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Spatial Interactions Between Public Health and Water Infrastructure in Coastal Communities

Tom Allen

Spatial Interactions Between Public Health and Water Infrastructure in Coastal Communities

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Acknowledgements

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Ms. Ariel Christensen, NC Dept. of Public Health

Purpose

- Better inform and empower communities to address sea level rise in a changing climate
- Support decision-makers to integrate public health, emergency mgt. and coastal planning
- Test new information and tools to boost resiliency
- Explore interacting threats
 - Sea level rise
 - Storm surges
 - Tidal flooding
 - Extreme rainfall
 - Groundwater

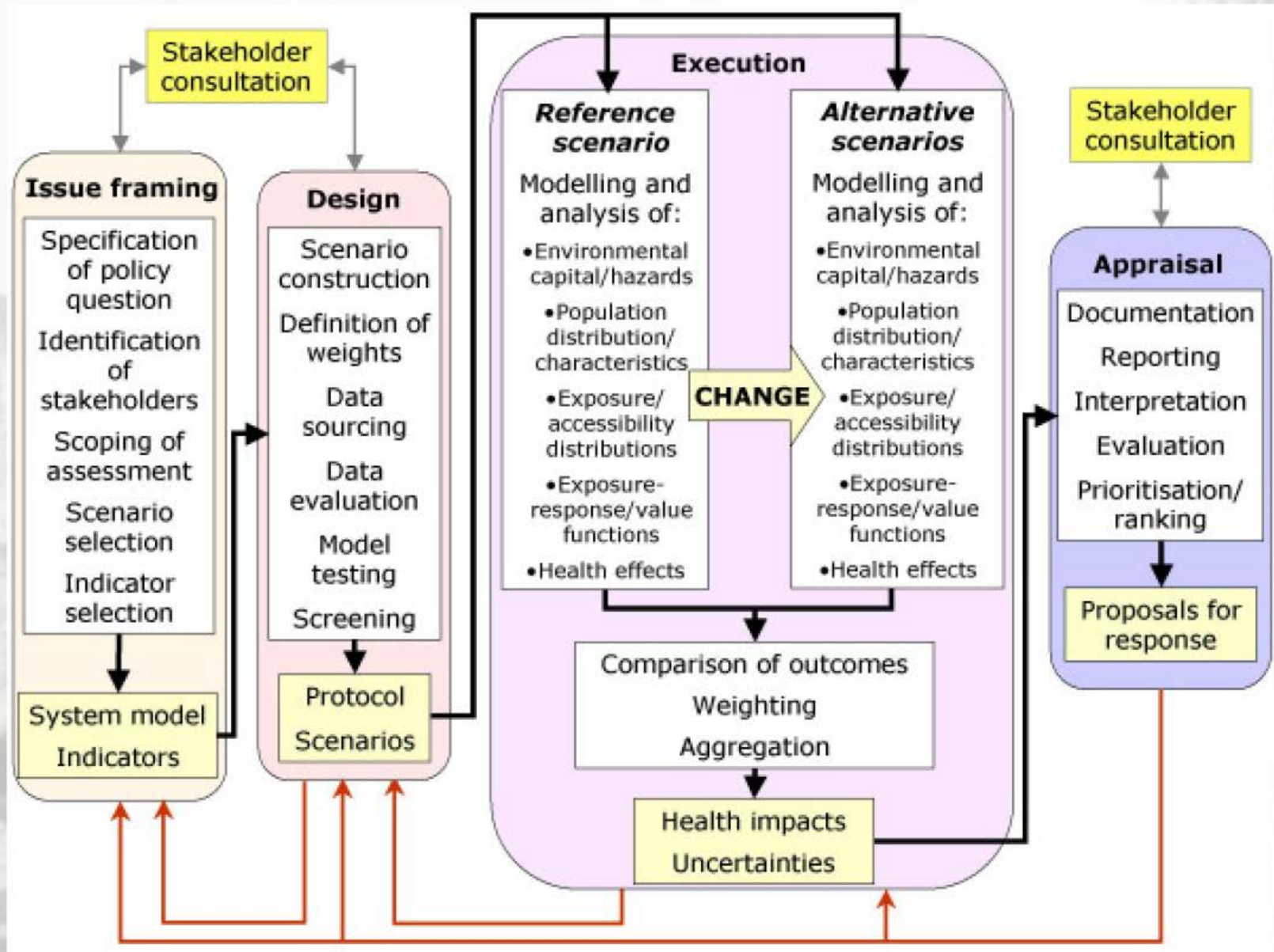
Steps to Resilience

US Climate Resilience Toolkit <https://toolkit.climate.gov/>

1. Explore Hazards
2. Assess Vulnerability & Risks
3. Investigate Options
4. Prioritize & Plan
5. Take Action



FRAMEWORK: Briggs (2008) *Integrated Environmental Health Impact Assessment*



Reveal Health Impacts & Reduce Uncertainties

Population Exposure

Census, cadastral and dasymetric mapping

Medically fragile and socially vulnerable

Limited health registry

Seasonal and transhumant population

Tourists and migrants

Environmental Health and Sanitation

Onsite wastewater treatment

Centralized wastewater

Groundwater

Infrastructure elevations

Effluent spills

System infiltration

Cascading failures

Health Care Access and Continuity

Hospitals and acute primary care

Outpatient tertiary care

Dialysis, Oxygen and medical technology

Indirect and Lagged Effects

Mosquito vectors and disease

Waterborne pathogens and contaminants

Shellfish, waterway, and beach closures

Two Cities with Recurrent Coastal Flooding

Morehead City, NC



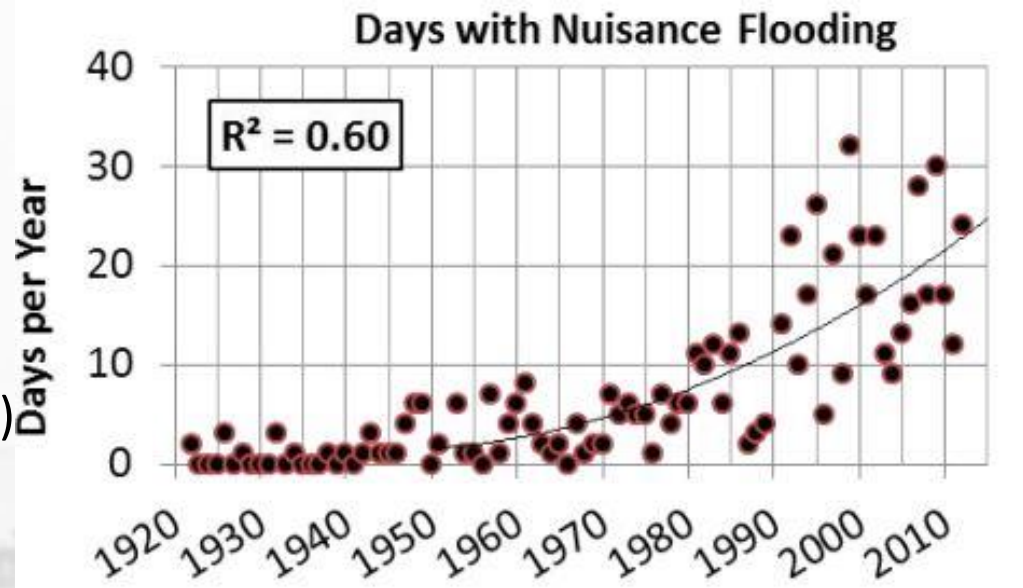
Charleston, SC



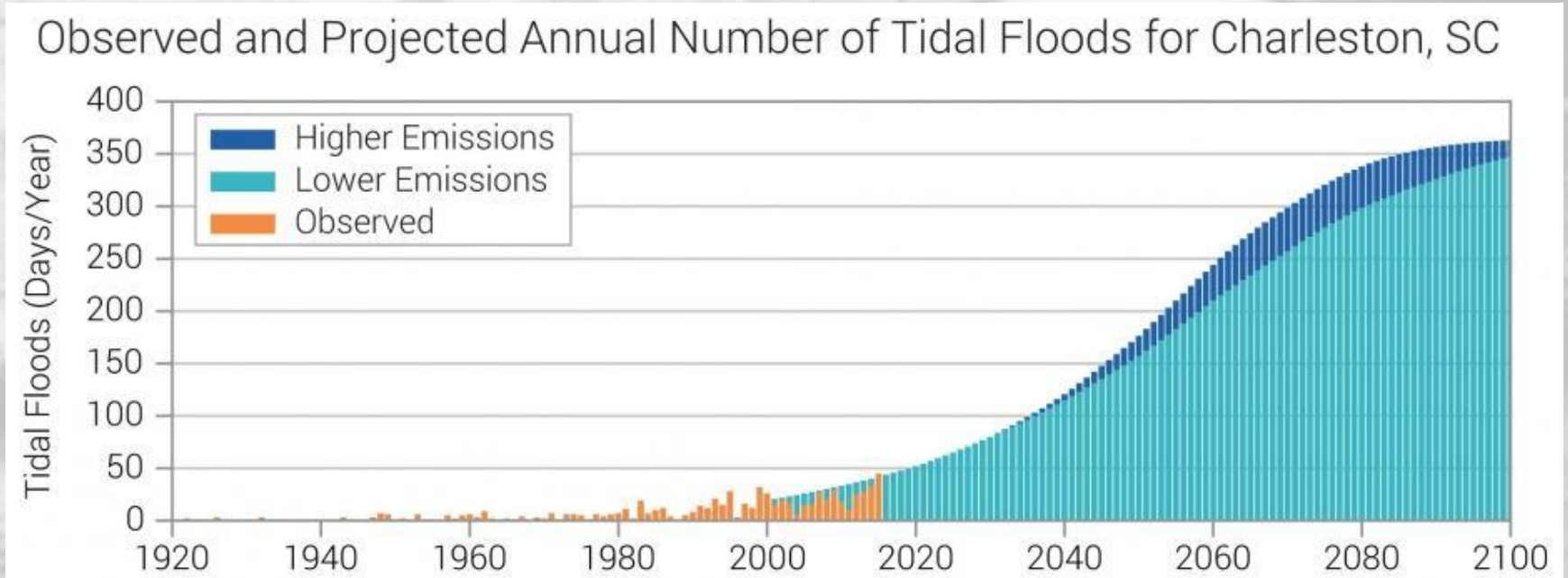
“Nuisance Flooding”

Localized, street-level impacts above mean high water

Sweet et al. (2014)



Charleston Sea Level Rise Plan (2016)



Multi-hazard flooding is modeled using NOAA SLOSH, LiDAR DEMs, tide gauges, and rainfall runoff for baseline flood events and SLR scenarios.

Sea Level Rise

Relative SLR scenarios
20cm
40cm
60cm

Nuisance Tidal Flooding

King tides from NOAA NGS tide gauge
MHHW tidal epochs
LiDAR-based inundation grids

Storm Surges

Downscaled NOAA SLOSH Maximum-of-Maximums
Saffir-Simpson 1-5
Inundation extents and depth grids

Rainfall Runoff

Hydrologic runoff model of hydro-corrected LiDAR DEMs
TauDEM D_∞

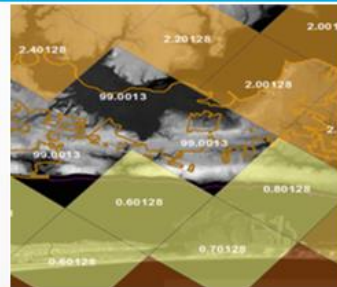
Surge Model Downscaling and Inundation

Acquire SLOSH MOMs



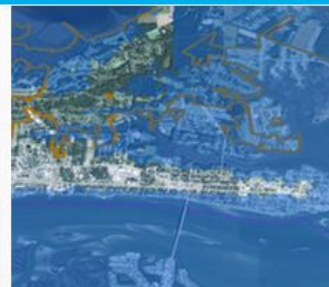
SLOSH
basins
ehatv2
hchsv2

Downscale SLOSH MOMs to LiDAR



Downscale
SLOSH
MOMs to
LiDAR DEM
10m cells

Inundation DEM



Inundate
DEMs
enforcing
hydro-
connectivity

Potential Impacts



Overlay and
spatial
analysis of
infrastructure
and other
impacts

Hydrologic Controls

Charleston Field Recon July 2016



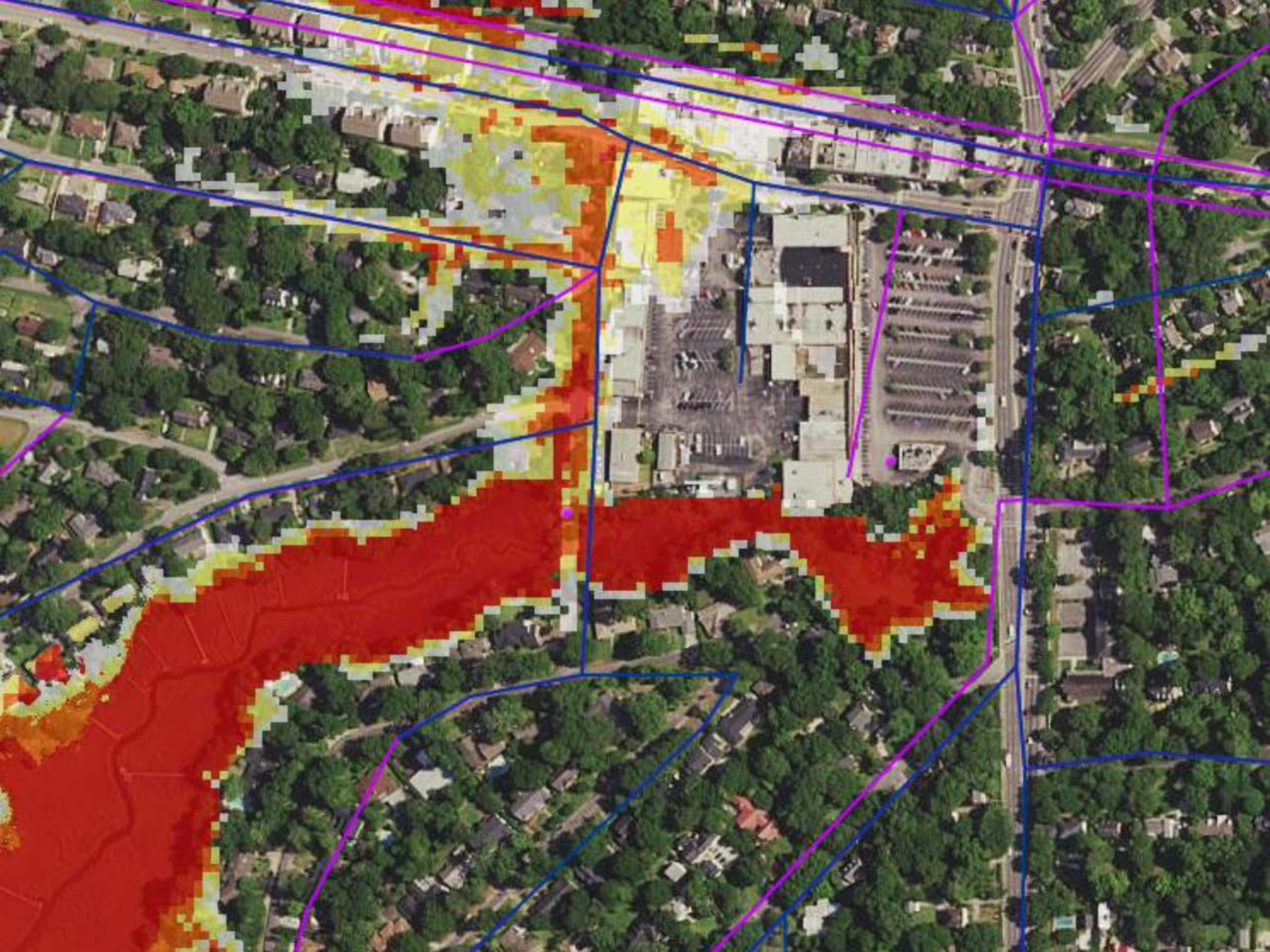
Causeway at Edgewater



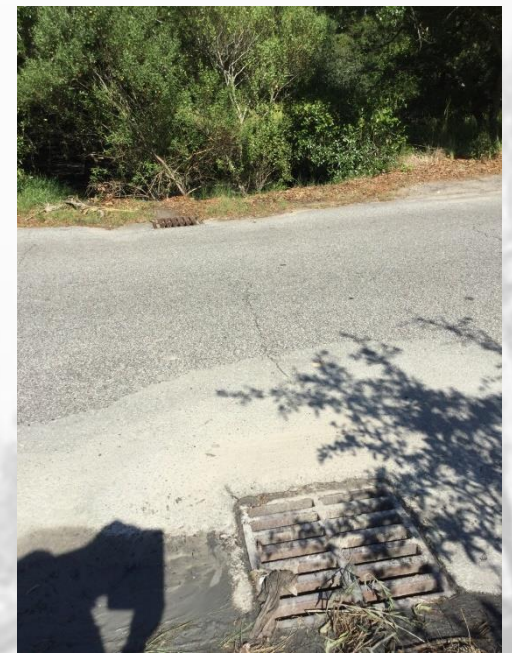
Pump infrastructure...and elevation

Hydro-Correction and Hydro-Conditioning

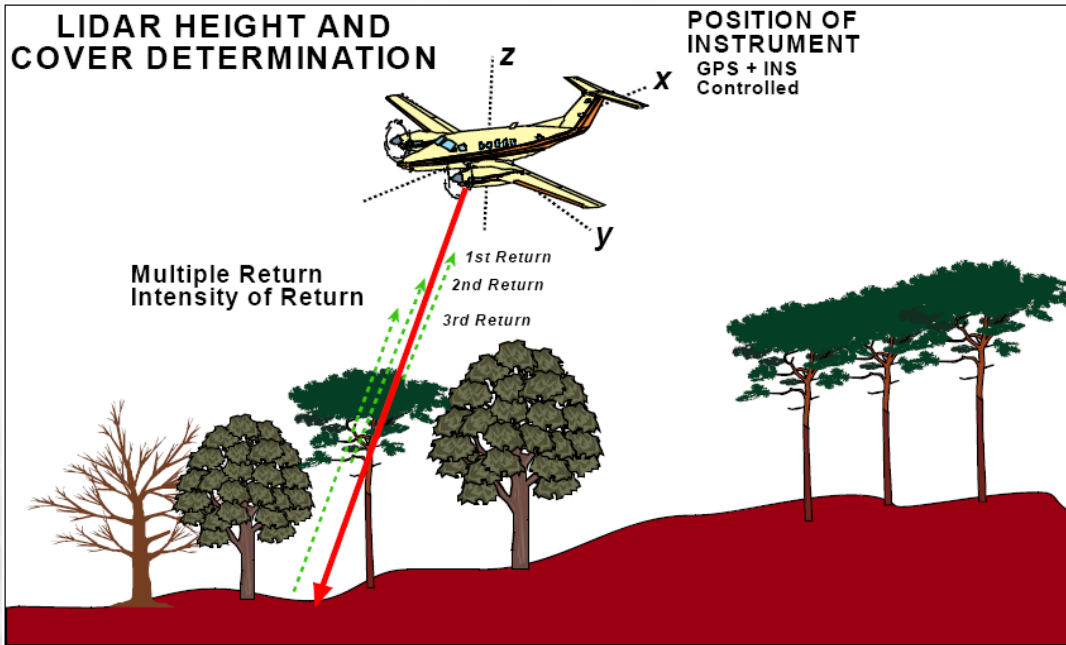




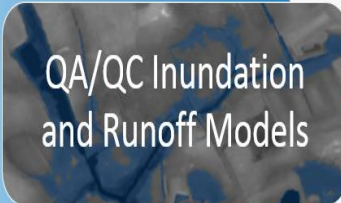
Culverts and Ditches



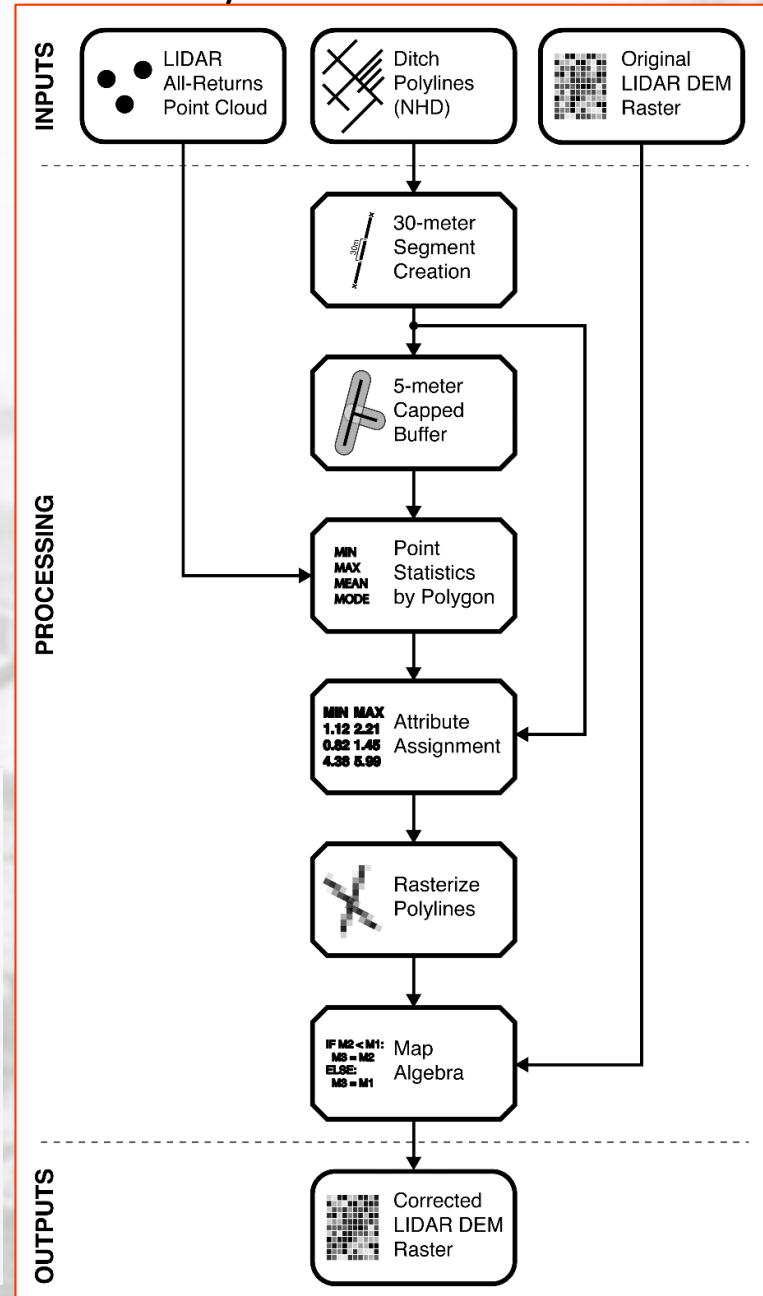
Hydro-correction of LiDAR Digital Elevation Models



Filtered LiDAR point clouds for “bare earth” DEMs, then post-process to correct them for flood mapping

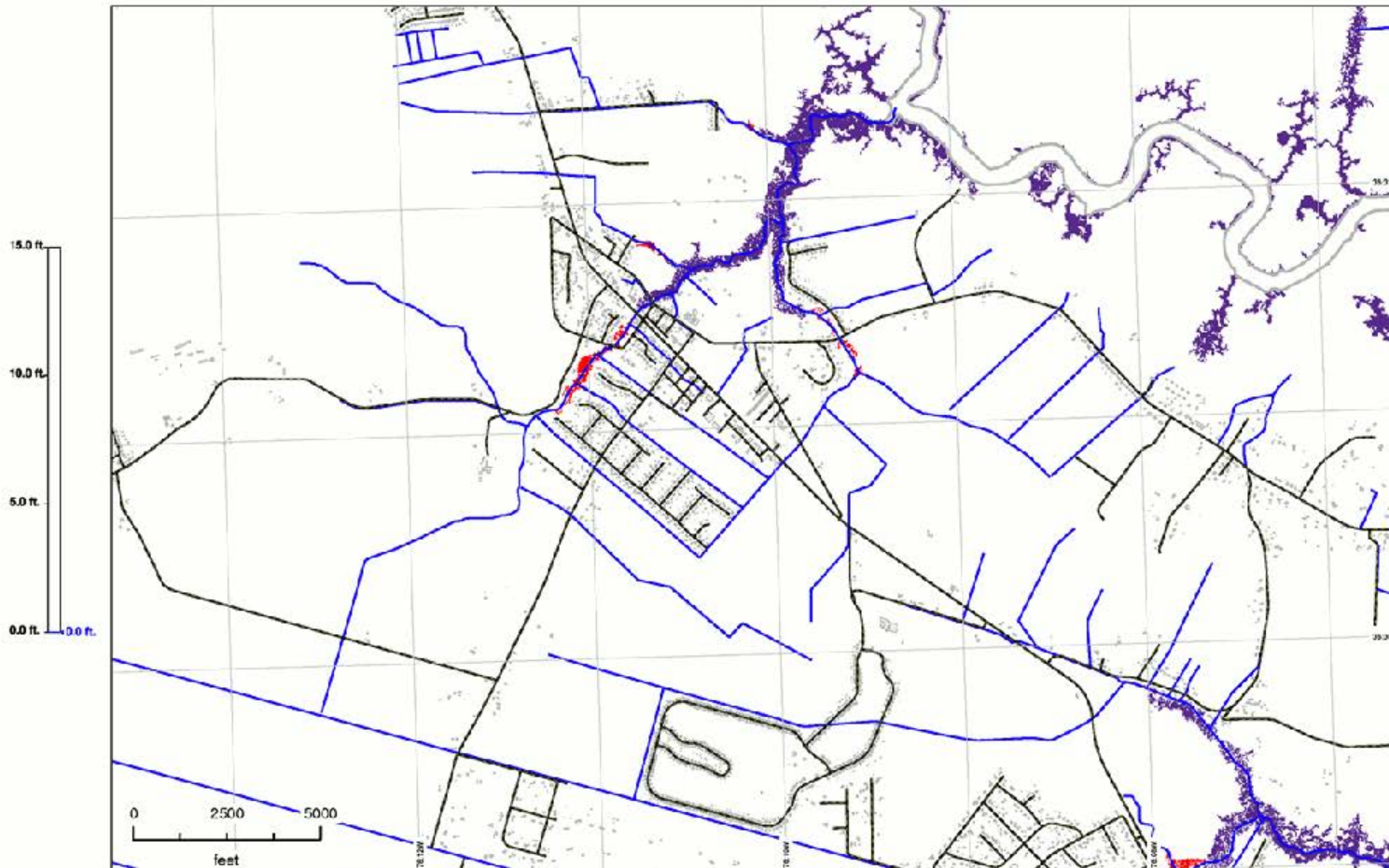


Hydro-correction Process



Reducing Flood Omission Error

GRASS r.flood simulation using 10m LiDAR DEM with ditch “*stream burning*” hydro-correction

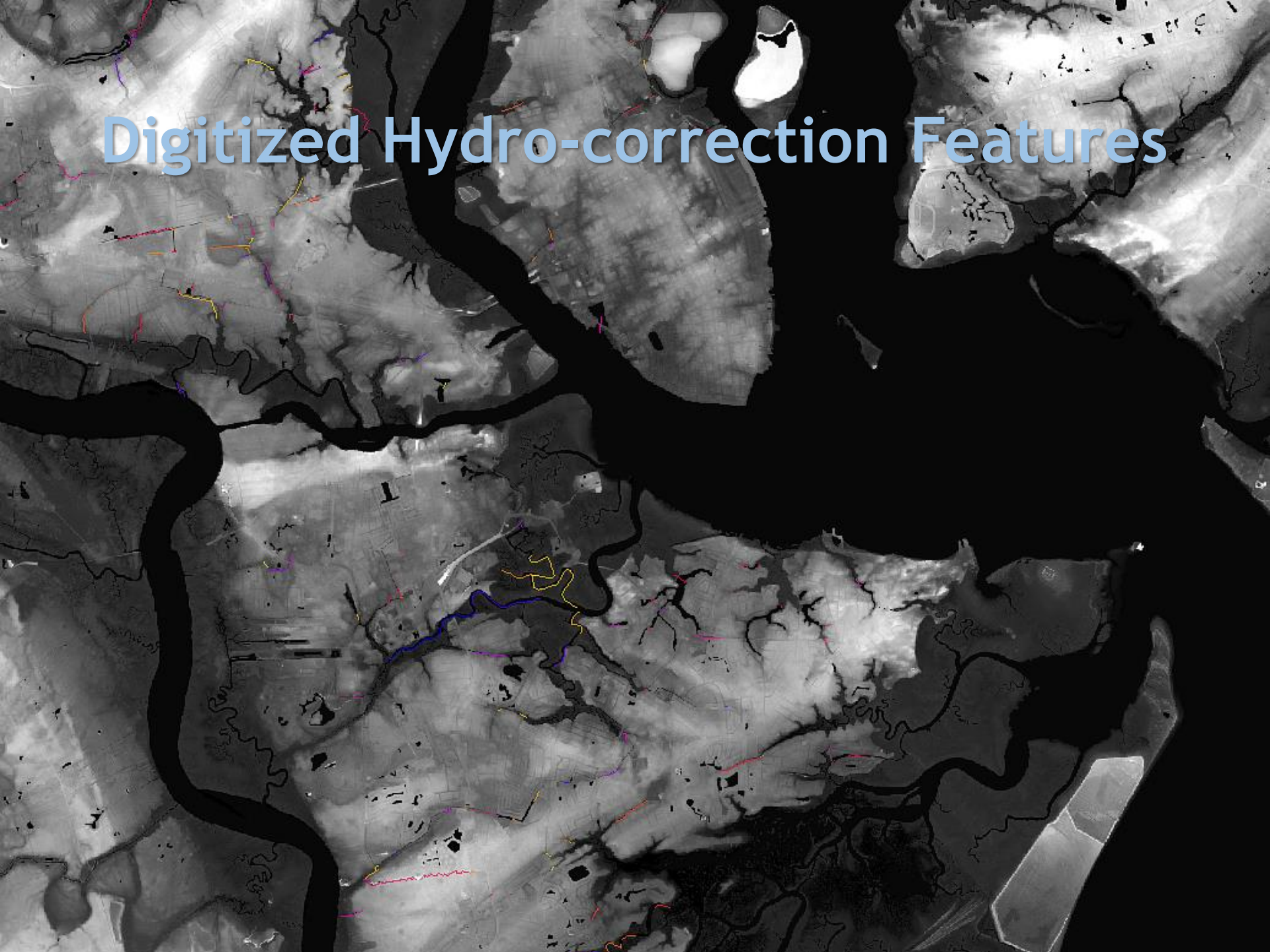


- Maintained Roads
- Inundated only in original DEM
- Inundated only in modified (burned) DEM
- Inundated in both original and modified DEMs
- Building Footprint

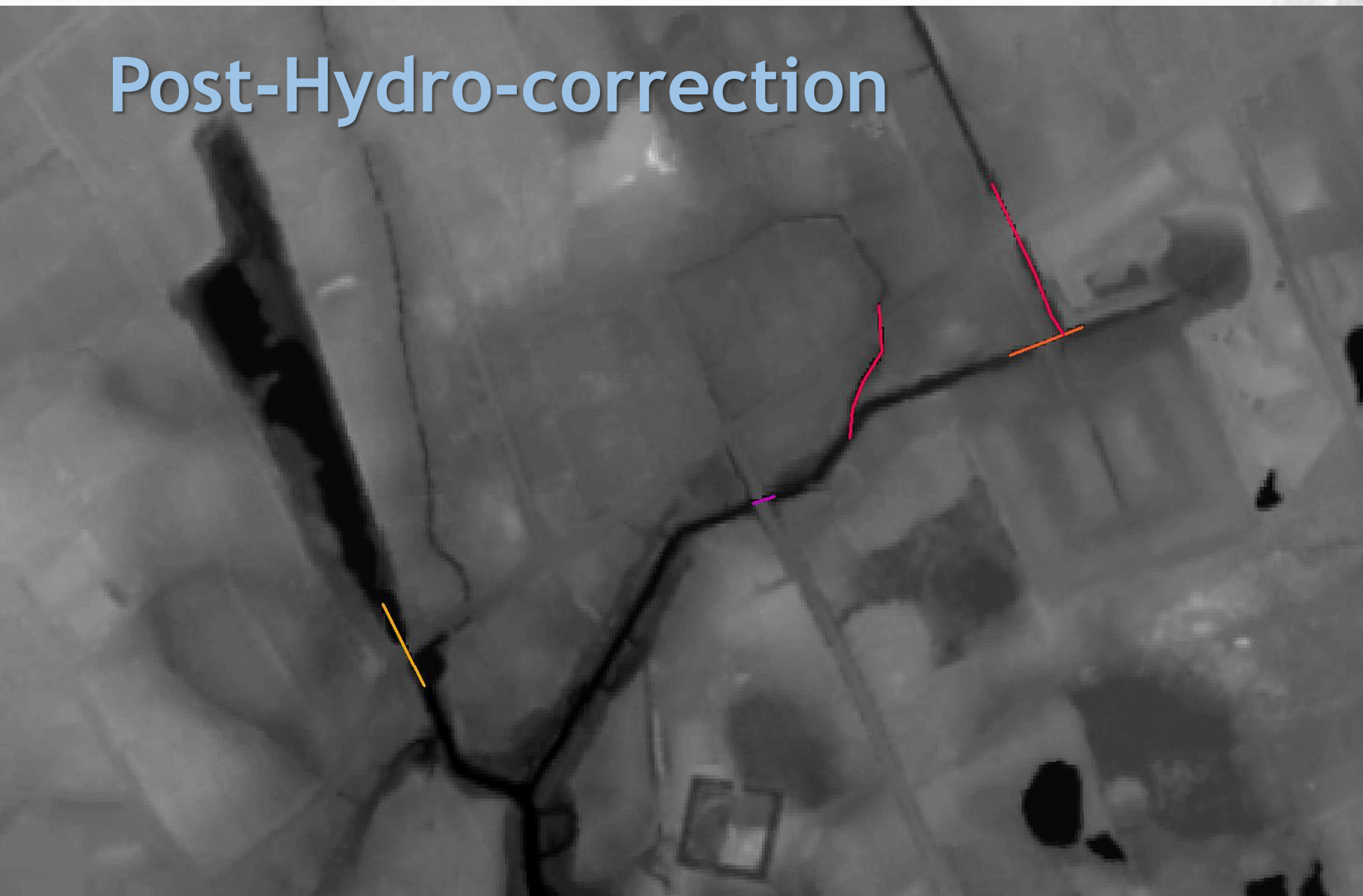
Category Information		% cover	square kilometers	hectares
2	Inundated only in modified (burned) DEM	0.19	0.143146	14.31456
3	Inundated in both original and modified DEMs	2.37	1.758298	175.82980
*	No data	97.44	72.287216	7228.72155
TOTAL		100.00	74.188651	7418.85511



Digitized Hydro-correction Features



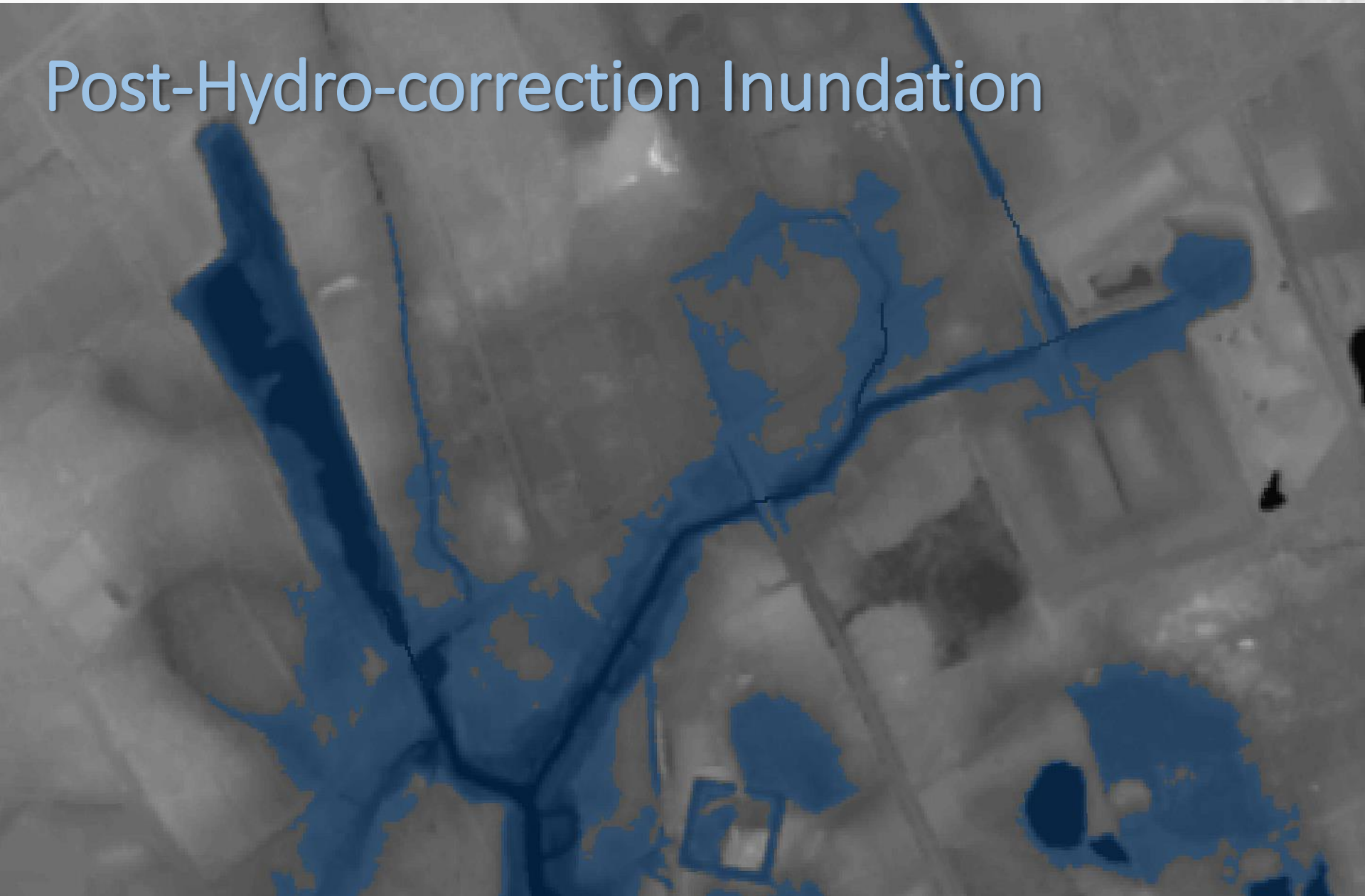
Post-Hydro-correction



Post-Hydro-correction



Post-Hydro-correction Inundation



Runoff Ponding and Groundwater



Street Runoff Flooding in a Mobile Home Park



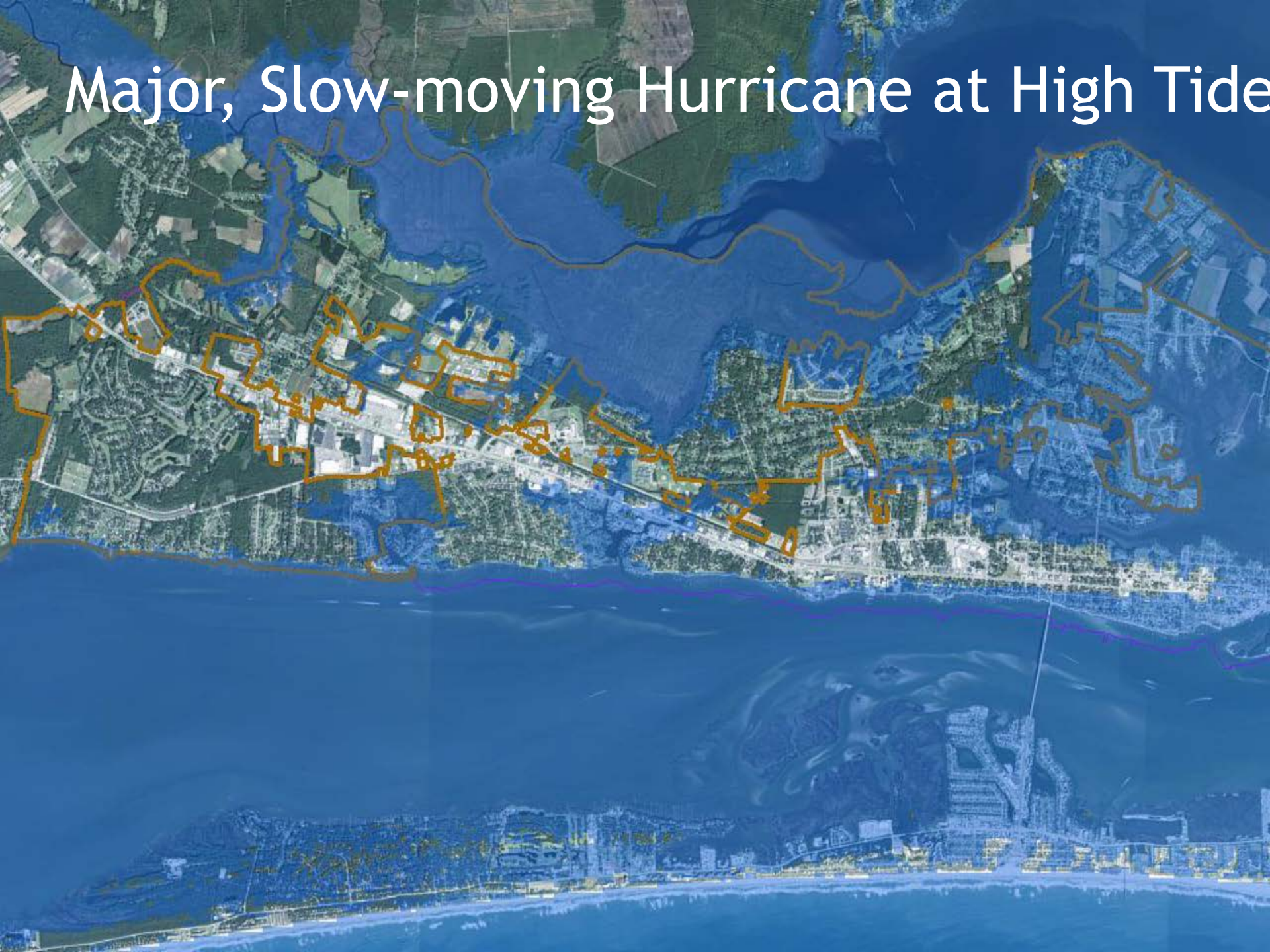
Hydro-correction for Tidal Flooding and Rainfall Runoff

Morehead City June 2016








Tidal Flooding and Runoff near a Sewer
Pump Station

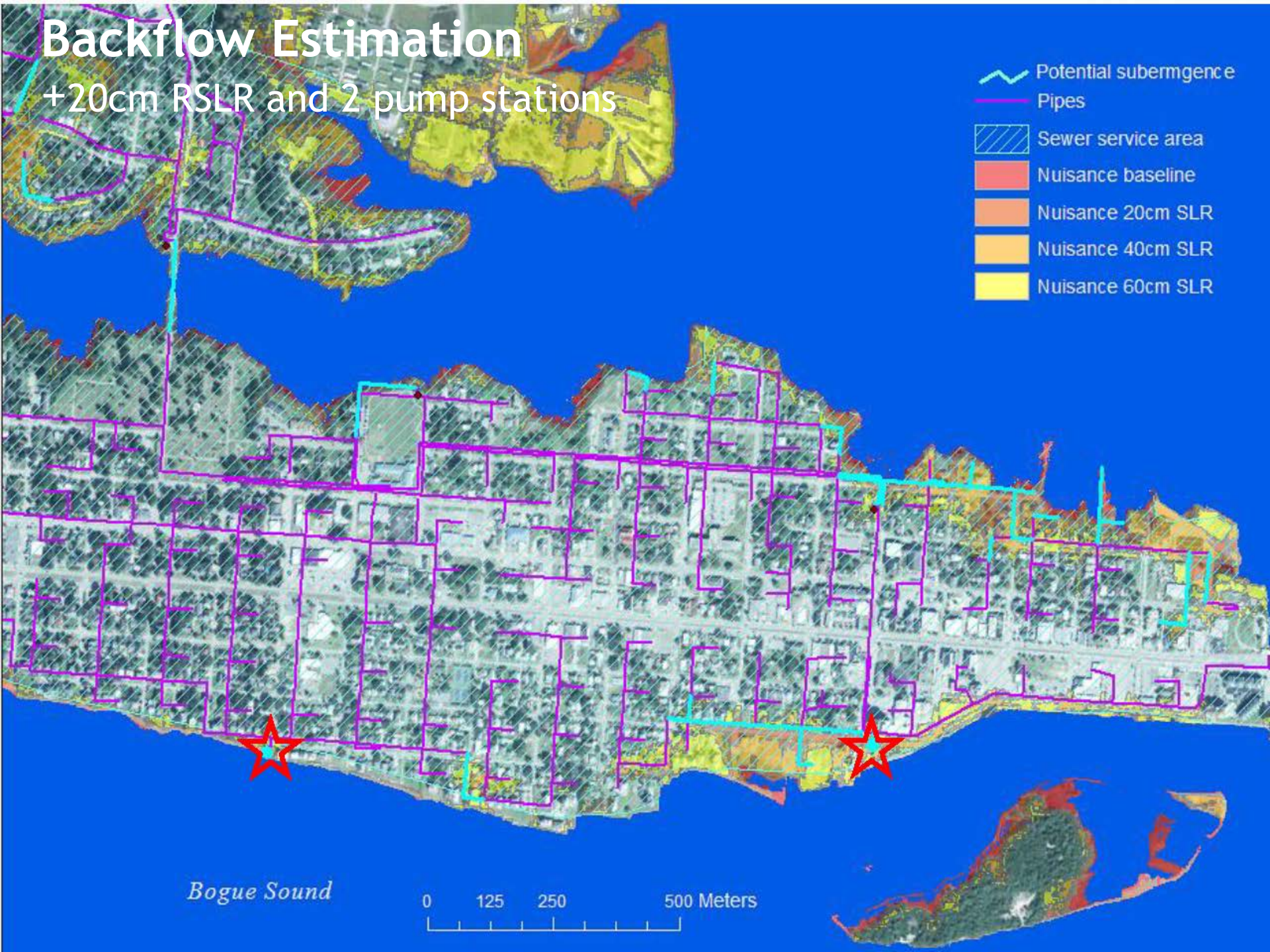
Major, Slow-moving Hurricane at High Tide



Backflow Estimation

+20cm RSLR and 2 pump stations

-  Potential subemrgence
-  Pipes
-  Sewer service area
-  Nuisance baseline
-  Nuisance 20cm SLR
-  Nuisance 40cm SLR
-  Nuisance 60cm SLR



Bogue Sound



Onsite Wastewater Treatment Systems (OWTS), Climate Change and Sea Level Rise

- Diminished volume of aerobic soil in vadose zone
- Lower O₂ solubility and decrease in the vadose/freeboard zone
- Overall pathogen removal functions of OWTS decline
- “*..the effects of climate change in humid regions receiving more precipitation and warmer temperatures are expected to result in complete loss of the infiltrative and water quality functions of OWTS.*”

Amador *et al.* (2014)



Amador, J., Loomis, G., Kalen, K. 2014. Soil-Based Onsite Wastewater Treatment and the Challenges of Climate Change. *Proceedings, Innovation in Soil-Based Onsite Wastewater Treatment*, Albuquerque, NM, April 7-8, 2014.

(<https://www.soils.org/files/meetings/specialized/full-conference-proceedings.pdf>)

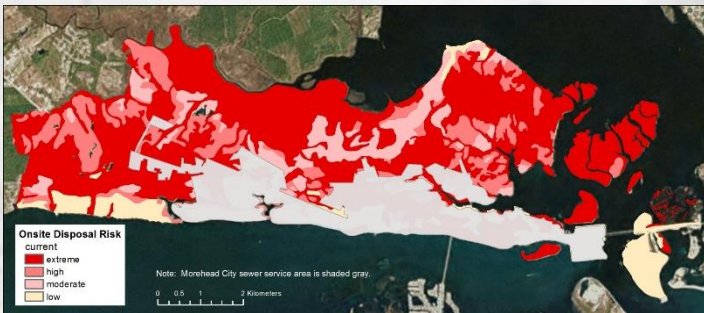
MHC+ETJ Onsite Wastewater Treatment Groundwater Risk



Today



+20cm RSLR



+40cm RSLR



+60cm RSLR

Note: Gray area is in Morehead City sewer coverage area..

Dasymetric Mapping – Putting People in Pixels

Census blocks with an example block in yellow containing 259 people.
Much of this block polygon contains tidal creek and marsh area.



James Island with Charleston Harbor to the north.

Dasymetric Mapping – Putting People in Pixels





Final population density at 20 ft pixel resolution.



Note: Highest legend values not present in this area but are present in Charleston urban core on the peninsula.

Public Health Workshop WebApp

Public Health Risk Assessment for Water Infrastructure, Charleston, SC

Supported by NOAA Coastal and Ocean Climate (COCA) Applications    

Population and Health Care

Water Infrastructure

Storm Surges

Sea Level Rise and Future Nuisance Flooding

Rainfall Runoff and Nuisance Tidal Flooding

All Layers Interactive

Welcome to the Charleston, SC, webmap of the NOAA-sponsored project *Community-Wide Public Health Risk Assessment of Vulnerable Water Infrastructure in Coastal Cities*.

This map shows the population density (Census 2010 block data) in units of *persons per acre* focused on residential parcels.

Hospital, health care, and nursing homes are shown from ESRI ArcGIS online. A series of other map tabs depict risk maps and interactive visual risk assessment tools.

For detailed information on this webmap contents, please contact Dr. Tom Allen of Old Dominion University (tallen@odu.edu)

USHS Health Resources Locations - Medical Centers



Hospitals



USHS Health Resources Locations - Hospitals

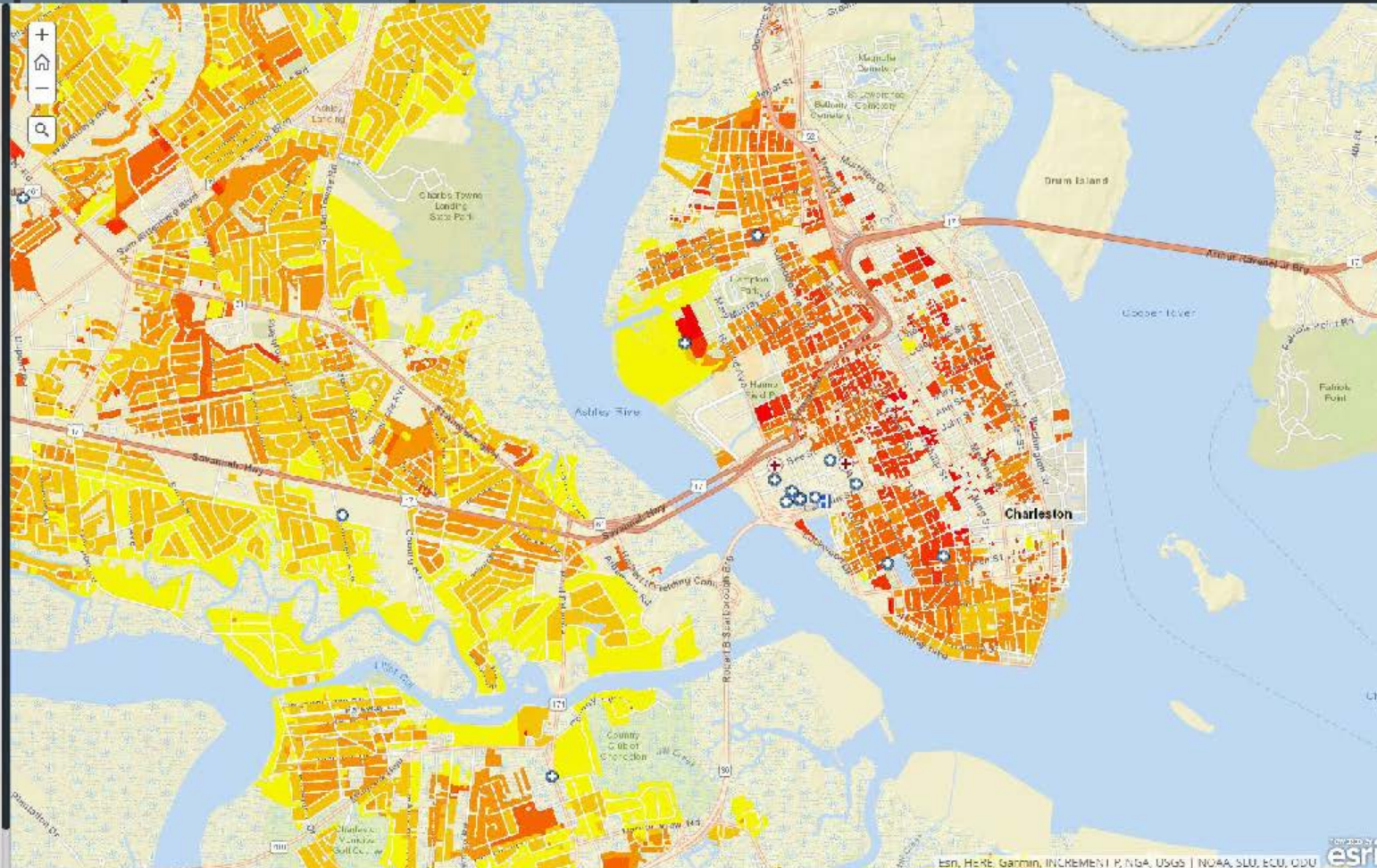
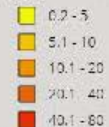


USHS Health Resources Locations - Nursing Homes



CHS_popdens_dasy

g_popden



ESRI, HERE, Garmin, INCREMENT P, NOAA, USGS | NOAA, SLU, ECU, ODU 

Hurricane landfall, surge and loss of power, gas, and water

Public Health Risk Assessment for Water Infrastructure

Population and Health Care

Water Infrastructure

Storm Surges

Sea Level Rise and Future Nuisance Flooding

Rainfall Runoff and Nuisance Tidal Flooding

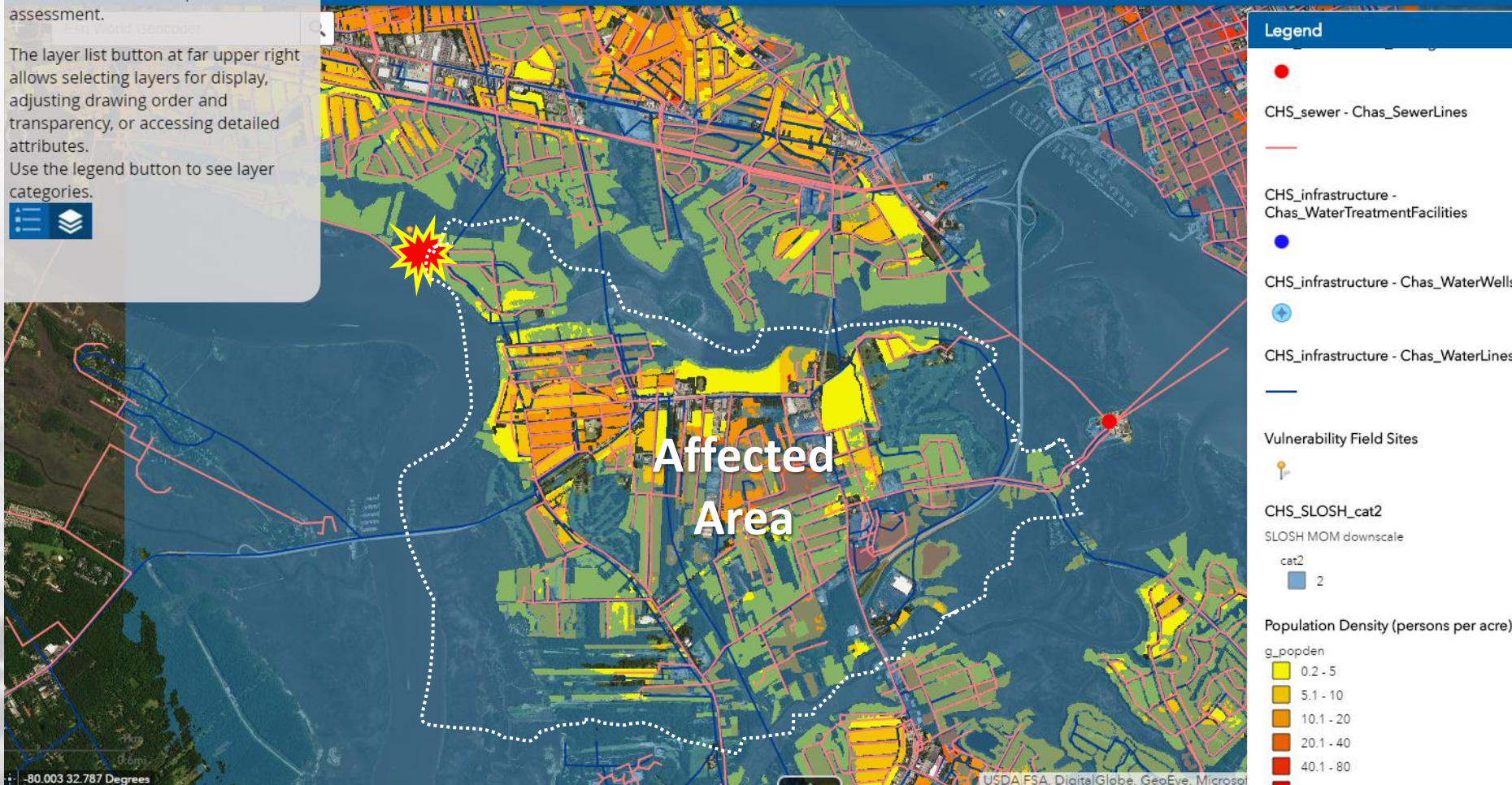
All Layers Interactive

Use this interactive map for visual risk assessment.

The layer list button at far upper right allows selecting layers for display, adjusting drawing order and transparency, or accessing detailed attributes. Use the legend button to see layer categories.



with Web AppBuilder for ArcGIS



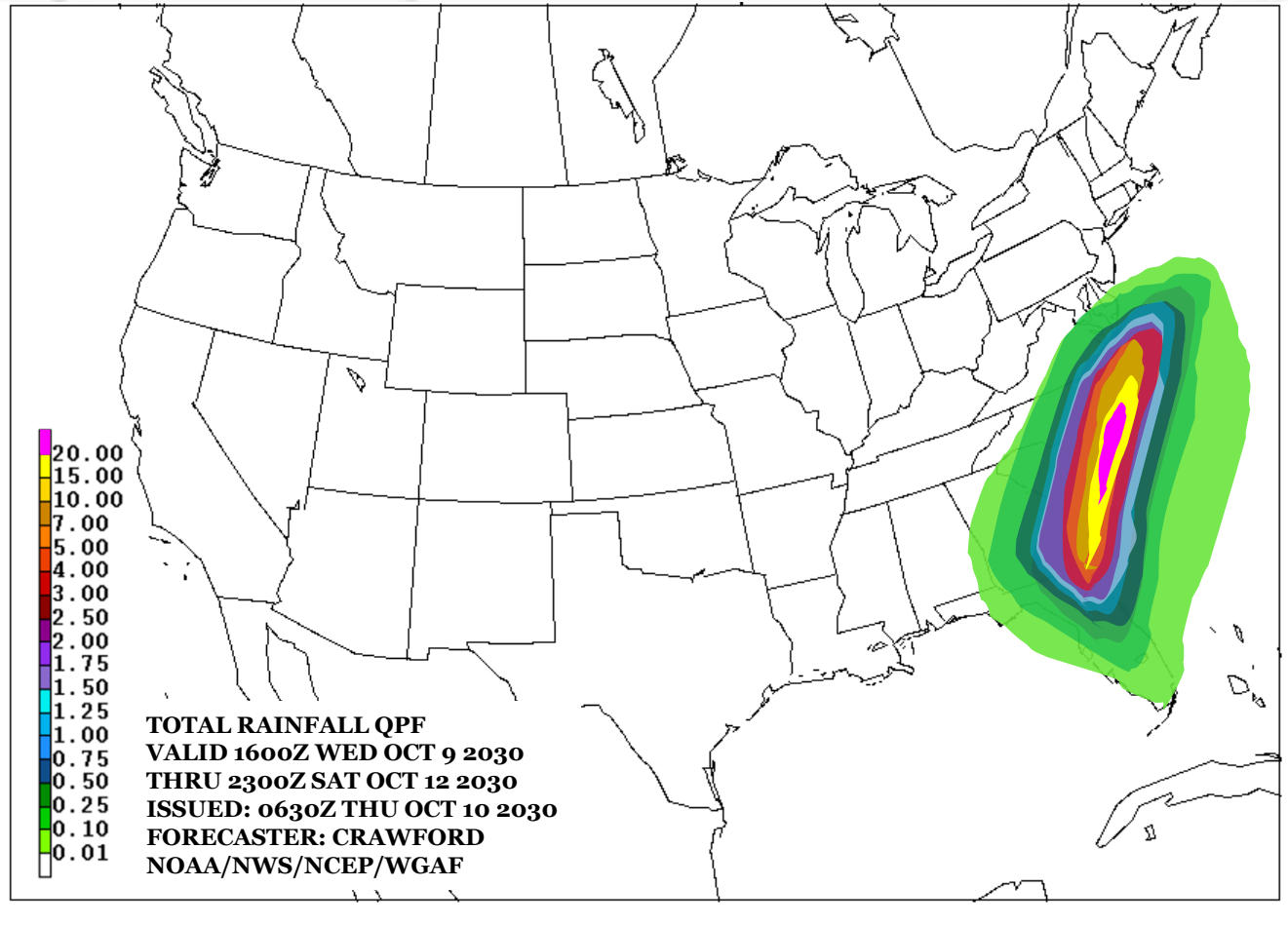
Legend

- CHS_sewer - Chas_SewerLines
- CHS_infrastructure - Chas_WaterTreatmentFacilities
- CHS_infrastructure - Chas_WaterWells
- CHS_infrastructure - Chas_WaterLines
- Vulnerability Field Sites
- CHS_SLOSH_cat2
SLOSH MOM downscale
cat2
- Population Density (persons per acre)
g_popden

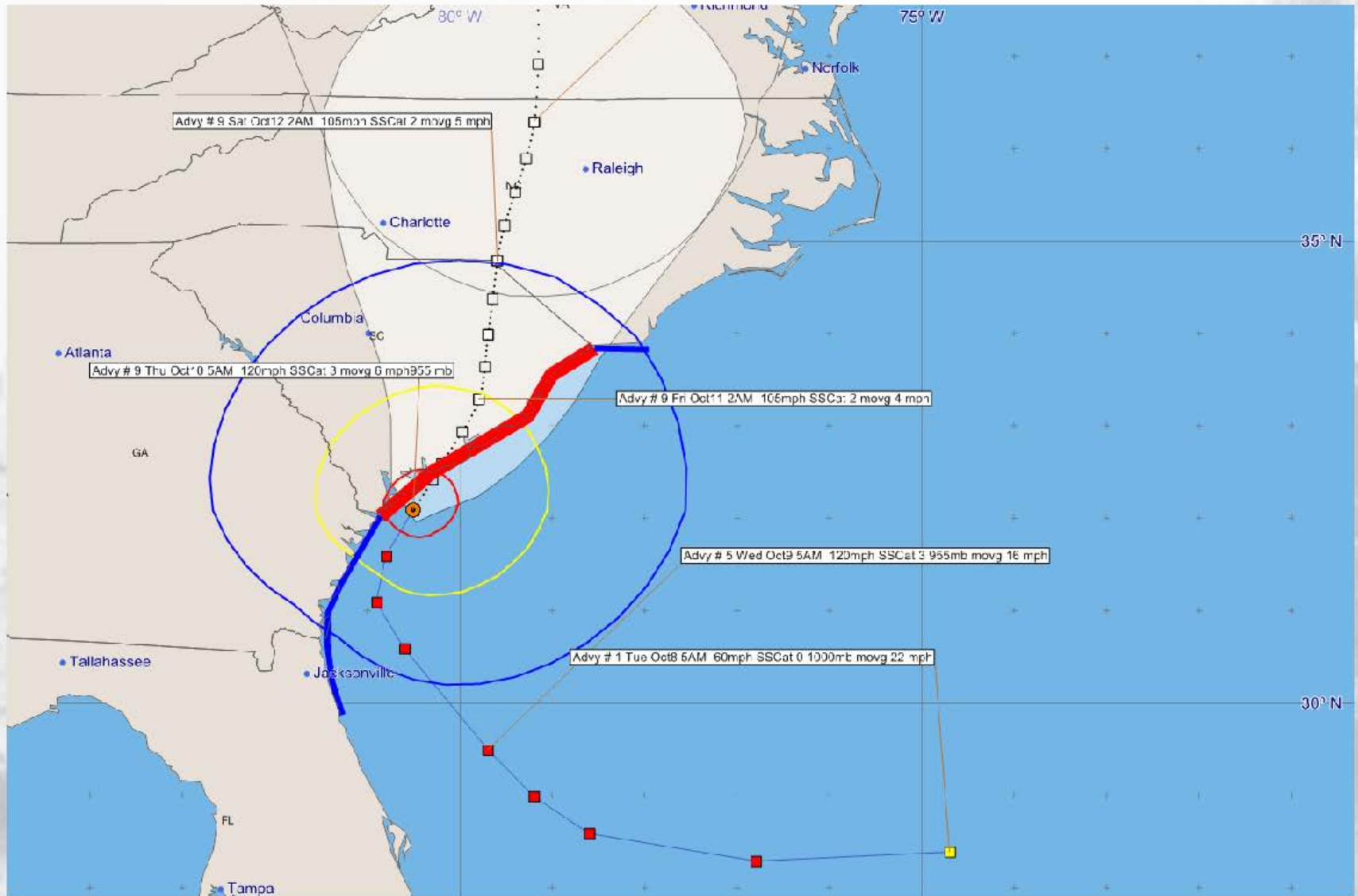
Tabletop Exercise

- Two workshops for Charleston and Morehead City, September 2017 and March 2018
- Functional scenario exercise
- Map analysis
- 2x2 matrix risk assessment
- 4x4 resilience assessment

Precursor Rainfall Event and Cumulative Rainfall



Hurricane Track and Evacuation Simulation



Hurricane Liz - Thursday, October 10, 2030 5 AM EDT Advisory #9

Center Location: 32.1 N 80.5 W Maximum Sustained Winds: 120 mph (Cat 3) Movement: 6 mph E

forecast positions Potential Track Area: day 1-3 day 4-5 Surface Wind Field: at current location

Watches: hurricane tropical storm Warnings: hurricane tropical storm

Sustained Wind Speeds: tropical storm >= 34kt/39mph strong tropical storm >= 50kt/58mph hurricane >= 64kt/74mph

Charleston Hurricane Liz 2030 Tabletop

- <https://arcg.is/qrCG5>

Hurricane Liz Tabletop 2017: Charleston, SC

A story map    

Background

Health and Hospitals

Municipal Govt. & Emergency Mgt.

Population

All Layers Interactive

Background

This webmap features a hypothetical future scenario of a hurricane and its potential impacts to Charleston, SC. The scenario was developed for an exercise in planning and risk assessment for Charleston area public health and water infrastructure and planning stakeholders as part of a Coastal Ocean Climate (COCA) project funded by the NOAA Climate Program Office. For the purpose of sharing the maps publicly, all sensitive spatial data have been removed. The maps provided herein were developed for a facilitated exercise in concert with spreadsheet-based assessment instruments. A guidebook will be provided for communities to replicate or adapt this structured exercise independently. The project team can be reached by contacts provided at the end of this box.

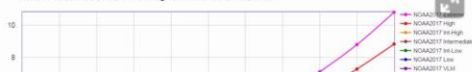
Scenario

In the year 2030, relative sea level has risen 1.5ft in the vicinity of Charleston, SC, since 2000. Higher King tides and heavy rainfall have become more routine and extreme.

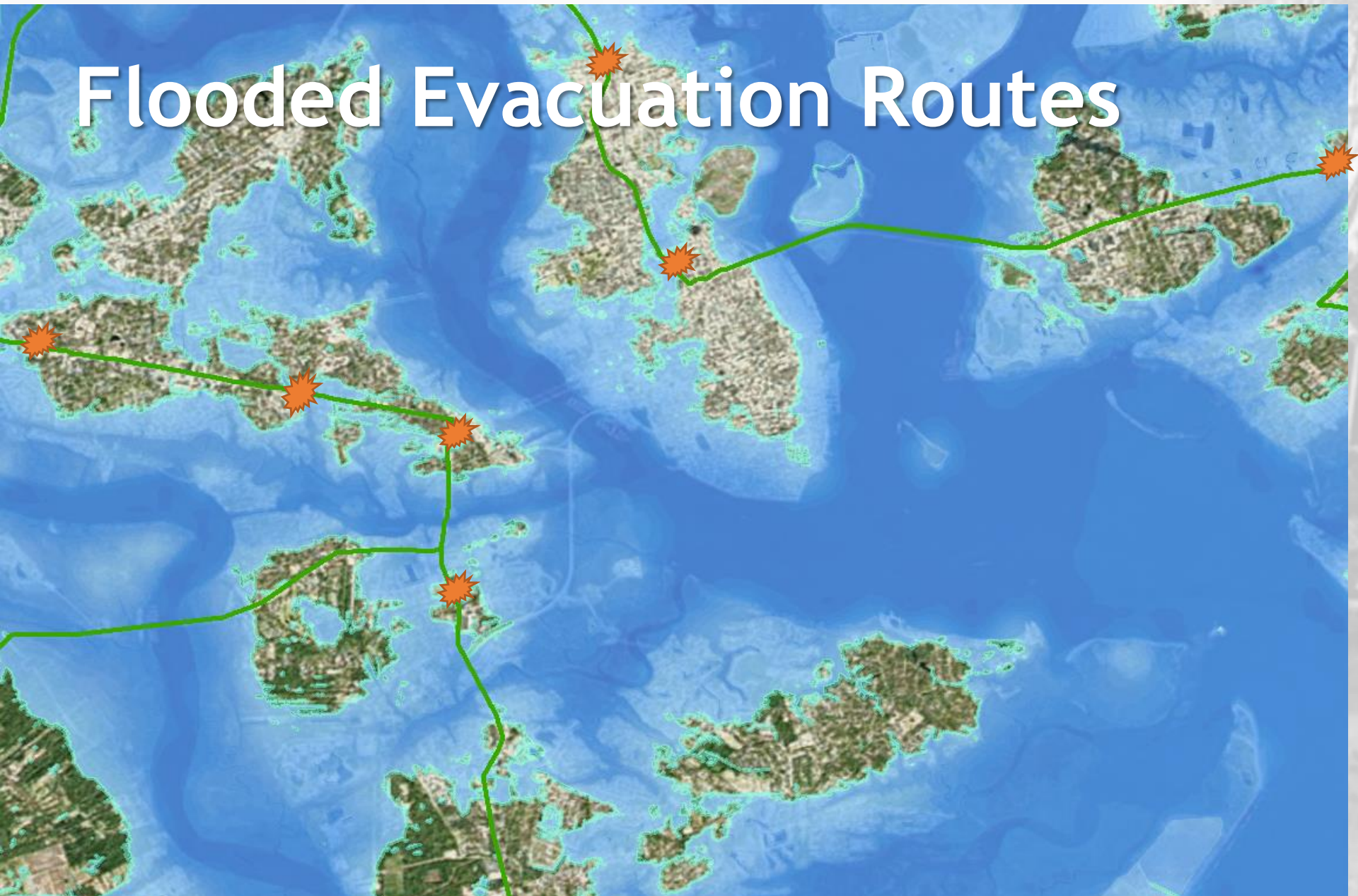
Charleston and the Southeast have been vigilant with the potential approach of Hurricane Liz for several days. A precursor rain event also poses to aggravate the potential hurricane strike.

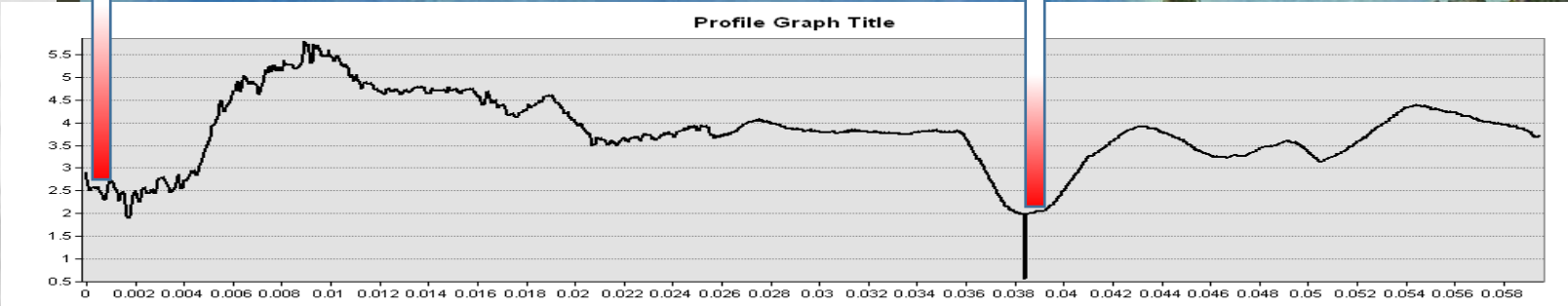


NOAA et al. 2017 Relative Sea Level Change Scenarios for CHARLESTON



Flooded Evacuation Routes





Water Infrastructure



Flood Depth at Pumps
(feet above ground)

SPump Stations
• 122 of 173
pump
stations
inundated
above ground
level

Tabletop_CWS_infra - Flooded pumps

Z

- 5.7 - 10.7
- 4.0 - 5.6
- 2.4 - 3.9
- 1.1 - 2.3
- 0.1 - 1.0

Tabletop_CWS_infra - SPumpStation



Tabletop_CWS_infra - wstoragesite



Tabletop_CWS_infra - SMain



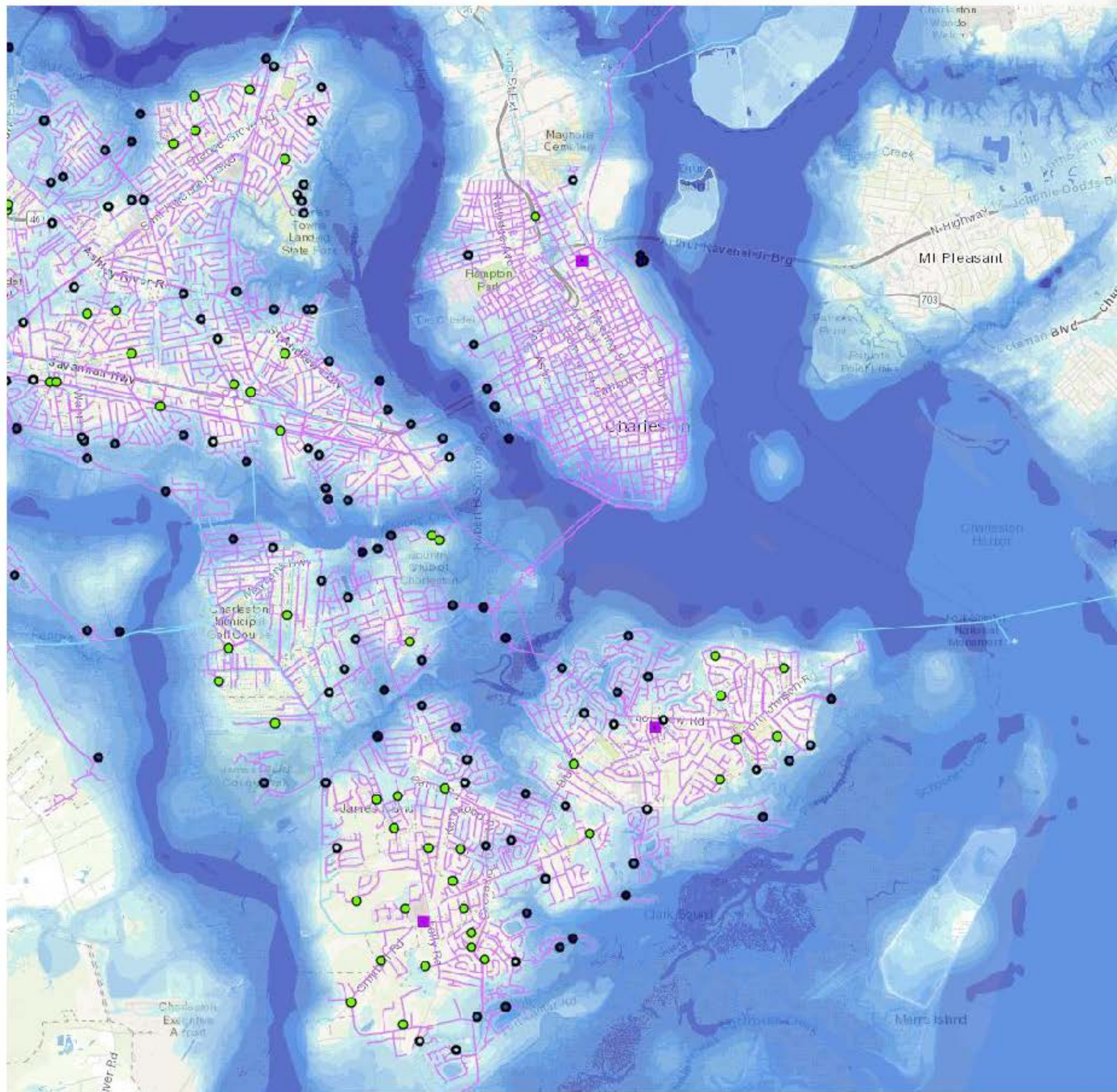
Tabletop_CWS_infra - WMain



Tabletop_Depthgrid

Depth grid

- 0.005 - 1
- 2 - 3
- 4 - 4
- 5 - 5
- 6 - 7
- 8 - 8
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 16



Map layers in this pane highlight public safety and emergency management, including evacuation routes and historical road closures during prior extreme coastal flooding.

Tabletop_Govt_EMgt - Police_Stations



Tabletop_Govt_EMgt - Fire_Stations



Tabletop_Govt_EMgt - Charleston_SC_Road_Closures

-  FLOOD 1/15/2016
-  FLOOD 10/1/2015 - 10/6/2105
-  FLOOD 10/27/2015 - 10/28/2105
-  FLOOD 10/9/2015
-  FLOOD 11/3/2015
-  FLOOD 11/9/2015
-  FLOOD 8/81/2015
-  TS COLIN / KING TIDE
-  TS JULIA

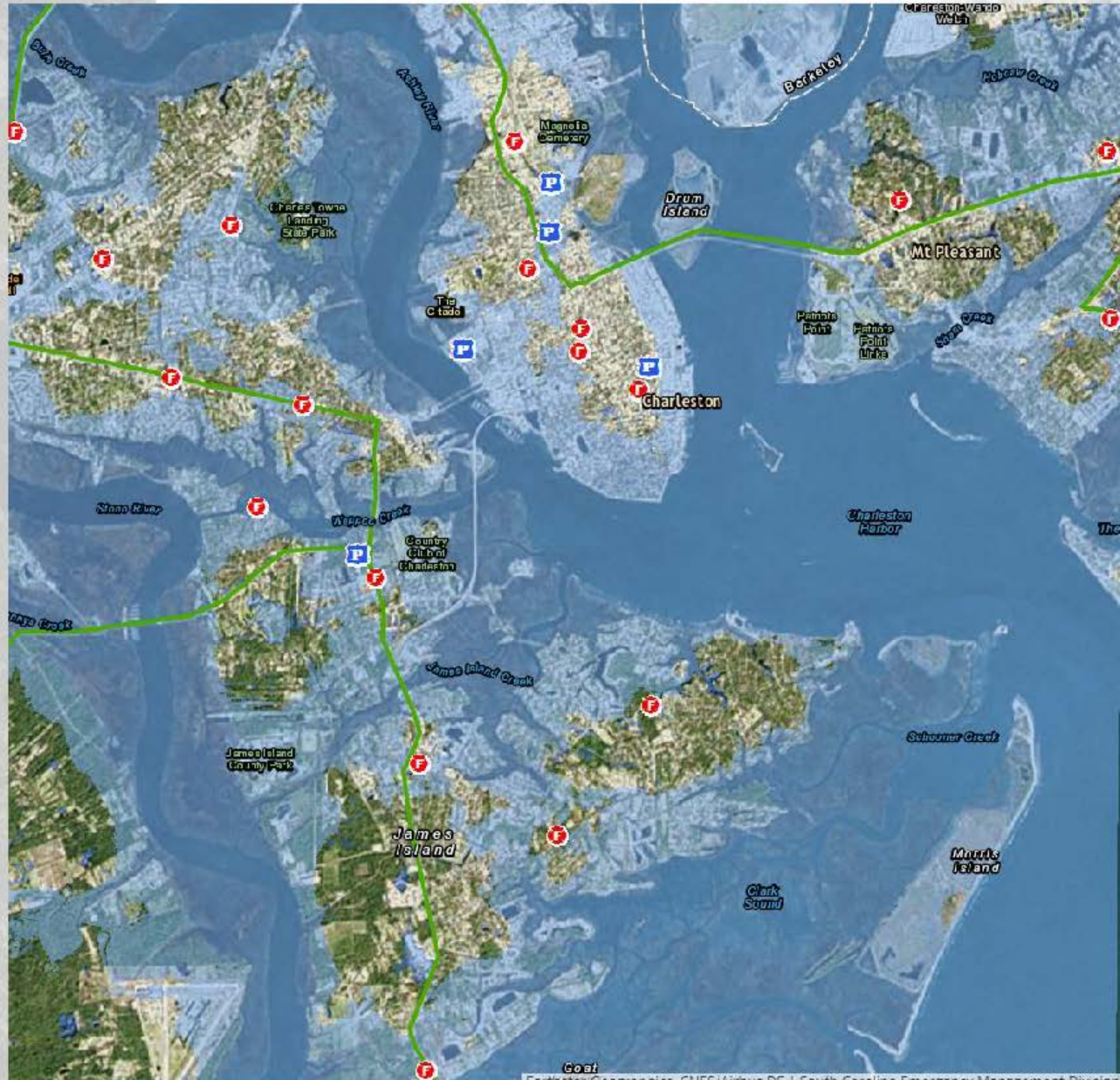
Tabletop_Govt_EMgt - Evacuation route



Tabletop_Govt_EMgt - Hurricane_Shelters_2013



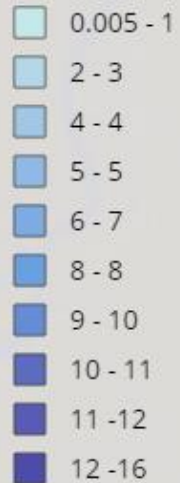
Tabletop_flooded_poly



Population Exposure to Flooding

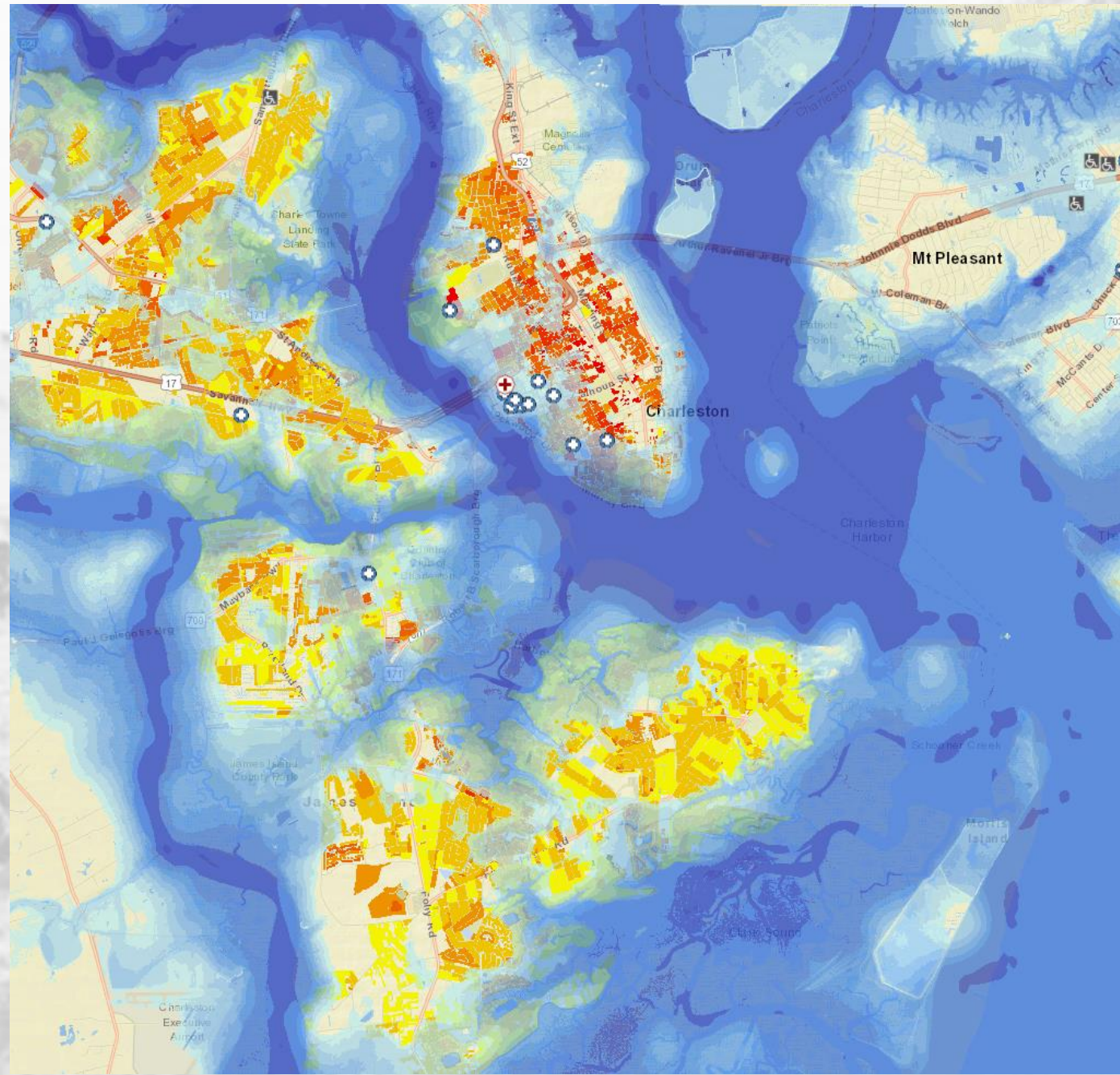
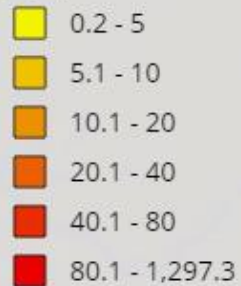
Tabletop_Depthgrid

Depth grid



CHS_popdens_dasy

g_popden



Hospital and Health Care



- Dialysis
- Pharmacies
- Nursing homes, elderly assisted living, group homes
- OB-GYN
- Mental health
 - Private counseling
 - Outpatient
 - Addiction therapy

Health Services

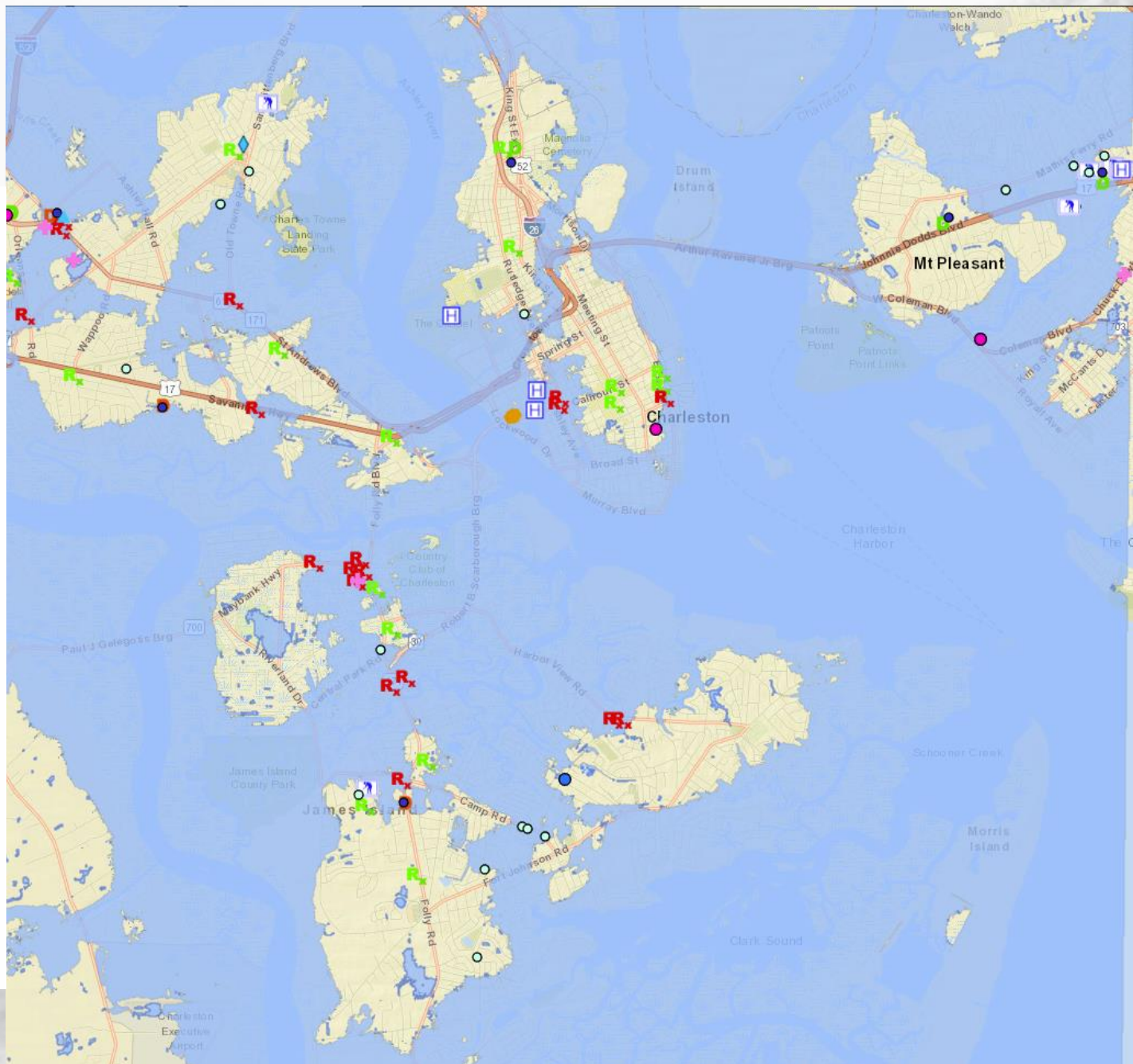
- ▲ HL- Adult Day Care
- ✚ HL- Ambulatory Surgery
- HL- Community Residential Care Facility
- HL- Habilitation R15
- HL- Hospice Program
- ⌊ H ⌋ HL- Hospital or Institutional General Infirmary
- ◆ HL- Inhome Care Provider
- 🏠 HL- Nursing Home
- HL- PSAD Inpatient
- HL- PSAD Outpatient
- HL- Renal Dialysis

Dialysis

- D Not flooded
- D Flooded

Pharmacy

- Rx Not flooded
- Rx Flooded



2X2 Matrix Model

Exposure vs. Sensitivity

EXPOSURE

Flooded Not-Flooded

SENSITIVITY

Compromised

X

X

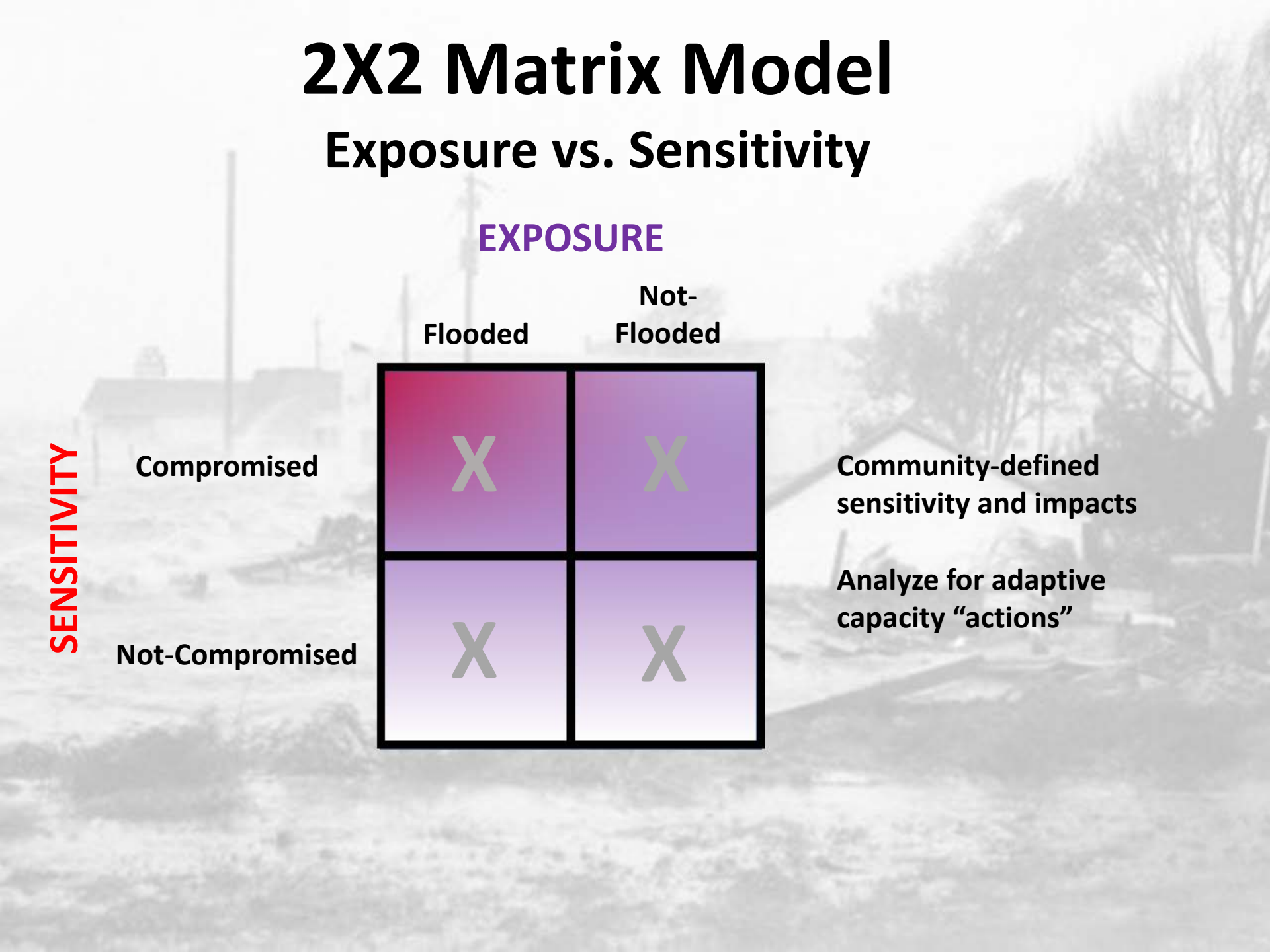
Community-defined sensitivity and impacts

Not-Compromised

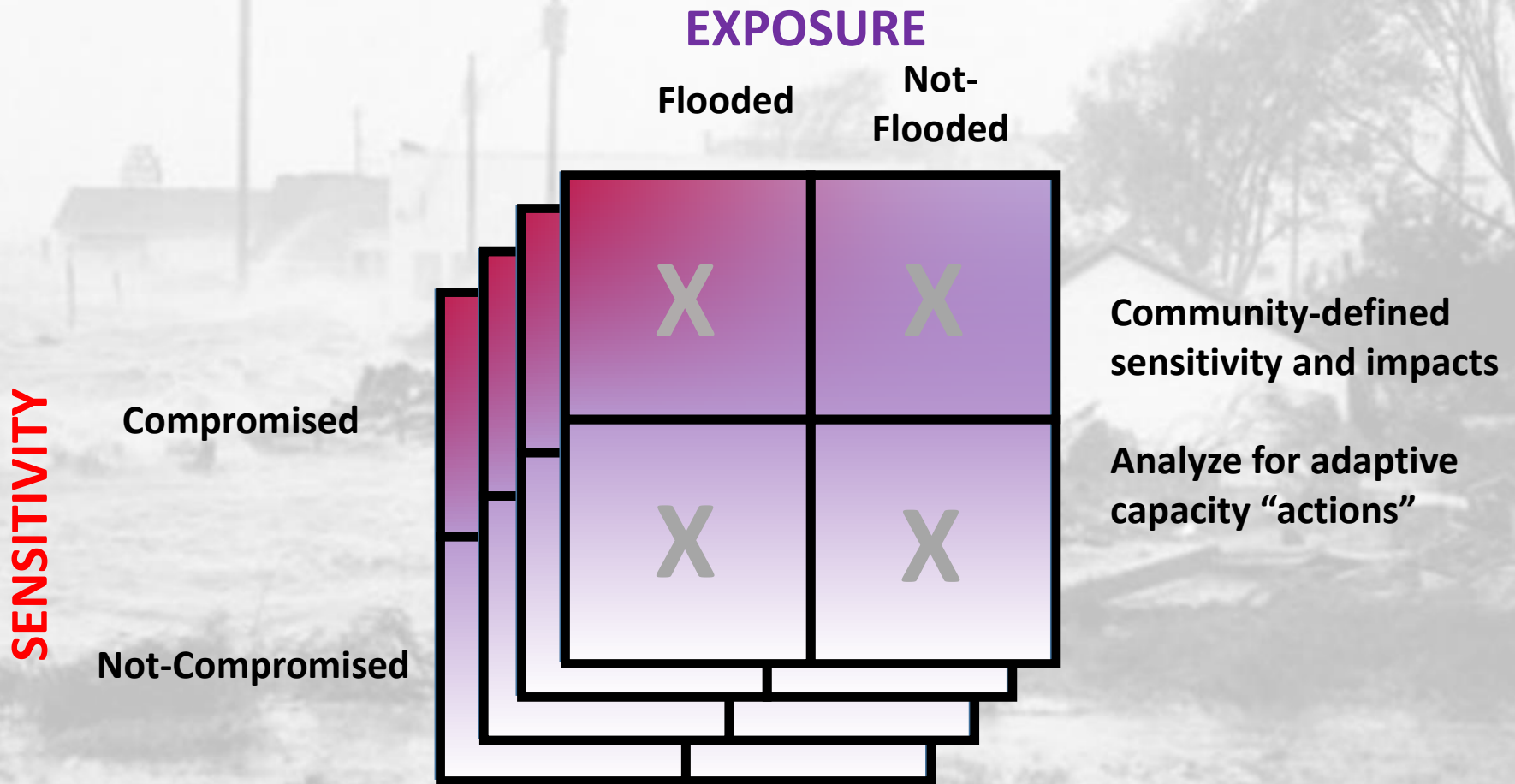
X

X

Analyze for adaptive capacity "actions"



2X2 Matrix Model of Exposure vs. Sensitivity



Sector: <input type="checkbox"/> Water Infrastructure <input type="checkbox"/> Healthcare System <input type="checkbox"/> Municipal Government <input type="checkbox"/> Population	Layer <input type="checkbox"/> Sewage Treatment <input type="checkbox"/> Facilities <input type="checkbox"/> Water Treatment <input type="checkbox"/> Sewer Lines <input type="checkbox"/> Water Lines <input type="checkbox"/> Wells	<input type="checkbox"/> Hospitals <input type="checkbox"/> Home Health Services <input type="checkbox"/> Medical Centers <input type="checkbox"/> Nursing Homes <input type="checkbox"/> Population Density	Area <input type="checkbox"/> Peninsul <input type="checkbox"/> West Ashley <input type="checkbox"/> James Island	Scenario <input type="checkbox"/> Nuisance Flooding <input type="checkbox"/> Runoff <input type="checkbox"/> Cat 1 <input type="checkbox"/> Cat 2 <input type="checkbox"/> Cat 3
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Inundated

Not Inundated

Compromised	Coverage/Score:	Impact Scoring: <ol style="list-style-type: none"> 1. No impact, full, normal function 2. Sporadic or partial disruption of service, local outage, minimal damages 3. Partial service disruption, localized functions offline 4. Widespread and prolonged service disruption, multiple core segments offline or damaged 5. Complete service disruption, emergency declared, long-term impact/recovery 	Coverage/Score:
	Notes: (i.e. expected etc.)		
Not Compromised	Coverage/Score:		Coverage/Score:
	Notes:		

Impact Scoring:

- 1: No impact, full function
- 2: Sporadic or partial disruption of service, local outage, nominal damages
- 3: Partial service disruption, localized functions offline
- 4: Widespread service disruption, multiple core segments offline or damaged
- 5: Complete service disruption, emergency declared, long-term impact

2x2 Lessons

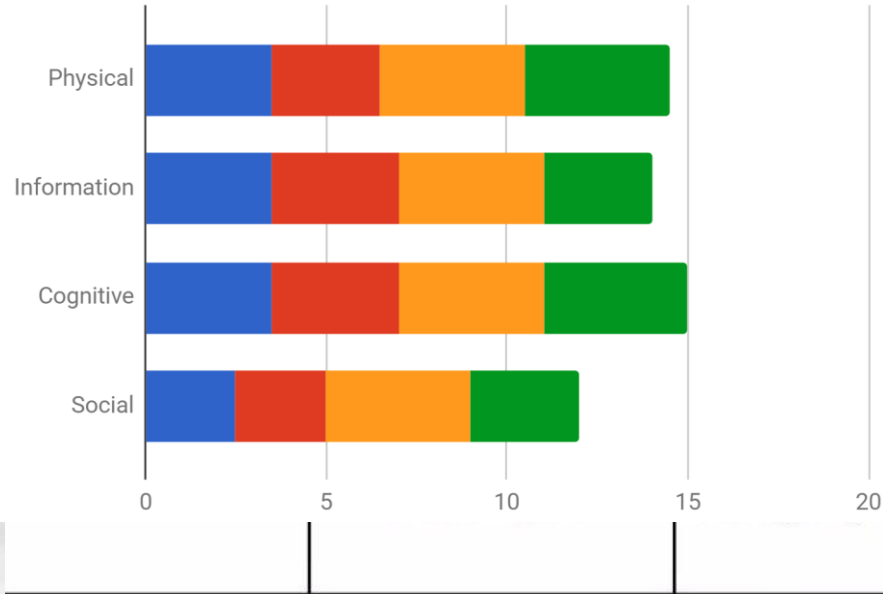
Water: Opened our eyes – 3 utilities here and some things we thought about, but some we took for granted (like bigger tires on vehicles). For us at CWS about to do hotwash for Irma on Friday – want to open this Google Doc and share with them because these are some things we should be thinking of.

Municipal: useful because knew County preparedness was good but adaptability not so much and it's a political fight. 4X4 shows that, need to get this in our annual exercises.

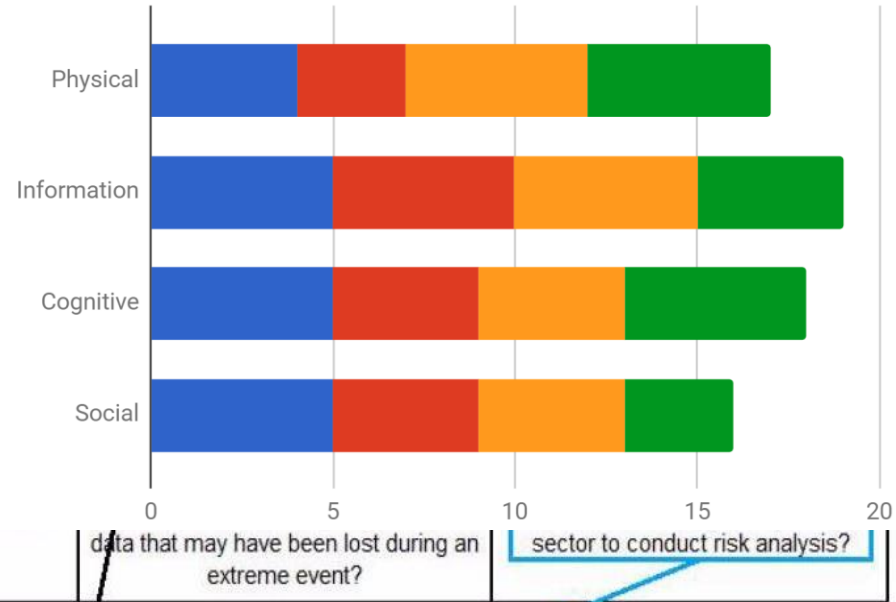
Health: Liked idea about the duck boat idea around Hospital district for amphibious use during event

4x4 Resiliency Matrix

Hospital System



Water System / Utility Network



data that may have been lost during an extreme event?

sector to conduct risk analysis?

Hospital System				
	Prepare	Absorb	Recover	Adapt
Physical				
Information				
Cognitive				
Social				

Lowest Capacity	1
Low Capacity	2
Med Capacity	3
High Capacity	4
Highest Capacity	5

4x4 Lessons

Above the first floor – where are the pumps located? Where is the airvent located, so it doesn't take water through the pipe. Pumps can be inundated by water. More than generator! Need to be grounded and protected from wind. (-80 fridges), lightning strike could take out generator → might be forced to evacuate

Freezers and fridges and kitchens often on first floor! Almost every hospital! Not all of the generators have external hookup

Try to conserve water, not eliminate need

Highest use in hospital is the HVAC system (500,000 gallons a day) – sterilizations, dialysis, ICUs, should be doing a business impact analysis before an event so they can divert flow of water, should have shut off valves and external hookups for water sources

Would like to see them do it, but do not have wells

Need to treat it as well, filter it for the HVAC system

Flush water after certain period of time to conserve water

Consider more water resistant vehicles (duck tours for example)

If hospital is not working then you can't have people being allowed back
Speed the recovery process

Utility wise – more data for us, projected power outages, winds?? Shut down
grids as a precautionary measure,

Transferrable to training, it can be used more than an exercise, can be used
for preparedness

Planning tool – utility sector

Water is the Achilles heel of every hospital in the country

Conclusions

- Value in exploring future scenarios
 - Exercises + planning + training
 - Multiple hazards
 - Critical review of data and models
- Decision-maker responses
 - Value in sessions across sectors
 - Differential vulnerability
 - Awareness of cumulative, cascading impacts
 - Prototype tools
 - Webapp
 - Tabletop exercise
 - 2x2 and 4x4 matrices
- Guidebook in preparation

**Assessment of Susceptibility Water Infrastructure in Coastal Cities:
A Multi-Sector Approach**

Guidebook for Community Level Assessment

Armon Hanks South Carolina Sea Grant, CoFC MES/MPA Candidate	Ariel Christensen Medical University of South Carolina MPH	Susan Lovelace South Carolina Sea Grant Assistant Director for Development and Extension
Elizabeth Fly South Carolina Sea Grant, CISA Climate Extension Specialist	Tom Allen Old Dominion University Associate Professor of Geography	Tom Crawford Virginia Tech Department Chair & Professor of Geography
Minh Phan East Carolina MS Geography Candidate	Burrell Montz East Carolina University Professor of Geography	Jessica Whitehead North Carolina Sea Grant Coastal Hazards Specialist
Greg Kearney East Carolina University Associate Professor of Public Health		

Contact:

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ODU Dept. of Political Science & Geography

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References

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