New Thoughts on Envisioning Climate Change Impacts to Coastal Communities: Providing Usable Metrics for Adaptation Planning

Katherine A. Serafin[1], Alexis K. Mills[2], Eva Lipiec[1], Peter Ruggiero[1], John P. Bolte[2], Chad M. Zanocco[3], Patrick E. Corcoran[1,4], John Stevenson[1], and Denise H. Lach[3]
[1]College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR,
[2]Biological and Ecological Engineering Department, Oregon State University, Corvallis, OR, [3]School of Public Policy, Oregon State University, Corvallis, OR,
[4]Oregon State Extension Service, Clatsop County, OR

CIRC Climate Impacts Research Consortium

OSU Oregon State University College of Earth, Ocean, and Atmospheric Sciences

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Objective: Explore the range of uncertainty in future extreme total water levels and their impact on the coast in metrics usable to stakeholders

Motivation

Several coastal communities in the Pacific Northwest (PNW) are presently at risk of coastal flooding and erosion from extreme total water levels (TWL). Uncertain forecasts for sea level rise (SLR), changes in storminess and changes in the frequency of major El Niños, only increases the future risk these communities may face. To display the uncertainty of future climate variability in a manner beneficial to decision-makers, here we combine a full simulation, total water level model (Serafin and Ruggiero, 2014) that allows for the robust estimate of extreme TWLs and the inclusion of future climate scenarios with Envision (Bolte et al., 2007), a multiagent-based framework for policy assessment and alternative futuring. Together, our approach merges flooding and erosion models with models for population, development, and public and private infrastructure, allowing for a depiction of the impacts of future climate variability across the coastal landscape. Model outputs are designed to be metrics of interest, such as beach accessibility, the number of buildings impacted by flooding, and the length of road impacted by flooding, across a variety of future climate scenarios (see most rightward panel, "*What does future climate variability look like on the landscape?*").

Methods

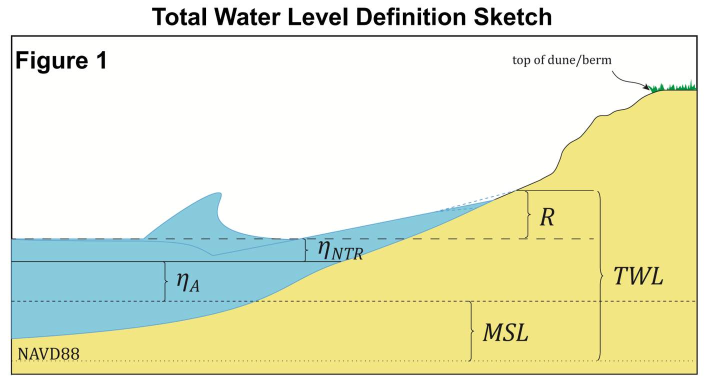
Full Simulation Total Water Level Model (TWL-FSM)

- Erosion and flooding events are driven by the combination of tides, nontidal residuals, and storm-wave induced water level variations (Figure 1). We define this combination as a total water level (TWL) where,

$$TWL = MSL + \eta_A + \eta_{NTR} + R \qquad (1)$$

MSL = **mean sea level**
η_A = **astronomical tide**
η_{NTR} = **nontidal residual**, any elevation change to the water level *not* due to tide (e.g., storm surge, El Niño effects, etc.)
R = **runup**, a storm-wave induced water level, a function of the deep-water wave height, wave length, and beach slope

Total Water Level Definition Sketch



- "Observational" TWLs can be calculated by combining wave buoy or hindcast measurements with tide gauge measurements using eqn. (1).
- Extreme return level events (i.e., the 100 year event, the event that has a 1% chance of occurrence in any given year) can be calculated by extrapolation from extreme value distribution fits to the time series of TWLs.
- **The problem: How do we know that the maximum TWL components have occurred concurrently in the relatively short observed record (e.g., the highest tide, the largest wave heights, and the highest nontidal residuals)?**

Simulated Total Water Level Component Dependencies Compared to Observed Total Water Level Component Dependencies

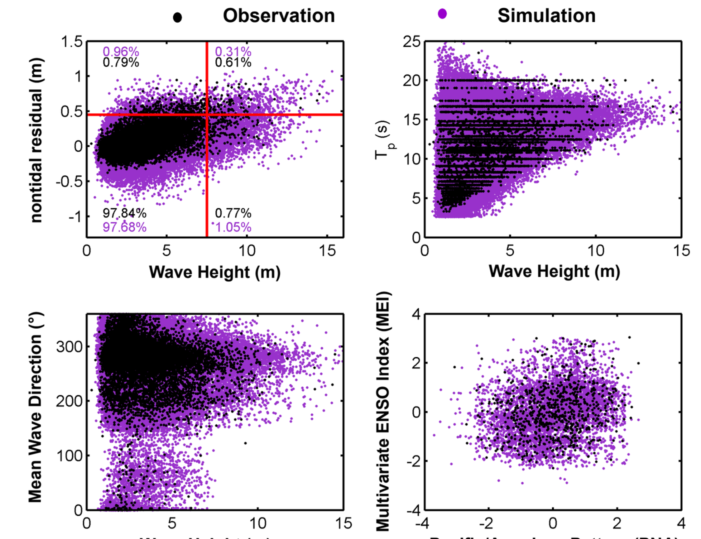


Figure 2

Simulated Total Water Level Components Compared to Observed Total Water Level Components

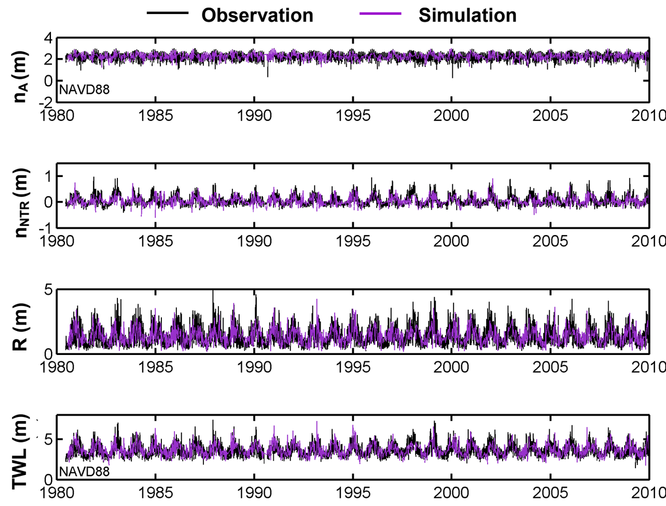


Figure 3

- We developed a time-dependent full simulation TWL model (TWL-FSM, Serafin and Ruggiero, 2014) that simulates the various components of a TWL in a Monte Carlo sense, taking into account the conditional dependencies existing between various components (Figure 2).
- Extreme events are modeled using nonstationary extreme value distributions (Coles, 2001) that include the effects of seasonality and climate variability (Figure 3).
- The resulting synthetic TWLs allow for extraction of return level events and the ability to robustly estimate flood and erosion hazards.

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For more information, contact Katy Serafin at kserafin@coas.oregonstate.edu.

Adding Future Climate Variability to Total Water Levels

Sea Level Rise Projections

- SLR projections from the National Research Council's *Sea Level Rise for the Coasts of California, Oregon, and Washington*, are used to define **low**, **medium**, and **high** impact climate scenarios.
- The NRC (2012) projects between 0.15 - 1.4 m of SLR by 2100 (Figure 4).
- Bounds on the SLR projections have a high range of variability, and are tailored 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).

Sea Level Rise Curves Relative to 2000

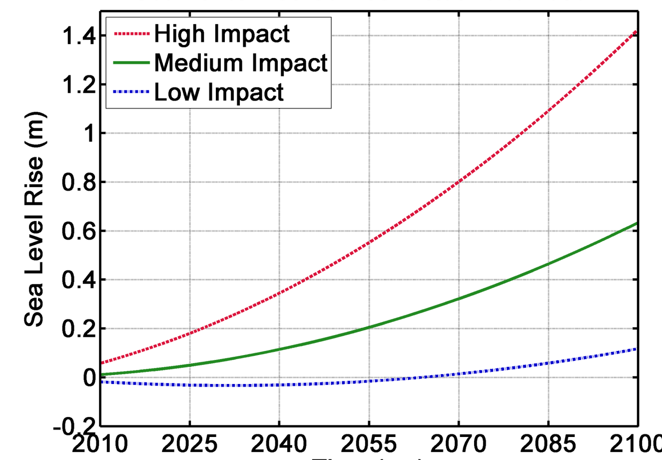

Figure 4

Wave Climate Variability

- Ruggiero (2013) found increases in wave height have had a more significant role in the increased frequency of coastal flooding and erosion than the rise in sea level over the "observational" record.
- 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).
- Monthly distributions of SWH fit lognormal distributions. The location (μ, related to the distribution's mean) and scale (σ, related to the distribution's skew) parameters for the present-day lognormal SWH distribution fits are increased or decreased by random numbers related to the range of variability in future SWH projections from various global climate model outputs (Figures 5 and 6, Wang et al., 2014; Hemer et al., 2013).
- SWH distribution shifts are sampled from a distribution centered around 0 with a standard deviation of 60 cm. This allows for the wave climate to increase or decrease across the various SLR scenarios.
- The solid line in the distribution figures (Figures 5 and 6) represents a "present-day" SWH distribution. The dotted line to the right of the solid line represents an increase to the present-day SWH distribution, while the dotted line to the left of the solid line represents a decrease in the present-day SWH distribution by 2100.

Cumulative Distribution Function (CDF) Depicting Shifts in Wave Height Distributions

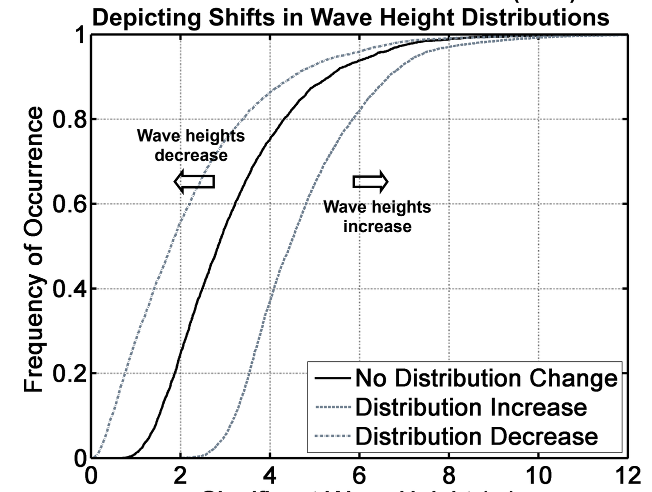

Figure 5

Probability Distribution Function (PDF) Depicting Shifts in Wave Height Distributions

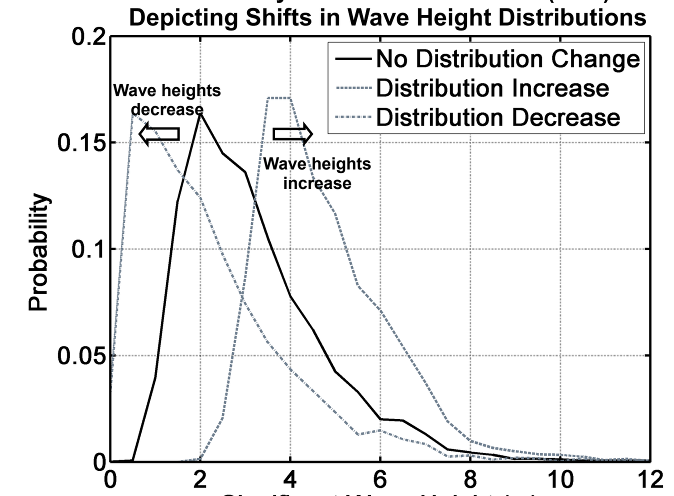

Figure 6

TWL Climate Scenarios

- 15 TWL simulations from 2010-2100 are combined with the SLR scenarios to create **High**, **Medium**, and **Low** Impact future TWL climate scenarios. This totals 45 different future climate scenarios for evaluating changes in extreme TWL events.
- The variability in the wave climate (shading around the average scenario, bolded colors) allows for variation in the range of TWLs for any given climate impact scenario. For example, the upper end of the **low** impact climate scenario may reach the lower bound on the **medium** impact climate scenario by 2100 (Figures 7 and 8).
- A **high** impact TWL scenario, with a negative shift in SWH is similar to a **medium** impact TWL scenario with a positive shift in the SWH (Figures 7 and 8).

Future Total Water Level Distributions by Climate Scenario

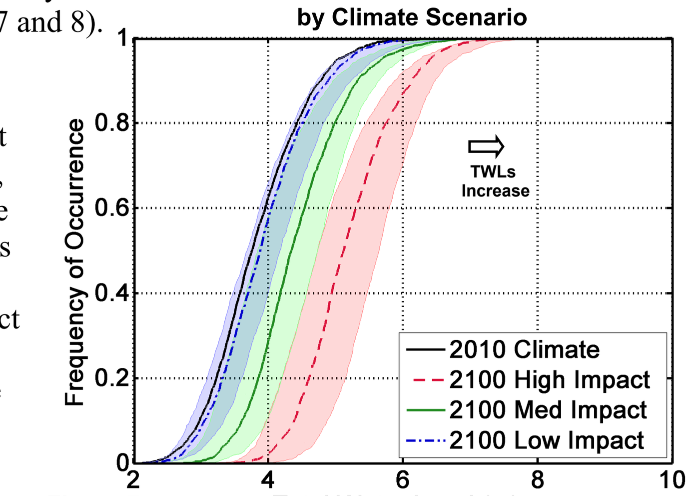

Figure 7

Future Monthly Maximum Total Water Levels by Climate Scenario

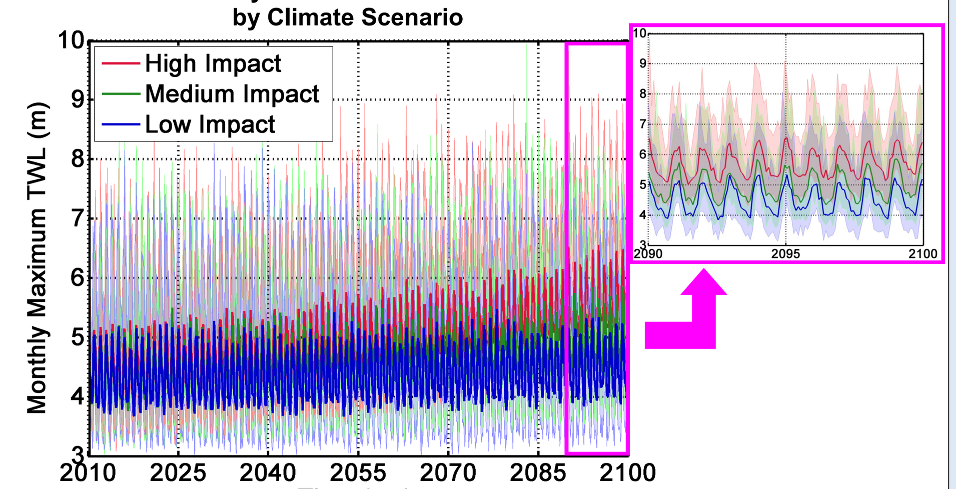

Figure 8

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Hemer, M.A., Fan, Y., Mori, N., Semedo, A., and X.L. Wang (2013), Projected changes in wave climate from a multi-model ensemble, *Nature Climate Change,* 3(5), 471-476.
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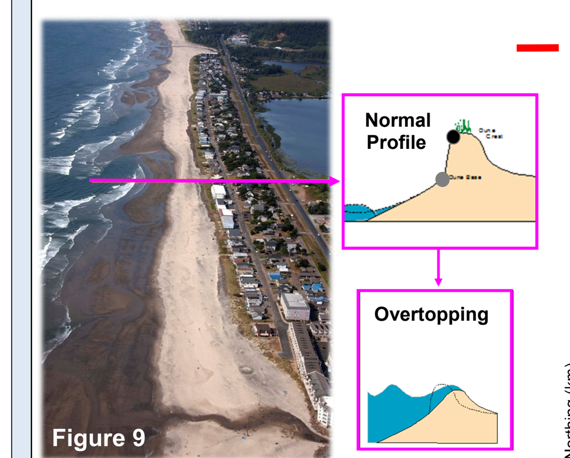
What Does Future Climate Variability Look Like on the Landscape?

Future Extreme Events



- Features such as dune toe and dune crest can be extracted from lidar data (Figure 9).
- Overtopping occurs when the TWL exceeds the elevation of the dune crest (Figure 9).

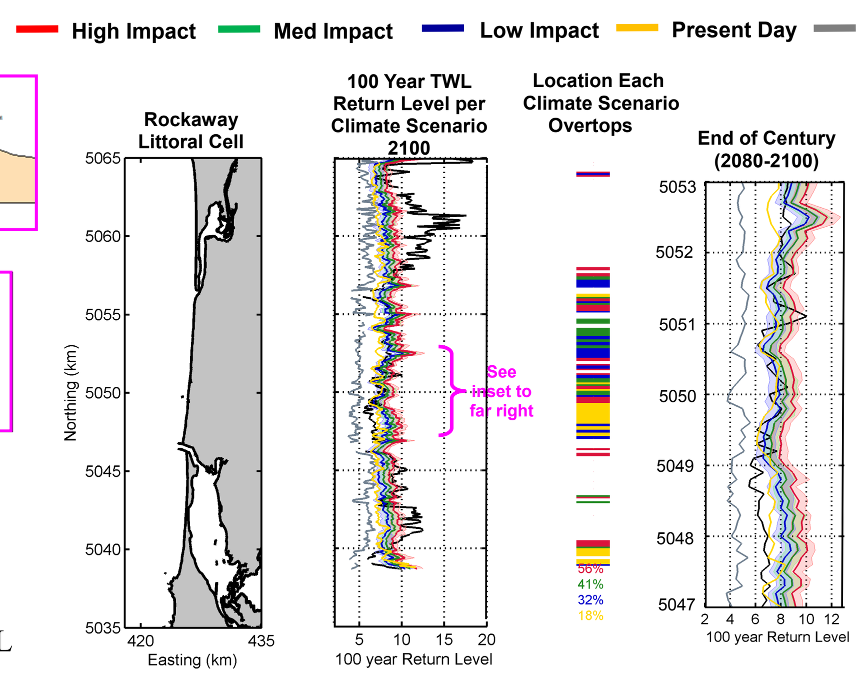
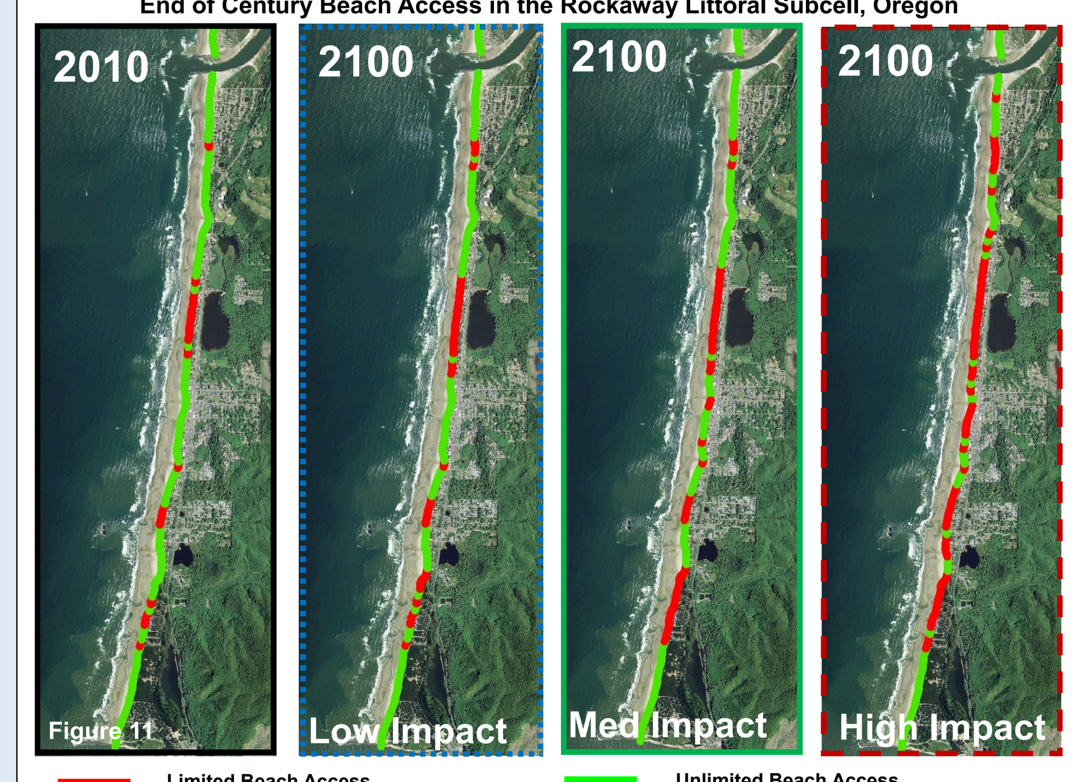


Figure 10

- The 100 year TWL return level overtops on average 56%, 41%, and 32% of the coastline in a **high**, **medium**, and **low** impact climate scenario by 2100 (Figure 10).
- In a **high** impact climate scenario, the minimum projected overtopping is 41% and the maximum projected overtopping is 65%, while in a **low** impact climate scenario, the minimum is 18% and the maximum is 45%, respectively.
- The variance within climate impact scenarios is due to the influence of the wave climate variability.

How will beach access change in the future?

End of Century Beach Access in the Rockaway Littoral Subcell, Oregon



Beach Access Over Time in the Rockaway, Oregon subcell by Climate Scenario

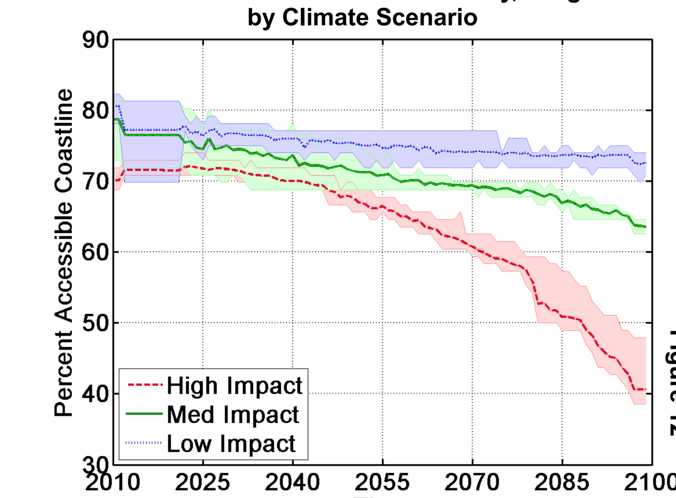


Figure 12

Beach Access Over Time in Tillamook County, Oregon by Climate Scenario

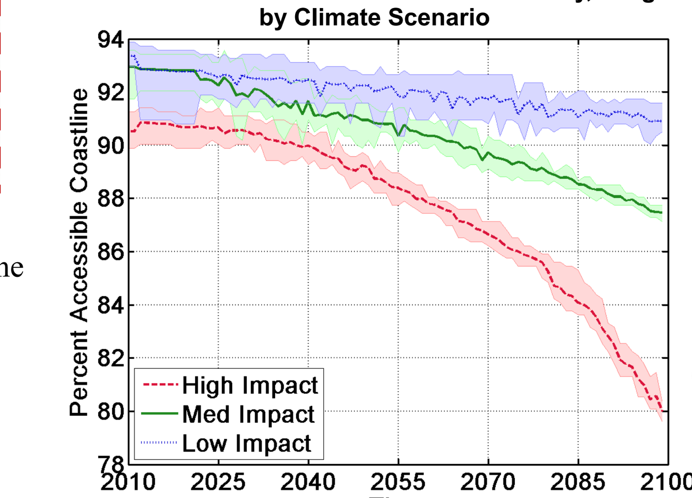


Figure 13

- "Unlimited" beach access is defined as the ability to walk on the beach 90% of the time during the daily maximum TWL.
- At the end of the century across all of the three climate impact scenarios, beach accessibility is decreased from 2010 levels. The average **high** impact climate scenario decreases beach accessibility the greatest amount (Figure 11).
- By 2100, a **high**, **medium**, and **low** impact climate scenario decreases beach accessibility in the Rockaway subcell by 30%, 15%, and 5%, respectively, compared to 2010 levels (Figure 12). Across the county, these values are lower at approximately 10%, 5%, and 2% (Figure 13).

How will coastal infrastructure be affected?

Number of Buildings Impacted by Flooding in Tillamook County, Oregon by Climate Scenario

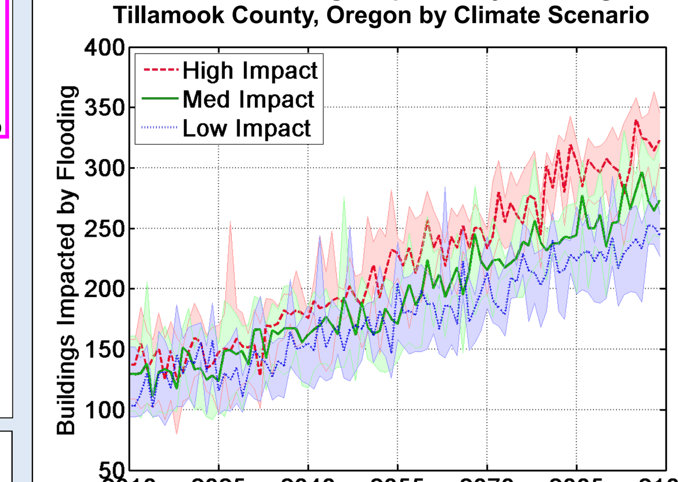


Figure 14

Length of Road Impacted by Flooding in Tillamook County, Oregon by Climate Scenario

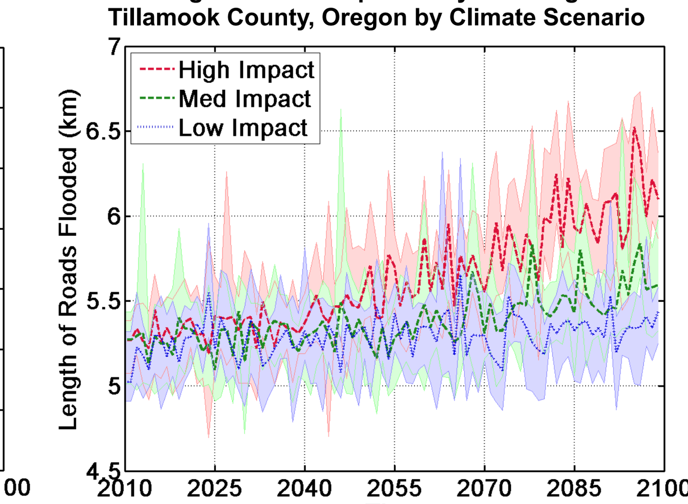


Figure 15

- By 2100 a **low** impact climate scenario impacts on average 250 buildings by flooding, while a **high** impact climate scenario impacts on average 325, but as many as 350 buildings by flooding (Figure 14).
- By 2100, between 6 and 6.5 km of road are impacted by flooding in a **high** impact climate scenario. In a **low** impact climate scenario, this decreases by approximately 1 km (Figure 15).