CHAPTER 3—CLIMATE SCIENCE FOR OLYMPIA
The Project Partners have acknowledged our local vulnerability to potential sea level rise for several decades. The Project Partners have tracked the science of climate change and gathered Olympia-specific information. The following is a summary of sea level rise dynamics in Olympia. More detailed data and information is included in the Plan’s Climate Science Review (Appendix C).

OLYMPIA’S LANDSCAPE

Olympia is located on Budd Inlet at the southern terminus of Puget Sound. The Deschutes River feeds Budd Inlet on the southwest side of the downtown peninsula and was dammed in 1951 to create Capitol Lake. Water levels within the lake are managed by a water control structure at 5th Avenue. This relationship between Puget Sound, the Deschutes River, and Capitol Lake affects Olympia’s propensity to flood, both currently and into the future.

The Olympia shoreline has been greatly altered by development over the past century. Large portions of the downtown area and the Port of Olympia are built on artificial fill that was placed over several decades which shifted downtown’s shoreline approximately 4,000 feet northward into Budd Inlet. These fill areas have been susceptible to subsidence and settling due to regional tectonic processes and natural soil compaction and are most susceptible to flooding from sea level rise. Currently available data indicates that the rate of subsidence in downtown Olympia is approximately 1 inch per decade. This will gradually increase the risk of flooding from sea level rise.

Flooding along the downtown peninsula is due to complex coastal processes, which include high astronomical tides, storm surge, Pacific Ocean basin phenomena, and local wind and wave processes. Each of these processes can raise water levels independently and two or more may combine to form exceptionally high coastal water levels – particularly along exposed sections of shoreline where wave effects are important. The City has made significant investments in its downtown area over the past several decades, many of which are now vulnerable to flooding.

WATER LEVELS AND WAVES

Olympia’s coastal water levels fluctuate naturally throughout the day due to astronomical tides produced by the gravitational pull of the moon and sun. Located at the southern end of Budd Inlet, Olympia experiences one of the largest tide ranges in Puget Sound. Typical daily tides reach heights of 14 to 15 feet above mean lower low water (MLLW) and the highest annual tides—called king tides—can exceed 16 feet.

Large storms associated with low pressure and high winds occur every winter in Puget Sound and can elevate water levels at the shoreline by 0.5 to 3 feet above normal tide conditions. Although the Olympia shoreline is protected from large ocean swells and waves, it is exposed to locally generated wind waves that can reach two to five feet.

In addition to coastal processes, large precipitation events also contribute to increases in local water levels. Heavy rainfall in the Deschutes River watershed can cause high river flows to overtop the river banks and overflow along the Capitol Lake shoreline.

LAND SUBSIDENCE IN OLYMPIA

Olympia is sinking in elevation (a process referred to as “subsidence”). This subsidence is tied to the underlying geology and history of fill placement in Budd Inlet. Over the next five years, we will take steps to improve our long-term ability to monitor subsidence and understand its implications for flood risk.
Figure 3 presents average tidal datums and extreme tide levels in Olympia. See call-out box for description of MLLW and NAVD88 vertical datums used to measure water levels and ground elevations in Olympia.

**CAUSES OF CLIMATE CHANGE AND SEA LEVEL RISE**

Recent State, federal, and international climate reports have reiterated that evidence of climate change is unequivocal and that the human influence on the climate system is clear (IPCC 2014, USGCRP 2018, Miller et al. 2018). Over the past few centuries, the composition of the atmosphere has changed as a result of human activity; there has been an increase in the concentration of various greenhouse gases, aerosols, and ozone. These changes are due to the combustion of fossil fuels, agriculture, deforestation, and land use changes. The cumulative impact of these atmospheric changes has been a net warming of the earth’s atmosphere and oceans at a global scale. As the planet has warmed, global sea levels have increased as a result of two primary processes:

- The warming of the oceans causes water to expand, thereby increasing sea levels at the coastline; and
- The warming of the atmosphere has caused melting of polar ice sheets and mountain glaciers, which increases the volume of water in the world’s oceans.
SEA LEVEL TRENDS

During the 20th century, global ocean levels increased at an average rate of 1.7 mm or 0.07 inches per year (IPCC 2013). Recent satellite altimetry observations show that this rate continues to accelerate every year due to increased melting of ice sheets in Greenland and Antarctica. Over the past 20 years, the rate has increased to 3.3 mm/year or 0.13 inches per year, roughly twice the average rate of the preceding 80 years (IPCC 2013; Chen et al. 2017).

Additionally, complex tectonic processes in the Pacific Northwest produce large spatial variations of land uplift and subsidence that lessen or amplify the relative rate of sea level rise with respect to the land. For example, large portions of the Olympic Peninsula are experiencing relatively high rates of uplift (3 to 4 mm/year), causing a relative drop in sea levels since the 1930s. In contrast, areas such as Olympia have experienced subsidence and more rapid relative rates of sea level rise. Analysis of long-term tide observations at Seattle indicates a 20th century sea level rise rate of 2.0 mm/year (equivalent to 8 inches/century), as indicated in Figure 4.
HOW MUCH SEA LEVEL RISE HAS OCCURRED RECENTLY?

Scientists have been measuring sea level rise over the last couple decades using a sophisticated technology known as satellite altimetry. Since 1993, satellites have been measuring changes in sea level across the global oceans. These measurements have shown that global sea level rise is not uniform, with some areas experiencing higher rates of sea level rise than others (see Figure 5—red areas indicate regions of relatively high sea level rise). On average, global sea levels have risen 3.4 inches since 1993 and 2.5 inches since 2000.

Estimating local sea level rise in Puget Sound during the 21st Century is challenging due to short-term sea level rise variations and a lack of long-term monitoring stations. Additionally, large-scale Pacific Ocean basin phenomena such as the El Niño-Southern Oscillation and Pacific Decadal Oscillation influence West Coast sea levels and make it difficult to accurately estimate short-term sea level rise trends. Observations at the Seattle tide station indicate sea level rise of approximately 1.5 to 3.3 inches since 2000. Continued observation of sea level trends in Puget Sound will be required to better understand this changing dynamic.
SEA LEVEL PROJECTIONS

The science associated with sea level rise is regularly updated, revised, and strengthened. Although there is no doubt that sea levels have risen historically and will continue to rise at an accelerated rate over the coming century, it is difficult to predict with certainty what amount of sea level rise will occur over a given time frame.

A 2012 study by the National Research Council (NRC) provided projections of sea level rise at the Seattle tide station. The NRC study projected likely rates of sea level rise of 3 ± 2 inches by 2030, 7 ± 4 inches by 2050, and 24 ± 12 inches by 2100. The NRC study also provided unlikely but possible high-range estimates of 9 inches by 2030, 19 inches by 2050, and 56 inches by 2100. The NRC projections for Seattle incorporated a regional rate of tectonic uplift of 1 mm/year into the sea level rise projections. However, measurements at Olympia indicate the ground may be subsiding at a rate of approximately 1-2 mm/year (0.4-0.8 inches per decade). Therefore, the NRC sea level rise projections could underestimate the local rate of sea level rise for Olympia since the ground is sinking as the water levels are rising. In this Plan, we have modified the NRC projects to account for subsidence in Olympia.

Table 3 shows the NRC sea level rise projections modified for Olympia to incorporate local subsidence.

Table 3: Sea Level Rise Projections for Olympia

<table>
<thead>
<tr>
<th>Year</th>
<th>Most Likely (inches)</th>
<th>High-Range (inches)</th>
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</thead>
<tbody>
<tr>
<td>2020</td>
<td>3</td>
<td>7</td>
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<tr>
<td>2030</td>
<td>5 to 7</td>
<td>11 to 13</td>
</tr>
<tr>
<td>2040</td>
<td>8 to 10</td>
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<tr>
<td>2100</td>
<td>32 to 36</td>
<td>64 to 68</td>
</tr>
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</table>
PRECIPITATION PROJECTIONS

As with sea level rise, there is considerable uncertainty surrounding the effects of climate change on precipitation. Local precipitation projections are one of the least certain aspects of global climate models, as the models do not resolve many of the fine-scale and complex interactions that produce spatially variable rainfall.

Researchers evaluate future precipitation trends using General Circulation Models (GCM) that capture relevant ocean, terrestrial, and atmosphere processes and their response to increased atmospheric greenhouse gas concentrations. An increase in the frequency and intensity of downpours is one of the clearest historical precipitation trends related to climate change in the United States and one that is expected to continue in the future.

GCM results for the Puget Sound region indicate that Olympia and the Deschutes River watershed may experience a 10 to 30% increase in extreme 24-hour precipitation by mid-century and a 10 to 30% increase by end-of-century, depending on storm event and emissions scenario. Results also indicate that moderate intensity events (such as the present day 20-year rainfall event) could occur more frequently.

Atmospheric rivers, bands of moisture that transport large amounts of water vapor from the tropics, are also projected to increase in frequency and duration. Atmospheric rivers can deliver a substantial amount of precipitation over the course of several days, amplifying storm conditions and elevating local water levels.

Increases in precipitation intensity could cause more frequent urban flooding in Olympia and require increased capacity or more active management of increasing peak flows entering the Budd Inlet Treatment Plant.
Future discharge rates from the Deschutes River are uncertain; however, adjacent watersheds show projected increases in total winter runoff and peak discharge events such as the 10-year, 50-year, and 100-year discharges. Increases in peak discharge events may cause more frequent and higher magnitude flooding along the Capitol Lake shoreline and adjacent low-lying areas.

The Project Partners continue to monitor emerging research on the impacts of climate change to local precipitation. Changes in precipitation that affect stormwater management and Budd Inlet Treatment Plant operations are of particular interest to the Project Partners. The University of Washington Climate Impacts Group is currently conducting research on future local precipitation trends, with a focus on the needs of stormwater modeling and combined sewer outflow planning. More information on this work can be found on the Group’s webpage.