Exploring the Impacts of Both Climate Change and Decision Making Uncertainty on Coastal Community Vulnerability in a Policy-Centric Framework

A. MILLS[1] , K. SERAFIN[2], E. LIPIEC[2], J.P. BOLTE[1] , P. RUGGIERO[2], P.E. CORCORAN[1,3], J. STEVENSON[1], D.H. LACH[4], C.M. ZANOCCO[4]

1.BIOLOGICAL AND ECOLOGICAL ENGINEERING, OREGON STATE UNIVERSITY, CORVALLIS, OR 2. COLLEGE OF EARTH, OCEAN, AND ATMOSPHERIC SCIENCES, OREGON STATE UNIVERSITY, CORVALLIS, OR 3. OREGON STATE EXTENSION SERVICE, CLATSOP COUNTY, OR 4.SCHOOL OF PUBLIC POLICY, OREGON STATE UNIVERSITY, CORVALLIS, OR

Motivation Background, and Objectives

Coastal communities throughout the U.S. Pacific Northwest face heightened risk of coastal flooding and erosion hazards due to sea level rise and increasing storminess. Incorporating uncertainty with respect to both climate change and policy decisions is essential to project the evolving probability of coastal inundation and erosion, and the associated community vulnerability through time.

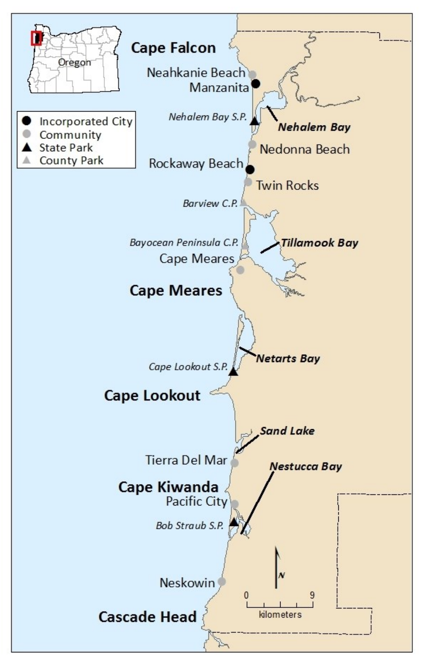

Figure 1: Study Area. Coastal Tillamook County, Oregon including incorporated cities and communities.

Objectives:

1. With a group of local stakeholders, co-develop a scenario analysis and modeling tool to explore strategies that may reduce vulnerability to coastal hazards within the context of uncertainty and climate change.
2. Explore a range of alternative futures related to policy decisions and socioeconomic trends as defined with input from stakeholders.
3. Quantify the relative contribution of uncertainty from both climate change and policy decisions in terms of multiple landscape parameters including impacts to private property and public goods.

Envision Framework

We use *Envision* (Bolte et al., 2007), a spatially explicit, multi-agent modeling platform that provides a scenario-based, policy-centric framework to examine interactions between coupled human and natural systems across a landscape (Figure 2).

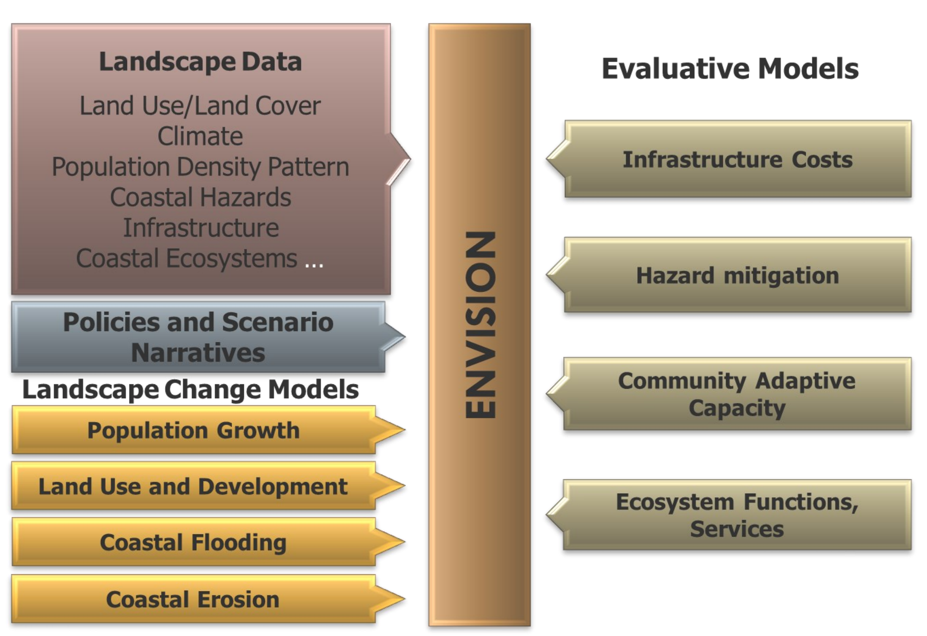

Figure 2: *Envision* inputs, landscape change models, and evaluative models specific to the modeling of coastal hazards in Tillamook County, Oregon.

ACKNOWLEDGMENTS: This work is supported by the Coastal and Ocean Climate Applications (COCA) program of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) under NOAA Grant NA12OAR4310109 and NA12OAR4310195 and the Pacific Northwest Climate Impacts Research Consortium (CIRC) under NOAA Grant NA10OAR4310218.

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Simulating Future Climate within *Envision*

Probabilistic simulations of alongshore varying total water levels (TWLs) capture the variability of sea level rise, wave climate, and the El Niño Southern Oscillation under a range of climate change scenarios through the end of the century (Serafin and Ruggiero, 2014).

Sea Level Rise Projections

- Sea level rise (SLR) projections from the National Research Council (NRC) report *Sea Level Rise for the Coasts of California, Oregon, and Washington,* are used to define low, medium, and high impact climate scenarios (Figure 3).
- The NRC (2012) projects between 0.15 - 1.4 m of SLR by 2100.
- Bounds on the SLR projections have a high range of variability and are specific to the west coast of the U.S. They include a combination of regional steric and ocean dynamics, cryosphere and fingerprinting effects, and vertical land motion (tectonics, glacial isostatic adjustment, and subsidence).

Wave Climate Variability

- Dynamically and/or statistically downscaled significant wave heights (SWH) have variable projections for the NE Pacific by the end of the century (Hemer et al., 2013, Wang et al., 2014).
- Present-day lognormal monthly SWH distribution fits are allowed to vary randomly based upon the range of SWH projections from global climate model inputs (Wang et al., 2014, Hemer et al., 2013).
- SWH shifts are sampled from a distribution centered around a mean of zero with a maximum deviation of 40 cm, allowing the wave climate to increase or decrease across the SLR scenarios (Figure 4).

Sea Level Rise (SLR) Scenarios 2010—2100

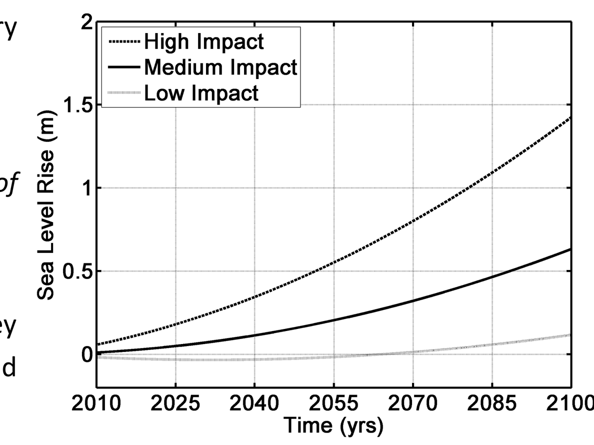

Figure 3: SLR projections from the National Research Council's Sea Level Rise for the Coasts of California, Oregon, and Washington.

Wave Height Distribution by 2100

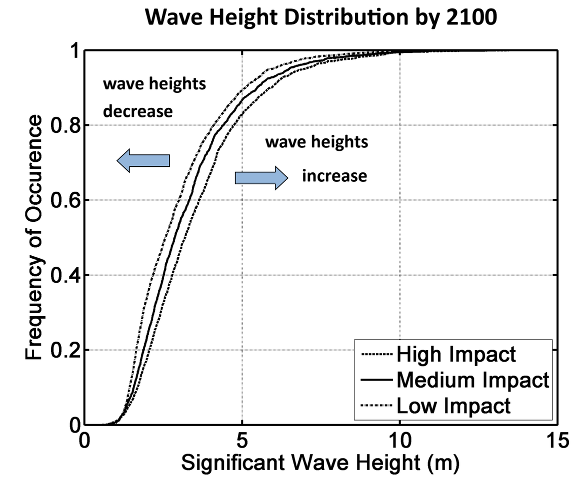

Figure 4: Future wave climate scenarios for Oregon. The solid line represents the present-day SWH distribution. The dotted line to the right of the solid line represents an increase to the present-day SWH distribution by 2100, while the dotted line to the left of the solid line represents a decrease in the present-day SWH distribution by 2100.

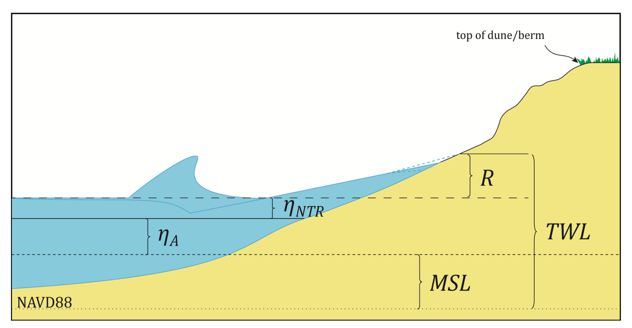

Figure 5: Various elements of a total water level (TWL). Coastal erosion and flooding are driven by the combination of tides, non-tidal residuals, and storm-induced water level variations as defined to the right.

$$Total\ Water\ Level\ (TWL) = MSL + \eta_A + \eta_{NTR} + R$$

Ruggiero, 2001; Serafin and Ruggiero, 2014, and Stockdon et al., 2006

MSL = mean sea level

η_A = astronomical tide

η_{NTR} = non-tidal residual

R = runup (a function of beach slope, wave height, and wave length)

See Poster GC21A-0494—Lipiec, et al. 2014 for more information regarding the modeling of erosion and flooding hazards.

TWL Climate Scenarios

- A full simulation TWL model (Serafin and Ruggiero, 2014) simulates the various components of TWLs, taking into account dependencies between components (Figure 5).
- Future climate variability is randomized by varying wave height distributions as well as by allowing the range of the frequency of major El Niño events to increase and decrease by a maximum of 2 and 1/2, respectively ,from 1950-2010 values.
- Fifteen TWL simulations from 2010 - 2100 are combined with each SLR scenario to create high, medium, and low impact future climate scenarios, totaling 45 different future climate scenarios.

Simulating Growth, Development, and Policies within *Envision*

Envision is used to assess alternative coastal management strategies in the form of individual policies and policy scenarios under various population and development trends, coastal and landscape processes and feedbacks, and climate change impacts.

- A constant population growth rate is used across all scenarios (an increase of approximately 12,000 people county-wide by 2100, OOEA, 2013).
- Individual policies within policy scenarios dictate where new growth (people and buildings) is allocated spatially (Table 1).
- Specific policies are applied across the landscape (i.e., backshore protection structures (BPS) constructed in Rockaway Beach, OR in Figure 6).
- The impact of policies are evaluated through landscape metrics that were identified as important by stakeholders such as beach accessibility (Figure 7).

Table 1: Example policies implemented within each of the four policy scenarios.

Policy Scenario	Example Policies Implemented
Status Quo	1. Maintain current development patterns with respect to urban growth boundaries (UGB).
Hold The Line	2. Add beach nourishment for locations where beach access in front of BPS has been lost (e.g., due to beach width reduction or frequent flooding). 3. Construct homes above a predetermined threshold elevation and in the safest site of each respective lot.
Laissez-Faire	4. Maintain current BPS and allow more BPS to be built on any lot.
ReAlign	5. Implement coastal hazard zones and restrict further development within the zones. 6. Establish conservation, open space, or recreation uses within the coastal hazard zones, via buyouts and rolling easements after buildings have been severely impacted by hazards.

Example Policy: Permit construction of backshore protection structures (BPS).

Figure 6: BPS constructed through time in a medium impact climate scenario under the Status Quo policy scenario in the Rockaway Beach littoral subcell.

Example Metric: Beach Accessibility in Rockaway Beach, Oregon

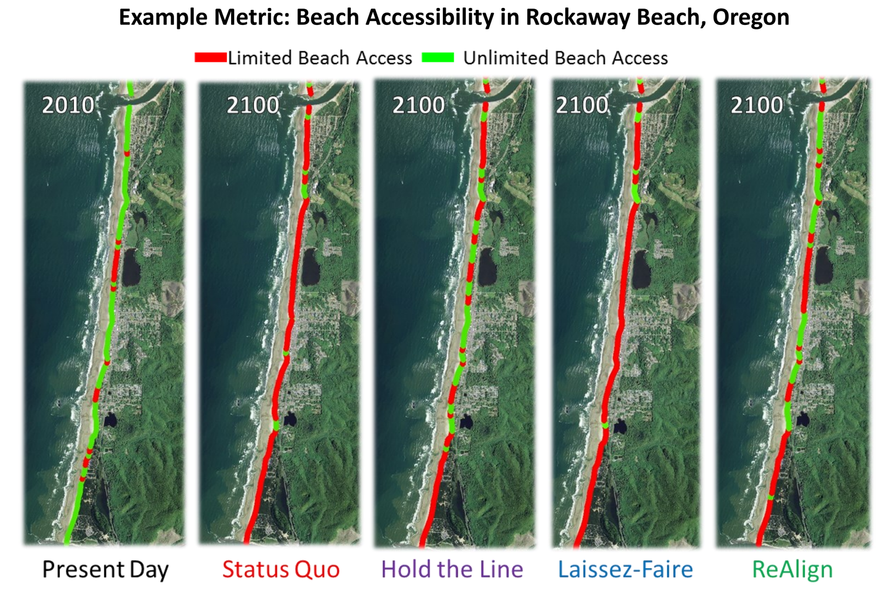

Figure 7: Beach accessibility in 2010 and in 2100 under each of the four policy scenarios (see Table 1) in the Rockaway Beach littoral subcell.

Exploring Variability Through Landscape Metrics

- Uncertainty due to climate change and decision making is quantitatively evaluated through three landscape metrics shown below: **beach accessibility, buildings impacted by flooding,** and **buildings impacted by erosion.**
- Time series plots indicate the variability within and across four policy scenarios under all 45 climate simulations (Figures 8, 10, & 12).
- The relative impact of both climate drivers and individual policies are measured against a **reference scenario** (Table 2). In this context, we use only one TWL simulation for each parameter (policy or climate) to assess impacts to the metric. **Blue** coloring indicates a positive impact to the metric and **red** coloring represents a negative impact to the metric (Figures 9, 11, & 13).

Table 2: Policy and climate parameters used in reference scenario.

Reference Scenario Parameter	Value
Growth and Development	Uninhibited
Policies Implemented	None
Sea Level Rise	Low (0.15 m)
Wave Climate	Decreased (0.4 m)
ENSO Frequency	Decreased (0.5x)

Metric 1: Beach Accessibility in Rockaway Beach

- Beach accessibility in the ReAlign and Hold the Line policy scenarios trend higher under all climate simulations (Figure 8).
- Allowing the construction of BPS reduces the accessibility of the beach by ~70% from the reference scenario by 2100 (Figure 9).
- The degree of variability resulting from changing individual climate parameters is due to the stochastic nature of the TWL simulations (Figure 9). Thus the decadal variability may differ through the century.

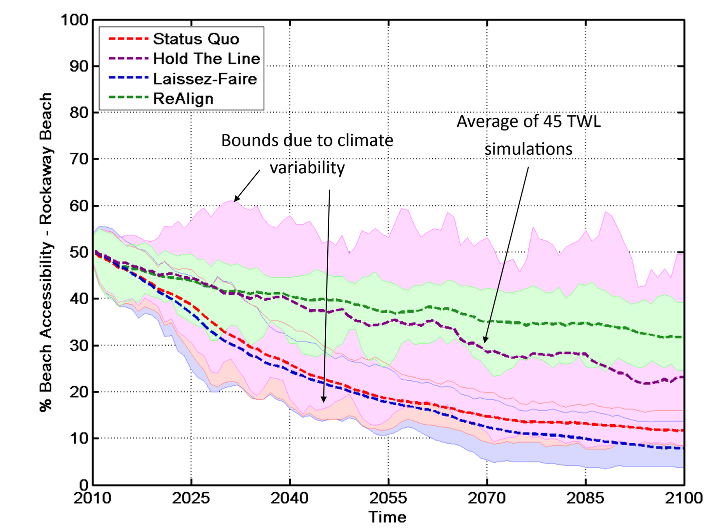

Figure 8: Percent of Rockaway Beach littoral subcell accessible under four policy scenarios. The beach is considered "accessible" if it can be walked the beach more than 90% of the year during the maximum daily TWL.

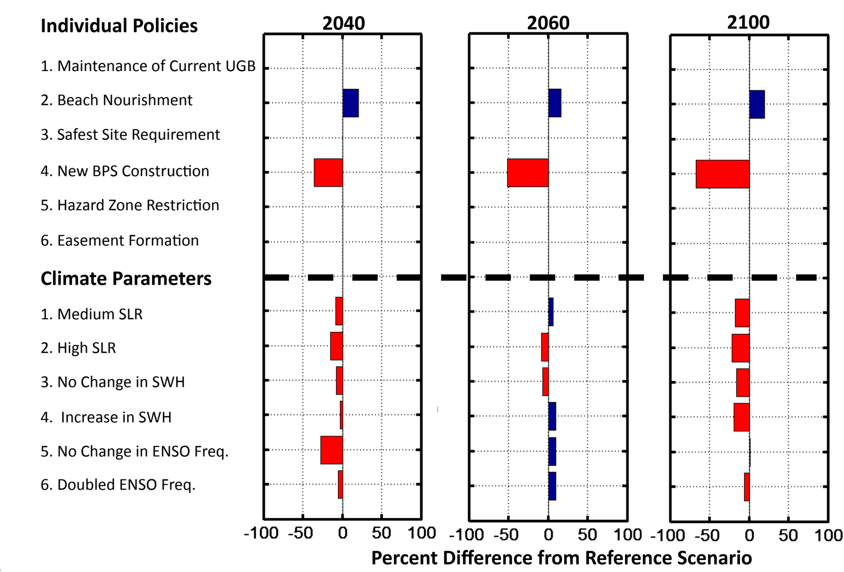

Figure 9: Percent difference in beach accessibility in the Rockaway Beach littoral subcell under six individual policies and six climate drivers as compared to the reference scenario.

Metric 2: Impacts to Buildings by Coastal Flooding in Tillamook County

- The decreased number of buildings impacted by flooding in the ReAlign and Hold the Line scenarios is due to the formation of easements and beach nourishment, respectively (Figures 10 and 11).
- The construction of BPS has a larger impact on buildings subject to flooding than any of the climate parameters at the end of the century (Figure 11).
- Policies that restrict development near the coast decrease the number of buildings impacted by flooding (Figure 11).

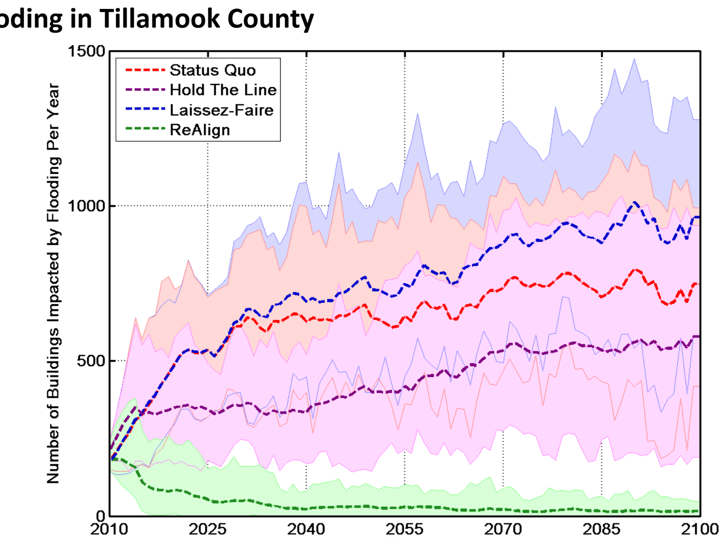

Figure 10: Number of buildings in Tillamook County impacted by flooding under four policy scenarios.

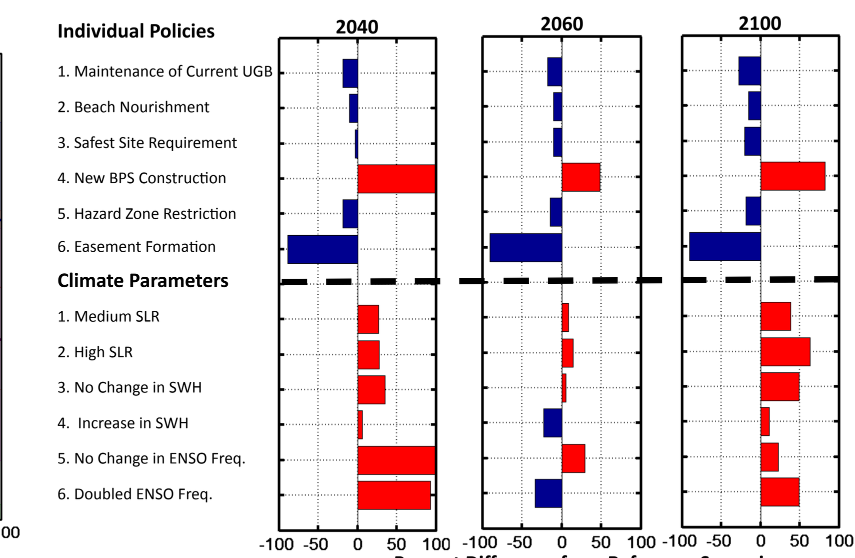

Figure 11: Percent difference in buildings impacted by flooding in Tillamook County under six individual policies and six climate drivers as compared to the reference scenario.

Metric 3: Impacts to Buildings by Coastal Erosion in Tillamook County

- BPS construction in the Laissez-Faire scenario prevents the erosion of buildings on the landscape (Figure 12).
- High SLR increases the number of buildings impacted by erosion (Figure 13).
- The ReAlign scenario is the most variable with respect to climate (Figure 12).
- Climate parameters have differing impacts to the metric throughout the century (Figure 13).

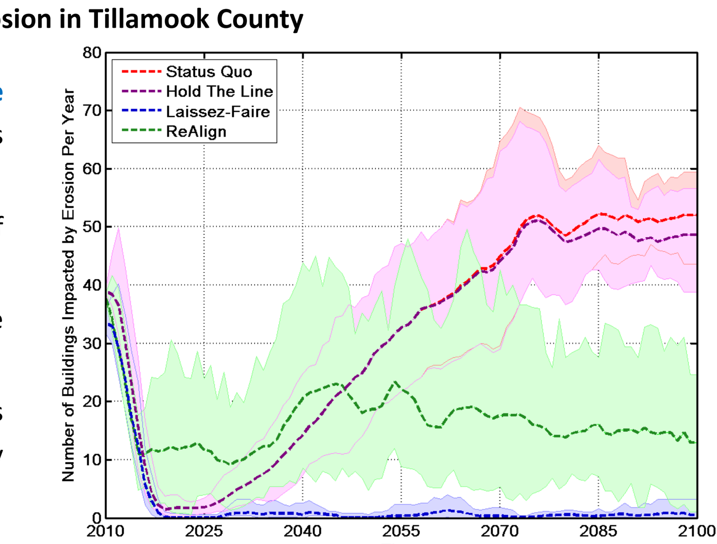

Figure 12: Number of buildings in Tillamook County impacted by erosion under four policy scenarios.

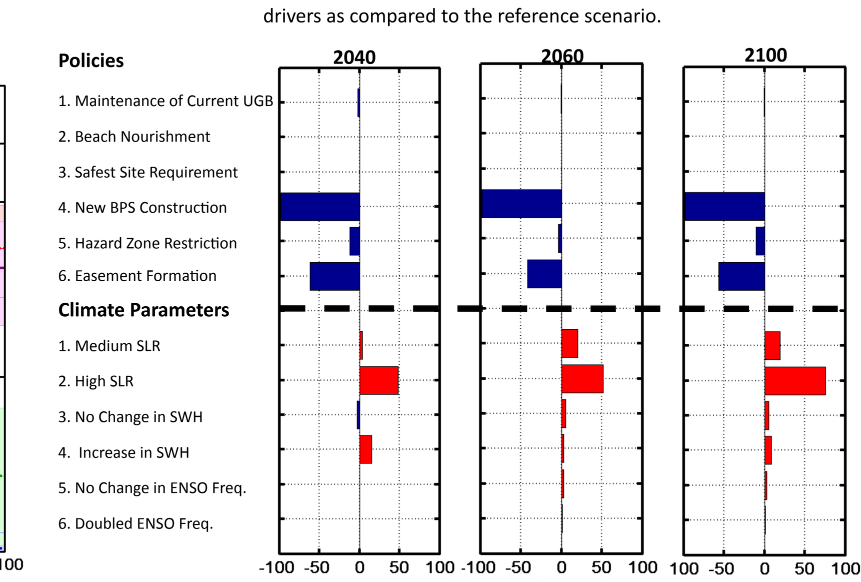

Figure 13: Percent difference in buildings impacted by erosion in Tillamook County under six individual policies and six climate drivers as compared to the reference scenario.

Table 3: Summary of variability related to climate and decision making uncertainty across the three metrics presented above.

	Variability	Beach Accessibility	Buildings Impacted by Flooding	Buildings Impacted by Erosion
Within Policy Scenarios	Max. Range Associated with Climate	48%	1,004 Buildings	43 Buildings
(Figures 8, 10, & 12)	Max. Range Associated with Human Decisions	29%	1,489 Buildings	51 Buildings
As Individual Policies	Max. % Change Associated with Climate	36%	101%	76%
(Figures 9, 11, & 13)	Max. % Change Associated with Human Decisions	67%	171%	329%

Conclusions and Take Home Messages:

- Probabilistic TWL simulations combined with multiple policy scenario simulations allow for the exploration of climate impacts to important stakeholder identified landscape metrics through the end of the century.
- In general, human decisions introduce greater variability to the number of buildings impacted by coastal hazards than climate change uncertainty, whereas beach accessibility is impacted differently by policy implementation and climate change depending upon whether it is examined within the context of policy scenarios or as individual policies (Table 3).
- Quantifying the impacts of uncertainty within the *Envision* framework helps to guide policy decisions aimed at increasing the adaptive capacity of Pacific Northwest communities under a range of future climate scenarios.
- Further analysis of the relative contribution of individual climate parameters to model uncertainty will help quantify the impact due to climate on various landscape metrics.