

Coast-to-Coast Examples of Integrated Natural-Human System Models for Consequence-Based Climate Analysis

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#### David R Judi, PhD

Feng Pan, Patrick Royer, Cindy Rakowski Conference on Innovations in Climate Resilience



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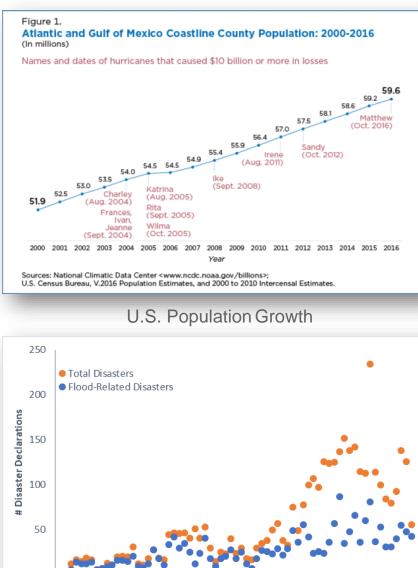
# Motivation: Changes in Natural and HumanSystems Increase RiskFigure 1.<br/>Atlantic and Gulf of Mexico Coastline County Population:

- Increase in Frequency, Intensity, Duration of Natural System Stressors
  - Coastal flooding (e.g., SLR, surge)
  - Nuisance flooding
  - Inland flooding
  - Drought

Pacific

Northwest

- Increasing Impacts to Human Systems
  - Population
  - Critical Infrastructure
  - Economic Disruption
- Human Systems are Changing
  - Continued population growth in coastal environments
  - High value real-estate
  - Infrastructure systems are aging



U.S. Natural Disaster Declarations

1970

1950

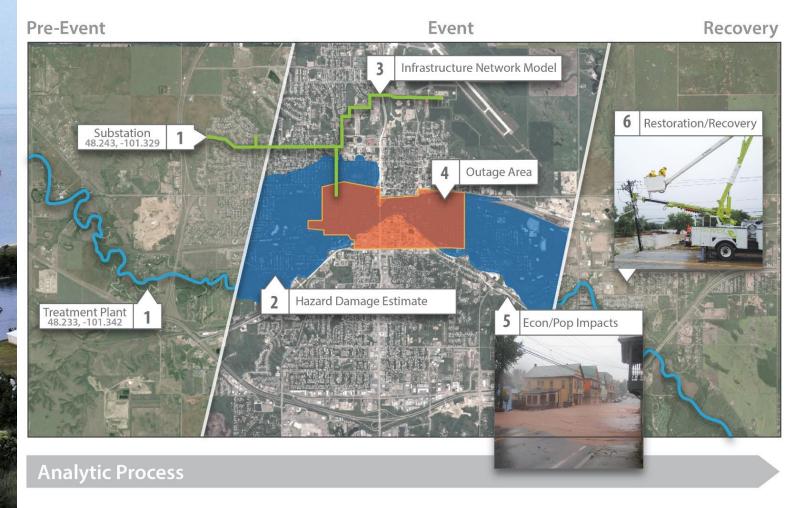
2020

2010

2000



## **Quantifiable Consequence Analysis**



- Direct Impacts
  - Infrastructure at Risk (counts)
  - Businesses at Risk (counts)
  - Population at Risk (counts)
  - Building Impact (\$\$\$)
- Secondary Impacts
  - Infrastructure Disruption (e.g., unmet demands)
  - Workforce & Business Disruption (GDP, employees)



### **Coastal Flood Risk Case Studies**

#### **Extreme Events Norfolk, VA**

- Storm surge, sea level rise
- Focus on critical infrastructure systems and workforce impacts

#### **Snohomish Watershed, WA**

- Rain, snow, rain on snow
- Focus on community flood risk (e.g., building exposure), no consideration of infrastructure

# Extreme Event Impacts to Infrastructure in Norfolk, VA

What are the changes in risk, considering infrastructure and workforce impacts, in Norfolk due to sea level rise?

Stakeholder-driven flood scenarios

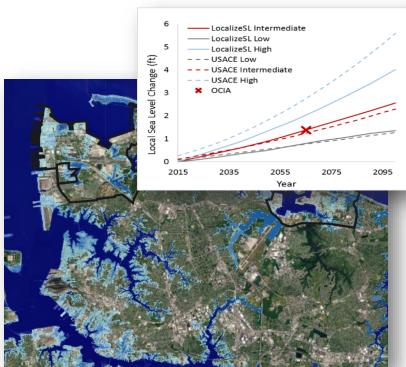
Pacific

Northwest

- Scenario-based sea level rise estimate (year 2065)
- Probability distribution of historical still water elevation
- Water, power, and transportation networks

Workforce residential and workplace locations (shown) inferred from census information





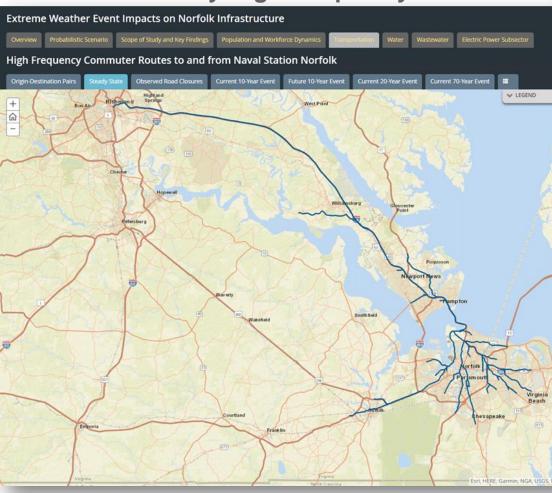
Ensemble of Flood Hazards Created for Historic and Future Coastal Flooding

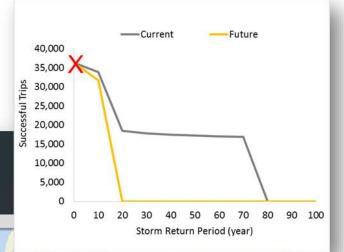


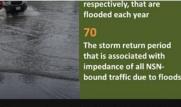
#### Normal Day High Frequency Routes

Mitigation and adaption have significantly reduced electric power and water system risk

Transportation and workforce impacts 4X more likely to have disruption



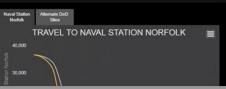




Naval Station Norfolk personnel commute throughout the Hampton Roads region and beyond. Using U.S. Census data, Origin-Destination pairs were developed to estimate personnel residential locations. These pairs were used to determine highest frequency routes from residential locations to Naval Station Norfolk under Steady State conditions (i.e., no storm). Each pair was also evaluated relative to the distribution of Current and Future storm flooding events to assess personnel access to the installation. Finally, this study also considered other military installations as potential Alternate Destinations for Naval Station Norfolk personnel.

Workforce access to Naval Station Norfolk begins to become inaccessible after a current 10-year storm event and is completely inaccessible after a 70year storm event. The risk significantly increases in the future with no access to the base between a 10 and 20-year event.

Explore the transportation routes in the maps on the left and view personnel access relative to the distribution of storms in the chart below.

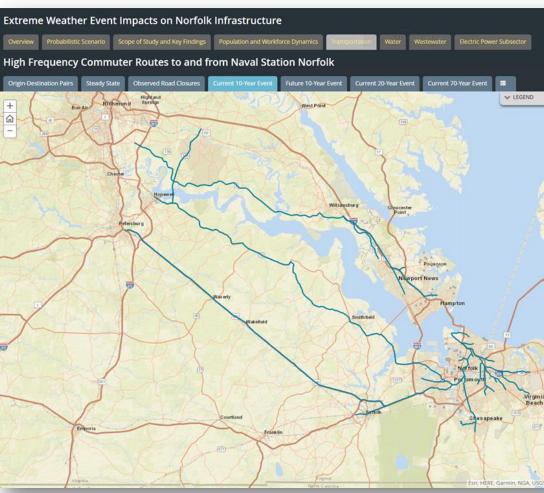


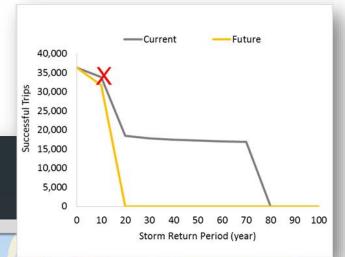


#### **10-Year Flood Event Routes**

Mitigation and adaption have significantly reduced electric power and water system risk

Transportation and workforce impacts 4X more likely to have disruption







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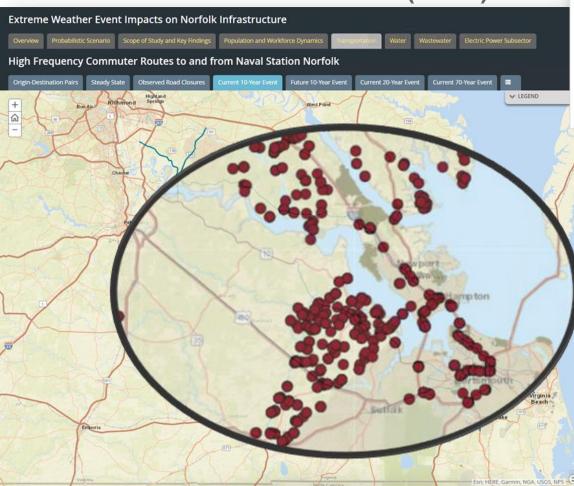
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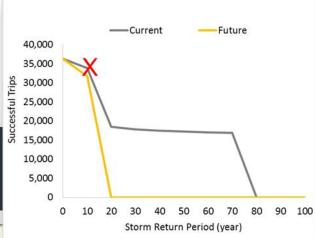


#### 8-Year Record of Road Closures (VDOT)

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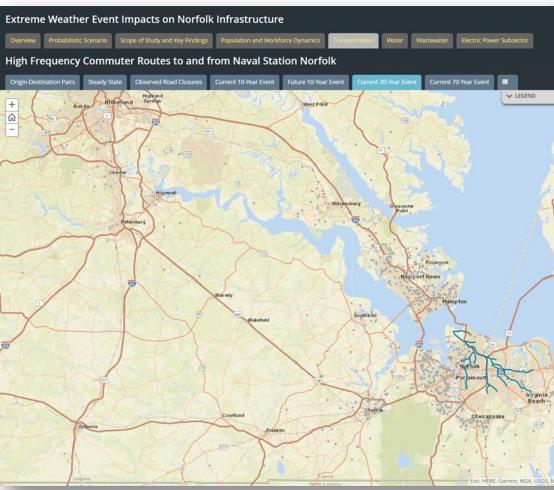


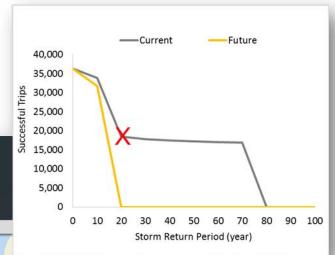


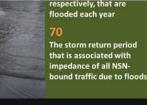
#### **20-Year Flood Event Routes**

Mitigation and adaption have significantly reduced electric power and water system risk

Transportation and workforce impacts 4X more likely to have disruption



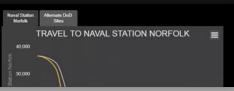




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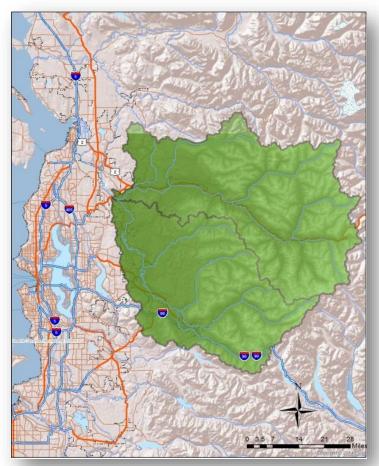
# **Study Area: Snohomish River Watershed**

How do changes in the natural system and the human system affect risk in Pacific Northwest Coastal Watersheds?

- Historically annual high risk of flooding
- Coastal watershed is sensitive to changes in rain, rain on snow, and snow melt



1990 Thanksgiving Flood was a result of 8-16 inches of rain, melting snow.



Snohomish Watershed Near Seattle, Washington

# **Integrated Modeling to Capture Flood Risk**

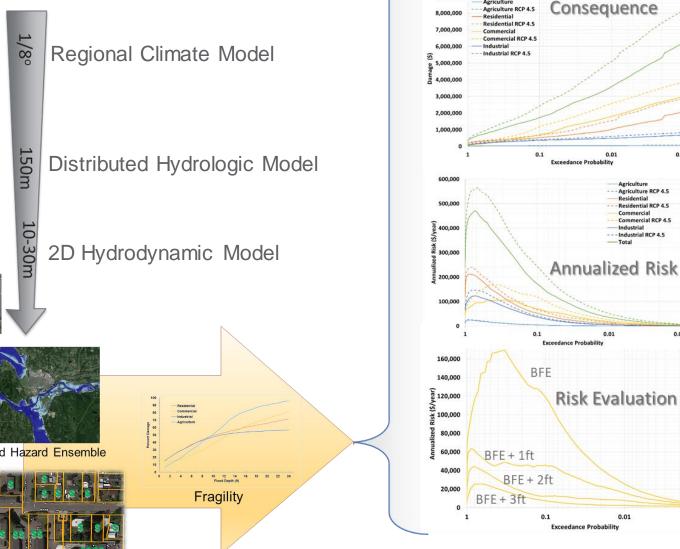
Integrated Natural System Modeling LO-30m Hydraulics Decision Support Human System **Exposure and** Flood Hazard Ensemble **Vulnerability** 

Climatology/Meteorology

Hydrology

Pacific

Northwest NATIONAL LABORATORY



Evaluate to **Risk Metrics** Agriculture RCP 4.5 **Residential RCP 4.5** Change Commercial RCP 4.5 Quantifiable

0.001

Judi, D., Rakowski, C., Waichler, S., Feng, Y., Wigmosta, M (2018). "Integrated Modeling Approach for the Development of Climate-Informed Actionable Information". Water, 10(6), 775, https://doi.org/10.3390/w10060775

0.01

0.01

0.01

Residential

Commercial

--- Industrial RCP 4.5

Industrial

Agriculture

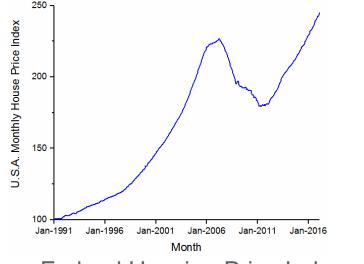
Agriculture RCP 4.5

Parcel/Tax Data

# **Changing Human Systems Influence Risk**

Human systems are subject to nonstationary conditions

Pacific Northwest



Federal Housing Price Index

Changes in socioeconomic conditions can counter and amplify changes in expected annual damage (EAD)

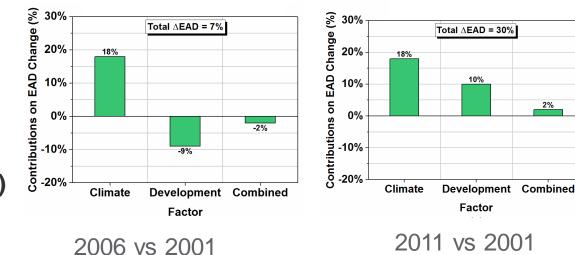


Image: 1992 Land CoverImage: 2011 Land Cover

Feng, Y., Rakowski, C., McPherson, T., Judi, D. (2019). "A partition of the combined impacts of socioeconomic development and climate variation on economic risks of riverine floods". *Journal of Flood Risk Management*, 12(52), https://doi.org/10.1111/jfr3.12508.

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### **Future Direction**

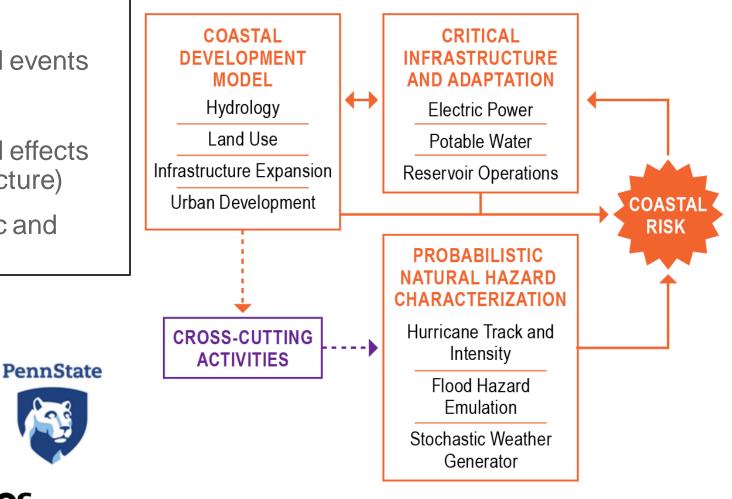
#### There are gaps in the research

- Limited evaluation of compound events
- Limited exploration of the "tails"
- Limited evaluation of compound effects (e.g., urban systems + infrastructure)

Pacific

 Limited ability to capture historic and future human system changes

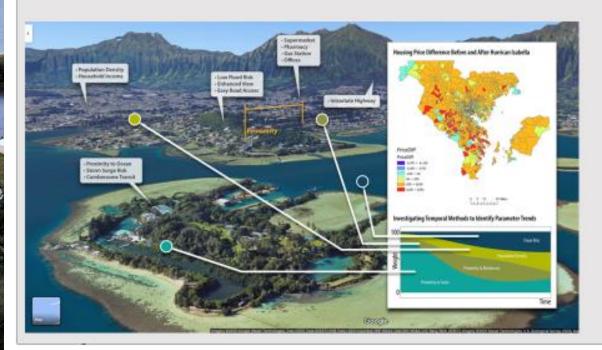
#### Integrated Coastal Modeling (ICoM)



#### **Understanding Development Patterns in Coastal Urban Environments**

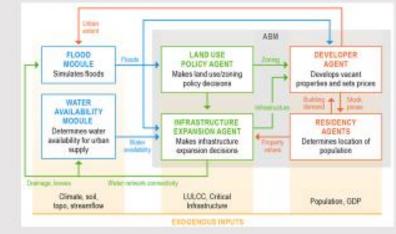
<u>Challenge</u>: Coastal urban landscapes are dynamic and development patterns are subject to natural and multisectoral influences

How might coastal development patterns influence community risk to extreme events (e.g., floods)?



<u>Methods and Approaches</u>: Developing a coupled human-natural systems model to capture key physical, demographic, economic, and institutional drivers of coastal development

- Spatial population downscaling and integrated hedonic price modeling to identify influential parameters and explore historical spatio-temporal patterns
- Development of a modular agent-based model to explore parameter sensitivity and human behavior uncertainty



#### MSD Vision:

Human System Modeling Uncertainty Quantification and Scenario Development Urban Systems





# Thank you

