



Oregon State  
University

# Assessing Alternative Adaptation Pathways to Multi-Hazard Resilience Under Climate Change



Peter Ruggiero

Zhenqiang Wang, Meredith Leung, John Bolte, Jenna Tilt





**Oregon State**  
University

# Chronic Coastal Hazards in Oregon



Flooding projected to double every five years in the 21<sup>st</sup> C due to SLR (Taherkhani et al., 2020)

By 2060, 1.39 billion people may be living within a 100-year flood zone globally (Neumann et al., 2015)

By 2100, 17-72 million people may be forced to migrate from coastal regions (Lincke et al., 2021)

## Central Oregon Problems



**Rockaway, OR**  
King tide flooding



**Northern Oregon Coast**  
Extra-Tropical Storm Induced  
Erosion and Overtopping

# 'The Really Big One'

## CSZ is **NEW**

- Only since late 1980s have scientist agreed there's a problem on the CSZ

## CSZ is **DUE**

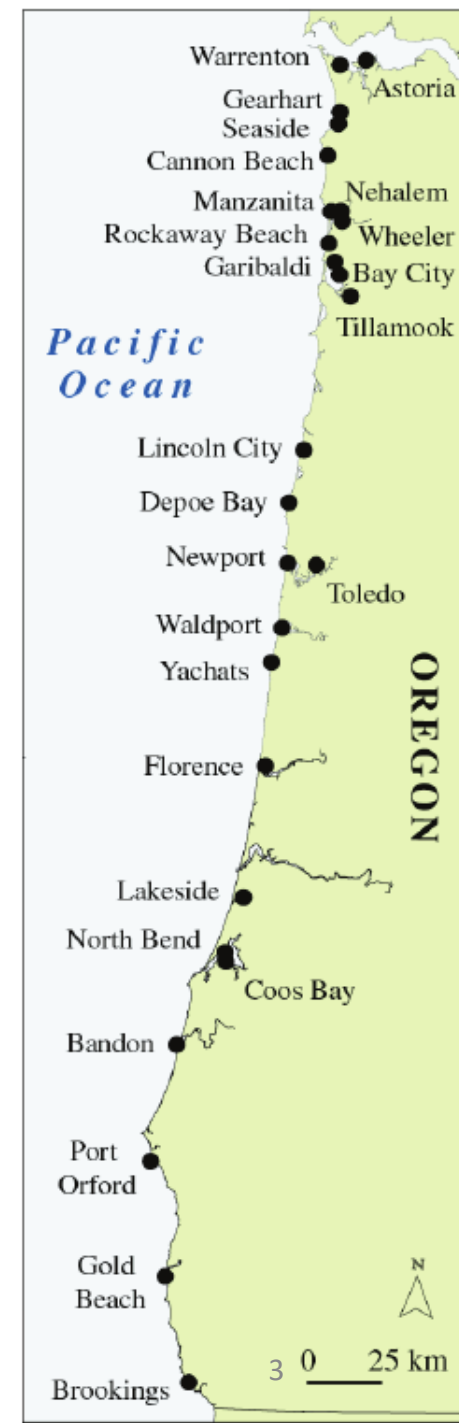
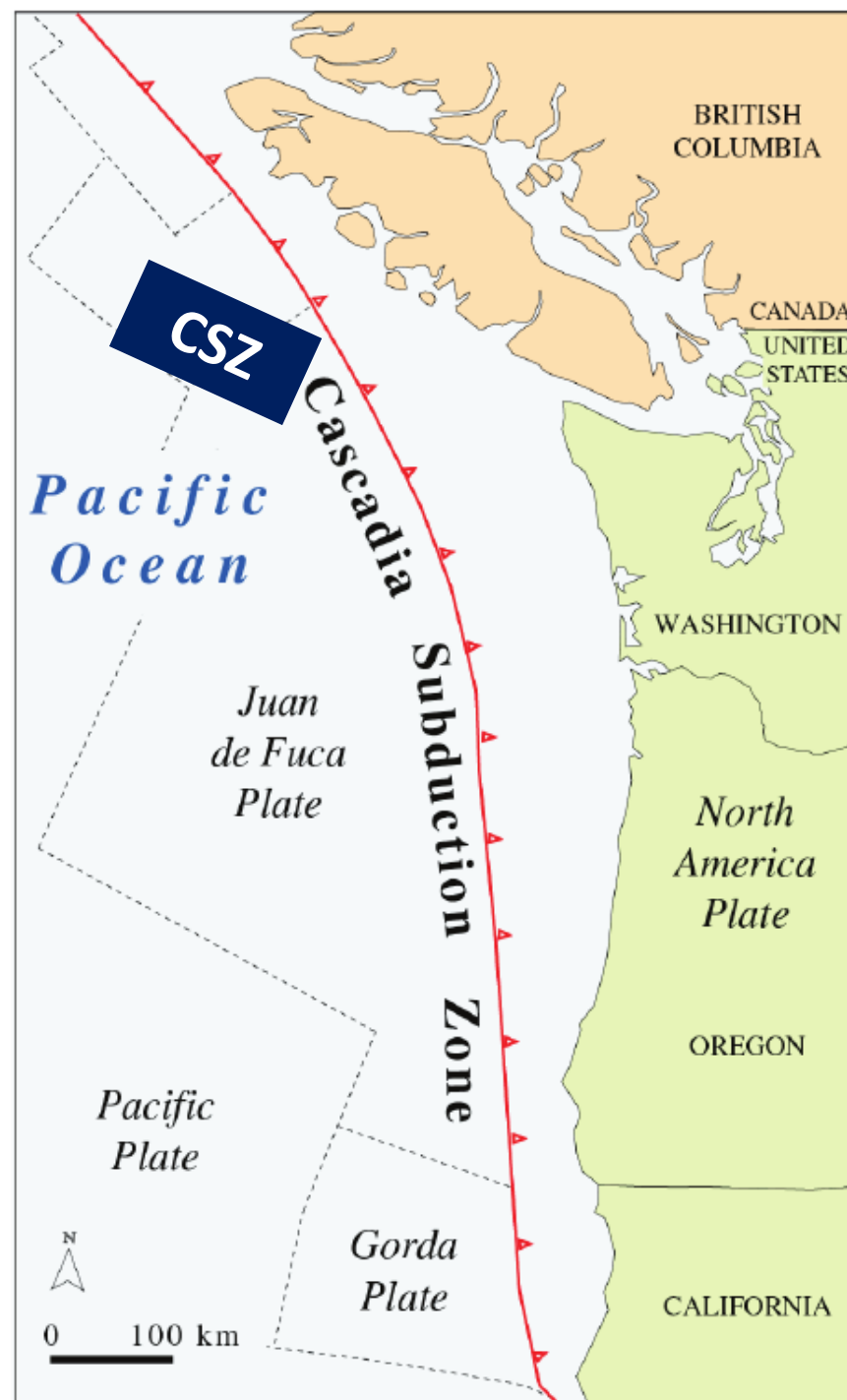
- Last CSZ event was 325 yrs ago- Jan 26, 1700
- Large ruptures happen every 300 – 500 yrs
- 15% chance of CSZ event in the next 50 years

## CSZ is **HUGE**

- North CA, OR and WA coast to BC
- Interior (Portland, Seattle) severely affected

## To be **RESILIENT** we must

- Increase life safety
- Increase our ability to absorb and recover quickly





# Objectives:

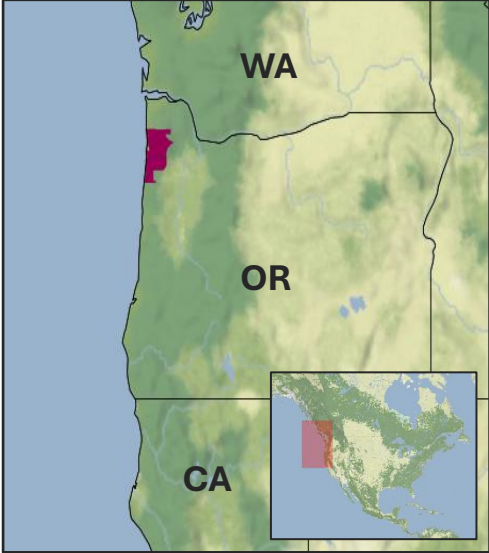
- Quantify **evolving coastal community resilience** to multiple hazards (erosion, flooding, earthquakes, tsunami) and climate change under alternative adaptation pathways. (Wang et al., in prep.)
- Assess **potential co-benefits** of policies that address chronic and acute hazards together
- Investigate the **distributional equity of future coastal hazard adaptation measures** assessing the differential exposure of sub-communities within Tillamook County, OR to chronic and acute hazards under multiple co-produced alternate future scenarios (Leung et al., in prep.).

Seaside, Oregon



Sendai, Japan March 11, 2011

# Study Site - Tillamook County, Oregon, Cascadia



## Coastal Hazards Context

- Acute (M8-9 earthquake and tsunami) hazards
  - Cascadia Subduction Zone (CSZ)
- Chronic (climate change-induced) hazards
  - flooding, erosion, loss of beach

## **Growing investment to:**

- Understand joint hazard risk
- Possible co-benefits in adaptation
- Prioritize equitable adaptation

## Hazard Exposure Context

- Acute: collaborative efforts to refine hazard uncertainty and risk (e.g., Oregon Resilience Plan, 2013)
  - **few studies on who is impacted** (Wood et al., 2010; Stanton and Tilt, 2023)
- Chronic: assessments on where hazards will intensify (e.g., Leung et al., 2024)
  - **no studies on who is impacted**

## Current Adaptation Efforts / Actions

- Acute: **Building retrofits (primarily ‘critical infrastructure’)**
- Chronic: **Riprap (armor) and dynamic revetments on select properties (prioritize retention of public beach)**

Neskowin



Rockaway Beach



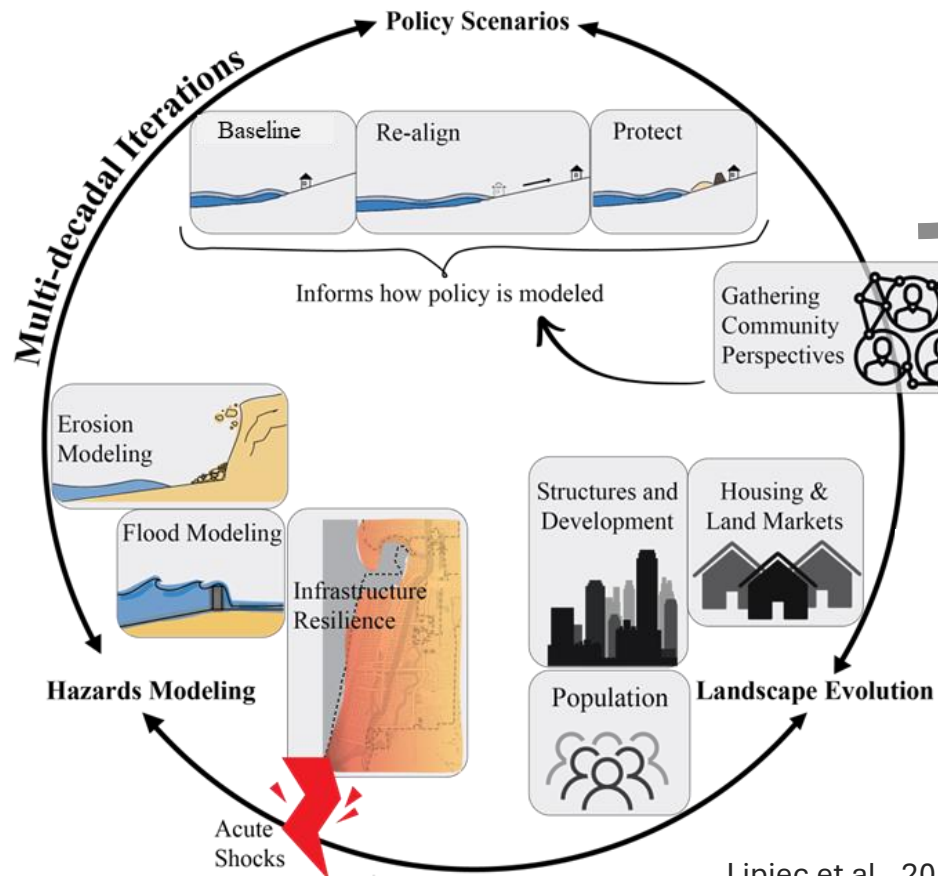
Cape Lookout  
State Park



# Convergent Research and Envision Model Framework

## ENVISION

agent-based model combining landscape change, hazard models, and policy scenarios to explore alternative futures

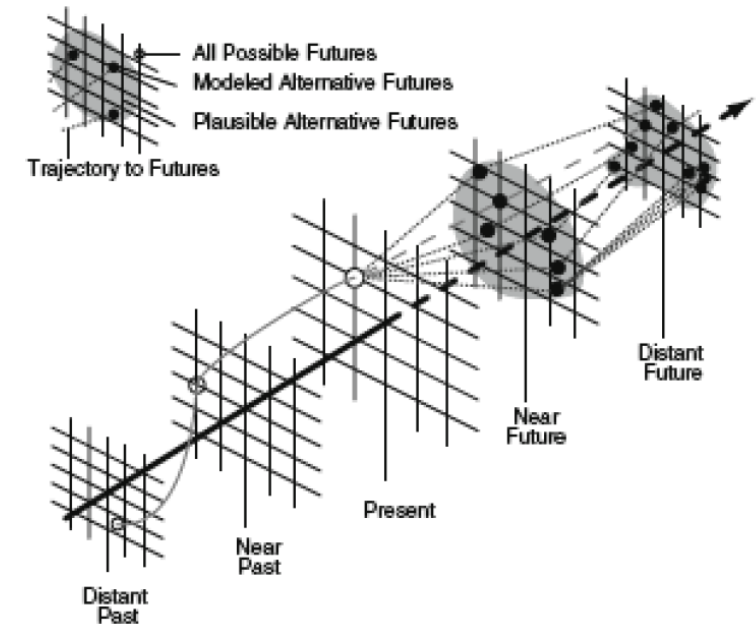


Lipiec et al., 2018; Mills et al., 2018;  
Evans-Wilent et al., 2020; Mills et al., 2021;  
Leung et al., 2024

## Trajectories of Change and Alternative Futures

Scenario analysis “aims to identify the **several most important issues responsive to policy and planning decisions**, along with the **widest range of options pertaining to these issues**... A scenario is then created to reflect choices among the possible options for each policy in the set.”

From Steinitz et al. 2003



Kolesar et al., 2024

## Exploration of Adaptation Engagement: Pathways/Scenarios

Semi-annual to quarterly meetings with an advisory council  
Supports decision making under uncertainty in three ways:

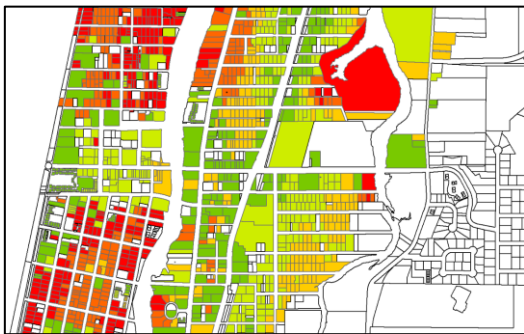
- commissioners, planners and emergency managers, city planners and city emergency managers, non-profit organizations, and academics
- overcome policy paralysis by creating manageable steps
- explicit visualization of alternative pathways
- what decisions and when decisions are needed by identifying policy objectives



# Framework for Assessing Resilience Strategies

## Hazard Exposure Modeling

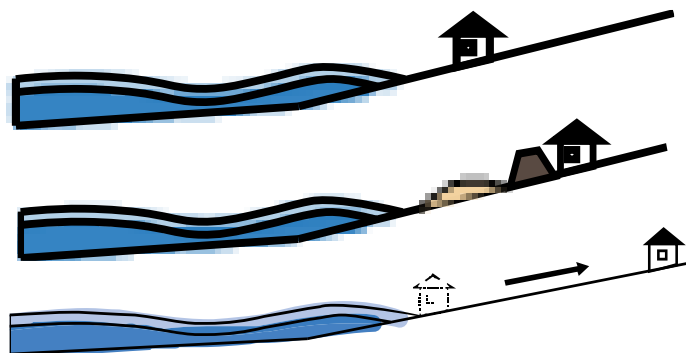
- CSZ: Earthquake + Tsunami
  - What scenario? (e.g., M9)
  - Timeframe? (e.g., 2040, 2060, ...)
- Coastal erosion and flooding
- Sea-level rise



Probability damage of ~1,000-year event

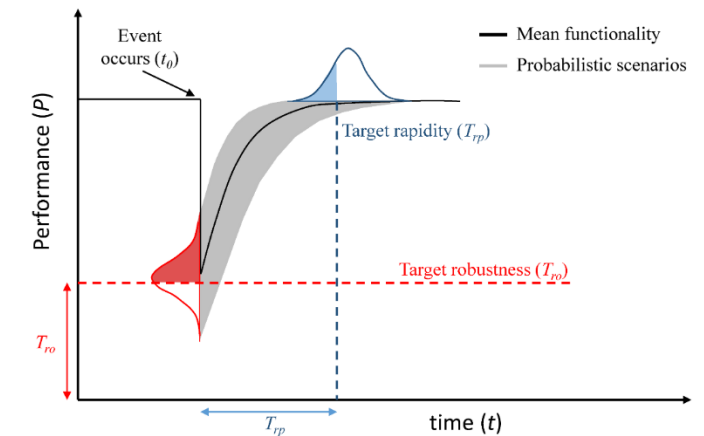
## Adaptation Scenarios (Pathways)

- Baseline
- Protect (e.g., retrofit)
- Realign (e.g., moving, zoning)
- Restore (e.g., accommodate)
- ...



## Resilience Metrics

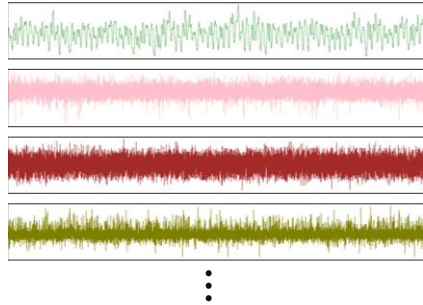
- Direct losses (life safety, capital)
- Indirect losses (recovery)
- Social equity (unequal loss)
- ...



# Chronic hazard (coastal flooding + erosion) modeling approach

Stochastic  
Climate  
Emulator  
MUSCLE

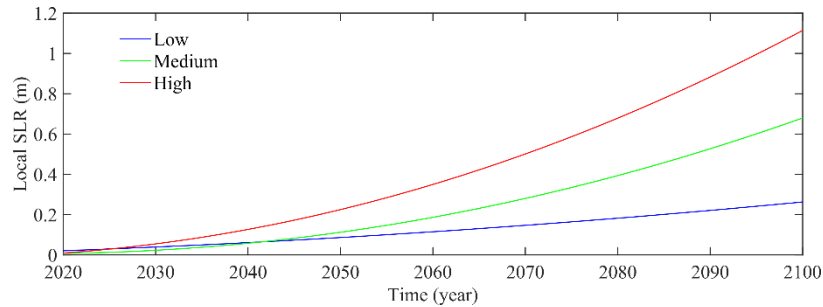
(Anderson et al. , 2019)



Time series of flood forcing  
(e.g., tides, waves)

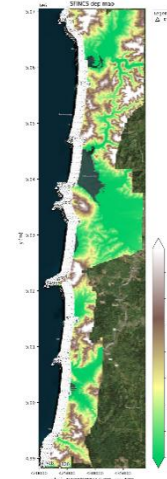


Time series of annual  
max total water levels  
(TWLs)



$$\text{Coastal erosion} = (\text{CCR}_{\text{SB}} + \text{CCR}_{\text{Climate}}) * T + \text{CC}_{\text{Event}}$$

(Baron et al. , 2015, Light 2021, Taherkhani et al., in review)



Hydrodynamic  
model  
(SFINCS)



Flood maps

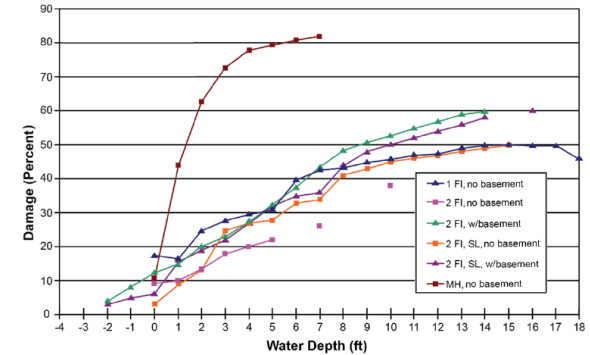
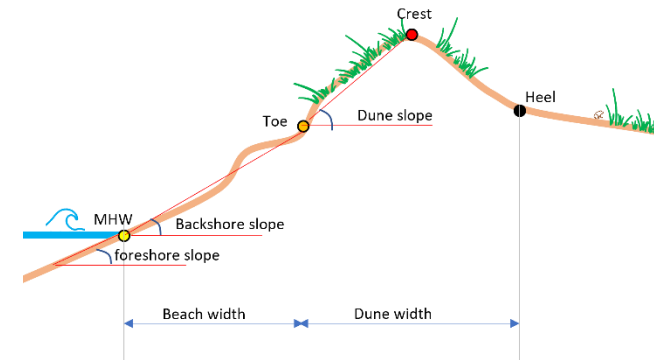


Figure 5-1. FIA Credibility-Weighted Building Damage Functions as of 12/31/1998

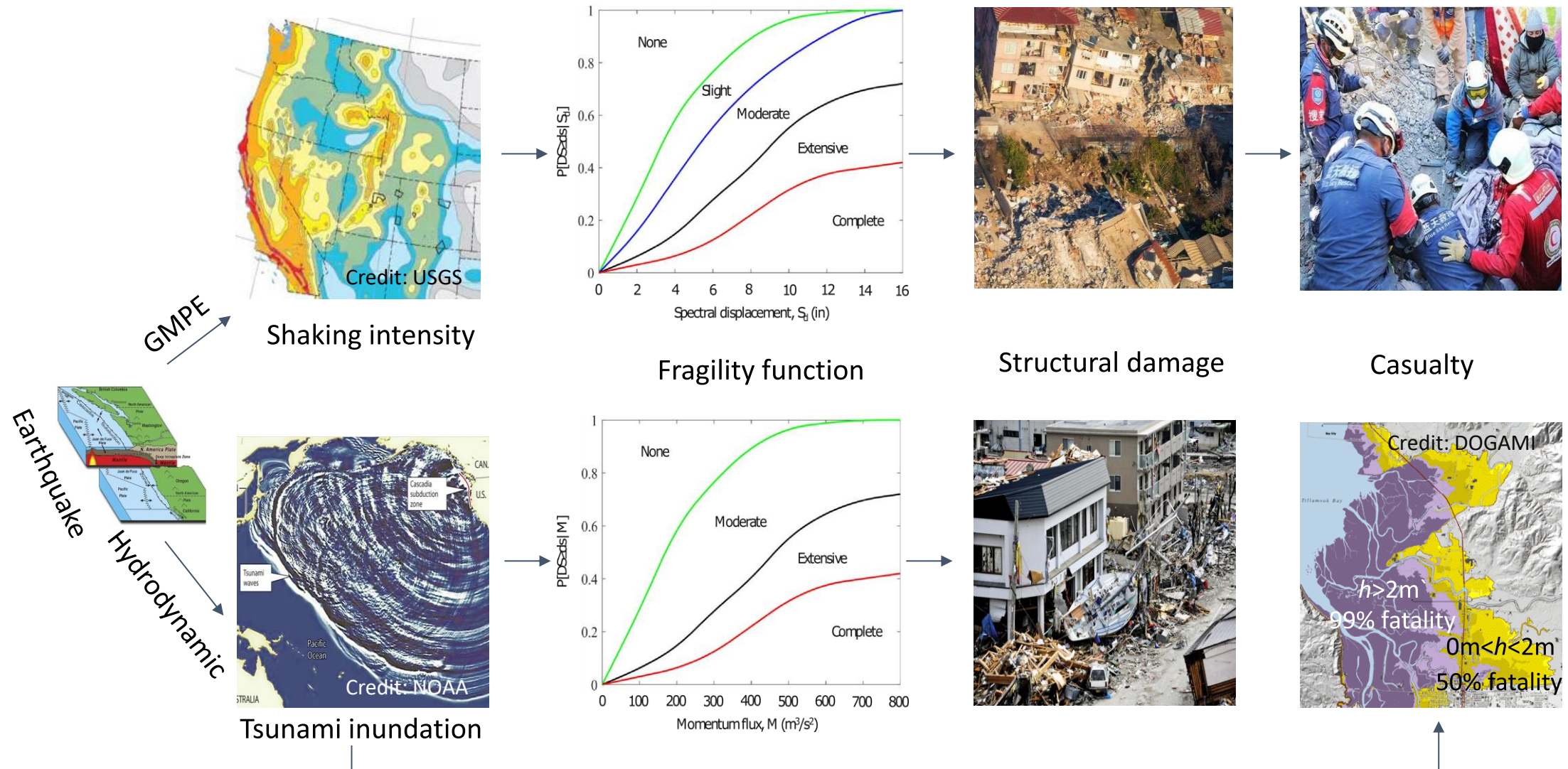
FIMA (FIA) Residential Damage Function - Coastal

Fragility functions for  
→ Flood damage





# Acute hazard modeling (earthquake + tsunami) approach



# Adaptation modeling approach

## Baseline



Continuing present-day policies (e.g., maintain backshore protection structure (BPS) for chronic hazards, repair damaged buildings after acute hazards)



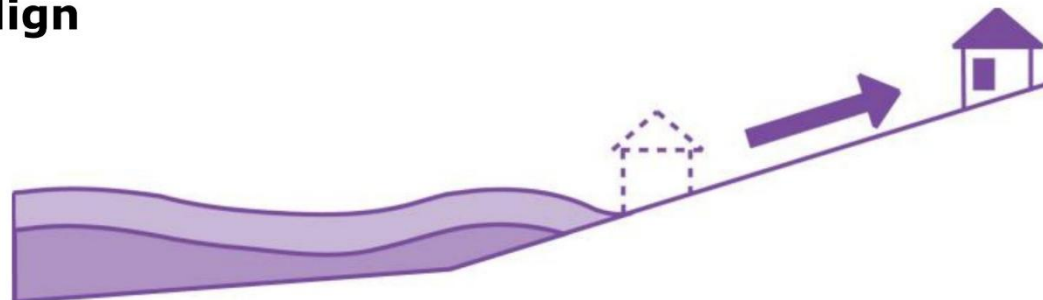
## Protect



Resisting changing environment to protect landscape (e.g., construct new BPS, retrofit buildings, etc.)



## Realign

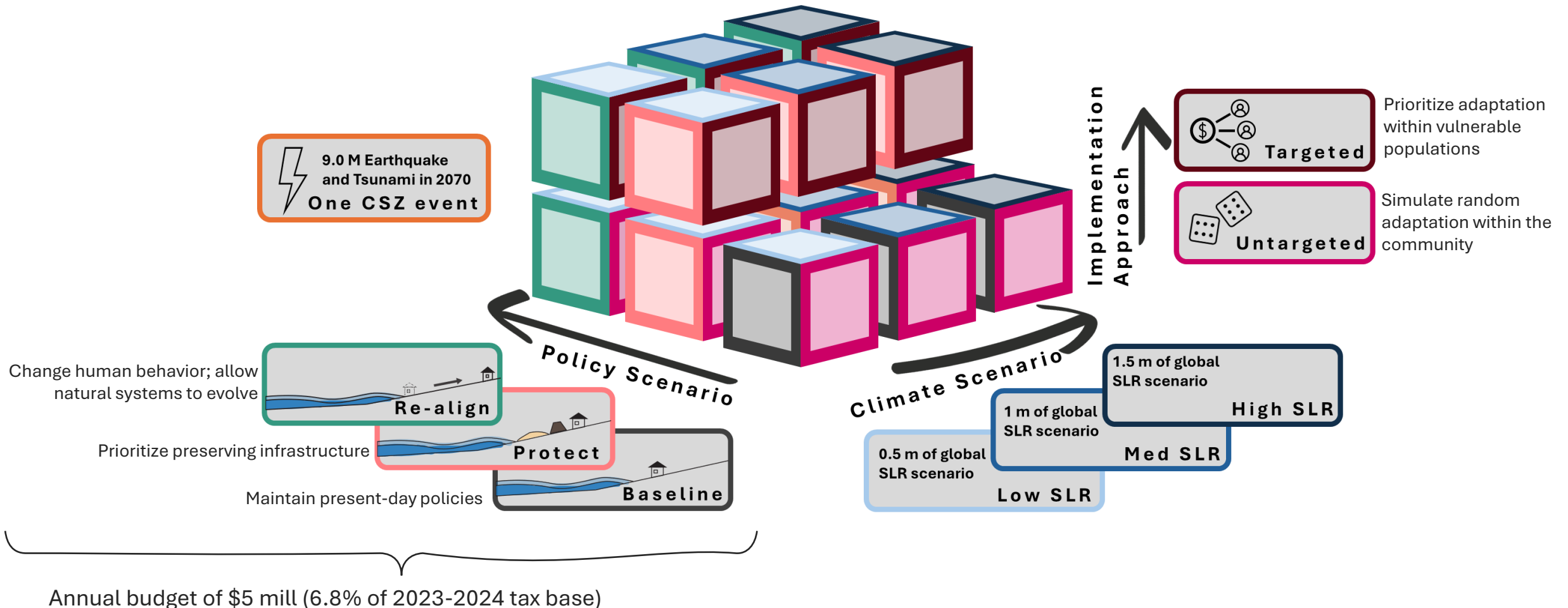


Changing human activities to align with environmental change (e.g., relocate buildings and people from hazard zones – managed retreat)



# Envision Scenarios and Implementation Approaches

Simulate end-members of potential adaptation pathways

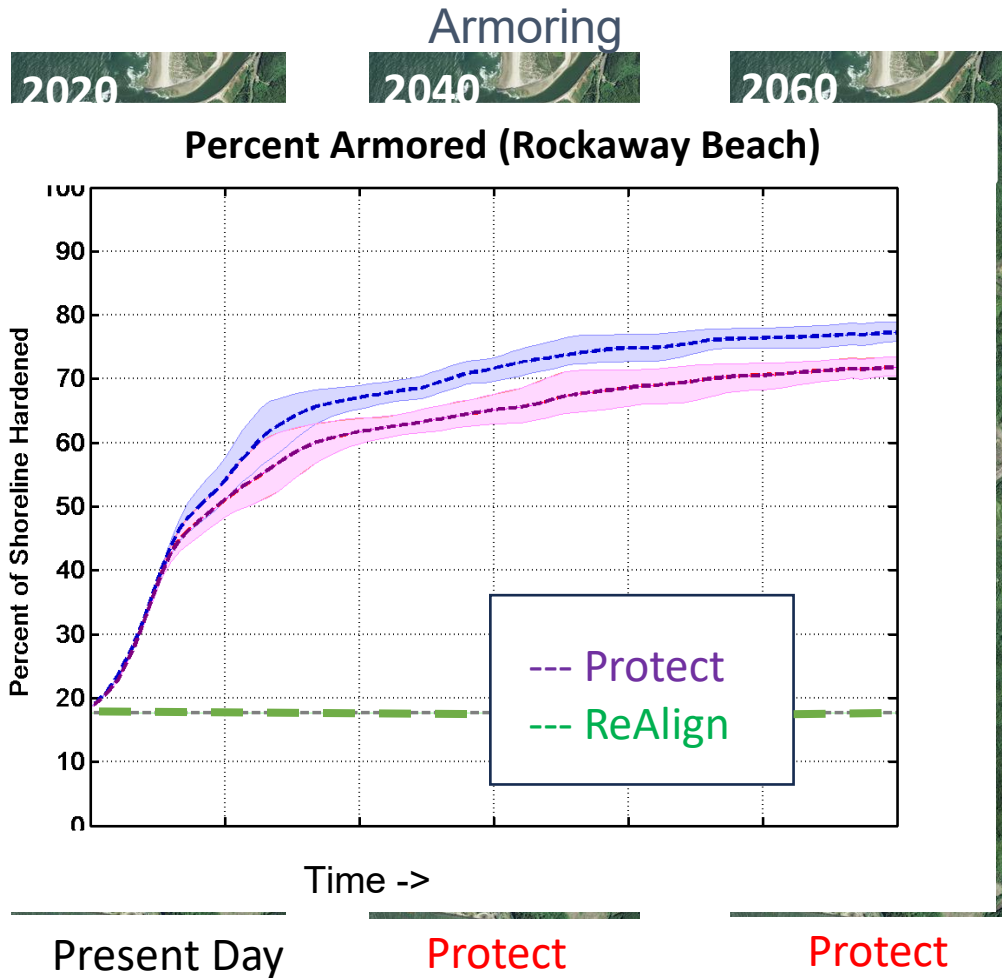




# Policy driven tradeoffs in resilience metrics: Protection vs Recreation

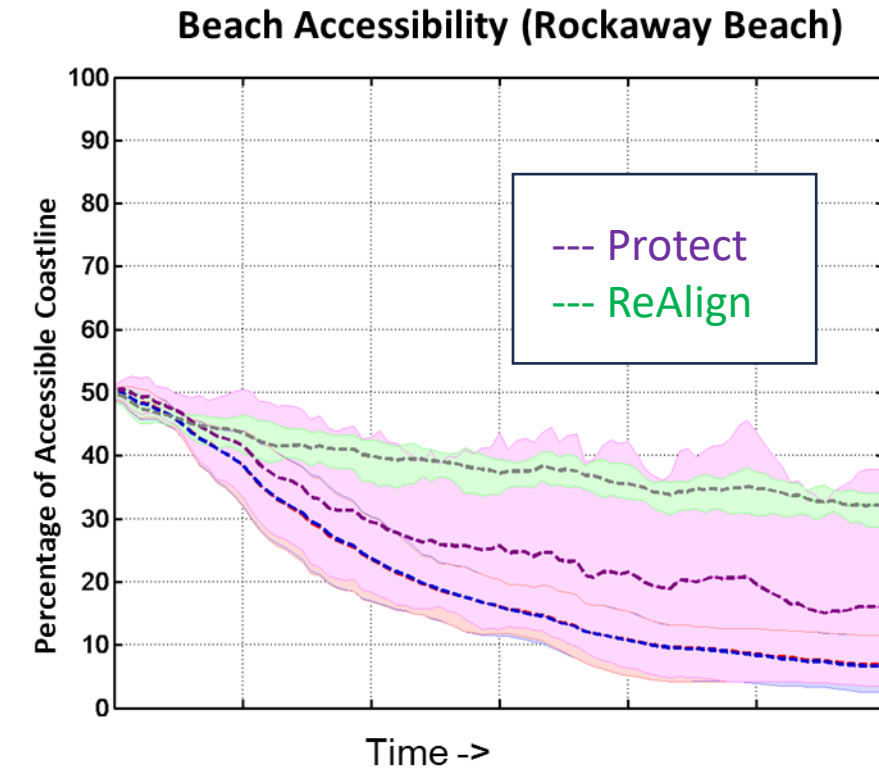


Oregon State  
University

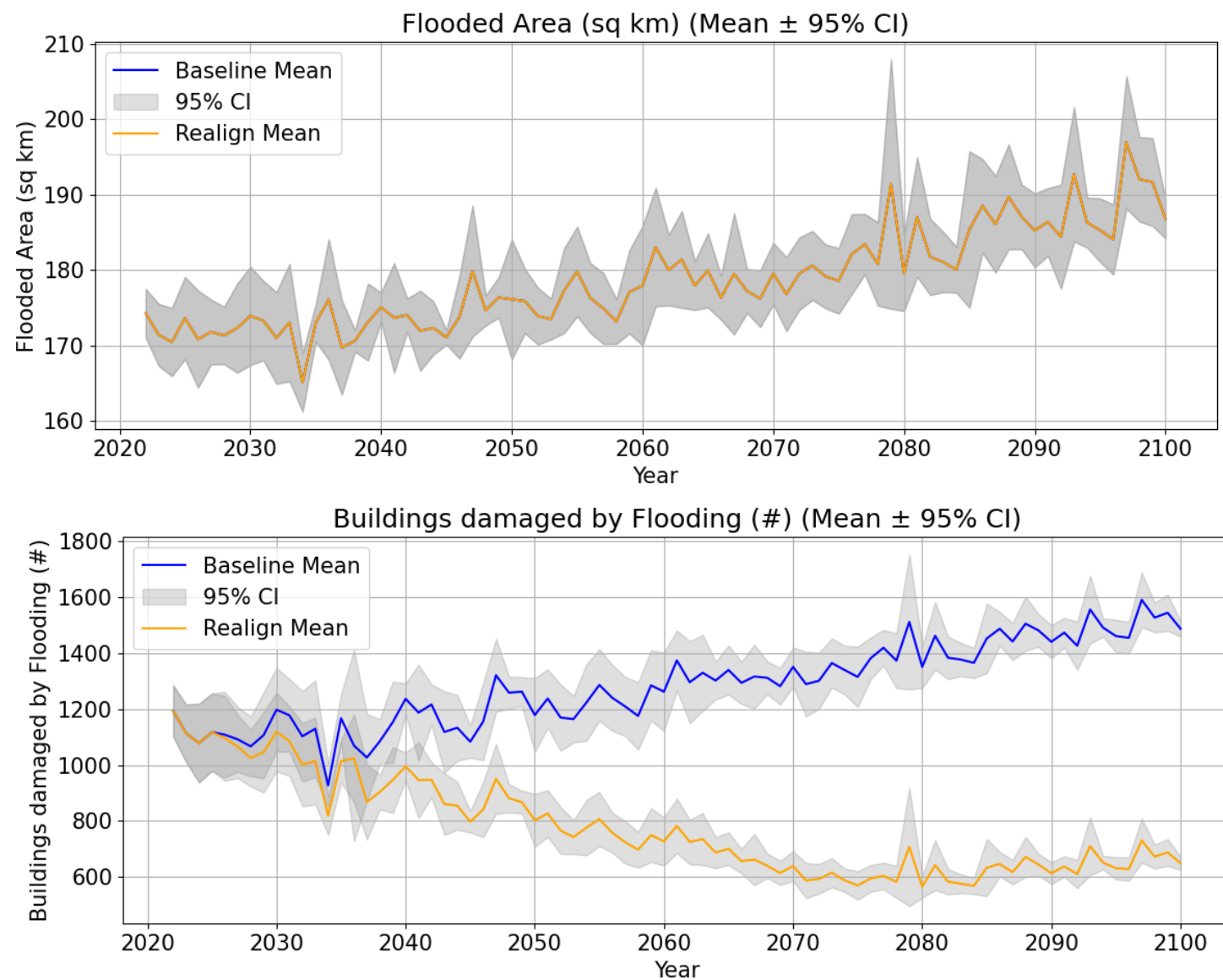


■ Limited  
Beach  
Access

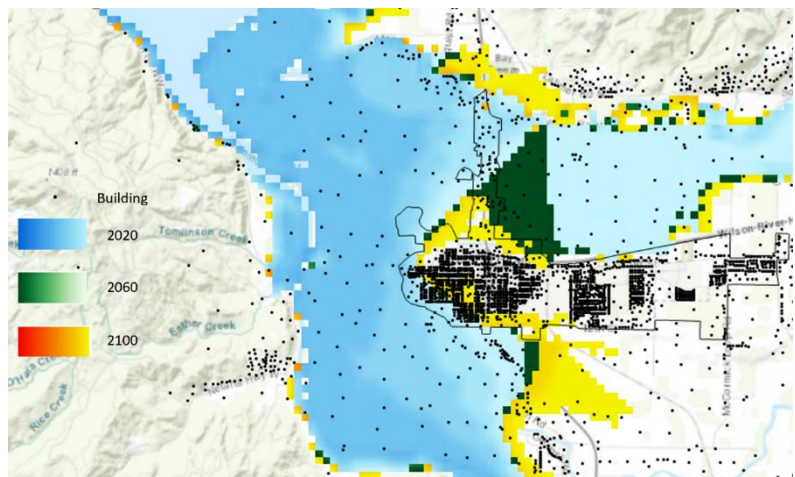
■ Unlimited  
Beach  
Access



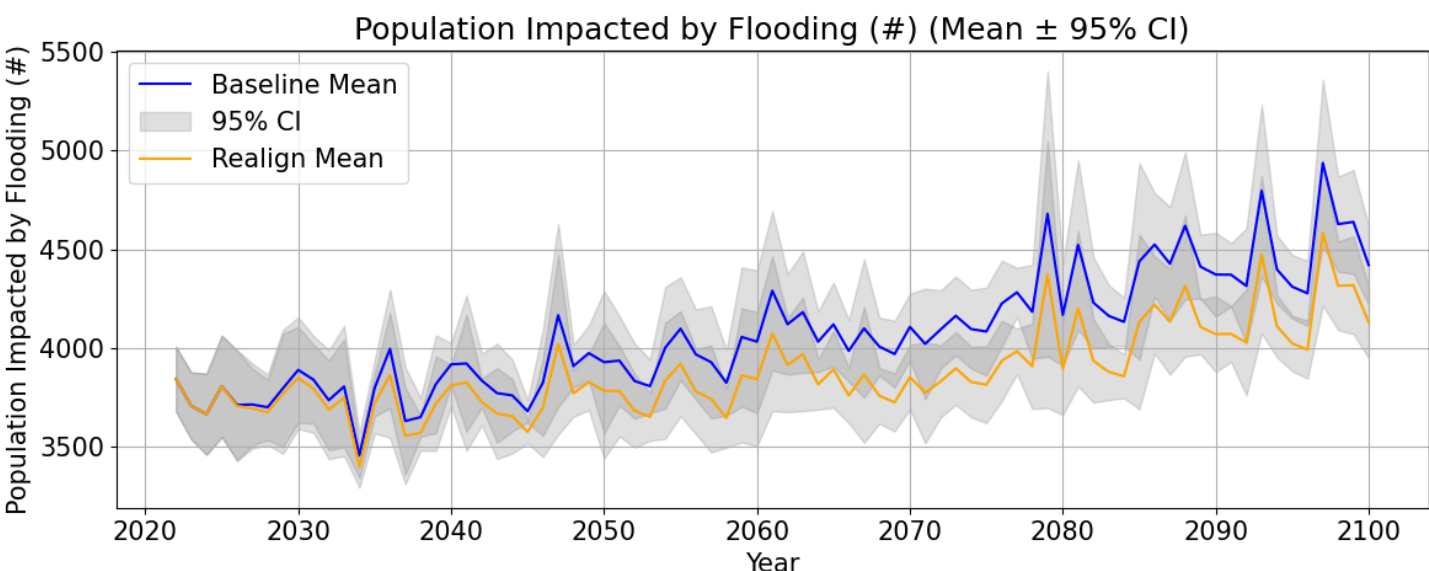
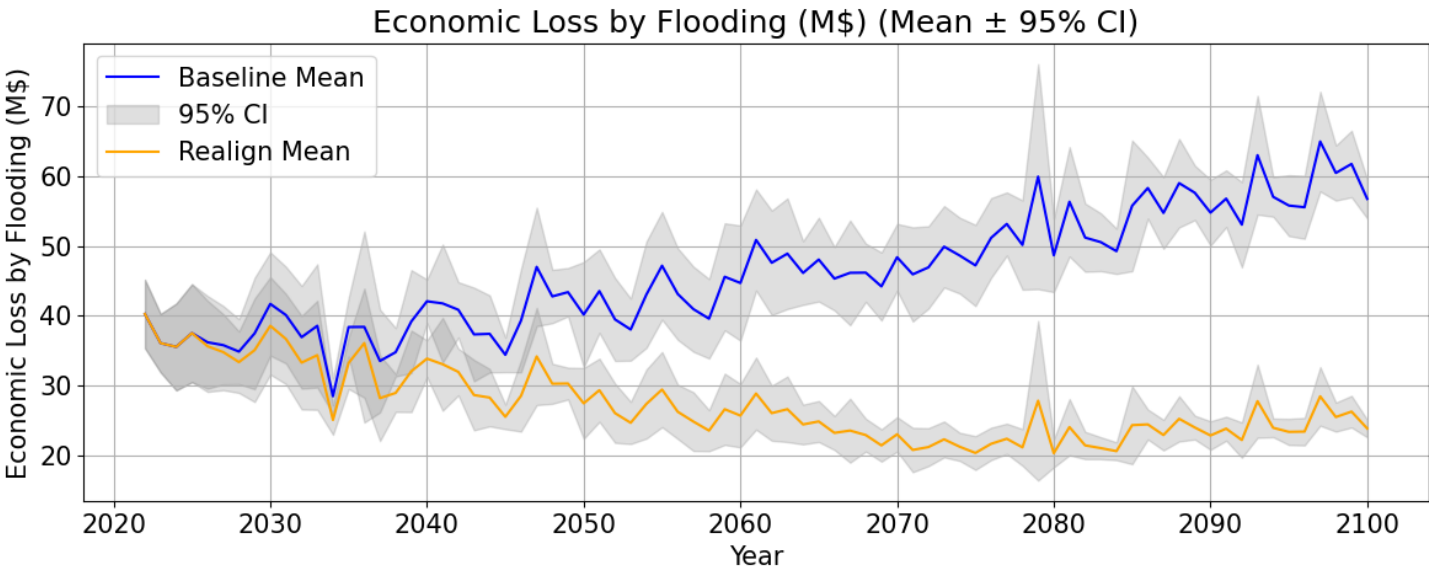
# Increase in Resilience via Adaptation



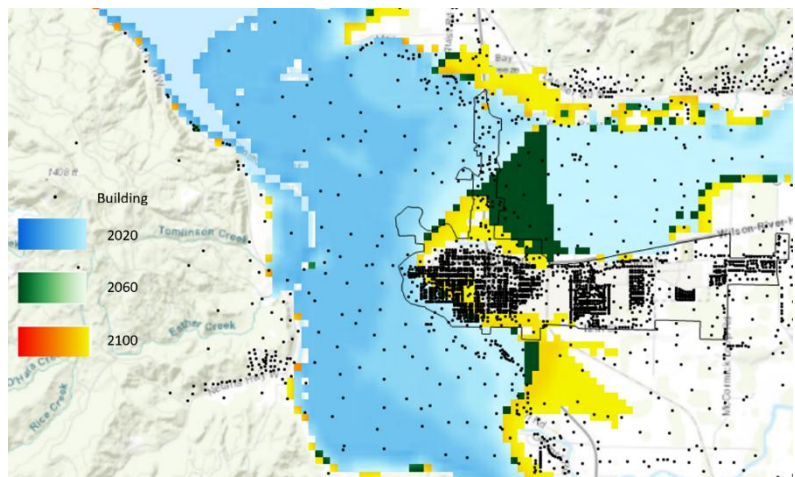
Realign out of FEMA flood hazard zone



# Increase in Resilience via Adaptation

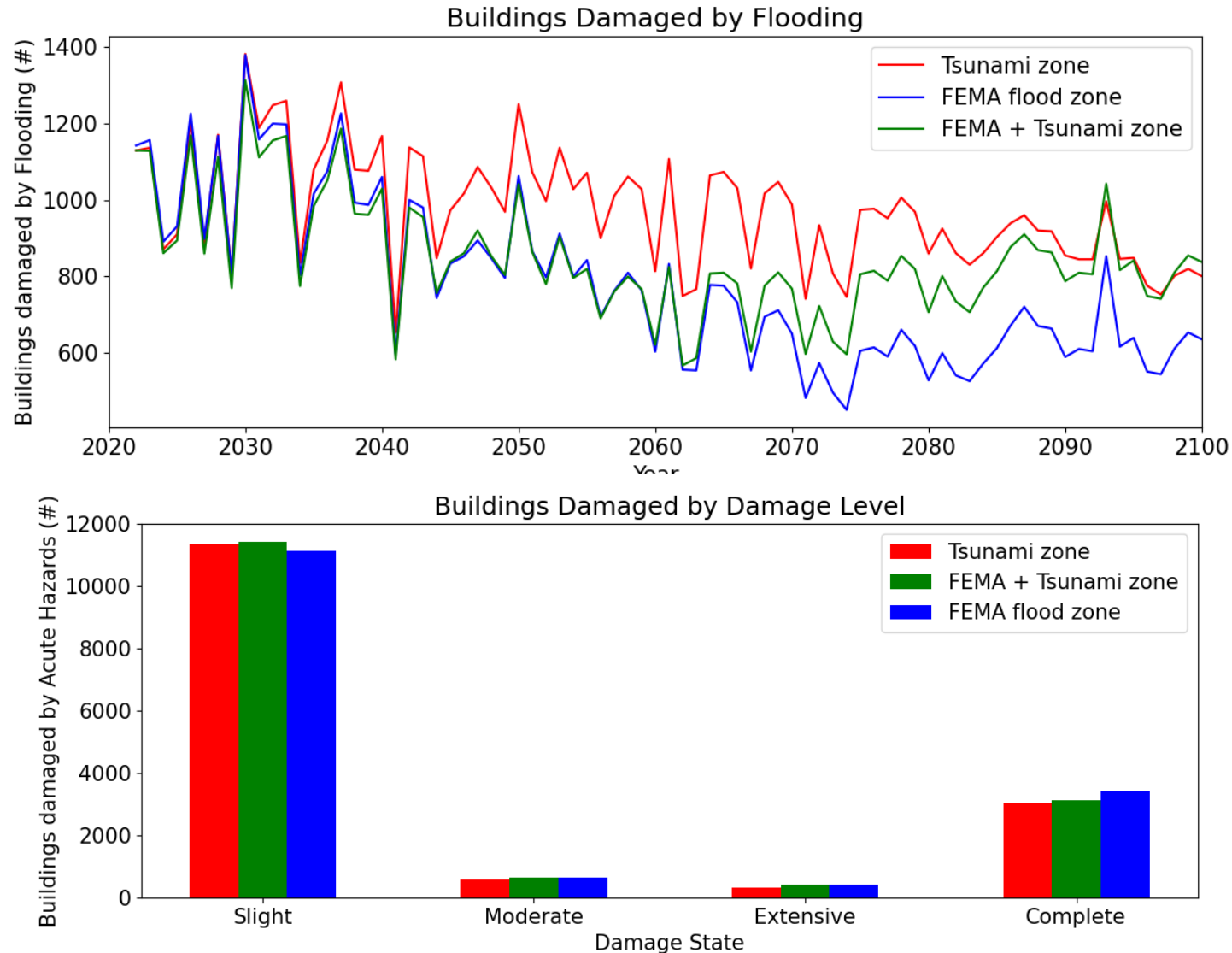


Realign out of FEMA flood hazard zone

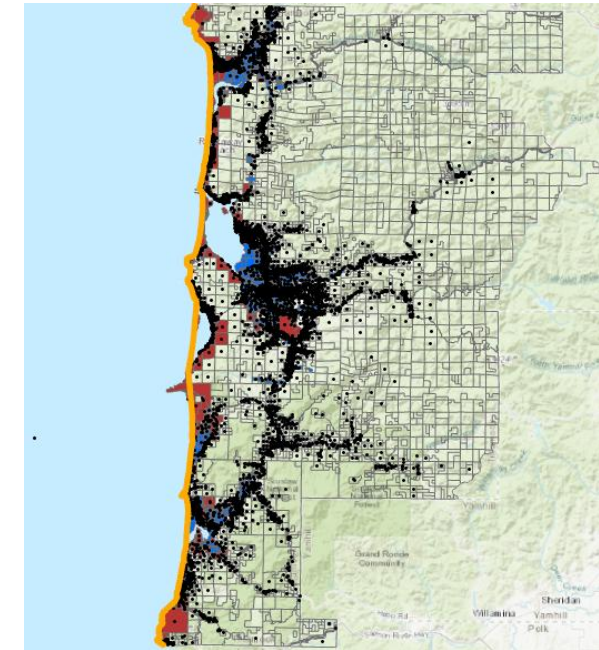






# Co-benefits of Adaptation to Multiple Hazards



Realign out of FEMA flood hazard zone or tsunami hazard zone or both

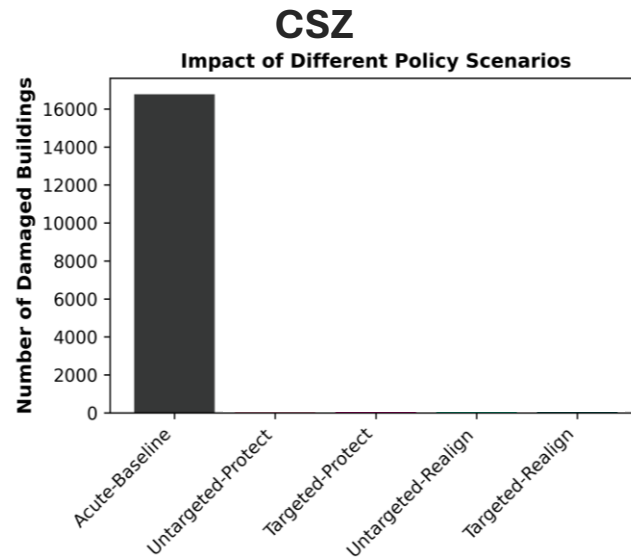


-  FEMA high-risk flood zone
-  M9 tsunami inundation zone

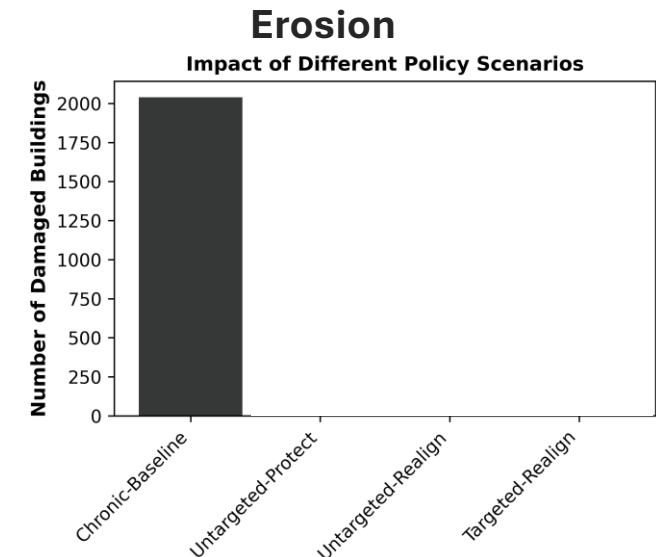
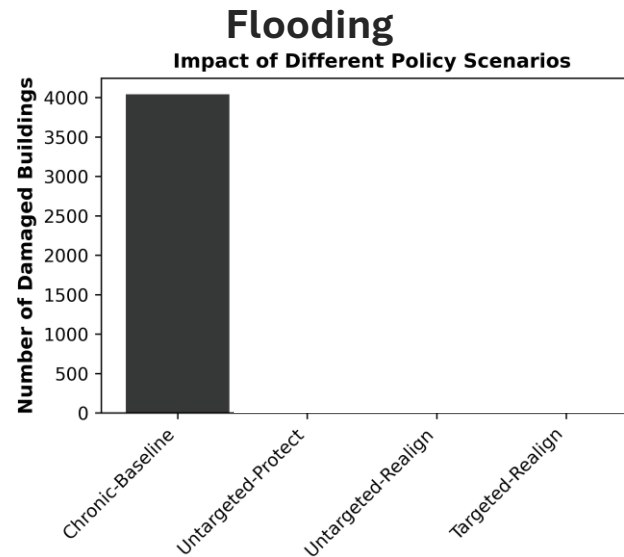
# Who is Impacted by Alternative Policy Scenarios?

How can alternative policy scenarios and implementation approaches affect differential exposure of vulnerable populations?

## Acute (CSZ Earthquake and Tsunami) Hazards



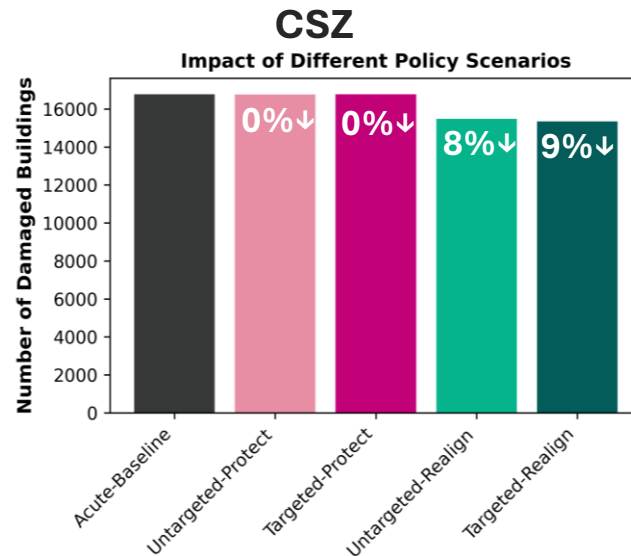
## Chronic (Climate Change-induced) Hazards



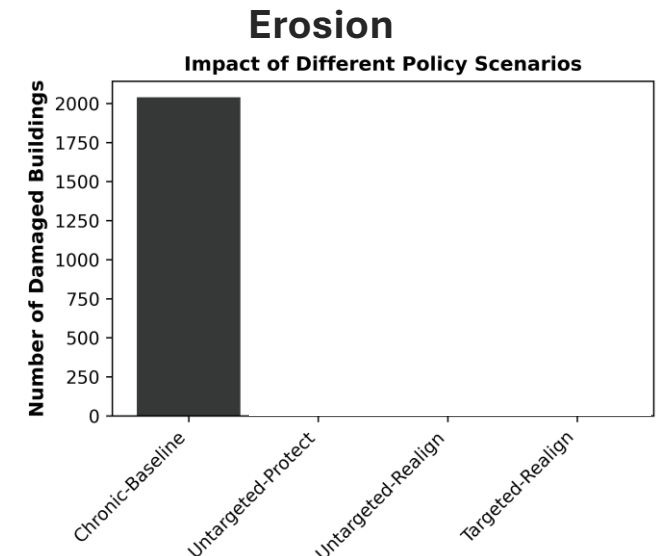
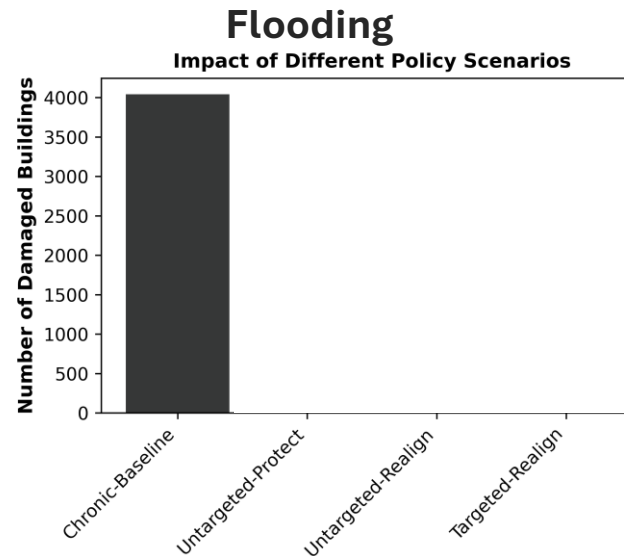
# Who is Impacted by Alternative Policy Scenarios?

How can alternative policy scenarios and implementation approaches affect differential exposure of vulnerable populations?

## Acute (CSZ Earthquake and Tsunami) Hazards



## Chronic (Climate Change-induced) Hazards



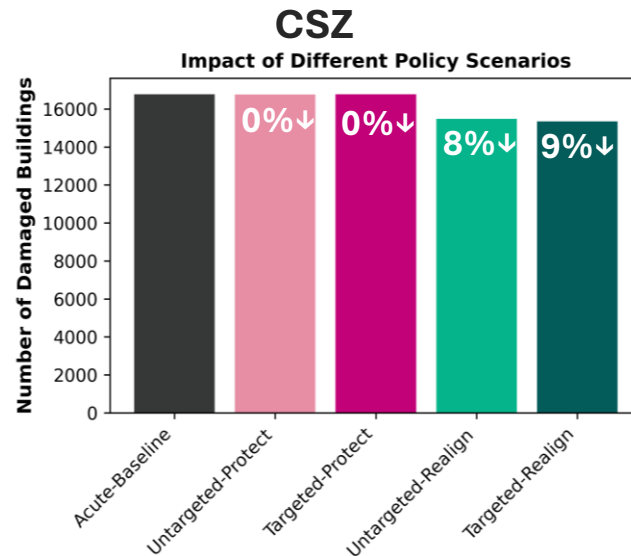
- Protect scenarios (retrofit buildings to meet current seismic standards) do not dramatically decrease the number of buildings damaged (**may reduce damage state**)
- Realign scenarios (remove buildings from inundation zone) **prevent CSZ damage to ~1,300 - 1,400 buildings by 2070**



# Who is Impacted by Alternative Policy Scenarios?

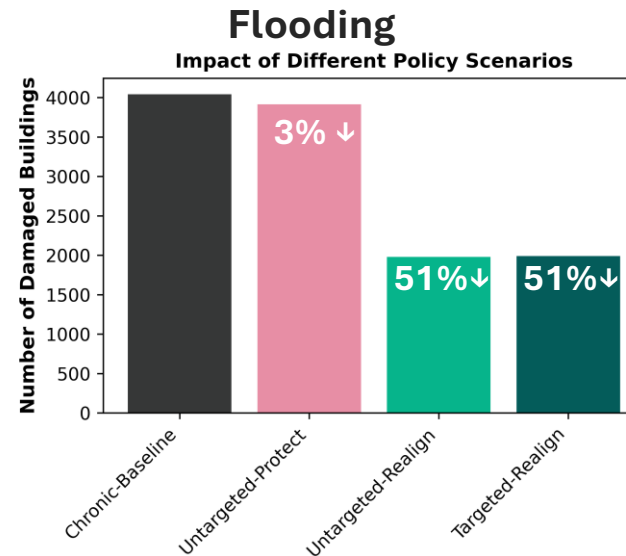
How can alternative policy scenarios and implementation approaches affect differential exposure of vulnerable populations?

## Acute (CSZ Earthquake and Tsunami) Hazards

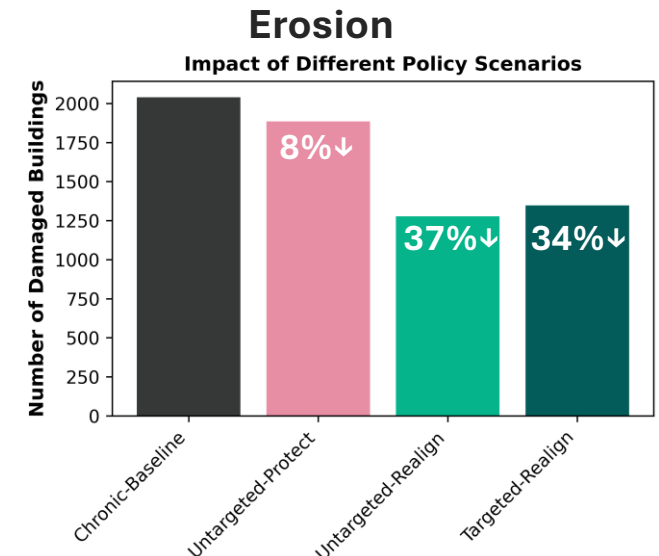


- Protect scenarios (retrofit buildings to meet current seismic standards) do not dramatically decrease the number of buildings damaged (**may reduce damage state**)
- Realign scenarios (remove buildings from inundation zone) **prevent CSZ damage to ~1,300 - 1,400 buildings by 2070**

## Chronic (Climate Change-induced) Hazards



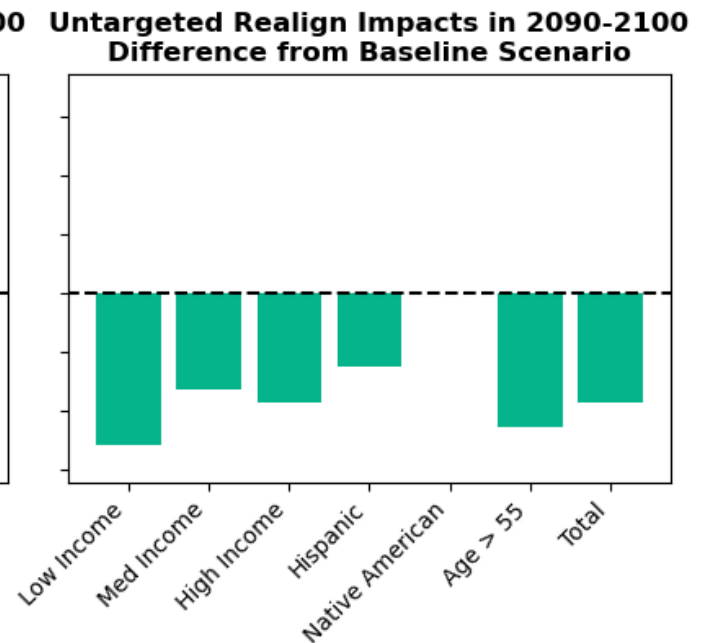
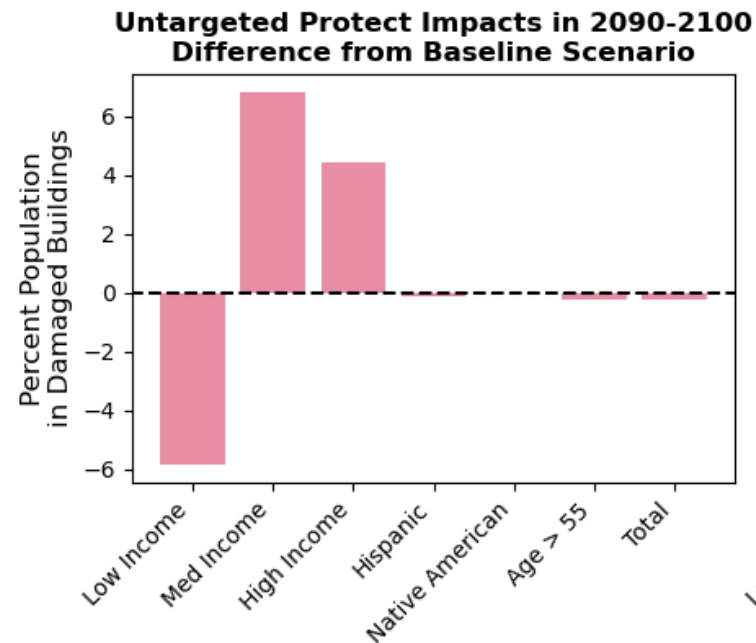
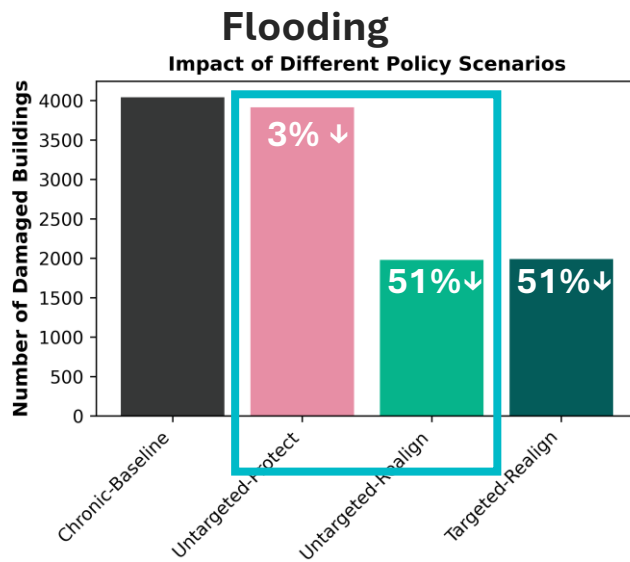
- Protect scenarios (**designed to limit erosion-** build riprap revetments, raise buildings to higher ground on same tax lot) **minorly reduce the amount of flooding damage**
- Realign scenarios (remove buildings from 100 year flood zone) reduce number of buildings flooded each year by ~2,000



# Who is Impacted by Alternative Policy Scenarios?

How can alternative policy scenarios and implementation approaches affect differential exposure of vulnerable populations?

## Chronic (Climate Change-induced) Hazards

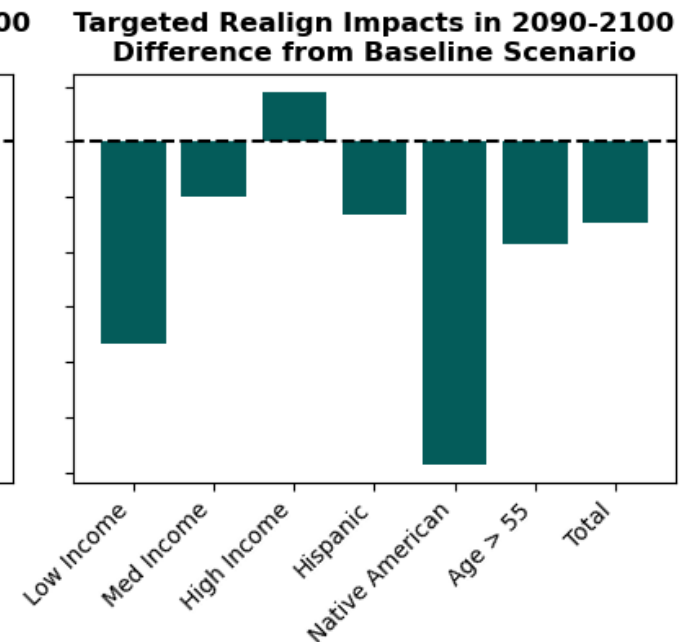
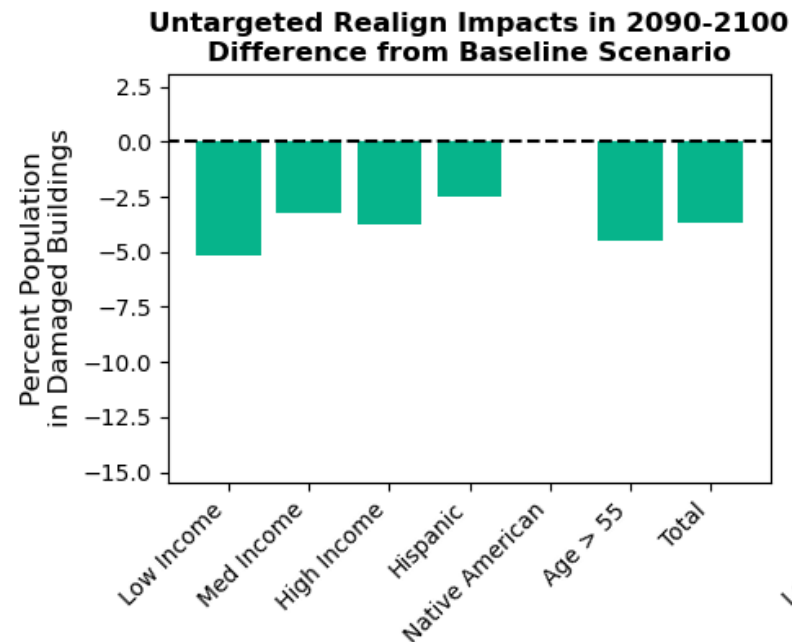
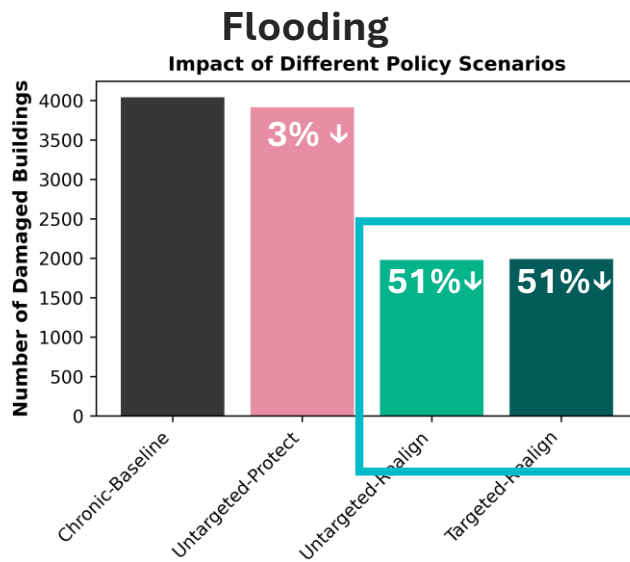


Disaggregate across policy scenario

# Who is Impacted by Alternative Policy Scenarios?

How can alternative policy scenarios and implementation approaches affect differential exposure of vulnerable populations?

## Chronic (Climate Change-induced) Hazards



Disaggregate across adaptation  
implementation approach



# Final Thoughts on Assessing Alternative Adaptation Pathways:

-How we manage our coast can potentially have as great of an impact (on resilience and equity) as climate change (at least over time scales of decades).

**Convergent research and deep engagement** with decision makers and coastal community members can inform emergency management and land use planning (adaptation pathways) to increase resilience.

- Supports decision making under uncertainty
- Crosses disciplinary and sectoral boundaries
- Supports common goal setting
- Develops integrated knowledge for science and society
- Creates new knowledge paradigms





**Oregon State**  
University

# Thanks!



**Cascadia CoPes Hub**  
THE CASCADIA COASTLINES AND PEOPLES  
HAZARDS RESEARCH HUB

**Peter Ruggiero**  
**Co-Director and PI, Cascadia Coastlines and Peoples Hazards Research Hub**  
**Professor, College of Earth, Ocean, and Atmospheric Sciences**

tel: 541.737.1239

email: [cascadia.copes@oregonstate.edu](mailto:cascadia.copes@oregonstate.edu)  
[peter.ruggiero@oregonstate.edu](mailto:peter.ruggiero@oregonstate.edu)  
<https://cascadiacopeshub.org/>



**Cascadia CoPes Hub**  
THE CASCADIA COASTLINES AND PEOPLES  
HAZARDS RESEARCH HUB



**Oregon State**  
University



UNIVERSITY of WASHINGTON



UNIVERSITY OF OREGON



HUMBOLDT  
STATE UNIVERSITY



WILLIAM D. RUCKELSHAUS CENTER



Sea Grant  
Oregon



Sea Grant  
Washington



SWINOMISH INDIAN  
TRIBAL COMMUNITY



USGS  
science for a changing world



GEORGIA TECH



ASU  
ARIZONA STATE UNIVERSITY

<https://cascadiacopeshub.org/>  
[cascadia.copes@oregonstate.edu](mailto:cascadia.copes@oregonstate.edu)