Pacific Northwest
NATIONAL LABORATORY

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

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Conference on Innovations in Climate Resilience

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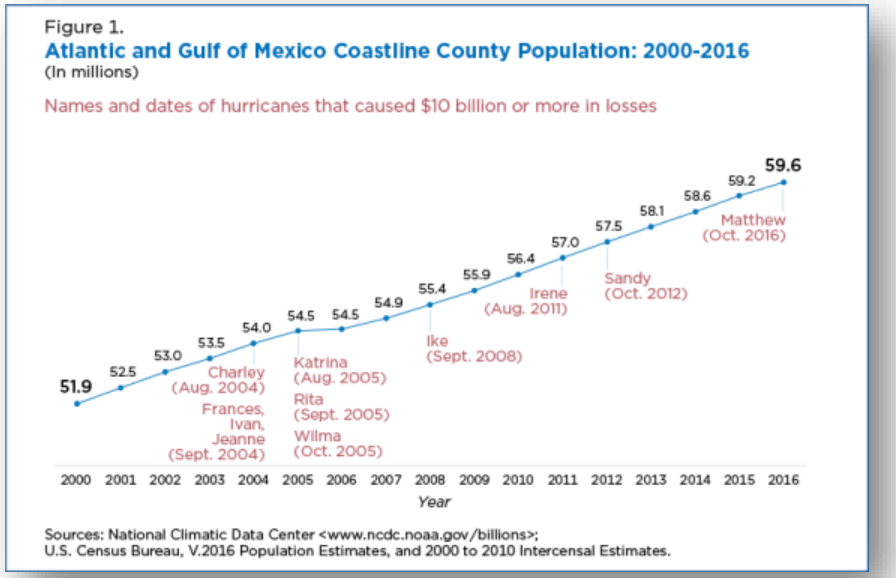
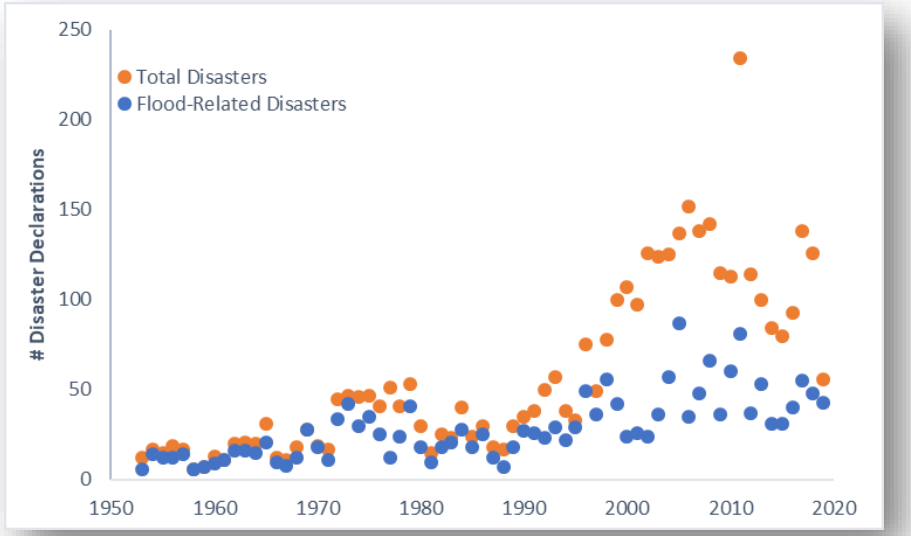
Motivation: Changes in Natural and Human Systems Increase Risk

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



U.S. Natural Disaster Declarations

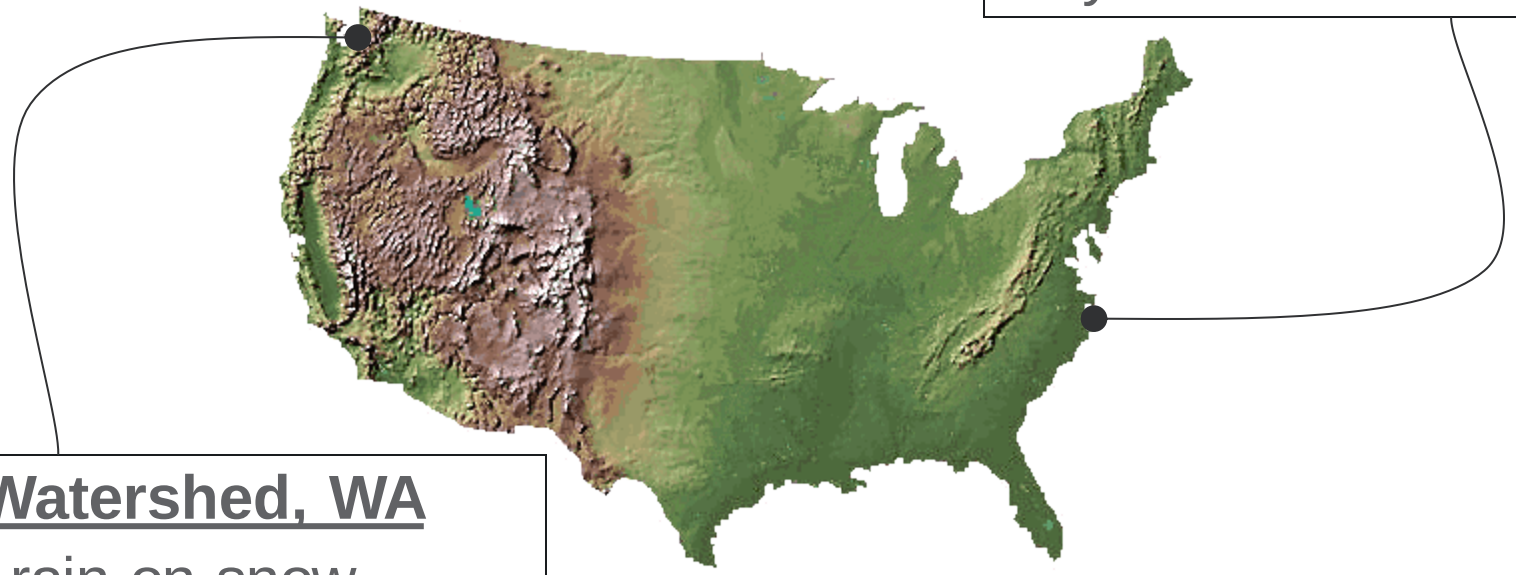
Quantifiable Consequence Analysis

- 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



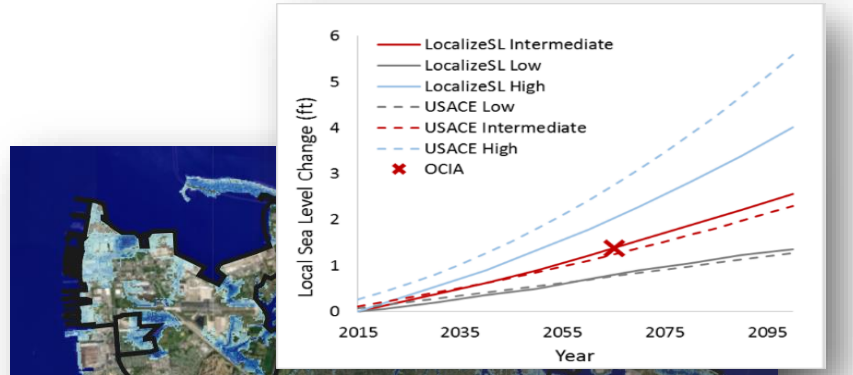
Snohomish Watershed, WA

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

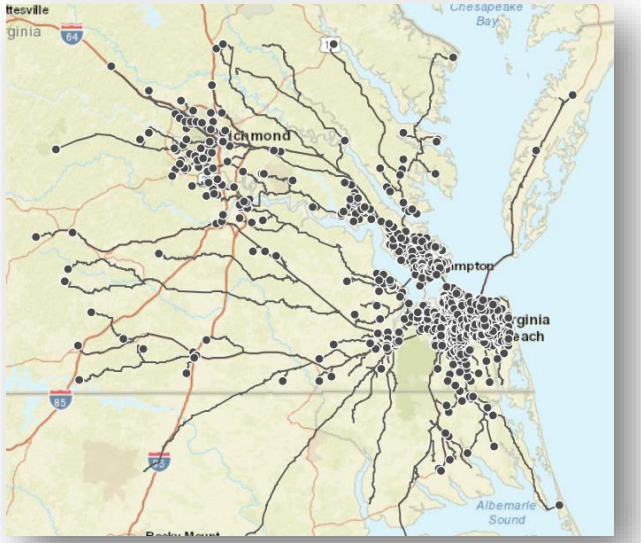
Extreme Event Impacts to Infrastructure in Norfolk, VA

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

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



Ensemble of Flood Hazards Created for Historic and Future Coastal Flooding



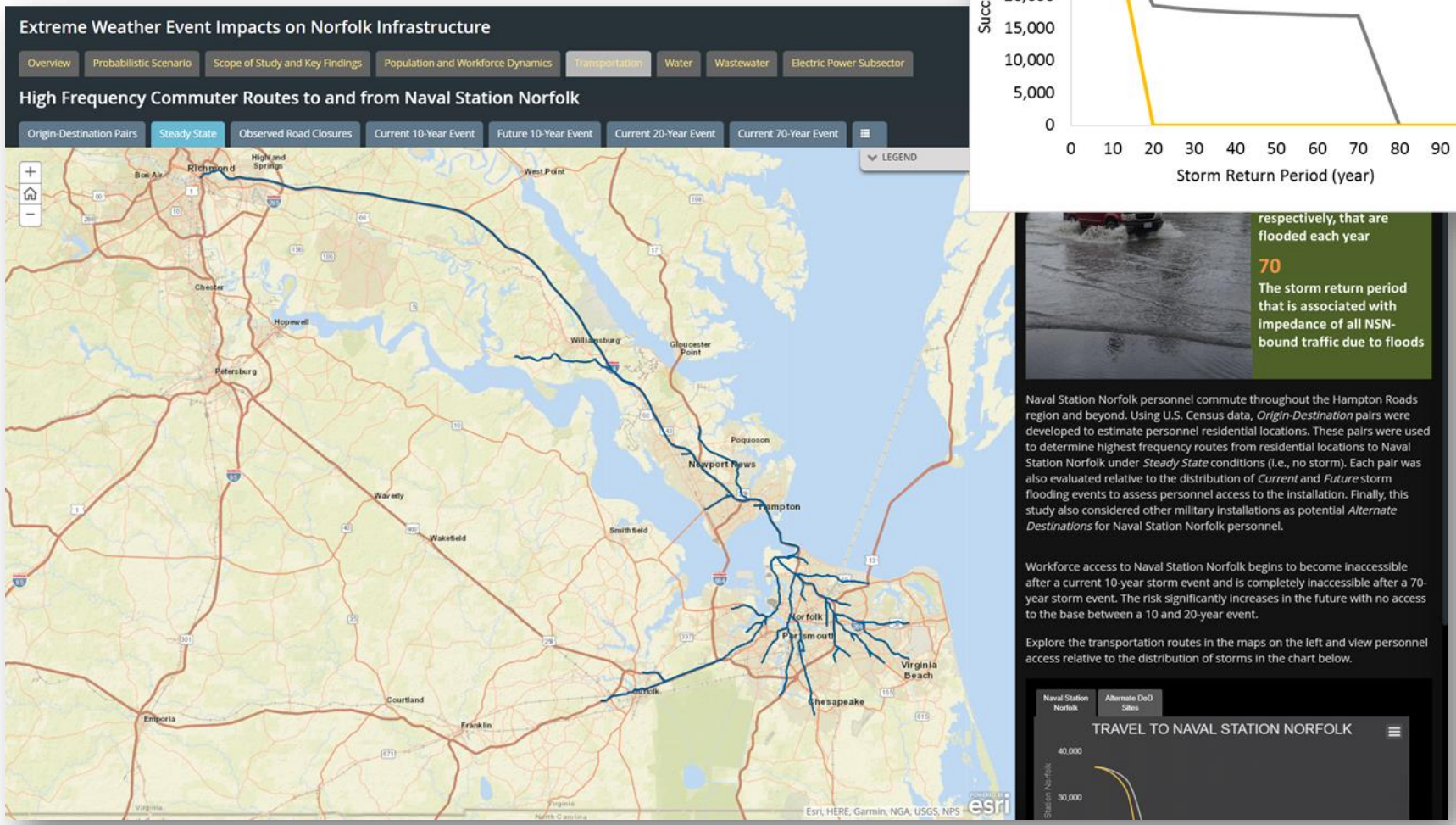
Workforce residential and workplace locations (shown) inferred from census information

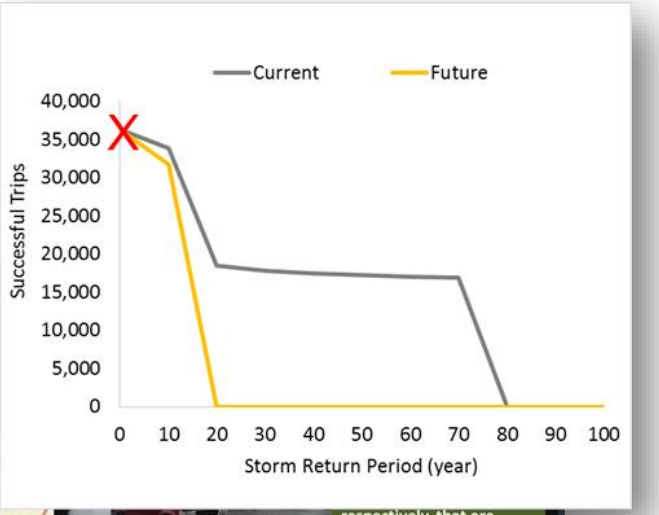
Significant Transportation Impacts in Norfolk

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

Transportation and workforce impacts 4X more likely to have disruption

Normal Day High Frequency Routes





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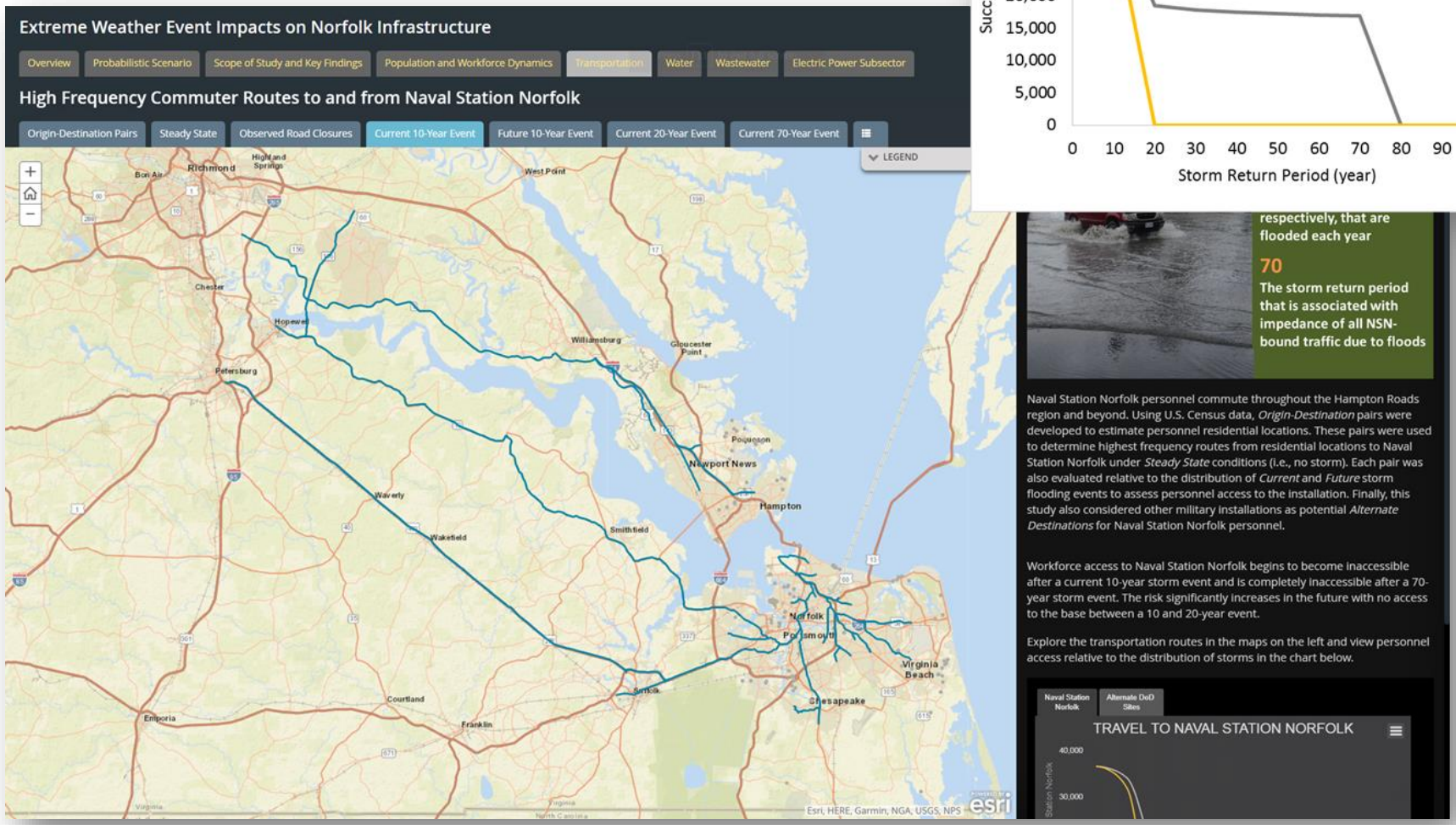
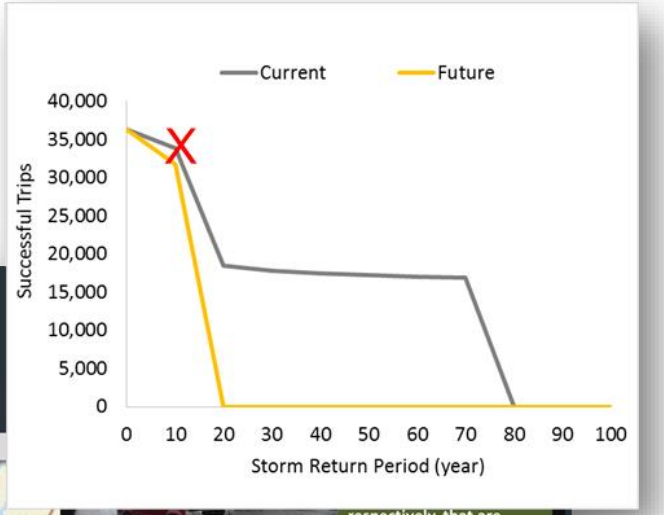
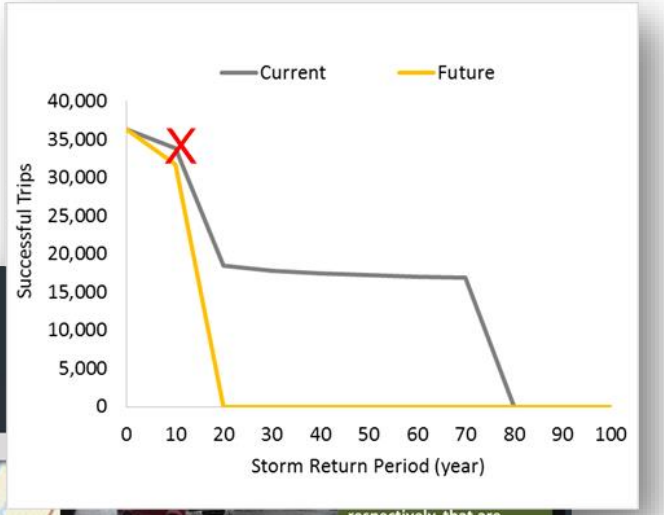
10-Year Flood Event Routes

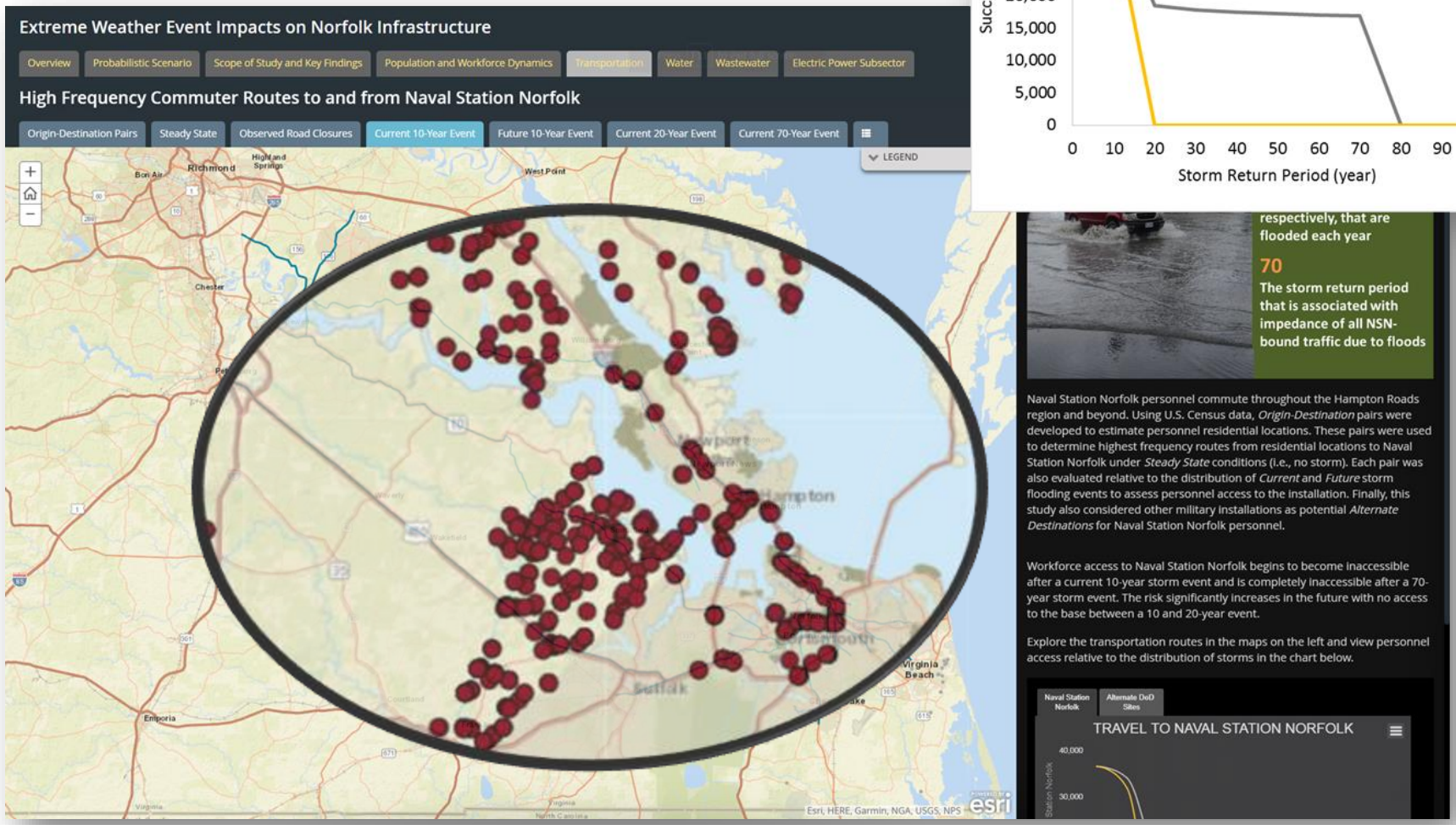




Significant Transportation Impacts in Norfolk

8-Year Record of Road Closures (VDOT)





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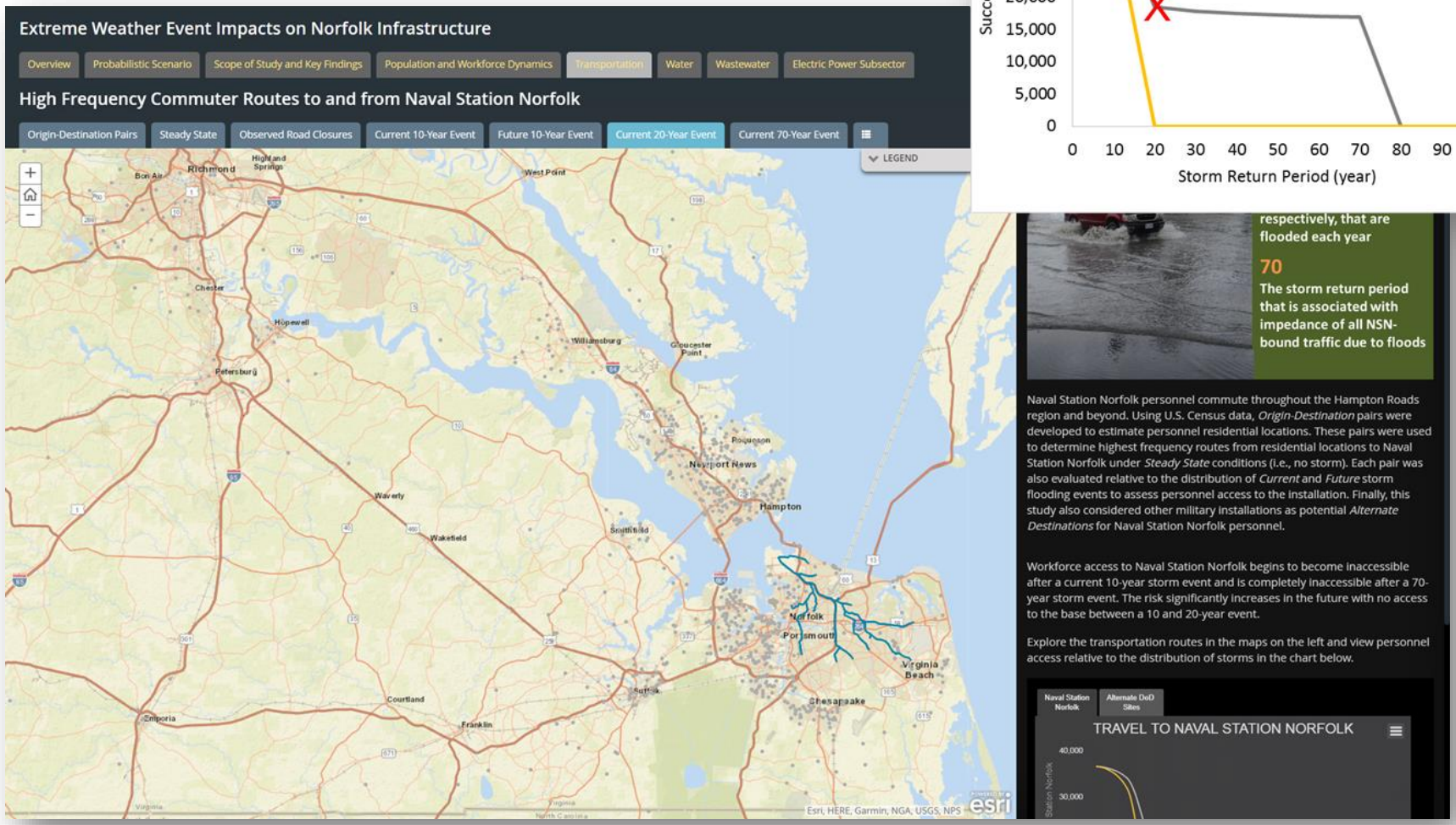
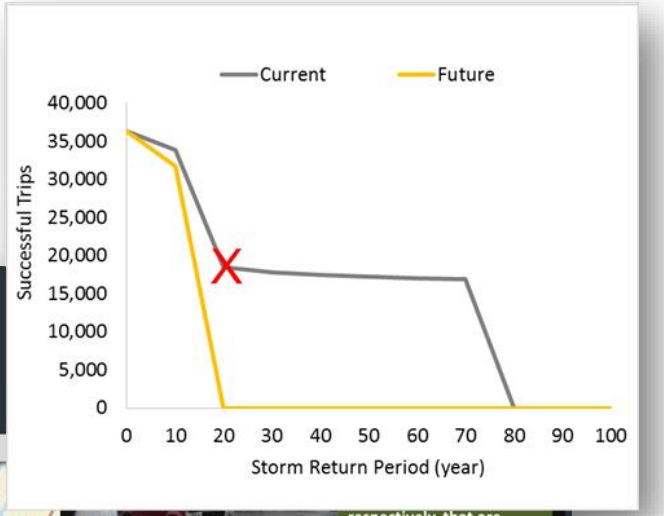


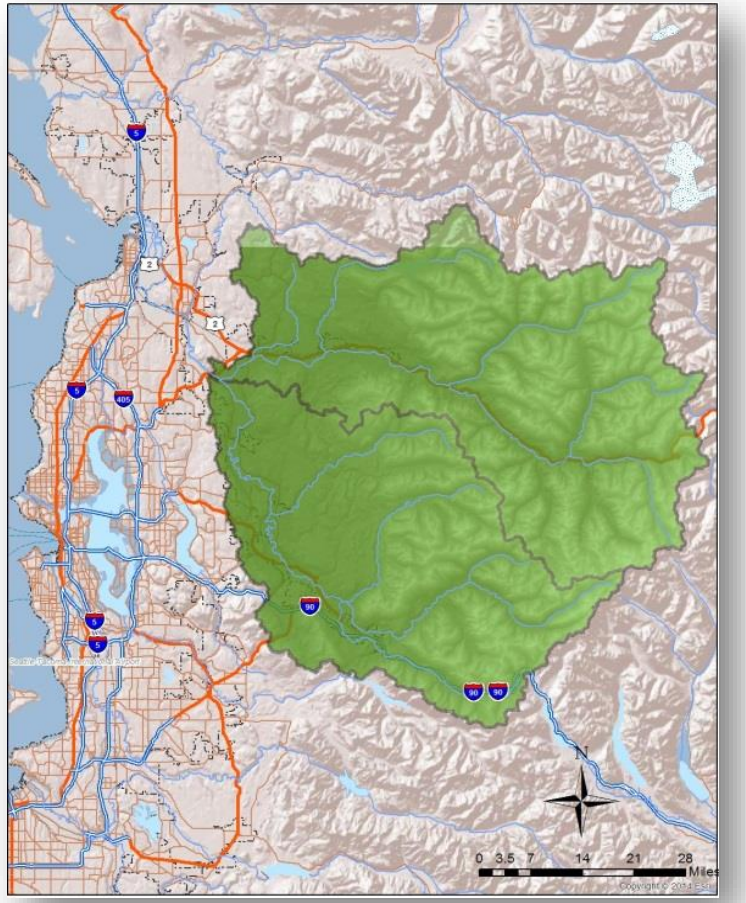


Study Area: Snohomish River Watershed

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

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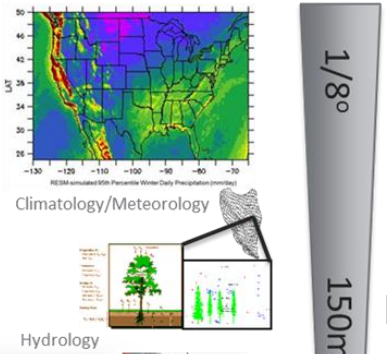
Integrated Natural System Modeling

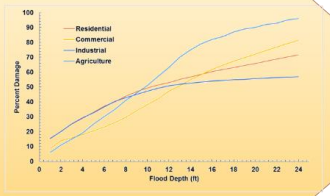


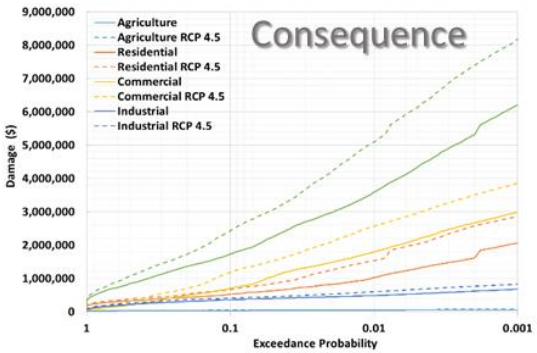
1/8° Regional Climate Model

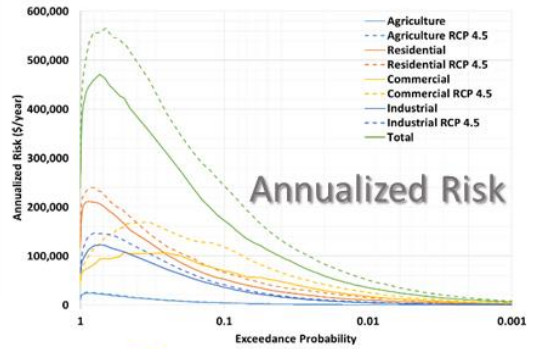
150m Distributed Hydrologic Model

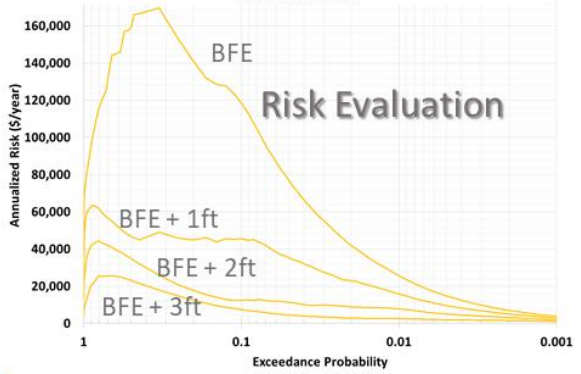
10-30m 2D Hydrodynamic Model

Human System Exposure and Vulnerability







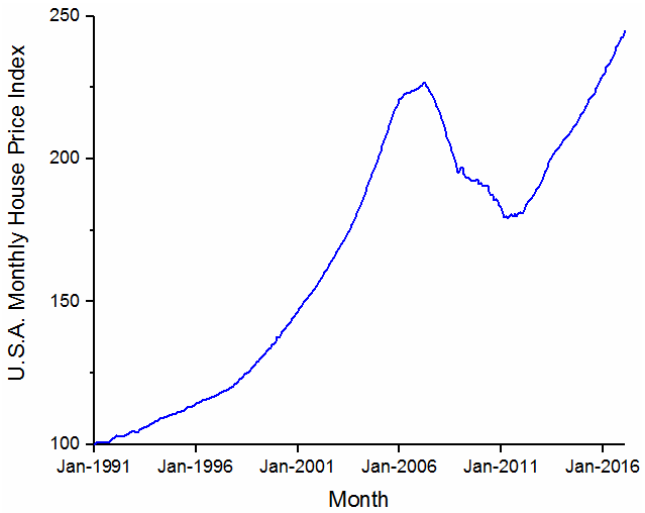


Quantifiable Risk Metrics to Evaluate Change

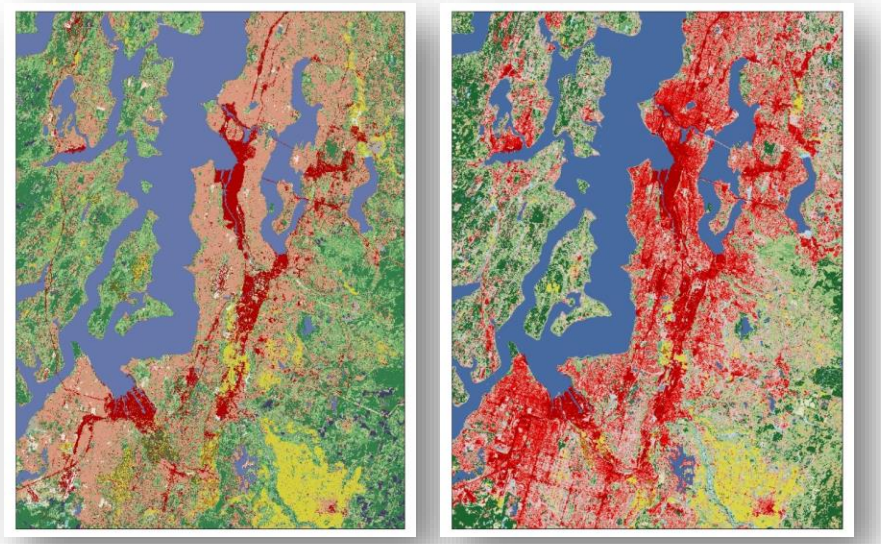
Judi, D., Rakowski, C., Waichler, S., Feng, Y., Wigmosta, M (2018). "Integrated Modeling Approach for the Development of Climate-Informed Actionable Information". *Water*, 10(6), 775, https://doi.org/10.3390/w10060775

Changing Human Systems Influence Risk

Human systems are subject to non-stationary conditions



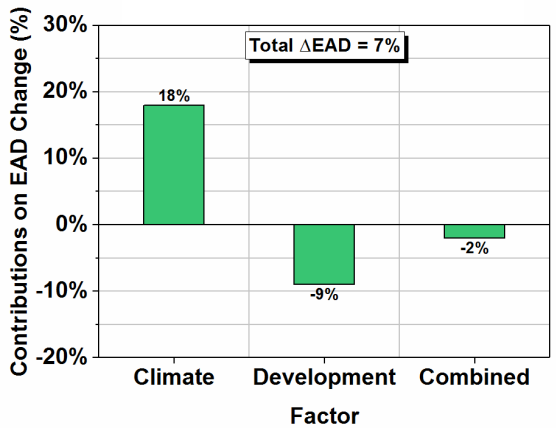
Federal Housing Price Index



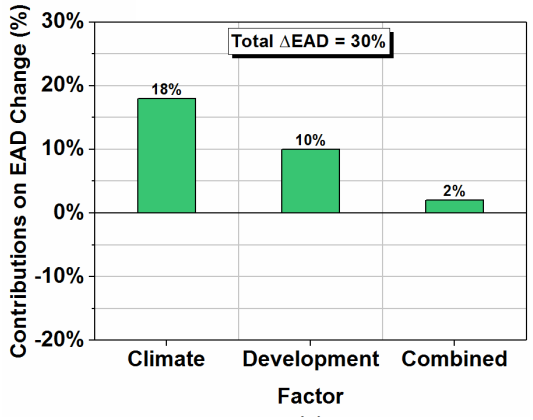
1992 Land Cover

2011 Land Cover

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



2006 vs 2001



2011 vs 2001

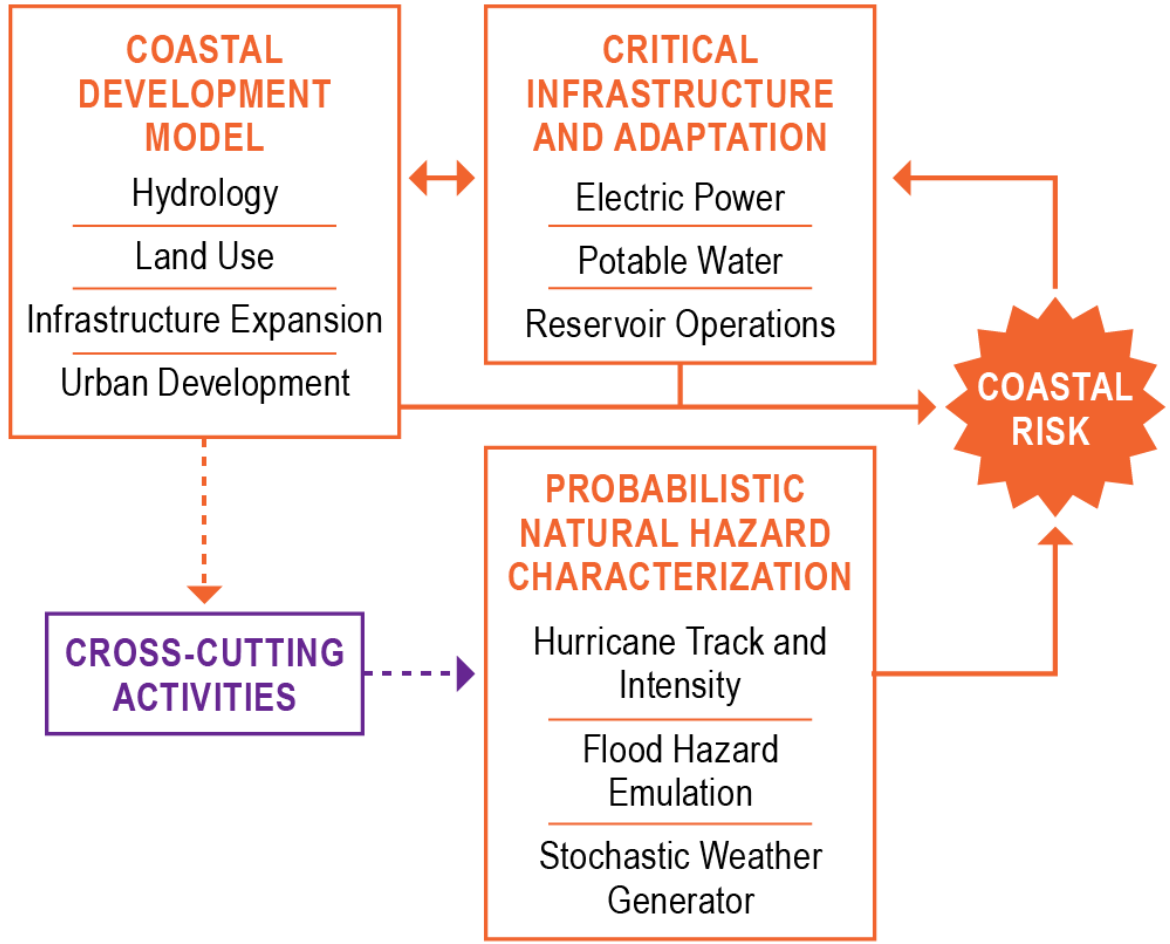
Feng, Y., Rakowski, C., McPherson, T., Judi, D. (2019). "A partition of the combined impacts of socioeconomic development and climate variation on economic risks of riverine floods". *Journal of Flood Risk Management*, 12(52), https://doi.org/10.1111/jfr3.12508.

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)
- Limited ability to capture historic and future human system changes

Integrated Coastal Modeling (ICoM)



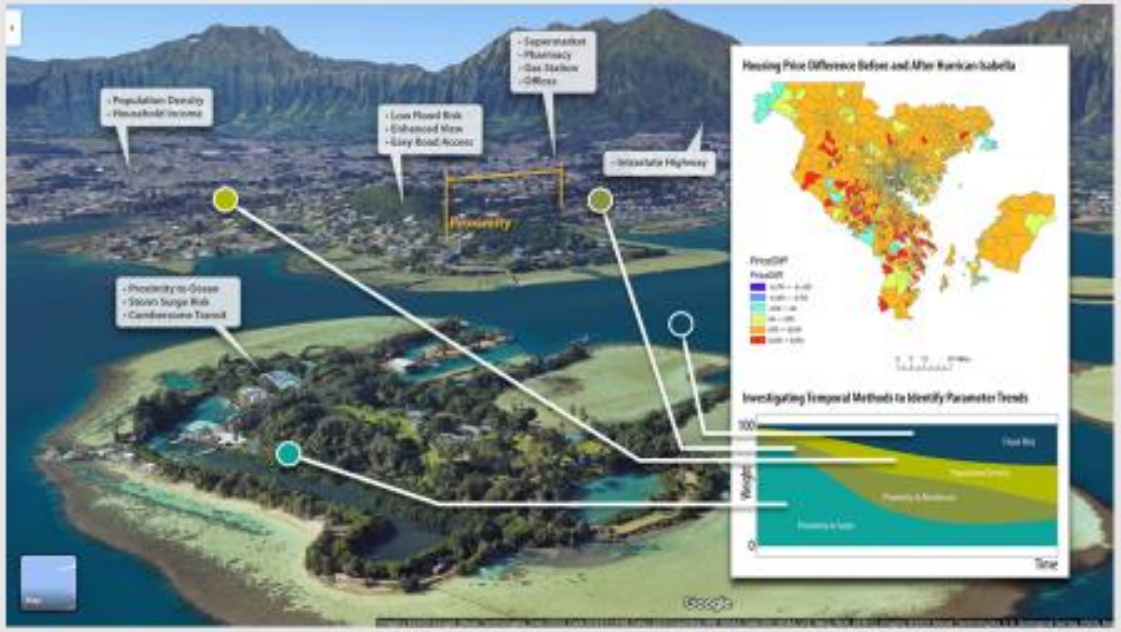
Understanding Development Patterns in Coastal Urban Environments

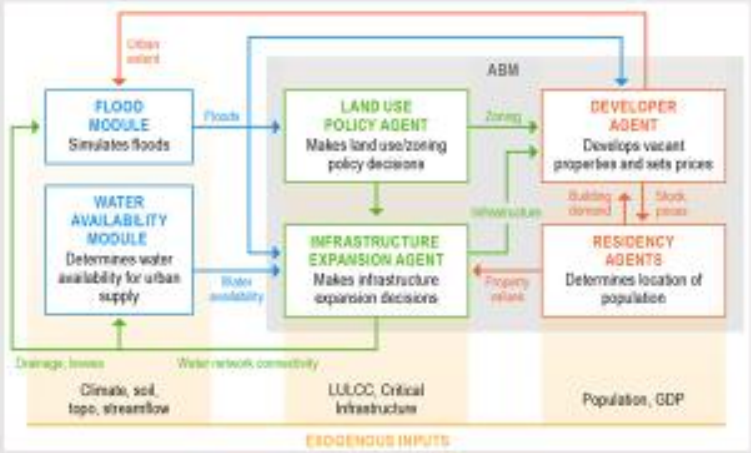
Challenge: Coastal urban landscapes are dynamic and development patterns are subject to natural and multisectoral influences

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

Methods and Approaches: 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

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Thank you