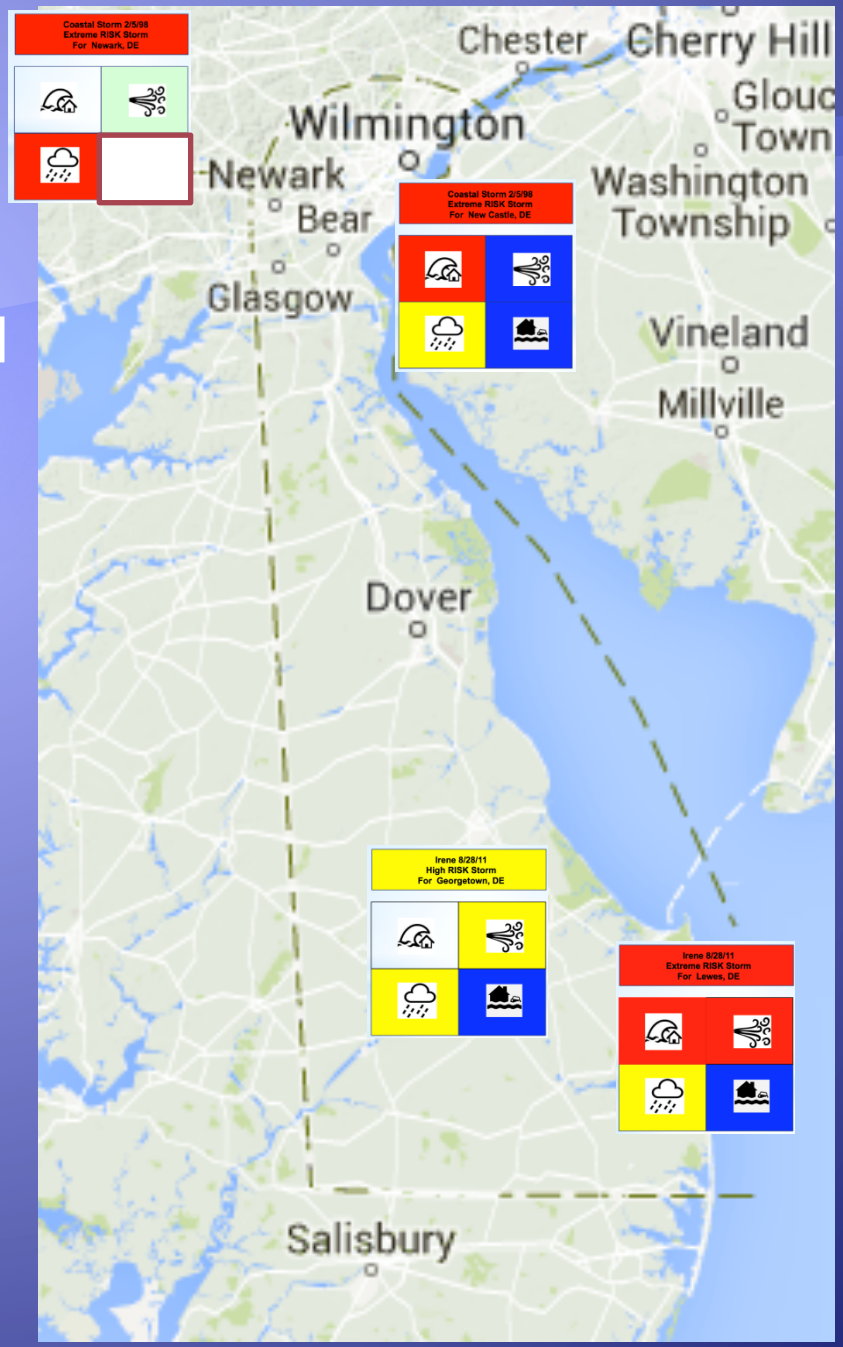
Moderate Risk

Low Risk

No Risk

Hurricane Irene

Aug 24-30, 2011



Extreme Risk

High Risk

Moderate Risk

Low Risk

No Risk

Education and Training

- Geared toward state and county emergency management personnel
- Initial user guide and training workshop was held in Summer 2012
- Ongoing training held as needed

Future Development

- Mobile-friendly version of website in Jan 2015
- Import of new lidar-based DEM
  - Collected in Winter 2014, post Sandy Funds
- Incorporation of wind forecasts
- Point and click function on water depth grids

- Possible integration with…
  - Statistical work for Delaware Inland Bays
  - Coastal Storm Severity Index

Regional Implementation

- Regional Forecast Models – CBOFS, ADCIRC-based, Next-generation ET-SURGE (ESTOFS)
- Output data and maps can be shared through open, interoperable services
  - Accessible to GIS or other applications
- Data does not have to stop at borders
  - Lidar DEM, wind and water level forecasts
- Keep it simple, but no simpler.

Thank You!

John Callahan
Delaware Geological Survey
john.callahan@UDel.Edu

Kevin Brinson, Daniel Leathers , and Tina Callahan
DEOS/DEMAC/ODSC

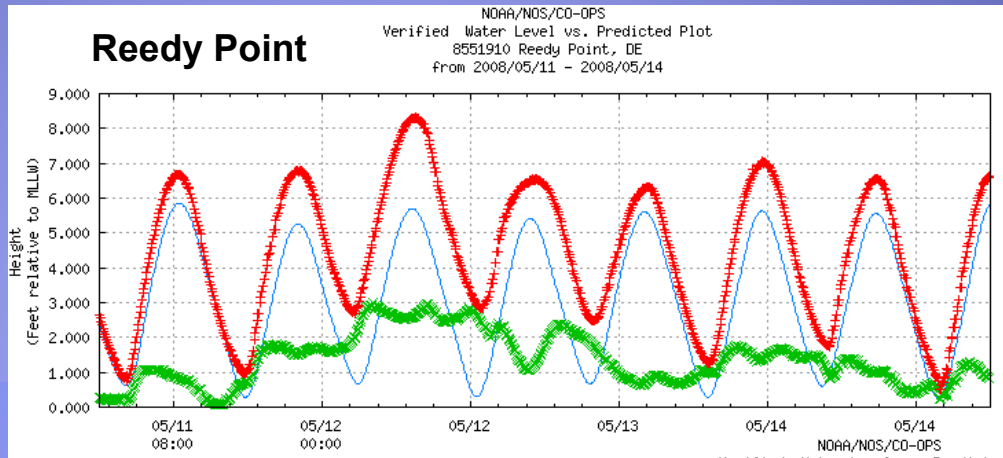
DELAWARE COASTAL PROGRAMS
DCMP

Special Thanks!

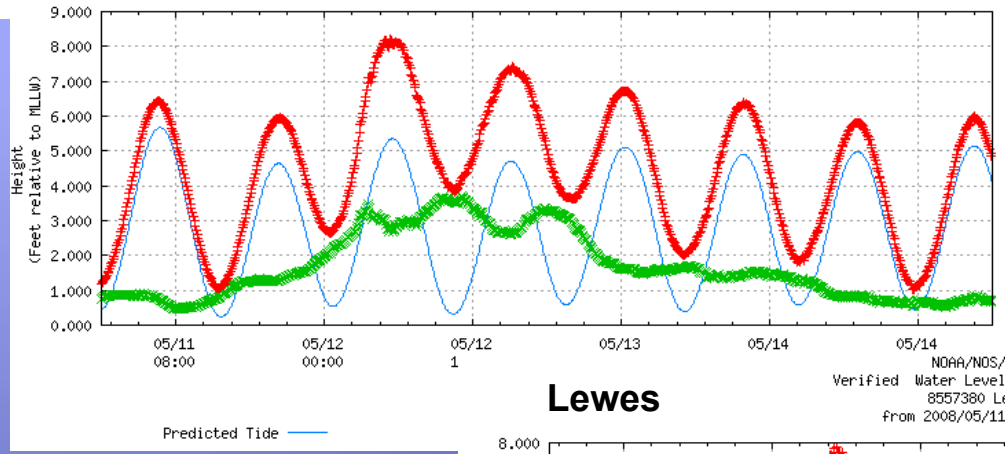
Mother's Day Storm
NOAA Tide Gages

2 – 3 ft above MHHW in Delaware Bay

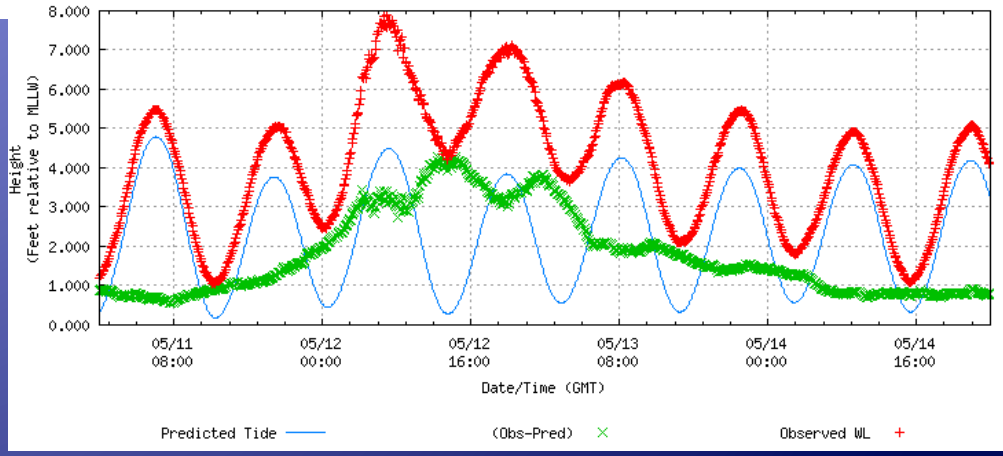
Reedy Point



Brandywine Shoal

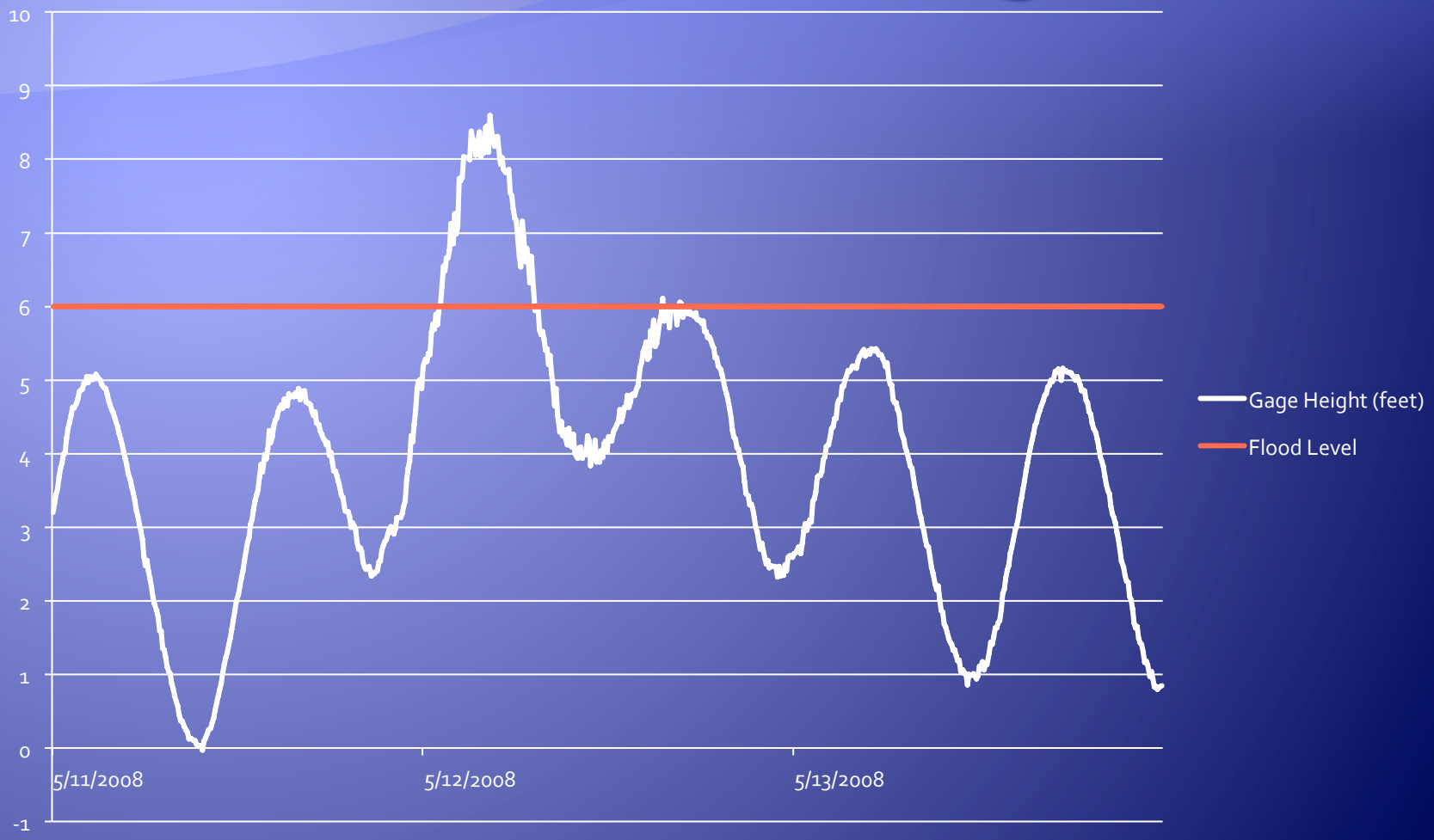


Lewes



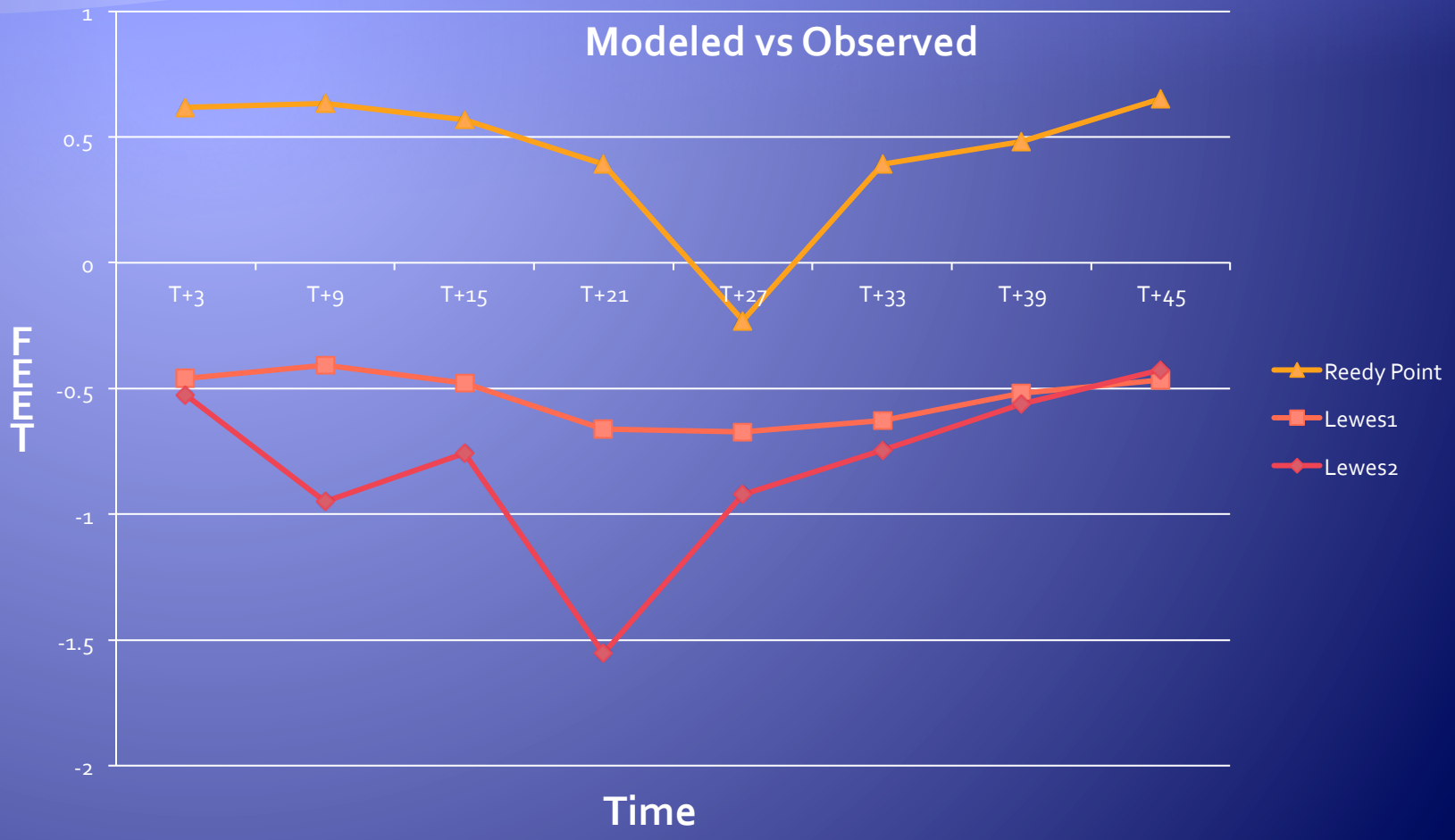
Hurricane Sandy was even worse… 3 – 4 ft above MHHW

Bowers Beach Tide Gage



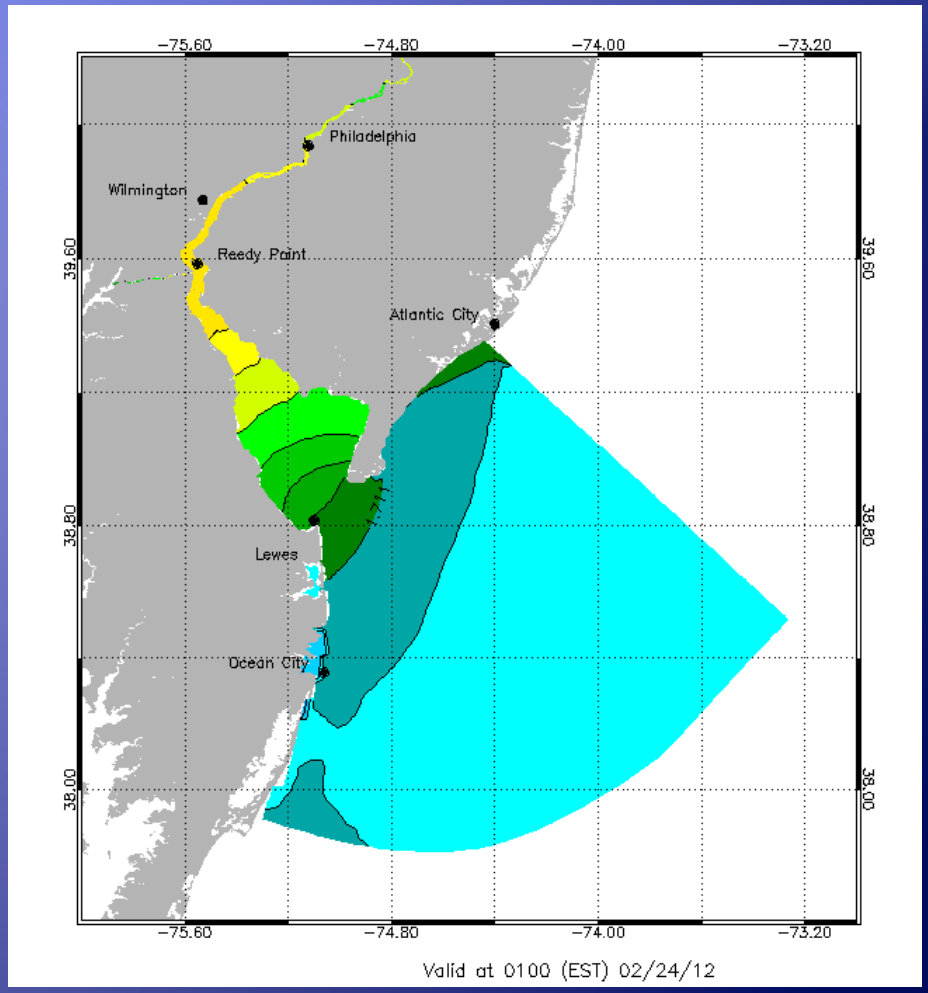
United States Geological Survey

March 6, 2013 High Tide



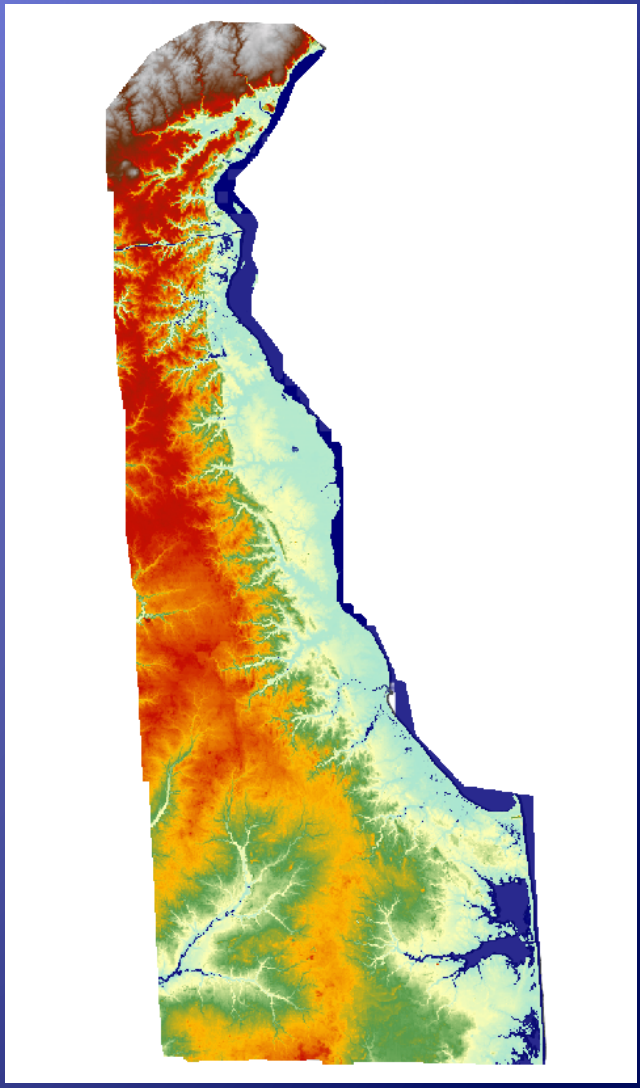
DBOFS Forecast Guidance

- NOAA Delaware Bay Operational Forecast System
- 48-hr prediction
- Water levels, temp, winds, salinity, currents
- Updated every 6 hours



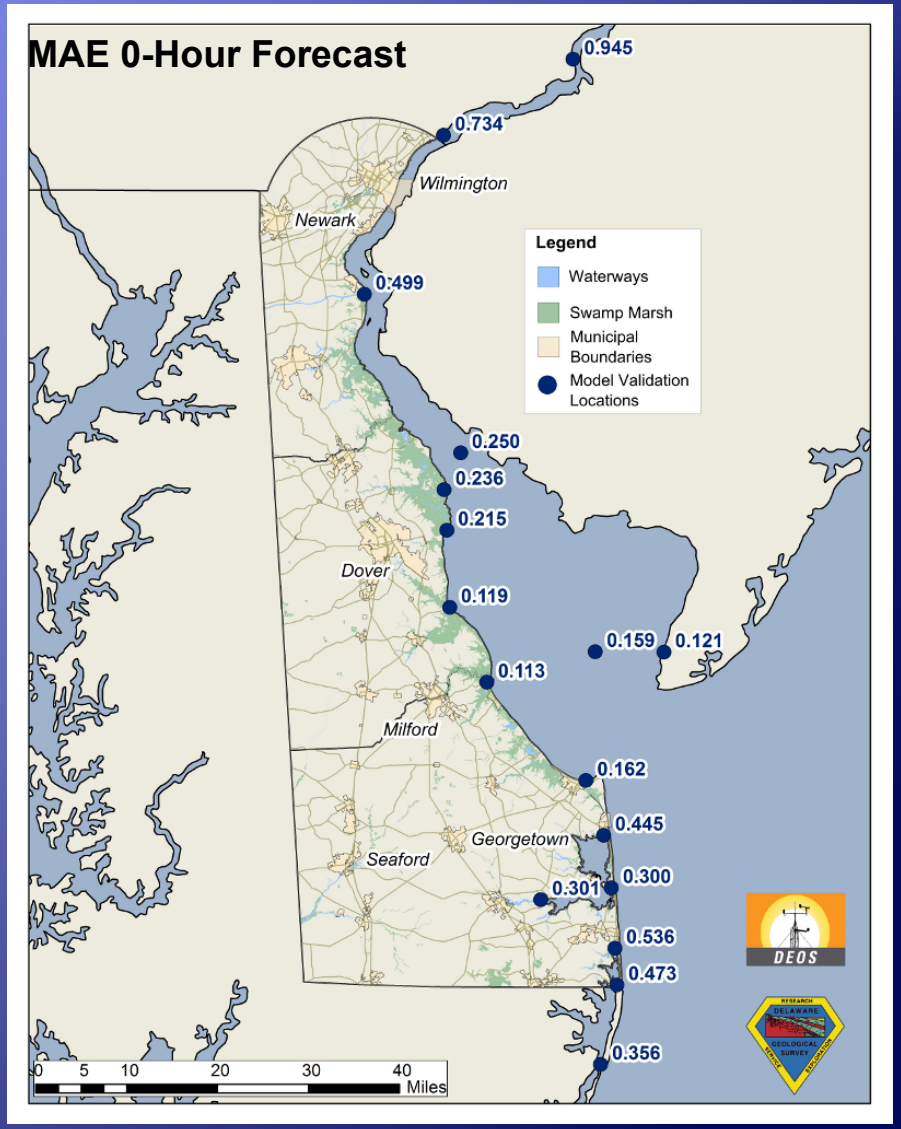
Lidar Elevation Data

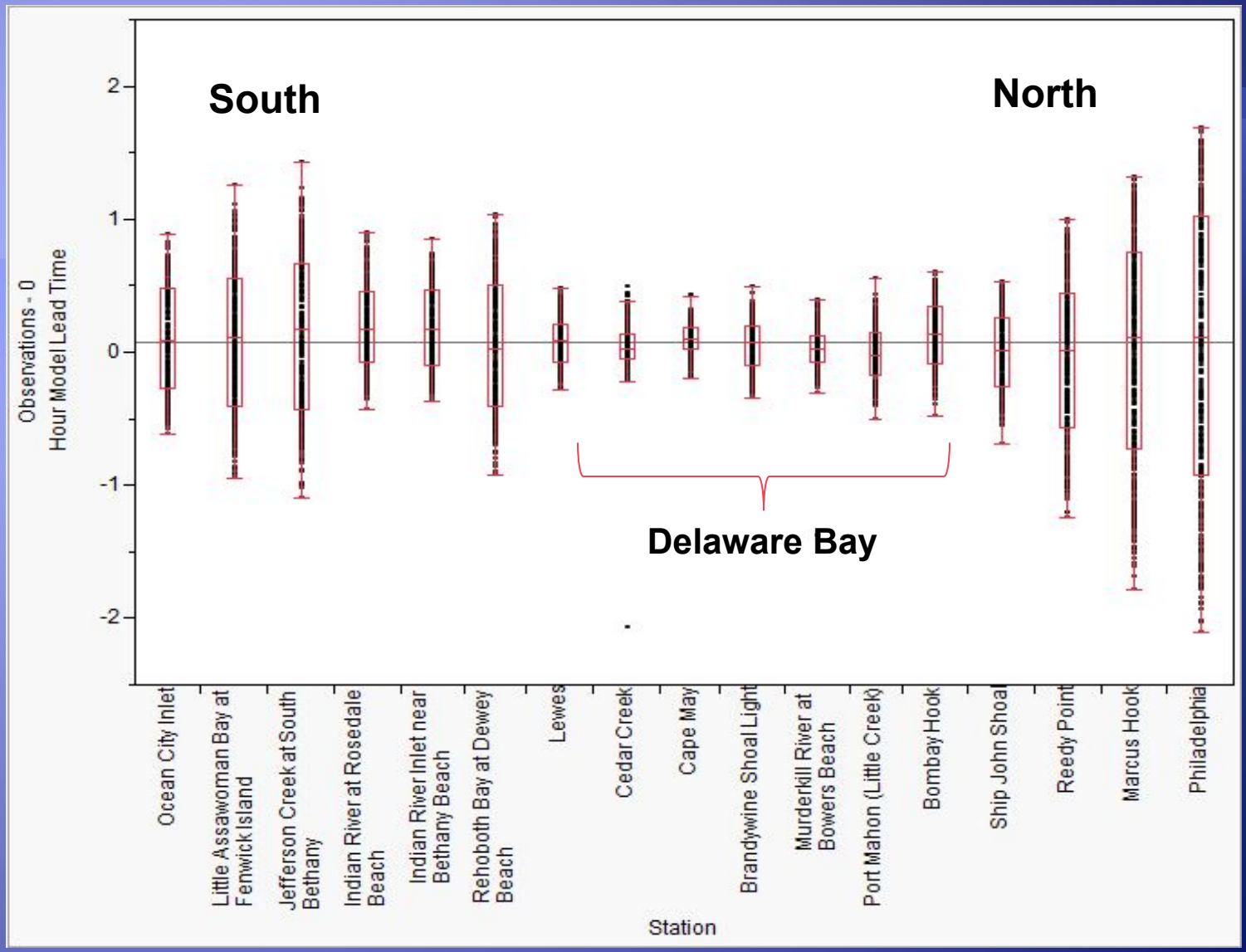
- Kent and New Castle Counties – 2007
- Sussex County – 2005
- Bare earth point observations reprocessed at NOAA CSC
  - state-wide, seamless, 2-meter
- RMSE: +/- 18.5 cm (37.5 for heavily veg areas)



DBOFS Model Statistics

- Optimum along Kent County and northern Sussex County
- Not as well near upper Delaware River and Inland Bays region
- Forecast lead time not a critical factor
- Timing off in Inland Bays





Box plots of DBOFS model comparison along DE coast

Some specific "severe weather" projects…

1. Stream and Tide "stormbooks"
2. Highwater Mark Database and Display System
3. Statistical Analysis of Storm Surge for DE Inland Bays
4. Community Flood Map Visualization Project
5. Coastal Storm Severity Index
6. Delaware Coastal Flood Monitoring System
   (Web demonstration)

All of these projects jointly developed by UD/DE team

Delaware Storm Response

DEMAC

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USGS Stream Hydrographs
River Flooding Forecasts

TIDES
NOS Tides and Predictions
USGS Tide Graphs
Delaware Bay Operational Forecast System (DBOFS)
NWS Tidal Impact Areas

Teleconnections
Pictures

Provided by Delaware Environmental Observation System (DEOS)

Site co-maintained by the Delaware Environmental Monitoring and Analysis Center (DEMAC) and the Delaware Geological Survey (DGS)

Questions? Suggestions?

John (DGS) or Tina (DEMAC).

Stream Stormbooks

Updated as of May 2014

Northern Gages

- Station 01477800 Shellpot Creek at Wilmington, DE
- Station 01478000 Christina River at Coochs Bridge, DE
- Station 01478245 White Clay Creek near Strickersville, PA
- Station 01478650 White Clay Creek at Newark, DE
- Station 01479000 White Clay Creek near Newark, DE
- Station 01479820 Red Clay Creek near Kennett Square, PA
- Station 01480000 Red Clay Creek at Wooddale, DE
- Station 01480015 Red Clay Creek near Stanton, DE
- Station 01481000 Brandywine Creek at Chadds Ford, PA
- Station 01481500 Brandywine Creek at Wilmington, DE

Southern Gages

- Station 01487000 Nanticoke River Near Bridgeville, DE
- Station 01488500 Marshyhope Creek near Adamsville, DE
- Station 01483155 Silver Lake Tributary at Middletown, DE
- Station 01483200 Blackbird Creek at Blackbird, DE
- Station 01483700 St Jones River at Dover, DE
- Station 01484100 Beaverdam Branch at Houston, DE

1. DGS and ODSC personnel use our jointly developed “Delaware Storm Response” web site during storm events.

Information in "Stream Stormbooks" includes all gage metadata, recurrence intervals, previous major events. Real-time information is also available through web page.

USGS 01481500 BRANDYWINE CREEK AT WILMINGTON, DE

LOCATION.--Lat 39°46'09.9", long 75°34'23.8", New Castle County, Hydrologic Unit 02040205, on left bank at upstream side of Rising Sun Bridge, in Wilmington, and 4.2 mi upstream from mouth.
DRAINAGE AREA.--314 mi².
PERIOD OF RECORD.--October 1946 to current year. Prior to December 1946 monthly discharge only, published in WSP 1302.
REVISED RECORDS.--WSP 1432: 1946, 1950; WDR-US-2011: 2007-2010.
GAGE.--Water-stage recorder and concrete control. Datum of gage is 68.23 ft above National Geodetic Vertical Datum of 1929
REMARKS.--Some diurnal fluctuation at low flow caused by mills upstream from station. Flow regulated since November 1973 by Marsh Creek Reservoir (see station 01480684 Marsh Creek Lake nr. Downingtown, PA), capacity 7,230,000,000 gal, about 27 mi upstream. No diversion just upstream from station by plant of E. I. du Pont de Nemours & Co. since June 13, 1950. Gage relocated to left bank at upstream side of Rising Sun Bridge, October 2006 at same gage datum. U.S. Geological Survey satellite collection platform at station. Water-quality records for some prior periods have been collected at this location.
EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 29,000 ft³/s, June 23, 1972, maximum gage height 15.49 ft, June 23, 1972 (at old gage location downstream of mill dam, prior to regulation). Maximum gage height, 18.71 ft, August 28, 2011 (at current gage location); minimum discharge, 30 ft³/s, Dec. 26, 1948.
COOPERATION.--Funding for the operation of this station is provided by the Delaware Geological Survey, the City of Wilmington, and the U.S. Geological Survey.
CRITICAL LEVELS.--Bankfull stage: 15.2 ft (5,375 ft³/s), flood stage: 16.5 ft (8,940 ft³/s), information provided by the National Weather Service.

NAVD88 - 67.167 ft above North American Vertical Datum of 1988.

WATERSHED CHARACTERISTICS.--Values derived from USGS National Land Cover Database 2006. Development intensity is an aggregate measure of various land use classes with differing percentages of development.
http://www.mrlc.gov/nlcd2006.php

Catchment Area (km²)	Forest Area (km²)	Wetlands Area (km²)	Developed Area (km²)	Development Intensity (%)	Impervious surface (km²)	Impervious surface (%)
824.94	271.75	14.02	194.72	4.92	39.68	4.81%

Magnitude and Frequency of Floods on Nontidal Streams in Delaware
Scientific Investigations Report 2006-5146
http://md.water.usgs.gov/publications/sir-2006-5146/index.html

Recurrence Interval of 24 hour Maximum Precipitation
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=de

Recurrence Interval (yr)	Discharge (cfs)	Rating Table Gage Height (ft)	NAVD88	Recurrence Interval (yr)	Precipitation (in)
2	7,840	15.51	82.68	2	3.28
5	12,500	16.62	83.79	5	4.13
10	16,200	17.35	84.52	10	4.83
25	21,500	18.41	85.58	25	5.87
50	26,000	19.23	86.40	50	6.74
100	30,900	>19.54	>86.71	100	7.68
200	36,300	>19.54	>86.71	200	8.71
500	44,200	>19.54	>86.71	500	10.2

USGS NWIS
Hydrographs http://waterdata.usgs.gov/nwis/uv?site_no=01481500
Rating table http://waterdata.usgs.gov/nwisweb/get_ratings?site_no=01481500&file_type=exsa

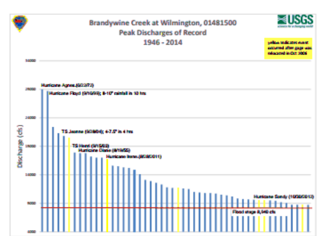
This report was developed by the Delaware Geological Survey (www.dgs.udel.edu) for the purpose of studying the historical record of flooding at selected USGS streamgages.
All gage height and discharge data were obtained from USGS.

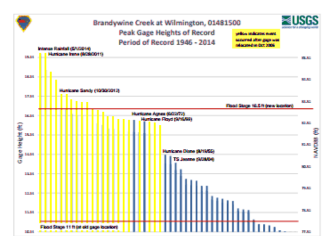
Date updated: May 2014

Brandywine Creek at Wilmington, Station 01481500
Data sorted by Peak Discharge and Gage Height

yellow indicates event occurred after gage was relocated in Oct 2006

Date	Peak Discharge	Date	Peak Gage Height	NAVD88	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Intense Rainfall; Missing data 3:30 - 10:15
					Hurricane Irene
					Hurricane Sandy
					Hurricane Agnes; RI – 76 yrs
					Severe Thunderstorms (Tornado in S. Newark)
					Hurricane Floyd (8-10"); RI – 74 yrs
					Hurricane Diane
					TS Jeanne
					TS Henri; RI – 17 yrs
					Snowmelt & 2-3" rain, minor flooding Rt. 100
					5.82" over 7 days at Porter;6.91" at ILG
					Hurricane Connie



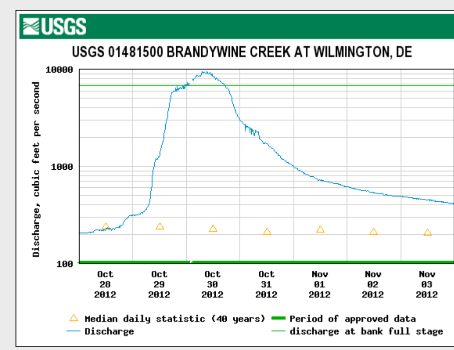


Brandywine Creek at Wilmington, Station 01481500
Chronological list of events

Date	PeakDisc	Gage Height (ft) Gage	NAVD88	Remarks
9/10/1948	5160	8.41	75.58	
11/25/1950	11500	11.34	78.51	
2/8/1951	6030	8.38	75.55	
11/7/1951	5450	8.29	75.46	
12/21/1951	5930	8.58	75.75	
3/11/1952	5300	8.22	75.39	
4/28/1952	5000	8.10	75.27	
7/9/1952	6960	9.32	76.49	
11/22/1952	5510	8.42	75.59	
12/11/1952	5590	8.47	75.64	
1/25/1953	5820	8.61	75.78	
3/16/1953	5080	8.13	75.30	
2/7/1955	5080	8.05	75.22	
8/13/1955	12600	11.76	78.93	Hurricane Connie
8/19/1955	17800	13.89	81.06	Hurricane Diane
3/14/1956	5020	7.75	74.92	
11/2/1956	9620	10.36	77.53	
12/21/1957	5070	7.78	74.95	
1/22/1958	5100	7.80	74.97	
1/25/1958	5690	8.18	75.35	
2/28/1958	7790	9.41	76.58	
4/7/1958	5200	7.87	75.04	
7/7/1958	5080	7.79	74.96	
12/13/1959	7290	8.13	75.30	
4/4/1960	5210	7.06	74.23	
9/13/1960	15600	11.42	78.59	
2/20/1961	6080	7.54	74.71	
2/26/1961	5280	7.10	74.27	
4/14/1961	7660	8.30	75.47	
2/24/1962	6580	7.95	75.12	
2/27/1962	6780	8.05	75.22	
3/13/1962	9750	9.28	76.45	
2/12/1963	5410	7.17	74.34	
3/7/1963	7990	8.45	75.62	
1/10/1964	9050	8.93	76.10	
2/8/1965	8740	8.79	75.96	
2/14/1966	10900	9.93	77.10	
3/7/1967	9510	9.47	76.64	
5/29/1968	5460	7.93	75.10	
6/13/1968	7500	8.76	75.93	
7/28/1969	8730	9.21	76.38	
4/2/1970	6500	8.30	75.47	
8/1/1970	7120	8.61	75.78	
2/8/1971	7820	9.41	76.58	Ice Jam
2/14/1971	14100	11.86	79.03	
8/28/1971	8700	9.85	77.02	
9/13/1971	21300	13.83	81.00	
10/10/1971	6010	8.34	75.51	
2/14/1972	5460	7.97	75.14	
6/23/1972	29000	15.49	82.66	Hurricane Agnes; RI – 76 yrs
11/15/1972	5460	7.97	75.14	

Date	PeakDisc	Gage Height (ft) Gage	NAVD88	Remarks
6/30/1973	10400	10.57	77.74	
12/21/1973	5890	8.26	75.43	
3/20/1975	7620	9.31	76.48	
7/14/1975	8400	9.70	76.87	6.53" between 0730 & 1430 hrs.
7/21/1975	5740	8.16	75.33	
1/28/1976	5240	7.96	75.13	
12/19/1977	7050	9.02	76.19	
1/9/1978	5060	7.84	75.01	
1/26/1978	17200	12.78	79.95	
3/15/1978	5780	8.30	75.47	
3/27/1978	5620	8.20	75.37	
7/4/1978	5820	7.53	74.70	
8/28/1978	6520	7.95	75.12	
12/9/1978	5610	7.40	74.57	
1/8/1979	5200	7.23	74.40	
1/21/1979	10700	9.90	77.07	
1/25/1979	22400	13.22	80.39	
2/24/1979	5110	7.07	74.24	
2/25/1979	11800	10.29	77.46	
2/26/1979	15300	11.37	78.54	
7/22/1979	5520	7.34	74.51	
9/6/1979	10500	9.79	76.96	
9/22/1979	13100	10.70	77.87	
9/30/1979	7440	8.44	75.61	
3/21/1980	5090	7.06	74.23	
1/5/1982	5400	7.91	75.08	
2/3/1982	5980	8.22	75.39	
3/28/1983	5190	7.79	74.96	
4/11/1983	7060	8.75	75.92	
4/16/1983	5380	7.90	75.07	
12/13/1983	10200	10.09	77.26	
2/15/1984	5980	8.22	75.39	
4/5/1984	5180	7.78	74.95	
5/30/1984	5540	7.99	75.16	
7/7/1984	8260	9.29	76.46	
2/13/1985	9690	9.88	77.05	
9/28/1985	6150	8.31	75.48	
11/30/1987	5690	8.07	75.24	
5/19/1988	5940	8.20	75.37	
7/5/1989	9850	9.94	77.11	
5/30/1990	5450	7.94	75.11	
3/5/1993	9440	9.78	76.95	Minor flooding Rt. 100
3/24/1993	6020	8.24	75.41	
4/11/1993	5750	8.10	75.27	
11/28/1993	5090	7.73	74.90	
12/6/1993	10600	10.34	77.51	
1/29/1994	11700	10.69	77.86	
3/10/1994	8750	9.50	76.67	
3/9/1995	7730	9.06	76.23	
1/20/1996	17800	12.69	79.86	Snowmelt & 2-3" rain, minor flooding Rt. 100
1/28/1996	6950	8.70	75.87	
4/16/1996	7310	8.87	76.04	
10/19/1996	15200	11.91	79.08	

Date	PeakDisc	Gage Height (ft) Gage	NAVD88	Remarks
11/9/1996	5020	7.69	74.86	
12/2/1996	6720	8.59	75.76	
12/14/1996	10800	10.34	77.51	
1/25/1997	6060	8.27	75.44	
4/2/1998	5770	8.11	75.28	
9/17/1999	28700	15.43	82.60	Hurricane Floyd (8-10"); RI – 74 yrs
3/22/2000	15500	11.99	79.16	
12/18/2000	9190	9.68	76.85	
2/23/2003	6890	8.67	75.84	
6/21/2003	14800	11.79	78.96	
8/10/2003	5300	7.85	75.02	
8/11/2003	5770	8.11	75.28	
9/15/2003	17900	12.73	79.90	TS Henri; RI – 17 yrs
10/28/2003	7230	8.83	76.00	
12/11/2003	8370	9.34	76.51	
2/4/2004	7870	9.12	76.29	
2/6/2004	11600	10.64	77.81	
2/7/2004	11000	10.41	77.58	
9/19/2004	6550	8.51	75.68	
9/29/2004	20800	13.52	80.69	TS Jeanne
11/28/2004	8370	9.49	76.66	
1/14/2005	6970	8.71	75.88	
3/29/2005	7640	9.02	76.19	
4/3/2005	8370	9.34	76.51	
10/9/2005	12300	10.91	78.08	
6/26/2006	6970	8.71	75.88	
6/27/2006	7360	8.89	76.06	
6/28/2006	17000	12.46	79.63	
6/29/2006	17000	12.46	79.63	5.82" over 7 days at Porter;6.91" at ILG
3/2/2007	8410	16.32	83.49	
4/16/2007	8730	16.43	83.60	
4/27/2007	5750	15.35	82.52	
2/14/2008	5870	15.40	82.57	
12/12/2008	6580	15.67	82.84	
12/9/2009	6180	15.52	82.69	
12/27/2009	6530	15.65	82.82	
3/14/2010	7410	15.97	83.14	
10/1/2010	12900	17.71	84.88	
3/11/2011	11700	17.35	84.52	
4/17/2011	6260	15.55	82.72	
8/28/2011	16800	18.71	85.88	Hurricane Irene
9/7/2011	7330	15.94	83.11	
9/8/2011	9550	16.70	83.87	
9/24/2011	8410	16.32	83.49	
11/23/2011	7080	15.85	83.02	
12/8/2011	6160	15.51	82.68	
10/30/2012	9550	16.70	83.87	
6/10/2013	6050	15.47	82.64	Severe Thunderstorms (Tornado in S. Newark)
8/13/2013	8410	16.32	83.49	
10/11/2013	5520	15.26	82.43	
5/1/2014	20500	19.54	86.707	Intense Rainfall; Missing data 3:30 - 10:15



A closer look at the White Clay Creek at Newark gage…

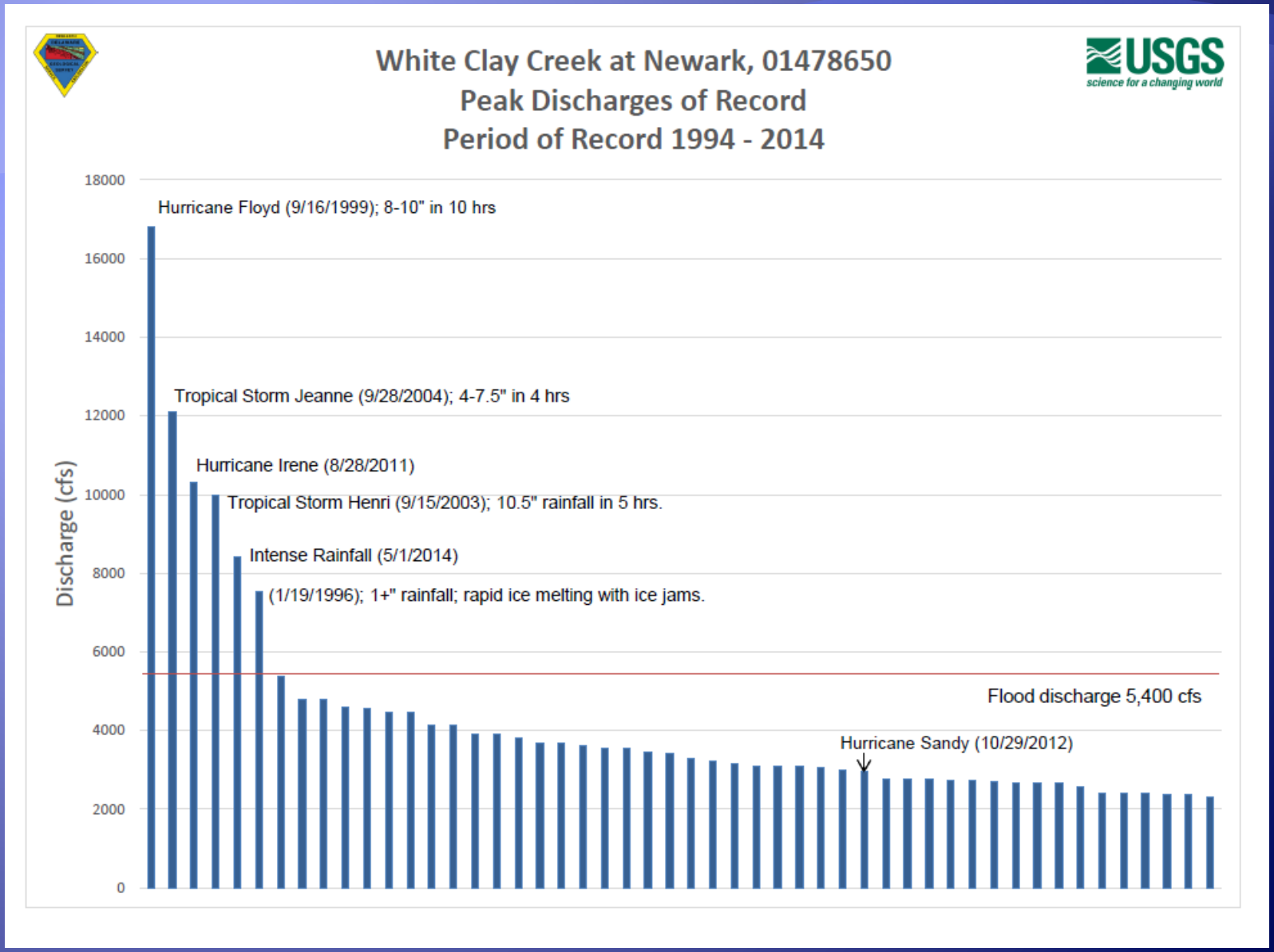
Magnitude and Frequency of Floods on Nontidal Streams in Delaware
Scientific Investigations Report 2006-5146
http://md.water.usgs.gov/publications/sir-2006-5146/index.html

Recurrence Interval (yrs)	Discharge (cfs)	Rating Table Gage Height (ft)	NAVD88
2	3,860	10.52	65.832
5	6,870	12.72	68.032
10	9,810	14.4	69.712
25	13,400	16.1	71.412
50	16,700	> 17.33	> 72.642
100	20,400	> 17.33	> 72.642
200	24,600	> 17.33	> 72.642
500	31,300	> 17.33	> 72.642

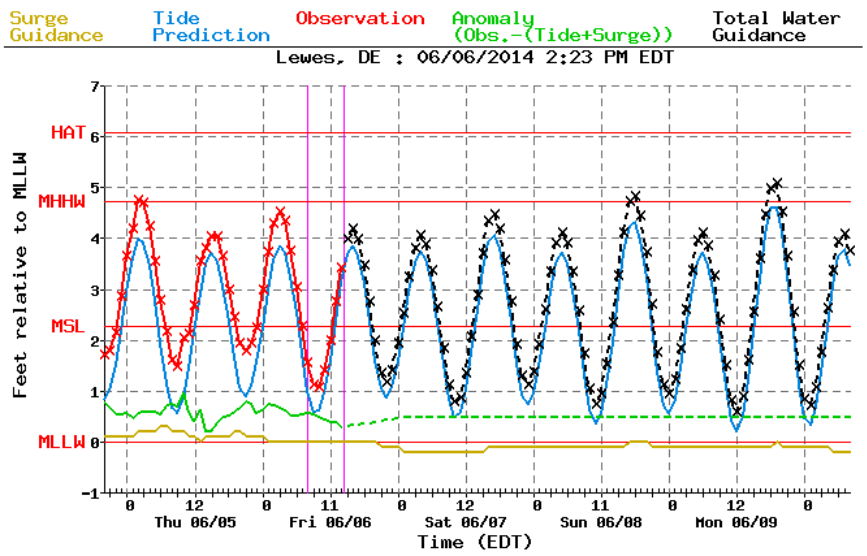
Recurrence Interval of 24 hour Maximum Precipitation
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=de

Recurrence Interval (yrs)	Precipitation (in)
2	3.24
5	4.08
10	4.79
25	5.82
50	6.69
100	7.63
200	8.66
500	10.2

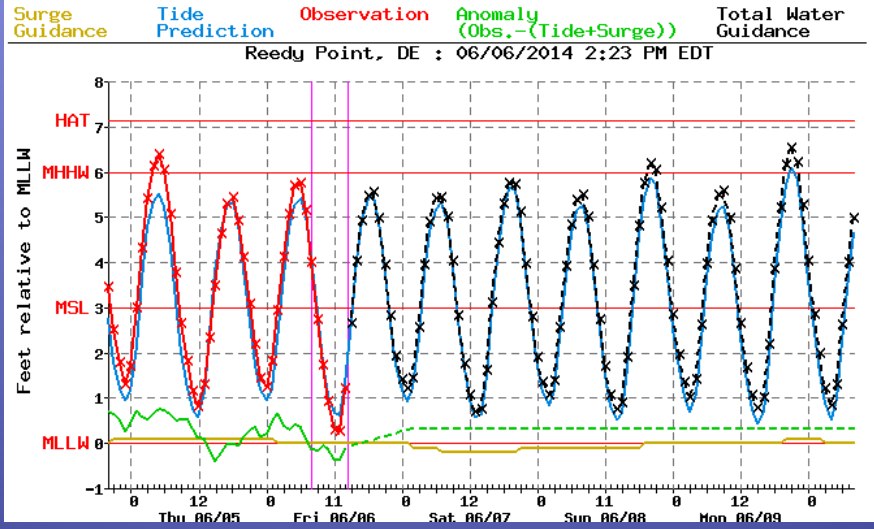
A closer look at the White Clay Creek at Newark gage…



Lewes Tide Gage (ET-Surge Forecast, NOS Station Homepage)
(Kent/Sussex: Minor Flooding @ 6.0 ft, Moderate @ 7.0 ft, Major @ 8.0 ft)



Reedy Point Tide Gage (ET-Surge Forecast, NOS Station Homepage)
(New Castle: Minor Flooding @ 7.2 ft, Moderate @ 8.2 ft, Major @ 9.2 ft)



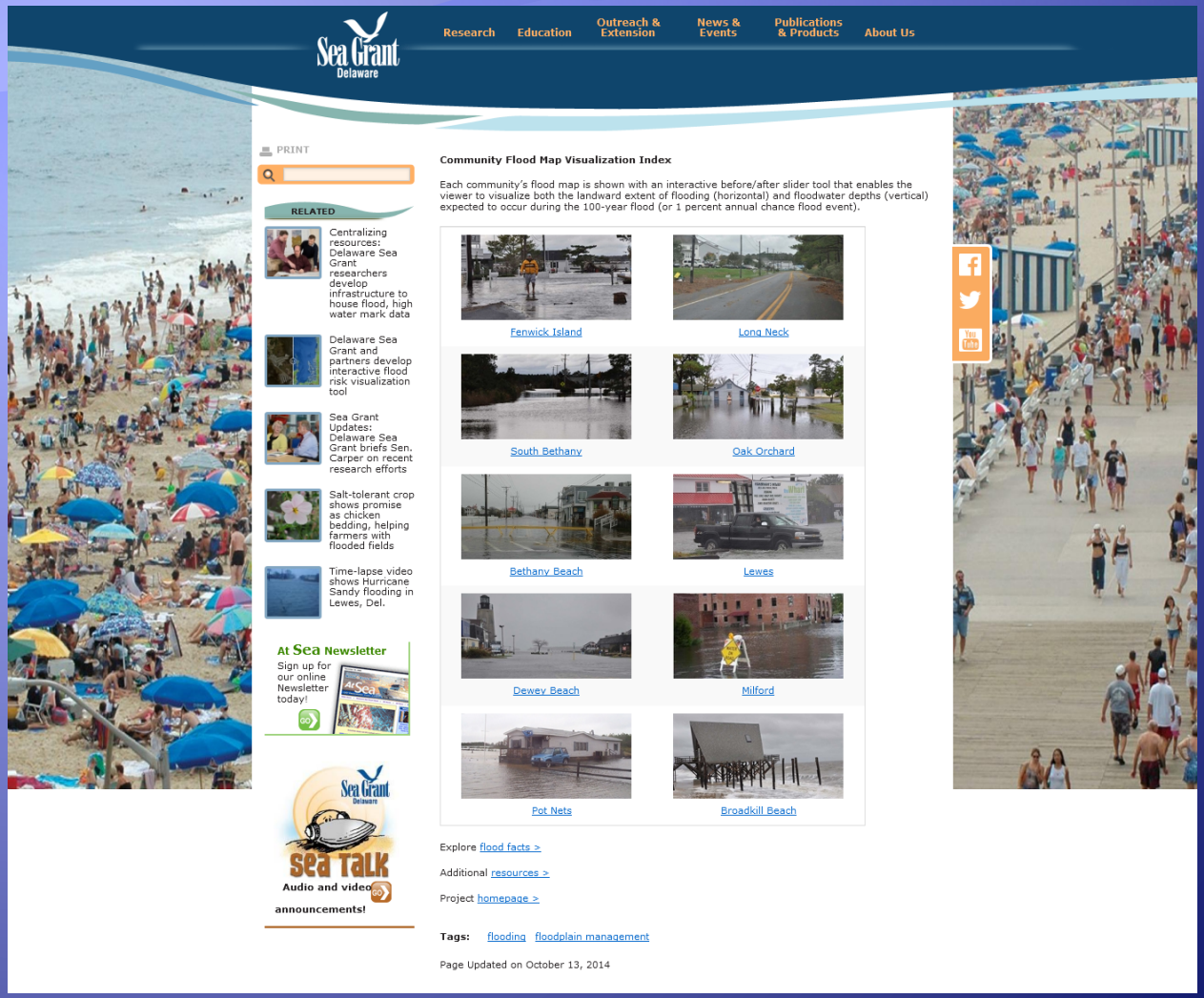
“Tide Stormbooks” are currently in the development stage by DGS and ODSC.

Many more newer, short term gages
Storm surge vs High tide
Station details very important!

4. Community Flood Map Visualization Project

- Partnership among UD Delaware Sea Grant, USGS, and Delaware Dept of Natural Resources and Environmental Control
- Risk awareness exercise
- Only communities in Delaware Inland Bays
- Mapped before and after inundation for 1% event based on new FEMA DFIRM maps
  - And for some selected storms

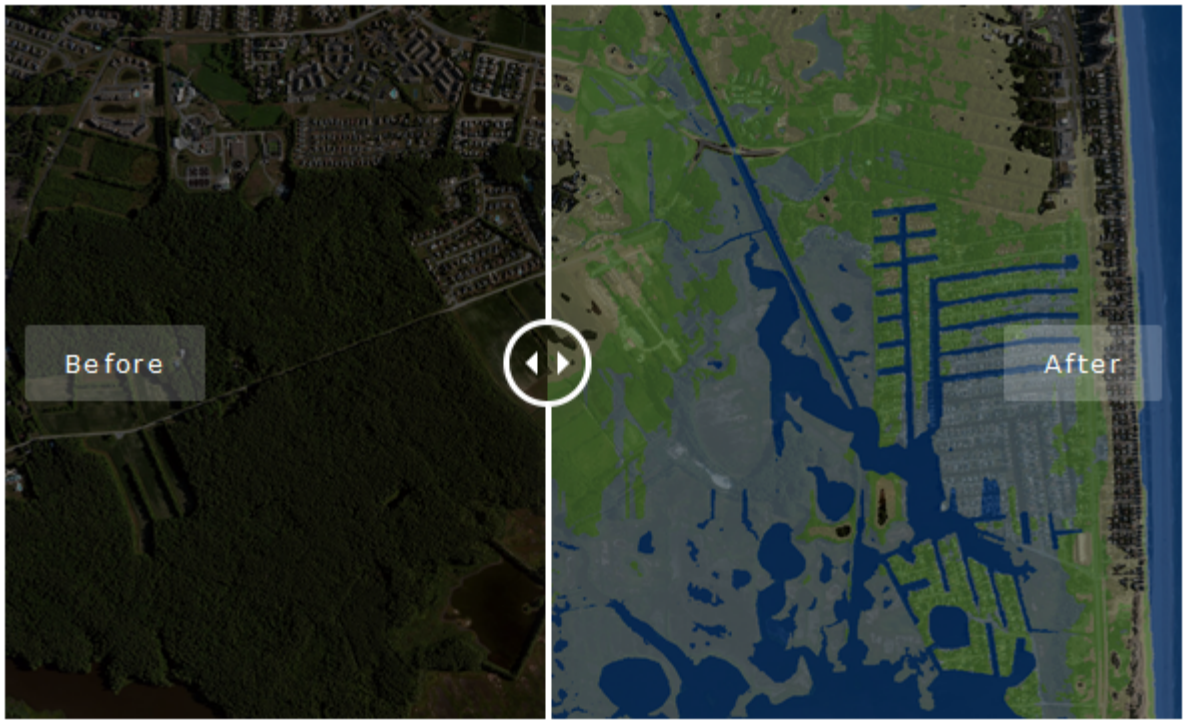
Community Flood Map Visualization Project



http://www.deseagrant.org/flood-risk-awareness

Community Flood Map Visualization Project

South Bethany Flood Risk Visualization Map - Water Depths Associated With 100-Year Flood Event



The flood map is shown with an interactive before/after slider tool that enables the viewer to visualize both the landward (horizontal) extent of flooding and floodwater depths (vertical) expected to occur during the 100-year flood (or 1 percent annual chance flood event). Data for the 100-year floodplain was obtained using FEMA's preliminary flood maps, and floodwater depths have been provided by Delaware DNREC through a project with AMEC, a London-based engineering company.

LEGEND
Water Depth During 100-Year Flood Event

Transparent	Dry
	0.01-1 feet
	1-2 feet
	2-4 feet
	Greater than 4 feet

You can also explore what this area looked like during Hurricane Sandy and a 1998 northeaster.