

Building Resilience into a System of Systems: Conceptualizing Vulnerability, Risk Perception, & Behavior

Dr. Joshua G. Behr

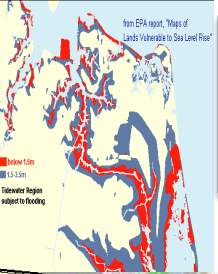
Virginia Modeling, Analysis, and Simulation Center -- VMASC

Old Dominion University

University of Virginia/National Science Foundation Workshop

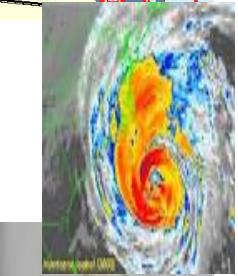
Systems of Systems Perspectives on Critical Infrastructure
Management in Response to Climate Change and Sea Level Rise

March 7-9, 2016



Research, Cooperation, a vision for combating rising seas

Virginian Pilot March 6, 2016



Joshua Behr, ODU

The region's approach to climate change thus far exhibits what is best about America: a belief that we can tackle any problem, an ability to engage and harness our collective ingenuity and an unyielding optimism for the future.

HAMPTON ROADS' changing climate holds enormous implications. These changes have the potential to fundamentally alter our physical landscape, economy, national readiness and quality of life. Responding to a changing climate is daunting, but we are making headway. There is reason for optimism.

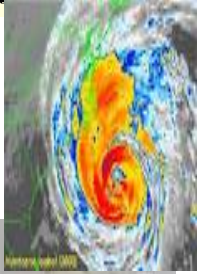
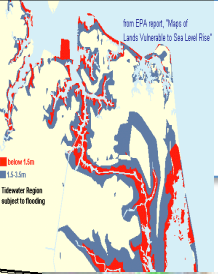
Old Dominion University has long produced cutting-edge research that advances the science of oceanography, climatology and geophysics. But the university is also at the forefront in deepening our understanding of the social, economic and health impacts of these changes and has articulated an approach to building resiliency. For example, we have combined the physical modeling of storm impacts with the economic health and well-being of vulnerable populations.

The approach emerging from ODU emphasizes the intersection of the physical, engineering and social sciences by recognizing that Hampton Roads is a "system of systems" — not only critical infrastructure like transportation, communications and water, but also critical social, economic and health systems. Through investment in mitigation and adaptation strategies, we can toughen these critical systems and, in turn, strengthen our region's resilience.

We must stay focused on the primary fronts.

Continue to mitigate storm-related risks, meaning that we must make less severe the immediate- and mid-term consequences of larger storm events. Our coastal region historically is subject to tropical storms, Nor'easters and hurricanes. Localities and the state have increased their investments in emergency operations centers and other critical infrastructure, as well as planning and exercising response, logistics and communications.

Continue to take adaptive measures. Last year, the General Assembly



Hampton Roads BEHAVIORAL STUDY REPORT



**advanced
ANALYTICS**
research laboratory

Rafael Diaz, Ph.D.
Josh Behr, Ph.D.
Virginia Modeling, Analysis
and Simulation Center





Prepared for the Hampton Roads
Regional Catastrophic Planning Team







VMASC
OLD DOMINION UNIVERSITY




ADAPTION RESPONSE TO RECURRENT FLOODING


Portsmouth Comprehensive Planning Support REPORT 1







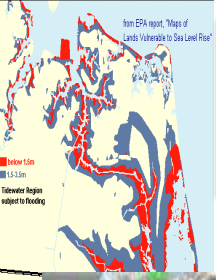
**OLD DOMINION
UNIVERSITY**
IDEA FUSION



VMASC
OLD DOMINION UNIVERSITY

Joshua Behr, Ph.D.
Rafael Diaz, Ph.D.
Bridget Giles, Ph.D.

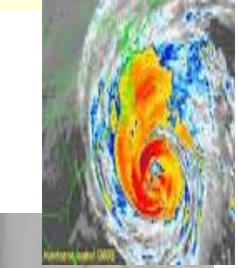
Virginia Modeling, Ana



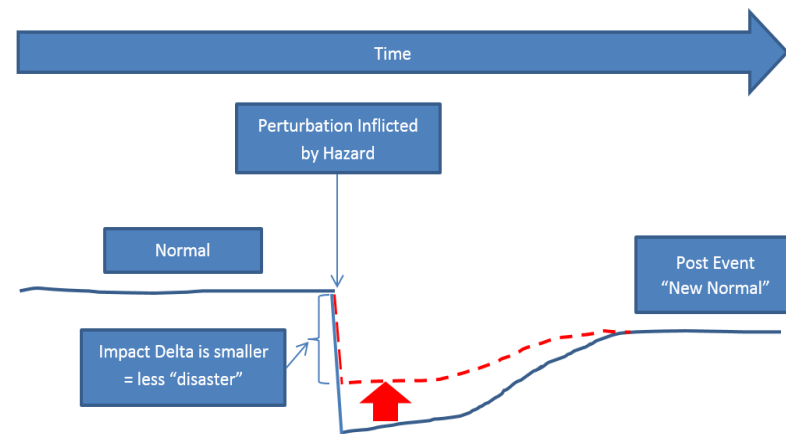
Guiding Principle #1

Building resiliency means altering the recovery curve.

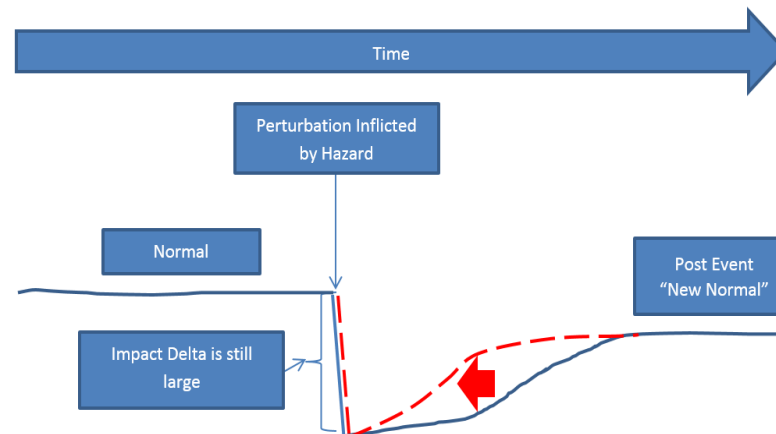
Resilience is the ability of the System of Systems, on the whole, to “bounce back” from a shock, to absorb the disruption from a perturbation as well as to rebound from the perturbation.



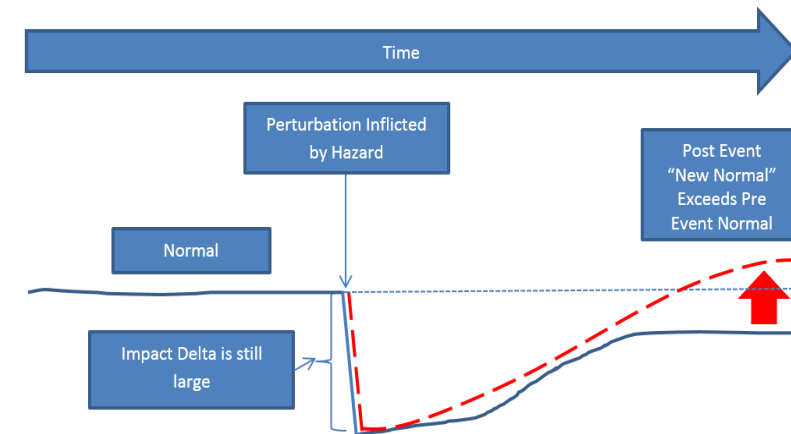
Decrease the Impact Delta

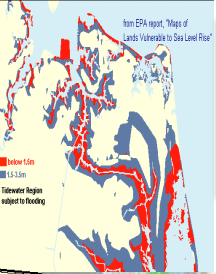


Shift Recovery Curve to the Left



New Normal Exceeds Pre-event Normal



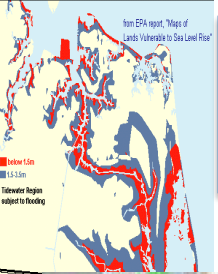


Guiding Principle #2

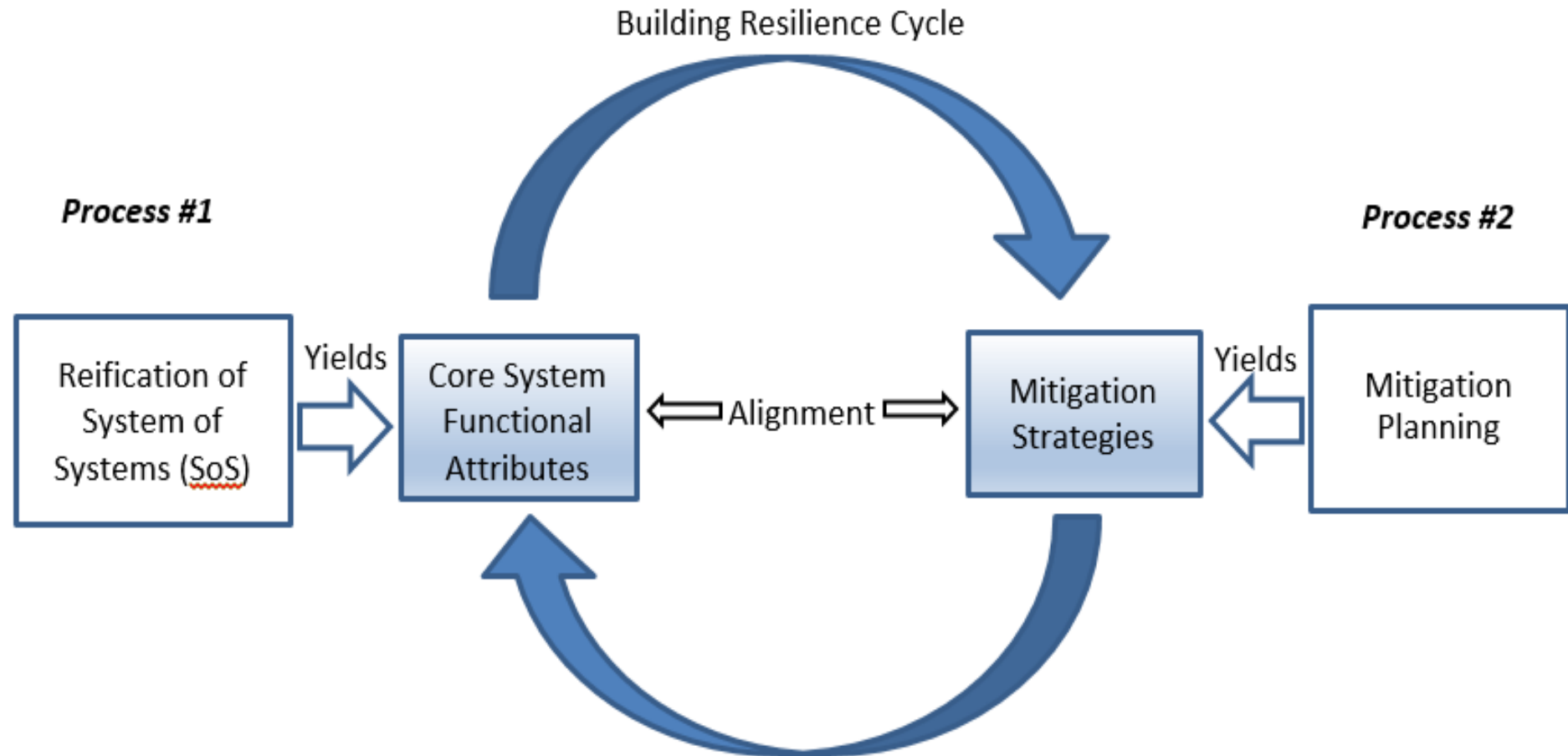
Our premise is that in order to enhance resilience, there must be an alignment between core systems and the prioritization of mitigation strategies.

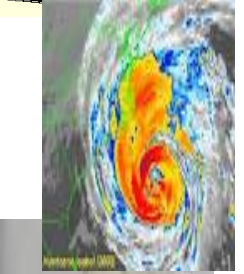
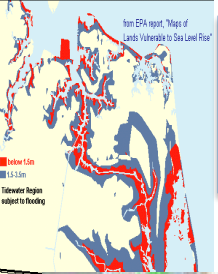
Core Systems are those that are essential to the life, limb, and wellbeing of the populations, especially vulnerable, medically fragile, and traditionally underserved populations.

Engage localities and stakeholders to identify core systems that may have a large ROI for particular population groups.



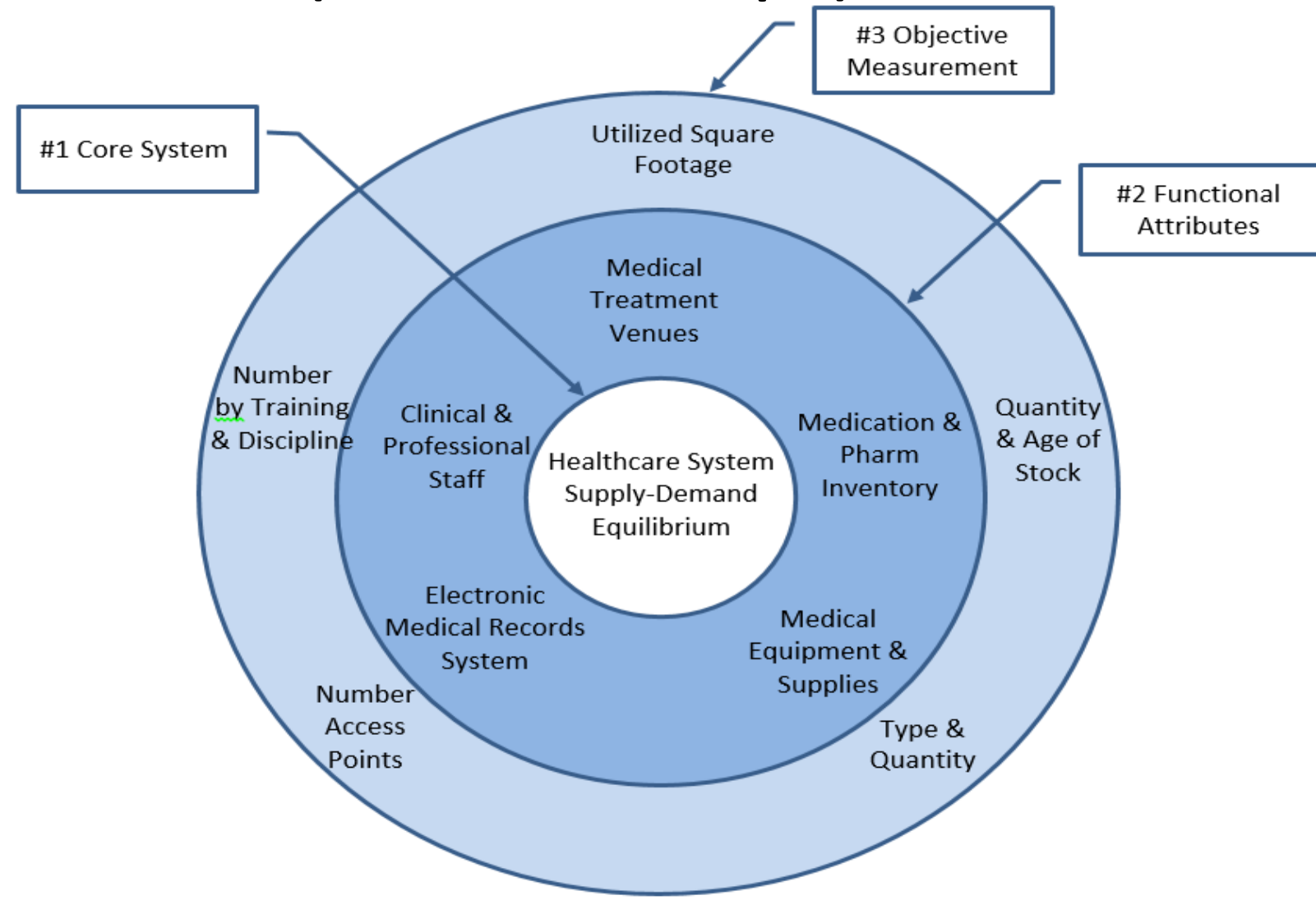
High Level Approach

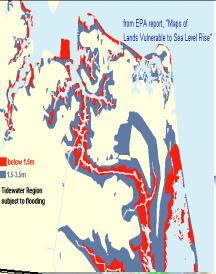




Core System & Attributes (Healthcare Example)

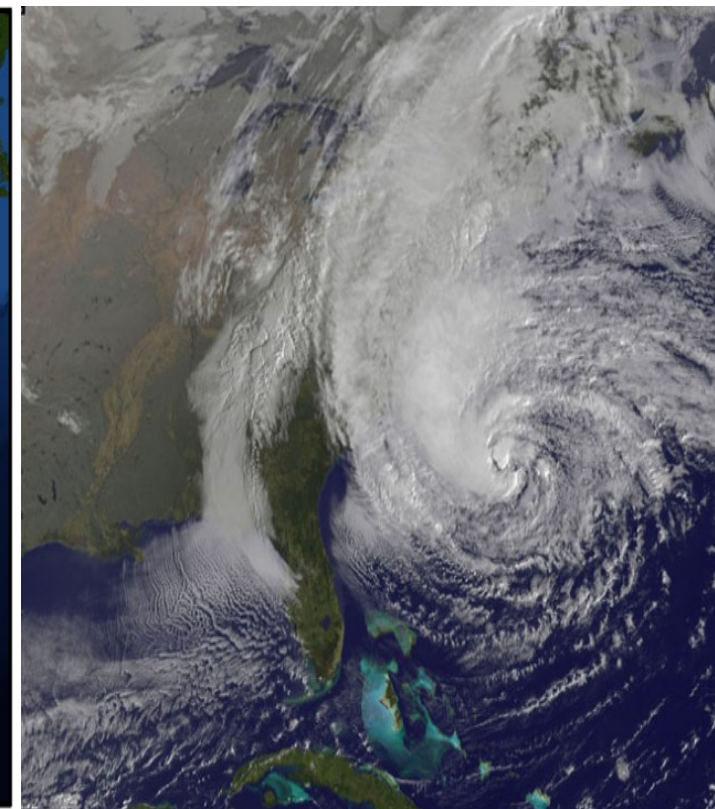
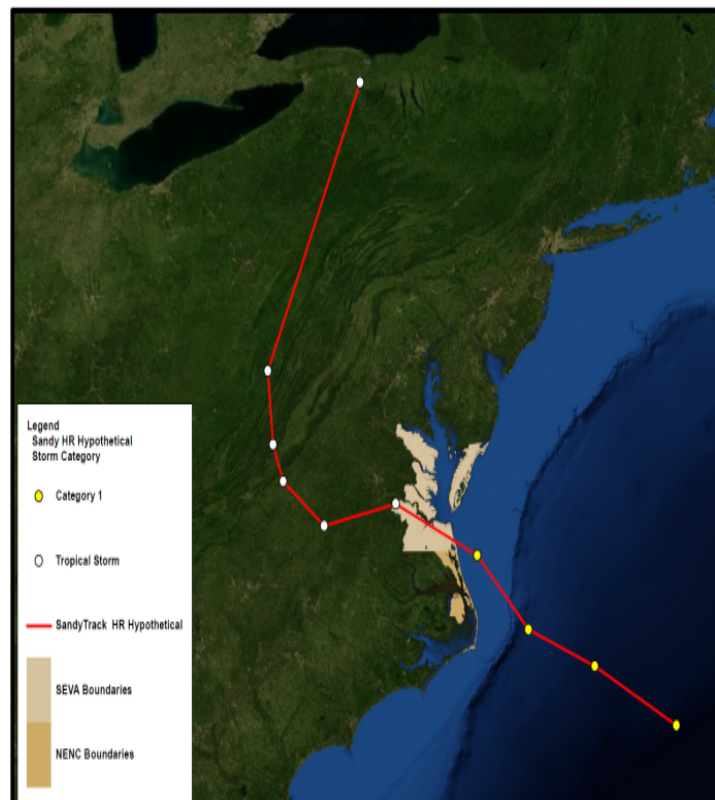
Process #1

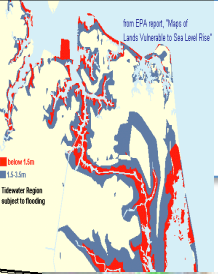




Sandtrina Scenario...

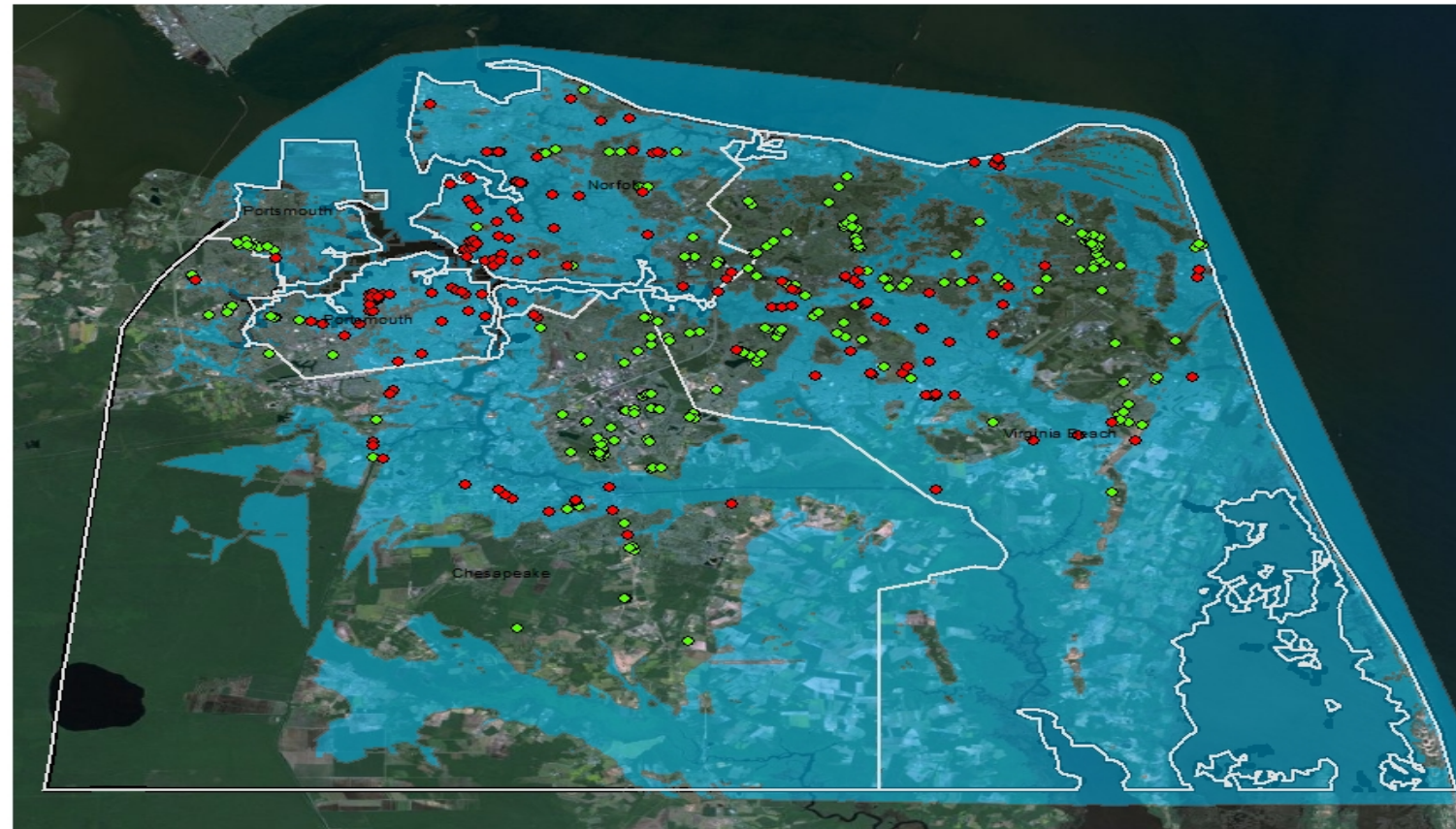
- The path of the Sandy passed through the Greater Hampton Roads Region.
- Intersecting natural systems data and built environment data with knowledge of household vulnerability.
- Informed by Hampton Roads experiential data and Katrina lessons learned.





Healthcare as a Core Infrastructure

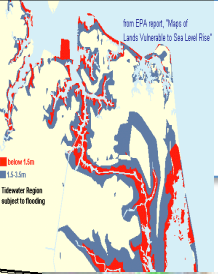
Southside Metro
Inundated Vs. Not Inundated



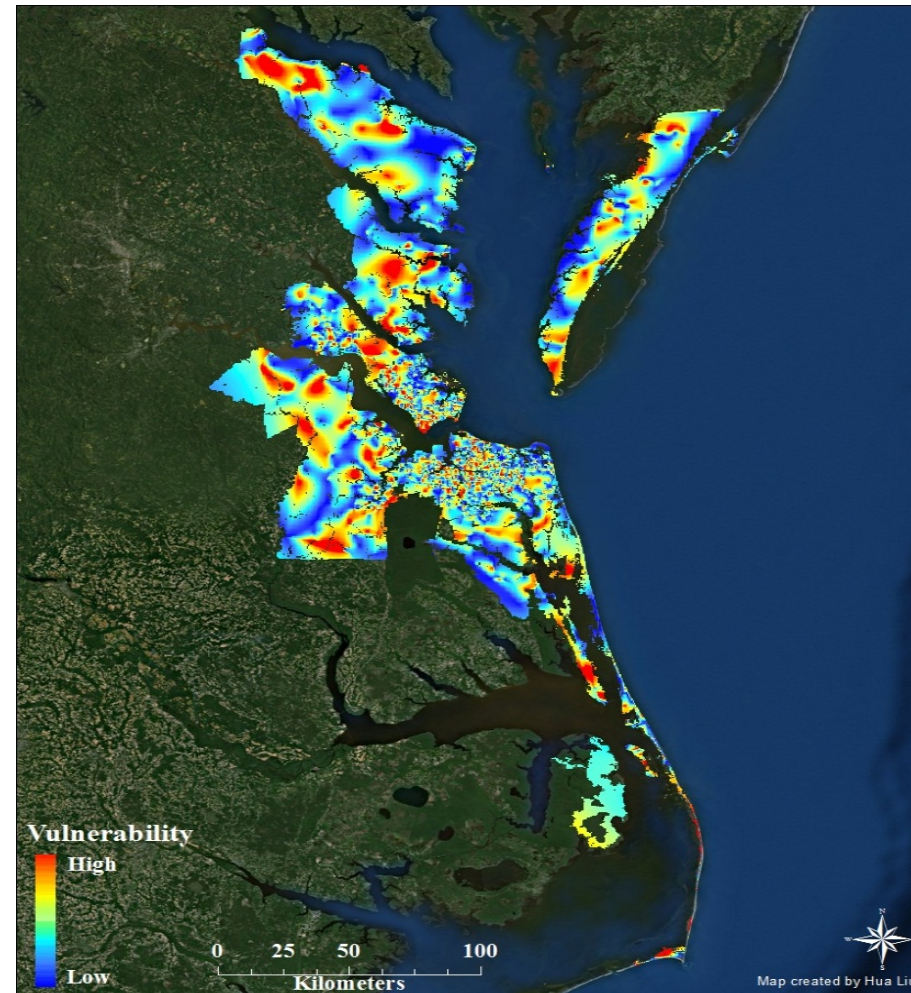
- Southside Metro Inundated
- Southside Metro Not Inundated
- Southside Metro Boundary
- Inundated Areas

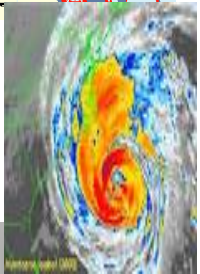
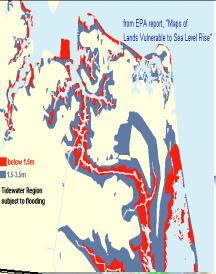
0 2 4 8 12 16 Miles





Vulnerability Mapping – Regional View

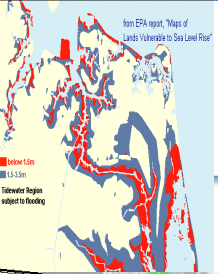




Dimensions of Vulnerability

- Financial Vulnerability
- Risk Perception Vulnerability
- Fatalism-Efficacy Vulnerability
- Mobility Vulnerability
- Sensory Vulnerability
- Mental Cognition Vulnerability
- Medical Regimen Vulnerability
- Healthcare Access Vulnerability
- Assistance Daily Living (ADL) Vulnerability
- Insurance Vulnerability
- Social-Familial Network Vulnerability
- Personal Responsibility Vulnerability
- Aged Vulnerability
- Single Parent Household Vulnerability
- Dependent Vulnerability
- Preparation Vulnerability
- Theft Vulnerability

Example:
Hyper
Vulnerability
“Composite
Medical
Vulnerability”

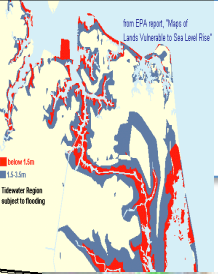


Hyper Vulnerability

“Dimensions of vulnerability do not necessarily stand alone; several dimensions of vulnerability may compound within one social group or within one geographic location”

(e.g., Tapsell et al. 2010)





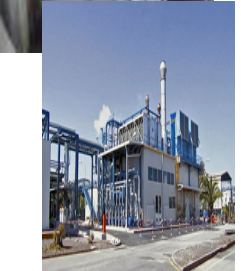
Risk Perception (2)

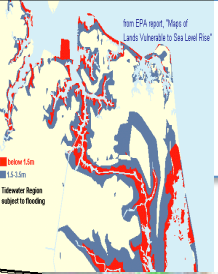
Safer Than Evacuation

- Safer than traveling in chaos or on highway.
- Risk of dying in evacuation is greater than sheltering at home, history supports this.

Fatalism

- Nothing we can do/out of our control
- Take chance, roll dice
- It is in God's hands





Storm as Opportunity => Risk

Cleanup = cash

- Debris removal
- Tree/yard waste removal

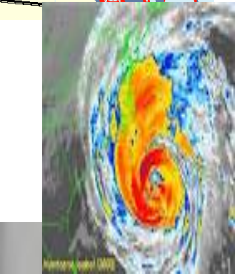
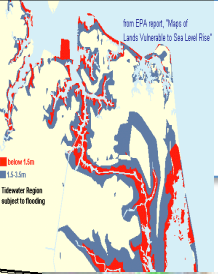
Skilled Labor & Trade Services

- Housing/roofing repair
- Auto repair

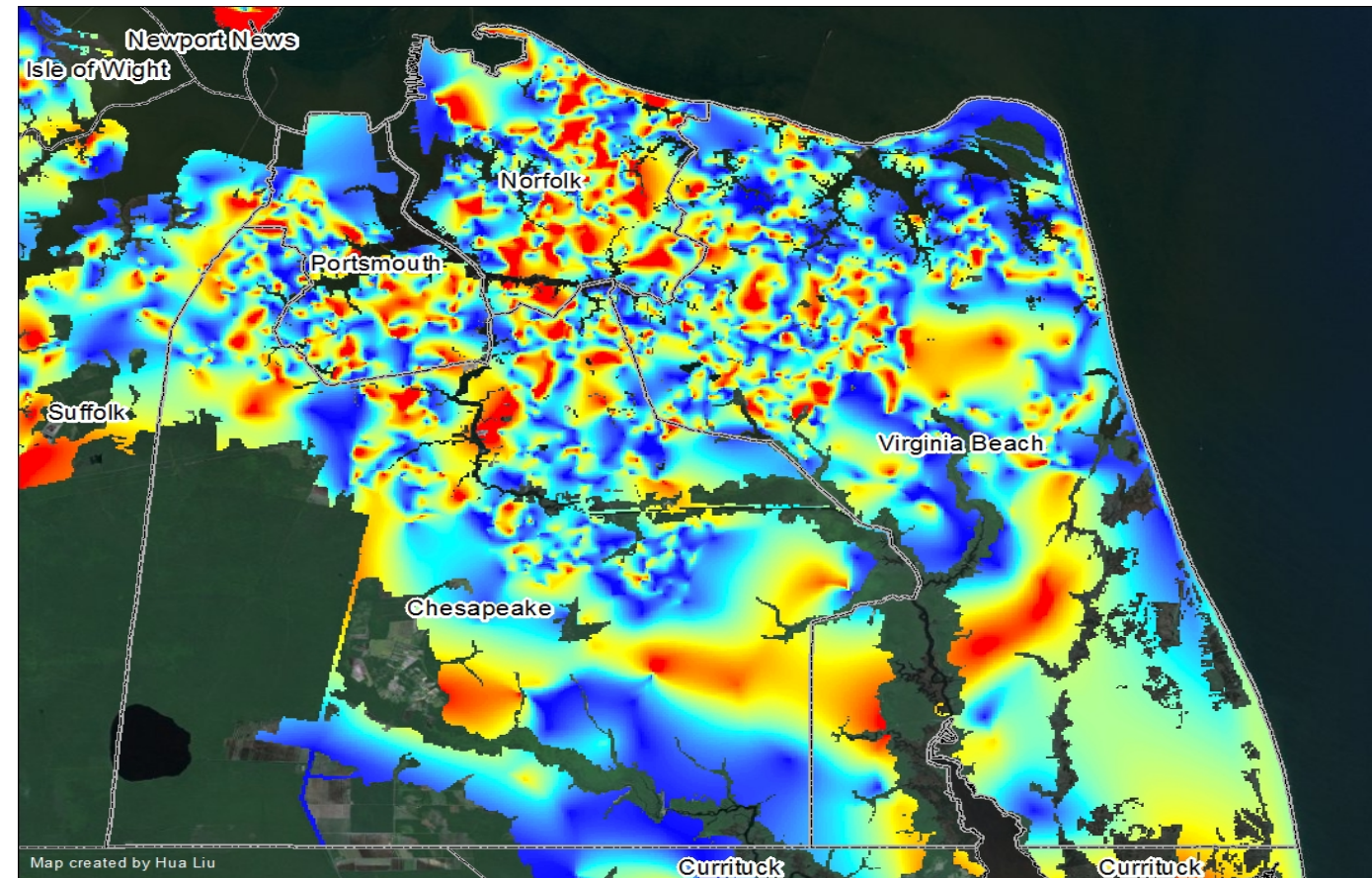
Catch-up

- House chores
- ‘Honey Do’ lists

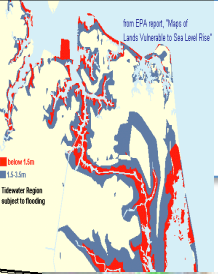




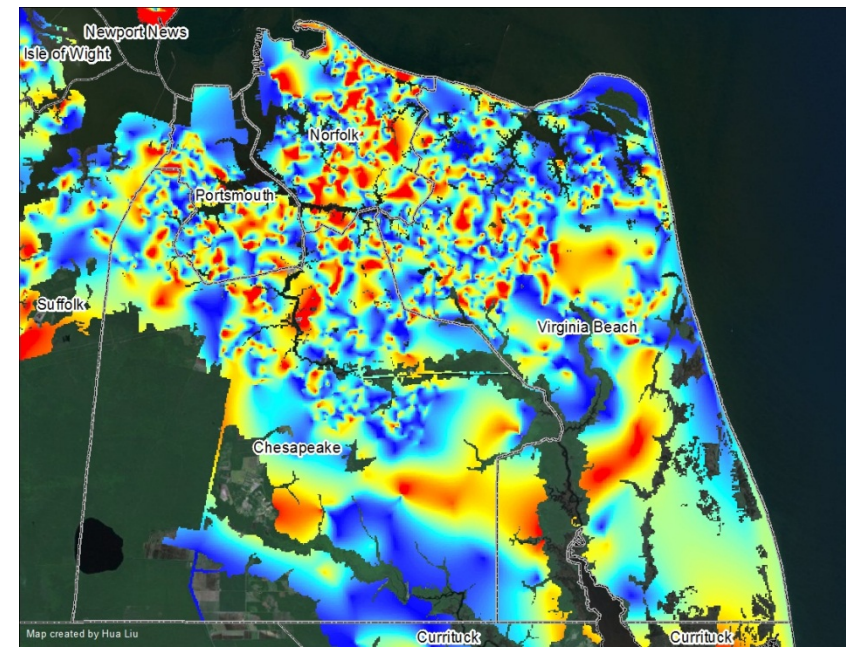
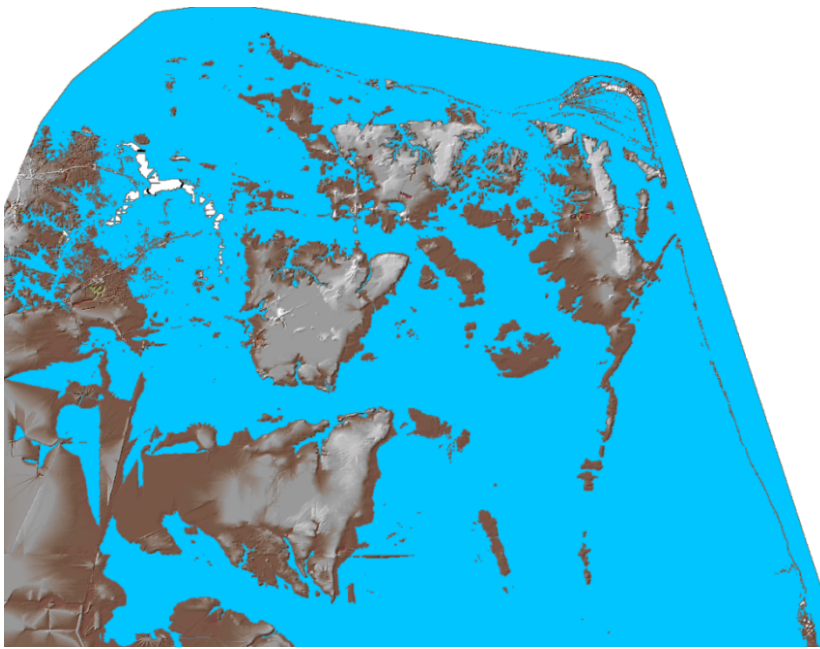
Vulnerability Mapping – Localized View

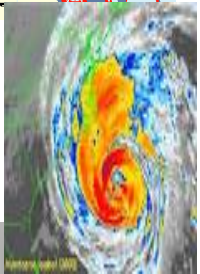
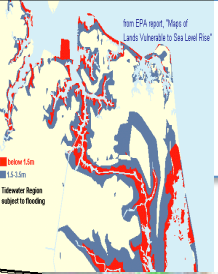


Neighborhood Variation in Financial Vulnerability

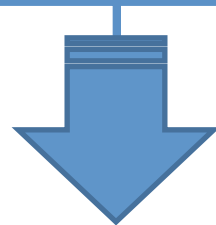


So far we have several data streams...



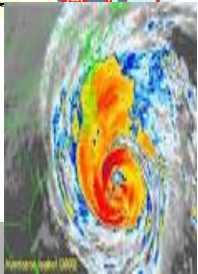
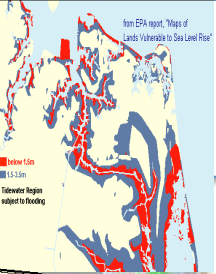


Sandtrina
Scenario
Modeling + Spatial
Vulnerability
Modeling



Yields...

Displaced Population
by
Vulnerability
by
Owner/Renter ... etc.

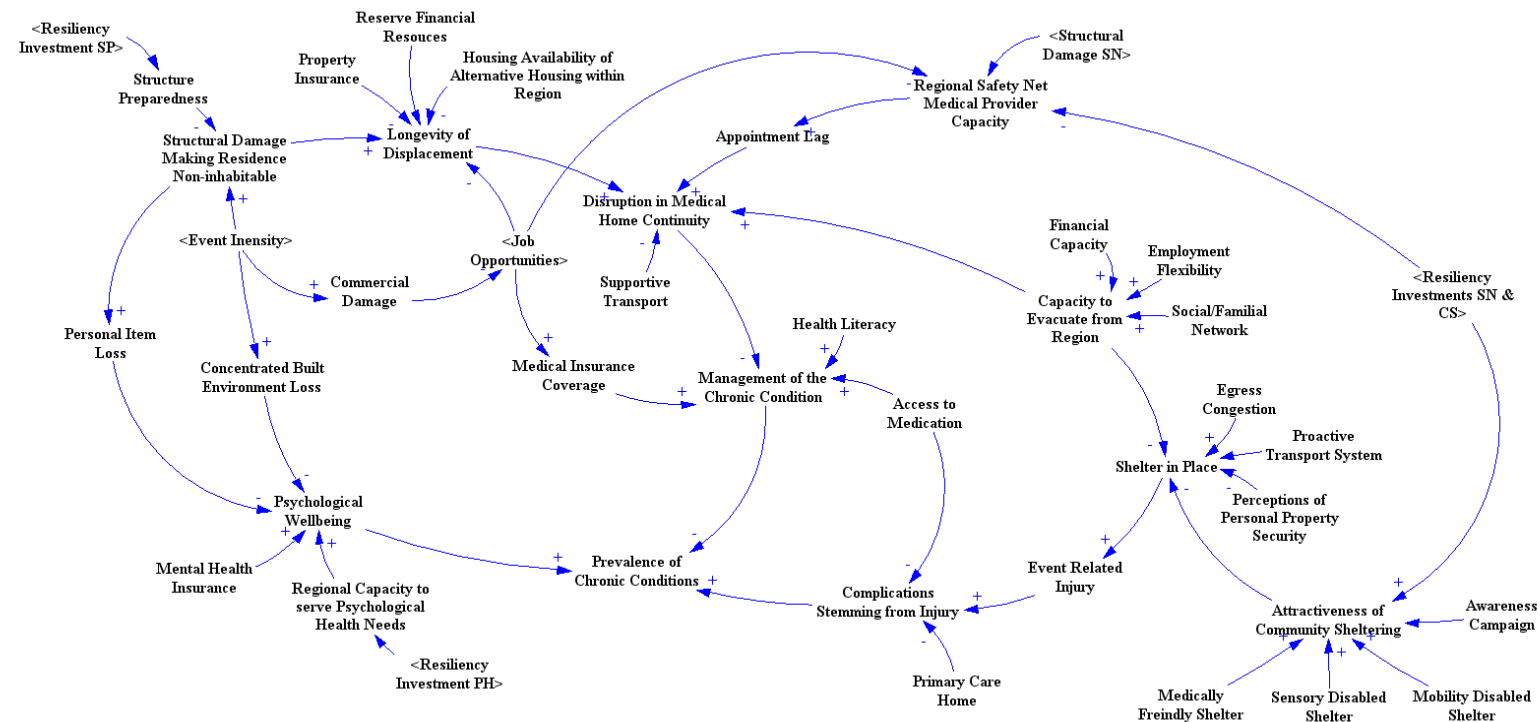


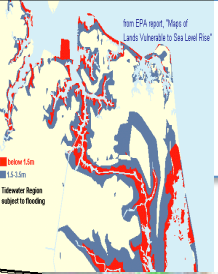
1	SEVA NENC Population Hazards			
2	Locality / Vulnerability	Sum of Displaced Population	Displaced Population (Owner)	Displaced Population (Renter)
3	Accomack County	13,027	9416	3611
4	1 - Low Vulnerability	9,238	6783	2455
5	2 - Medium Vulnerability	3,326	2293	1033
6	3 - High Vulnerability	463	342	121
7	Chesapeake city	75,087	57746	17341
8	1 - Low Vulnerability	32,259	26113	6146
9	2 - Medium Vulnerability	37,307	27857	9450
10	3 - High Vulnerability	5,521	3377	2144
11	Currituck County	16,399	13322	3077
12	1 - Low Vulnerability	4,418	3631	787
13	2 - Medium Vulnerability	9,511	7803	1708
14	3 - High Vulnerability	2,470	1884	586
15	Dare County	26,117	19675	6442
16	1 - Low Vulnerability	6,727	5477	1250
17	2 - Medium Vulnerability	13,684	9968	3716
18	3 - High Vulnerability	5,706	4174	1532
19	Gloucester County	8,810	7272	1538
20	1 - Low Vulnerability	6,497	5424	1073
21	2 - Medium Vulnerability	1,969	1552	417
22	3 - High Vulnerability	344	305	39
23	Hampton city	105,525	63356	42169
24	1 - Low Vulnerability	32,098	22561	9537
25	2 - Medium Vulnerability	63,993	36651	27342
26	3 - High Vulnerability	9,434	3948	5486
27	Isle of Wight County	2,868	2351	517
28	1 - Low Vulnerability	1,329	1088	241
29	2 - Medium Vulnerability	1,385	1124	261
30	3 - High Vulnerability	154	137	17
31	James City County	3,482	2785	697
32	1 - Low Vulnerability	2,511	2173	338

*Theoretical/
Illustrative
Figures*

System Dynamics Model: MICRO

Conceptual Localized Dynamics...



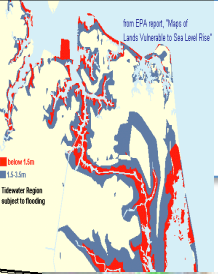


Household Adaptive Capacity Recurrent Flooding

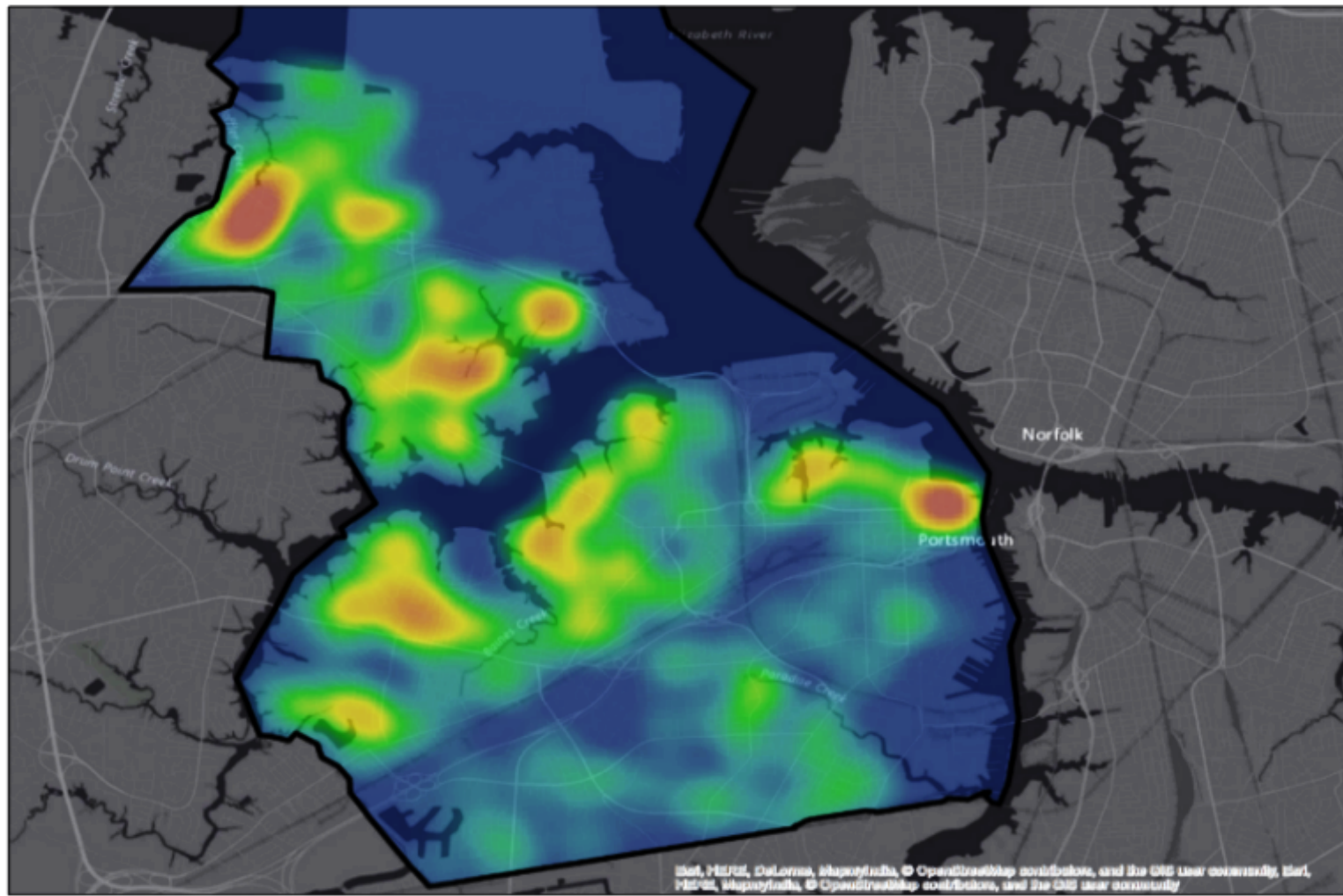


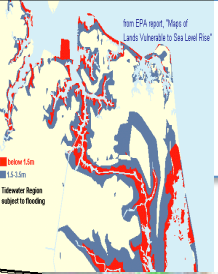
Sampling East Side of City





Residential Neighborhood Street Flooding

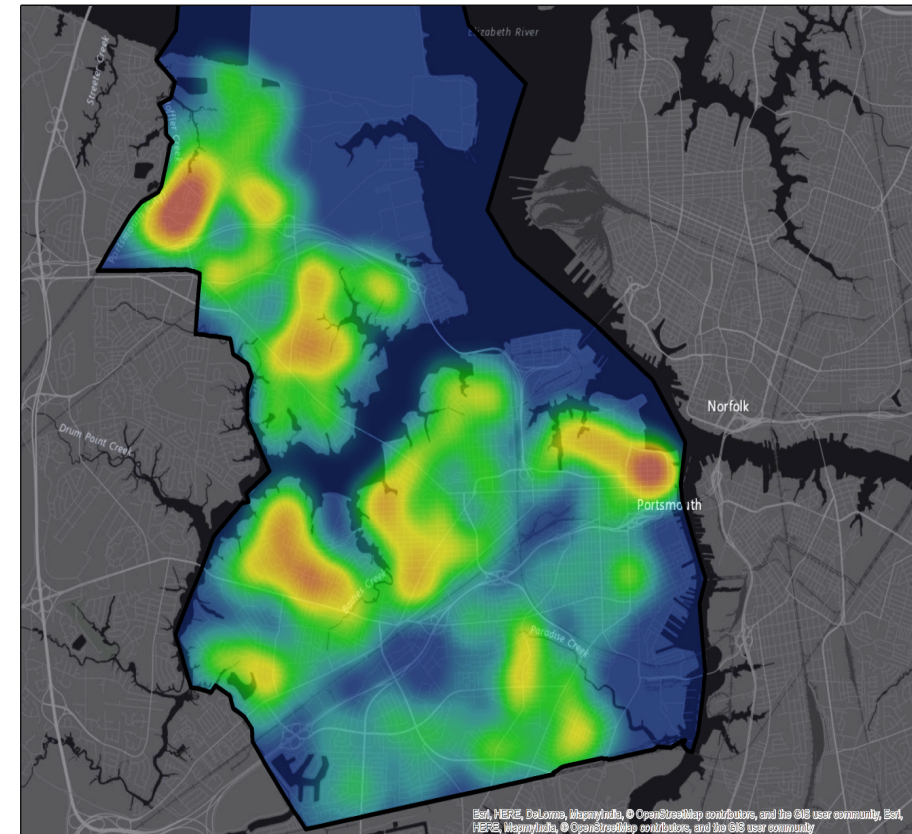
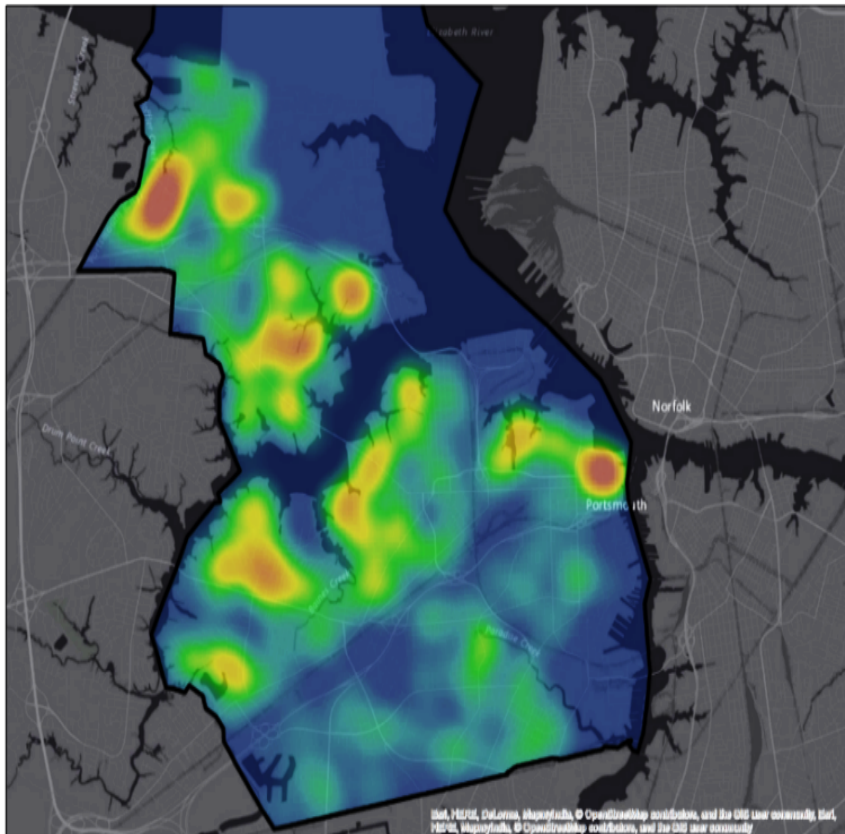


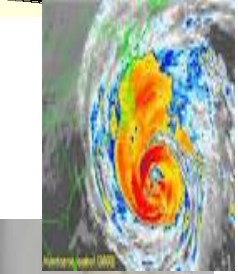
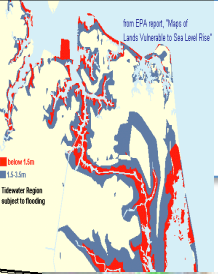


Perception Variable: SLR Will Limit Economic Opportunity for Citizens

Neighborhood Flooding

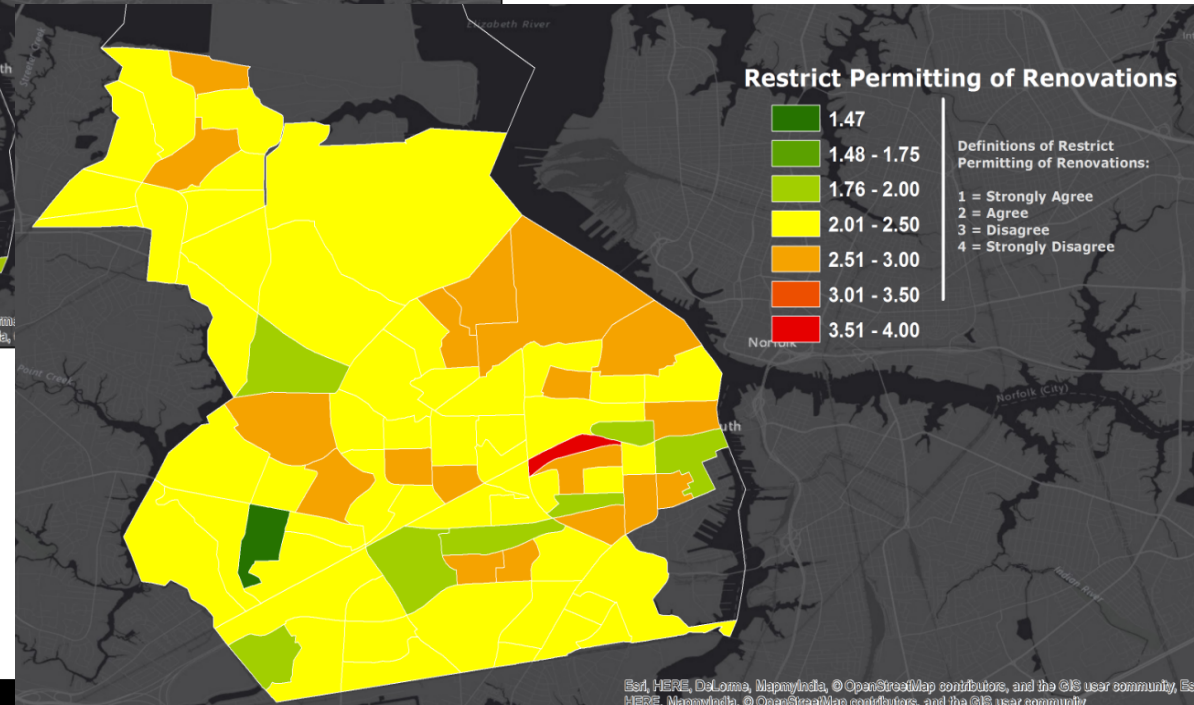
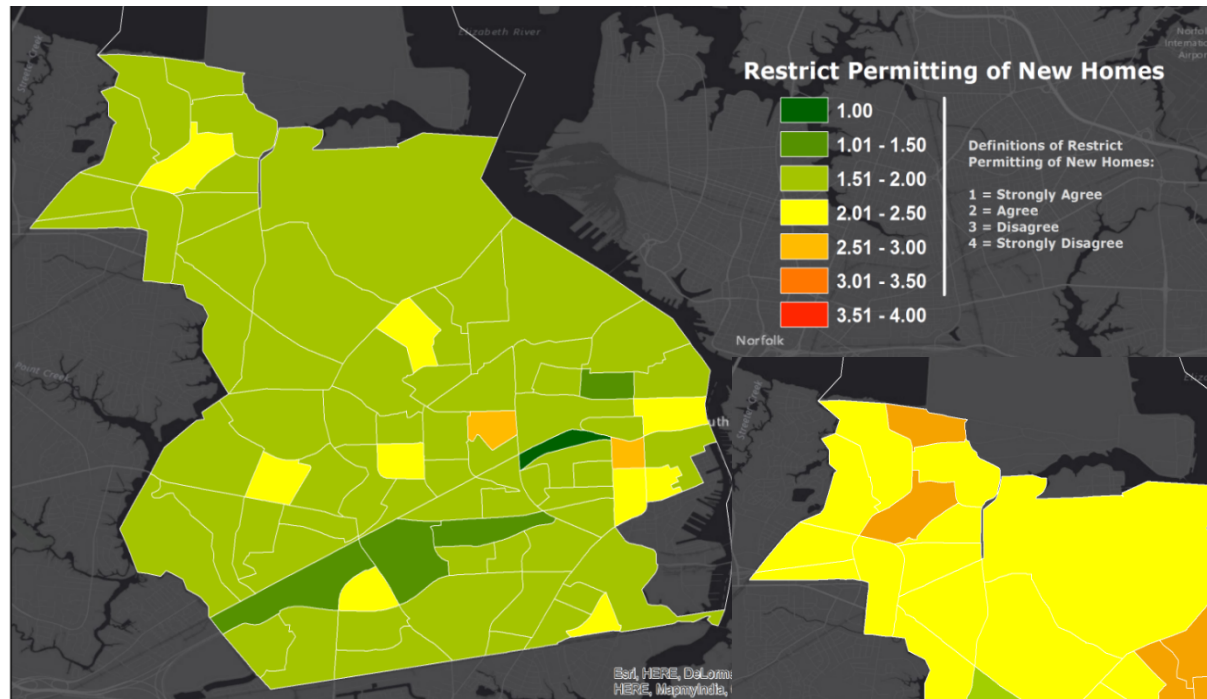
Economic Opportunity





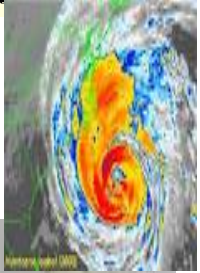
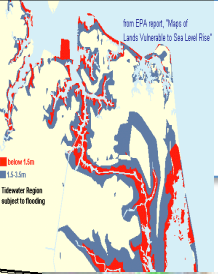
NIMBY: Restrict Permitting....

Renovations

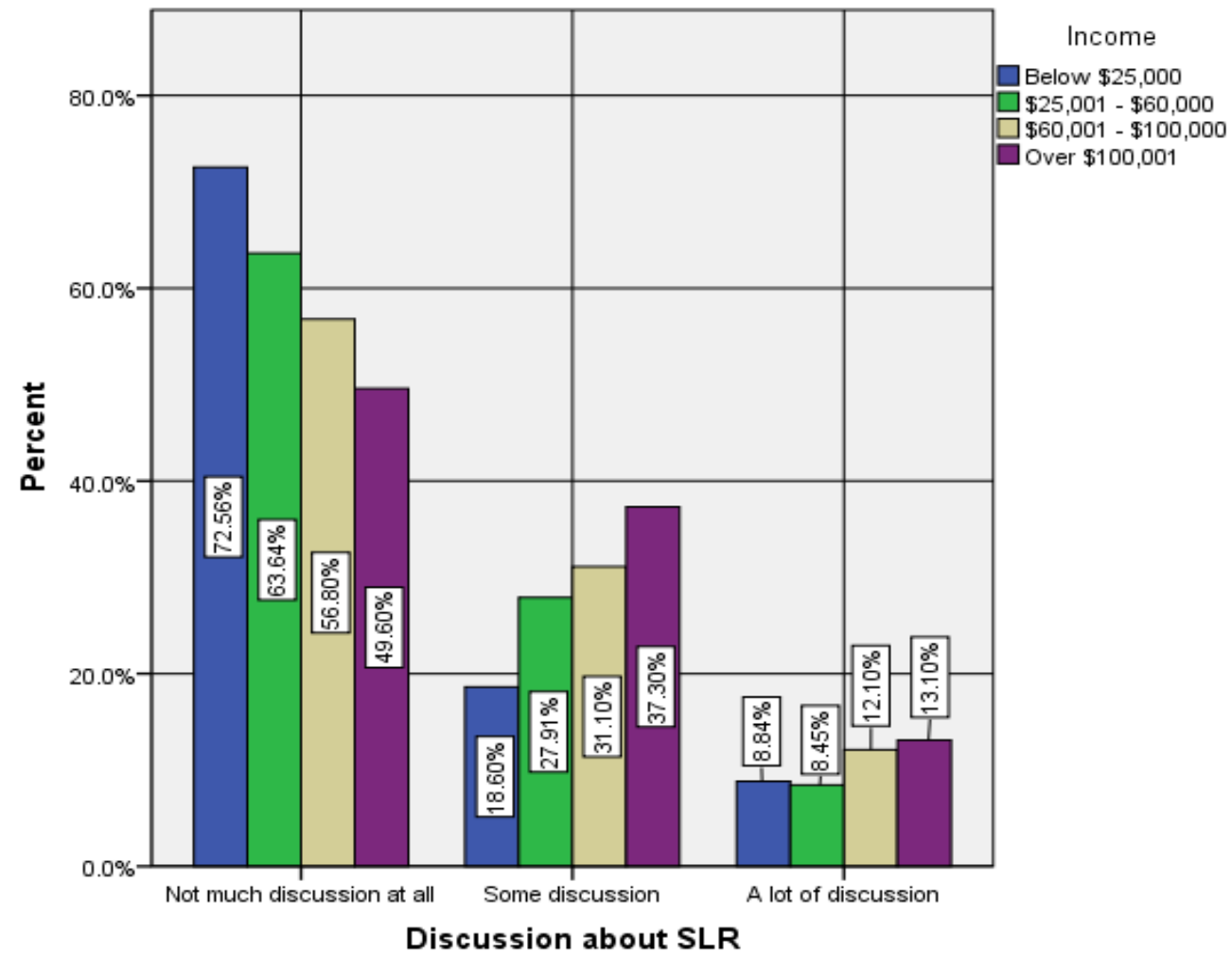


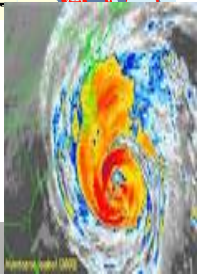
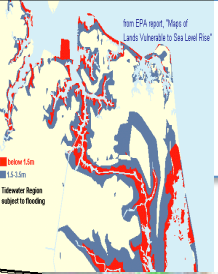
New Homes



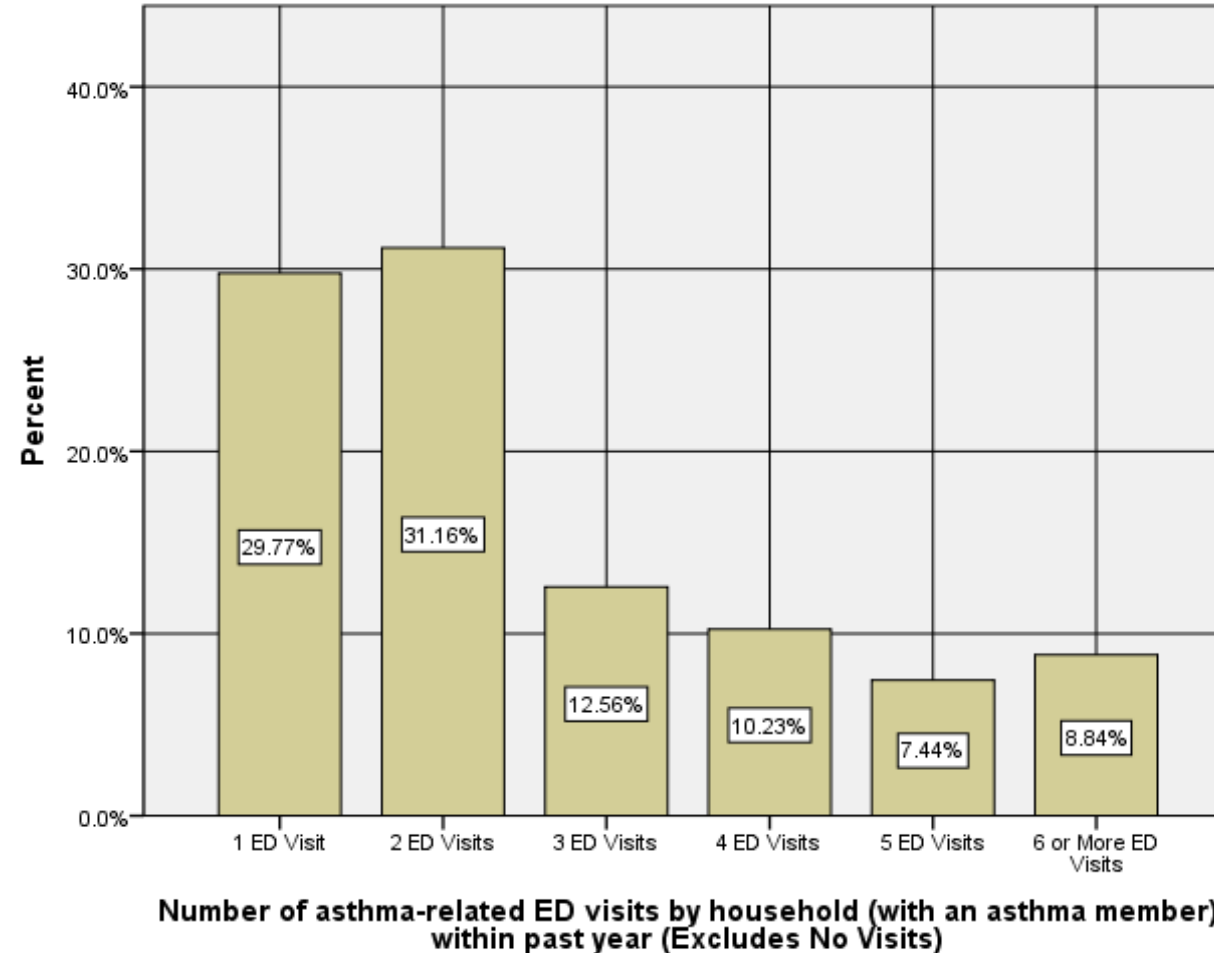


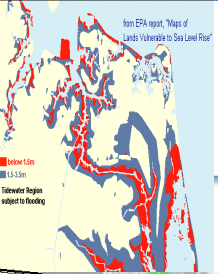
Discussion about Sea Level Rise



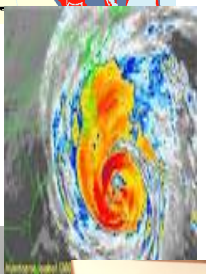


Mold, Asthma, & ED Visitation

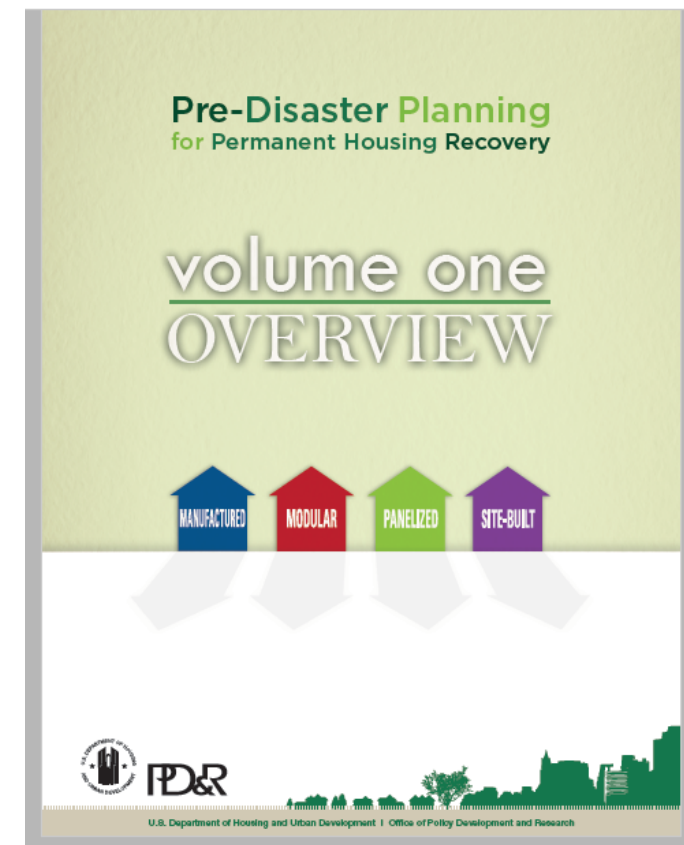




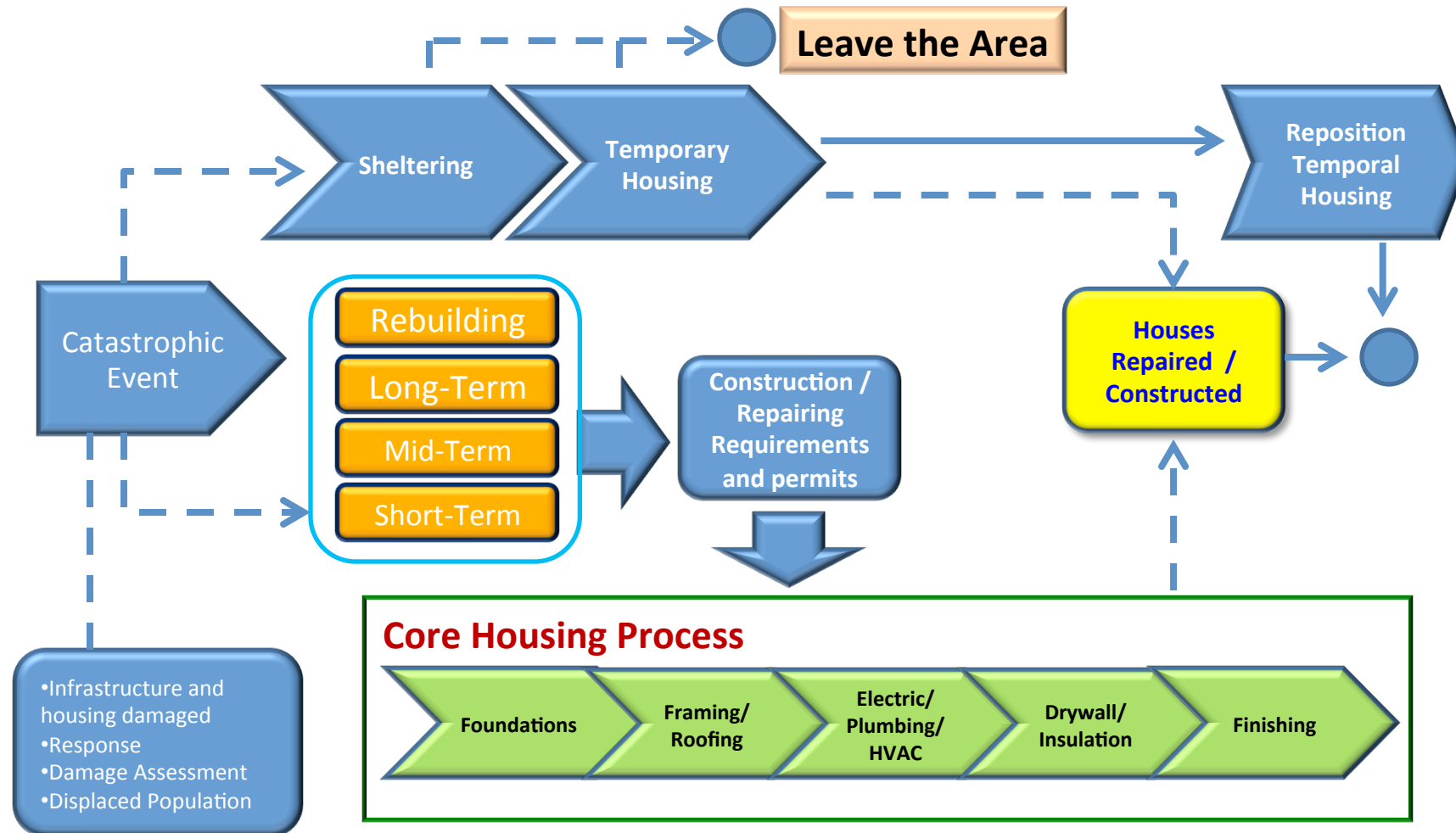
HUD Pre-planning: Modeling Housing Stock Recovery

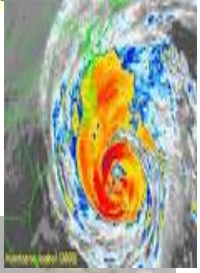
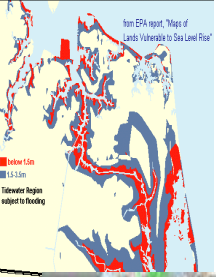


HUD Group Model Building Events Norfolk & Portsmouth



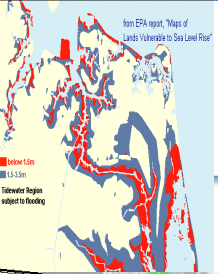
HUD Pre-planning: Modeling Housing Stock Recovery





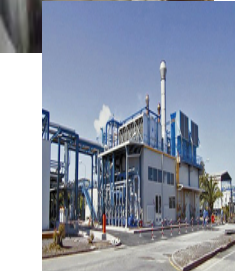
Part-2

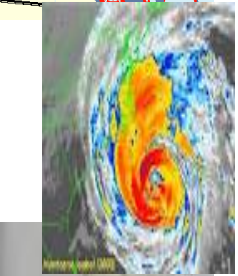
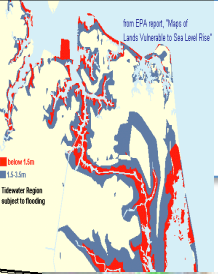
Conceptualizing Household Vulnerability



Vulnerability Scaling

- Identified 17 dimensions of vulnerability + 2 'hyper' measures vulnerability.
- Constructed set of weighted indicators intended to 'capture' the substantive nature of household vulnerability on each dimension.
- SMEs engaged through a structured process to establish the relative weights of the indicators within each dimension.

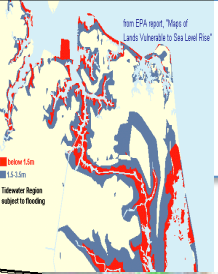




Financial Vulnerability...

A forecast of a household's inability to absorb the financial impact of a disrupting severe storm event.

That is, disrupted household income or storm-related preparation & response costs (food, fuel, shelter, and logistics) may be difficult to absorb and, thus, conditions propensity to evacuate.

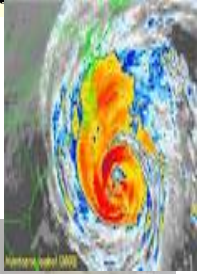
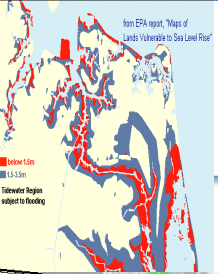


Financial Vulnerability

Scale Indicators:

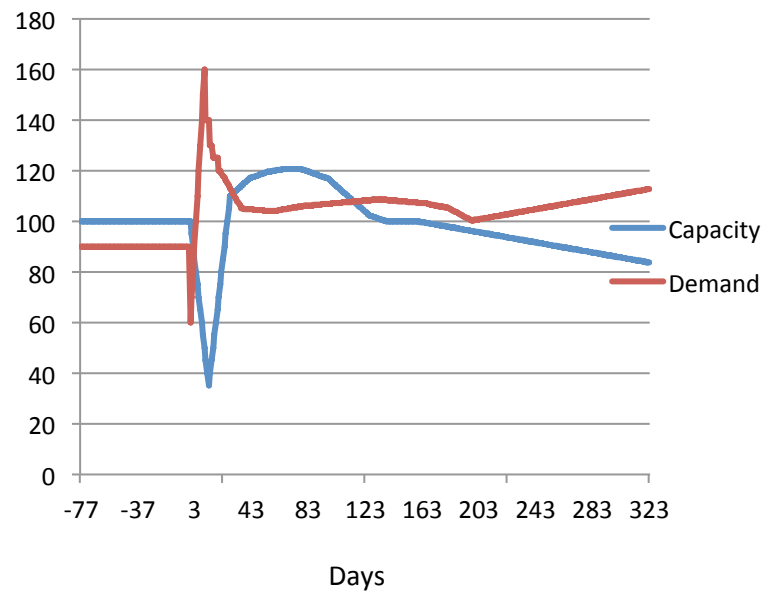
1. Anyone in the household lose pay.
2. Anyone in the household lose vacation time or use sick time.
3. If lose a week's pay, would have trouble paying next month's rent or making the mortgage.
4. If lose a month's pay, would have trouble paying next month's rent or making the mortgage.
5. Enough cash or credit to support the household for five days outside the region.



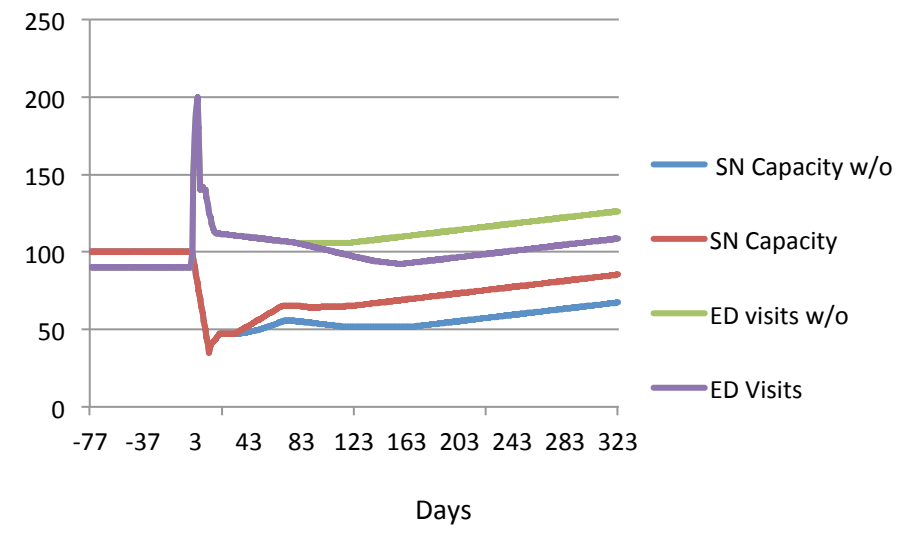


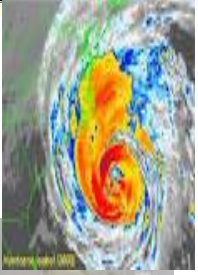
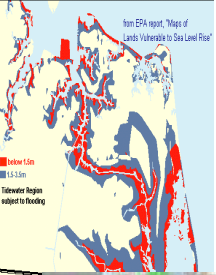
Dynamic System Behavior

Demand-Capacity for Acute Care



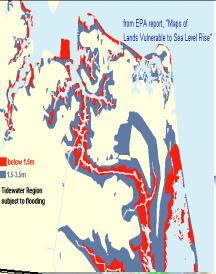
Safety Net Capacity & ED Visits, by resiliency investment





Part-3

Household Risk Perceptions



Risk Perception ⁽¹⁾

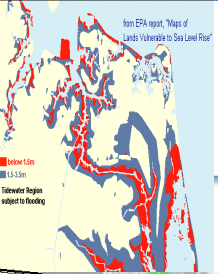
“I am not stupid!”

- Visualize the extremes of a ‘L-R Risk Continuum’
- Those that sheltered see negligible risk and those that exited see imminent risk, yet it is the same event.

“I live on the 1st (or is it the 2nd) floor!”

- 1st floor is low and safe from the wind
- 2nd floor is high and safe from the water

Note: Use of contextual/environmental elements to rationalize less risk than neighbors



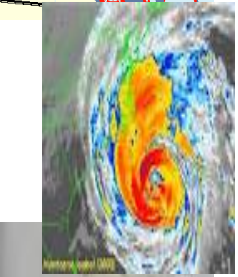
Policy Resistance

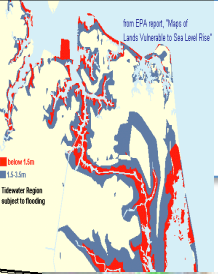
Neighborhood Shelters, Fire & Police Stations

- Have known shelter in neighborhood (e.g., school), that's our 'insurance'
- Neighborhood shelter will be on the radar of emergency officials and will meet our needs.
- *"...live right by a fire department and police station – can't get any safer than that..."*

Preparation Efficacy

- Follow what Red Cross and EMs tell us we can do to reduce our vulnerability...
 - Food + Water + Fuel + Generator + Medications
- Increase in sense of efficacy = perception that household can weather the storm and its aftermath





Tethers* & Anchors*

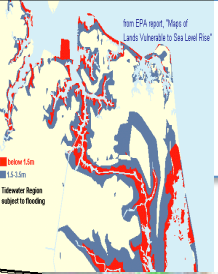
Tethers...

- Member within network either cannot or is unwilling to depart region.
- Other network members remain out of obligation, guilt, professional commitment.
- Deference given to opinion leader within network.

Anchors...

- Member employed in hospitality/service employment not relieved from job until 12-48 hours before landfall.
- Other network members remain.
- Protective Services and associated network.

*Original concept & term coined by the authors.



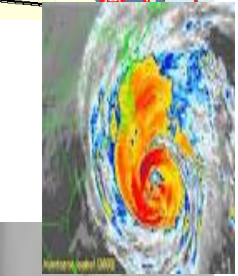
Evacuation

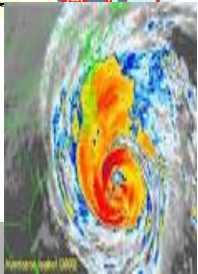
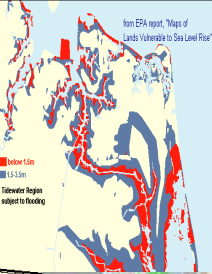
Evacuation Costs are Burdensome

- Fuel + Food + Accommodations

Delay & Exponential Costs

- Those households with financial constraints are more likely to delay – exiting means expense!
- Practice wait-and-see tactics.
- Delay is associated with increased exit costs:
 - More congestion means burn more gas.
 - Close hotels fill up first, have to travel farther.
- Those households who are least able to afford financial costs are more likely to incur heavier financial costs.





A Few Observations on Evacuation Mode...

Number of Vehicle Occupants

- Not optimal
- 2 person, 2 car family – take both

Recreational vehicles & trailers

- Slower acceleration
- Increased breakdowns

Caravanning

- Multiple vehicles

Exit paths

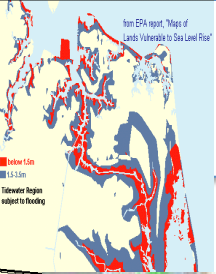
- Not intuitive
- Crisscross region – more activity than Monday morning commute.

Departure timing

- Not linear; imminent/landfall triggers exit
- About 7.5% of those departing delay their departure close to storm landfall so they can miss or lessen anticipated congestion

Exit destination

- Vacations and social visiting



Message Credibility

Message Discounting

- Know that officials/weather reports are exaggerated, discount the severity of forecast to arrive at the ‘real’ threat

Manipulation of Population

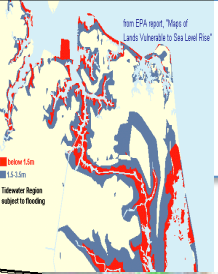
- Past forecasts/reports have been purposely exaggerated to get people to move

Incompetence of Weather Experts & EMs

- Storm alarms in past have been false
- Weather reports cannot be relied upon

Conspiracy

- Evacuation orders are hoaxes
- Conspiracy to sell more food and supplies



Medical Fragility⁽¹⁾

Access

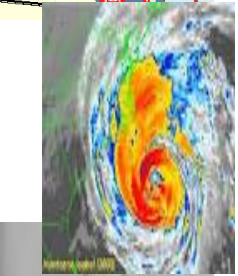
- Don't want to be away from familiar doctors
- Pain management regimen (e.g., chemo for RA)

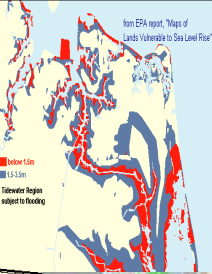
Disabilities & Comorbidity

- Sensory, Mobility, or Cognitive disabilities
- Chronic conditions (COPD, diabetes, obesity, etc.)
- Disruption/dislocation may exacerbate medical condition

Aging

- Unfamiliar places are upsetting
- Logistical arrangements are overwhelming





Medical Fragility⁽²⁾

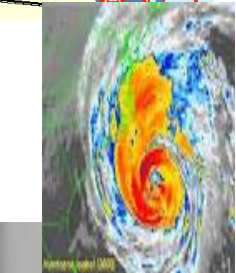
Propensity to Evacuate?

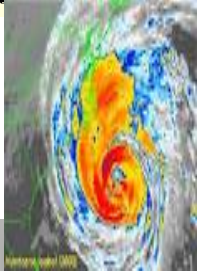
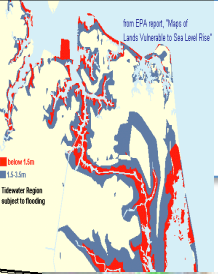
Theory:

- Elderly and medically fragile populations are least able to cope with storm-related disruptions to normal routines (power loss, acute injuries, heat sensitivity etc).
- Thus, more vulnerable and propensity to evacuate should increase.

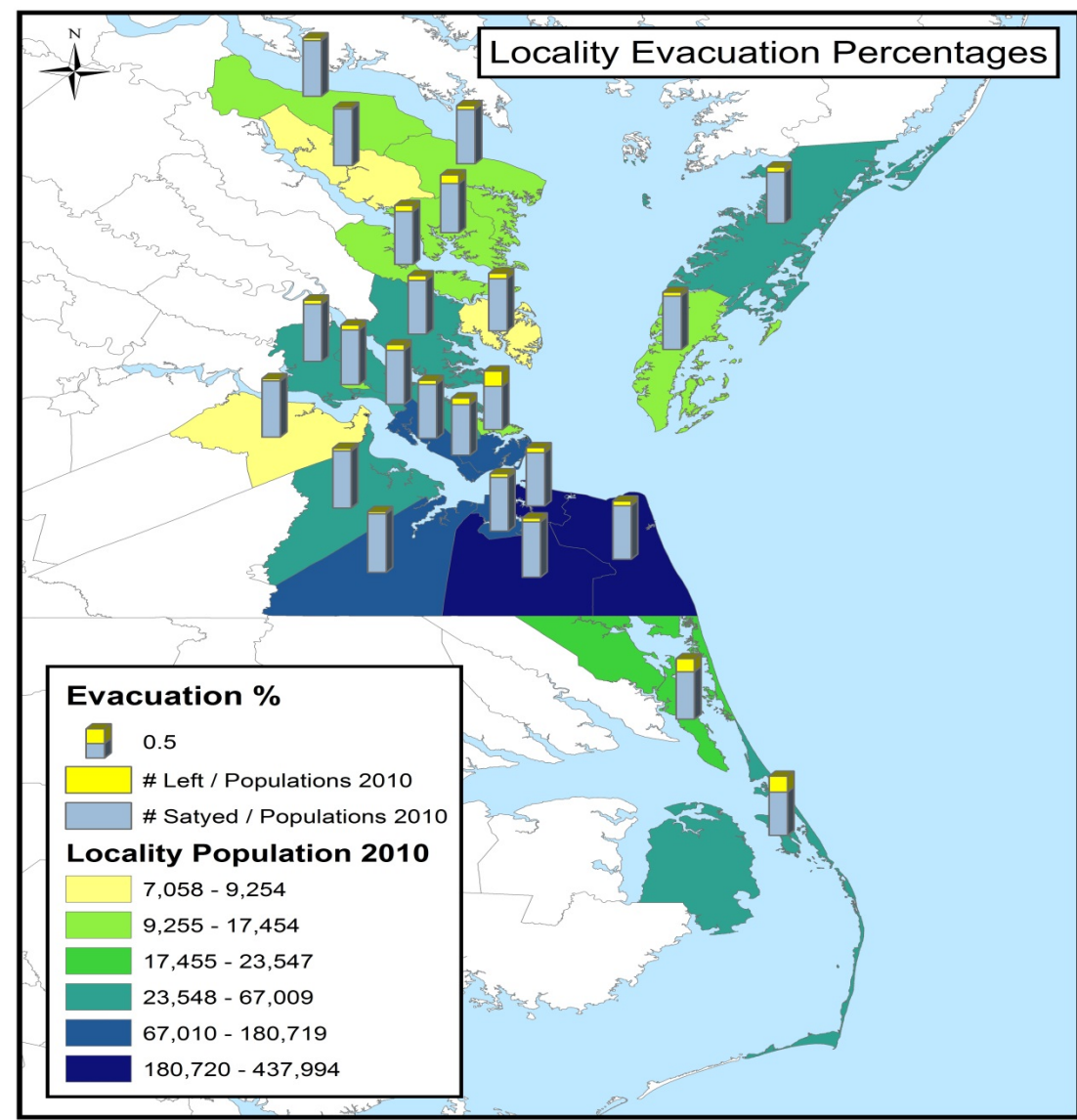
Ground Truth:

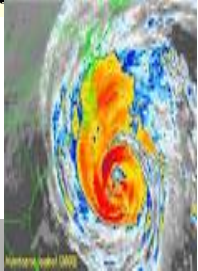
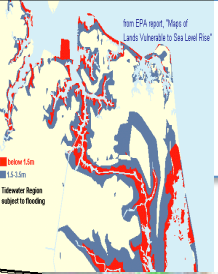
- These populations are equally likely to shelter in place.



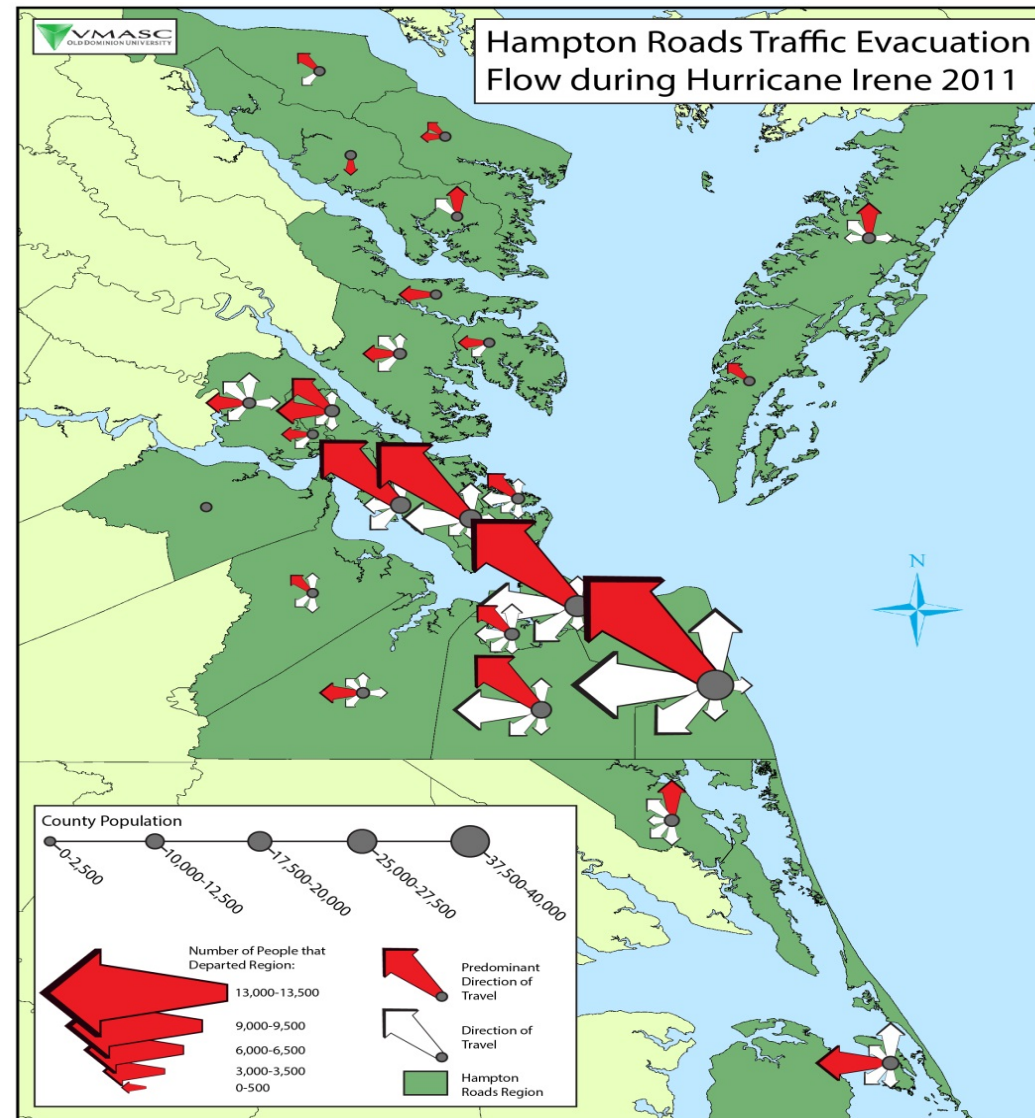


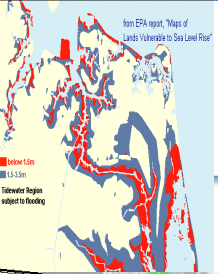
Relative Percent Departing Region



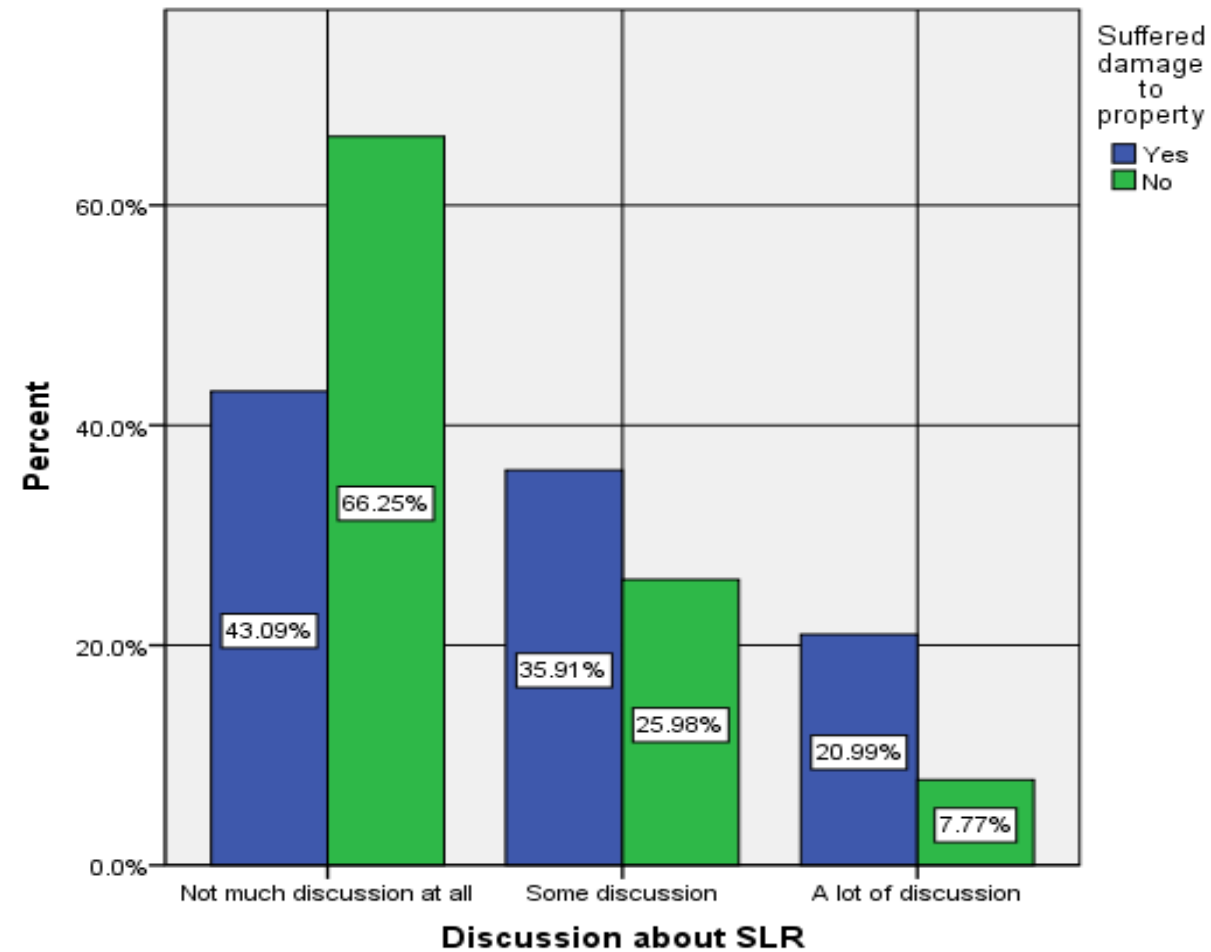


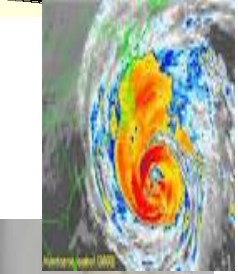
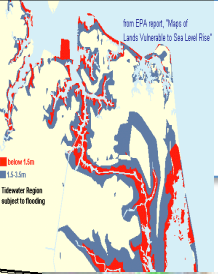
Multiple Direction Departure Numbers



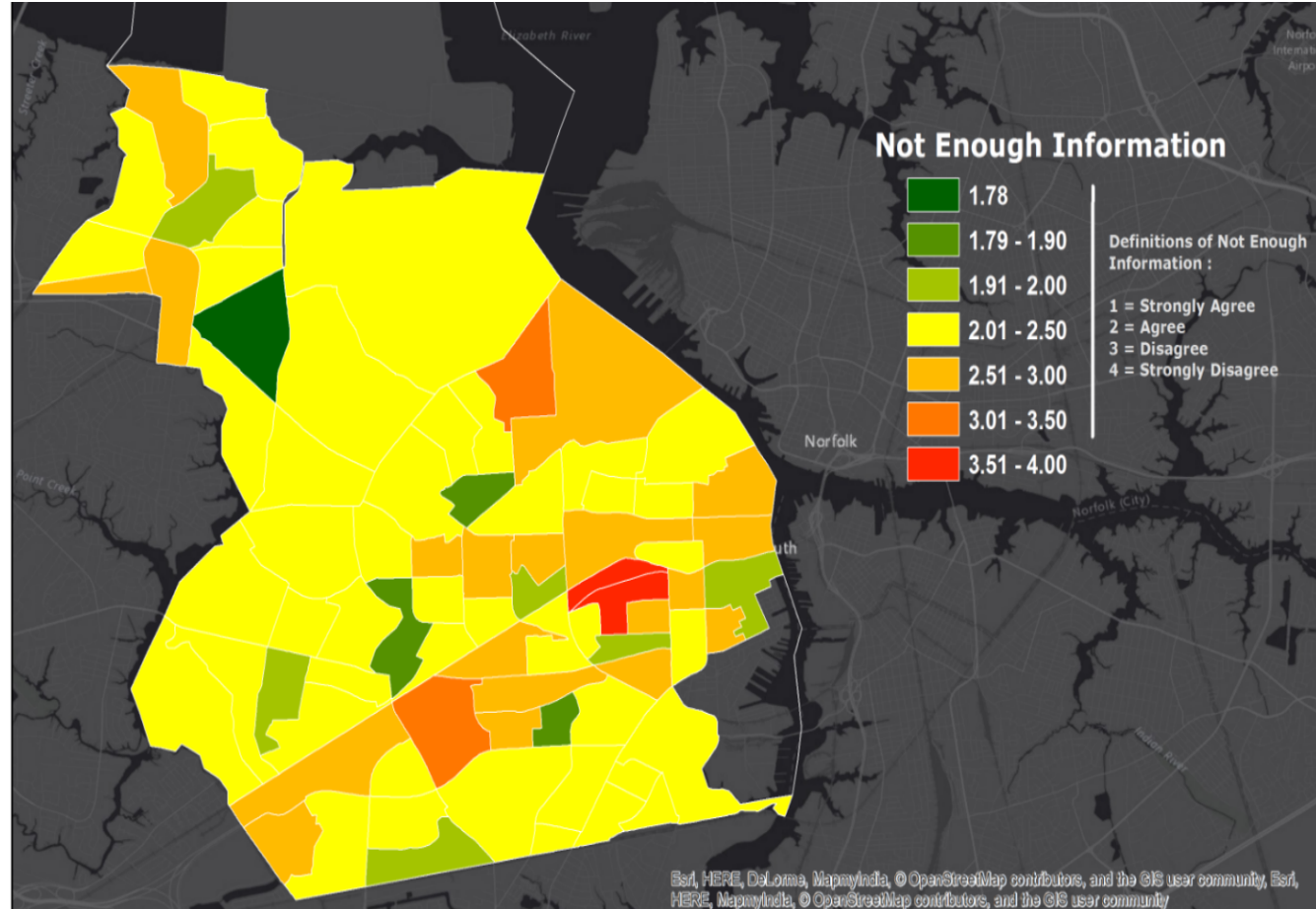


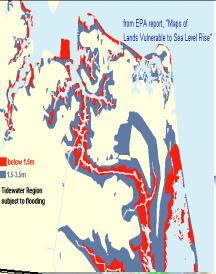
Discussion about Sea Level Rise





Not Enough Information

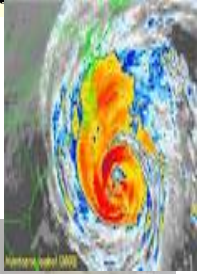
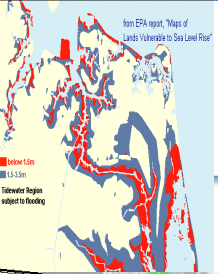




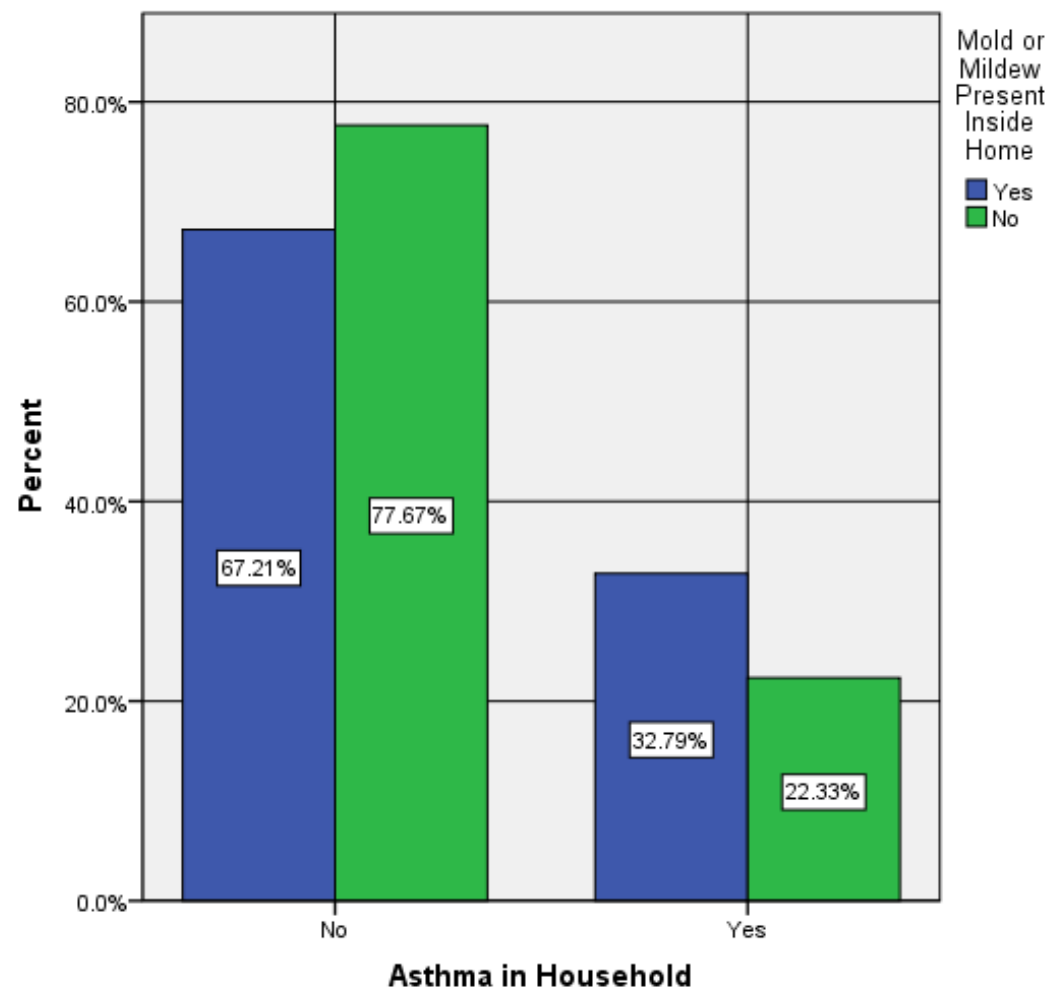
Mold, Asthma, & ED Visitation

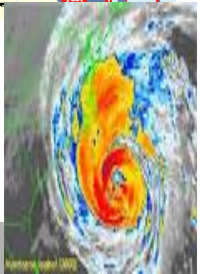
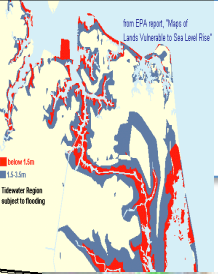
- **Asthma in Household (diagnosed)**
- **Asthma Triggers**
- **Mold or Mildew within Interior**
- **Asthma-related Emergency Department Visits**



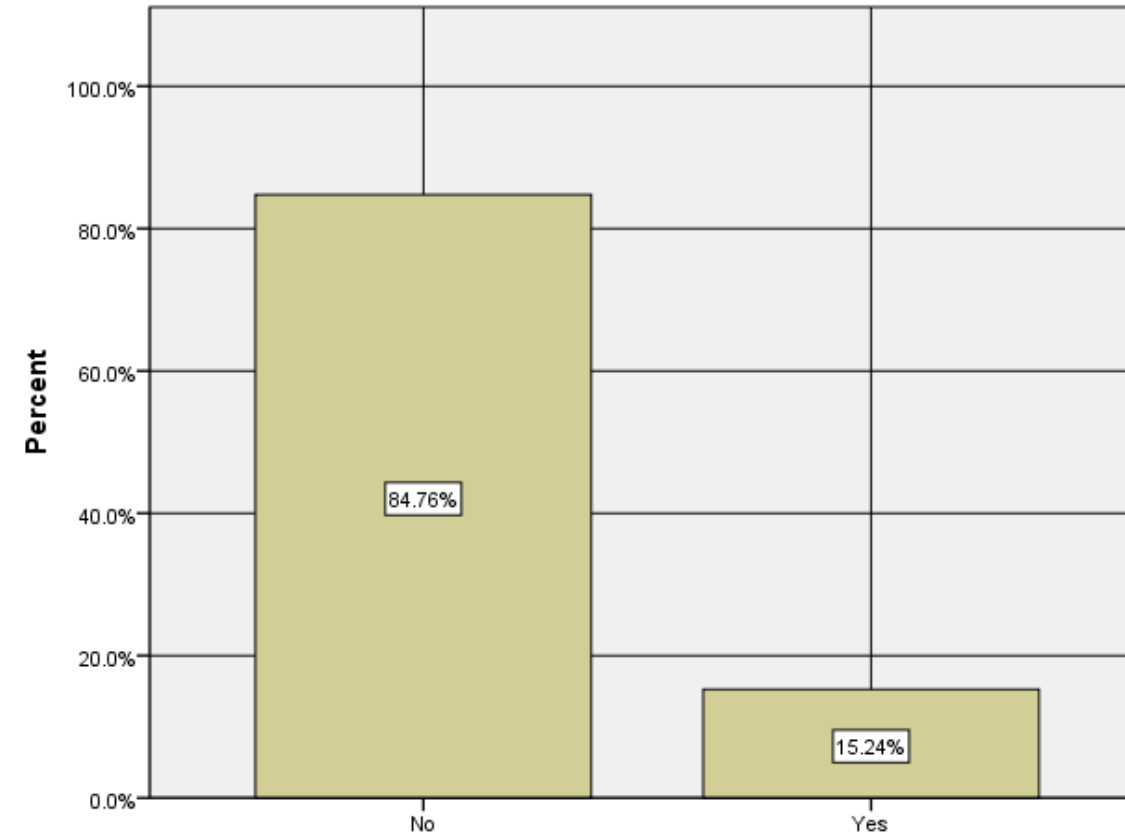


Mold, Asthma, & ED Visitation

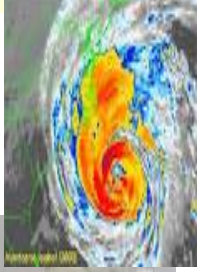
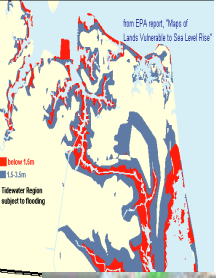




Mold, Asthma, & ED Visitation



Among the households that have at least a single child under 6, there is at least one pediatric asthma case (5 years or less) in household.



Part-5

Pre-planning and Housing Stock Recovery