

Valuing Ecosystem Services of Coastal Wetlands: Protection from Hurricane Storm Surge

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Resources for the Future

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Overview

Outline of talk:

- Ecosystem functions, services, values
- Storm surge and wetlands
- Reviewing the literature
- The Chesapeake Bay region
- Our methods:
  - Two approaches using ADCIRC+SWAN modeling, GIS, regressions, avoided damage calculations
- Results (preliminary)
- Next Steps

This work is related to our projects focused on properties of surge in the region, including field work (Ferreira team) and broader coastal resilience issues (Walls, Ferreira and other researchers). Part of current NOAA proposal.

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Ecosystem Functions & Services

- Natural lands in coastal areas perform a variety of ecosystem functions
  - e.g., carbon sequestration, habitat provision, fish nurseries, water purification, floodwater storage, storm surge attenuation
- These functions provide a set of services that has value to humans
- A service that is getting increasing attention is protection from flooding. Especially the flooding associated with hurricane storm surge.

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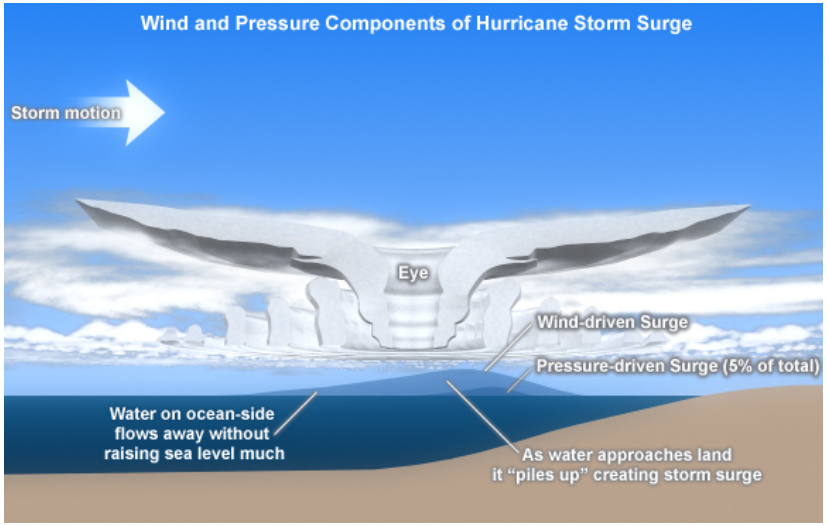
Storm Surge

- Surge is the abnormal rise of floodwaters generated by the wind and atmospheric pressure changes in a tropical storm
- Often responsible for largest damage and loss of life
- Several factors influence surge:
  - Storm intensity, size, forward speed
  - Width and slope of ocean bottom
  - Shape of coastline, topography
  - Land cover



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Storm Surge and Wetlands

- Wetlands attenuate surge by slowing its advance across the landscape and delaying arrival of water on the landward side

- USACE (1963) seminal study:
  - *Simple rule of thumb: surge heights reduced by, on average, 1m for every 14.5km of wetlands over which the surge travels*
- But range is large: 1m/5km – 1m/60km, depending on location and storm

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Storm Surge and Wetlands (cont.)

More recent studies:

- 1m/4km – 1m/25km (based on field measurements after Hurricane Rita, McGee et al. 2006)
- 1m/6km – 1m/25km (based on ADCIRC+SWAN modeling, coastal Louisiana, Wamsley *et al.* 2010)
- 5-40% reduction in surge depending on vegetation height, density and width (based on 3D modeling, Sheng *et al.* 2012)

These results mean that the value of the protective services of wetlands will vary by storm and by location

Value will also vary by the number & value of nearby properties

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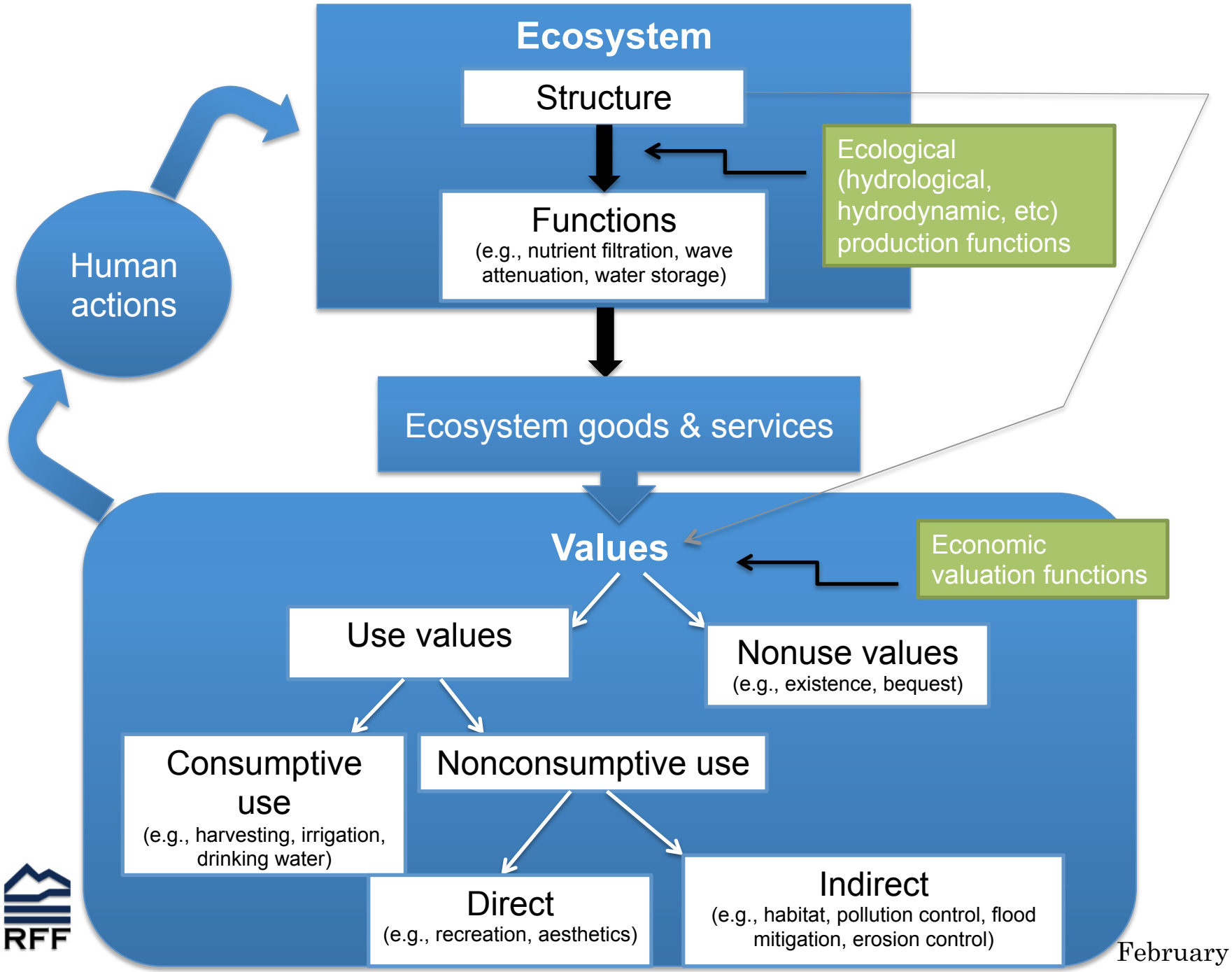

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Methodology

- Two methods, both of which rely on mathematical modeling of surge and waves:
  1. Statistical analysis of modeling results—surge heights at a parcel level as a function of the extent of wetlands in surrounding land cover
  2. Counter-factual modeling run—all estuarine wetlands replaced with bare land *[incomplete at this point]*
- Then convert difference in surge heights to difference in property damages…avoided damages is measure of value of protective service

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Chesapeake Bay Region

Numerical Modelling

Hydrodynamic Model
ADCIRC
(Luettich & Westerink 1994)

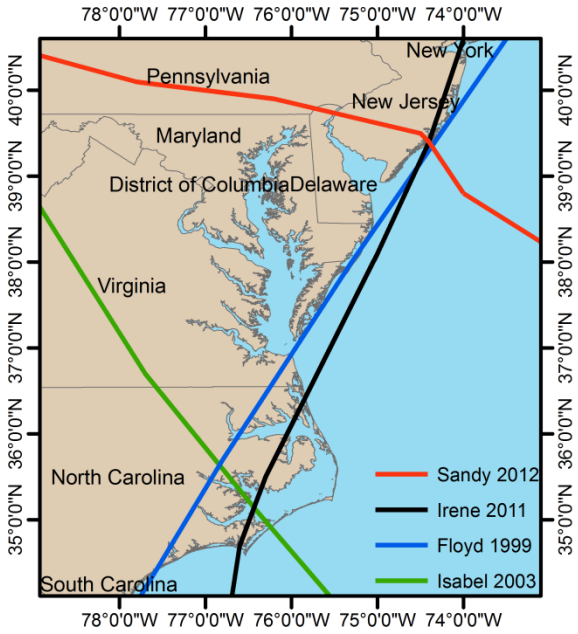
Wave Radiation Stress

Water Levels, Currents, Wind field, Bottom Friction, Roughness Length

Wave model
SWAN
(Booij 1999)

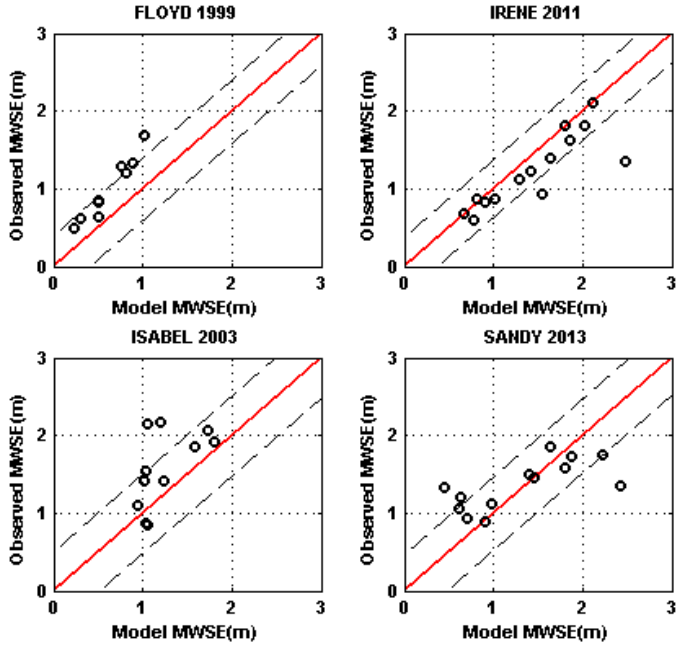
Meteorological Forcing

- **LeProvost Tidal Database**
- **National Hurricane Center (NHC) Best Track:**
  - Hurricane Track
  - Central Pressure (Cp)
  - Radius of storm (Rp)
  - Forward Speed (Vf)
  - Approach Angle (Θ)



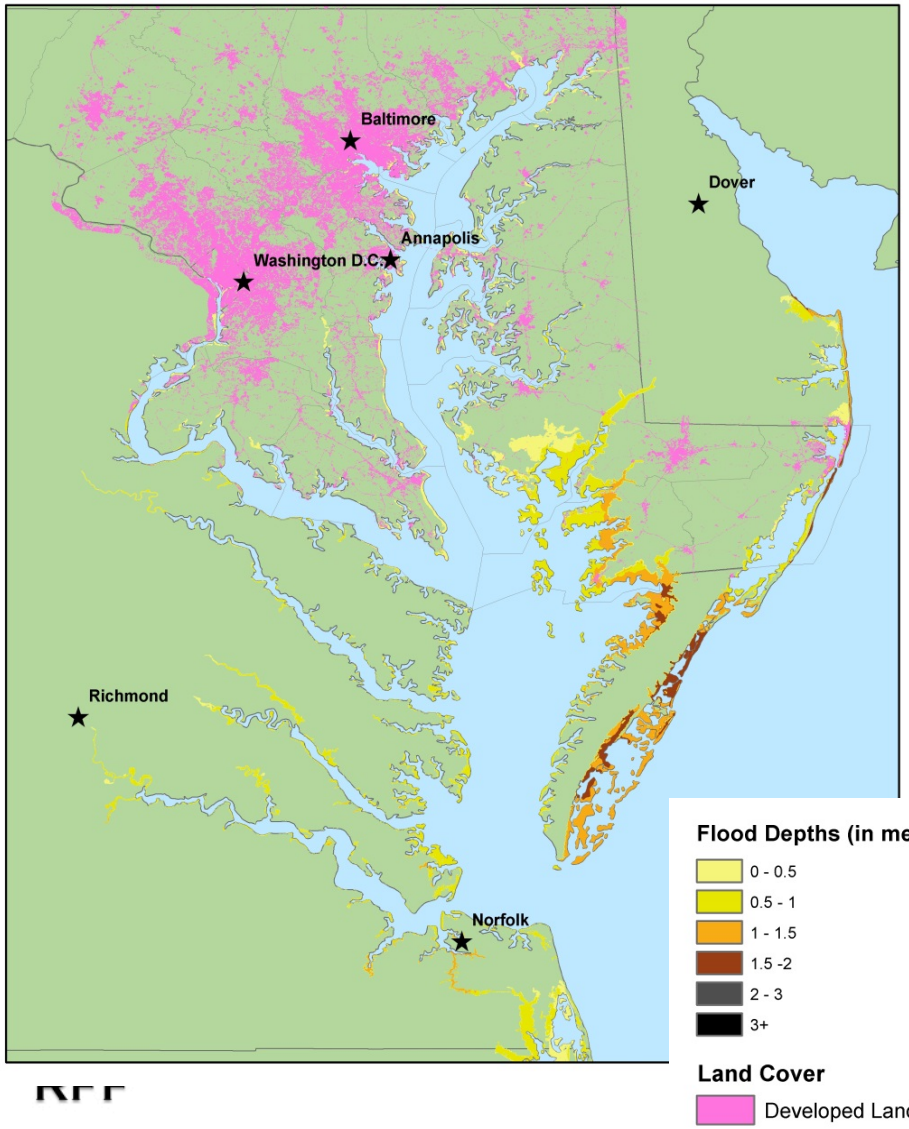
Model Validation

- Observed maximum water surface elevations (MWSE) at Chesapeake Bay NOAA stations for each storm compared with model MWSE
- 14 NOAA stations (data used as available)
- Root Mean Square Error (RMSE) computed for each storm:

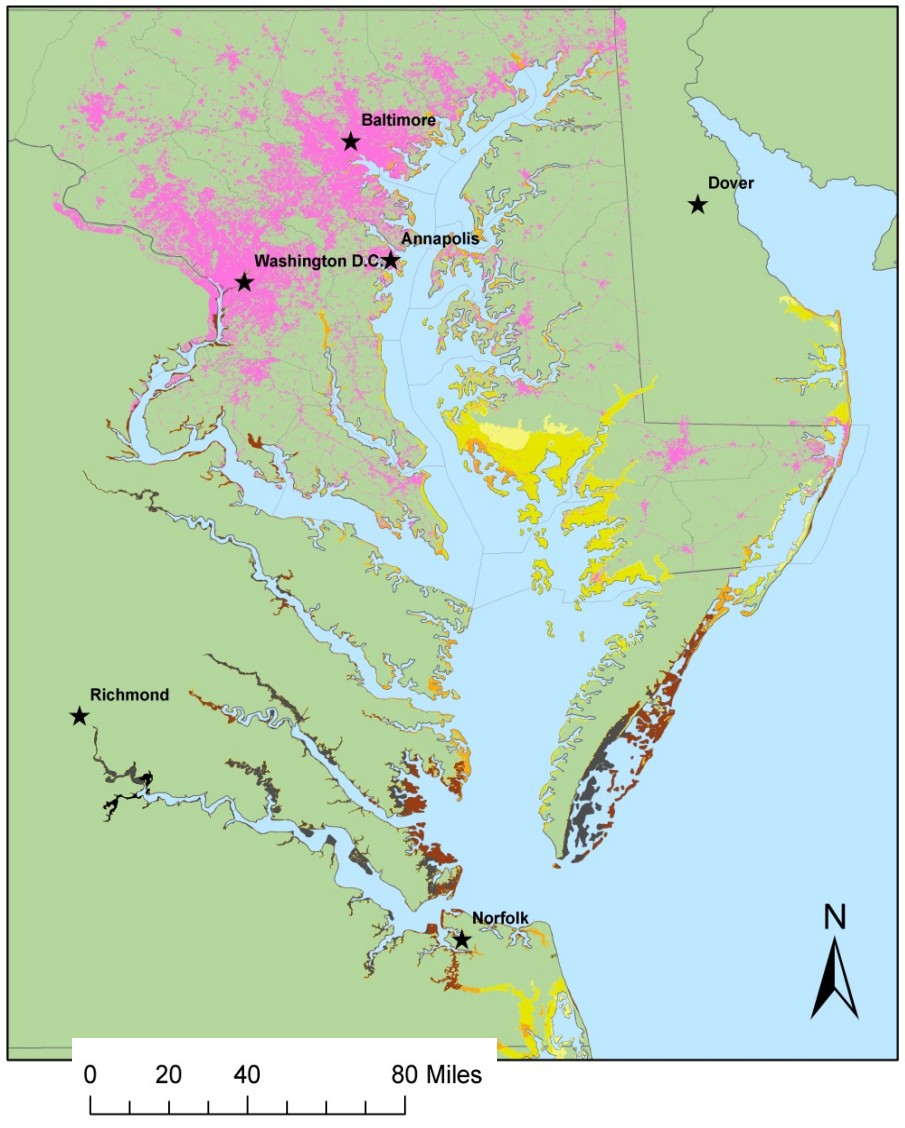


Storm Surge Heights

Hurricane Floyd (1999)



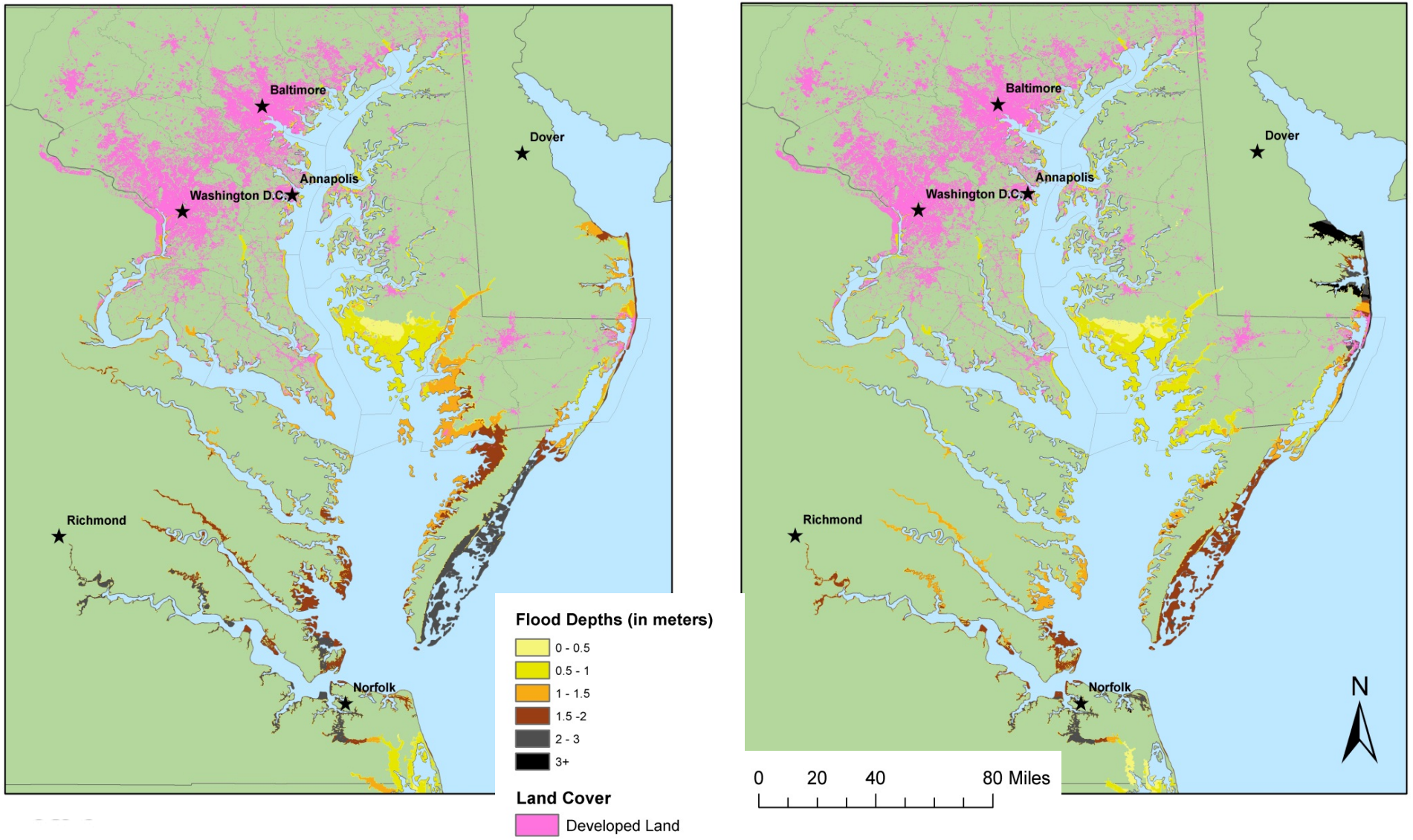
Hurricane Isabel (2003)



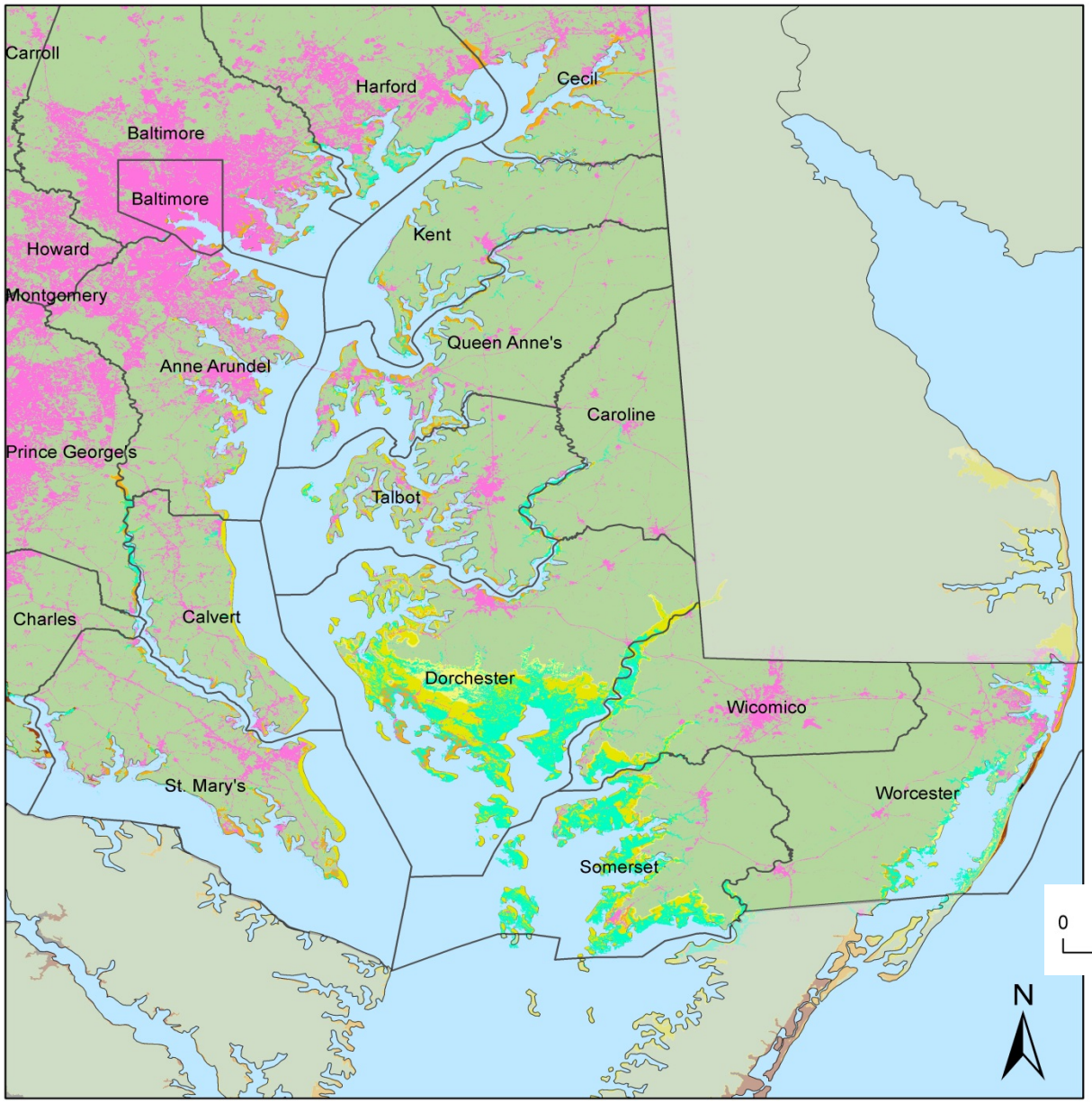
Storm Surge Heights (cont.)

Hurricane Irene (2011)

Hurricane Sandy (2012)



Surge Heights and Wetlands



Hurricane Isabel

Flood Depths (in meters)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3+

Land Cover

- Developed Land
- Estuarine Wetland

0 10 20 40 Miles

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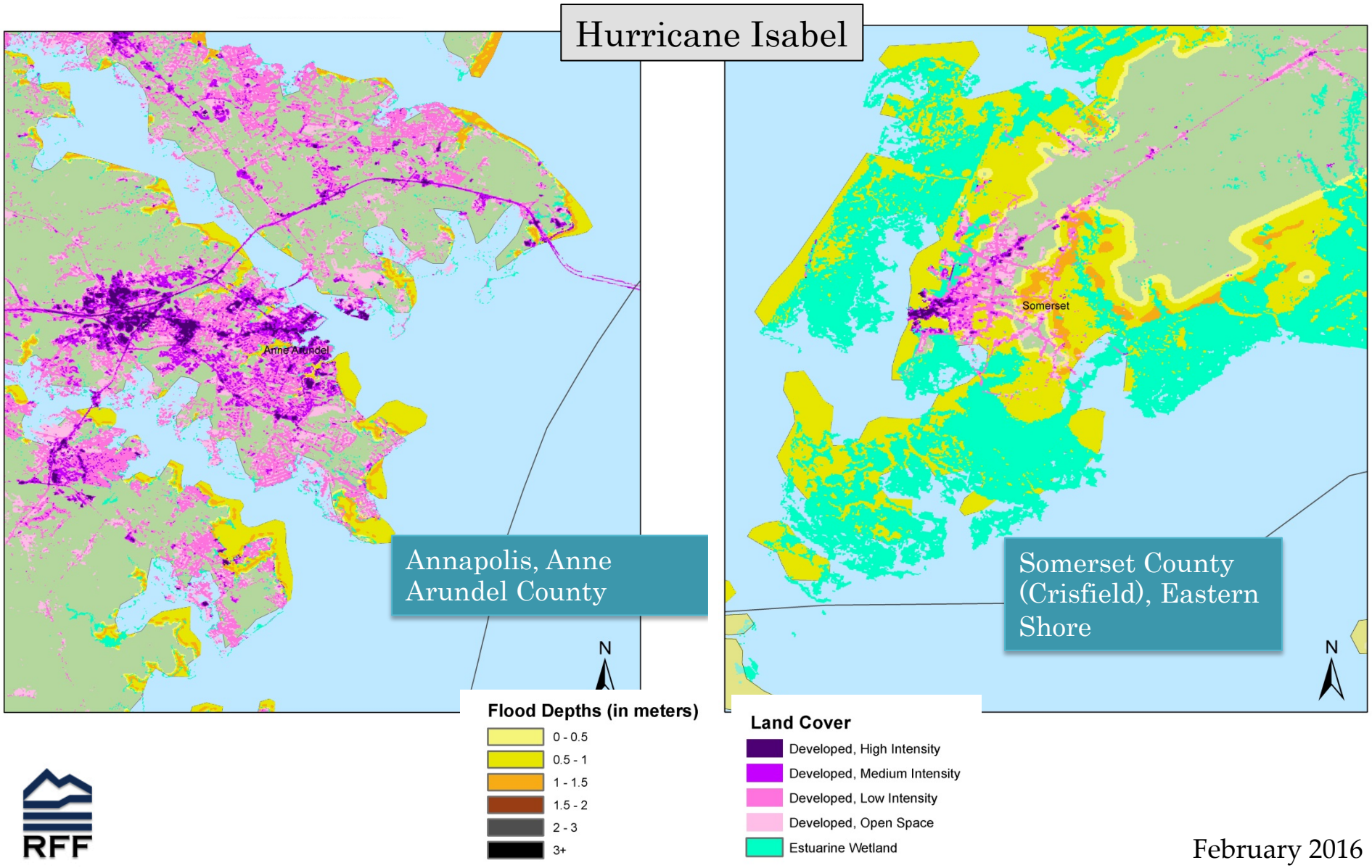
Surge Heights and Wetlands (cont.)



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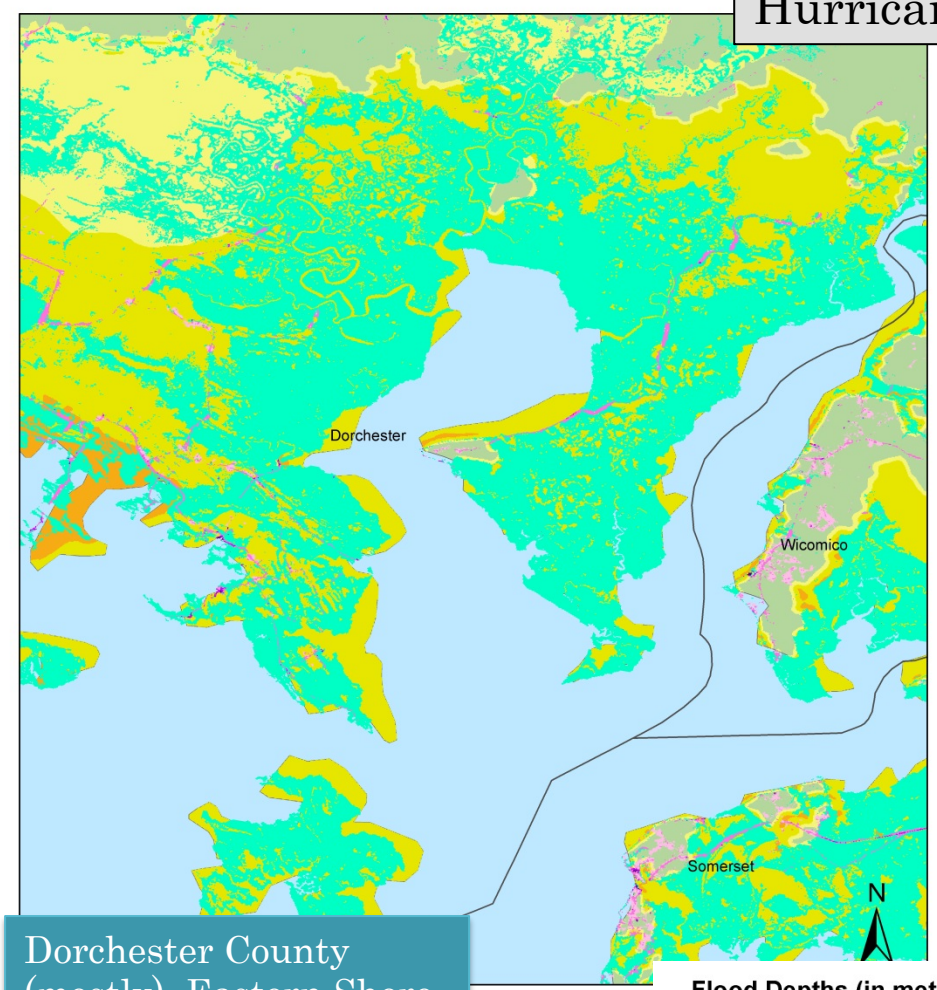
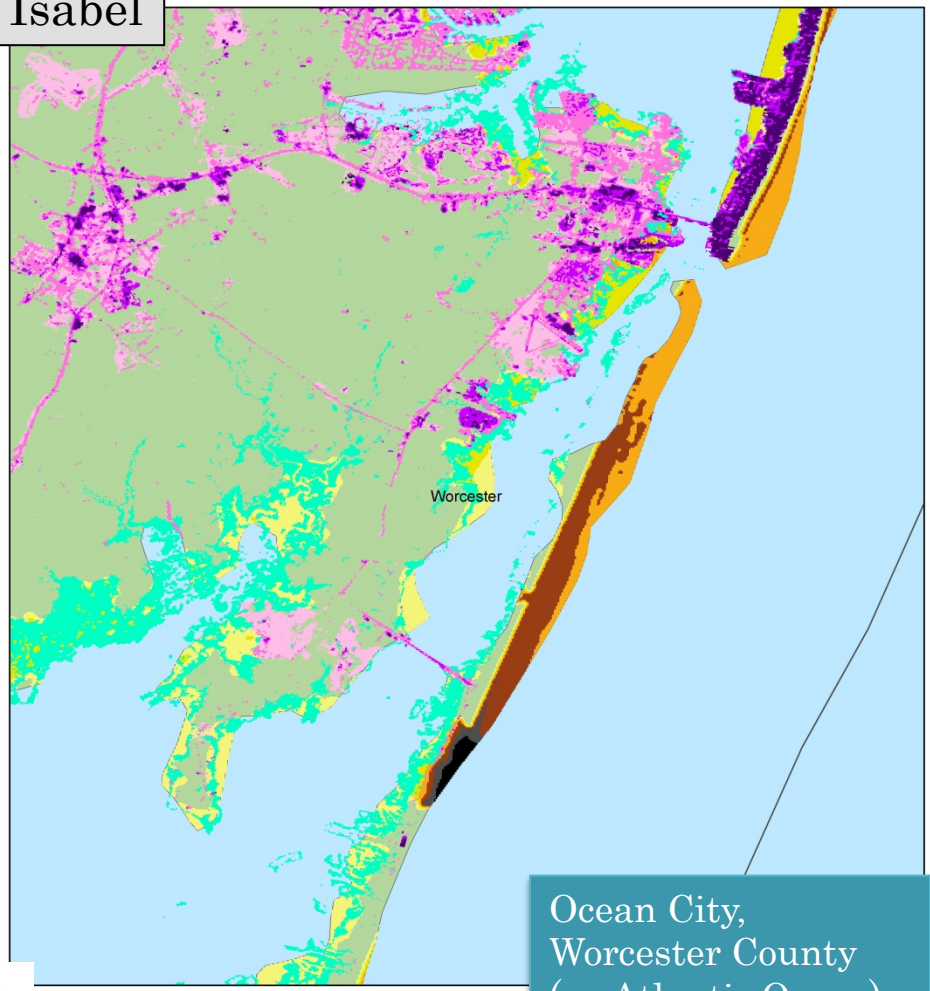
Surge Heights and Wetlands (cont.)

Hurricane Isabel





Dorchester County (mostly), Eastern Shore

Ocean City, Worcester County (on Atlantic Ocean)

Flood Depths (in meters)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3+

- Developed, High Intensity
- Developed, Medium Intensity
- Developed, Low Intensity
- Developed, Open Space
- Estuarine Wetland

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Valuation Method 1: Statistical Analysis

- MDProperty View data on all parcels in Maryland
- Construct 500-m buffer around each flooded parcel
- Calculate % of flooded area of buffer that is wetlands
- Econometric model:
  - Use data for 3 hurricanes (omit Sandy)
  - Estimate surge heights as a function of %wetlands, and several control variables
  - Allow effects to vary by hurricane

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Regression Results

Dep. Variable = flood height on parcel (in m)	Basic model	Hurricane-specific wetlands effects
Parcel elevation (m)	-0.0576***	-0.0575***
	(0.00333)	(0.00336)
A zone	0.0854**	0.0847**
	(0.0124)	(0.0131)
V zone	-0.0458*	-0.0441
	(0.0155)	(0.0155)
Buffer area flooded (as fraction of total buffer area)	0.674	0.676
	(0.232)	(0.232)
Open water in buffer flooded area (as fraction of total flooded area)	-0.540**	-0.542**
	(0.0681)	(0.0680)
Wetlands in buffer flooded area (as fraction of total flooded area)	-0.175*	-0.318**
	(0.0520)	(0.0700)
*Wetlands in buffer flooded area*Isabel*		0.171*
		(0.0440)
*Wetlands in buffer flooded area*Irene*		0.188***
		(0.00277)
Constant	0.466**	0.465**
	(0.0900)	(0.0908)
Hurricane FEs	yes	yes
Observations	125,058	125,058
R-squared	0.368	0.369

** p < .10; ** p < .05; *** p < .01*. Standard errors in parentheses.

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Interpreting Regression Results

- Doubling wetlands in the flooded portion of a 500-m buffer around a parcel reduces average surge heights by
  - 0.318 meters (~68%) in Hurricane Floyd
  - 0.147 meters (~30%) in Hurricane Isabel
  - 0.130 meters (~20%) in Hurricane Irene

- Wetlands have differential effects across hurricanes

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Value of Protective Services of Wetlands

- Calculate damages at individual property level using FEMA depth-damage functions
  - Residential parcels only
  - Account for no. of stories & basement
- Do same calculation for a % reduction in flood heights

- Use the econometric results to back out change in wetlands necessary to bring about this reduction
- Calculate avoided damages per acre of wetlands

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Value of Protective Services, by Hurricane

Hurricane	*Marginal Value of Wetlands, per acre*
Floyd	$144
Isabel	$134
Irene	$179

Differences across hurricanes due to:

- Hurricane intensity & track (many more properties damaged in Isabel and Irene)
- Estimated relationship between wetland area and surge heights, by parcel, differs across hurricanes

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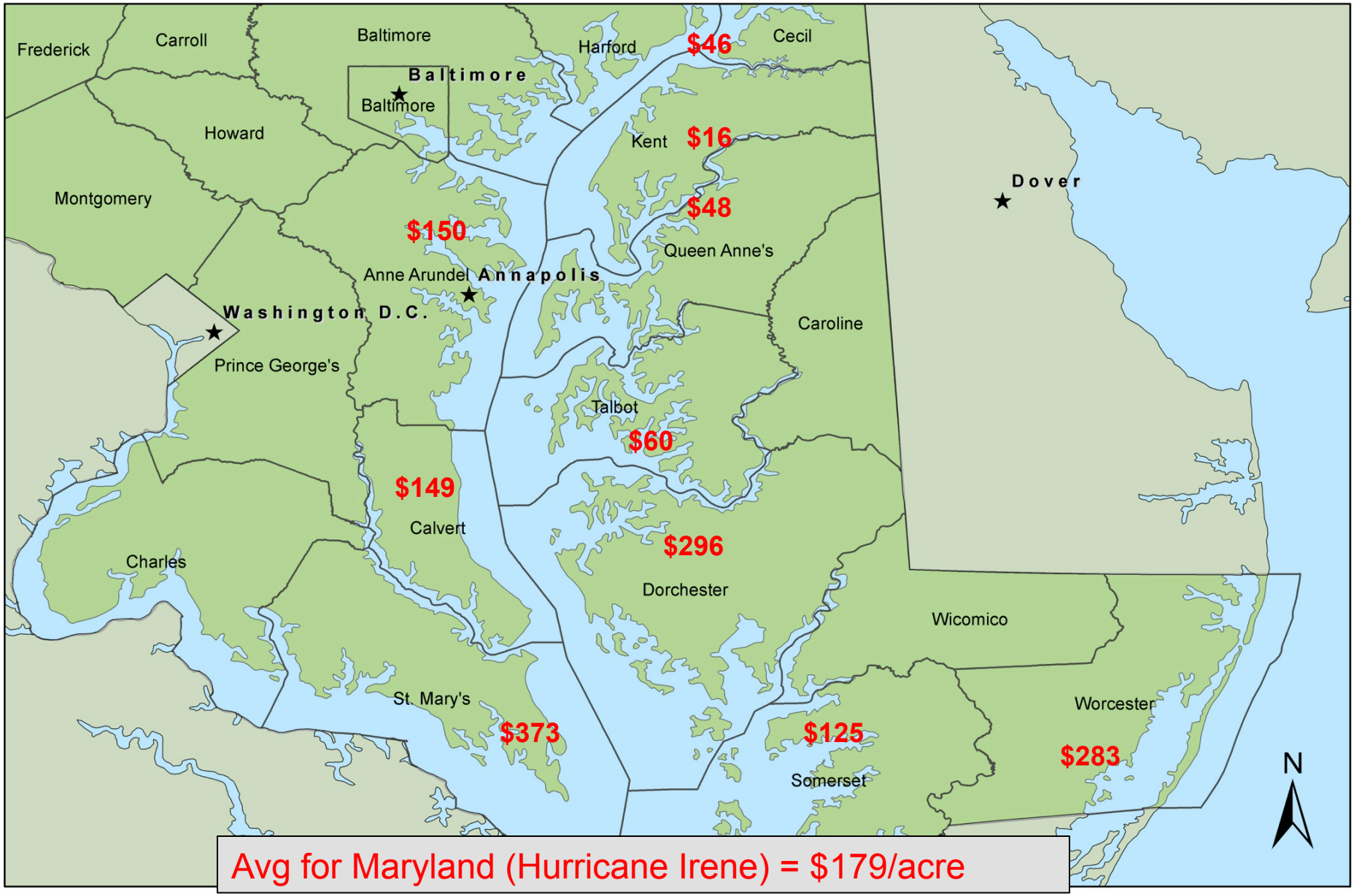
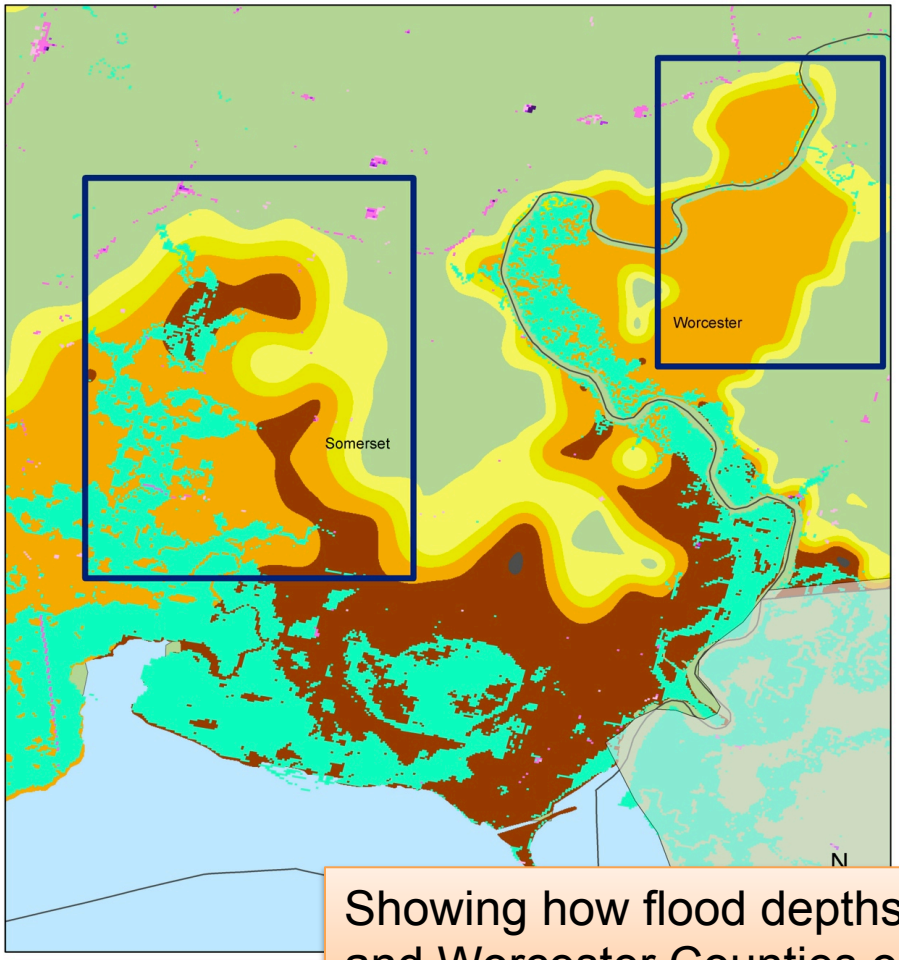
Value of Protective Services, by County

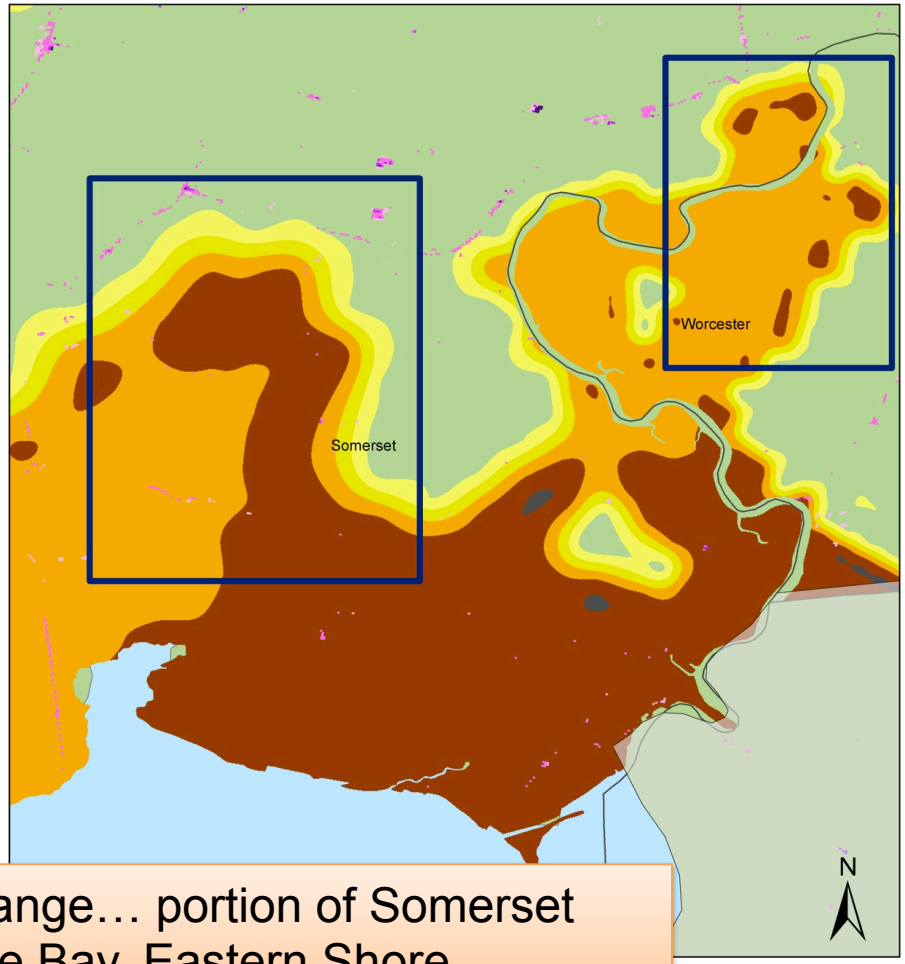


Avg for Maryland (Hurricane Irene) = $179/acre

Valuation Method 2 Results (prelim)

Storm Surge Model Runs with Hypothetical Land Cover…all estuarine wetlands replaced with bare land in ADCIRC + SWAN modeling





Showing how flood depths change… portion of Somerset and Worcester Counties on the Bay, Eastern Shore

Method 2 Results (cont.)

- Results:
  - Additional 4,525 acres flooded – 1.2% increase
  - Average surge height increases by 0.02m, 2.8%
  - Add'l $10 million damage (based on MDProperty View data and depth-damage functions)

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Some Comments, Thoughts, Conclusions

Strengths of the approach(es):

- Linking change in ecosystem function to ecosystem services & values
  - Most similar to Barbier *et al.* (2013); better than regressing aggregate $ damages on wetland acreage

Both valuation methods look only at difference in flooding on developed properties

- If nothing to damage, value of protective services = $0
- Add "option value"?
  - Wetlands protect some lands that could be developed in future
- So far, calculations based on three hurricanes only; other properties could flood in other hurricanes

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Next Steps

Short Run:

- Method 1:
  - Alternative buffer sizes
  - 40 storms instead of 4
  - Sensitivity of results to depth-damage functions
  - Merge with NFIP claims (data that we have at RFF) as an alternative measure of damages
- Method 2: first, better understand surge model results…
- Both: calculate expected annual value, not per-hurricane

Longer Run:

- Sea level rise and wetlands loss
- Marsh migration
- More economics: efficient targeting of new wetlands conservation areas

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Thank you!

Comments/questions: walls@rff.org