Using SLOSH to model storm surge vulnerability for coastal communities

RIGIS User Group Meeting: Catastrophe Planning

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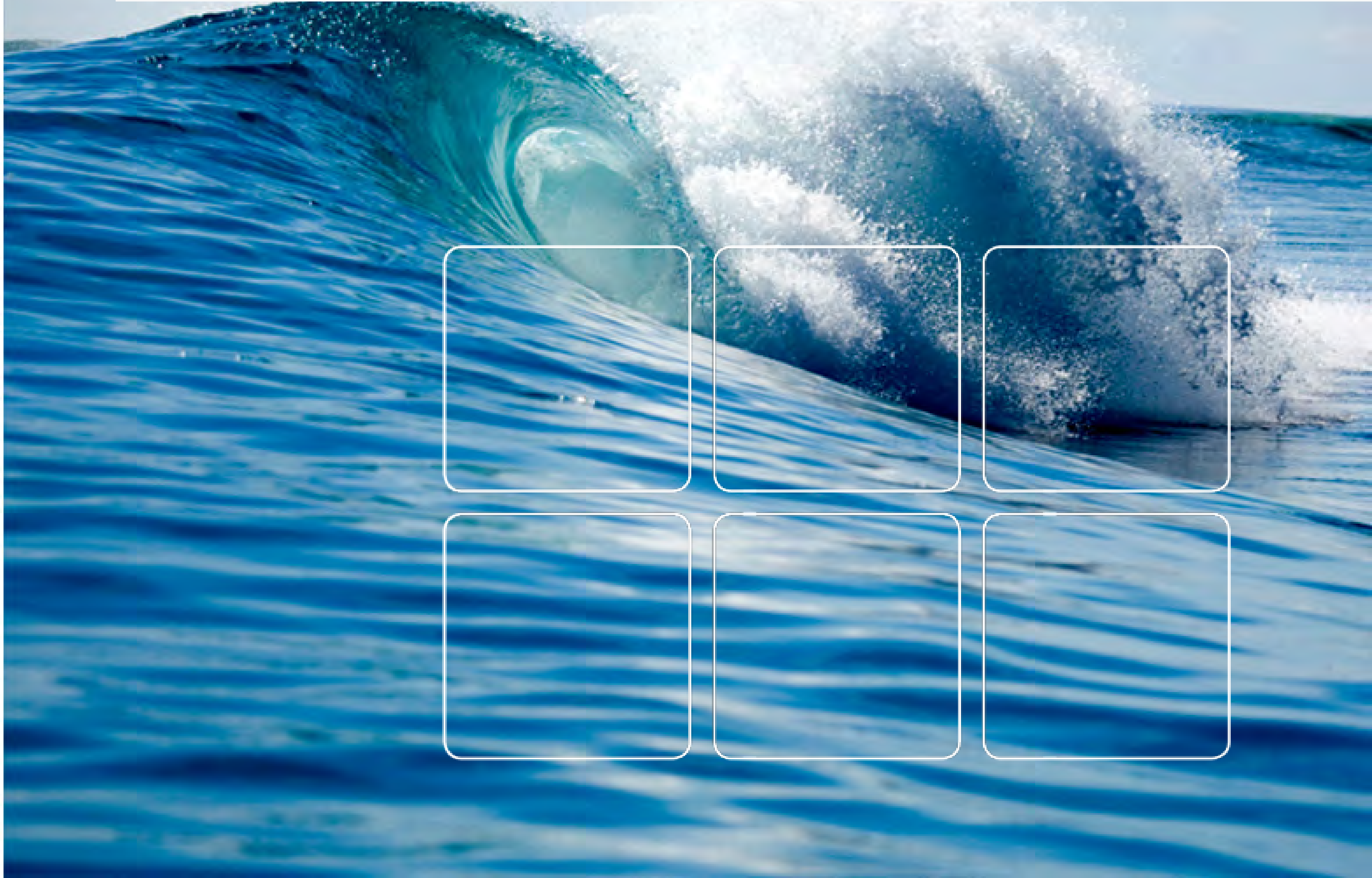


What is SLOSH?

- Sea Lake Overland Surges from Hurricanes (SLOSH)
- Two-dimensional numerical model developed by NOAA/NWS Meteorological Development Lab
- Estimates storm surge from historical, hypothetical, or predicted storms

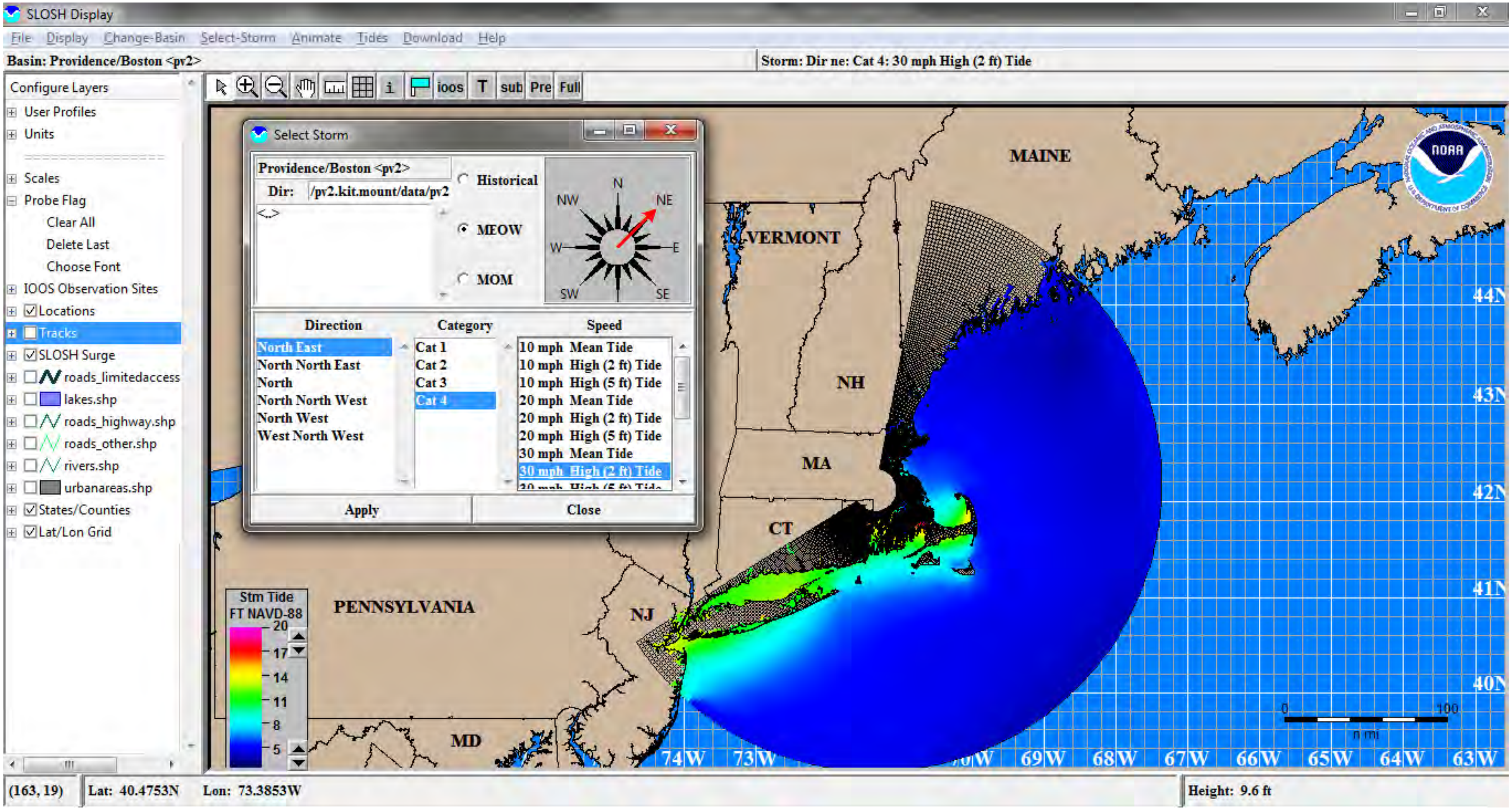
How is SLOSH Used?

- Provide guidance for storm surge forecasts during real-time events
  - Deterministic: single simulation
    - Strong dependence on accuracy of meteorological inputs
  - Ensemble/Probabilistic:
    - Uses error statistics from past hurricane forecasts (track, intensity)
    - Creates an ensemble of scenarios and calculates probability of a specified storm surge for locations at risk
- Assess vulnerability to storm surge
  - Use thousands of hypothetical storms scenarios to predict surge
  - Calculate composite of results (MEOW, MOM)

SLOSH Model vs. SLOSH Display Program

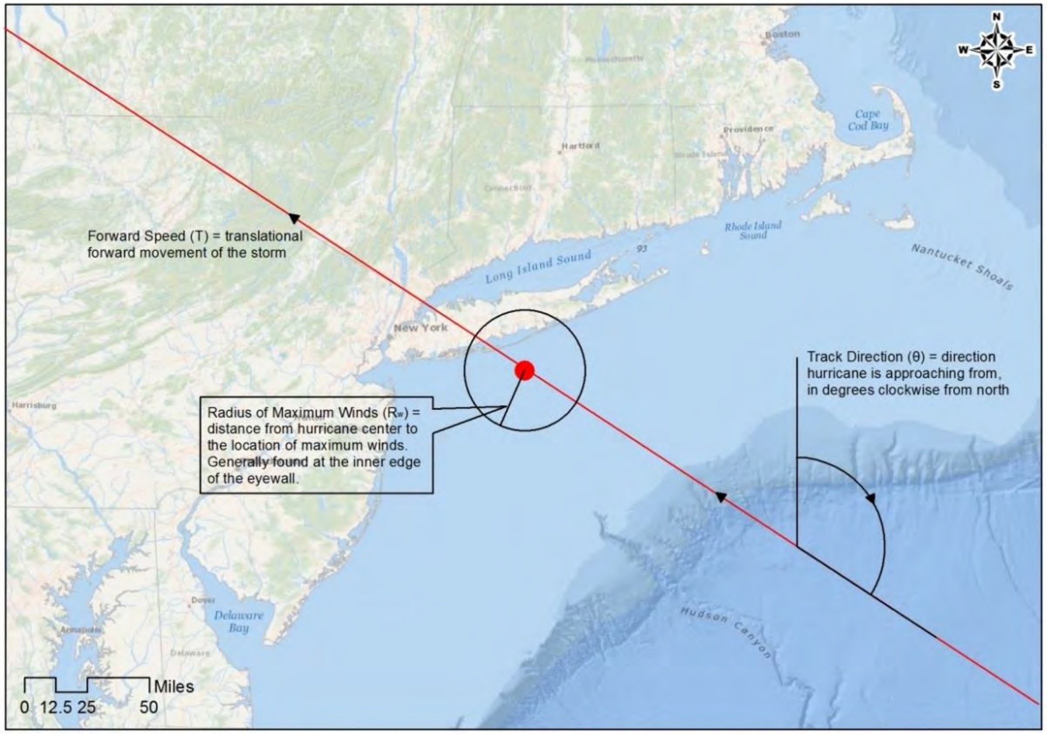
- SLOSH Display Program:
  - Packaged with an atlas of pre-computed surge maps
  - widely used by local planners and emergency managers to visualize composites of storm tide predictions (MEOW and MOM) for a specific area
  - the user to downloads an interface and views previously run model simulations
- SLOSH Model:
  - Used to estimate winds and resulting storm surge resulting from historical, hypothetical, or predicted hurricanes defined by ‘track’ (text) files
- SLOSH model and the SLOSH Display program are *two different tools.*

SLOSH Display Program



Model Inputs

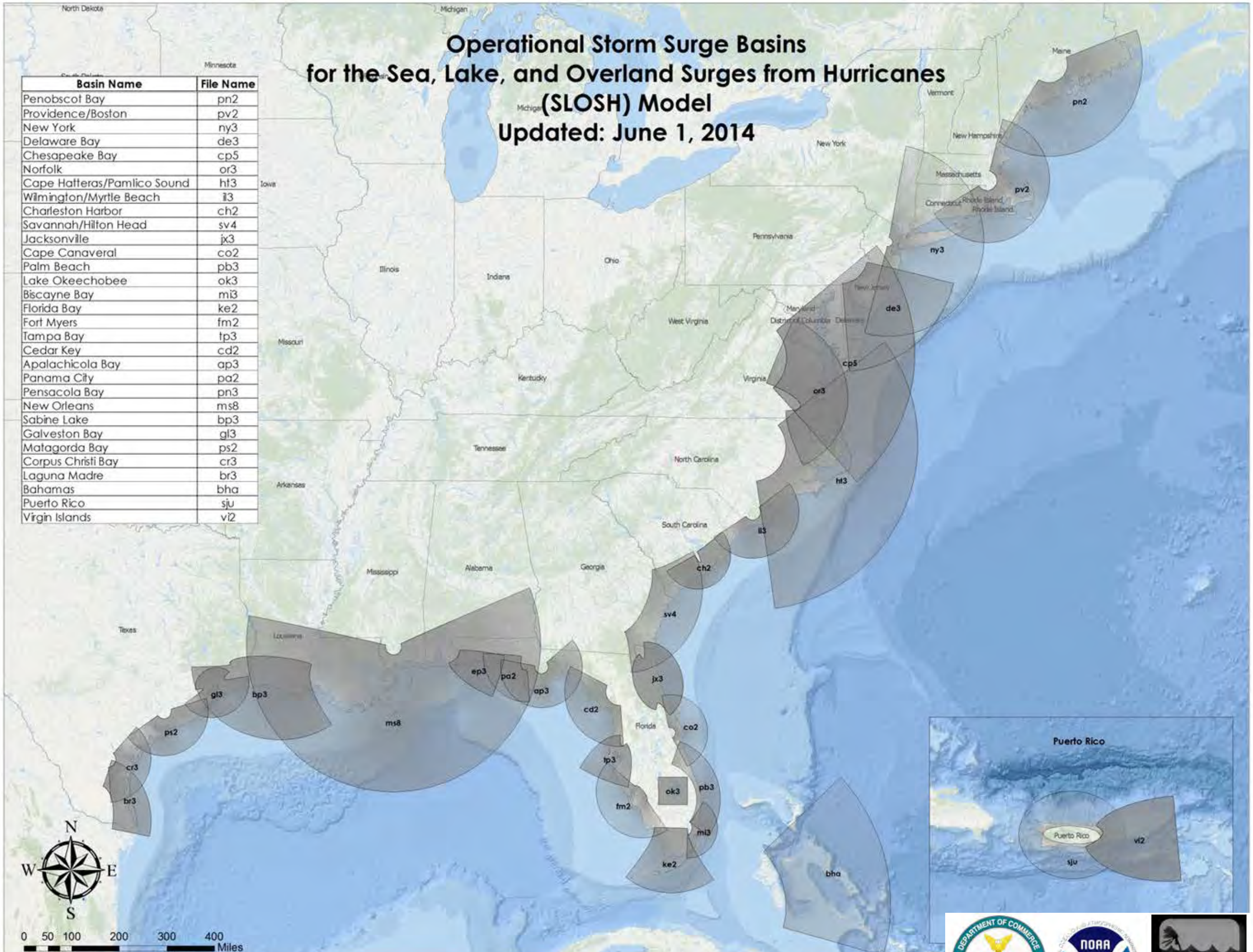
- Parameterization of tropical cyclone wind field
  - Track direction, forward speed, pressure, radius of maximum winds
- Other factors affecting storm tide predictions
  - Landfall location
  - Base water level



Model Inputs

- SLOSH Basins
  - Polar, elliptical, or hyperbolic grid centered on an area of interest
  - Integrated topography/bathymetry
  - Provides finest resolution at area of interest & coarsest resolution along grid boundaries
  - Model Coverage:
    - Entire US Atlantic and Gulf of Mexico coasts
    - Hawaii, Puerto Rico, Virgin Islands, and Bahamas
    - 37 operational basins

The SLOSH Model
Sea, **L**ake, and **O**verland **S**urges from **H**urricanes



Basin Name	File Name
Penobscot Bay	pn2
Providence/Boston	pv2
New York	ny3
Delaware Bay	de3
Chesapeake Bay	cp5
Norfolk	or3
Cape Hatteras/Pamlico Sound	ht3
Wilmington/Myrtle Beach	il3
Charleston Harbor	ch2
Savannah/Hilton Head	sv4
Jacksonville	jx3
Cape Canaveral	co2
Palm Beach	pb3
Lake Okeechobee	ok3
Biscayne Bay	mi3
Florida Bay	ke2
Fort Myers	fm2
Tampa Bay	tp3
Cedar Key	cd2
Apalachicola Bay	ap3
Panama City	pa2
Pensacola Bay	pn3
New Orleans	ms8
Sabine Lake	bp3
Galveston Bay	gl3
Matagorda Bay	ps2
Corpus Christi Bay	cr3
Laguna Madre	br3
Bahamas	bha
Puerto Rico	sju
Virgin Islands	vi2

Strengths & Limitations

- Strengths
  - Computationally efficient
  - Flow through barriers, gaps, passes
  - Overland inundation (wet or dry cells)
  - Overtopping of barriers, levees, and roads
  - Coastal reflection
  - Astronomical Tides (new!)

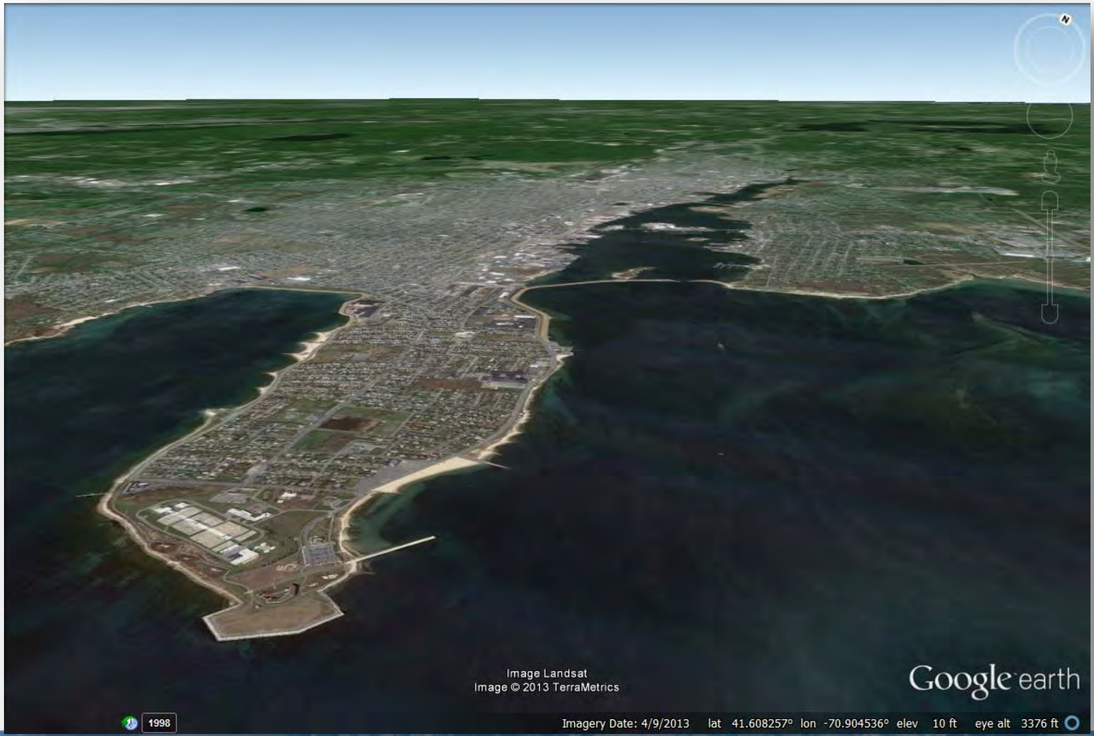
- Limitations
  - Wave impact
  - River flow
  - Precipitation

Model Validation

- Jarvinen and Lawrence 1985
- Glahn et al. 2009
- Forbes and Rhome, 2012
- RPS ASA, 2013
- Jelesnianski et al. 1992
  - SLOSH predictions w/in +/- 20% for significant surges
  - Using HWMs from Katrina, SLOSH accuracy approached +/- 5%

Objective and Methodology

- Climate Change Vulnerability Assessment and Adaptation Planning Study for Water Quality Infrastructure
- Dynamically model water levels resulting from the combination of hurricanes and sea level rise for New Bedford Harbor
  - Using
    - NOAA's SLOSH Model
    - Existing NOAA SLOSH Grid
    - Tide + SLR
    - Many variations of Hurricane Parameters



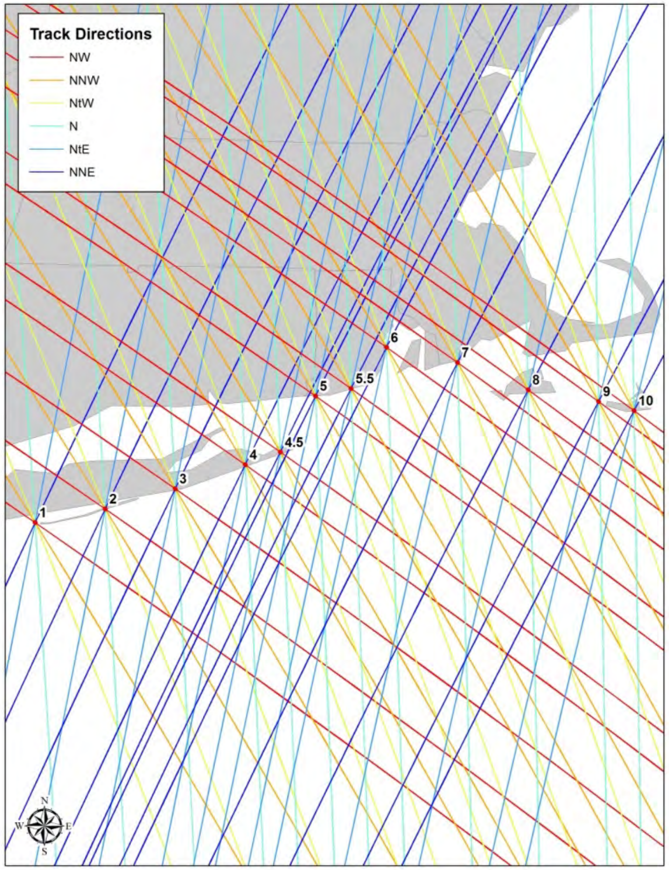
Project-Specific Inputs: Base Water Level

- Defined as tidal elevation + applicable sea level rise
- Tidal elevation defined as MHHW (average of the higher high water height of each tidal day and thus represents areas that are, on average, wet once per day)
- Sea level rise = 1, 2, and 4 feet

	New Bedford, MA	New Bedford, MA with Sea Level Rise		
	Feet Relative to NAVD88	1 ft	2 ft	4 ft
MHHW	1.9	2.9	3.9	5.9

Project-Specific Inputs: Hurricane Parameters

Parameter	Values	# Variations
Landfall Location	Evenly spaced along the shoreline	12
Pressure Deficit (ΔP)	20, 40, 60, 80, 90* mb	5
Radius of Maximum Winds (R)	**20***,30, **40**, 45, **50**, **55*** NM	6
Forward Speed (T)	20, 30, 40, 50, 60,**70*** mph	6
Track Direction (Θ)	N, NNE, NNW, NW, **NtW*, NWtW, NtE***	7
	Matrix Total Cases	**15,120 per water level 60,480 total**



Composite Products

MEOW (Maximum Envelope of Water)

- Maximum storm tide elevation for particular storm category, forward speed, trajectory, and initial tide level, incorporating uncertainty in forecast landfall location.

MOM (Maximum of MEOWs)

- Ensemble product of maximum storm tide elevations for all hurricanes of a given category and initial tide regardless of forward speed, storm trajectory, landfall location, etc.

Aggregate Model Output

- The MOM approach was used to aggregate the 60k+ scenarios into 20, one for each combination of Category and Base Water Level

60,000 + Scenarios

Aggregate by pressure difference and water level scenario

20, 40, 60, 80, 90 mb × 0, 1, 2, 4 ft SLR = 20 Storm Tide Elevation Grids

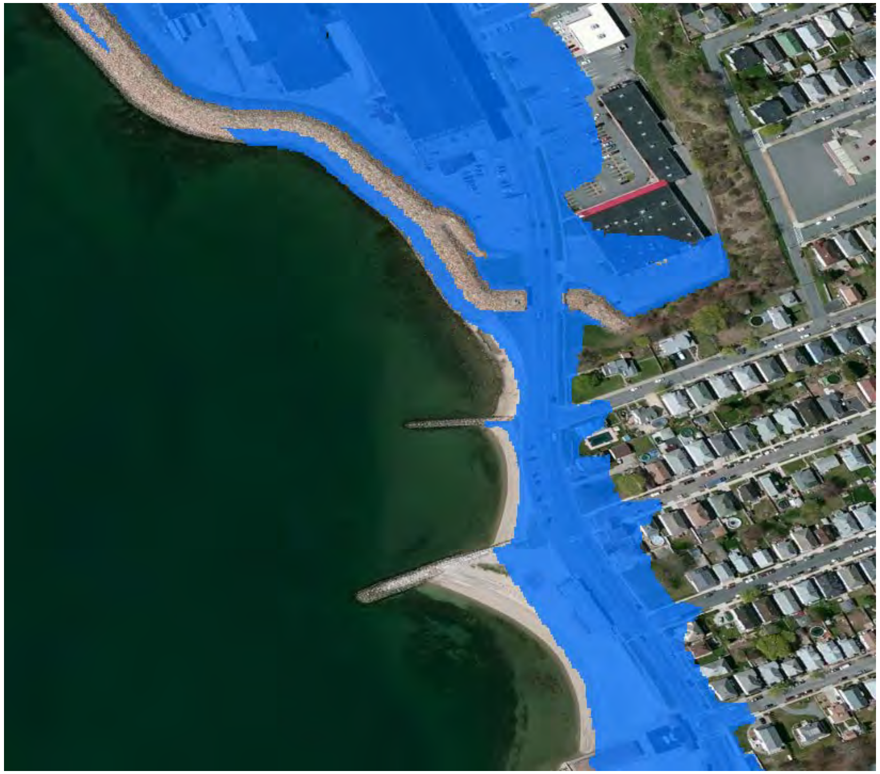
Processing of Results:

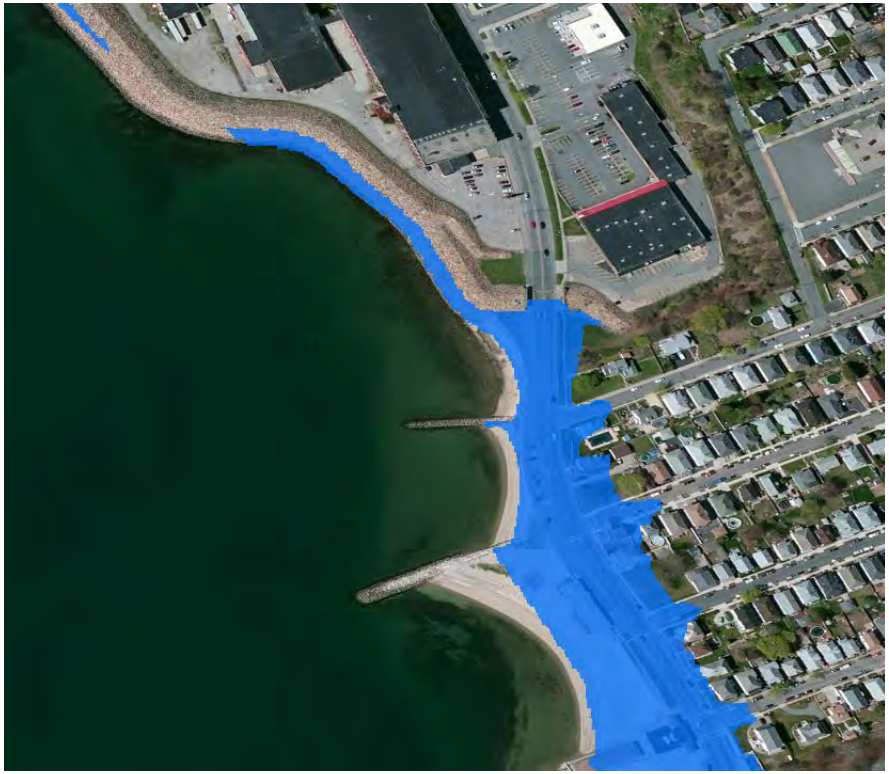
Step 1: Plot SLOSH water levels onto LiDAR data to create depth grids

Water levels on SLOSH Grid → Depths on LiDAR Grid

Processing of Results:

Step 2: Account for site specific features





Remove flooding entering through barrier swing gates

Shown: Category 1 Hurricane with 4 ft of SLR

Summary of Results

Depth grids used to derive inundation depth values for selected infrastructure

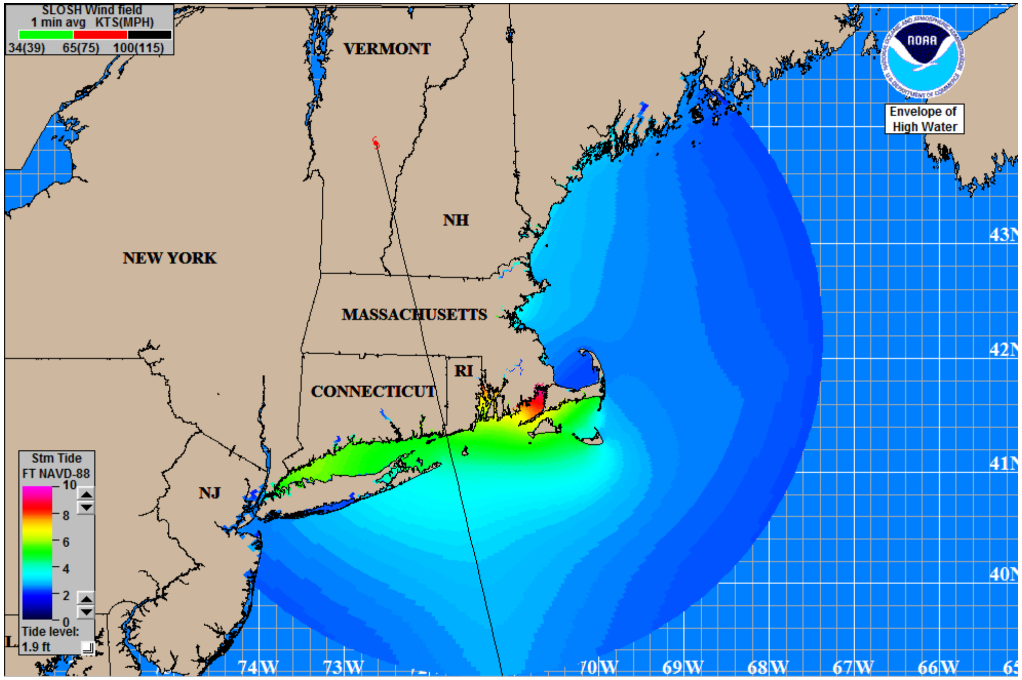
Simplified polygon used to show inundation extent on maps

Shown: Category 1 Hurricane with 4 ft of SLR

Summary of Results: Controlling Hurricane Parameters

- Highest Water Levels:

1. Storm landfall in eastern CT and Rhode Island
2. Angle of approach (ϴ) between 168° and 180° from North (storm headed NtW to N)
3. Radius of maximum wind (Rw) 40 to 50 NM
4. Highest forward speed (60 or 70 mph)



Summary of Results: Scenarios resulting in inundation beyond the barrier

Summary of Results: Scenarios resulting in inundation beyond the barrier

Scenarios Resulting in Inundation Beyond the Hurricane Barrier:

Storm Scenario	New Bedford Barrier (mouth of New Bedford Harbor)	Clarks Cove Dike (west of New Bedford Harbor)	Fairhaven Dike (east of New Bedford Harbor)
Cat 2, 4’ SLR	Inundates around barrier	Inundates around dike	No impact
Cat 3, 0’ SLR	Inundates around barrier	Inundates around dike	No impact
Cat 3, 1’ SLR	Inundates around barrier	Inundates around dike	Inundates around and over dike
Cat 3, 2’ SLR	Inundates around and over barrier	Inundates around barrier; begins to inundate over barrier	Inundates around and over dike
Cat 3, 4’ SLR Cat 4, all SLR scenarios	Inundates around and over barrier	Inundates around and over barrier	Inundates around and over dike

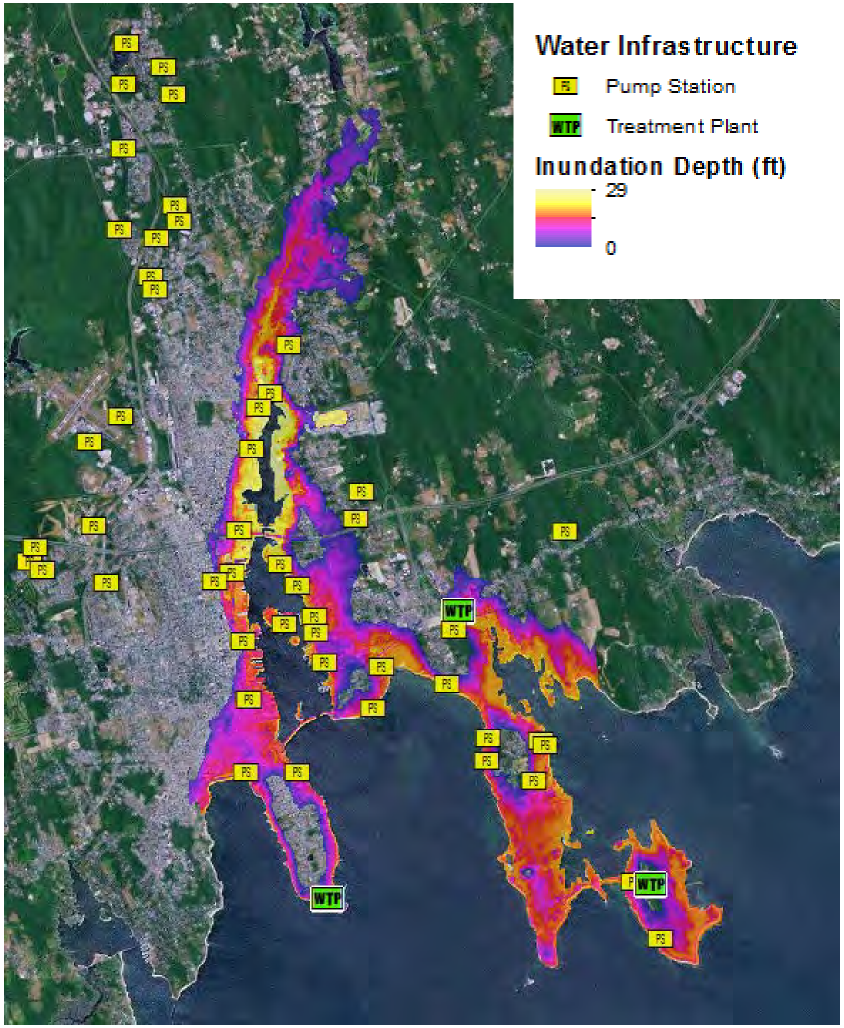
Vulnerability Analysis

Determine Inundation depths for:

- Water Infrastructure
- Coastal Protection Structures
- Municipally-Owned Structures
- State-Owned Buildings
- Designated Port Areas
- Census Blocks
- Environmental Justice Populations

Use FEMA HAZUS Model to:

- Quantify economic losses
    - # of substantially damaged buildings
    - Wastewater facility damage
    - Building Replacement Value



Conclusions & Summary

- SLOSH Model
  - Dependable & valuable tool
  - Predicts storm surge in real-time
  - Assists in hazard analysis for hurricane planning
- No model can account for hurricane forecast uncertainty
  - Storm surge model specifications (physics, resolution, etc.) cannot make up for uncertainty in meteorological parameters
  - SLOSH provides efficient mechanism for ensemble modeling
- Most appropriate model should be chose based on project specifics and goals

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ricane inundation scenarios and selected infrastructure, property, and population features for three Massachusetts municipalities.

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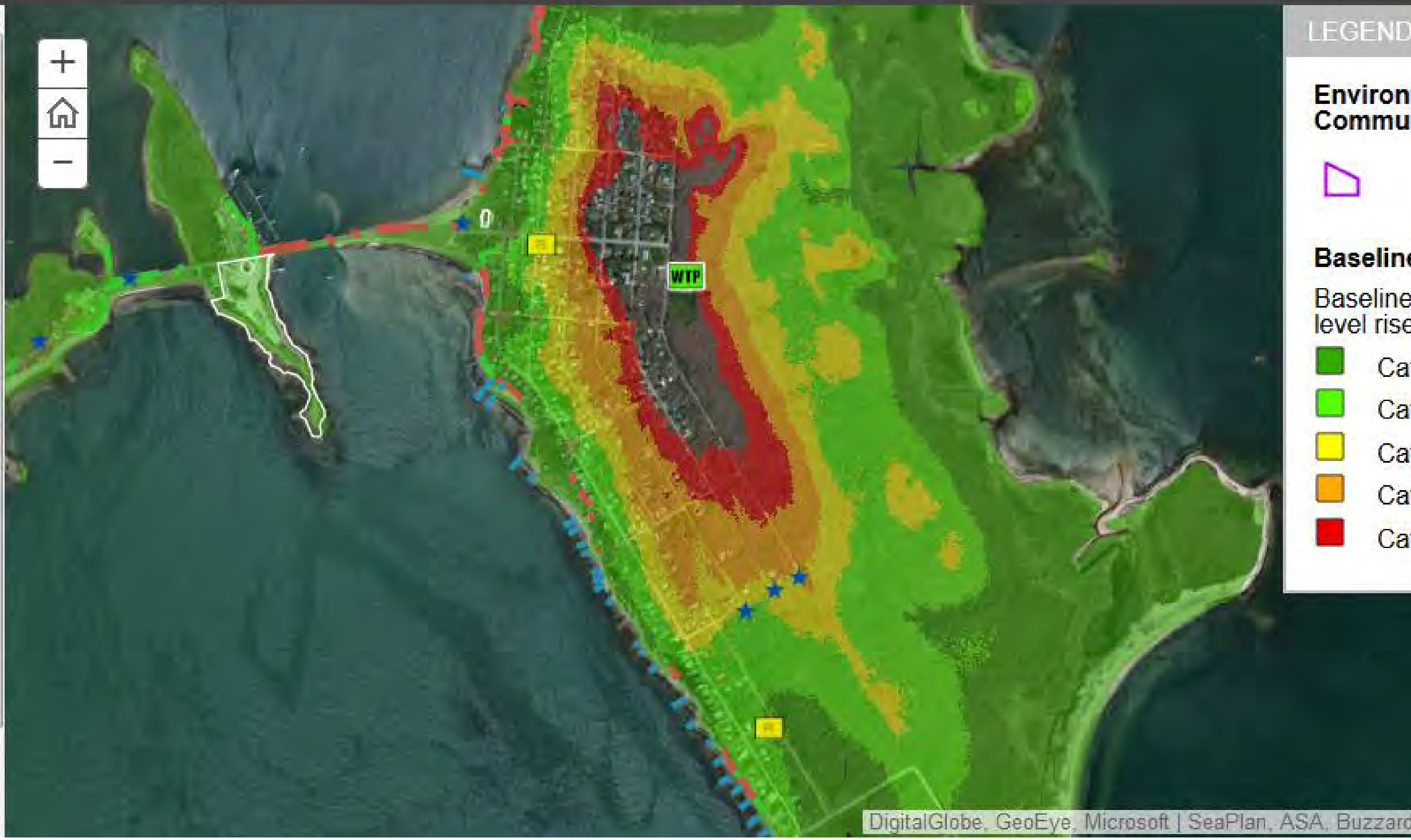

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Inundation Scenarios for Acushnet, Fairhaven, and New Bedford

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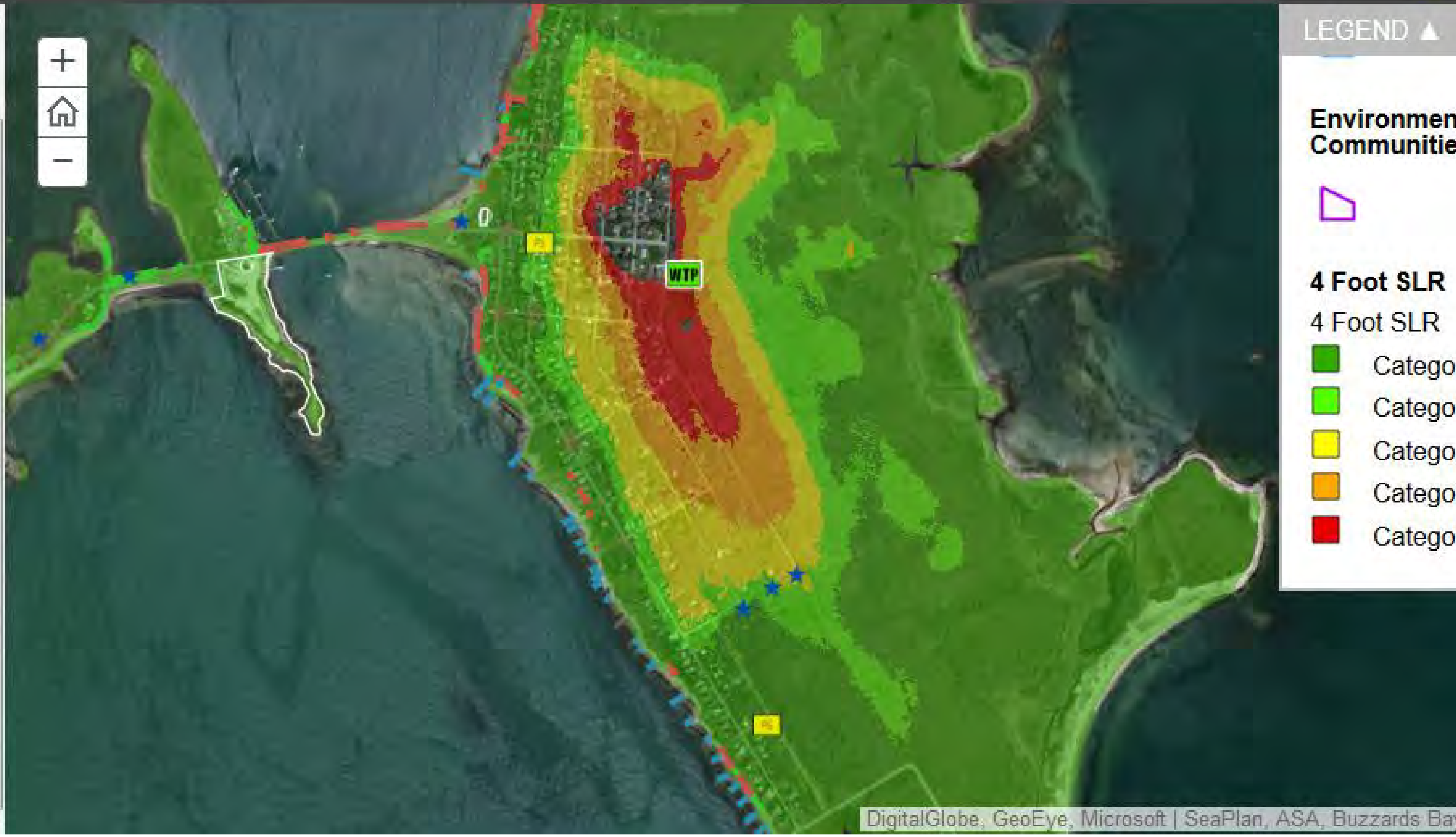

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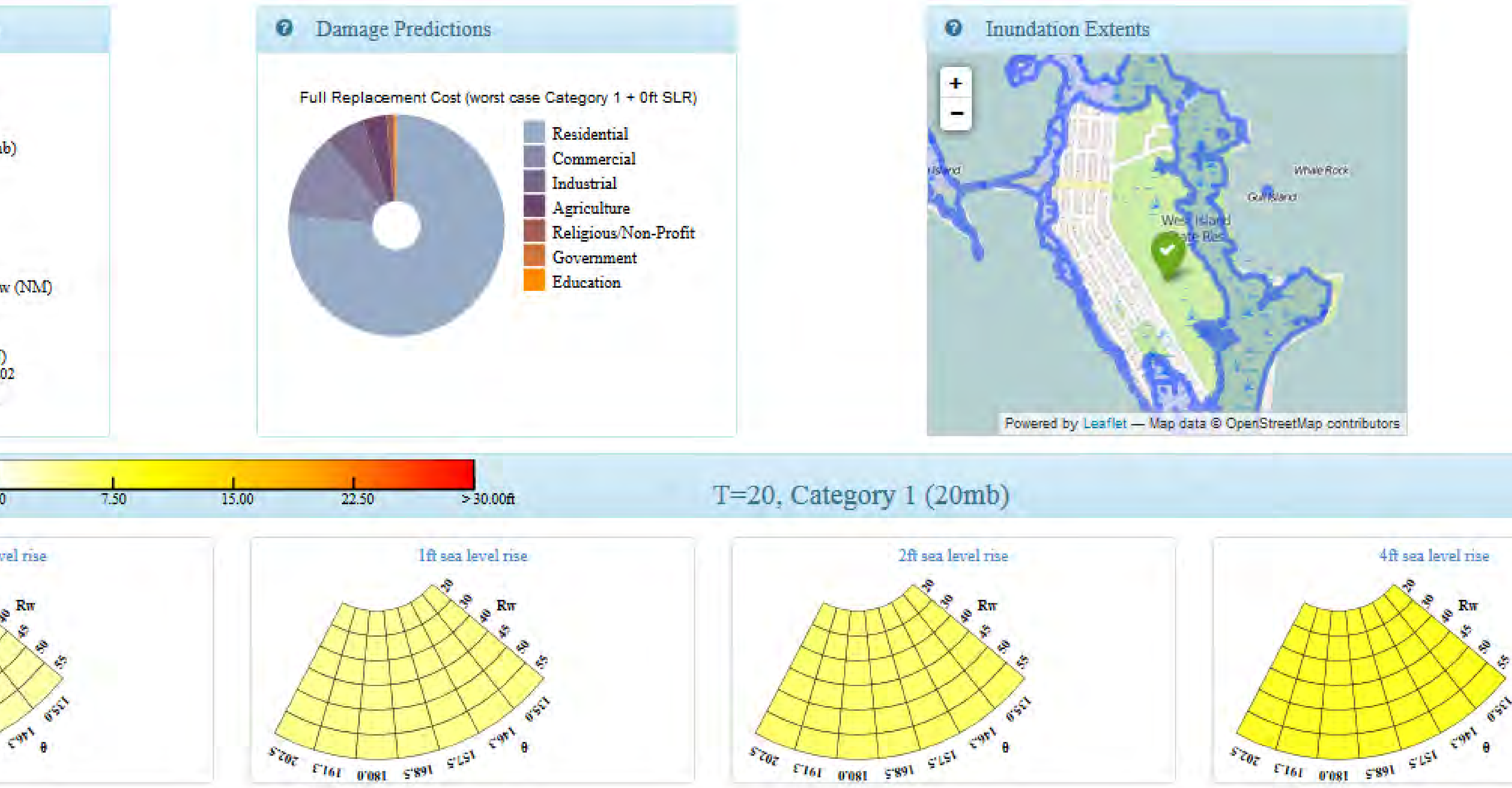

Damage Predictions
Full Replacement Cost (worst case Category 1 + 0ft SLR)
Residential
Commercial
Industrial
Agriculture
Religious/Non-Profit
Government
Education
Inundation Extents
Whale Rock
Gull Island
West Island
Powered by Leaflet — Map data © OpenStreetMap contributors
7.50
15.00
22.50
> 30.00ft
T=20, Category 1 (20mb)
1ft sea level rise
2ft sea level rise
4ft sea level rise
Rw
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