

HOW TO CHOOSE

A PRIMER FOR SELECTING SEA LEVEL RISE PROJECTIONS FOR WASHINGTON STATE





The Washington Coastal Resilience Project (WCRP) is a three-year effort to rapidly increase the state's capacity to prepare for coastal hazards, such as flooding and erosion, that are related to sea level rise. The project will improve risk projections, provide better guidance for land use planners and strengthen capital investment programs for coastal restoration and infrastructure. Partners include:

Washington Sea Grant
Washington Department of Ecology
Island County
King County
NOAA Office for Coastal Management
Padilla Bay National Estuary Research Reserve
The City of Tacoma
The Nature Conservancy
U.S. Geological Survey
University of Oregon
University of Washington Climate Impacts Group
University of Washington Department of Earth and Space Sciences
Washington Department of Fish and Wildlife
Pacific Northwest National Laboratory

WASHINGTON COASTAL
RESILIENCE PROJECT

The project is primarily funded by a grant from the NOAA Regional Coastal Resilience Grants Program (grant #NA16NOS4730015). Additional funds were provided by the State of Washington as well as the Pacific Northwest Climate Impacts Research Consortium (CIRC), which is partially funded by the Regional Integrated Sciences and Assessments program under NOAA grant #NA15OAR4310145.

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6-20 WSG-AS 20-01

Prepared for the Washington Coastal Resilience Project

March 2020 | University of Washington

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Acknowledgments

Thanks to reviewers of this primer; Ian Miller, Paul Dye and Jackson Blalock (Washington Sea Grant), Amy Snover and Guillaume Mauger (Climate Impacts Group), Bobbak Talebi (Washington Department of Ecology), and Lara Whitely Binder (King County).

Recommended Citation

Raymond, C.L, Faghin, N., Morgan, H., and Roop, H, 2020. How to Choose: A Primer for Selecting Sea Level Rise Projections for Washington State. A collaboration of Washington Sea Grant and University of Washington Climate Impacts Group. Prepared for the Washington Coastal Resilience Project.

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INTRODUCTION

As global sea levels rise – and preparing for these and other consequences of climate change increases in priority – we have seen an increasing demand for detailed local sea level rise projections and for guidance that supports their use in planning, policy development and project design. Recognizing gaps in existing sea level rise (SLR) information for Washington state, in 2018 a team of scientists developed updated projections for Washington's coast under the auspices of the Washington Coastal Resilience Project (WCRP).

These projections show a range of SLR magnitudes that Washington state could experience, associated with different potential climate change futures driven by society's choices about greenhouse gas emissions. The 2018 SLR projections provide more insight into the potential range of SLR that Washington state could experience than has been available before, bringing new information to potential users. However, using these projections requires careful consideration of certain choices described in this primer when selecting values to use in planning and design.

The 2018 Sea Level Rise Projections for Washington State

The 2018 SLR projections for Washington state show the long-term change in average sea surface height through the year 2150 (relative to the 1991–2010 average), and include three features that distinguish them from previous projections for the state:

1. **New science:** The 2018 projections include the latest science on SLR based on a comprehensive assessment of global and regional SLR studies. This assessment incorporated the projections from recent research that indicates the potential for higher sea level rise in the 21st century, relative to previous assessments.
2. **Locally specific:** SLR projections are available for 171 locations distributed along Washington's coastline. The localized projections account for variation in the vertical movement of the land along the coast. Previous projections were only available for a few locations, creating an information gap for many of Washington's coastal communities. Localized projections are critical because some areas of the coast are subsiding, while others are uplifting, creating variation in the actual local exposure to rising seas.
3. **Probabilistic:** The 2018 SLR projections are probabilistic, meaning that the range of projections is based on the likelihood, that sea level will rise at least a certain amount by a specified time. This probabilistic approach was designed to be applicable to risk management and provides more information than previous projections, which only provided low, medium, and high scenarios without any indication of how likely each scenario is to happen.

How this Primer is Organized

This primer is designed to guide potential users of the 2018 SLR projections through the choices necessary to select and use SLR projections for their particular context. The intended audiences include coastal planners, engineers, climate adaptation specialists, restoration ecologists and others who seek more direction on how to use and choose from the 2018 SLR projections. Although the approach described here is intended to facilitate the use of the 2018 projections, it represents fundamental principles of selecting climate change scenarios for use in risk assessment, planning, and decision making, and could be applied in other locations with other datasets.

This primer provides information to assist the user with selecting from the range of projections for use in a variety of contexts including: (1) climate change or coastal vulnerability assessments and adaptation plans, (2) policies and plans for coastal management, (3) the design of projects in the built environment, and (4) the design of projects for nearshore restoration. The choice of which projections to use may differ in each context, but the process of choosing projections and the decisions that need to be made when selecting projections are similar for all contexts. We describe some factors to consider when making each of these choices:

- Which of the 171 locations to use?
- How to select relevant timeframes?
- How to select appropriate probabilities?
- Which greenhouse gas scenarios to use?

For each choice, we direct the user to the reports that contain more scientific detail on the projections and to a SLR data visualization that allows the user to explore the full range of projections.

The primer begins with a brief description of the series of reports developed for the WCRP and the SLR data visualization. Section 2 provides an overview of how to use the SLR projections in combination with information on existing water levels to assess exposure to expected future water levels. Sections 3–6 describe some factors to consider for each of the necessary choices when selecting from the range of projections. Section 7 describes some additional options for visualizing and mapping SLR projections, which can be useful for the process of selecting projections, as well as for conveying information about selected projections to a broader audience.

It is important to recognize that the choice of which SLR projections to use is a policy decision that should be informed by science, but science cannot dictate which projections to use. There is no right answer; evaluating a range of projections will be the most robust approach in most planning and decision contexts.

BACKGROUND

This primer is designed to support the use of the 2018 SLR projections produced for the WCRP. In doing so, it draws on a series of reports (described below) associated with the WCRP. These reports provide more scientific background and technical detail on the development and use of the projections. The projections themselves can be accessed through an online data visualization developed by the UW Climate Impacts Group. The reports listed below and SLR data visualization are all available on the Coastal Hazards Resilience Network website, <https://wacoastalnetwork.com/chrm/research/sea-level-rise/>

Projected Sea Level Rise for Washington State (Miller et al., 2018)¹ provides updated, local relative sea level projections through 2150 for Washington's coast. The report describes the science and process used to develop these projections, including information on vertical land movement which is incorporated into the projections to develop the location-specific relative SLR values. For each location, the projections describe the likelihood that sea level will reach or exceed a certain magnitude by a given time, which is called a "probability of exceedance." The report includes three appendices with additional details on the science and modeling:

- Appendix A: Absolute Sea Level Methods and Projection
- Appendix B: Global and Regional Sea Level Rise – A Review of the Science
- Appendix C: Vertical Land Motion Background and Analysis.

Guidelines for Mapping Sea Level Rise Inundation for Washington² (Norheim et al., 2018) provides guidelines for mapping SLR inundation that are designed to assist people with a background in geographic information systems (GIS) to design maps that show the spatial extent of inundation.

Sea Level Rise Considerations for Nearshore Restoration Projects in Puget Sound (Raymond et al., 2018)³ is designed to assist restoration professionals with how to consider SLR in the planning and design of nearshore restoration projects in Puget Sound. The report identifies the potential impacts that SLR could have

1. Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., and Grossman, E. (2018). Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project.
2. Norheim, R.A., G.S. Mauger, I.M. Miller, 2018. Guidelines for Mapping Sea Level Rise. Report prepared for the EPA National Estuary Program (NEP). Climate Impacts Group, University of Washington, Seattle
3. Raymond, C., Conway-Cranos, L., Morgan, H., Faghin, N., Spilsbury Pucci, D., Krienitz, J., Miller, I., Grossman, E. and Mauger, G., 2018. Sea level rise considerations for nearshore restoration projects in Puget Sound. A report prepared for the Washington Coastal Resilience Project.

on process-based restoration projects, as well as the types of information that can assist with evaluating exposure to these impacts.

Extreme Coastal Water Level in Washington State (Miller et al., 2019)⁴ provides guidelines for assessing flood exposure during extreme coastal water levels. The report includes information on the current and future magnitude and frequency of extreme water levels, as well as the underlying processes that influence them. Maps and a decision tree help the user determine which data to use for which locations along the coast when combining the 2018 SLR projections with extreme water level information.

Sea Level Rise Data Visualization produced by the Climate Impacts Group and partners on the Tableau platform enables users to explore: (1) projections across all the locations along Washington's coast, (2) change in the projections through the year 2150, (3) probabilities of exceedance, and (4) differences in projections due to different greenhouse gas scenarios. These features of the SLR data visualization align with the key decisions described in this primer.

Glossary of Sea Level Rise Terms provides definitions for terms commonly used in the referenced resources related to SLR and this primer.



Photo Credit: MyCoast Washington King Tides, Suzanne Conway, Cama Beach, WA.

4. Miller, I.M., Yang, Z., VanArendonk, N., Grossman, E., Mauger, G. S., Morgan, H., 2019. Extreme Coastal Water Level in Washington State: Guidelines to Support Sea Level Rise Planning. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, Pacific Northwest National Laboratory and U.S. Geological Survey. Prepared for the Washington Coastal Resilience Project.

USING SEA LEVEL RISE PROJECTIONS

When assessing, planning, or designing projects to reduce SLR impacts, it is important to consider which aspects of rising water levels are of concern for your particular context. Are you concerned about daily tidal conditions, or higher water levels that occur during less frequent events? For example, when evaluating the migration of salt marsh habitats you may be interested in assessing the expected changes to the daily average high tide, whereas when designing infrastructure near the shoreline, you may be more interested in assessing exposure to less frequent, but higher water levels that are associated with storm surge and waves.

The 2018 SLR projections provide the expected change in average sea level relative to the 1991–2009 mean. The projections can be used to evaluate expected changes to any contemporary tidal datums, which are baseline water levels that are used as references for reporting the observed water levels at tide gauges or other shoreline locations (see callout box in Miller et al. 2018, pg. 13 for further explanation about tidal datums). For example, the Mean Higher High Water (MHHW) is the tidal datum that describes the average height of the highest of the two daily high tides. It is common to add the SLR projection values to the MHHW to get the expected future height of this water level. Similarly, you could add the SLR projection values to Mean Lower Low Water (MLLW), the average height of the lowest of the two daily low tides. This approach is relevant for planning associated with marine navigation in ports or assessing habitat transitions in the lower intertidal for nearshore restoration projects.

A user may also be concerned about extreme water level events, during which the water is higher than the average daily tides due to the combination of tides, storm surge, and, in some places, wave run-up. The 2018 SLR projections can be used in combination with observed or modelled current extreme water level magnitudes to assess this exposure. Extreme Coastal Water Level in Washington State (Miller et al., 2019) provides information about the current magnitude and frequency of extreme water levels along Washington's coast and describes how to combine this information with the 2018 SLR projections to assess the expected change in future extreme water levels. It is important to note that the approaches described in Miller et al., 2019 assume that the magnitudes of storm surges and wave run-up themselves are not changing because of climate change. Currently there is no evidence from modeling or observations that climate change will alter the magnitude of storm surges or wave run-up. However, while the magnitude of storm and waves may remain the same, the sea levels will continue to rise leading to an overall increase in flooding.

If the user is concerned about the impacts of higher extreme water levels, another factor to consider is the frequency of extreme water levels events. Extreme water level heights are defined based on the probability that an event of a particular magnitude will occur in any given year. For example, the commonly used FEMA “100-year flood” event is the magnitude of an event that has a 1-in-100 chance of occurring in any given year (a 1% chance event). In some contexts, a more frequent, smaller magnitude event may be of concern, such as the 2-year flood event which has a 1-in-2 (50%) chance of occurring in any given year. Miller et al., 2019 provides information to assess the future change in extreme water levels for a range of event frequencies.

Another option for assessing change in future extreme water levels is to use local data when available. Local information could include: (1) extreme water levels recorded at a site of interest during a single storm, such as a storm of record; (2) detailed information recorded by a local tide gauge; (3) local modeling of current extreme water levels; or (4) existing base flood elevations for the 100-year flood as modeled by FEMA. If using the fourth option, it is important to note whether FEMA flood maps have been updated for your location of interest. The 2018 SLR projections can be added to these locally derived values.

Finally, when assessing exposure to SLR it is important to recognize that higher water levels and inundation due to rising seas is only one the many potential impacts of SLR. SLR may affect rates of bluff and shoreline erosion, saltwater intrusion into drinking water wells or agriculture fields, and groundwater flooding. You may need to consider exposure to these impacts when planning for SLR. In most cases, assessing exposure to these impacts will require additional data and modeling at a particular site.



HOW TO SELECT LOCATIONS

In this section we describe options for selecting from the 2018 SLR projections either for a single location or for a planning area. Projections are available for 171 sections along Washington's coast. These locations correspond to the spatial resolution of the gridded vertical land movement data (0.1 degree-grid, roughly 5-7-mile grid cells) used to develop the localized projections. The coastal segments differ in length because of the irregular shape of the coastline relative to the grid. The relative SLR projections themselves differ along the coast because they account for the variation in the vertical movement of the land. Some locations will experience higher rates of relative sea level rise because the land is subsiding; the opposite will be true at other locations where the land is uplifting. For more details on vertical land movement see Miller et al. 2018 Appendix C.

Users can select projections for a single location for use in a project design or use the information for a larger planning area. Given the large number of sections along the coast, users may want a value for a larger planning area, such as the coastline of a county or island. In this case, the user can select a representative point for the larger planning area or use the values for the multiple segments that make up the planning area by averaging the data for all sections along the area of interest. However, it is important to note that it may not be appropriate to average the SLR projections for an area with large variation in vertical land movement. Averaging the SLR values in these areas would lead to meaningless values that do not account for the contribution of vertical land movement to sea level rise. Miller et al., 2018 describes the variability in vertical land movement along the coast and where differences are greatest.



Photo Credit: MyCoast Washington King Tides, J Custer, Cama Beach.

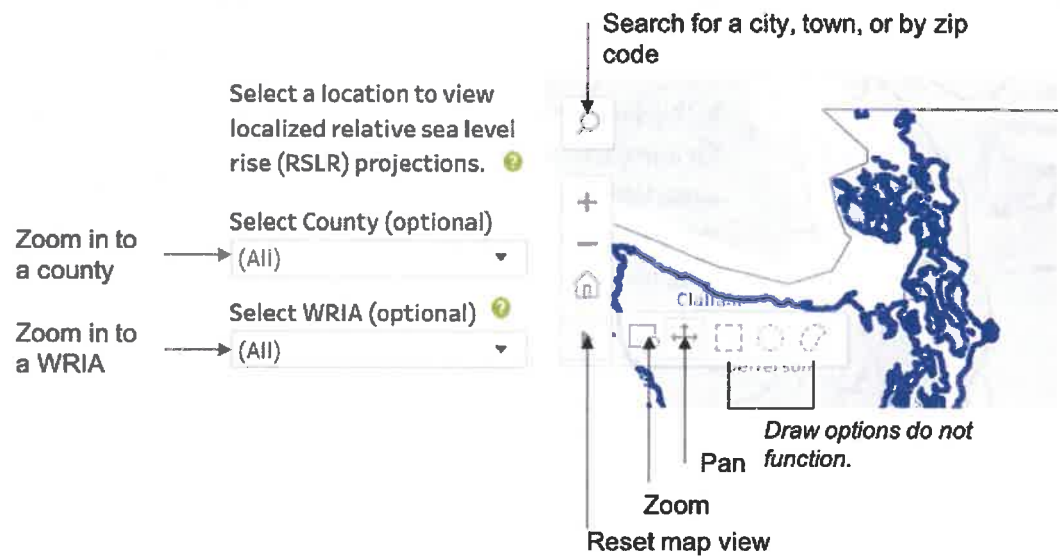


Figure 1. This visualization allows the user to select, explore, and download SLR projections for 171 sites along Washington's coastline by selecting a blue coastline segment on the map. Users can search for a specific location using the search function or utilize the dropdown menus to zoom in to a specific county or WRIA. Simple pan and zoom functions are also available on the map interface.

Using the SLR Data Visualization to Explore Locations

With the SLR data visualization, users can explore the SLR projections for a specific location and see how the projections vary along Washington's coastline. Select the relevant section of coastline in the data visualization by clicking on a blue line segment on the map (only one line segment can be selected at a time). The user can also navigate the map using a range of tools, including searching by city or zip code, or manually zooming and panning to the location. Zoom to a specific county or Water Resource Inventory Area (WRIA) using the drop-down menu to the left of the map. Once the location is selected on the map, the projections will automatically populate on the graph to the right of the map (Figure 1). The user can download the projections for a location directly from the visualization. The visualization can be used to explore the differences among projections for an area of coastline. To average the values for an area, download the projections for each segment in an area.

HOW TO SELECT TIMEFRAMES

The 2018 SLR projections show the change in average sea surface height for each decade from 2010 to 2150, relative to the 1991 to 2009 average. The availability of projections by decade gives the user the flexibility to select projections for the timeframe that is most relevant for their specific use, but it also requires the user to make this choice. Different timeframes will be relevant for different decision contexts.

Key factors to consider when selecting timeframes for different decision contexts include:

- **Vulnerability or risk assessments:** For vulnerability or risk assessments, or when initially exploring potential exposure to SLR, the user should consider multiple timeframes and explore how water levels will change over time. It is important to evaluate whether there is a time when sea level reaches a critical threshold to cause significant impacts of concern.
- **Planning or policy development:** For planning and policy contexts, the user should consider the time horizon of the plan or policy (e.g., a shoreline master plan or comprehensive plan), as well as the timeframe that is relevant for decisions that are made under the plan. For example, a 20-year plan may rely on projections for 20 years from present. Also consider how often the plan will be updated. If updated frequently, a more near-term timeframe could be appropriate with longer-term impacts addressed in future updates. However, also consider whether decisions made based on the plan or policy may have consequences beyond only the time horizon of the plan (such as building structures with a long design life), in which case it may be appropriate to use a timeframe near the end of the century or beyond.
- **Project design:** For the design of projects and structures, the expected design life of the infrastructure may be the most appropriate timeframe to use in selecting projections. For example, when designing a bridge that is expected to last 80 years, using projections for 80 years into the future is appropriate. Also consider whether the design life of the infrastructure is a realistic guide. In some cases, structures may be upgraded or replaced before the end of the expected design life due to changing design standards or technology, in which case a more near-term timeframe would be appropriate. In other cases, a lack of funding or capacity can result in infrastructure that remains in use well beyond its expected design life, in which case a timeframe longer than the design life may be appropriate. Consult with engineers, manufacturers, and design manuals and standards to determine the appropriate design life.

More near-term timeframes may also be appropriate when project design includes the ability to adapt the project easily in the future, such as structures that can be moved or elevated relatively easily. In contrast, if adjusting the decision or design is not possible or would be difficult financially, logistically, or politically, using projections for a more long-term timeframe may be more appropriate.

Nearshore restoration projects: When designing nearshore restoration projects, particularly those focused on restoring ecological processes, the goal is restoration in perpetuity. Sea Level Rise Considerations for Nearshore Restoration Projects in Puget Sound (Raymond et al. 2018) describes how to consider SLR in the design of nearshore restoration projects. Given the focus on restoring ecological processes, the rate of SLR over time relative to the rate of other ecological processes, such as sediment deposition and accretion, is an important factor in considering the timeframe. Faster rates of SLR will outpace other processes and may require more design modifications than slower rates. The 2018 SLR projections are not presented in terms of rates, but rates can be calculated for any location based on the expected amount of SLR over a given amount of time. Short timeframes (20-30 years) can be used to assess the potential impacts on short-term objectives for restoring habitat and ecological processes, whereas assessing impacts using a long-term timeframe (>100 years) may be necessary to ensure the resilience of habitat and ecological processes in perpetuity.



Photo Credit: MyCoast Washington King Tides, Jeff Taylor, Port Townsend, WA

RSLR for Selected Location

Projected changes relative to the average sea level over 1991-2009.
Hover for details.

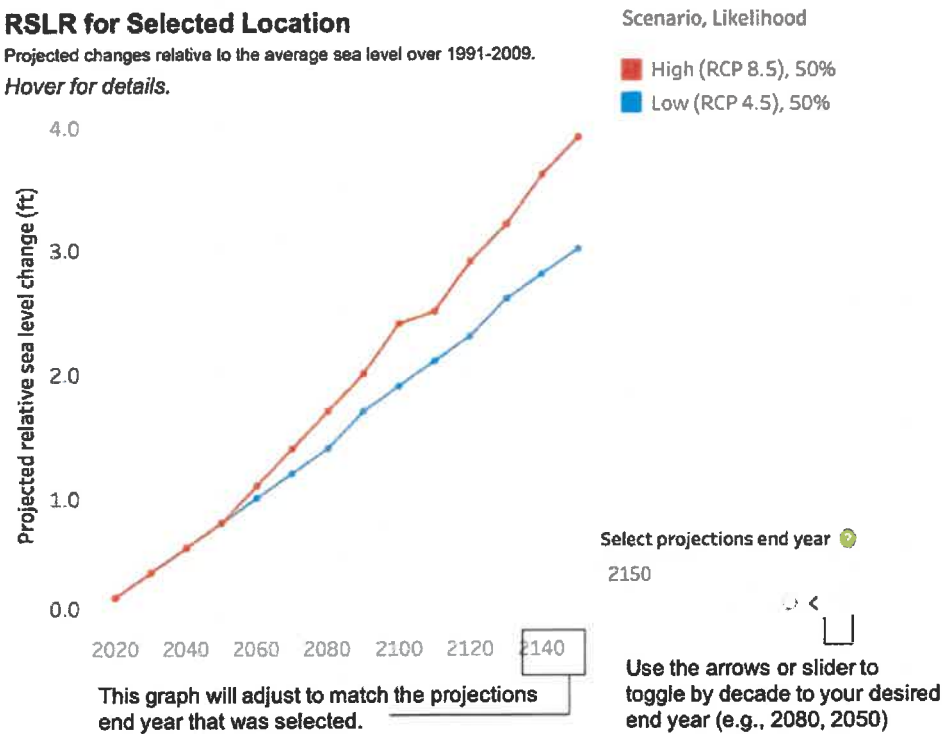


Figure 2. The visualization tool enables users to explore the SLR projections through time, out to 2150. Using the toggle bar in the bottom right of the visualization, users can select various projection end years at decadal intervals. The graph on the left of the visualization will adjust as end years are altered.

Using the SLR Data Visualization to Explore Timeframes

The SLR data visualization enables users to explore projections at decadal intervals from 2010 through the year 2150. Use the SLR data visualization to see how SLR changes over time in a particular location (Figure 2). The SLR values are the average for a 19-year time period centered on the decade shown. For example, the value given for the year 2050 is the average for the period 2041-2059. All projections are in feet relative to the 1991-2009 average sea level. Use the slider bar on the bottom right of the visualization to adjust the end year of the projections. For example, slide the toggle bar to 2080 and the graph on the left side of the visualization will change from an x-axis that goes to 2150, to one that extends to only the 2080s.

HOW TO SELECT PROBABILITIES

The 2018 SLR projections are probabilistic: they describe the full range of possible future sea level changes for a given greenhouse gas scenario, with the associated probabilities of exceedance within that range. The probability of exceedance in this case is an assessment of the likelihood that SLR will meet or exceed a certain magnitude by a specific decade. Probabilities were determined based on the current science concerning each individual component of SLR. Probabilistic projections provide powerful information that allows the user to plan for an amount of SLR that is consistent with the level of risk that their organization is willing to accept in a particular context. This acceptable level of risk will differ among organizations, and possibly also among policies, plans, and projects within the same organization depending on the potential consequences of SLR in each context. In this section, we explain how to interpret the probabilities when choosing which projections to use.

The probabilistic approach uses several sources of evidence — modeling, observations, and expert opinion — to assess the uncertainties associated with each of the processes that contribute to SLR (e.g., ocean processes, land-based glaciers and ice caps, and the melting of the Greenland and Antarctic Ice Sheets). For more information, see Miller et al. 2018 Appendix A, for details on how the probabilities were developed and account for the uncertainties in each of these processes. See Miller et al. 2018 Appendix B for details on the processes that contribute to SLR and their associated uncertainties.

The choice of which probabilities to use is not a scientific one. Rather, it should be based on the tolerance of the user's organization for risk and the consequences if SLR exceeds the levels for which you plan or design. In choosing probabilities, consider how the risk tolerance within your organization may differ depending upon the context in which the projections are being used. For example, does it differ for a general plan that is widely applied compared to an individual project design, or among different projects for which the consequences of SLR differ?

Key factors to consider when selecting from among the probabilities include the following:

- In most contexts, it will be important to evaluate the consequences of a range of probabilities before deciding on a single probability for use in a policy, plan, or project.
- In public planning and policy, the decision may require, or benefit from, outreach and engagement within and outside of your organization to arrive at a decision regarding an acceptable level of risk.

- Given the interdependencies of infrastructure built and managed by different organizations, consider the probabilities being used by other organizations that have affected plans, policies, or projects.

The 2018 SLR projections include likelihoods from 99% (magnitudes that are very likely to be exceeded) to 0.1% (magnitudes that are currently assessed as being very unlikely to be exceeded) and include a likely central range (83% - 17%). Here we describe how these probabilities relate to risk tolerance.

High-probability projections (>83%) are for lower values of SLR, meaning sea level is highly likely to exceed these values. In choosing to use these high-probability projections, there is a significant risk that SLR will be higher than the values for which you plan. Using high-probability projections is most appropriate for risk-tolerant situations, such as non-critical infrastructure or infrastructure that can easily accommodate SLR impacts. High-probability projections may also be appropriate for projects that have significant flexibility and adaptability, such as being easily modified or moved if SLR exceeds the values for which they were designed. For example, designing a beach path that can be easily moved uphill if it becomes necessary in the future.

Mid-range probability projections (83% - 17%) provide a current assessment of the most likely range of future SLR. Based on the Intergovernmental Panel on Climate Change definition of “likely” as the central 66% (between 83% and 17%) of a range. “Likely” is defined for the SLR projections as between 83% and 17% of the probability range. The 50% exceedance probability indicates the central estimate of the range, meaning that SLR is just as likely to exceed this value as not. The 50% probability is the sea level that is currently assessed as being most likely to occur based on current available science. This probability is appropriate for users who want the most likely future values and are not particularly risk-averse or risk-tolerant.

Low-probability projections (<17% likelihood) are associated with higher magnitudes of SLR. These higher magnitude projections are assessed as being less likely to occur but cannot be excluded as a possibility. In choosing to use low-probability projections, you are planning for a higher amount of SLR, and therefore taking on less risk that sea level change will have impacts. Using low-probability projections is a conservative approach most appropriate for risk-averse situations, such as those that involve the design of critical infrastructure (i.e. a sewage treatment plant) that would be seriously compromised by flooding.

Extremely low-probability projection (0.1% likelihood) is a particular case of a low-probability projection designed to provide a physical upper limit for SLR. We provide this value in light of recent scientific research showing an increase in the potential high-end projections of SLR. It is consistent with high-end projections provided in other SLR guides, such as the H++ scenario provided in the State of California Sea-Level Rise Guidance . Users should consider this probability for only an extremely conservative decision or when planning for a worst-case scenario. It is also an option for users who want a value for SLR that is unlikely to be revised upwards with additional scientific research.

Using the Data Visualization to Explore Probabilities

The various SLR probabilities of exceedance can be compared at a specific location using the SLR data visualization. Use the SLR data visualization to explore various likelihoods of exceedance by clicking on one or multiple checkboxes on the left side of the visualization (Figure 3). The graph on the right side of the visualization populates with the selected likelihoods, with one line per likelihood.



Photo credit: MyCoast Washington King Tides, Laura Goodrich, Seattle, WA

Using the Data Visualization to Explore Probabilities

The various SLR probabilities of exceedance can be compared at a specific location using the SLR data visualization. Use the SLR data visualization to explore various likelihoods of exceedance by clicking on one or multiple checkboxes on the left side of the visualization (Figure 3). The graph on the right side of the visualization populates with the selected likelihoods, with one line per likelihood.

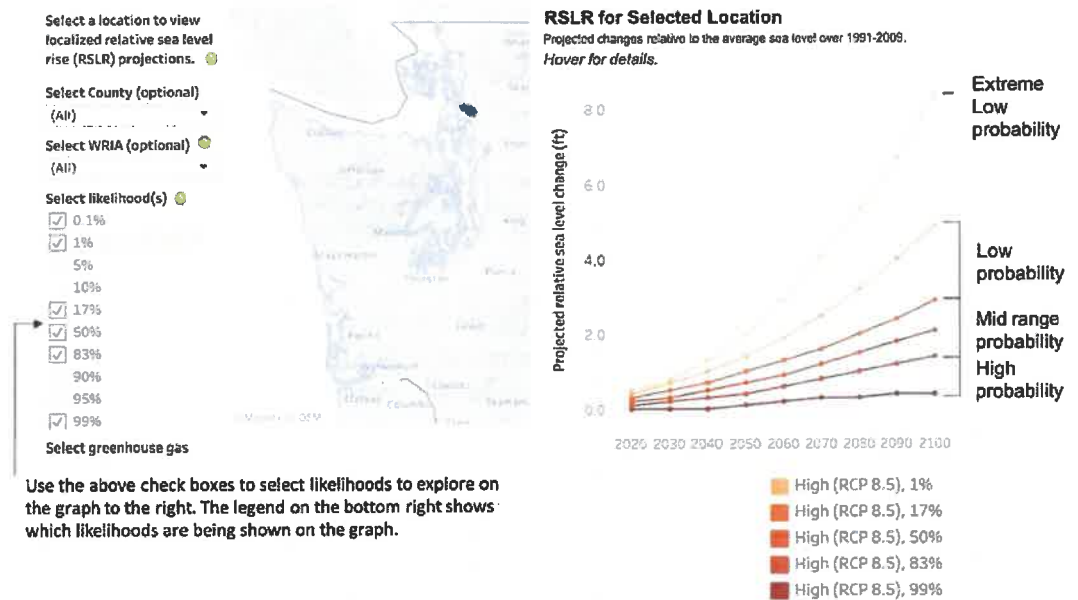


Figure 3. Compare SLR projections under different probabilities of exceedance by using the checkboxes on the left side of the visualization. Selected checkboxes are used to generate the line graphs on the right side of the visualization.

The SLR data visualization also enables the user to determine the timeframe when a specific SLR height will be exceeded with different probabilities. This can be useful in situations when the amount of SLR is anticipated to be problematic or when a plan or project has already been designed for a specific amount of SLR. For example, some organizations have designed infrastructure to current standards plus one ft to account for changing flood risk. You can use the SLR data visualization to determine when SLR is expected to exceed one ft, and with what probability.

For the example location shown in Figure 4, there is a 2% probability that sea level will exceed the additional 1 ft elevation by 2050 and a 67% probability that sea level will exceed the 1 ft elevation by 2100 under a high greenhouse gas scenario. Viewing probabilities with time in this way can inform whether additional modifications are needed to account for changing water levels or if this level of risk is acceptable.

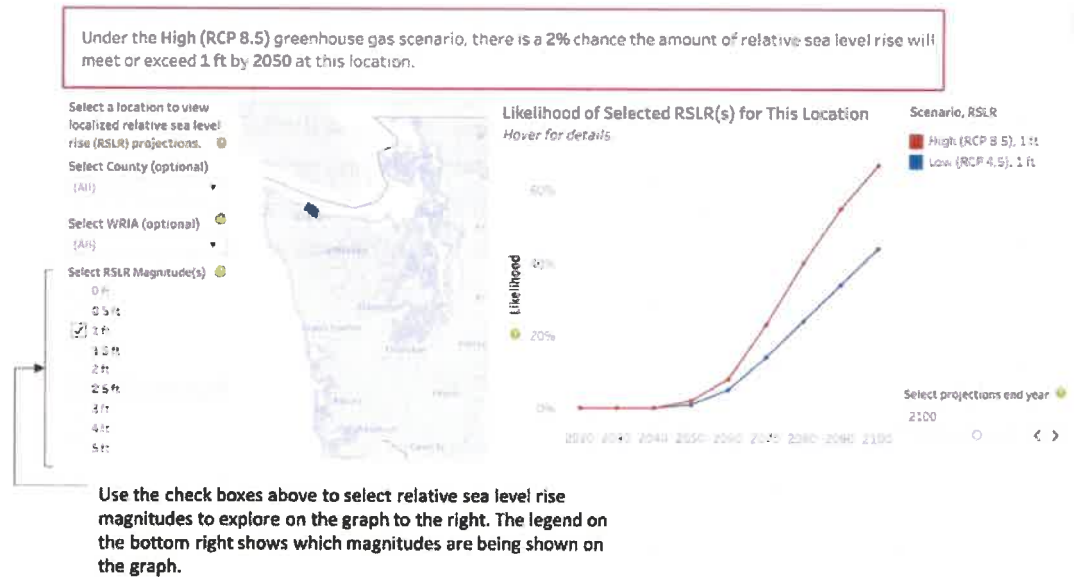


Figure 4. This visualization allows the user to explore the likelihood of a certain amount of SLR for a given decade (e.g., the user knows the amount of sea level change they are planning for [1 ft] and wants to know the likelihood that that amount will be exceeded for a given decade). In this example, there is a 2% chance that sea level rise at this location will be one ft or greater by 2050 under a high greenhouse gas scenario and a 67% chance that sea level rise will be one ft or greater by 2100 under a high greenhouse gas scenario. The tool tip on the visualization (shown in the red box) provides the user with a take-away sentence of what the graph is showing for a specific location, time period, greenhouse gas scenario, and magnitude.



Photo credit: MyCoast Washington King Tides, Steven Simmons, Ocean Shores, WA.

HOW TO SELECT GREENHOUSE GAS SCENARIOS

The 2018 SLR projections provide a full range of probabilities for future SLR associated with two greenhouse gas (GHG) scenarios, called representative concentration pathways (RCP). Choosing from among the SLR projections requires the user to select one or both scenarios. In this section, we provide some factors to consider when choosing between the two GHG scenarios, and when to consider using both.

These GHG scenarios affect how quickly the earth warms – higher GHG concentrations (RCP 8.5) will cause faster warming than lower GHG concentrations (RCP 4.5) – and thus how quickly the sea surface rises. Under the low GHG scenario, sea level would rise at a slower rate and is projected to reach lower magnitudes by 2150, compared to SLR projections for a high GHG scenario. However, it is important to note that SLR for the two scenarios is essentially the same through 2050 because warming through mid-century is primarily due to past greenhouse gas emissions.

Key factors to consider when selecting a GHG scenario(s) include the following:

- The timeframe of interest is relevant. SLR projections for the two GHG scenarios begin to diverge after 2050 (See Figure 5). If using projections for values before 2050, either RCP can be used with little difference. If using SLR values for beyond 2050, consider which GHG scenario to use more carefully.
- For vulnerability assessments or other initial impacts assessments, consider comparing both GHG scenarios and how the timing and amount of SLR, and thus impacts, will differ between them.
- Consider other climate change information being used within your organization. These GHG scenarios are commonly used to model and assess a range of climate impacts other than SLR. If GHG scenarios have been selected to evaluate other impacts, consistency within your organization may be useful in planning and project design, as well as for the purpose of communication

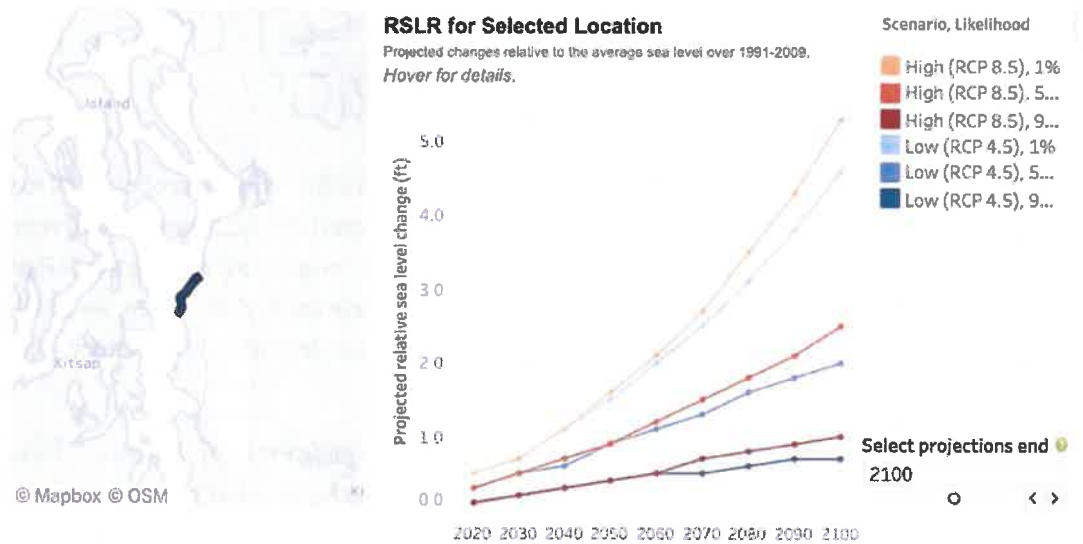


Figure 5. Projected SLR for low (RCP 4.5; blue lines) and high (RCP 8.5; orange lines) GHG scenarios. The visualization allows the user to select for viewing one or both GHG scenarios. Prior to 2050, the orange and blue lines for each likelihood selected (in this example, 1%, 17%, 83%) are almost identical. After the 2050s (shown in the red rectangle), the blue (low greenhouse gas scenario) and orange (high greenhouse gas scenario) lines diverge.

ADDITIONAL OPTIONS FOR VISUALIZING AND MAPPING SEA LEVEL RISE PROJECTIONS

The SLR data visualization described in this primer can assist with exploring, choosing, and using the 2018 SLR projections, but it does not allow you to visualize the spatial extent (i.e., mapping) of inundation associated with rising water levels. In this section, we describe some additional options for users who want to visualize or map the SLR projections in other ways, including inundation. Visualizing and mapping SLR projections can be a useful step in assessing potential exposure in an area. It can also help inform each of the choices described above by illustrating which assets and locations will be exposed to rising water levels. Visualization and mapping can also be critical for (1) any engagement process used to select SLR projections or for (2) any outreach process used to convey selected projections.

Here we describe three additional options for mapping SLR projections depending on your organization's capacity and commonly used tools.

1. For an initial exploration of the projected SLR inundation, consider using the NOAA Sea Level Rise viewer [Sea Level Rise and Coastal Flooding Impacts]. This viewer allows a user to view inundation with SLR in one-foot increments. The NOAA SLR viewer is a mapping tool ideally suited to initial planning or vulnerability efforts. The data used for this tool, shown as feet above MHHW, is not directly related to the 2018 SLR projections for Washington. However, the viewer can be used to see what the 2018 SLR projections might look like (to the nearest foot) on the land surface.

It is important to note that extreme water levels are not included in the NOAA viewer. However, by adding additional feet of SLR, the user can view the extent of inundation for SLR and an extreme water level. For example, to view the full extent of inundation including extreme water assuming two feet of SLR in Puget Sound, add three extra feet on the viewer beyond two feet of SLR to show the total of five feet of inundation.

2. The 2018 SLR projections can be mapped using Geographic Information System (GIS) software. *Guidelines for Mapping Sea Level Rise Inundation for Washington State* (Norheim et al., 2018) provides information for GIS professionals on how to map any selection of the projections. This option offers more flexibility than the NOAA Sea Level Rise viewer because SLR projections other than 1 ft increments can be mapped, any tidal datum can be used as a baseline, and changes in extreme water levels can also be mapped.
3. A final option is to incorporate the elevation changes associated with selected SLR projections into drawings for specific projects that rely on detailed computer-aided design (CAD). Norheim et al., 2018 also includes an example of using the SLR projections in CAD drawings.

NEXT STEPS

The next step after selecting values from the 2018 SLR projections for use in planning, policy, or project design, is to determine how to adapt those plans, policies, or projects to reduce the potential impacts of SLR. There are multiple options for adapting to higher water levels, including moving projects, modifying project designs, refining building codes, or requiring existing building codes in new at-risk locations. Selecting adaptation options will depend on how sensitive the area or project is to flooding and other impacts of SLR.

We expect that the 2018 SLR projections developed for the WCRP will remain the best estimates of SLR for Washington's coast for at least the next several years. The science of SLR is evolving rapidly and these projections will likely need to be revised as new SLR science emerges. Climate science is also evolving, and similarly new greenhouse gas scenarios and climate change projections will be released by the Intergovernmental Panel on Climate Change (IPCC) Sixth assessment in 2021. However, it could take several years to incorporate those scenarios and climate projections into new local SLR projections. Historically, SLR projections have been updated when there is new science, a demand for updated projections by local decision makers, and funding to support their development. The updated climate change projections of the IPCC could change the probabilities associated with the 2018 SLR projections for Washington state, although they are unlikely to shift projections outside of the full range of the projected values. Even with changes to the SLR projections, the decision-making framework presented here will continue to be relevant. Climate science, like most science, continuously evolves, so when using the 2018 SLR projections, consider a process to update the use of SLR projections over time or develop adaptation options that are robust to changing SLR projections.

