# Tacoma Climate Change Resilience Study

**Environmental Services Department**
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City of Tacoma
WASHINGTON

# ACKNOWLEDGMENTS

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# CONTENTS

# ACRONYMS

| | |
|---|---|
| **BMP** | Best management practices |
| **CAPO** | Critical areas ordinance |
| **CARA** | Critical aquifer recharge area |
| **CEMP** | Comprehensive Emergency Management Plan |
| **CIG** | University of Washington Climate Impacts Group |
| **CIP** | Capital improvement project |
| **CMIP5** | Coupled Model Intercomparison Project Phase 5 |
| **FEMA** | Federal Emergency Management Agency |
| **GIS** | Geographic Information Systems |
| **GMA** | Growth Management Act |
| **HRSA** | Health Resources and Services Administration |
| **HUD** | U.S. Department of Housing and Urban Development |
| **LID** | Low impact development |
| **LIDAR** | Light Detection and Ranging |
| **MACA** | Multivariate Adaptive Constructed Analogs |
| **MHHW** | Mean higher high water |
| **OEPS** | Office of Environmental Policy and Sustainability |
| **PPM** | Parts per million |
| **RCP** | Representative concentration pathway |
| **SLR** | Sea level rise |
| **SUFMP** | Strategic Urban Forest Management Plan |
| **SWE** | Snow water equivalent |
| **WWTP** | Wastewater treatment plant |

Tacoma

**City of Tacoma**

April 26, 2016

In October of 2015, the City of Tacoma joined 484 other cities worldwide in the Compact of Mayors, the largest coalition of city leaders addressing climate change. By joining the Compact of Mayors the City of Tacoma is recognizing our commitment to reduce greenhouse gas emissions, track our progress and prepare for the impacts of climate change.

With over thirty miles of shoreline, soaring bluffs and a significant estuary at the mouth of a mighty glacier-fed river that joins Commencement Bay, Tacoma is the pearl of the Puget Sound. An uncomfortable truth is that many of our unique and treasured natural assets are threatened by climate change. Climate change threats extend to the built environment and people as well.

We are already seeing impacts of climate change, which will only get more pronounced over the coming decades. The purpose of the Climate Change Resilience Study is to help prepare the City of Tacoma to be more resilient in the face of these threats by enhancing our capacity to prevent, respond and adapt to threats posed by climate change.

Sincerely,

Marilyn Strickland
Mayor, City of Tacoma

T.C. Broadnax
City Manager

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# 1. INTRODUCTION

Climate-driven changes in temperature, precipitation, and sea level are projected to have wide-ranging impacts on the Puget Sound region in the coming decades, exacerbating other stresses such as those caused by urbanization and shoreline alteration. The City of Tacoma has been a leader in addressing environmental challenges created by legacies from our past. Climate change is a new threat, one that we must position ourselves to mitigate and adapt to both now and in the future. While many problems are already manifesting themselves, for the most part they will not be fully quantified for several more years or decades. This study marks the beginning of a process undertaken by the City of Tacoma to better understand and proactively manage climate risks in order to protect local residents, make sound investments, and ensure that the City can accomplish its long-term goals of growth and economic prosperity, even in a changing climate.

This report describes key climate impacts and vulnerabilities in Tacoma's built infrastructure, natural systems, and social systems. It also lays out priority adaptation actions that have been vetted by City departments and community partners. Finally, the document highlights remaining information gaps that the City may consider filling through additional research and analysis in the coming years.

# 2. METHODS AND SYSTEMS

The study began with a summary of climate drivers—such as increasing temperature, changes in precipitation and streamflow, and sea level rise—which are described in Section 3 and in more detail in Appendix 2. The summary was completed by the University of Washington Climate Impacts Group (CIG) using statistical downscaling methods and regional climate model simulations of the latest global climate scenarios, as well as recent regional impacts analyses.

That information about projected changes in key climate variables was then correlated with potentially exposed City services, asset types, and neighborhoods. The methodology involved four steps:

1. Identifying key features and evaluating exposure;
2. Analyzing sensitivity;
3. Evaluating adaptive capacity; and
4. Considering relative vulnerability.

Three systems were considered for this study:

1. **Social systems**, including general health, safety, and key social services;
2. **Natural systems**, including streams, lakes, open spaces, restoration sites, slopes, and freshwater and tidal wetlands; and
3. The **built environment**, with a focus on surface water, wastewater, and transportation assets.

The assessment team looked at vulnerabilities in these three systems in parallel, in order to facilitate the identification of potential adaptation methods that would provide multiple benefits.

For the built environment and natural systems, particular attention was paid to sites that were identified with City input. These included:

- Ruston Way, including Mason Gulch.
- Salmon Beach slopes.
- Marine View Drive.
- Commencement Bay, tideflats, and shoreline.
- Puyallup River, including delta, levees, historic channel zone, and restoration sites.
- First Creek.
- Leach Creek basin, including holding basin, pump station, and conveyance.
- Flett Creek basin.

### DEFINITIONS

Consistent with the Intergovernmental Panel on Climate Change (IPCC), we define climate vulnerability as a function of exposure, sensitivity, and adaptive capacity.

### EXPOSURE

The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.

Exposure is primarily a function of geography. For example, system components at low elevations close to the shore are more exposed to sea level rise than components further from the shore and at higher elevations.

### SENSITIVITY

The degree to which a system is affected by climate variability or change.

A system can be exposed to a climate impact, but that doesn't matter if it is not sensitive to that impact.

### ADAPTIVE CAPACITY

The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Greater adaptive capacity means lower vulnerability and greater resilience.

The social systems analysis took a broader look and used 2010 census data and City input to identify potentially at-risk populations and critical health and social services.

The team facilitated two stakeholder workshops with representatives from City Environmental Services, Planning and Development and Fire/Emergency Management departments, Pierce County Emergency Management, the Pierce County Sustainability Office, Metro Parks Tacoma, the Tacoma Pierce County Health Department, Tacoma Public Utilities and the Port of Tacoma.

One workshop was conducted midway through the project to share the findings of the climate driver analysis and discuss the implications for particular systems, and to identify additional City data sources. The second was conducted towards the end of the project to validate the results of the resilience study and conduct a participatory multi-criteria analysis exercise to screen potential adaptation strategies. Input from these workshops was incorporated into the resilience study and the final list of recommended adaptation strategies.

# 3. SUMMARY OF CLIMATE DRIVERS

## BACKGROUND

This document draws from existing datasets and literature; therefore, the time periods and spatial scale of the information vary. We provide projections specific to the City of Tacoma and the Puyallup River watershed where possible. Other data is reported at the scale of Puget Sound, Washington State, or the Pacific Northwest.

Most projections in this report are for the 2050s or similar mid- to later-century periods.[1] Sea level rise projections are included for 2050 and 2100. The 2050s are relevant to many management decisions and the maintenance or upgrading of existing infrastructure, whereas anticipated conditions in 2100 may be more relevant for siting new infrastructure assets and other decisions that will have long-lasting implications. There is more certainty around climate conditions through mid-century because they reflect the greenhouse gas emissions that we are producing today. Conditions later in the century will be influenced by economic trends and policy decisions about greenhouse gas emissions over the next several decades, and so the different climate scenarios have a wider range of possible futures to evaluate.

Key technical terms and definitions are listed in Appendix 1. More detail on all of the impacts summarized in this section is provided in Appendix 2.

While this project is focused on assessing vulnerability to climate change, it is worth noting that **natural climate variability** will continue to influence the Pacific Northwest climate—and through that, its communities and natural resources—even as human activities cause global warming. While average temperature is going up, for example, we will continue to see warmer-than-average years as well as colder-than-average years.

## CHANGES TO DATE

This section summarizes trends in the regional climate related to temperature, precipitation, and hydrology. It is important to note that **natural variability tends to be the dominant factor behind the shorter-term (yearly to decadal) fluctuations in temperature and precipitation.** Climate change is more relevant over longer time frames.

Observed changes include the following:

- **Average annual temperature increased.** Average annual temperature in the Pacific Northwest increased by 1.3°F between 1895 and 2011, with statistically-significant warming occurring in winter, fall, and summer [1] [2]. Trends in the vicinity of Tacoma vary by location. For example, the trend in average annual temperature at the Buckley monitoring station is consistent with the regional trend, while the McMillin station, which is a bit closer to Tacoma, has had an annual warming trend that is about half that of the Pacific Northwest average.

[1] For all projections except sea level rise, the "2050s" refers to the 30-year average spanning from 2041 to 2070. Other periods reported here include the 2040s (2031-2060) and the 2080s (2070-2099). Sea level rise projections for 2050 and 2100 are specific to those years, as reported in NRC 2012.

- **The frost-free season lengthened.** The frost-free season for the Pacific Northwest increased by 35 days (+6 days) from 1895 to 2011 [1]. This translates into a longer growing season for farmers.
- **Nighttime heat waves increased.** In general, west of the Cascades, nighttime heat waves occurred more and more frequently over the last century (1901 to 2009). There was no clear trend in daytime heat waves.[2]
- **Precipitation changes are less clear, but there is some indication that extreme precipitation may have increased.** There was no detectable trend in annual or seasonal precipitation in the Pacific Northwest between 1895 and 2011 [1]. Some studies have found an increased frequency in extreme precipitation events in the Pacific Northwest, but it depends on the study period and analysis method that they used. Locally, an increase in extreme precipitation has been observed in Tacoma since 2010, although it is not known at this time if the observed changes are statistically significant..
- **Snowpack has lessened.** Snowpack (measured on April 1 each year) in the Washington Cascades declined from the mid-20$^{th}$ century to 2006, with substantial natural year-to-year variability [3] [4].
- **Peak spring streamflow has been happening earlier.** The timing of peak spring streamflow shifted earlier by 0-20 days in many snowmelt-influenced rivers in the Pacific Northwest between 1948 and 2002 [5].
- **Mt. Rainier's glaciers have been shrinking.** Cumulatively, the area of Mt. Rainer's glaciers decreased by 27 percent between 1913 and 1994. Emmons Glacier, which feeds the headwaters of the White River, has lost about 14% of its volume since 2003 [6].
- **Sea level has risen.** The closest tide gauge is in Seattle. According to NOAA, sea level has risen by 7.8 inches over the last century.[3]

## FUTURE CHANGES

The concentration of greenhouse gases in the atmosphere is projected to increase dramatically in the 21$^{st}$ century absent changes in policies and practices to substantially reduce these emissions. Prior to the start of the Industrial Revolution, the concentration of carbon dioxide in the atmosphere was 280 parts per million (ppm). In 2014, three individual months (April, May, and June) exceeded 400 ppm.[4] If our future tracks with the high greenhouse gas emission scenario (RCP 8.5), often referred to as a "business as usual" scenario, by 2100 we can expect to reach an atmospheric concentration of carbon dioxide of 936 ppm [7].

Understanding how those changes in greenhouse gases translate into changes in 21$^{st}$ century climate requires the use of global climate models and scenarios of future emissions. These models and scenarios incorporate assumptions about future changes in global population, technological advances, and other factors that influence the amount of carbon dioxide and other greenhouse gases emitted into the

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2 Bumbaco et al. 2013 defined a heat wave as three or more consecutive days above the 99$^{th}$ percentile for the maximum (for daytime heat waves) or minimum (for nighttime heat waves) temperature anomalies.

3 According to NOAA, the long-term trend is an increase of +0.65 feet, or +7.8 inches, for 1899-2014. While there is also a gauge in Commencement Bay, it was installed in 1996 and therefore has not been in service long enough to calculate statistically meaningful sea level rise trends.

4 Monthly average concentrations in carbon dioxide will vary due to seasonal and monthly variations in carbon dioxide emissions from human and natural sources (e.g., plant respiration). For example, monthly values in 2014 ranged between 395.26 ppm (Sept 2014) and 401.78 ppm (May 2014). The highest monthly mean value reported to date since measurements began at Mauna Loa in March 1958 is 403.94 ppm (May 2015).

atmosphere as a result of human activities. The findings summarized in this report, which are drawn from various published studies or datasets, are based on two sets of scenarios. The first is the current generation of greenhouse gas scenarios, known as the Representative Concentration Pathway (RCP) scenarios. The second is the previous generation of scenarios, known as the SRES scenarios, which were used for many studies between 2001 and 2013. Key characteristics of the scenarios most frequently used in climate studies are listed in Appendix 2.

## Temperature

**All climate models project warming in the Pacific Northwest during the 21st century as a result of rising greenhouse gas concentrations in the atmosphere.** Warming is expected in all seasons, with the most warming occurring in the summer. The total amount of projected warming depends on the greenhouse gas scenario and time period. For the 2050s in the City of Tacoma:

- The average change in average annual temperature is +4.0°F to +5.3°F, depending on the emissions scenario, compared to 1970-1999 [6].[5]
- Temperatures are projected to warm more during the summer months (June to August) than the winter months (December to February). Winter warming contributes to an increase in minimum temperatures. In other words, the coldest days in the future will likely not be as cold as those of today. Maximum temperatures also increase, contributing to a greater likelihood of more intense heat waves [8].

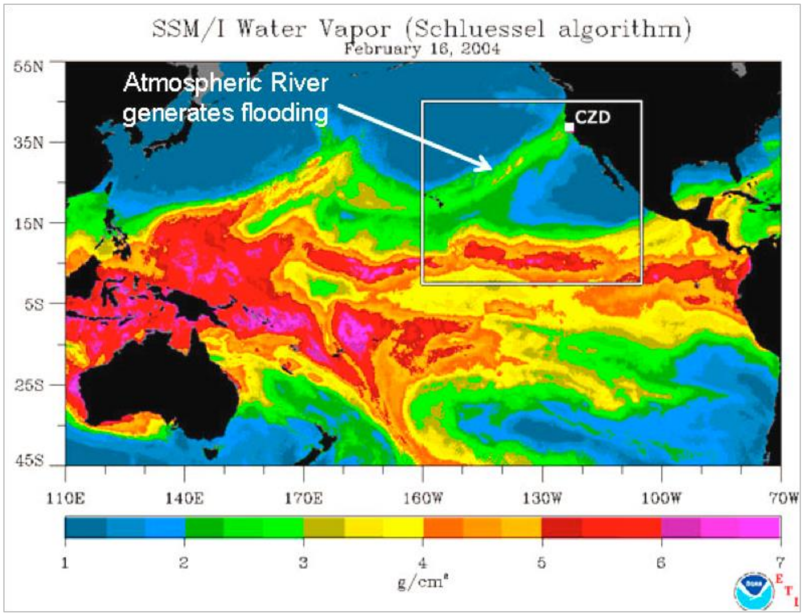
## Precipitation

**Climate models do not project significant changes in total annual precipitation for the Pacific Northwest.** We anticipate a slight increase in winter, spring, and fall precipitation (2 to 7 percent increase by the 2050s compared to 1950-1999) and slight decrease in summer (6 to 8 percent decrease over the same time frame).

**However, more of that precipitation could fall in extreme events, creating greater challenges for Tacoma's stormwater system.** Regionally, extreme precipitation events are primarily attributable to "atmospheric rivers," which are narrow bands of water vapor transport extending from the tropical Pacific to the west coast of North America during the winter months. Figure 1 shows a satellite image of a typical atmospheric river. Climate models show a rise in the frequency and intensity of atmospheric river events during the winter months along the U.S. west coast [1] [9] [10].

[5] "2050s" refers to the 30-year average spanning from 2041 to 2070.

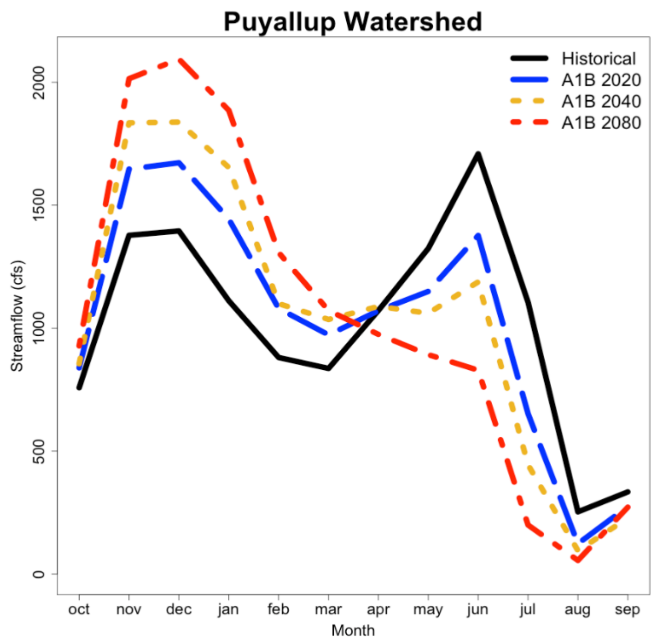
Figure 1. Satellite image of an atmospheric river. Source: NOAA.




**More precipitation will fall as rain, and snow will melt earlier in the spring**, due to changes in temperature and precipitation. Overall, this means a shorter snow season and earlier peak streamflow timing.

Figure 2 shows how peak streamflow timing and amounts are expected to change in the Puyallup watershed by the 2020s, 2040s, and 2080s for a moderate emissions scenario.

Figure 2. Monthly graph of streamflow estimated for the Puyallup watershed. Changes are shown for three time periods: the 2020s (blue line), the 2040s (gold line), and the 2080s (red line) for the A1B (moderate) emissions scenario. All changes are relative to average historical flows (1916–2006; black line). Source: Data from the PNW Hydroclimate Scenarios Project.




**Snowpack will continue to decline.** Under a medium emissions scenario, April 1st snow water equivalent (SWE)[6] in the Puyallup watershed is projected to decline by 52 percent by the 2050s and 58 percent by the 2080s. Under a higher emissions scenario, it is projected to decline by 63 percent by the 2050s and 80 percent by the 2080s.

**There are no quantitative projections for glacial recession for Mt. Rainier at this time.** However, current trends indicate that Mt. Rainer's glaciers—and others contributing to summertime streamflows and sedimentation in Puget Sound watersheds—will continue to melt as temperatures warm.

## Flood risk

**Flooding in the Puyallup watershed is expected to shift** as a result of changes in snowpack and increases in extreme precipitation events. Increasing temperatures projected for the region will force snowlines to rise in elevation, enlarging the effective basin area during storm events. Currently, there are no flood projections specific to the Puyallup watershed as a whole; however, projections for a major tributary to the Puyallup, the White River, can be assessed as a proxy for future floods in the watershed:

- **The magnitude of the 100-year flood for the White River at Buckley is projected to increase by 79%** (ranging from +40% to +145%) by the end of the century (2070 – 2099) compared to historical conditions (1970 – 1999) under a moderate emissions scenario [11].

[6] SWE is a measure of the total amount of water contained in the snowpack. April 1st is the approximate current timing of peak annual snowpack in the mountains of the Northwest.

- **Flood risk in the Puyallup watershed is expected to increase** along with the anticipated increase in heavy precipitation events [10].

## Stream temperature

**The warmer air temperatures projected as a result of climate change will increase water temperatures in watersheds throughout the Puget Sound region**, including the Puyallup watershed [12]. Increases are generally found in the lower elevation, downstream portions of watersheds where rivers slow, widen, and encounter warmer air temperatures.

## Landslides and sediment transport

**While there are no specific projections for changes in landslide frequency or location in the City of Tacoma as a result of climate change, landslides are expected to become a more common occurrence** due to projected increases in extreme precipitation events and increasing winter precipitation, particularly in areas most prone to present-day landslides. Changes in landslide frequency and sediment transport can affect water quality, aquatic and coastal habitat, flooding, and relative sea level rise.

**Sediment loads in the Puget Sound rivers, including the Puyallup, White, and Carbon Rivers near Tacoma, are expected to increase, further contributing to flood risk,** as declining snowpack and glacial recession expose more unconsolidated soils to rain, flood flows, and disturbance events [11] [12] [13] [14]. The Puyallup, White, and Carbon Rivers drain the glaciated, volcanic landscape of Mt. Rainier, delivering large amounts of sediment downstream to Commencement Bay. In the past, vast volumes of sediment were regularly dredged from the lower Puyallup basin, offsetting the immense inputs from the upper basin. However, this practice ceased in the mid-1990s to prevent detrimental effects on Chinook and steelhead habitat. From 1984 to 2009, the channel elevations of the Puyallup, White and Carbon Rivers rose by 7.5 feet, 6.5 feet, and 2 feet, respectively [15].

## Extreme wind events

**Preliminary research has not shown a clear trend in the frequency or intensity of extreme wind events over western Washington to help us anticipate changes in the coming decades** [16]**.** There is some indication that extreme wind events could shift earlier in the fall by as much as a week, increasing the chance that events occur when more leaves are on trees, but more research is needed in this area.

## Sea level rise

**In Washington State, sea levels are projected to increase by -1 to 19 inches by 2050, and by 4 to 56 inches by 2100, relative to 2000 levels** [17]**.** The amount of sea level rise at any specific location will be influenced by seasonal wind patterns, vertical land movement resulting from plate tectonics, thermal expansion of seawater, and sedimentation. Primary impacts include inundation of low-lying areas, increased exposure to storm surge, increased coastal flooding and erosion, and shifting or loss of habitat types. Higher sea level amplifies the inland reach and impact of high tides and storm surge, increasing the likelihood of today's extreme coastal events; with 24 inches of sea level rise, the 100-year flood event would become an annual event [18].

In the rest of this report, we use the high end of these estimates (19 inches by 2050 and 56 inches by 2100) to show the upper limit of what would be affected under current sea level rise projections – in other words, what could currently be considered a reasonable upper limit based on current scientific understanding. Figure 3 and Figure 4 use those estimates to illustrate areas that are at risk of flooding during extreme high tide events (i.e., 100-year events) under current conditions, and under projected future conditions in the years 2050 (Figure 3) and 2100 (Figure 4). Note that these illustrations of potential flooding areas are based purely on ground surface elevation and do not account for the presence or absence of flow pathways.

Figure 3. Potential flooding area during extreme high tides in 2050 using the high emissions scenario.

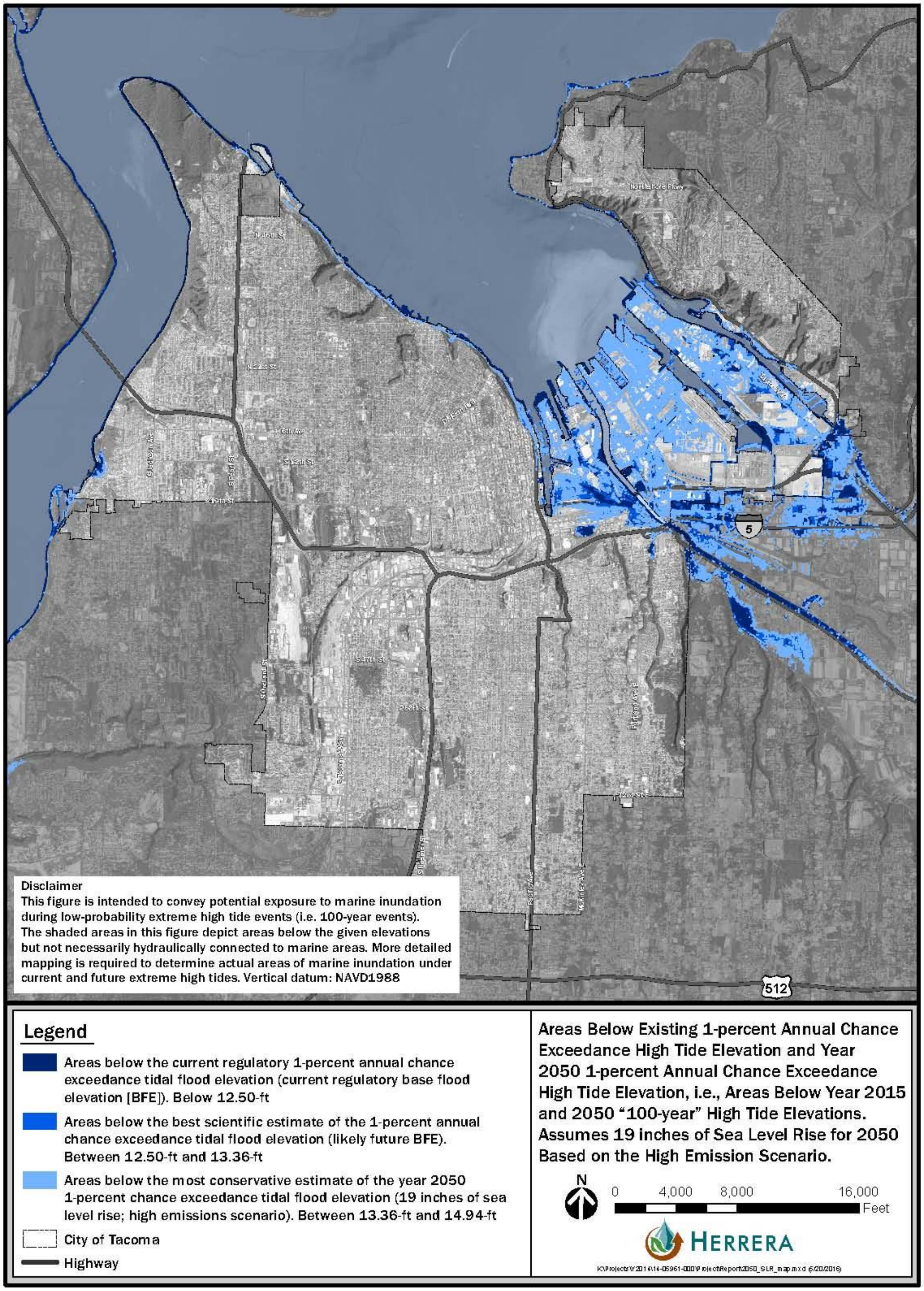
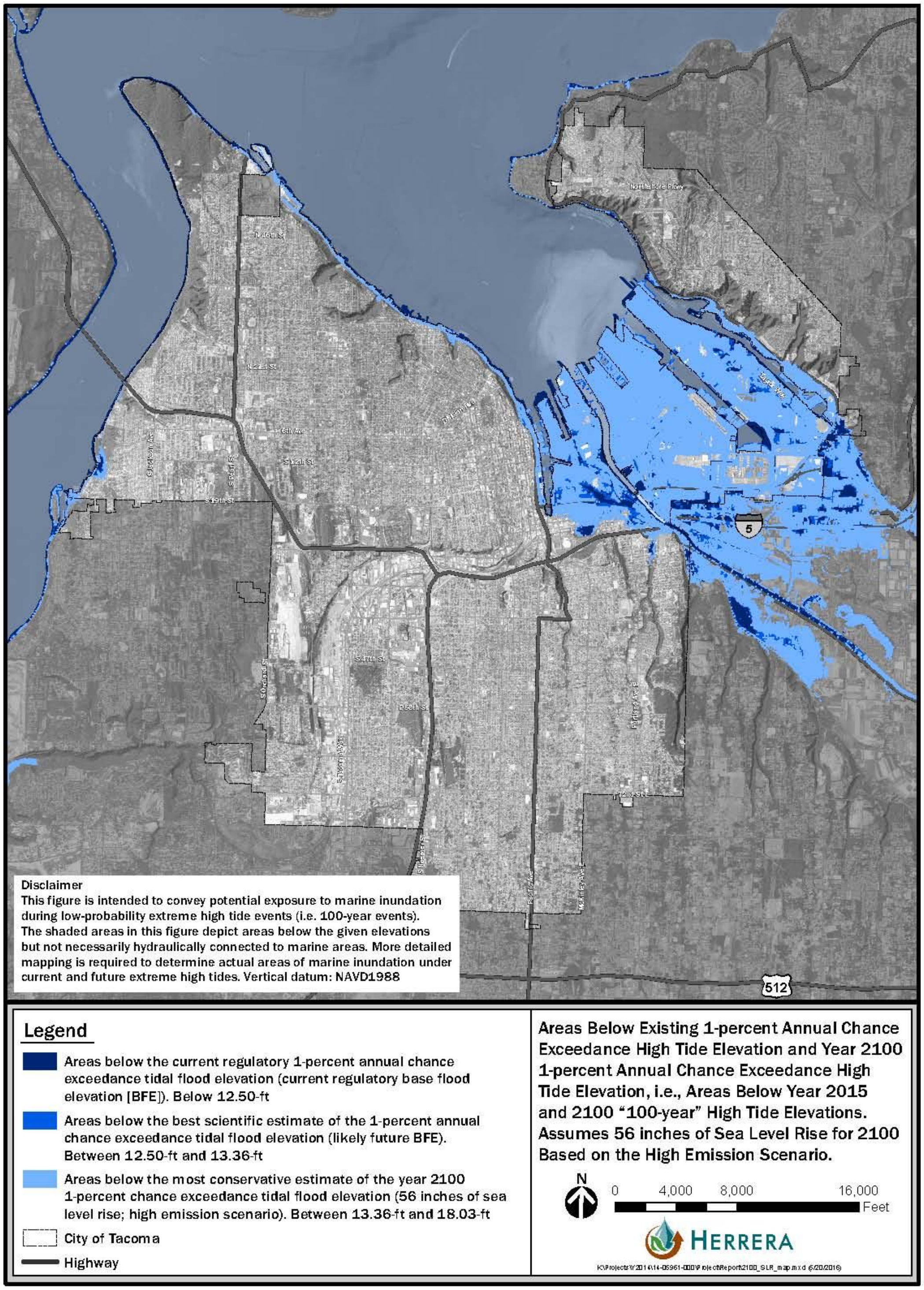


Figure 4. Potential flooding area during extreme high tides in 2100 using the high emissions scenario.



## Ocean acidification

Worldwide, the oceans have absorbed about 25 percent of the carbon dioxide associated with human activities, which has increased the acidity of the ocean by about 30 percent relative to pre-industrial times [19] [20]. Washington's marine waters are particularly susceptible to ocean acidification because of the influence of regional upwelling, which transports offshore, carbon-rich water to the continental shelf [21]. In urbanized estuaries and restricted inlets of Puget Sound, runoff from land brings nutrients and organic carbon that also influence pH levels [22] [20]. Ocean acidity is expected to increase in Puget Sound as a result of these regional factors and changes in global ocean acidification resulting from human activities, leading to impacts such as increased corrosiveness and inhibited shellfish development.

# 4. BUILT ENVIRONMENT

## STUDY AREAS AND METHODS

The assessment of built infrastructure vulnerability and risk focused on four primary systems:

- Surface water systems, including gravity conveyance pipes, streams and other open channel conveyances, major holding basins, and pump stations.
- Wastewater systems, including gravity conveyance, pump stations, force mains, and treatment plants.
- Transportation systems, including city-owned streets and bridges as well as state routes that lie within the study focus areas.
- Solid waste systems, including the closed Tacoma Landfill and infrastructure systems within that property.

The team evaluated infrastructure on a citywide scale, and then conducted a more detailed assessment in specific study areas. These study areas included:

- Tacoma tideflats, including low-lying areas between the Thea Foss Waterway and the Hylebos Waterway. This area includes the Central Wastewater Treatment Plant, numerous city streets, Port of Tacoma operational areas, and Burlington Northern Santa-Fe and Tacoma Rail operational areas.
- Shorelines, including all areas adjacent to the shoreline, except the tideflats.
- Landslide-prone areas.
- Leach Creek, including the Leach Creek pump station and holding basins.
- Flett Creek, including the Flett Creek pump station and holding basins.
- Marine View Drive.
- Ruston Way/Schuster Parkway.
- The downtown waterfront, including Dock Street.
- The closed landfill.

Within those study areas, special attention was given to sites with the greatest exposure to climate change impacts, and parts of the system that were determined to be most critical.

Infrastructure vulnerability was evaluated qualitatively through interactions with City staff during two workshops and review of available reference material. The qualitative review considered the systems' exposure to climate change impacts, the sensitivity of systems to those impacts, and the adaptive capacity of the systems to prevent or minimize effects. Table 1 provides an example to illustrate the vulnerability assessment process.

Table 1. Sample vulnerability assessment results.

| Asset Description | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|
| Ruston Way | High<br>Exposed to sea level rise in multiple areas and increase landslide potential. | High<br>Not protected from sea level rise by dikes. | Low<br>Modifying road would require work on an arterial street in a shoreline zone. | High<br>Significant flooding expected and increased landslide potential. |

In addition, the team used GIS to evaluate exposure to extreme high tides under both current conditions and projected future sea levels.

# KEY FINDINGS

## Climate Impacts

Key climate impacts and exposure of infrastructure systems include the following:

- **Sea level rise**: All infrastructure systems along the shoreline and in the tideflats focus areas will be exposed to sea level rise.
- **Extreme precipitation events**: All infrastructure systems in the city will be exposed to more frequent and more intense precipitation events.
- **Drought**: Infrastructure that is comprised of natural elements—such as street trees and vegetated stormwater systems—will be exposed to higher summer temperatures, more seasonal precipitation, and increased drought stress.
- **Puyallup River flooding**: Climate change impacts such as rising sea levels and more intense and frequent precipitation events are combining with non-climate stressors to increase the likelihood of damaging flooding events in the Puyallup River. River dredging was discontinued in the mid-1990s, allowing sedimentation to build up; as a result, portions of the Puyallup River levee system no longer provide adequate protection from the 100-year flood elevations and therefore no longer meet design certification criteria of FEMA’s National Flood Insurance Program [23]. Without accounting for climate change, the Puyallup River bottom elevation is expected to rise by 1.5 to 3 feet over the next 50 years, with a rise of up to 5 feet in some locations [24]. If the Puyallup River overtops levees near Tacoma, the flooding could adversely affect many types of infrastructure, including Interstate 5, as water flows towards Commencement Bay.

The new flood wall around the Central Wastewater Treatment Plant was designed to provide protection from a 500-year event plus 1 foot [25]. The level of protection provided by the wall is anticipated to decrease over time as a result of sediment deposition on the Puyallup River bottom.

Other key risks and projected impacts of climate change include:

- Increased repair and maintenance costs for the Central Wastewater Treatment Plant due to saltwater intrusion and inflow causing corrosion or system upsets.
- Increased landslide risks on Ruston Way and Marine View Drive.

- Disrupted economic activities and transportation in the tideflats area and other low-lying parts of the city.
- Increased flooding in portions of the surface water system that are already under capacity.

Table 2 summarizes the results of the built infrastructure vulnerability assessment.

Table 2. Summary of infrastructure vulnerability assessment results.

| System | Vulnerability | | |
|---|---|---|---|
| | **High** | **Medium** | **Low** |
| **Wastewater** | • Central Wastewater Treatment Plant<br>• Pump stations | • Conveyances (landslide-prone; already under capacity)<br>• Overflow points (surface water cross connections)<br>• North End Wastewater Treatment Plant | • Gravity conveyances in the tideflats and shoreline area<br>• Western slopes Wastewater Treatment Plant |
| **Surface water** | • Conveyances (that are already under capacity)<br>• Culverts and small bridges | • Conveyances (landslide-prone areas)<br>• Street trees and plants | • Pump stations and holding basins |
| **Transportation** | • Ruston Way<br>• Marine View Drive<br>• Tideflats<br>• Roads within the Puyallup River delta floodplain | • Roads near landslide-prone areas<br>• Dock street<br>• Street trees | • Pavement |
| **Solid Waste** | | | • Landfill |
| **Other** (with potential to affect several systems) | • Puyallup River levees | | |

More detailed vulnerability assessment results for each infrastructure system are provided below, including a summary of exposure, sensitivity, adaptive capacity, and criticality for each part of the system that was evaluated. Criticality of system components is also considered in the tables.

# DETAILED RESULTS

## WASTEWATER SYSTEM

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**The wastewater system is exposed to sea level rise, and therefore to the increased potential for saltwater intrusion and inflow into the system.** Large portions of the wastewater system in the tideflats are below the existing Base Flood Elevation [26] and several feet below projected future extreme high tides (see Figure 5, and additional maps in Appendix 3). There is no data on the current levels of salinity in the City's wastewater system to evaluate whether today's high tides are causing increased salinity levels.

**The wastewater system is less exposed to heavy flows from storm events.** The City of Tacoma no longer has a combined stormwater-wastewater system, although stormwater can still flow into the wastewater system through leaks. There are four sanitary overflow points that may allow salt water or stormwater to flow into the wastewater system during high tides or storms. This can be confirmed through additional analysis of the elevation of each weir. (Weirs are the components that, in times of heavier flow, control when water can flow into another pipe.)

**High tides may also flood pump stations and associated controls**. In a future study, this type of exposure should be evaluated for each asset within the marine flooding area. As a result of more frequent and intense precipitation, flow rates and potential for overflows will increase most in the leakiest parts of the system. Portions of the wastewater system are also located in landslide-prone areas, and are therefore exposed to a potential increase in landslide risk.

**Sensitivity to the higher flow rates will be greatest where the wastewater system is already under capacity or where system condition is poor.** Capacity was most recently evaluated comprehensively nearly a decade ago [27]. The City has made large investments to construct storage facilities and reduce inflow and infiltration; these actions reduce sensitivity to climate change impacts. Metal components of the wastewater system, including parts of the wastewater treatment plants, are sensitive to higher salinity in wastewater. Chronic exposure to salinity can increase rates of corrosion. The wastewater treatment plants could also be sensitive to an upset of biological processes if salinity concentrations of wastewater become high enough, such as from an extreme high tide that floods multiple portions of the system.

Detailed vulnerability assessment results for the wastewater system are provided in Table 3. See the text box on page 5 for definitions of exposure, sensitivity, and adaptive capacity.

Figure 5. Projected tideflats wastewater system exposure to sea level rise in 2050 under the high emissions scenario.

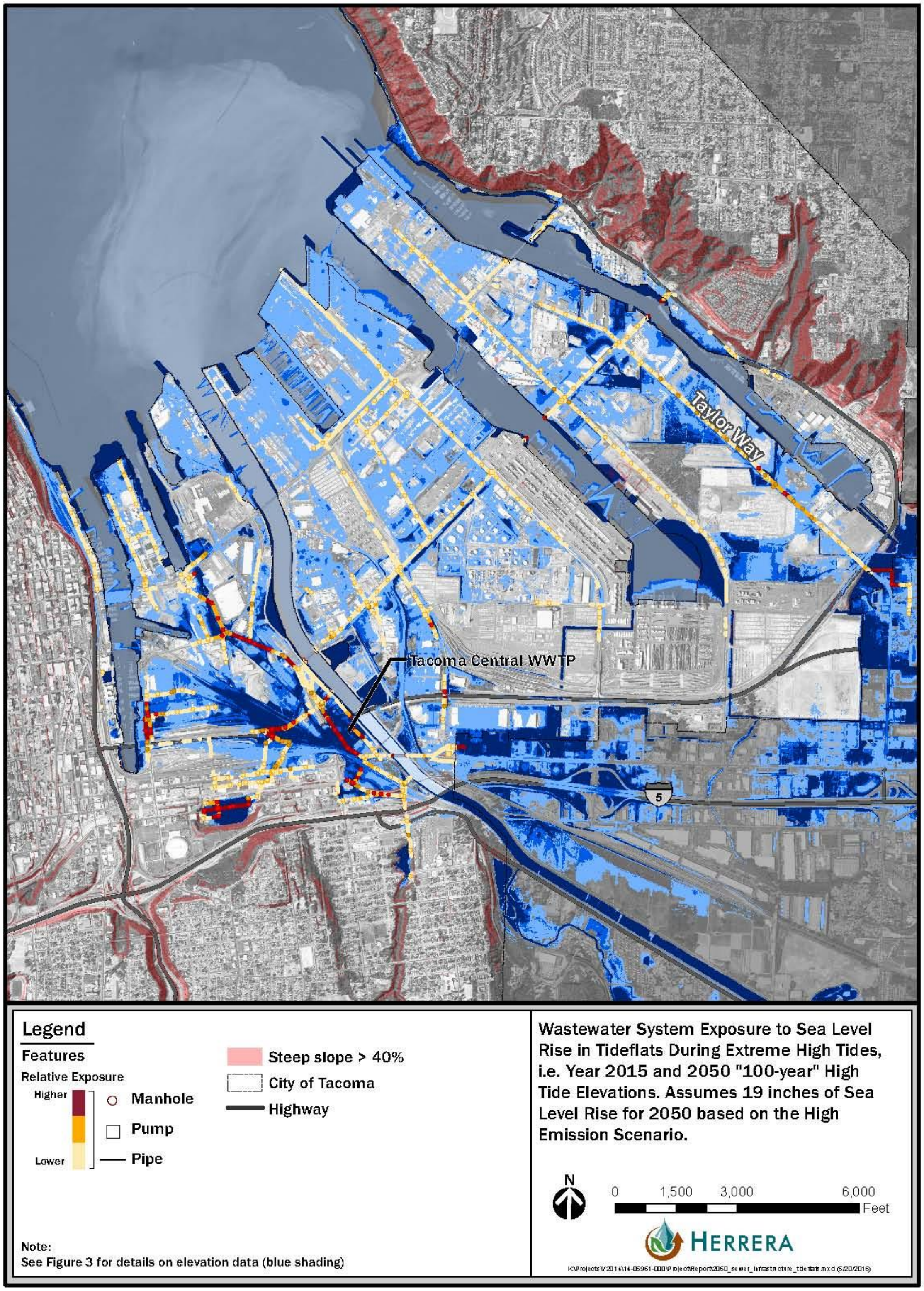


Table 3. Wastewater system vulnerability to climate change impacts and system criticality.

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Citywide** | Entire System | **Varies** | **Varies** Exposure is highest for areas with the most inflow and infiltration, within marine inundation areas, and in landslide hazard areas. | **Varies** Sensitivity is highest for portions of the system that are already at or under capacity. | **Varies** Adaptive capacity is highest where small improvements can reduce exposure or decrease sensitivity. | **Varies** Vulnerability to overflows is highest in areas that have high inflow and infiltration and are under capacity. Vulnerability to damage is highest in landslide-prone areas and at the wastewater treatment plant. |
| **Landslide-prone areas including gulches** | Conveyance system | **High** System failure in these zones can cause significant environmental impacts and affect property and health and safety. | **High** Study area was selected due to landslide risk. | **Varies** Sensitivity depends on location relative to landslide areas and existing condition. | **Low** Protecting or improving pipes in landslide zones is expensive and landslides are not feasible to prevent. | **Moderate** Vulnerability is highest in areas where landslide risk is greatest. |
| **Landslide-prone areas including gulches** | North End Treatment Plant | **High** A critical piece of wastewater infrastructure. | **Moderate** Exposed to increased potential for high flows and landslides in Mason Gulch, and increased potential for salinity in wastewater. | **Moderate** System components are sensitive to increased corrosion. Protection from landslides is limited. | **Low** Installing landslide protection or prevention would be costly. | **Moderate** Vulnerable to landslides and corrosion, but not at risk of marine inundation. |
| **Shoreline** | Gravity conveyance in marine inundation areas (see Figure 43) | **Moderate** System failure in these zones can cause significant environmental impacts. Less important than WWTP. | **Varies** Varies with elevation relative to sea level. | **Low** System would not likely be damaged by increased flow but excessive inflow could contribute to sewer overflow. | **Moderate** Reducing inflow and infiltration is moderately expensive. Some actions, like sealing manhole lids, have a low cost. | **Low** Vulnerability is highest in areas with lowest elevation (relative to SLR), highest leakage, and existing capacity problems. However, these system components are not likely to be damaged. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Shoreline** | Pump stations | **Moderate** System failure in these zones can cause significant environmental impacts. Less important than WWTP. | **Varies** Exposure varies by elevation and salt water inflow in tributary area. | **Varies** Sensitivity varies by level of flood protection in controls and corrosion resistance of other system components. Marine inundation could damage control panel and cause corrosion. | **Moderate** Pump station components can be raised or sealed at moderate relative cost. | **High** Rated as high until exposure and sensitivity are better understood, because the consequences could be relatively significant. |
| **Shoreline** | Wastewater overflows (stormwater-wastewater cross connections) | **Moderate** Important to prevent sea water from flowing to the WWTP. | **High** Exposure is higher for lower weir elevations. Higher sea level will backwater the stormwater outfalls and increase the frequency of flow through cross connections (sea water or stormwater) into the wastewater system. | **Moderate** Evaluate each asset individually. | **Moderate** Raising the weir elevations would not be difficult but would need to consider the potential for redirecting future wastewater overflows to less desirable locations. | **Varies** Varies with weir elevation and backflow prevention measures. |
| **Tideflats** | Central Wastewater Treatment Plant (see Figure 5) | **High** Most critical piece of wastewater infrastructure. | **High** Higher sea level and Puyallup River levels could flood the plant. | **Moderate** Flood wall provides protection from Puyallup. Sea level connectivity not well understood (flooding from perimeter, storm drain connections to marine areas, impacts on outfall). | **Low** Installing protection around entire tideflats area would be costly. Plant is governed by environmental regulations. | **High** Rated as high until exposure (Puyallup River flooding, saltwater intrusion) and sensitivity (flood protection, corrosion) are better understood. The consequences would be high. |
| **Tideflats** | Gravity conveyance in marine inundation areas (see Figure 5) | **Moderate** System failure in these zones can cause significant environmental impacts. | **Varies** Varies with elevation relative to sea level. | **Moderate** Conveyance system would not be damaged by increased flow but could contribute to sewer overflow. | **Moderate** Reducing inflow and infiltration is moderately expensive. Some actions, like sealing manhole lids, have a low cost. | **Low** Vulnerability to overflows is highest in areas with lowest elevation (relative to SLR), highest leakage, and existing capacity problems. But system is not likely to be damaged. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Tideflats** | Pump stations (see Figure 5) | **Moderate** System failure in these zones can cause significant environmental impacts. Less important than WWTP. | **Varies** Exposure varies by elevation and salt water inflow in tributary area. | **Varies** Sensitivity varies by level of flood protection in controls and corrosion resistance of other system components. | **Moderate** Pump station components can be raised or sealed at moderate relative cost. | **High** Rated as high until exposure and sensitivity are better understood. |
| **Shoreline** | Western Slopes Treatment Plant | **Low** Mothballed facility. | **Low** Above most conservative sea level rise elevation. Possible exposure to landslide potential in Narrows Creek Gulch. | **Low** Mothballed facility not providing services, therefore low sensitivity. | **Moderate** Geotechnical actions in Narrows Creek Gulch to reduce landslide risk would be costly. | **Low** Mothballed facility with limited exposure. |

## SURFACE WATER SYSTEM

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**The entire surface water system is exposed to more frequent and intense precipitation events, including those associated with atmospheric rivers in the winter months.** Flow response to more frequent and intense precipitation will be greatest in impervious areas; therefore, the assessment team evaluated land cover within each of the City's watersheds as an indicator of relative exposure (Table 4) [28]. The tideflats, Foss Waterway, Leach Creek, and Flett Creek watersheds have the highest percent imperviousness and thus can be said to have the highest exposure to more frequent and intense precipitation. In some areas, increased flow will be compounded with increased backwatering from higher tides. Portions of the surface water system are also located in landslide-prone areas and exposed to increased landslide risk. In addition, natural elements of the surface water system, such as vegetation used in stormwater facilities, will be stressed by increased drought.

Table 4. Tacoma watershed imperviousness.

| Watershed | Percent Impervious |
|---|---|
| Flett Creek | 52% |
| Foss Waterway | 61% |
| Joes Creek | 37% |
| Leach Creek | 54% |
| Lower Puyallup | 45% |
| North Tacoma | 47% |
| Northeast Tacoma | 42% |
| Tideflats | 78% |
| Western Slopes | 34% |

It is also important to note that the surface water system provides a conduit for sea water to flow into low-lying areas, and therefore is relevant to assessing the vulnerability of tideflats and shoreline areas to sea level rise.

**Sensitivity to increases in flow will be greatest in locations where the stormwater system is already overburdened, or where system condition is poor.** The City has evaluated capacity and condition for portions of the system and can use the results of those assessments as indicators of sensitivity to climate change. However, some system capacity problems are undocumented.

Sensitivity to increasing drought stress will be lower in portions of the surface water system that have irrigation and use native plant species.

See Figure 6 for a map of surface water assets in the tideflats that are projected to be exposed to sea level rise by mid-century. Detailed vulnerability assessment results for the surface water system are provided in Table 5.

Figure 6. Projected tideflats surface water system exposure to sea level rise in 2050 under the high emissions scenario.

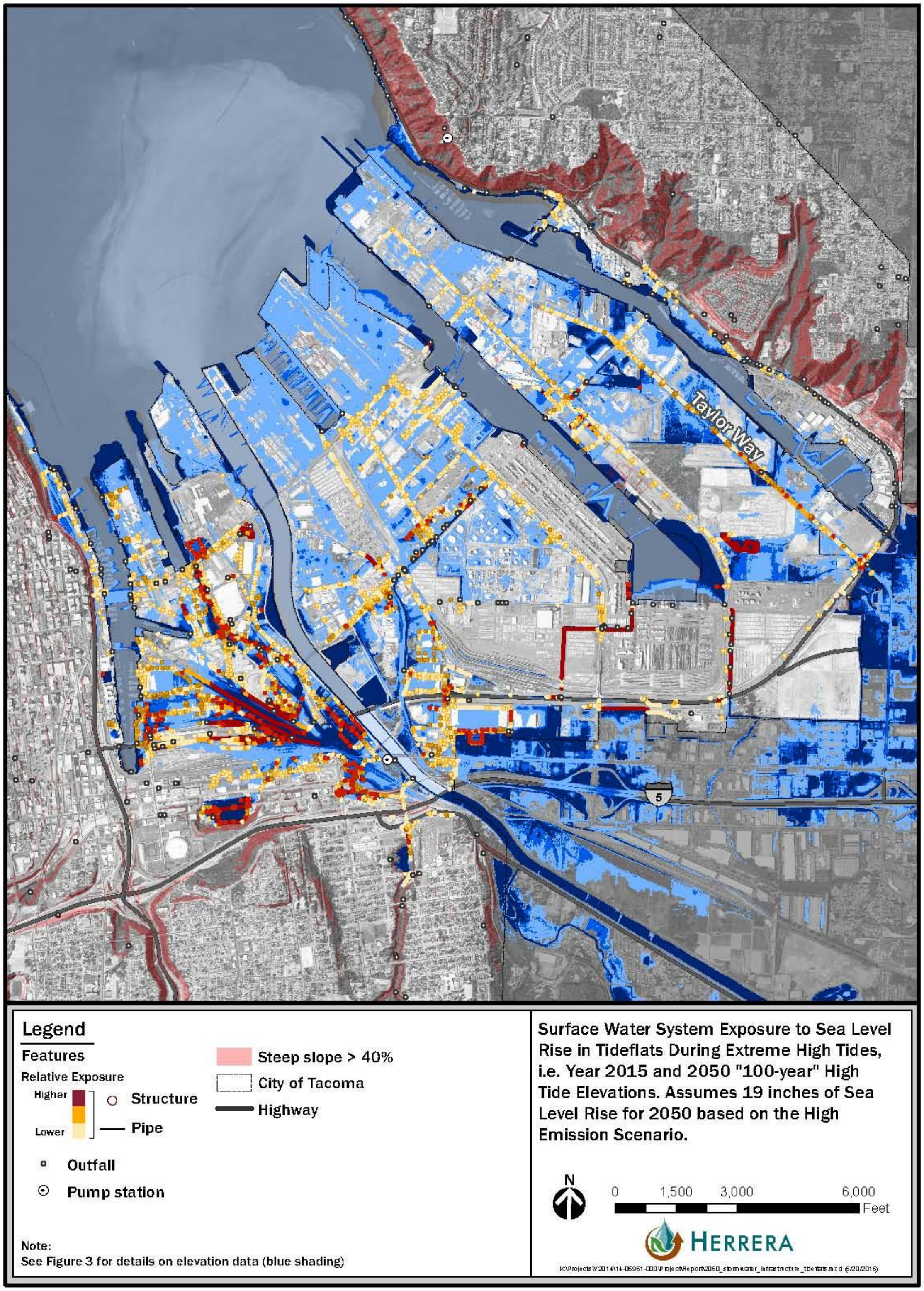


Table 5. Stormwater system vulnerability to climate change impacts and system criticality.

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Citywide** | Entire System | **Varies**<br>Depends on system component. | **Varies**<br>Exposure is highest for areas with the most impervious surface, tidal backwater influence, and in landslide hazard areas. | **Varies**<br>Sensitivity is highest for portions of the system that are already at or under capacity. | **Varies**<br>Adaptive capacity is highest where maintenance can reduce sensitivity. | **Varies**<br>Highest vulnerability in areas that are currently under capacity and areas that are affected by tidal backwater. |
| **Landslide-prone areas including gulches** | Conveyance system and outfalls | **High**<br>System failure in these zones can significantly impact property and health and safety. | **High**<br>Exposed to more frequent high flow events and greater potential for landslide impacts. Level of exposure depends on location relative to landslide areas. | **Varies**<br>Sensitivity depends on existing condition and system capacity to handle increased flow. | **Low**<br>System repairs or improvements in landslide-prone areas are expensive. | **Moderate**<br>Vulnerability is highest in areas where landslide risk is greatest and the system is in need of maintenance. |
| **Shoreline** | Tidally-influenced conveyance and outfalls (see Figure 44) | **High**<br>Shoreline infrastructure is typically in the vicinity of important roads and densely developed places. | **High**<br>Higher sea level will backwater tidally-influenced stormwater outfalls. More frequent extreme precipitation will increase flow rates. | **Varies**<br>Depends on existing system capacity. Areas without backflow prevention devices could contribute to flooding of low-lying areas. | **Low**<br>Backflow can be reduced through addition of backflow prevention devices but capacity issues are difficult to address. Working in the shoreline zone is expensive. Extensive permitting likely required. | **Moderate**<br>Highest in low-lying areas where backflow prevention devices are not present and areas with existing capacity problems. |
| **Leach Creek** | Leach Creek holding basin | **Moderate**<br>Attenuates flow to the pump station and downstream water bodies. | **Moderate**<br>Increased frequency of high flow events increases flow into holding basin. | **Moderate**<br>System capacity has been an issue at the holding basin, with large storms leading to flooding. | **Moderate**<br>Installing active management of the detention storage and conducting system maintenance are moderate-cost adaptation measures. | **Low**<br>Low because the downstream pump station has low vulnerability. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Leach Creek** | Leach Creek pump station | **High** Pump station is the system's only outlet. | **Moderate** Increased frequency of high flow events increases demand on pump station. | **Low** Pump station was built in 1991 and has adequate pumping capacity but discharges to surface water system in vicinity of S 25th Street and Hosmer Street where the system is already under capacity. | **Low** Upgrading the pumps would be expensive. | **Low** Flow increases are not expected to overwhelm pumping capacity. |
| **Leach Creek** | Conveyance downstream of Leach Creek Pump Station | **Moderate** Key infrastructure resides along this flow path. | **Moderate** Increased frequency of high flow events increases flow but impacts are dampened by Leach Creek holding basin. | **High** Surface water system from the vicinity of S 25th Street and Hosmer Street is already under capacity. | **Moderate** Upgrades to this large system would be expensive. | **Moderate** Flow increases in this sensitive part of the system will be attenuated by the Leach Creek holding basin. |
| **Flett Creek** | Flett Creek holding basins, includes Hosmer Holding Basin, Ward's Lake, gravel holding basin, and Flett Creek holding basins | **Moderate** Attenuates flow to the pump station and downstream water bodies. | **Moderate** Increased frequency of high flow events increases flow into holding basin. | **Moderate** System capacity has not been an issue at the holding basin to date. | **Moderate** Installing active management of the detention storage and conducting system maintenance are moderate-cost adaptation measures. | **Low** Low because the downstream pump station has low vulnerability. |
| **Flett Creek** | Flett Creek pump station | **High** Pump station is the system's only outlet. | **Moderate** Increased frequency of high flow events increases demand on pump station. | **Moderate** Pump station was built in 2014 and has adequate pumping capacity; however, the surface water conveyances (wetlands and streams) have limited capacity. | **Low** Upgrading the pumps would be expensive. | **Low** Flow increases are not expected to overwhelm pumping capacity. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Tide flats** | Cleveland Way Pump Station | **High** Pump station is the only outlet of this portion of the stormwater system. | **Moderate** Operating floor is roughly 17.1 ft., which is about 1 ft. lower than the conservative 2100 SLR elevations. May be exposed to Puyallup River flooding. | **Low** Facility includes flood protection measures such as removable stop logs on doors. | **Moderate** Additional flood protection measures could be installed at moderate cost. | **Low** Facility is only exposed to most conservative marine inundation estimate and it is equipped with flood protection. |
| **Tide flats** | Tidally-influenced conveyance and outfalls (see Figure 6) | **Varies** Depends on upstream property and infrastructure. | **High** Higher sea level will backwater tidally-influenced stormwater outfalls and more frequent extreme precipitation will increase flow rates. | **Varies** Depends on existing system capacity. Areas without backflow prevention devices could contribute to flooding of low-lying areas. | **Low** Backflow can be reduced through addition of backflow prevention devices but capacity issues are difficult to address. Working in the shoreline zone is expensive. Extensive permitting likely required. | **Varies** Highest in low-lying areas where backflow prevention devices are not present and areas with existing capacity problems. |
| **Landfill** | Landfill Pump Station | **Moderate** Pump station is the only outlet. | **Moderate** Exposed to more frequent high flow events. | **Low** System Is believed to have adequate capacity to accommodate larger events. | **Low** Upgrading the pumps would be expensive. | **Low** Low sensitivity due to additional available capacity. |
| **Citywide** | Culverts and small bridges | **Varies** Varies by exposed infrastructure, population, and property. | **High** Increased frequency of high flow events increase risk of flooding, erosion, and sedimentation. | **Varies** Depends on site conditions and design resiliency. | **Low** Upsizing typically involves complex work in streams, disruptive road projects, or expensive bridge projects. | **High** These areas of the stormwater system will be most affected by increases in flow. |
| **Citywide** | Areas with known capacity problems | **Varies** Varies by exposed infrastructure, population, and property. | **Moderate** Increased frequency of high flow events. | **High** These areas are already experiencing flooding. | **Low** Flow reductions and pipe upsizing entail expensive projects. | **High** These areas of the stormwater system will be most affected by increases in flow. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Citywide** | Street trees and vegetation for stormwater management | **Moderate** Street trees have moderate importance for stormwater management and heat reduction. Plantings have moderate importance for best management practices. | **Moderate** Exposed to higher temperatures and longer dry season. | **Varies** Native species and irrigated areas are less sensitive. | **High** Increased watering during plant establishment or dry summers, addition of irrigation, or planting more drought tolerant / native plants are all options. | **Moderate** Drier and hotter climate will increase stress on plants, especially on new plantings, but there are many low-to-moderate cost adaptation options. |
| **Puyallup River** | Levee system | **High** Breach of the levees could cause large-scale flooding and significant economic impacts. | **High** Exposed to increased and poorly understood flood levels along with combined hydrologic changes, sea level rise, and sediment deposition (delta progradation) effects. Projected increased flows. | **High** Small changes in sea level can be expressed over large distances in river channel, in combination with a feedback in sediment deposition within the main channel. Sensitivity depends on levee freeboard and internal condition of levees. | **Varies** Would require raising levees, which would require in-water work and potential property acquisition. Varies depending on space available for footprint expansion. | **High** Depends largely on levee freeboard, internal condition of levees and space available for footprint expansion. |

## TRANSPORTATION SYSTEM

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**The transportation system is exposed to rising sea levels in the tideflats and along the entire city shoreline.** For example, large segments of the system in the tideflats are below the existing Base Flood Elevation [26] and several feet below projected future extreme high tides (see Figure 7). All parts of the transportation system within the Puyallup River delta floodplain may be exposed in the event of a large Puyallup River flood. Portions of the transportation system, including Ruston Way and Marine View Drive, are located in or below landslide-prone areas and exposed to increased landslide risk. The entire system is also exposed to higher temperatures and increased drought risk.

**In most cases, coastal flooding associated with high tide events is not expected to cause widespread damage to road and rail infrastructure, but it would disrupt transit, particularly in the tideflats area.** Wind waves or scour could cause erosion in some locations.

**River flooding could be more of a problem.** The transportation system is very sensitive to erosion caused by Puyallup River flooding because most of system is not reinforced to withstand such flooding. Meanwhile, older and deteriorated pavement will be most sensitive to higher temperatures. Unirrigated and newly planted street trees will be most sensitive to drought.

The transportation system will also be exposed to potential erosion or flooding from increased surface water flows. See the surface water section for discussion of this exposure and related sensitivity and adaptive capacity.

Detailed vulnerability assessment results for the transportation system are provided in Table 6.

Figure 7. Projected tideflats road exposure to sea level rise in 2050 under the high emissions scenario.

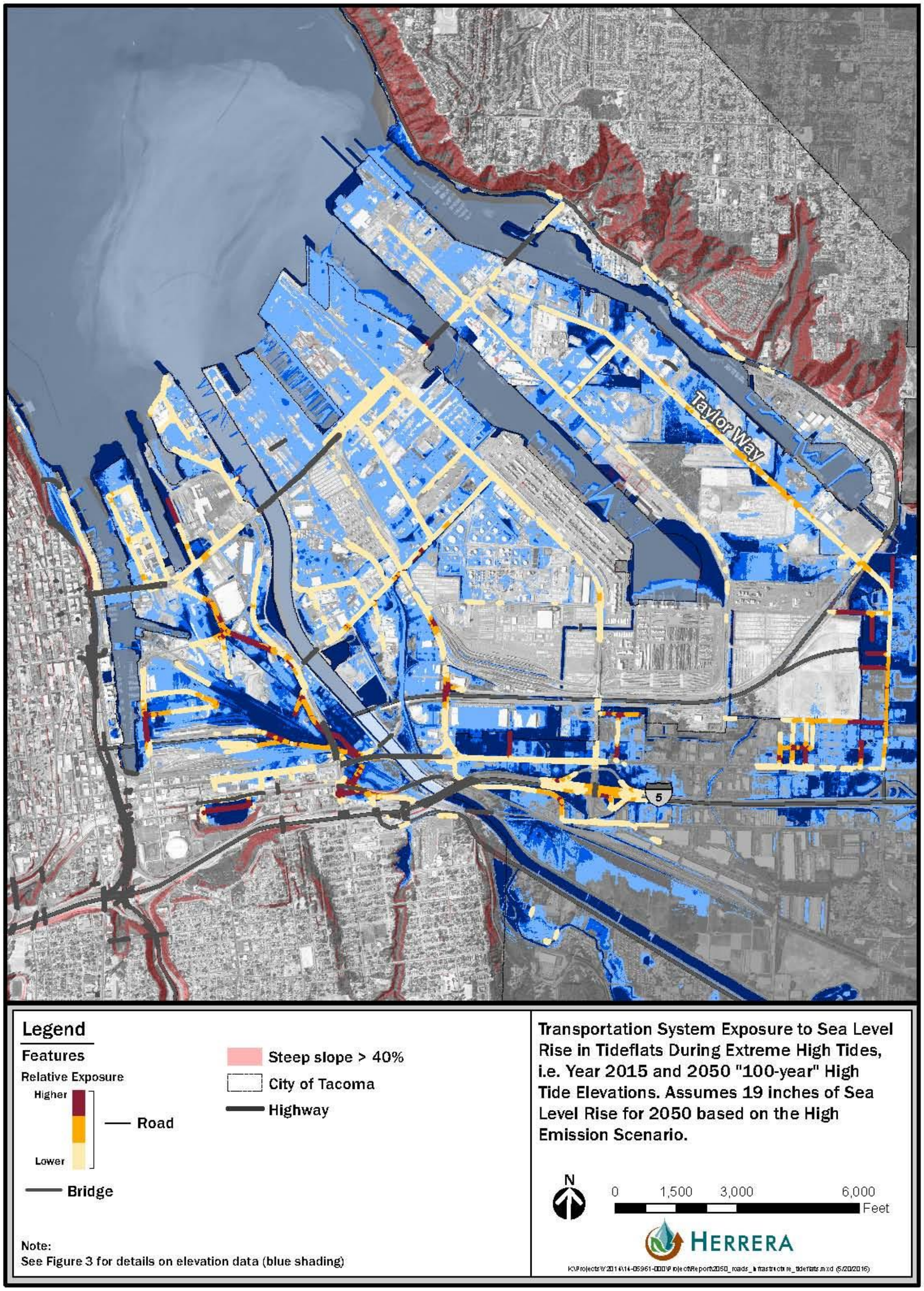


Table 6. Transportation system vulnerability to climate change impacts and system criticality.

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Citywide** | Roads | **Varies**<br>Varies with level of use and availability of alternate routes. | **Varies**<br>Varies with proximity to shoreline, landslide-prone areas, and surface water problem areas. | **Varies**<br>Sensitivity varies with existing road condition. | **Low**<br>Protection or modification of roads is expensive and disruptive. | **Varies**<br>Varies by road. |
| **Landslide-prone areas including gulches** | Roads | **Varies**<br>Varies with level of use. | **High**<br>More frequent landslides will affect roads above and below landslide-prone areas. Exposure varies with road location relative to potential slide areas. | **Varies**<br>Sensitivity varies with road condition and existing protection. | **Low**<br>Road modification or protection typically requires work in or near landslide-prone areas or along the shoreline. Stabilizing slopes can be expensive. | **Moderate**<br>Slide frequency and location are not well defined. |
| **Ruston Way** | Ruston Way (see Figure 45) | **Moderate**<br>Population and commercial areas along the street are limited. Alternate routes exist. | **High**<br>Exposed to sea level rise and increased landslide potential in multiple areas. | **High**<br>Not protected from sea level rise by dikes or levees. | **Low**<br>Modifying and protecting road would require work on a busy street in a shoreline zone. | **High**<br>Increased flood and landslide risk. |
| **Marine View Drive** | Marine View Drive | **Moderate**<br>Population and commercial areas along the street are limited. Alternate routes exist. | **Moderate**<br>Most of the road is higher than conservative sea level rise estimates but wind and waves may result in flooding. Exposed to increased landslide risk in multiple locations. | **High**<br>Not protected from sea level rise by dikes or levees. No protection from landslides. | **Low**<br>Modifying and protecting road would require work on a busy street in a shoreline zone. Stabilizing slopes can be expensive. | **High**<br>Significant flooding may result from sea level rise combined with storm surge. Increased landslide potential. |
| **Tide flats** | Roads (see Figure 7) | **High**<br>Significant potential for economic impact. | **High**<br>Exposed to sea level rise throughout the tideflats areas. | **High**<br>Only a few areas are well protected from sea level rise by dikes or levees. | **Low**<br>Construction of protection measures (e.g., walls) would be costly and difficult (permitting / coordination with ongoing Port activities). | **High**<br>Low elevation roads are highly vulnerable to flooding from sea level rise, which would disrupt tideflats operations. |

| Study Area | Asset Description | Criticality | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|---|---|
| **Downtown Waterfront Transportation Infrastructure** | Dock Street | **Moderate** Population along the street is limited but access within the areas could be affected. | **Moderate** Exposed to sea level rise at the southern tip of Thea Foss Waterway. | **Moderate** Not protected from sea level rise by dikes or levees. | **Low** Raising or protecting the road would be costly. | **Moderate** Limited roadway flooding expected. |
| **Citywide** | Bridges | **High** Bridges provide important connections around geographic obstacles. | **Low** Exposed to increased temperature. Older (small) bridges over streams may be affected by increased flow if they weren't designed for 3 ft. of clearance (see surface water). | **Low** Sensitivity to temperature is not well understood. Increased temperature could increase expansion and contraction and wear and tear. | **Low** Retrofits would be costly. | **Low** Limited understanding of effect of temperature increases on life cycle. |
| **Citywide** | Street Trees | **Moderate** Street trees have moderate importance for stormwater management, heat reduction, and aesthetics. | **Moderate** Exposed to higher temperatures and longer dry season. | **Varies** Native species and irrigated areas are less sensitive. | **High** Increased watering during plant establishment or dry summers, addition of irrigation, or planting more drought tolerant / native plants are all options. | **Moderate** Drier and hotter climate will increase stress on plants, especially on new plantings, but there are many low-to-moderate cost-adaptation options. |
| **Citywide** | Pavement | **Varies** Varies by road type. | **Moderate** Exposed to increased temperatures. | **Low** Change in rate of pavement deterioration may not be noticeable. | **Moderate** No in-place adaptation options for existing pavement. New hot mix asphalt (HMA) pavement can use more resilient binder. | **Low** Pavement sensitivity to changes in temperature and potential for increased maintenance cost is not well understood. |
| **Puyallup River historic channel migration zone** | Streets | **Varies** Breach of the levees would cause large-scale flooding and significant economic impacts. | **High** Increased and poorly understood flood levels associated with combined hydrologic changes, sea level rise, and sediment deposition (delta progradation) effects. Projected increased flows. | **High** City streets in this area are not reinforced to withstand river flooding. | **Low** Would require raising levees, which would require in-water work permits and potential property acquisition. | **High** High long-term vulnerability. |

# EXISTING PROGRAMS THAT CONTRIBUTE TO BUILDING RESILIENCE TO IDENTIFIED IMPACTS

In some ways, Tacoma's existing capital facilities programs, development regulations, and groups within Environmental Services already build infrastructure resilience to climate and non-climate stressors, both directly and indirectly. These programs can also provide additional opportunities for mainstreaming adaptation into City infrastructure and operations.

**Capital Facilities Program**. The City identifies, prioritizes, and implements infrastructure improvement projects for stormwater, wastewater, and transportation through the Capital Facilities Program and by developing capital project plans. Many of these projects build resilience to impacts identified in this assessment by addressing existing problems that will be exacerbated by climate change. For example, a capital project that addresses an existing capacity problem in the stormwater system also reduces sensitivity to increased flow resulting from climate change. Systems that are not well suited for current climate variability are also underprepared for future climate change impacts.

**Development regulations**. The City has regulations that restrict development within landslide and flood-prone areas. By restricting development in these areas, the City also reduces its exposure to the increased landslide and flood risks that are projected under climate change scenarios.

**The Asset Management group** of the Environmental Services Department. Although climate change resilience is not the explicit goal, the Asset Management group's support of the operation, maintenance and replacement of Environmental Services' damaged and aging infrastructure serves to reduce sensitivity to increased flow and other climate impacts.

**The Capital Delivery group** of the Environmental Services Department. This group provides project planning, design, and construction engineering services for capital improvement and maintenance projects, administers wastewater related programs, and conducts engineering studies.

**The Environmental Programs group** of the Environmental Services Department. This group is responsible for conceptualizing, developing, and implementing programs to improve and restore the City's valuable natural resources. The group's work falls into three categories: natural systems, built environment, and contaminated sites.

**The Office of Environmental Policy and Sustainability (OEPS)** of the Environmental Services Department. The OEPS develops and helps implement citywide policies and programs that highlight the potential effects of climate change and the types of mitigation or adaptation actions necessary to deal with those effects. By educating residents, businesses, and City staff, the OEPS is increasing the adaptive capacity of a range of stakeholders.

There is a need to consider climate change impacts (e.g., higher sea level, increased flow, and increased landslide risk) more explicitly in all of the existing programs listed here. For example, climate change considerations should be integrated into the process the City uses to prioritize CIP projects, and used to modify design standards. Climate change projections should also be factored in when reviewing and updating development regulations. Furthermore, the City's comprehensive plan policies could request that climate change adaptation be considered when prioritizing and designing future projects, and climate change resilience and adaptation could also be considered project criteria within the Capital Facilities Program.

# RECOMMENDED ADAPTATION STRATEGIES: BUILT ENVIRONMENT

**Adaptation options for the wastewater water system** include reducing exposure by raising the infrastructure above projected high tide elevations, and reducing sensitivity by installing measures to address inflow and infiltration. Such adaptation measures will be easiest to implement in portions of the system that are outside of critical areas—and, therefore, have relatively easier and less expensive permitting—and in less intensively developed settings where construction will be cheaper and less disruptive.

**Adaptation options for the surface water system** include reducing exposure through implementation of flow control best management practices, increasing canopy cover, and reducing the amount of impervious surface. Sensitivity can be reduced by conducting more frequent maintenance and expanding system capacity or making better use of existing capacity.

**Many potential adaptation measures to reduce exposure to extreme high tides and Puyallup River flooding will be costly and difficult**. These include potentially raising the elevation of infrastructure and building new and higher seawalls and setback levees. In the near term, the City could develop a plan to reroute traffic around isolated flooding areas, but it would first need to develop detailed maps of marine flooding. Different pavement binder could be employed to reduce the sensitivity of new pavement. For drought preparedness, planting native species, extending plant establishment periods, installing irrigation, or funding tree watering programs are all adaptation options.

Specific adaptation strategies are listed below in three groups: near-term windows of opportunity, low-hanging fruit, and longer-term measures.

## Near-Term Needs and Windows of Opportunity

- **Review ongoing and near-term capital improvement projects for climate change considerations** including future increases in flow, higher sea level, higher groundwater, increased landslide risks, and increased stress on plants, possibly through existing Design Integration Review Team processes.
- **Encourage the leads of existing Puyallup River flood planning and reduction work to integrate relevant climate change considerations** (e.g., increased sediment, increased flow, increased sea level) into current and near-term work, including work being conducted under the Floodplains by Design program and work proposed in the Phase 2 Application for HUD's National Disaster Resilience Competition.
- **Evaluate the development code related to landslide and flooding hazards** to ensure that development practices and future projects reduce risk to public safety and infrastructure from climate change impacts. Loss of property taxes may be one consideration during this process.
- **Develop a city standard of practice that accounts for climate change (e.g., higher flow, higher sea level, higher temperature) in the design of capital projects** (e.g., surface water and wastewater conveyance infrastructure, infrastructure near the shoreline, infrastructure near landslide zones, planting, pavement design). The standard would be integrated into the City's current design standards for use on all projects or selective use on certain projects depending on risk and level of certainty related to specific climate impacts. The standard would be updated as climate change projections evolve. Currently, US Army Corps of Engineers standards exist for addressing sea level rise in design, but the City may choose to provide additional clarification on how to use the Corps'

standards and how they apply to the City. The City should also consider what can be gleaned from other jurisdictions as standards are developed locally and regionally. Examples include defining a standard for modeling tidal influence on stormwater outfalls and selecting design storm.

## Low-Hanging Fruit

The following low hanging fruit includes strategies that can be addressed at low cost and with limited additional data collection:

### WASTEWATER

- **Identify manholes at risk of marine flooding using GIS; install gasketted and bolted manhole lids.** This would require consideration of system venting requirements.
- **Raise the elevation of weirs at wastewater-stormwater cross connections (e.g., wastewater overflow points) that are vulnerable to sea level rise.** This requires evaluation of weir elevations relative to sea level and consideration of whether modification of the weir could have negative effects, such as leading to sewerage overflows in other, less desirable locations.

### SURFACE WATER

- **Prioritize inspection and maintenance of holding basins and other stormwater system components** (e.g., inlets) that contribute to reducing sensitivity to increased storm intensity or volume.
- **Encourage low impact development (LID) practices for stormwater management where feasible.** This can provide multiple benefits, including reduced heat island effects.
- **Upgrade critical stormwater inlets (or nearby inlets that are easily modified) to reduce the sensitivity to intense storms in the fall (e.g., by installing curb inlets).** Consider potential downstream effects of inlet modifications, such as increased debris or sediment in the downstream pipe network.

## Longer-Term Projects

The following longer-term projects include strategies that may be expensive or require additional analysis or planning prior to development and implementation:

### WASTEWATER

- **Develop and implement capital improvement projects to address sea level rise impacts on the Central Wastewater Treatment Plant and wastewater system** based on the outcome of salinity data collection and detailed marine inundation mapping. Measures could include sealing manholes, lining pipes, modifying structures, or raising control panels.

### SURFACE WATER

- **Install backflow prevention devices on marine outfalls that are likely to contribute to flooding of low-lying areas.** Activities depend on the results of detailed marine inundation mapping.
- **Encourage the US Army Corps of Engineers and Pierce County to investigate raising and setting back the Puyallup River levees** to reduce flood risk.

- **Consider prioritizing surface water system improvements downstream of Leach Creek pump station outfall to Foss Waterway twin 96'ers** where increased flow would strain a part of the system with existing capacity problems.
- **Enhance urban forest canopies** for urban heat reduction, surface water management, and habitat. This requires careful consideration of short-term and long-term benefits and impacts. For example, more trees may contribute to clogging of storm drain inlets or the need for additional maintenance, but adding a leaf pickup program may address this potential issue.

### TRANSPORTATION

- **Explore ways to increase the resilience of transportation system components such as roads,** beginning with an evaluation of landslide potential in particular sites and detailed marine inundation mapping.

## RECOMMENDATIONS FOR FURTHER STUDY

The following data needs are critical for understanding the city's risks from climate change and sea level rise. The data can be used to plan out adaptation strategies and prioritize capital improvement projects.

- **Study and plan for the interaction between sediment production, flow, and sea level rise in the Puyallup River.**
- **Conduct marine inundation area mapping.** This process would include:
  - Checking topographic data for all infrastructure within the tideflats and shoreline areas, and comparing with sea level rise elevations.
  - Evaluating sea level rise impacts in more detail by examining flow connectivity to determine whether tideflats and shoreline areas are protected by existing flood structures and which areas are at risk either due to surface flow pathways or due to storm drain or utility connections with water sources. Use results for planning adaptation strategies for all infrastructure (e.g., Ruston, Marine View, Tide Flats, and Dock Street).
- **Conduct more detailed site-by-site evaluation of exposure to landslide risks** focusing on most critical roads, infrastructure, and vulnerable populations, as well as areas where under-capacity surface water conveyance may lead to steep slope erosion or landslide potential (e.g., Ruston Way, Stadium, Stadium Bowl).
- **Coordinate with the Port of Tacoma, BNSF Railway, Tacoma Public Utilities, and other property owners within the tideflats** to evaluate the impacts of projected future flood risk on tideflat operations.
- **Integrate increased inflow and infiltration potential resulting from climate change into future inflow and infiltration evaluation projects.**
- **Develop a comprehensive and prioritized list of capacity-related surface water problems for the whole city.** These problem areas are likely to have the greatest risk from increased flow.
- **Develop a list of existing surface-water problem areas along the shoreline,** consider whether these problems are likely to become much worse with sea level rise, and integrate the results into capital project prioritization.

- **Collect salinity data on wastewater treatment plant influent** to determine whether saltwater intrusion or inflow could be contributing to corrosion of system components.
- **Evaluate the existing level of saltwater intrusion and inflow into the wastewater system**, and analyze how exposure and sensitivity are likely to change as a result of sea level rise.
- **Pinpoint where culverts, bridges over natural streams, and other components of the stormwater conveyance system intersect with the greatest potential for flood damage to property or people** and integrate that knowledge into capital project planning and prioritization**.**
- **Confirm that the landfill drainage system has adequate capacity to handle increased flow**.

# 5. NATURAL SYSTEMS

The City of Tacoma covers several distinct landscapes that support a number of key natural systems. The Puyallup River, for example, drains over 1,065 square miles, integrating both glacial and volcanic inputs from Mt. Rainier. Tacoma also includes approximately 33.6 miles of Puget Sound shoreline, where the landscape is shaped by local sediment supply, winds, and tides.

The glacial history of the Puget Sound lowlands is manifested through the city in a number of ways, including the broad glacial till plains in the north and south, the expansive glacial outwash that underlies much of the city and is exposed in ravines, and the South Tacoma Channel that remains from the glacial meltwater channels that flowed from the once ice-dammed Puyallup River valley. More recent processes, particularly within the Puyallup River valley, have also formed key aspects of the city at low elevations.

Urbanization has altered most of the city's natural systems. Most notably, development within the tideflats has removed around 98 percent of the former intertidal wetland areas [29]. Urbanization has also dramatically altered land cover characteristics. More urban land cover has replaced forest cover, bringing more impervious surfaces which have significantly changed the ways water moves through the landscape. Significantly more surface runoff is generated and routed through local lakes, wetlands, and streams, changing the form and function of those systems. Built stormwater systems address this issue throughout the city; see Section 4 for more detail on the built environment.

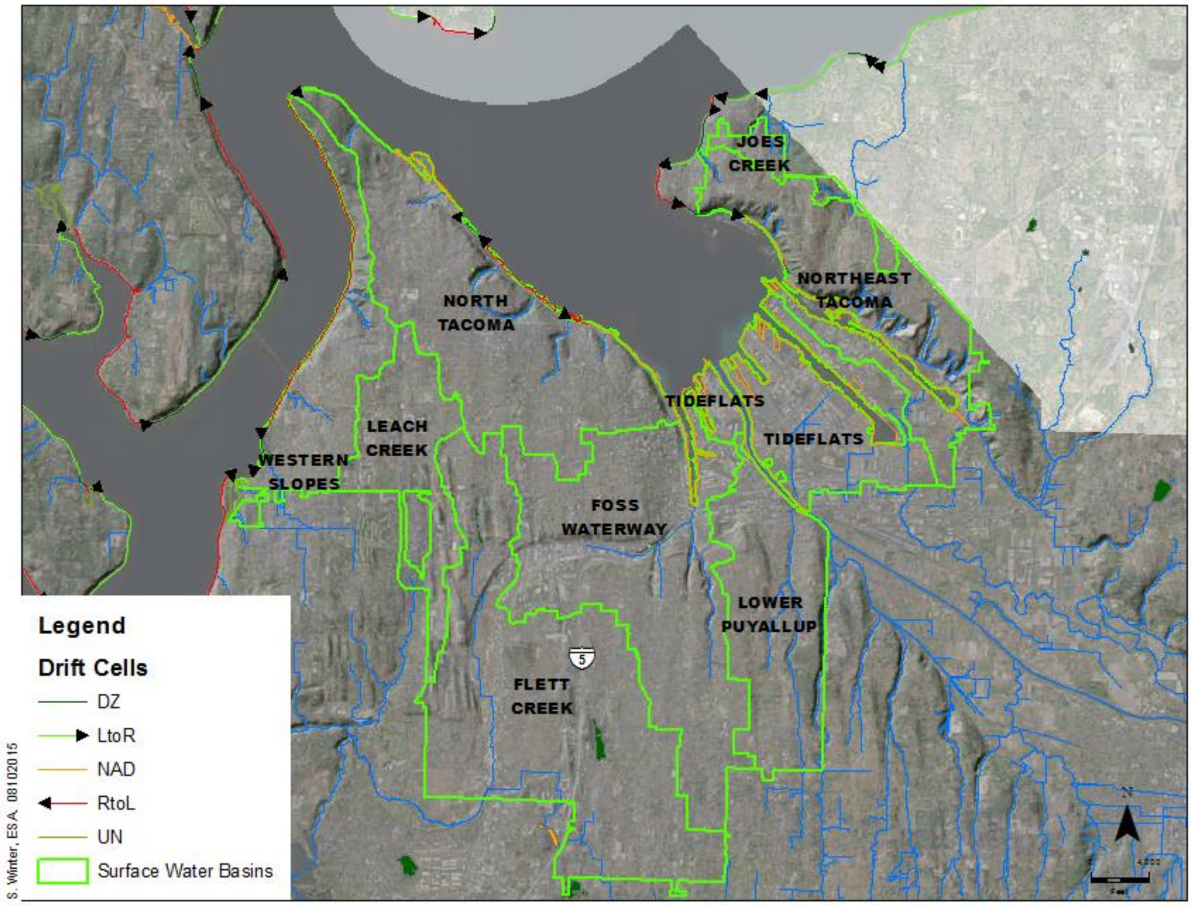
## STUDY AREAS AND METHODS

To assess the overall vulnerability of natural systems, we identified groups of systems that have both similar ecological functions and exposure, sensitivity, and adaptive capacities to the primary local climate drivers identified by the Climate Impacts Group. These systems were also developed considering designations under the City of Tacoma's Critical Areas Preservation Ordinance (CAPO) (TMC Chapter 13.11) as well as the shoreline areas designated under the City's Shoreline Master Program (SMP) (TMC 13.10). They include:

1. Marine ecosystems (beaches, tidal wetlands, mudflats, eelgrass beds)
2. Puyallup River
3. Freshwater tributary streams
4. Freshwater wetlands
5. Open spaces
6. Aquifer Recharge Areas
7. Lakes

As an overview of surface water processes in the city, Figure 8 shows the major surface watersheds and nearshore drift cells. For this assessment, surface water basins were selected to be consistent with previous City planning efforts. Drift cells were selected for the nearshore, as they are a reasonable way of subdividing the shoreline based on physical processes of sediment delivery and transport. Each drift cell identifies discrete sections of the shoreline that have the same type and net direction of sediment movement. These cells include areas with no appreciable drift, areas that are net depositional, or areas that have net right-to-left or left-to-right drift (when facing the shoreline from the water). Sediment dynamics lend themselves to this vulnerability analysis because they are a key factor in habitat types and resilience.

Figure 8. Map of watersheds and drift cells in the City of Tacoma.




## KEY FINDINGS

We stratified Tacoma's natural systems into two categories regarding climate change and its effects (see Table 7). Note that this table is only for relative comparison of natural systems within Tacoma and does not apply to any systems or areas outside of the study.

Table 7. Natural systems with greater and less vulnerability to climate change drivers.

| Natural Systems with Greater Vulnerability | Natural Systems with Lesser Vulnerability |
|---|---|
| **Marine Ecosystems** | Freshwater Wetlands |
| **Puyallup River** | Critical Aquifer Recharge Areas |
| **First Creek** | Most Tributary Streams with bypass systems |
| **Wapato Lake** | Open Spaces |

Each system is discussed further below, and the qualitative assessment of exposure, sensitivity, and adaptive capacity is summarized in Table 8.

# DETAILED RESULTS

## MARINE ECOSYSTEMS

The City of Tacoma has 33.6 miles of nearshore marine shoreline areas in Puget Sound and Commencement Bay [30]. The nearshore marine shoreline area is a narrow zone of land and shallow water that includes important natural systems, such as tidal wetlands, shoreline bluffs, tidal areas of streams and rivers, as well as shallow waters to a water depth of about 10 feet (PSNERP, 2014). The nearshore of Commencement Bay has also been identified as a key focus area in the restoration of Puget Sound salmon [31].

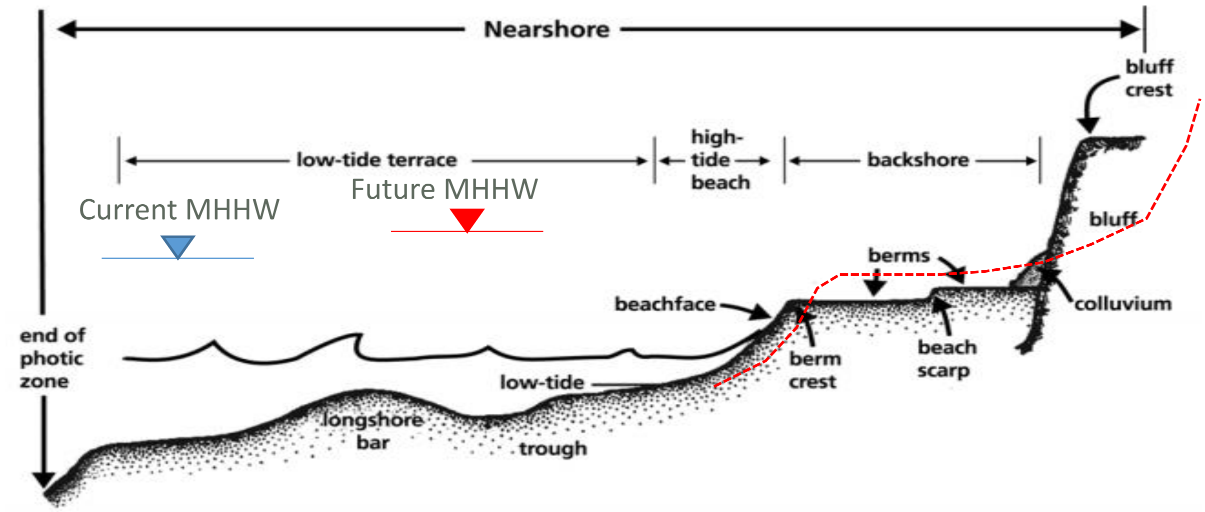
Just as upland areas can be defined by surface water drainage patterns, the nearshore areas of Tacoma can be defined in terms of net shore drift patterns. Drift patterns tell the orientation of beach-sediment transport resulting from wave and tidal action along the shoreline. In the City of Tacoma, nearshore drift patterns reflect the different orientations of the Commencement Bay shoreline (see Figure 5-1). To the north, right-to-left oriented drift patterns wrap around Browns Point into Commencement Bay. The tideflats area at the mouth of the bay is dominated by a broad area of No Appreciable Drift (NAD), as befits the former Puyallup delta. Along the western edge of the bay on Ruston Way, drift patterns vary, generally switching to a pattern that sweeps sediment north around Point Defiance then south down the Narrows.

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**Marine ecosystems within Tacoma are both highly exposed and highly sensitive to rising sea levels.** Rising sea levels (ranging from about -1 to 19 inches of rise by 2050, and 4 to 56 inches by 2100) would increase the frequency and duration of inundation. There are a number of secondary effects as well. Changing sea levels can alter sediment dynamics, which form the basis of many of these systems. The adaptive capacity of these systems varies, typically in relation to the backshore area; if there is room for these systems to adjust, then they are likely to persist under a changing climate, but if the backshore is armored or otherwise removed, they will shrink or disappear.

Potential changes along the nearshore can be conceptualized in two ways. First, rising sea levels will result in higher high tides and a higher base level for storm surges. These factors will force the existing beach profile to adjust, typically building a higher beach face and littoral berm. Changes in beach profile have a number of secondary impacts on marine ecosystems, which will need to migrate along with the physical system. In the case of bluff-backed beaches along Point Defiance and a portion of Marine View Drive, as the beach builds back, it has the potential to erode the toe and accelerate bluff erosion (Figure 9).

Figure 9. Depiction of current and future estimated MHHW in nearshore marine shoreline areas (figure adapted from Johannessen and MacLennan, 2007).




Where marine shoreline with natural bluff-backed beaches can migrate back, as is the case at Point Defiance, adaptive capacity can be high. However, in other places, armoring of the upper beach profile with substantial infrastructure development prevents upward migration of these landforms and habitats. This is the situation with the beach along Ruston Way. **These alterations are typical for the majority of Tacoma's shoreline, making the adaptive capacity and therefore the resilience of these systems low in many locations.**

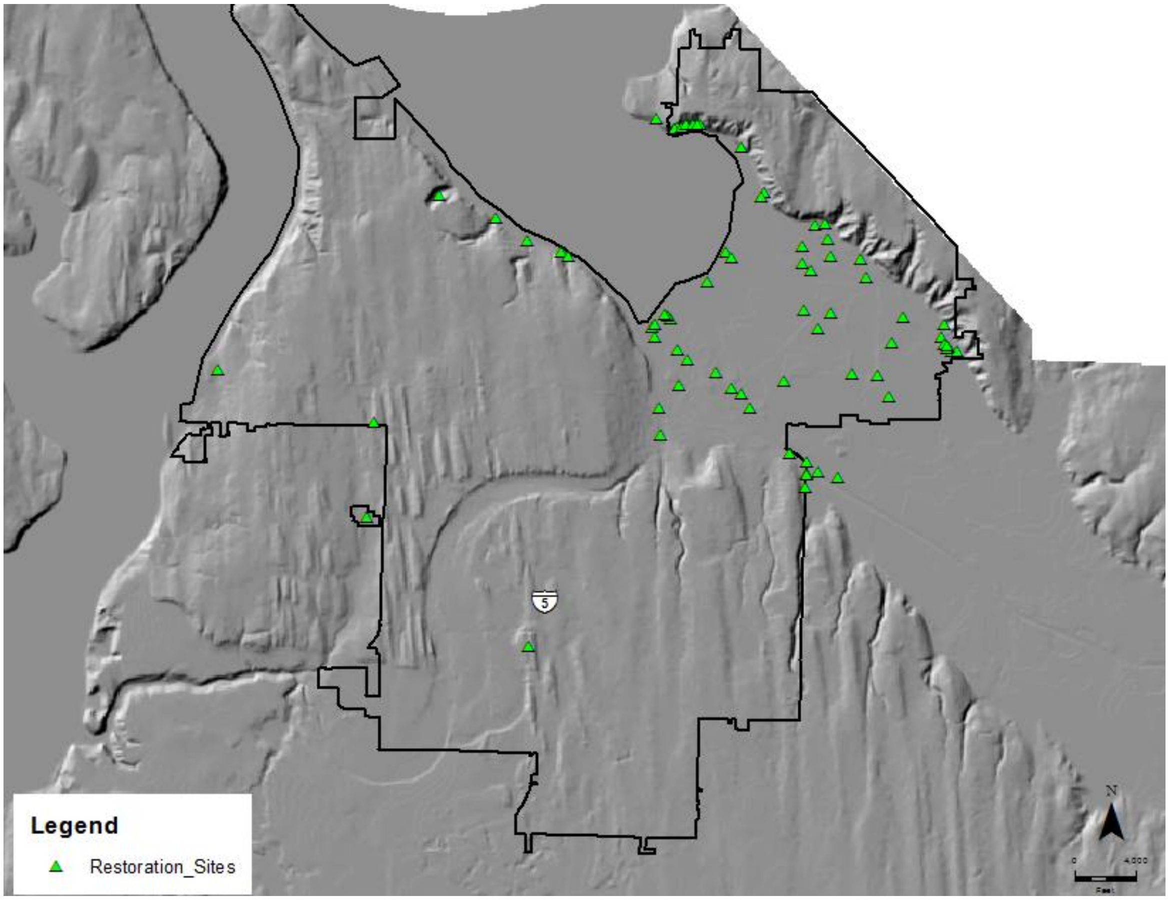
Second, marine ecosystems are, in general, defined by substrate and elevational relationship to tides. **Rising sea levels will alter existing ecosystems, forcing them to adjust upwards or transition into systems adapted for deeper water (e.g., salt marsh becoming mudflat).** Tidal wetlands occur in a narrow vertical range, typically near the high end of the tide range. This makes tidal wetlands—which are now relatively rare in Commencement Bay—highly vulnerable to changes in sea level.

Where these systems have room and appropriate substrate, they have the potential to adjust upgradient. If sea level rise occurs quickly, or there isn't available space, tidal wetlands are likely to become unvegetated mudflats.

The restored Tahoma Salt marsh is an example of a site that is vulnerable to sea level rise (see Figure 10). This small tidal wetland is separated from the bay by a short, steep beach face with an abrupt transition from intertidal to supratidal habitats (2H: 1V slope). The wetland has very limited adaptive capacity to transition landward because of the adjacent topography and infrastructure. This pattern is typical of many of the habitat restoration projects in Commencement Bay and the former Puyallup Delta (Figure 11).

Figure 10. Tahoma Salt Marsh located on Ruston Way (Ecology Oblique Aerials).

Figure 11. Restoration sites in the City of Tacoma.



**Sediment supply is a key variable that generates uncertainty about how these systems will respond.** Particularly for tidal wetlands, there may be sufficient fine sediment generated from the Puyallup River, which would allow remaining tidal wetlands to aggrade with sea level rise and thereby maintain their productivity.

**Overall, marine ecosystems in Tacoma are highly vulnerable to climate change as they are fundamentally dependent on sea levels.** These kinds of systems can adapt, in theory; however, those found in the city have been substantially altered in the past, and development in the backshore has eliminated much of their adaptive capacity, leaving them less resilient.

## PUYALLUP RIVER

The Puyallup River drains over 1,000 square miles, from Mount Rainier to its mouth within the City of Tacoma. The City of Tacoma includes less than 3 miles of the river, but it is located at the highly important transition from the channel to Commencement Bay.

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

As noted in the CIG analysis (see Appendix 2), the Puyallup River is highly exposed to climate change due to the overall size and diversity of its contributing basin. The Puyallup River is also highly sensitive to climate change drivers since the majority of its floodplain, which helps the river adjust to changing conditions, has been eliminated through past river management practices. Management and levee placement have also left the Puyallup River with very limited capacity for adaptation. This combination of factors makes the Puyallup River system highly vulnerable to climate change impacts.

## FRESHWATER TRIBUTARY STREAMS

Tributary streams drain the majority of Tacoma's surface area. These channels are typically small, draining low gradient portions of the upland till plain to the nearshore via erosional gulches. The City has identified the surface water basins shown earlier in this chapter in Figure 8.

### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**Smaller streams are primarily exposed to climate change drivers that affect peak flow and water quality.** Increases in extreme rainfall are expected to increase peak flows in these streams. Increased winter runoff is also anticipated to transport more pollutants from urbanized areas into these streams. Higher temperatures in the summer may also translate into higher stream temperatures.

**City streams vary widely in terms of their sensitivity to these changes.** Very small streams that flow through erosion-resistant materials and include engineered high-flow bypass channels are likely to be insensitive. Streams in erodible sediments without high flow bypass, on the other hand, are expected to be sensitive to these changes, as the channel is likely to adjust to conform to the new flow regime.

Key uncertainties regarding the overall vulnerability of these streams relate to a lack of data regarding existing channel conditions. We also have limited information about which systems have pipe bypasses, and whether these pipes have additional capacity.

To ascertain the presence of a bypass, we reviewed the City's GIS pipe network at the locations of mapped streams or apparent gulches. If a gravity drain pipe is mapped along or parallel to the stream corridor, a bypass is assumed. This review suggests that almost all of the gulches around the city include a high flow bypass.

Adaptive capacity in natural stream systems can be high, as floodplains can diffuse the energy of peak flows and limit channel adjustment. However, in Tacoma, the adaptive capacity of streams was determined to be low. This is due to existing development, with substantial impervious areas, as well as to valley configurations where gulches do not typically allow for floodplain development.

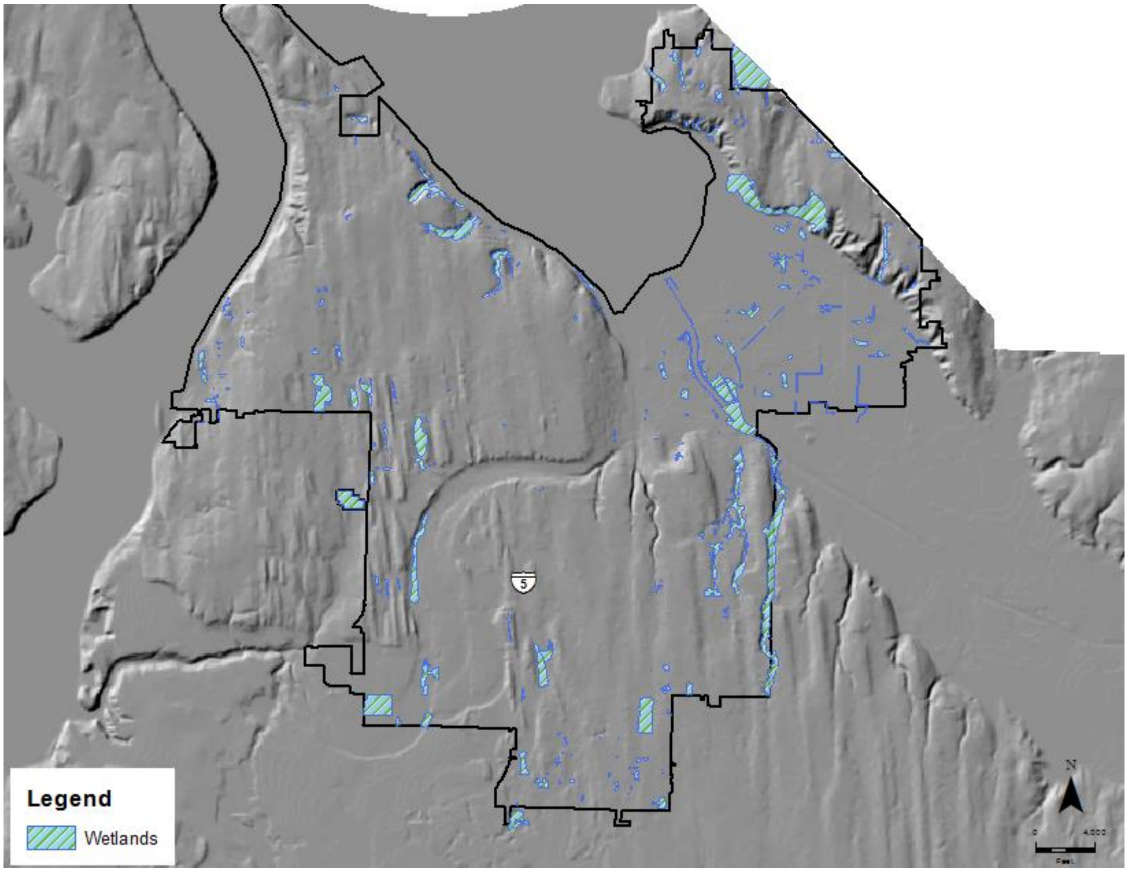
In sum, smaller tributary channels that flow through highly erodible glacial sediments are expected to be most vulnerable. Based on our preliminary analysis, only First Creek appears to fit this profile (see Figure 12).

Figure 12. Adjustable channel of First Creek (Cosmopolitan Engineers, 1997).

## FRESHWATER WETLANDS

Tacoma includes freshwater wetlands. These systems can occur throughout the City. Available mapping is shown in Figure 13.

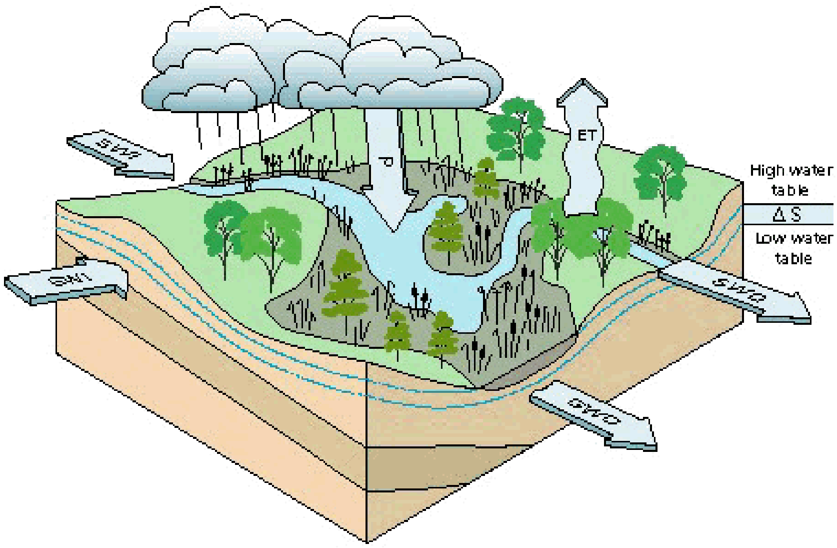
Figure 13. Mapped wetlands within the City of Tacoma.




### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

Seasonal changes such as increased evaporation rates and prolonged summer droughts, compounded by warmer summer temperatures, can change the hydrology of many freshwater wetland systems. The degree of change will vary depending on the wetland's primary water source. These changes would affect the water balance of wetlands (see Figure 14), leading to changes in wetland hydrology. Wetland hydrology is defined by a water balance where the net sum of the inputs exceeds the net sum of the outputs, at least during portions of the year. The types of climate change identified for Tacoma include more seasonal precipitation and warmer summer temperatures; both trends would directly affect how much water is available to the wetland system. Changes to wetland hydroperiod can have significant consequences for wildlife species such as frogs and salamanders that depend upon these types of wetlands for habitat [32].

Figure 14. Wetland system water budget (USGS, 1996). P is precipitation, SWI is surface-water inflow, SWO is surface-water outflow, GWI is groundwater inflow, GWO is groundwater outflow, ET is evapotranspiration, and ΔS is change in storage.




**Wetlands supported primarily by groundwater will be much less sensitive to changes in the water budget, while wetlands dominated by surface water will be more sensitive.**

The capacity for freshwater wetland systems to adapt to climate change impacts will relate to the local topography, existing wetland vegetation, and existing buffer vegetation. **Wetlands with established and diverse vegetation communities are expected to have greater adaptive capacity.**

Since the overall vulnerability of freshwater wetlands is highly dependent on local factors, we were not able to assess specific wetlands in Tacoma using remote methods. In general terms, freshwater wetlands in Tacoma are expected to be less vulnerable to climate change given their lower elevations (i.e., not montane) and because the larger systems (e.g., Tacoma Community College and China Lake) are suspected to be groundwater-supported.

## OPEN SPACE

Open spaces are natural areas that provide important community space, habitat for plants and animals, and various recreational opportunities. Open space lands in Tacoma include a wide variety of passive land uses, habitats, and values. While some lands contain habitat for rare or endangered wildlife species, many lands also serve other open space functions that contribute to a complete and livable urban environment. Consistent with the City of Tacoma's Comprehensive Plan update, we can broadly define open spaces as the following.

- Parks and recreational lands.
- Natural areas regulated under the City's Critical Areas Preservation Ordinance.
- Areas used for the conservation of plant and animal life, including habitat for fish and wildlife.
- Areas used for ecologic and other scientific study purposes.
- Areas of outstanding scenic, historic, cultural, scientific, and/or educational value.
- Areas providing a natural separation or buffer between land-uses.

- Rivers, streams, wetlands, bays, and estuaries.
- Forested areas, oak woodlands, and meadows.
- Areas providing important habitat connectivity, including utility easements and unimproved rights-of-way.

#### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

**Both natural and landscaped open space systems are exposed to temperature increases and changes in seasonal precipitation patterns. The sensitivity of these systems is directly related to their degree of establishment.** Newly planted or establishing areas are much more likely to be impacted by seasonal variations than established natural areas like Point Defiance Park. Landscaped areas would be similarly impacted, as the majority are often small patches of land within developed areas, which makes them hard to establish and to maintain long-term.

Established natural areas and forests have greater capacity for adjusting to higher temperatures and reduced precipitation because they have a diverse range of plant species.

Overall, as Tacoma has ongoing maintenance plans for the larger park systems, it appears that these established open spaces are less vulnerable to climate change, primarily due to the adaptive capacity within the system and the City's maintenance regime. Newly established areas will be more vulnerable.

### AQUIFER RECHARGE AREAS

The South Tacoma aquifer system is a large groundwater resource area that encompasses central Pierce County and areas to the south and west of Tacoma, and extends into Tacoma city limits, most notably in the South Tacoma area.

Numerous individual and public water systems in Pierce County, including the City of Tacoma, use this aquifer as a water supply. The aquifer provides a significant amount of drinking water for Tacoma, supplying as much as 40 percent of the total water demand during periods of peak summer use. It is, however, still the secondary source of drinking water, after the Green River watershed [33].

#### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

The critical aquifer recharge area (CARA) systems in the city appear to be less vulnerable to projected changes in precipitation patterns. Climate change projections suggest that overall annual precipitation will be comparable to past experience, and changes in precipitation are likely to occur at times of lower evapotranspiration. Therefore, the overall annual volume is likely to continue to adequately recharge local aquifers.

### LAKES

Wapato Lake is located on the glacial till plain in South Tacoma, within a large park east of Interstate 5. Water quality within the lake has been a challenge since at least the 1940s [34].

#### EXPOSURE, SENSITIVITY, ADAPTIVE CAPACITY

Given the existing challenges with water quality in Wapato Lake, our assessment is that the lake is vulnerable to climate change impacts. Additional pollutant loading from peak storm events and higher summer temperatures are likely to exacerbate water quality issues.

Table 8. Vulnerability matrix for natural systems in the City of Tacoma.

| System | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|
| **Marine ecosystems** | **High**<br>High exposure due to increased inundation frequency and duration resulting from sea level rise. | **High**<br>High sensitivity due to narrow elevational ranges within the intertidal zone and the complex inter-relationships with physical nearshore processes relating to tides and wind waves. | **Varies**<br>Varies by location. Wetlands with steep surrounding slopes and locations bounded by infrastructure will have low adaptive capacity; other wetlands can likely transition landward given adequate sediment supply from the Puyallup River. | **High**<br>Fundamental dependency on sea levels combined with substantial historic alteration leaves most marine ecosystems highly vulnerable. |
| **Freshwater wetlands** | **Moderate**<br>Changes in rainfall to more pronounced seasonal patterns will change the timing of when water reaches wetlands, which could in turn affect the wetland's hydroperiod.. | **Moderate**<br>Wetland systems are likely to persist, but with an altered hydroperiod. Groundwater-supported wetlands are less sensitive because annual rainfall is expected to remain generally the same and shallow aquifers will continue to persist. | **Moderate to Low**<br>Established native wetland vegetation communities should be able to adjust to altered hydroperiods. Disturbed or altered wetlands are likely to be less resilient. | **Moderate**<br>Although highly dependent on local factors, most wetlands are low in elevation (i.e., not montane) and the larger freshwater systems are groundwater-fed (e.g., Tacoma Community College and China Lake). |
| **Tributary streams** | **Moderate**<br>Moderate exposure due to increased peak flows and water quality impacts from more frequent and intense rainfall events. | **Varies**<br>Varies by location. Small streams in basins where most surface flow is directed through piped systems will have low sensitivity; streams with natural channels in glacial sediments will have high sensitivity. | **Varies**<br>Varies by sensitivity and level of alteration – some piped or other engineered systems may be easy and others will be expensive to adapt. | **High**<br>For streams in highly erodible glacial sediments (First Creek is the only one).<br>**Low**<br>For streams with bypass pipes (most gulches in the city), because infrastructure could be modified. |
| **Puyallup River** | **High**<br>Larger streams integrate climatic conditions over a much larger and more diverse contributing basin. Changes in hydrology and sediment load directly impact primary geomorphic drivers of channel form and ecological functioning. | **High**<br>High sensitivity due to past river management practices that eliminated most of the floodplain, which limits the ability of the river system to adjust to changing conditions. | **Low**<br>Low adaptive capacity due to the existing levee system. | **High**<br>High long-term vulnerability due to size and complexity of contributing basin combined with the history of alteration and current limited capacity for adaptation (i.e., due to levee system). |

| System | Exposure | Sensitivity | Adaptive Capacity | Vulnerability |
|---|---|---|---|---|
| **Wapato Lake** | **High**<br>High exposure due to direct temperature impacts of shallow systems and impacts on water quality from increased runoff. | **High**<br>Many of the existing lakes are already on the state 303(d) lists for water quality issues. | **Moderate**<br>Recent work by the City has improved the water quality of Wapato Lake, so systems may be in place to further buffer and adapt to additional impacts. | **High**<br>Additional pollutant loading from increased peak storm events and higher summer temperatures are likely to exacerbate water quality issues. |
| **Open space (natural areas)** | **Low**<br>Low exposure due to temperature increases and precipitation changes that may lead to changes in vegetation. | **Varies**<br>Varies by vegetation maturity. *Low* for established vegetated areas and *moderate* for establishing areas. | **Moderate to High**<br>*Moderate* for establishing areas as there may be a need to change plant palettes and extend management efforts. *High* for established areas since the habitats can adjust to changes. | **Moderate**<br>Drier and hotter climate will increase stress on established and establishing vegetation; some species will adjust but others will be at risk. |
| **Open space (landscape areas)** | **Low**<br>Low exposure due to temperature increases and precipitation changes that may lead to changes in vegetation. | **Moderate**<br>These are often marginal planting areas already compromised by surrounding land use. | **Moderate**<br>May need changes in management (e.g., irrigation, drought-tolerant plants). | **Moderate**<br>Drier and hotter climate will increase stress on plants, but there are many low- to moderate-cost adaptation options. |
| **Aquifer recharge areas** | **Low**<br>Low exposure due to stable levels of annual precipitation available for recharge (average precipitation amounts are not projected to change). | **Moderate**<br>Use is currently below 20,000 AF capacity based on past use, but overall recharge is unknown (source: Tacoma Water). | **Moderate**<br>Recharge is dependent on rainfall and land cover characteristics, so increasing infiltration or injection would allow for adjustment. | **Low**<br>Limited effects on aquifers are expected because overall annual precipitation will remain generally the same. |

# EXISTING PROGRAMS THAT CONTRIBUTE TO BUILDING RESILIENCE TO IDENTIFIED IMPACTS

**Critical Areas Protection Ordinance & Comprehensive Plan.** Natural systems in this assessment typically fall within one of the critical areas designated by the City of Tacoma under their critical areas ordinance (CAPO), which covers critical aquifer recharge areas, flood hazard areas, geologically hazardous areas, streams, and wetlands. The CAPO defines and designates critical areas and provides standards to manage development in these areas and thereby protect them from degradation. These regulations are required under the Growth Management Act (GMA) (Revised Code of Washington [RCW] 36.70A), which mandates that all cities and counties in Washington planning under the GMA manage growth by identifying and protecting critical areas, designating urban growth areas, and implementing comprehensive plans through development regulations.

The Comprehensive Plan developed by the City of Tacoma sets goals, policies, and strategies to guide decisions made by the City Council and City administration regarding land use, development, capital improvements and services. Many individual plans or programs (referred to as elements) comprise the Comprehensive Plan, including the Environmental Element, the Open Space and Recreation Element, and the Urban Forest Policy Element. These elements apply to the resiliency of all natural systems assessed in this study, as they provide the baseline protection for these areas. These plans do not explicitly include climate change components, but they have the overall goal of no net loss of ecosystem functioning for these systems.

**Shoreline Master Program.** The City of Tacoma Shoreline Master Program (SMP) (TMC Title 13.10) is required under the Washington Shoreline Management Act (SMA) (RCW 90.58) to manage and protect shorelines by providing goals, policies, and regulations for shoreline use. Shorelines protected under the SMP include several of the natural systems in this assessment: marine shoreline ecosystems, lakes, wetlands (tidal and freshwater), and streams. In addition, the SMP designates the Puyallup River as a shoreline of statewide significance where specific priority uses are preferred. Similar to the City's CAPO and Comprehensive Plan, the SMP does not currently integrate climate change considerations into any of its goals, policies, or regulations.

**Metro Parks & Green Tacoma Partnership.** The Strategic Parks and Program Services Plan (Strategic Plan) developed by Metro Parks Tacoma is another program that sets several goals for the organization, one of which is to protect and restore natural systems for conservation and learning. The Strategic Plan includes a number of strategies and actions to meet this goal, such as preserving and protecting open spaces, developing restoration plans, and promoting conservation (Metro Parks, 2006).

Metro Parks Tacoma has also partnered with the City of Tacoma, Forterra and other non-profits, businesses, and community members as part of a public-private venture called the Green Tacoma Partnership. This program provides resources, trainings, and public outreach for the restoration and maintenance of open spaces throughout the city, which helps to reduce sensitivity to climate change impacts (e.g., temperature increases, changes in precipitation) and build resilience.

# RECOMMENDED ADAPTATION STRATEGIES: NATURAL SYSTEMS

Adaptation to the key vulnerabilities discussed above can occur at many scales, and many time frames. The following lists focus on near-term and longer-term strategies.

## Near-Term Needs and Windows of Opportunity

Strategies that could be implemented in the near-term for natural systems adaptation to climate change drivers include the following.

- **Preserve remaining natural areas.** Conserving existing habitats and undeveloped natural areas is typically the first strategy suggested for any climate adaptation plan. Conversations with City staff revealed that Tacoma is generally in good shape: existing policies, regulations, and programs provide mechanisms for the preservation and protection of natural systems. Additional rulemaking to determine and administer appropriate setbacks from geologically hazardous areas could further enhance both natural system resilience and public safety.
- **Establish stronger, more resilient landscapes in open spaces** by increasing plant diversity, extending establishment periods, using smaller planted stock, and adding more habitat types. It will be important to adjust plant palettes, incorporating more plants that can thrive in drier summer conditions. The successful establishment of resilient native vegetation communities will provide the best resistance against invasive plants, which will have more opportunities to colonize natural areas as changing climate conditions stress existing systems.
- **Incorporate greater resilience in habitat restoration projects** by considering the following during the restoration planning process:
  - Adding diverse features into restored systems that allow for transition zones;
  - Allowing for greater seasonality in hydrologic performance and targets; and
  - Analyzing and/or considering higher peak flows for restored wetland and stream systems.
- **Provide more explicit design guidance or performance specifications** for considering climate science in habitat restoration plans.

Habitat restoration planners should consider the most up-to-date climate science available and consider the future climate in which the system is intended to survive, and make project design adjustments to increase long-term resilience. These efforts are ongoing in Tacoma, but may benefit from more explicit design guidance or performance specifications.

## Low-Hanging Fruit

- **Coordinate resilience efforts for natural systems with existing plans**, such as the CAPO and Comprehensive Plan.

## Longer-Term Strategies

Strategies and projects that could be implemented in the long term for natural systems adaptation include:

- **Develop an urban landscape strategy or framework** that values and expands upon the natural features of the landscape, including urban forests, critical areas, and open spaces. This strategy would include ways to develop additional natural areas—and preserve the functioning of existing ones—under changing climatic conditions.
- **Reduce non-climate stressors** (e.g., vegetation clearing, stormwater runoff, and impaired water quality) affecting fish, wildlife, plants, and ecosystems. This will put them in a position to face other stressors—including climate change impacts—with a higher baseline level of resilience.
- **Establish transitional zones around the nearshore** where armoring or other infrastructure currently restricts the ability of marine ecosystems to adjust to sea level rise. Identify places where infrastructure can be set back (also known as "managed retreat") as part of capital improvement project implementation.
- **Continue to engage in and support regional efforts** within the Puyallup River basin to consider river management related to floods, sediment, agriculture, and infrastructure protection.

# RECOMMENDATIONS FOR FURTHER STUDY

Specific studies that would be useful to reduce data gaps and better inform adaptation planning include:

- **Spatial mapping of specific natural systems in the city.** Mapping is necessary for identifying the climate vulnerability and adaptive capacity of specific natural systems, and prioritizing adaptation actions. Currently available spatial data layers show the general location of wetlands and streams, but the actual extent of these systems is likely underestimated.
- **The geologic and geomorphic characteristics of streams in Tacoma.** Identifying these characteristics would help determine their susceptibility to increases in peak flow resulting from climate change. This, in turn, would help the City establish which stream systems would benefit most from stormwater retrofit projects.
- **GIS spatial data improvements and hydrogeomorphic typology of freshwater wetlands in the city.** Developing a more robust spatial database of freshwater wetlands would provide a mechanism to better track wetland spatial coverage. This database could include hydrogeomorphic type and other characteristics to refine the understanding of the wetlands' climate change vulnerability. City staff have knowledge of these systems developed through the permit review process, but these systems are not typically captured in the citywide dataset.
- **Site-specific studies on the sedimentation/marsh aggradation of tidal wetlands.** This information would improve the understanding of specific tidal wetlands' sensitivity to climate change drivers.

# 6. SOCIAL SYSTEMS

The nature and degree of climate change risks vary across Tacoma's diverse social systems, geographies, and populations. More sensitive populations such as the very young and elderly and those within highly exposed areas such as coastlines and urban heat islands will be at higher risk. A community's ability to cope and respond to climate change risks will depend on many factors, including income, social connectivity, and access to support services. City services related to emergency management, public health, and social services also play a critical role in ensuring community resilience and preparedness. In this section, we assess the vulnerability of Tacoma's social systems—including neighborhoods, socioeconomic groups, and the City services that support them—to projected impacts of climate change.

## STUDY AREAS AND METHODS

We assessed the vulnerabilities of citywide social systems at the census-block level, focusing on neighborhood-level exposure, sensitivity, and adaptive capacity (see Figure 15 and Figure 16, below). This approach allowed us to identify neighborhoods and "hot spots" of greatest vulnerability to projected flooding, extreme heat, sea level rise, and landslides.

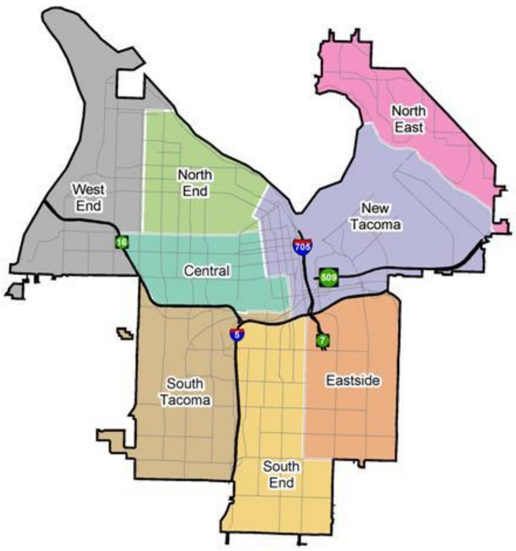



Figure 15. Tacoma neighborhoods [35].

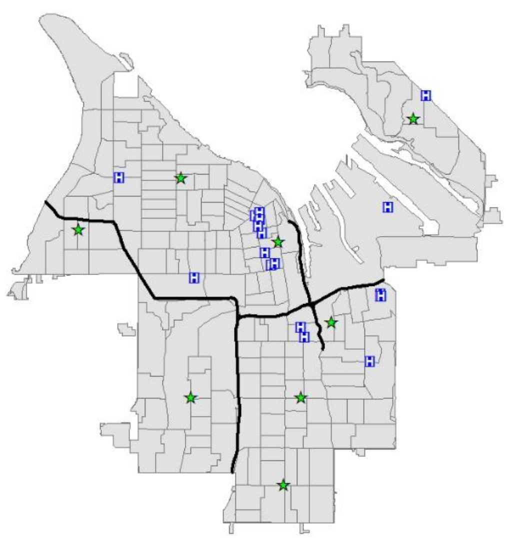


Figure 16. Tacoma census blocks.

## KEY FINDINGS

The most prominent climate hazards for Tacoma's social systems and population centers are extreme heat and inland flooding. Coastal flooding and landslide hazards are less of a concern for these systems than they are for natural systems and the built environment.

Our analysis suggests that particular focus should be placed on extreme heat preparedness and resilience in the following areas of the city:

- South Tacoma
- New Tacoma near downtown
- The southwest area of West End
- Eastside

# DETAILED RESULTS

## Existing Stressors

Climate change impacts like extreme heat and flooding will not only introduce new and unique challenges to Tacoma communities, but also put extra strain on existing social challenges and stressors such as crime, poverty, pollution, and access to quality education.

The 2012 Tacoma Community Data Report presents trends and challenges related to the city's current state of social and health service access and provision. The observations, listed below, underscore the importance of building social systems resilience at the city and neighborhood level [36]:

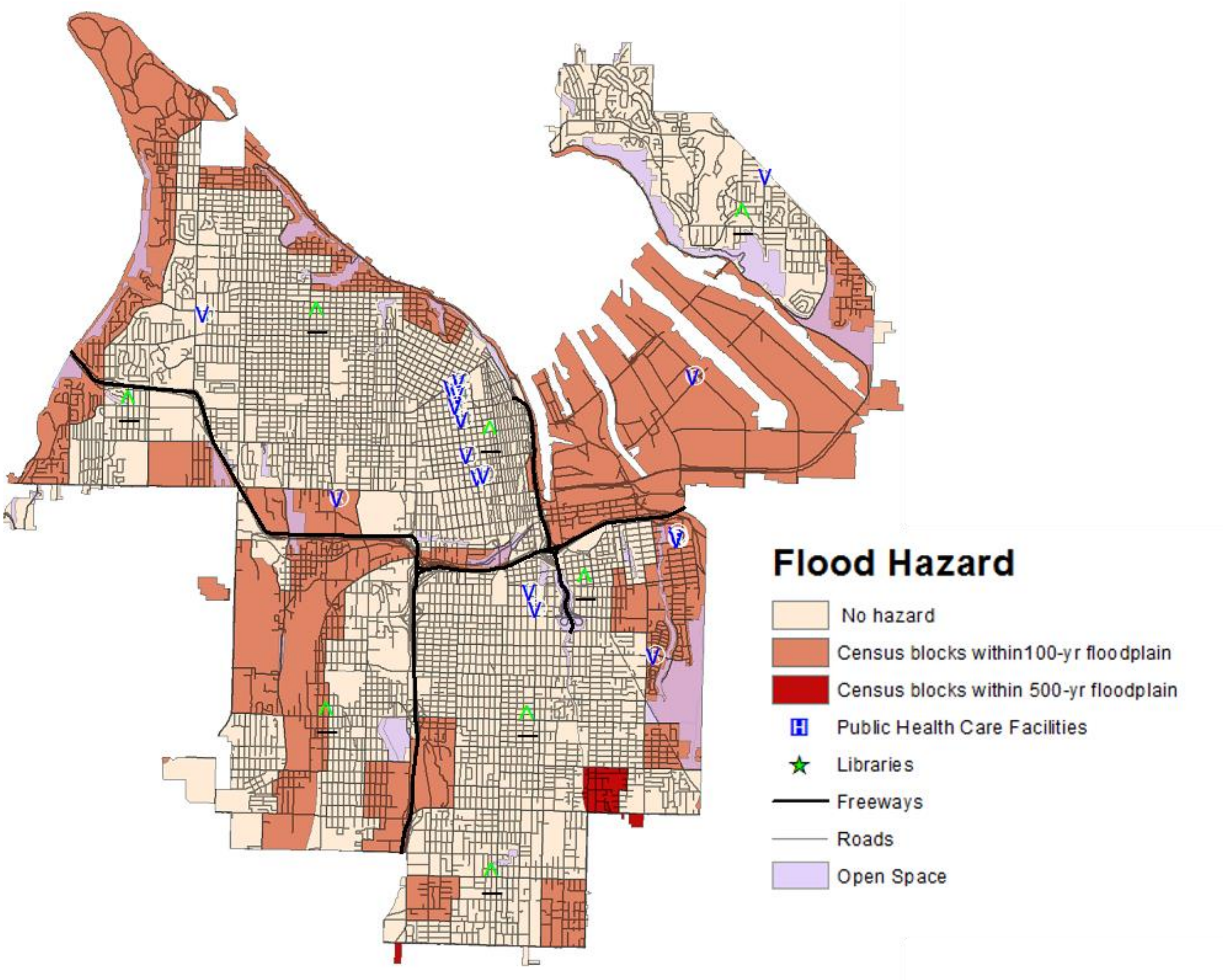
- The demand for human services has increased both the number of persons needing service and the complexity of their needs.
- Many people have difficulty finding appropriate services when they need them, which may be due to lack of service availability, lack of knowledge about existing services, or lack of culturally appropriate access.
- Meeting the services needs of a highly diverse population is challenging.
- Administrative and reporting burdens impinge on the capacity to deliver service.
- Unmet needs include educational and employment services for youth and adults, transportation, affordable housing, services and housing for unaccompanied youth and young adults, and greater access to mental health care and medical care.

The 2012 Community Data Report also cited many of the City's strengths in providing adequate social services to its citizens, including funding to service providers; advocacy for equity, justice, and human rights; consideration of both system and program outcomes; stakeholder engagement in service design; and demonstration of cultural competence.

## Primary Climate Impacts (Exposure)

The city's exposure to climate change will vary by neighborhood and, in some cases, by street. To identify local variations, we overlaid flood, landslide, extreme heat, and sea level rise impact areas with U.S. census blocks. This approach allowed us to identify the most and least exposed populations and neighborhoods within Tacoma.

Figure 17. Census blocks within the current 500- and 100-year floodplains.

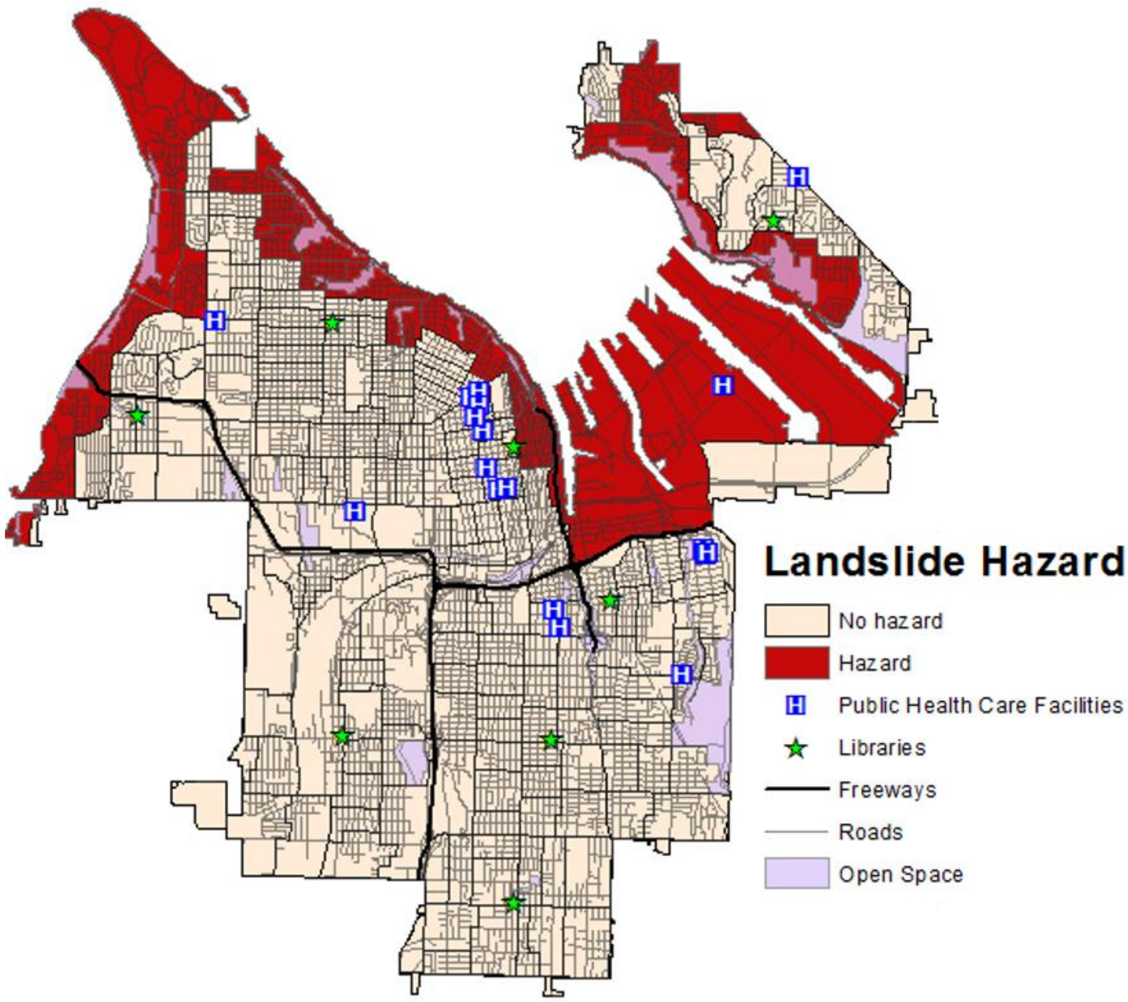



## FLOODING

We overlaid current 500- and 100-year floodplains with U.S. census block boundaries to identify populations that are already flood-exposed and that are therefore likely to be hardest hit by increased flooding as the climate changes.

**Populations along the city's coastlines, such as West End and North End residents and businesses, will experience higher flood risk than inland communities** (see Figure 17). South Tacoma and the port area of New Tacoma are also at higher risk.

Figure 18. Census blocks within current landslide hazard areas.

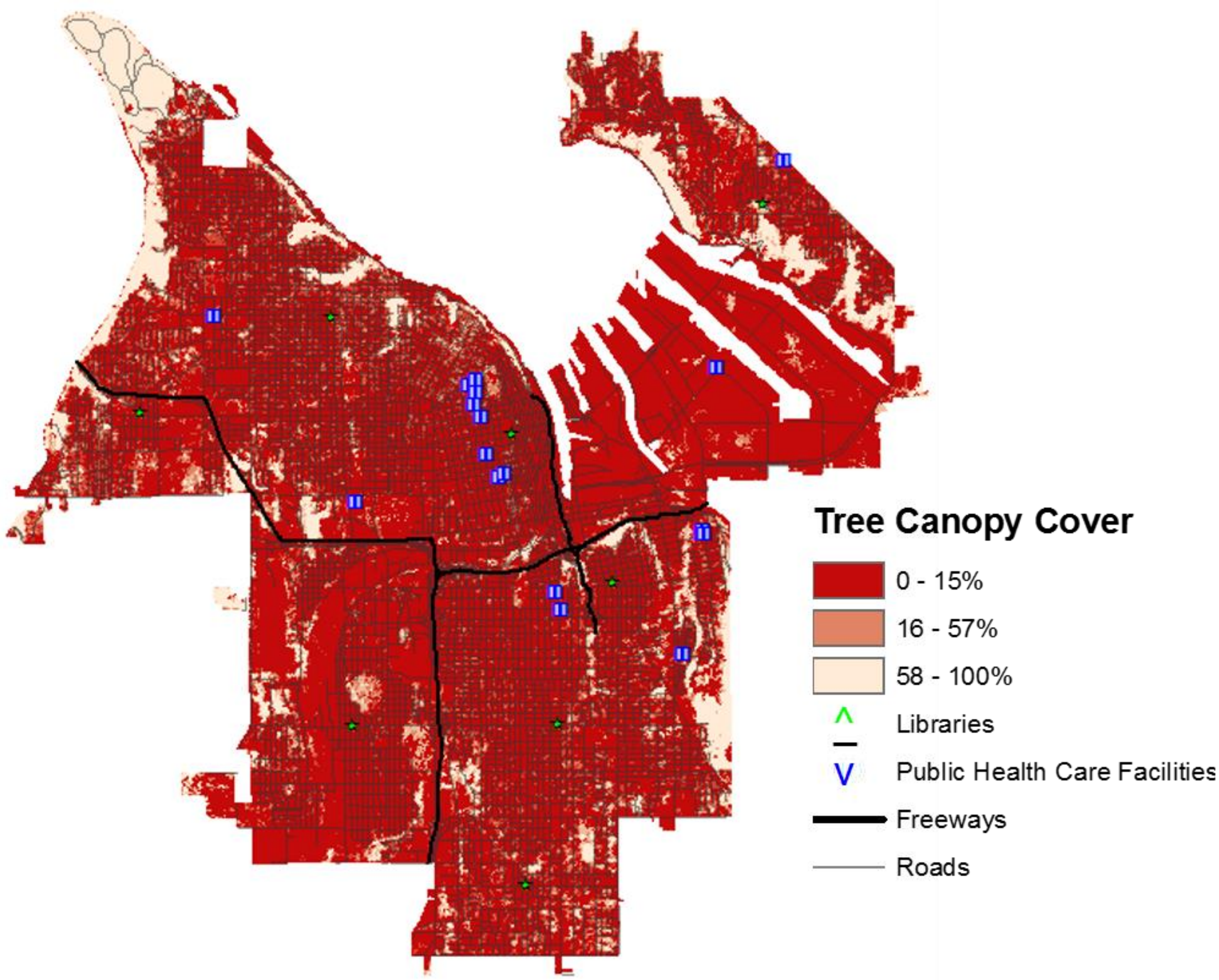



## LANDSLIDE

Although little research has been completed on how climate change may affect sediment loads and landslides in the Puget Sound region, past events and current risks can provide some insights. The assessment team overlaid current landslide hazard areas with census block boundaries to identify landslide-exposed populations (Figure 18).

**Similar to flooding, populations along the City's coastlines, such as West End, the port area of New Tacoma, and North End residents and businesses, have higher landslide risk than inland communities.**

Figure 19. Canopy cover in Tacoma.

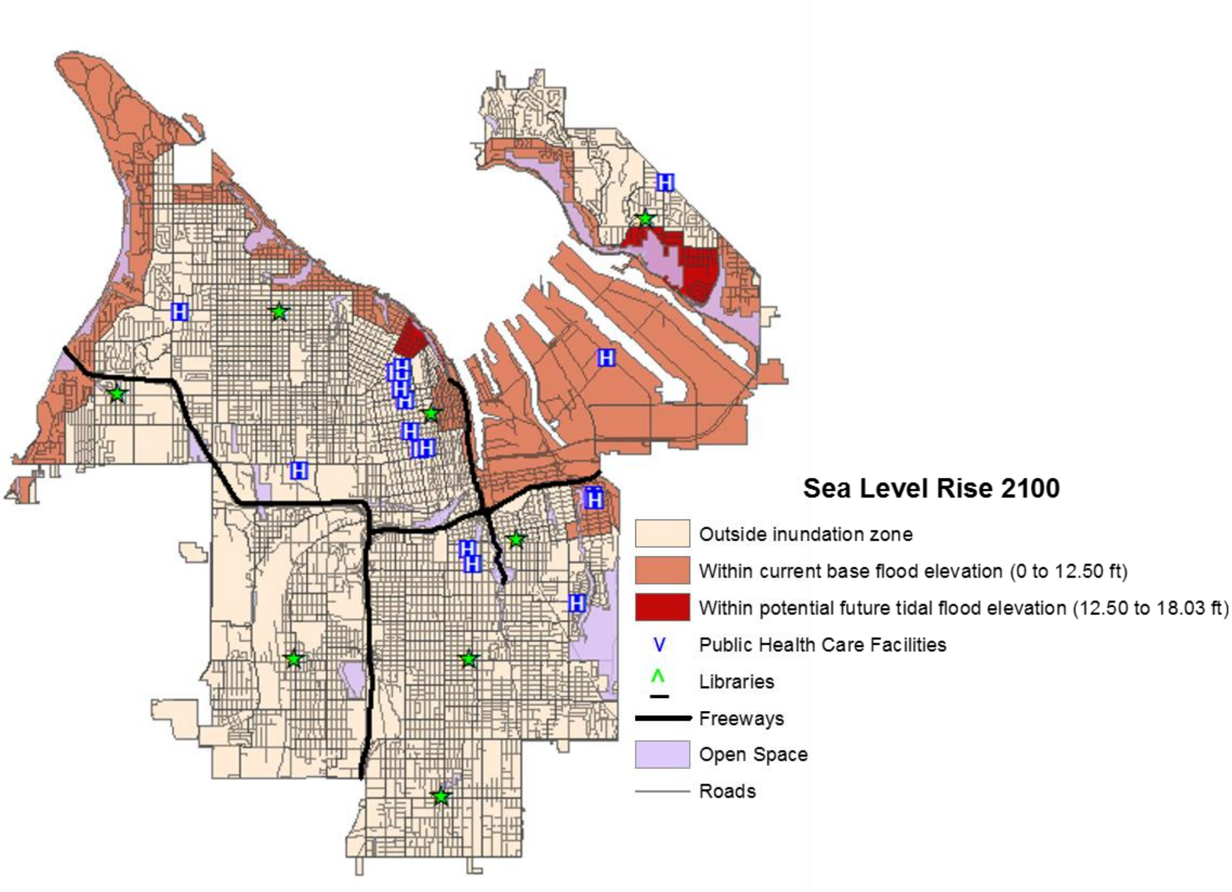



## TEMPERATURE

Future increases in the frequency and duration of extreme heat events will disproportionately affect populations located in known urban heat islands and in areas with low canopy cover.

**Areas that are most exposed include New Tacoma and the central part of the city** (Figure 19). According to a 2011 report by the University of Washington, only 19 percent of Tacoma's land area is covered by trees, leaving a very large area more exposed to extreme heat events.

Figure 20. Census blocks within projected high tide inundation areas given sea level rise projections for 2100. See Figure 4 for more information.




## SEA LEVEL RISE

The assessment team overlaid census block boundaries with areas expected to be inundated during extreme high tides in 2100 at the high end of current sea level rise projections. Figure 20 shows census blocks that intersect with current base flood elevation levels (0 to 12.5 feet in elevation) and potential future tidal elevation levels projected for 2100 (see Figure 4 for more information about sea level rise projections).

**Sea level rise will most significantly affect coastal communities and services, including two important public health facilities in the central part of Tacoma** (Figure 20).

## Secondary Impacts

### HEALTH

Climate change impacts, particularly extreme heat events, pose a considerable threat to human health. In the last decade, more Americans died from extreme heat than from any other weather-related cause. Anticipated health impacts from climate change include increased rates of the following [37]:

- Heat-related illnesses such as heat exhaustion and stroke.
- Air quality-related respiratory illnesses such as asthma and allergies due to wildfire smoke, ozone, and increased allergen production.
- Extreme weather-related physical and mental health injuries.
- Some infectious diseases transmitted by food, water, and insects, such as West Nile Virus and fungal diseases.

The precise nature and extent of projected impacts on human health in the Pacific Northwest is not well understood. The comprehensive 2013 State of Knowledge report released by the University of Washington Climate Impacts Group indicated that no studies on the individual and societal costs of climate change impacts on human health have been conducted to-date in the Pacific Northwest. However, we anticipate that those over age 65, children, poor and socially isolated individuals, people with mental illnesses, outdoor laborers, and those with cardiac, respiratory, or other underlying health problems will be most vulnerable to climate impacts on health.

Access to medical care plays a critical role in effectively addressing these impacts. One indicator of such access is the frequency with which emergency departments are used for providing services ordinarily dispensed in primary care settings. Those without health insurance are more likely to use emergency departments for these purposes than those with insurance. A 2010 study by Tacoma-Pierce County Health Department found that despite high rates of insurance coverage in Pierce County, increasing numbers of children are being treated in the emergency department for services ordinarily dispensed in primary care settings [38]. Although Tacoma has not been designated a Health Professional Shortage Area in primary care, dental care, or mental health care, the entire county is considered to be a medically underserved area by the Health Resources and Services Administration (HRSA) [38]. **These findings indicate a need for improved healthcare access in the Tacoma-Pierce County area, which could help build climate resilience as well as improve community health and livelihoods.**

### SAFETY AND SECURITY

While health implications are certainly the most recognizable social systems impact, climate change is projected to also affect human safety and security.

A recent study by an economist in Cambridge suggests that rising temperatures will lead to an increase in criminal activity in the United States [39]. The reason for this relationship is unknown—it may be that when temperatures are warmer, there are more opportunities to commit crime due to open windows and more potential victims who are outside and interacting with one another. Another theory is that temperature has a direct effect on human aggression; studies have found that subjects make more aggressive choices when they are in a hot room. Regardless of the cause, this relationship warrants careful consideration of how governments deploy police and other resources to combat future crime in the context of a changing climate.

Neighborhoods with higher crime rates may also experience more significant health impacts from extreme heat. During the 1995 heatwave in Chicago in which 739 deaths were recorded, a higher death rate occurred in an abandoned, dangerous neighborhood with a history of violent crime where people were afraid to leave their homes than in an adjacent suburb with high social capital and busy commercial activity [40]. This observation could be an important consideration in developing resilience strategies in Tacoma neighborhoods.

### ECONOMY

**Many facets of Tacoma's economy are closely linked to climate and weather conditions.** Changes in temperature, precipitation, and water quality can directly affect operations, productivity, and management practices in natural resource sectors like agriculture, shellfish harvesting, and forestry, as well as indirectly affect outdoor service sectors such as construction and landscaping.

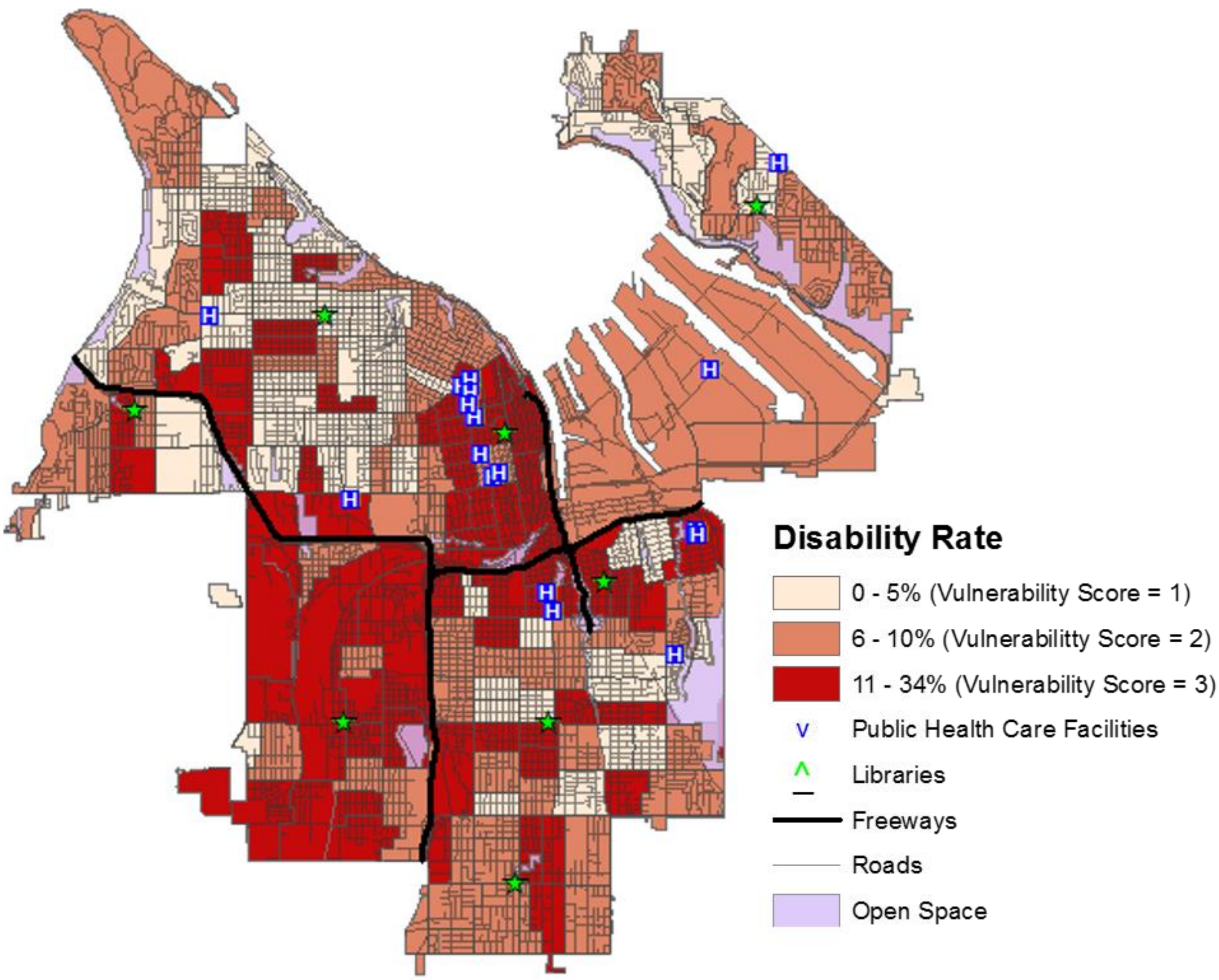
Tacoma is an important center for agricultural and forest products: the first established business in Tacoma was a sawmill, and regional enterprises produce more flower bulbs than the Netherlands [41]. CIG's 2013 State of Knowledge report notes that while the consequences of climate change will be different for different crops and locations, warming temperatures, rising carbon dioxide concentrations, and changes in water availability could introduce pest, water, and heat stress concerns to regional agriculture and forestry [42].

Potential direct inundation of the tideflats area could also carry considerable consequences for Tacoma's economy. Tacoma has the seventh busiest container handling port in the United States, handling imports and exports for a wide range of products including lumber, apples, grain, automobiles, and electronics [41]. Tacoma is also an important rail shipping hub, served by both the Burlington Northern-Santa Fe and Union Pacific railroads. Dependable operation of these systems in a future changing climate will be critical to Tacoma's continued economic livelihood. Impacts on these assets will affect both social systems and the built environment.

## Sensitivity

Populations with especially high sensitivity to climate impacts include the sick, disabled, young, elderly, and those who work outdoors or lack access to cooling or shelter. For this assessment, we considered five sensitivity indicators: 1) rates of disability, 2) age (0-5 and over age 65), 3) housing type and rates of homelessness, and 4) access to cooling. Two of these indicators are publically available at the census block level, and we ranked and scored census blocks from high to low sensitivity based the relative prevalence of sensitive persons. Other indicators such as homelessness and access to cooling are discussed qualitatively below but were not included in the sensitivity scoring because data were not available by census block.

Figure 21. Disability rates, number of disabled persons per total population per census block.

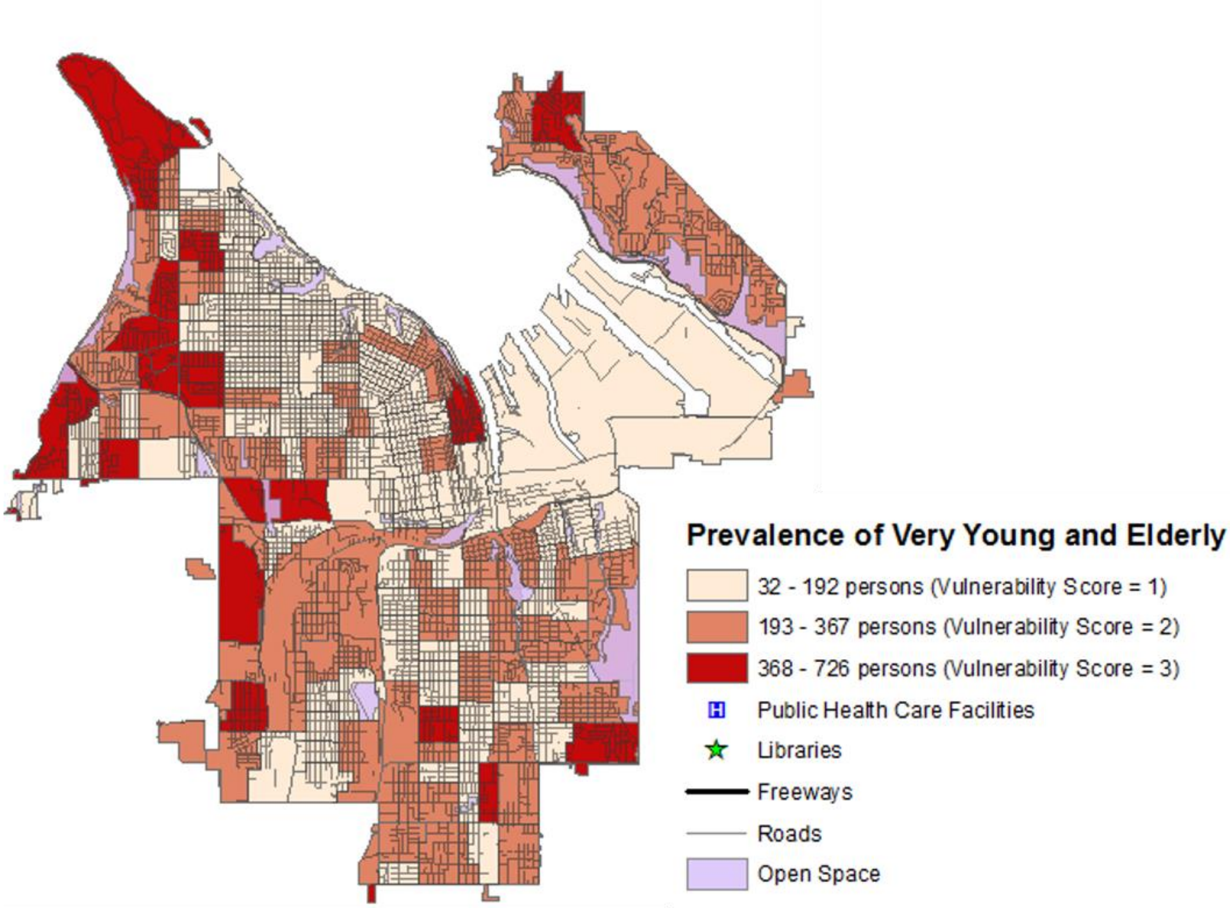



## DISABILITY

The team summarized census blocks by the proportion of disabled people to the total population.

**South Tacoma and Downtown display relatively high proportions of people with disabilities**, while the North End, West End, and Central neighborhoods contain fewer disabled persons per capita (Figure 21).

Figure 22. Relative prevalence of the very young (0-5 years) and elderly (+65 years) in Tacoma, number of persons per census block.

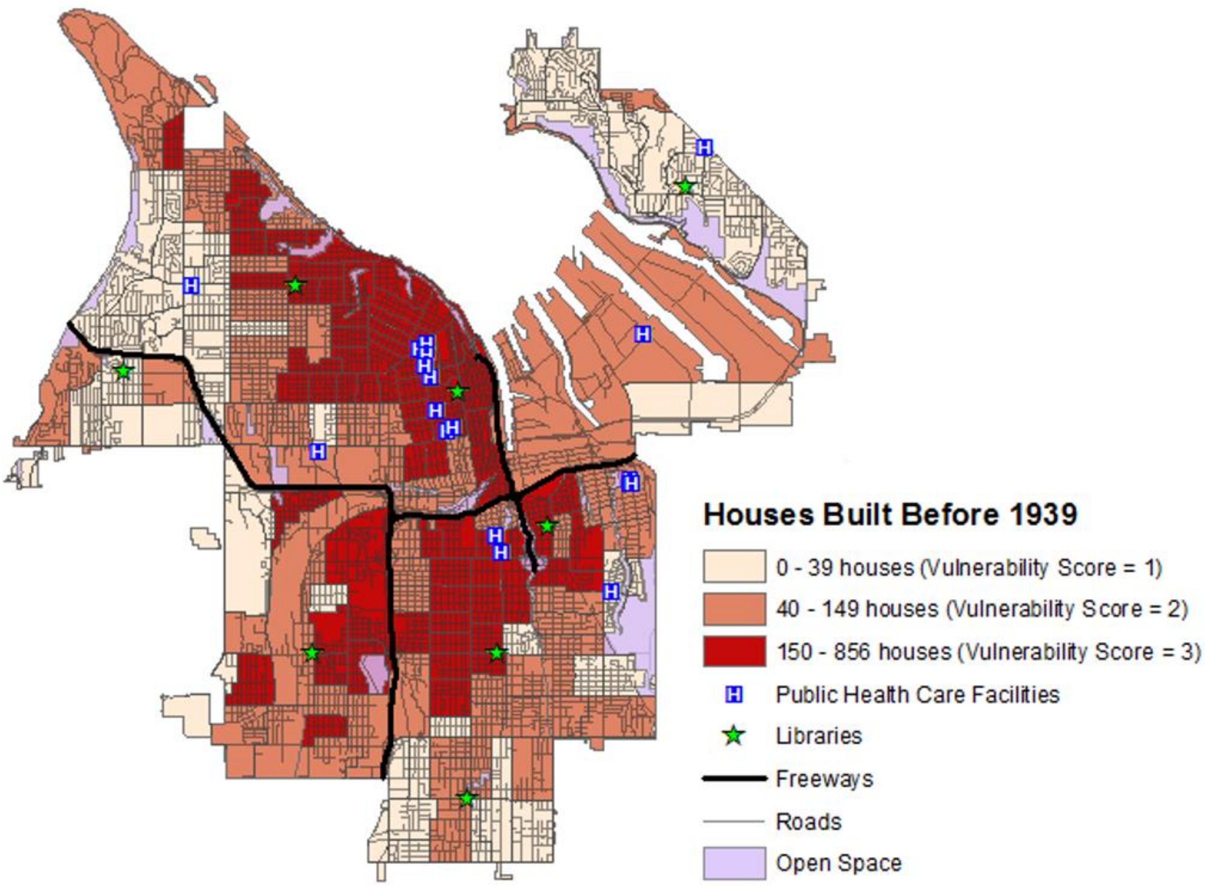



## AGE

We summed the number of young (under the age of five) and elderly persons (over the age of 65) per census block to assess age-based sensitivity to climate impacts. Note that the map reflects current demographic distributions, which may differ from future demographics in mid-century when climate change impacts become more visible.

**Relatively more of the very young and/or elderly reside in the West End and North East areas of the city** (Figure 22). These areas of the city also have relatively fewer medical facilities than other areas such as New Tacoma.

Figure 23. Number of homes built before 1939, ranked by census block.




## HOUSE TYPE

**Persons in older or rented housing may lack adequate protection from extreme heat, landslide, or flood risks.** Although house age data are available at the Census Block level and depicted in Figure 23, many older homes might have been recently renovated or retrofitted, limiting our ability to assess sensitivity based on this metric.

**Older homes in Tacoma are more abundant in the North End, New Tacoma, and South End neighborhoods of the city.**

The team did not examine home ownership rates due to the close relationship with income. Income is assessed as an adaptive capacity indicator in the section below.

## HOMELESSNESS

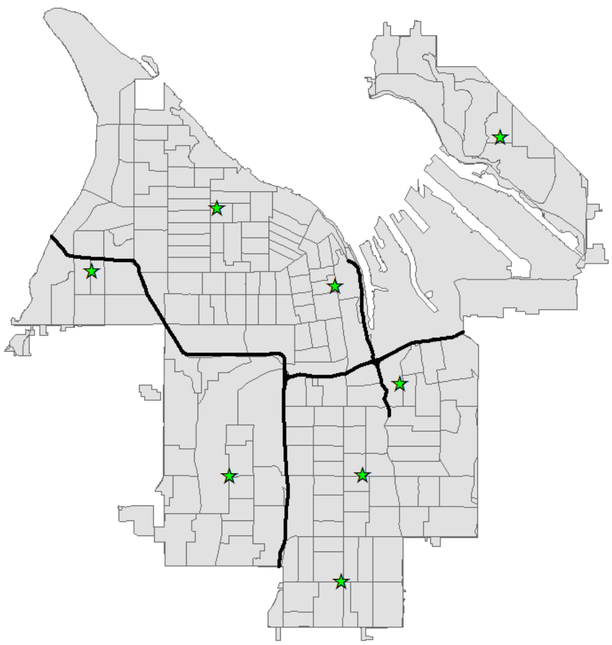
**Increased frequency and duration of extreme heat and precipitation events can be especially harmful to those without shelter.** The 2012 Community Data Report cites that on any given night, there are 1,997 homeless adults and children in Tacoma and Pierce County, and over 3,000 unaccompanied youth experience prolonged homelessness at any given time. The geographic distribution of homeless persons was not known at the time of this study.

### AIR CONDITIONING AND COOLING CENTERS

**Persons without air conditioning at their homes or workplaces will be especially sensitive to extreme heat events.** Identified cooling centers in Tacoma include public libraries and the Tacoma Mall. As shown in Figure 24, libraries appear to be equally distributed across the city, allowing for equitable access to cooling centers among Tacoma neighborhoods. However, it is unknown whether all libraries have air conditioning, and it is unknown how accessible the libraries are via walking, biking, or public transit. Furthermore, libraries have limited hours of operation, leaving few cooling options on hot evenings and weekends.

At the time of this assessment, no data were available on the prevalence of air-conditioned homes in Tacoma. Further analysis is needed to identify neighborhoods and communities that currently lack access to cooling either through air-conditioned homes or public cooling centers.

Figure 24. Tacoma cooling centers (libraries), indicated with green stars.



## Adaptive Capacity

A person or community's ability to adapt, bounce back, or otherwise mitigate the impacts of climate change depends on many factors. A person's income, level of education, first language, and level of insurance coverage will affect their ability to rebuild, retreat, or respond to extreme events and stresses. We examined relative adaptive capacity in Tacoma using the following five indicators: 1) median income, 2) poverty, 3) access to health care, 4) level of education, and 5) prevalence of persons for whom English is a second language. Data for four of these indicators were available at the census block level.

## INCOME AND POVERTY

**Approximately 17.1 percent of Tacoma residents live below the federal poverty level, compared to 12.1 percent statewide**, and the median household income is nearly $10,000 less than the statewide median income ($47,862 to $57,244 respectively) [43, 36].

Since 2005, the unemployment rate in Tacoma has ranged from 4.6 percent in October 2007 to 12.1 percent in February 2010 [44]. The current (August 2015) unemployment rate for Tacoma is 6.5 percent.

**Areas with higher concentrations of low income households in Tacoma include New Tacoma, South Tacoma, and the Eastside** (see Figure 25 and Figure 26).

Figure 25. Number of people under the poverty line, persons per census block.

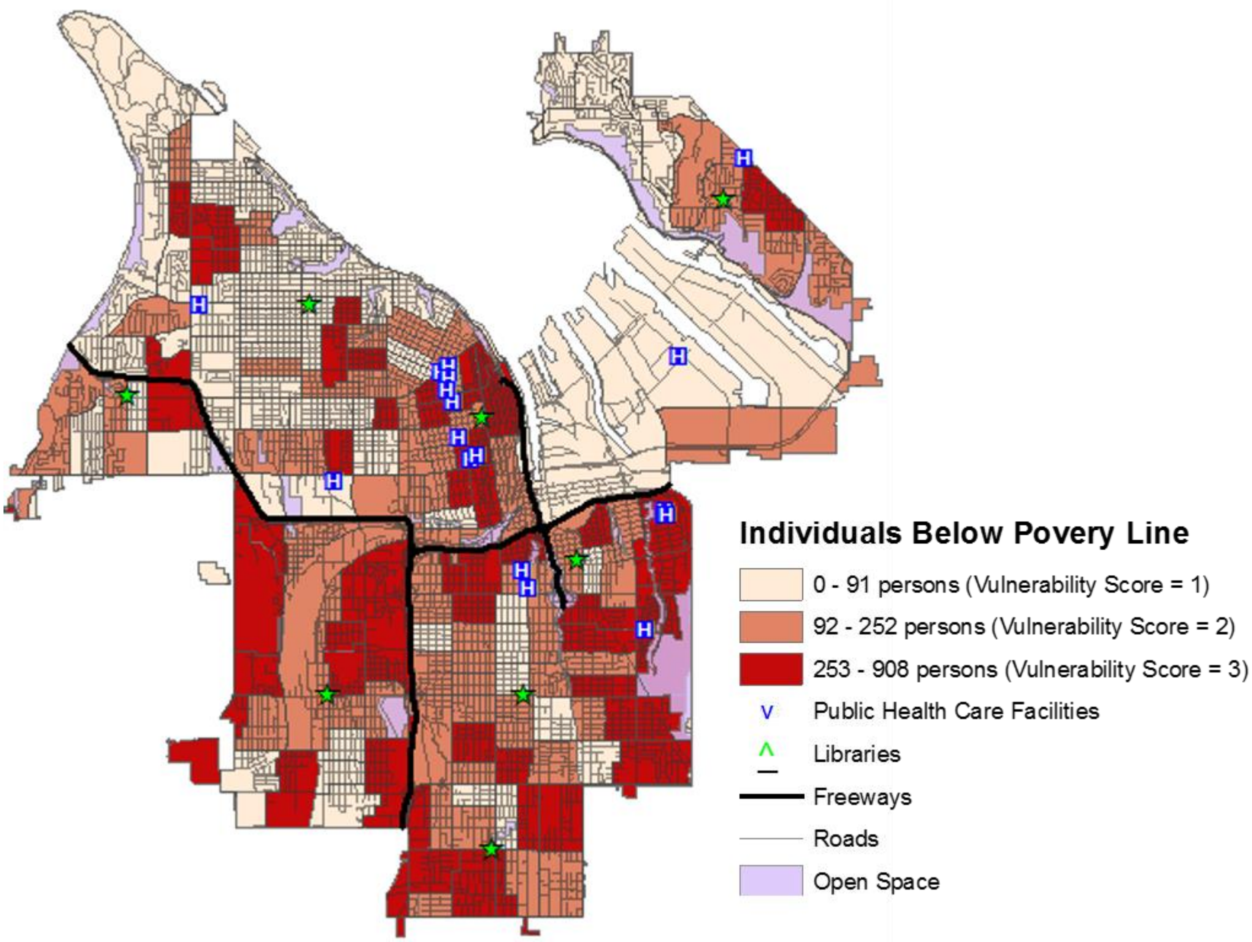
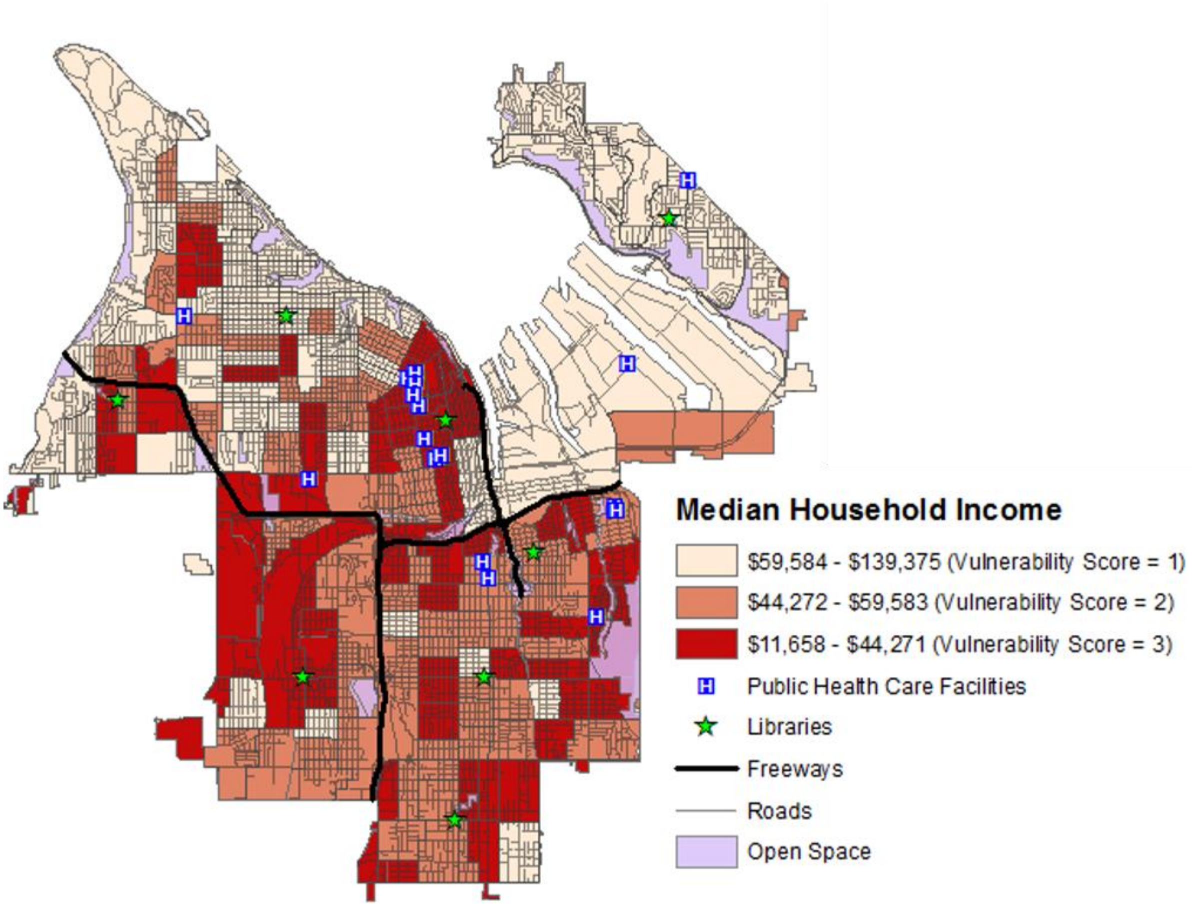


Figure 26. Median household income, dollars per census block.




## HEALTH INSURANCE AND ACCESS TO MEDICAL CARE

Access to quality health care is an important component of social resilience. However, although having health insurance suggests sufficient healthcare access, it does not assure that medical care is accessible or affordable to all. Co-pays, deductibles, and lack of coverage for certain services or conditions can limit health access to even those who have health insurance [45]. According to the Tacoma-Pierce County Health Department, about 20 percent of Pierce County adults reported there was a time in the past year when they could not afford to see a doctor [45]. As shown in Figure 27, **areas with a higher proportion of people without health insurance include New Tacoma, Eastside, and South End neighborhoods of Tacoma.**

Figure 27. Access to health care, by census tract [45].

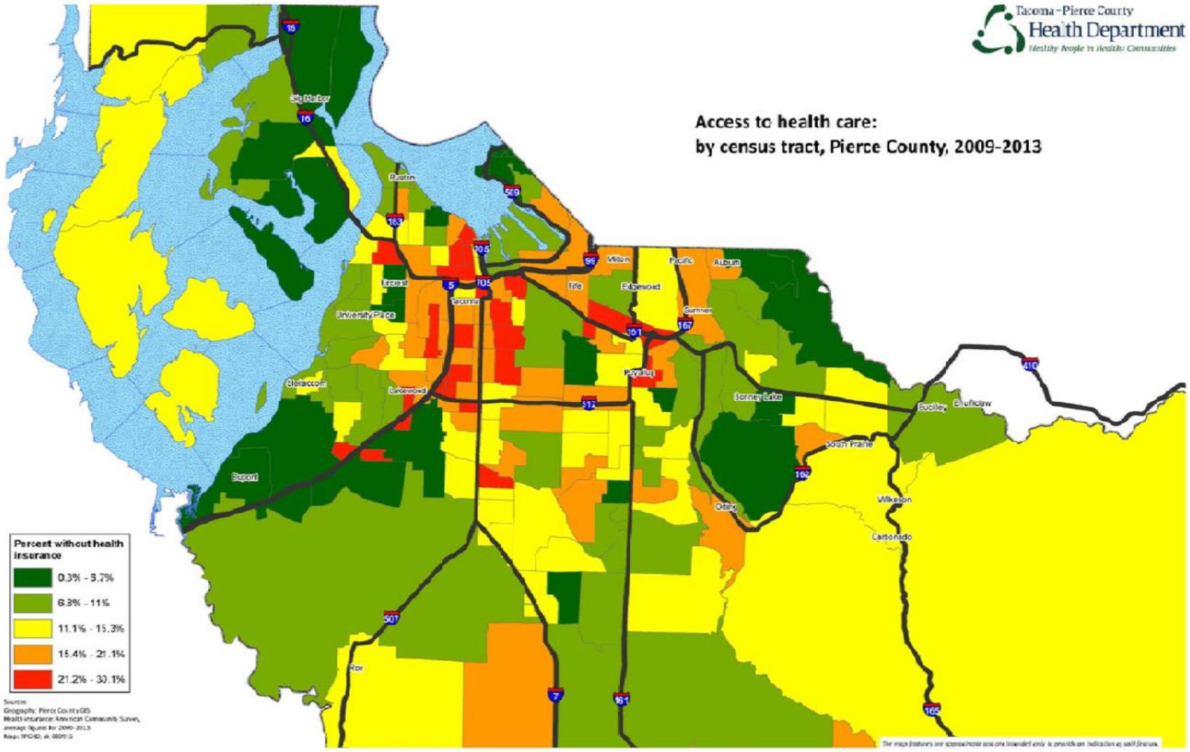
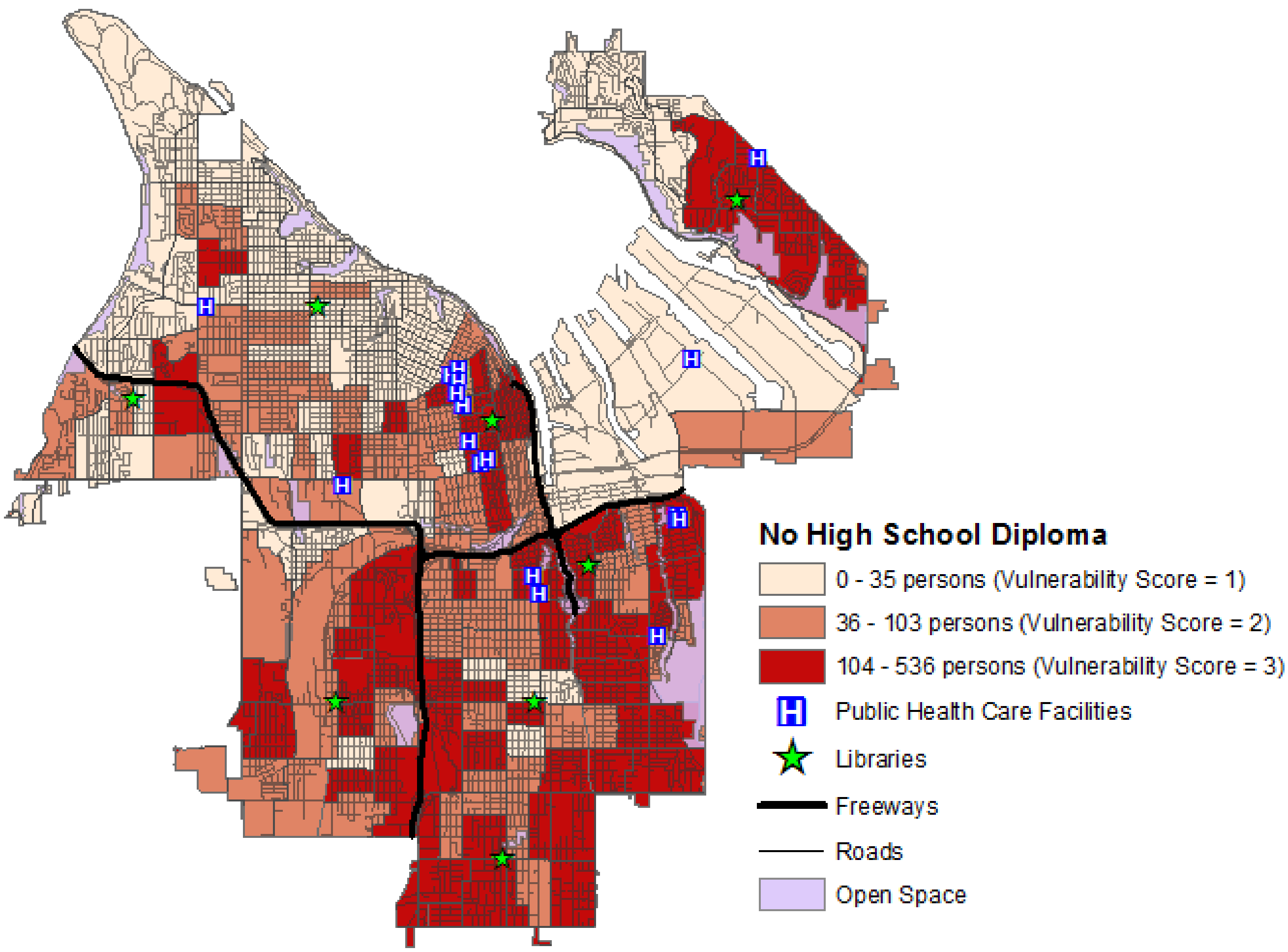


Figure 28. Number of people without a high school diploma, persons per census block.

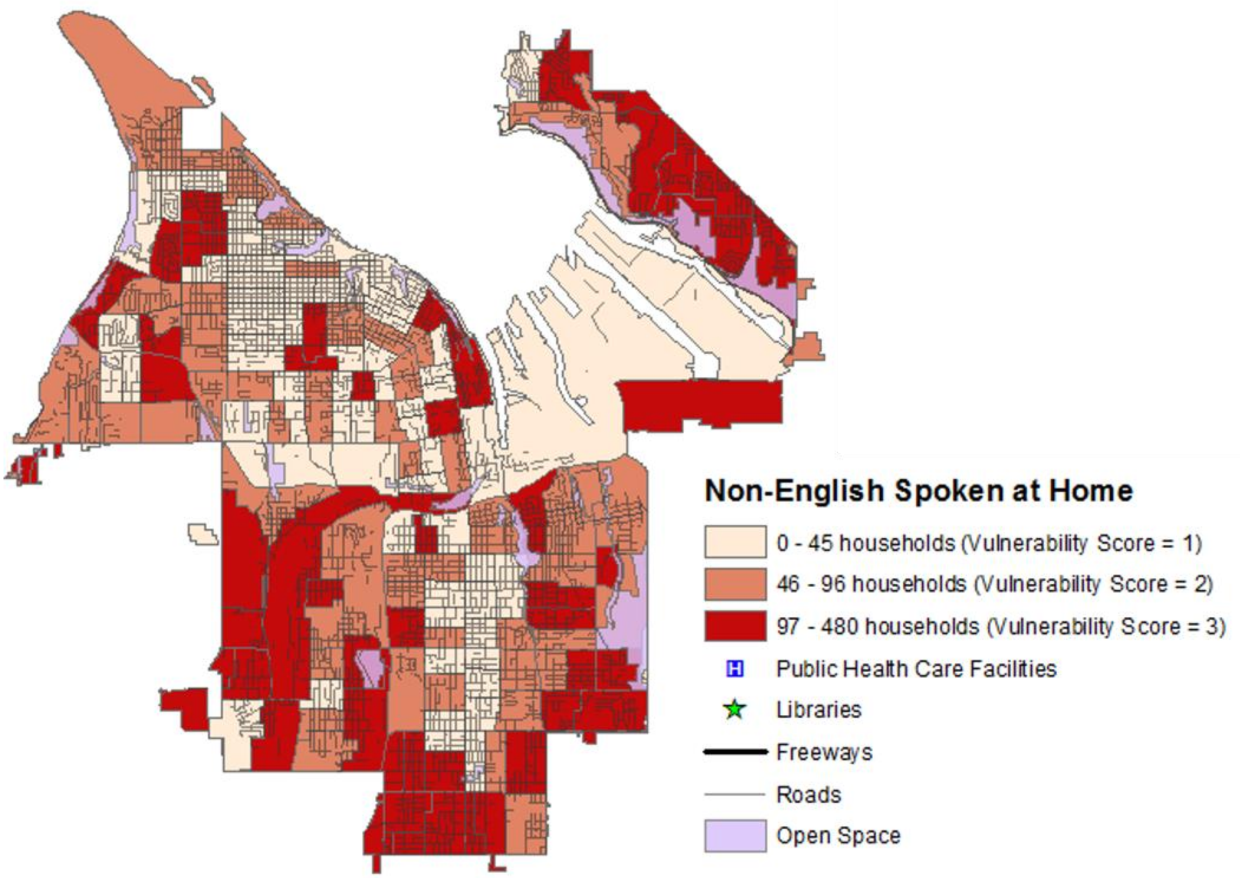



## EDUCATION

Research suggests that education plays a role in coping with disaster over the long term. The better educated have been shown to be less likely than others to live in temporary housing and to be in better psycho-social health after a disaster [46].

**There are higher concentrations of people without a high school diploma in the North East, South End, and Eastside neighborhoods** (see Figure 28).

Figure 29. Number of people for whom English is a second language, by census block.




## ENGLISH AS A SECOND LANGUAGE

Language competency is a critical component of social resilience. Those for whom English is a second language may have less access to essential communication and messaging around proper preparation and response to extreme events.

As shown in Figure 29, **the South Tacoma and North East neighborhoods have higher concentrations of people speaking English as a second language, compared to other Tacoma neighborhoods.**

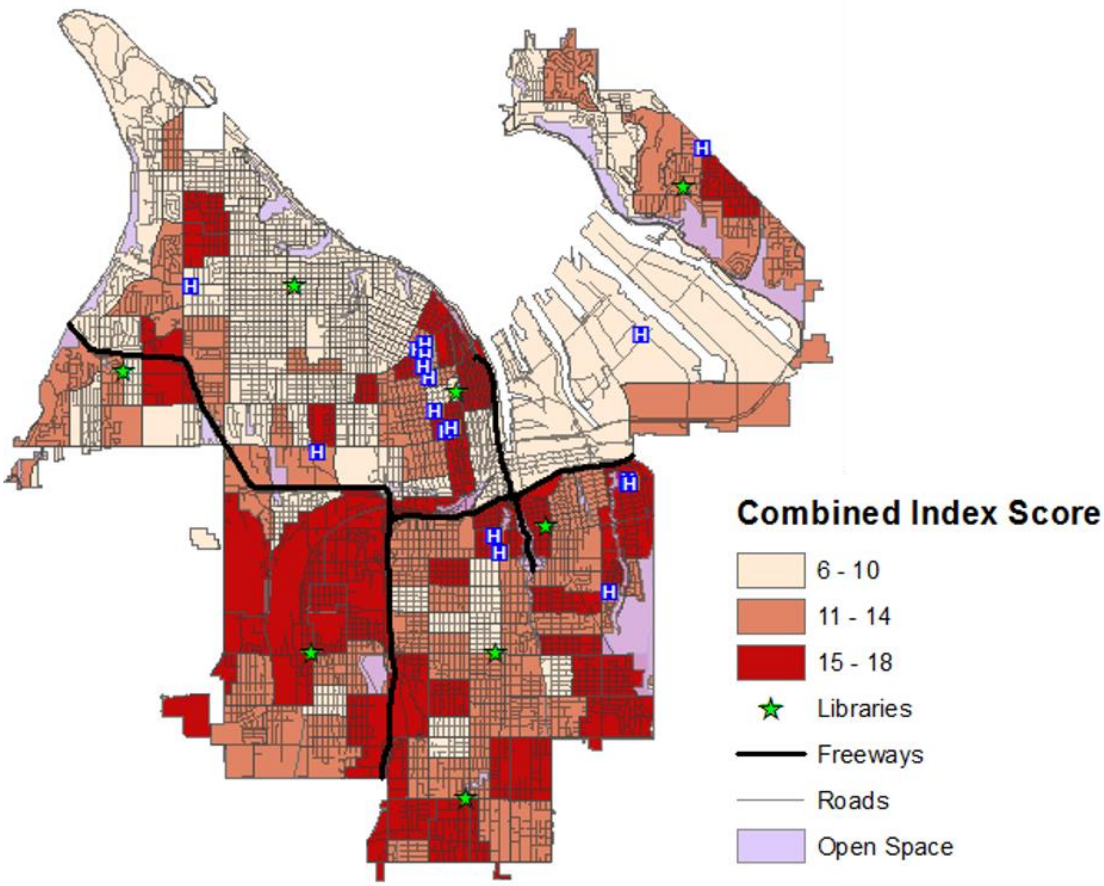
## OTHER CONSIDERATIONS

Other adaptive capacity considerations not included in this assessment include employment type and access to adequate food and transportation. Those employed in the service industry, for example, may have limited ability to take days off during extreme heat or flood events. Car owners and those with easy access to public transit could have an easier time evacuating or accessing medical services or shelters. Those with ready access to healthy food could be more resilient to heat-related illnesses and could have more food on-hand in case of a disaster. Further research on these attributes would allow for a more nuanced assessment of community vulnerability and potential targeted adaptation strategies.

## Overall Vulnerability

The assessment team combined the sensitivity and adaptive capacity indicators that were available at the census block level to arrive at an overall score. Each sensitivity and adaptive capacity indicator was equally weighted. As shown in Figure 30neighborhoods with the highest scores, indicating the greatest concern, were South Tacoma, South End, New Tacoma (near downtown), and Eastside.

Figure 30. Combined index score, as defined by six sensitivity and adaptive capacity indicators.




### INDICATORS

#### SENSITIVITY:

- Disability rate
- Age (number of very young or elderly persons)

#### ADAPTIVE CAPACITY:

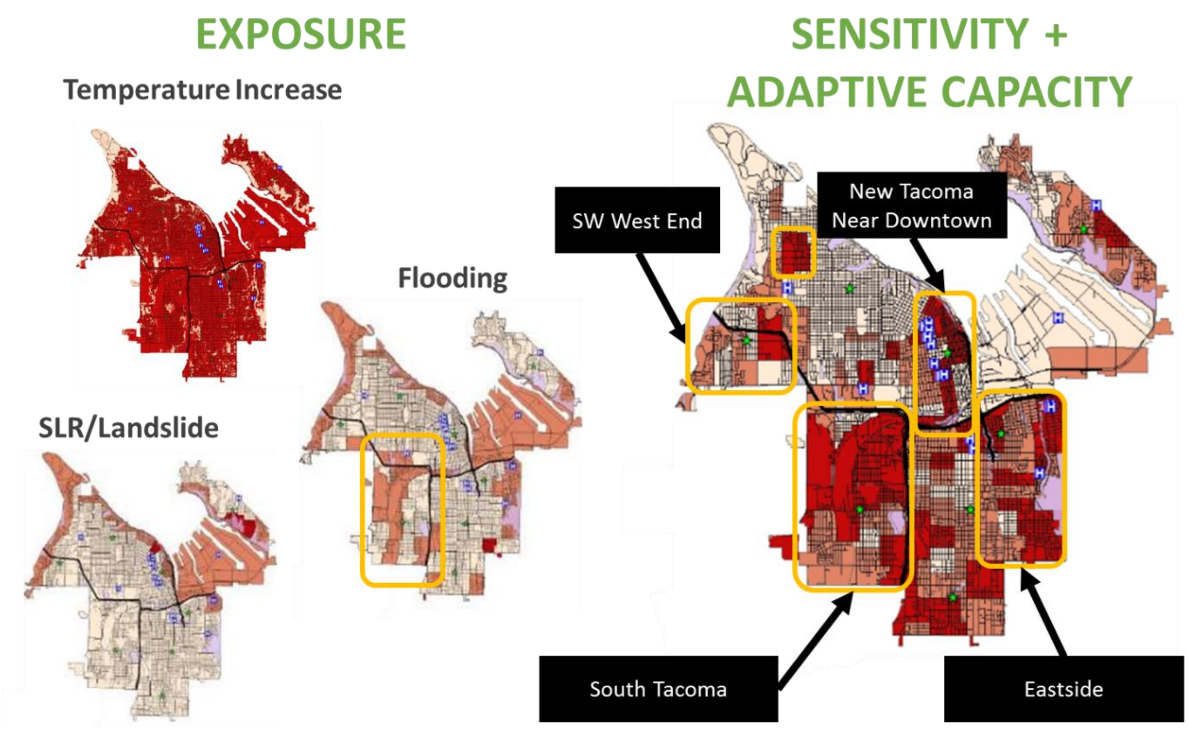
- Median income
- Number of people below poverty line
- Number of people without high school diploma
- Number of households where a language other than English is spoken at home

Each census block was given a relative score of low (1), medium (2), or high (3) for each of these indicators. A total score was then calculated for each census block with equal weighting for each indicator. Figure 30maps the total scores to show an estimate of relative sensitivity and adaptive capacity by census block.

Comparing the climate change exposure maps (Figure 17, Figure 18, Figure 19, and Figure 20) to the social sensitivity and adaptive capacity map (Figure 30) leads to the following conclusions regarding the climate vulnerability of Tacoma's social systems (see Figure 31):

- Coastal flooding and landslide hazards are of less concern in this context because areas exposed to those shocks generally have low sensitivity and high adaptive capacity.
- The most prominent climate hazards to Tacoma's social systems are extreme heat and inland flooding.
- Neighborhoods with high sensitivity and/or low adaptive capacity, as well as high extreme heat exposure, include South Tacoma, New Tacoma near downtown, the southwest area of West End, and Eastside. These areas should be prioritized for adaptation interventions.
- The priority neighborhood for social systems adaptation to flood risk is South Tacoma.

Figure 31. Priority neighborhoods for climate resilience building.



## EXISTING PROGRAMS THAT CONTRIBUTE TO BUILDING RESILIENCE TO IDENTIFIED IMPACTS

Tacoma's residents and businesses benefit from a variety of City strategies, programs, policies, and research that collectively build climate resilience, although it is often not the explicit goal. . A number of relevant programs are listed below.

- **Tacoma Power's Residential Energy Efficiency Rebate Program** helps residents and businesses save money by making buildings and homes more efficient. Rebates for cooling equipment such as ductless heat pumps can help build resilience against heat-related impacts on health and energy demand.
- **Healthy Homes, Healthy Neighborhoods** offers workshops and door-to-door outreach and communication on sustainability actions that can build community resilience. Workshops and outreach on reducing utility costs, planting trees and edible gardening, and natural yard care and rain gardens help address flooding, heat, and disaster risks through improved economic wellbeing, health, and heat and stormwater management.
- The **Strategic Urban Forest Management Plan (SUFMP)** for Neighborhood Business Districts lays out neighborhood-level summaries of canopy cover and strategies for improving canopy cover, which would help address the urban heat island effect.
- The recently published report ***Fairness Across Places? Your Health in Pierce County*** from Tacoma-Pierce County Health Department outlines key considerations and priorities that should be considered in implementing adaptation measures.
- The ***Summit to Sea Collective: Building Resilience into the Whole System*** HUD National Disaster Resilience Competition proposal compiled by Pierce County and others calls for a number of resilience-building activities and studies, including public engagement and flood reduction projects in the Puyallup watershed; farming resilience initiatives; climate adaptation planning and a resiliency program within Pierce County Emergency Management; and a "Communities for Opportunity" social disparity mapping and outreach program. The proposal also includes studies—such as an urban canopy survey by the WA Department of Natural Resources—that could address key information gaps.
- The **2012 Community Data Report** sets forth strategic priorities and opportunities for growth related to community livelihoods, health, and human services. Priorities include increasing employability and self-sufficiency for adults; improving access to nutrition and health services; providing secure, permanent housing for those in need; and making prevention of and pathways out of homelessness available. Taking action toward meeting these objectives will foster community resilience to climate change and other stressors.

## RECOMMENDED ADAPTATION STRATEGIES: SOCIAL SYSTEMS

Priorities for near-term adaptation action in Tacoma, detailed below, focus on leveraging and expanding existing programs, policies, and organizations. Most actions can be applied across climate impacts and locations; however, resilience study outcomes suggest that particular focus should be placed on extreme heat preparedness and resilience in South Tacoma, New Tacoma near downtown, the southwest area of West End, and Eastside.

## Near-Term Needs and Windows of Opportunity

A variety of activities already underway in Tacoma could integrate climate change considerations and actions. These unique windows of opportunity include the following:

- **Incorporate outcomes from the *Fairness Across Places? Your Health in Pierce County* report into targeted resilience activities and initiatives.** This report sheds light on why inequities in Tacoma's communities exist and what can be done to improve health for all. Identified areas of highest priority and actions such as increasing education, partnerships, and advocacy should be emphasized in climate resilience activities to make them more inclusive and more effective.
- **Consider climate change risks in the Tacoma Mall Neighborhood Subarea Plan.** Funded by a National Estuaries Program Watershed Protection Grant, this planning effort seeks to develop and promote a vision for positive growth and change within the Tacoma Mall Neighborhood Subarea. These plans should consider future climate change risks and resilience opportunities.
- **Incorporate climate resilience actions into equity initiatives and programs.** Current programs that could incorporate resilience activities, education, and actions include the Healthy Homes, Healthy Neighborhoods program, Puyallup Watershed Initiative, Tacoma Office of Equity, Family Support Centers, and the Tacoma-Pierce County Health Department's Health Equity Initiative.
- **Contribute to and leverage HUD grant activities, should the grant be awarded.** Pierce County's application to HUD's Natural Disaster Resilience Competition included a variety of activities that would enhance the social system resilience of Tacoma, including climate action planning within Pierce County's Emergency Management department, an urban canopy survey, and development of a "Communities for Opportunity" social disparity mapping and outreach program. Ensuring that grant activities consider future climate change as well as current climate variability would enhance the sustainability of outcomes.
- **Integrate future climate risk in emergency planning and hazard mitigation planning updates.** Relevant plans that could consider and provide response actions for climate-related impacts include the Hazard Mitigation Plan and Comprehensive Emergency Management Plan (CEMP).

## Low-Hanging Fruit

- **Begin a conversation with the business community around climate impacts and resilience.** Businesses play an integral role in a community's resilience. They provide essential services for the public during extreme events, are a critical source of income for Tacoma residents, and are also vulnerable themselves to direct climate impacts and secondary implications for supply chains and product prices. Forums such as chambers of commerce and business district meetings provide venues for conversations around the private sector role in climate resilience. Given the vulnerabilities in the tideflats and those related to transportation assets, the Port and trade-dependent industries should be among those engaged.
- **Engage with and support community organizations that enhance community resilience.** Organizations that are already working with the community on the ground, such as Citizens for a Healthy Bay and the Puyallup Watershed Initiative, play essential roles in fostering economic development, environmental protection, and social connectivity. The City could work through these existing organizations to assess the resilience landscape, respond to needs, and potentially build a

network of neighborhood "resilience champions" who could spearhead on-the-ground education and action.

## Longer-term Strategies

- **Develop a coordinated strategy for addressing extreme heat risks.** Potential actions to combat extreme heat risks in Tacoma include enhanced public education and outreach around heat risks and preparedness; improved urban design and planning around passive and active cooling solutions; and coordinated preparedness and response efforts among local and regional government, community organizations, and businesses. The City should work with stakeholders to identify a comprehensive and coordinated strategy for addressing extreme heat risks to its social, natural, and built systems that includes public engagement, policy, and development solutions.
- **Adjust and/or amend the Critical Areas Ordinance and drainage code under development regulations to build resilience to increased landslides and flooding.** Current regulations and ordinances were developed under a current landslide and flood risk scenario. These requirements should be updated to reflect future changes in risk due to climate change.
- **Maintain and expand utility rebate programs for cooling equipment, especially for lower-income households.** Tacoma Power's energy efficiency rebates provide critical infrastructure for more heat-resilient homes and businesses while also minimizing energy loads associated with traditional air conditioning systems.
- **Prioritize South Tacoma, New Tacoma near downtown, the southwest area of West End, and Eastside** in capital improvement, development, and planning activities as relevant to ensure that these communities receive the services they need to adequately build resilience to climate change and other stressors.

## RECOMMENDATIONS FOR FURTHER STUDY

This social systems assessment identified the following areas for further research:

- **Study urban heat at key locations.** Locations such as identified vulnerable neighborhoods and critical transportation centers such as stations and bus stops should be evaluated for extreme heat vulnerability. Such a study would allow the City to prioritize extreme heat resilience investments such as installation of cool roofs and passive cooling systems and identify available cooling centers.
- **Evaluate the prevalence of air conditioning.** Currently, no dataset is available that outlines the prevalence of air conditioning systems among Tacoma homes and businesses. A survey of air conditioning prevalence could help the City identify priority areas and populations for cooling capacity investment and improvements.
- **Study accessibility and effectiveness of identified cooling centers.** Libraries and malls currently serve as the primary cooling centers for the city. Although these facilities are equally distributed throughout the city, the extent to which they are accessible to everyone by public transit, biking, and/or walking is unknown. Furthermore, it is unknown how effective they are as cooling centers, as many have limited hours of operation and may not provide services such as infant care. A more in-depth assessment of the accessibility and effectiveness of Tacoma's cooling centers would allow the City to identify areas for improvement and, if needed, areas in need of new cooling centers.

# 7. RECOMMENDATIONS AND NEXT STEPS

## RECOMMENDED ADAPTATION STRATEGIES

Recommended adaptation strategies and areas for further study are listed below in three categories: 1) urgent near-term needs and windows of opportunity, 2) measures with clear co-benefits, and 3) longer-term strategies. More detail about the individual recommendations is available at the end of Sections 4, 5, and 6.

### Near-Term Strategies

#### URGENT NEEDS

1. **Ensure that near-term capital improvement projects consider climate change risks.** Develop a city standard of practice that accounts for climate change impacts (e.g. higher flow, higher sea level, and higher temperature) in design of capital projects (e.g. surface water and wastewater conveyance infrastructure, plantings, pavement, and infrastructure near the shoreline or in landslide zones). Reviews could potentially be done through the existing Design Integration Review Team processes.
2. **Gather additional data on existing infrastructure problems that will be exacerbated by climate change impacts like sea level rise.** For example, develop a list of existing capacity-related surface water problems for the whole city and existing problems along the shoreline. Conduct more detailed site-by-site evaluations of exposure to landslide risks, focusing on most critical roads, infrastructure, and vulnerable populations, as well as areas where under-capacity surface water conveyance may lead to steep slope erosion or landslide potential (e.g., Ruston Way, Stadium, Stadium Bowl). Determine whether the wastewater treatment plants are vulnerable to corrosion as a result of current and future salt water inflow and infiltration
3. **Inspect, maintain, and upgrade critical infrastructure.** This includes prioritizing inspection and maintenance of holding basins and other stormwater system components (e.g., inlets) that help reduce sensitivity to increased storm intensity or volume. It is also important to upgrade critical stormwater inlets (or nearby inlets that are easily modified) to reduce the sensitivity to intense storms in the fall (e.g., by installing curb inlets).
4. **Preserve remaining natural areas, and provide more explicit design guidance or performance specifications on considering climate science in habitat restoration plans.** Greater resilience can be built into habitat restoration projects by planning for transition zones, allowing for greater seasonality in hydrologic performance and targets, and considering higher peak flows for restored wetland and stream systems. It will also be important to establish stronger, more resilient landscapes in open spaces by increasing plant diversity, extending establishment periods, and adding more habitat types.
5. **Increase preparedness for greater climate variability and more frequent and/or more severe extreme events, including heat waves and floods.** Study urban heat at key locations such as identified vulnerable neighborhoods and critical transportation centers to inform prioritization of investments in cool roofs, passive cooling systems, and other measures. Evaluate the prevalence of air conditioning to help identify priority areas and populations for cooling capacity

investment and improvements. In addition, study the accessibility and effectiveness of identified cooling centers (libraries and malls).

6. **Prioritize South Tacoma, New Tacoma near downtown, the southwest area of West End, and Eastside in capital improvement, development, and planning activities as relevant** to ensure that these communities receive the services they need to adequately build resilience to climate change and other stressors.
7. **Invest in further research on key risks, particularly sea level rise and Puyallup River flooding.** Of particular importance is more detailed marine inundation area mapping, including update/review of topographic data for specific infrastructure assets and examination of flow connectivity. The results would be useful for planning adaptation strategies along Ruston Way, Marine View Drive, Dock Street, and in the tideflats. Also study and plan for the interaction between sediment production, flow, and sea level rise in the Puyallup River.
8. **Conduct additional studies to reduce uncertainty around the vulnerability of specific natural systems in the city, including through detailed spatial mapping.** Research the geologic and geomorphic characteristics of streams in Tacoma and their susceptibility to increases in peak flow resulting from climate change. Collect GIS spatial data and identify the hydroperiod or hydrogeomorphic typology of Tacoma's freshwater wetlands in the city. Study the sedimentation/marsh aggradation of specific tidal wetlands.
9. **Evaluate the development code related to landslide and flooding hazards** to ensure that development practices and future private projects reduce risk to public safety and infrastructure from climate change impacts.

## WINDOWS OF OPPORTUNITY AND LOW-HANGING FRUIT

There are also near-term windows of opportunity for considering climate change projections in current planning and design efforts. This list also includes actions that are relatively low-cost or easy to implement.

1. **Encourage the leads of existing Puyallup River flood planning and reduction work to integrate climate change considerations (e.g., increased sediment, increased flow, increased sea level) into current and near-term work**, including work being conducted or proposed under the Floodplains by Design program and the Phase 2 Application for HUD's National Disaster Resilience Competition. Several activities in Pierce County's HUD grant application would also enhance the resilience of Tacoma's social systems. Ensuring that grant activities consider future climate change as well as current climate variability will enhance the sustainability of outcomes.
2. **Incorporate climate resilience actions into equity initiatives and programs, and consider future climate risk in emergency planning and hazard mitigation planning updates,** including the Hazard Mitigation Plan and Comprehensive Emergency Management Plan (CEMP). Incorporate outcomes from the *Fairness Across Places? Your Health in Pierce County* report into targeted resilience activities and initiatives to make those activities more inclusive and more effective.
3. **Begin a conversation with the business community around climate impacts and resilience,** starting with forums such as chambers of commerce and business district meetings.
4. **Engage with and support community organizations that enhance community resilience** in order to assess the resilience landscape and respond directly to needs.

5. **Consider climate change risks in the Tacoma Mall Neighborhood Subarea Plan,** including assessment of development possibilities and stormwater and open space improvements.
6. **Identify wastewater and stormwater system components—such as manholes, pump stations, and treatment plants—that may be put at risk by sea level rise, marine flooding, related corrosion, and adjust system components accordingly.** For example, install gasketted and bolted manhole lids, and raise the elevation of weirs at vulnerable wastewater-stormwater cross connections (e.g. wastewater overflow points).
7. **Confirm that the landfill drainage system has adequate capacity to handle increased flow**.

## Strategies with Multiple Benefits

There are adaptation strategies that have the potential to provide benefits across all three systems addressed in this study: built, natural, and social.

1. **Evaluate development surrounding steep slopes** to ensure that development practices do not either (1) put people or property at risk of harm, or (2) disconnect a vital sediment source from the nearshore. Extend development restrictions and/or setbacks in these areas to provide additional protection from future climate-related risks.
2. **Preserve and expand urban forest canopies**. Expanding forest canopies can provide benefits by reducing stormwater runoff, reducing urban heat, and providing valuable habitat. Complement canopy expansion with additional interventions as needed (e.g., a leaf pickup program).
3. **Encourage low impact development (LID) practices for stormwater management** where feasible.
4. **Reduce non-climate stressors (e.g., vegetation clearing, stormwater runoff, and impaired water quality) affecting fish, wildlife, plants, and ecosystems.** This will put them in a position to face other stressors—including climate change impacts—with a higher baseline level of resilience. Many of these activities will have co-benefits for human health and/or the maintenance of built infrastructure.
5. **Where possible, reestablish flood pathways in altered former natural floodplains.** This may involve purchasing properties that are currently flooded or at risk of flooding in order to recreate historical drainage pathways.

## Longer-Term Strategies

These measures are less urgent and/or may require more time to plan and implement, but they are important for building resilience to change over the coming decades. Strategies listed in this category may also depend on the results of studies recommended above.

1. **Explore ways to increase the resilience of transportation system components such as roads,** beginning with an evaluation of landslide potential and detailed marine inundation mapping.
2. **Develop and implement capital improvement projects to address sea level rise impacts on the Central Wastewater Treatment Plant and wastewater system** based on salinity data collection and detailed marine inundation mapping. Measures could include sealing manholes, lining pipes, modifying structures, or raising control panels.

3. **Consider prioritizing surface water system improvements downstream of Leach Creek pump station outfall to Foss Waterway twin 96'ers**, where increased flow would strain a part of the system with existing capacity problems. Also install backflow prevention devices on marine outfalls that are likely to contribute to flooding of low lying areas through backflow.
4. **Collect additional data and identify risk hotspots across several infrastructure systems.** For example, collect salinity data on wastewater treatment plant effluent to determine whether saltwater intrusion or inflow could be contributing to corrosion of system components. Pinpoint where culverts, bridges over natural streams, and other components of the stormwater conveyance system intersect with the greatest potential for flood damage to property or people. Integrate knowledge about increased inflow and infiltration potential resulting from climate change into future inflow and infiltration evaluation projects.
5. **Collaborate with other agencies and institutions to tackle cross-jurisdictional information needs and adaptation opportunities.**
    a. Coordinate with the Port of Tacoma, BNSF Railway, Tacoma Public Utilities, and other property owners within the tideflats to evaluate the impacts of projected future flood risk on tideflat operations. Encourage the U.S. Army Corps of Engineers and Pierce County to investigate raising and setting back the Puyallup River levees to reduce flood risk. Continue to engage in and support regional efforts within the Puyallup River basin to consider river management for floods, sediment, agriculture, and infrastructure protection.
    b. Coordinate with the Tacoma Pierce County Health Department regarding potential zoning or development changes to protect against flood displacement of hazardous material; potential impacts of sea level rise and flood events on leaking side sewers and the pockets of septic systems in the city; and saltwater intrusion into wells used for drinking water.
6. **Establish transitional zones around the nearshore**, and identify places where infrastructure can be set back as part of CIP implementation.
7. **Develop an urban landscape strategy or framework** that values and expands upon the natural features of the landscape, including urban forests, critical areas, and open spaces. This strategy would include ways to develop additional natural areas and preserve existing ones under changing climatic conditions.
8. **Develop a coordinated strategy for addressing extreme heat risks**, which could include actions such as enhanced public education and outreach around heat risks and preparedness; increased use of passive and active cooling solutions; and coordinated preparedness and response efforts. Maintain and expand utility rebate programs for cooling equipment, especially for lower-income households.
9. **Adjust and/or amend the Critical Areas Ordinance and drainage code under development regulations to build resilience to increased landslides and flooding.** Current regulations and ordinances were developed under a current landslide and flood risk scenario. These requirements should be updated to reflect future changes in risk due to climate change.

# APPENDIX 1: TERMS AND DEFINITIONS

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| **Adaptation** | In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate. |
| **Adaptive capacity** | The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. |
| **Aquifer** | A geologic stratum containing groundwater that can be withdrawn and used for human purposes. |
| **Atmospheric river** | A narrow band of water vapor transport extending from the tropical Pacific to the west coast of North America during the winter months. |
| **Backflow** | The undesirable reversal of the flow of water from its intended direction in any pipeline or plumbing system. |
| **Base flood** | A flood having a one percent chance of being equaled or exceeded in any given year. This is also referred to as the 100-year flood. |
| **Base flood elevation** | The water surface elevation of the base flood. It shall be referenced to the National Geodetic Vertical Datum of 1929 (NGVD). |
| **Berm** | A constructed barrier of compacted earth, rock, or gravel. In a stormwater facility, a berm may serve as a vertical divider typically built up from the bottom. |
| **Best Management Practice (BMP)** | The schedules of activities, prohibitions of practices, maintenance procedures, and structural and/or managerial practices, that when used singly or in combination, prevent or reduce the release of pollutants and other adverse impacts on waters of Washington State. |
| **Capital Improvement Project or Program (CIP)** | A project prioritized and scheduled as a part of an overall construction program or, the actual construction program. |
| **Catch basin** | A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow. |
| **Channel** | A feature that conveys surface water and is open to the air. |
| **Climate** | The statistics of weather. In other words, the average pattern for weather over a period of months, years, decades, or longer in a specific place. |

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| **Conveyance system** | The drainage facilities, both natural and man-made, which collect, contain, and provide for the flow of surface and stormwater from the highest points on the land down to a receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities. |
| **Critical areas** | At a minimum, areas which include wetlands, areas with a critical recharging effect on aquifers used for potable water, fish and wildlife habitat conservation areas, frequently flooded areas, geologically hazardous areas, including unstable slopes, and associated areas and ecosystems. |
| **Emissions** | The release of greenhouse gases and/or their precursors and aerosols into the atmosphere over a specified area and period. |
| **Exposure** | The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected |
| **Extreme weather event** | An event that is rare within its statistical reference distribution at a particular place. |
| **Flow control facility** | A drainage facility designed to mitigate the impacts of increased surface and stormwater runoff flow rates generated by development. |
| **Greenhouse gas** | Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. |
| **Heat island** | An area within an urban area characterized by ambient temperatures higher than those of the surrounding area because of the absorption of solar energy by materials like asphalt. |
| **Hydrogeomorphology** | The study of landforms created or modified by water. |
| **Hydroperiod** | The period of time during which a wetland is covered by water. |
| **Impervious surface** | A hard surface area, which either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development. |
| **Levee** | A natural or manmade earthen barrier along the edge of a stream, lake, or river. |
| **LIDAR** | A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system— generate |

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| | precise, three-dimensional information about the Earth's surface characteristics. |
| **Littoral** | Related to or situated on the shore of a sea or lake. |
| **Low impact development** | A stormwater management strategy that emphasizes conservation and the use of existing natural site features, including planted and retained trees, integrated with engineered, small-scale stormwater controls to more closely mimic predevelopment hydrologic conditions. |
| **Mitigation** | A human intervention to reduce the sources or enhance the sinks of greenhouse gases. |
| **Ocean acidification** | Increased concentrations of carbon dioxide in sea water causing a measurable increase in acidity (i.e., a reduction in ocean pH). This may lead to reduced calcification rates of calcifying organisms such as corals, mollusks, algae and crustaceans. |
| **Outfall** | The place where a sewer, drain, or stream discharges; the outlet or structure through which reclaimed water or treated effluent is finally discharged to a receiving water body. |
| **Peak flow** | The maximum instantaneous discharge of a stream or river at a given location. |
| **Projection** | A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. |
| **Resilience** | The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions. |
| **Scenario** | A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. |
| **Sensitivity** | The degree to which a system is affected, either adversely or beneficially, by climate variability or change. |
| **Storm surge** | The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). |

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| **Surface water and stormwater** | Water originating from rainfall and other precipitation that is found in drainage facilities, rivers, streams, springs, seeps, ponds, lakes, and wetlands as well as shallow groundwater. |
| **Vulnerability** | The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity. |
| **Wastewater** | Water that has been used in homes, industries, and businesses, contains dissolved or suspended waste materials, and is not for reuse unless it is treated. |
| **Weather** | The atmospheric conditions at a specific place at a specific point in time. |
| **Weir** | Device for measuring or regulating the flow of water |
| **Wetlands** | Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. |

These definitions are from the 2012 City of Tacoma SMMP, the EPA Glossary of Climate Terms, the USDA Forest Service Climate Change Glossary, the USGS Water Science Glossary of Terms, the IPCC, and the University of Washington Climate Impacts Group website.

# APPENDIX 2: FULL CIG REPORT ON PROJECTED CHANGES FOR THE CITY OF TACOMA

## INTRODUCTION

The City of Tacoma Climate Change Resilience Study project seeks to establish a baseline understanding of how climate change is likely to affect infrastructure, operations, critical areas, and natural systems in or otherwise important to the City of Tacoma. Information from the assessment will guide future efforts to develop climate adaptation strategies where necessary.

This document, developed as technical input for the project, summarizes projected changes in Pacific Northwest climate and climate-sensitive attributes relevant to the project scope that can influence vulnerability to climate change. These attributes include projected changes in air temperature, precipitation, snowpack and streamflow (as it relates to flood risk and summer low flows), sedimentation, landslide risk, and sea level rise.

Because this document draws from existing datasets and literature, the time periods and spatial scale of the information varies. Where possible, projections specific to the City of Tacoma and the Puyallup River watershed are provided. Other frequently reported geographic scales in this report are the U.S. Pacific Northwest (covering the states of Washington, Oregon, and Idaho), Washington State, Puget Sound, or the Washington Cascades. Most projections are for mid-century (generally the 2050s) and end of century (2100).

## OBSERVED TRENDS: OVERVIEW

Instrumental and observational data show that climate in the Pacific Northwest is warming. While observed warming at the global scale can be conclusively attributed to rising greenhouse gas emissions, attribution at the regional scale (like the Pacific Northwest) is more difficult due to the strong influence of natural variability at smaller scales (Box 1).

As summarized in *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers* [1], observed changes in regional temperature and precipitation include the following:

- **Average annual temperature increased.** Average annual temperature in the Pacific Northwest warmed about +1.3°F between 1895 and 2011 (Figure 32), with statistically-significant warming occurring in all seasons except spring [2].
- **The frost-free season lengthened.** The frost-free season (and the associated growing season) for the Pacific Northwest has increased by 35 days (±6 days) from 1895 to 2011.

**Box 1. The Role of Climate Variability Observed Trends and in a Changing Climate**

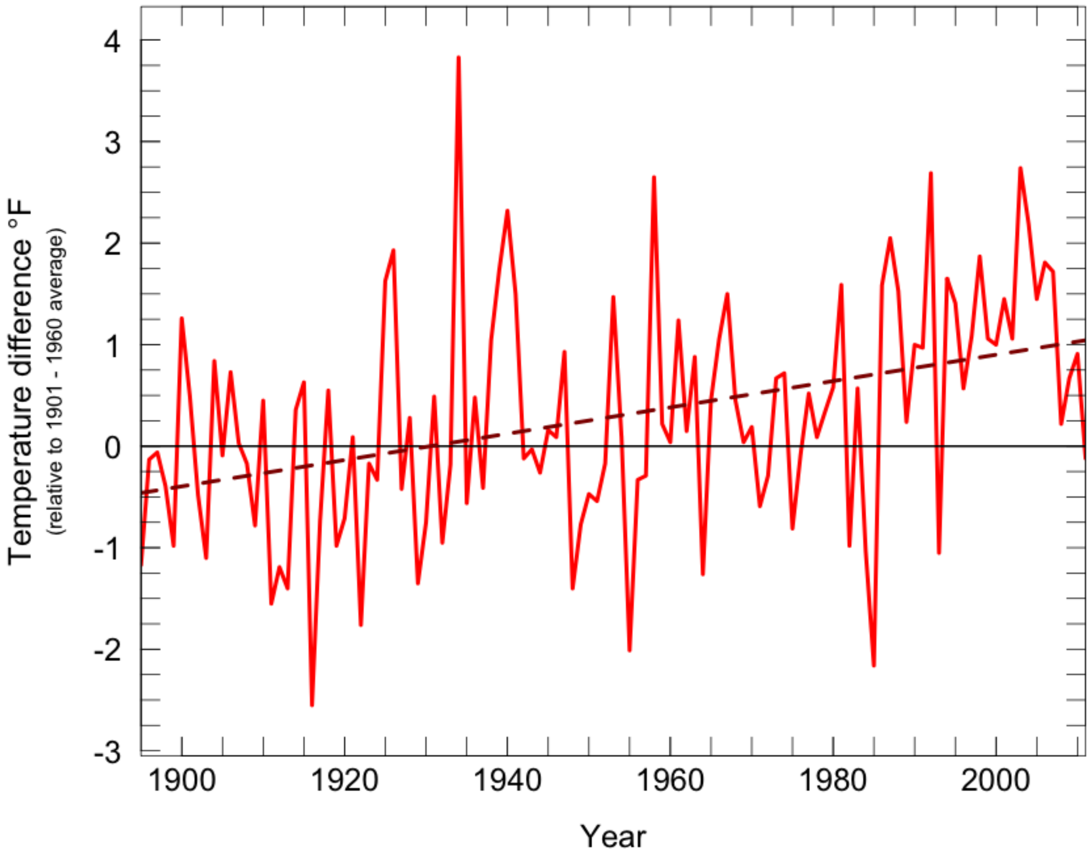
While this project is focused on assessing vulnerability to climate change, it is important to note that natural climate variability will continue to influence Pacific Northwest climate -- and through that, its communities and natural resources -- even as human activities cause global warming.

Climate variability in the Pacific Northwest is largely governed by two large-scale oceanic and atmospheric oscillations: the El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO cycles last for up to a year, typically peaking between December and April; warm phases are referred to as “El Niño” and cool phases as “La Niña” [47]. The PDO is also characterized by warm and cool phases, but unlike ENSO the cool/warm phases of PDO typically persist for 10 to 30 years [48].

El Niño and warm phase PDO tend to, but do not always, result in above average annual temperatures and drier winters in the Pacific Northwest. El Niño and warm phase PDO are also more likely to result in lower than average snowpack, lower flood risk, and higher forest fire risk. In contrast, La Niña and cool phase PDO increase the odds for cooler than average annual temperatures and wetter winters, leading to higher winter snowpack, higher flood risk, and lower forest fire risk while in those phases. When the same phases of ENSO and PDO occur simultaneously (i.e., years characterized by both El Niño and warm phase PDO or by La Niña and cool phase PDO), the impact on Pacific Northwest climate is typically larger. If the ENSO and PDO patterns are in opposite phases in a given year, their effects on temperature and precipitation may offset each other to some degree.

How (and whether) ENSO and PDO will change in the future as a result of climate change remain open questions. Some studies suggest that climate change may cause a prolonged persistence of El Niño conditions in the equatorial Pacific, although the reasons remain uncertain [49] [50]. Despite this uncertainty, we expect ENSO and PDO to continue influencing Pacific Northwest climate in the coming decades, sometimes reinforcing or counteracting the effects of climate change. For example, if PDO were to persist in its cool phase for another decade or two, the long-term global warming trend could be masked in the Pacific Northwest, leading to smaller near-term changes and the possibility of more rapid changes when the PDO returns to warm phase conditions.

Figure 32. Rising temperatures in the Pacific Northwest. Average annual temperature (red line) shown relative to the 1901–1960 average (indicated by the solid horizontal line). The dashed line is the fitted trend, indicating the +0.13°F/decade warming for 1895-2011. Figure source: Snover et al. 2013; Data source: Kunkel et al. 2013.




- **Nighttime heat waves increased.** Although daytime heat waves demonstrate no increased trend over the region, nighttime heat waves occurred more frequently west of the Cascades (1901 – 2009). Specific trends vary by location.[7]
- **Precipitation changes are less clear.** There was no detectable trend in annual or seasonal precipitation in the Pacific Northwest over the observed period 1895 – 2011.
- **Extreme precipitation may have increased.** Some studies find an increased frequency in extreme precipitation events in the Pacific Northwest depending on choice of study period and analysis method. However, no studies find statistically significant trends in extreme precipitation over the long-term observed period (1895 – 2011).
- **Natural variability dominates short time frames.** Natural variability tends to be the dominant factor behind the shorter-term (yearly to decadal) fluctuations in temperature and precipitation.

[7] Bumbaco et al. 2013 defined a heat wave as three or more consecutive days above the 99th percentile for the maximum (for daytime heat waves) or minimum (for nighttime heat waves) temperature anomalies. [80]

## Observed Changes for the Tacoma Area

In the absence of long-term temperature and precipitation monitoring stations in the City of Tacoma, we report trends for the two nearest stations: Buckley 1NE (Station 450945) and McMillin RSVR (Station 455224) (see Figure 33). Observed temperature trends for Buckley follow long-term trends similar to those noted for the Pacific Northwest, including a larger increase in minimum temperatures than in maximum temperatures (Table 9, top). The station closer to Tacoma, located in McMillin, has an annual warming trend that is approximately half that of the regional average (Table 9, bottom). Long-term precipitation trends for McMillin show that precipitation increased in all seasons between 1895 and 2014 but that increase is still within the range of variability for the area and therefore not necessarily attributable to climate change. Precipitation trends for Buckley were more mixed. Note that single station trends will vary by location and may not be reflective of conditions elsewhere in a region (for example, in the foothills or mountains).

Figure 33. Location of monitoring stations used in this report for observed trends in temperature and precipitation. Figure source: Office of the Washington State Climatologist.

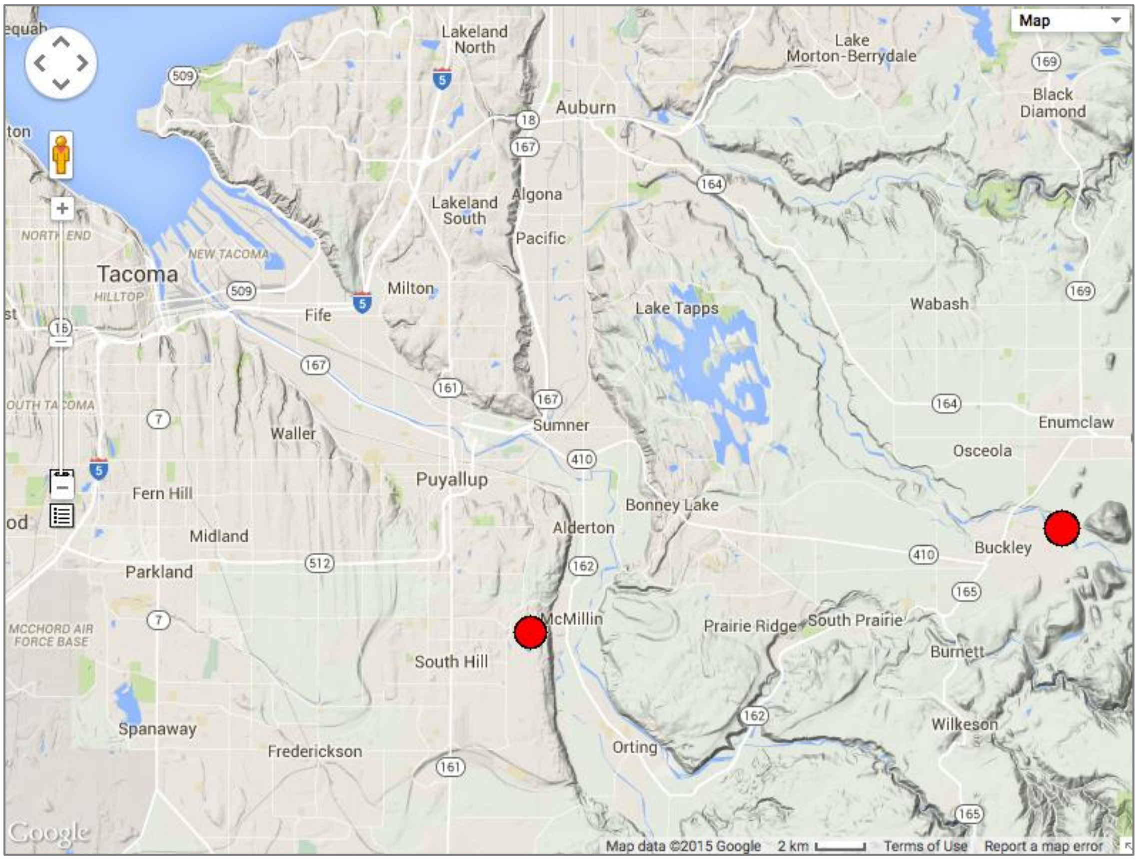


Table 9. Temperature and Precipitation Trends (changes over the time period 1895 – 2014) for Buckley, WA (top) and McMillin, WA (bottom). Note that trends at individual stations are not necessarily representative of regional or sub-regional trends, due to the effects of topography, land cover, and other factors. Data source: Office of the Washington State Climatologist.

| | Change in Temperature (˚F) | | | Change in Precipitation (inches) | | | | |
|---|---|---|---|---|---|---|---|---|
| BUCKLEY | Annual Mean | Annual Max | Annual Min | Annual Average | Winter *(Dec-Feb)* | Spring *(Mar-May)* | Summer *(June-Aug)* | Fall *(Sept-Nov)* |
| **Trend, 1895-2014** | +1.1 | +0.74 | +1.31 | -2.02 (-4.1%) | -2.02 (-12%) | +1.2 (+9.8%) | +0.23 (+4.1%) | -1.31 (-9.3%) |
| **Variability** | ±1.11 | ±1.29 | ±1.08 | ±7.72 | ±4.51 | ±2.89 | ±2.34 | ±4.02 |

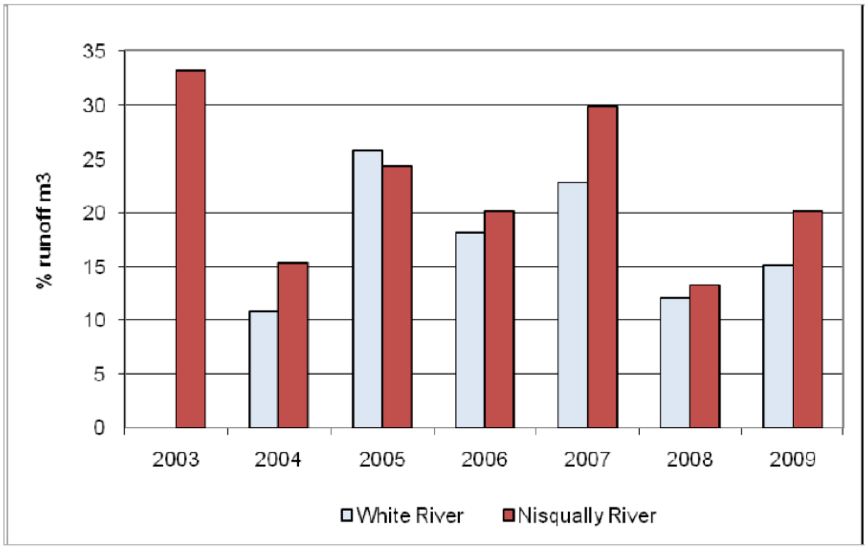
| | Change in Temperature (˚F) | | | Change in Precipitation (inches) | | | | |
|---|---|---|---|---|---|---|---|---|
| McMILLIN | Annual Mean | Annual Max | Annual Min | Annual Average | Winter *(Dec-Feb)* | Spring *(Mar-May)* | Summer *(June-Aug)* | Fall *(Sept-Nov)* |
| **Trend, 1895-2014** | +0.6 | +1.0 | +0.24 | +3.93 (9.7%) | +0.24 (1.5%) | +2.5 (27%) | +1.07 (30%) | +0.36 (3.1%) |
| **Variability** | ±0.98 | ±1.22 | ±0.95 | ±7.06 | ±4.31 | ±2.8 | ±1.56 | ±3.52 |

## Observed Changes in Hydrology

In addition to observed changes in temperature and precipitation, many Pacific Northwest rivers have experienced shifts in seasonal streamflow timing and volume due to long-term changes in temperature, snowpack accumulation, glacial melt, and sedimentation. Long-term changes in glaciers are particularly important to summer streamflow trends; glacial melt from the headwaters of the White River, a major tributary to the Puyallup, contributed an estimated 10–25% of summer streamflows (May – Sep) between 2004 and 2009 (Figure 34) [51].

- April 1 snowpack in the Washington Cascades declined from the mid-20$^{th}$ century to 2006, with substantial year-to-year variability due to natural variability [3] [4].
- The timing of peak spring streamflow shifted earlier by 0-20 days in many snowmelt-influenced rivers in the Pacific Northwest (1948-2002) [5].
- Cumulatively, the area of Mt. Rainer's glaciers decreased -27% between 1913 and 1994. Emmons Glacier, which feeds the headwaters of the White River, has lost about -14% of its volume since 2003 [51].

Figure 34. Total summer glacial melt contributing to streamflows for two watersheds with headwaters in Mount Rainier's glaciers. Source: Riedel and Larrabee (2011).




## PROJECTED CHANGES IN PACIFIC NORTHWEST CLIMATE

Projecting changes in 21st century climate requires the use of global climate models and scenarios of future greenhouse gas emissions, which incorporate assumptions about future changes in global population, technological advances, and other factors that influence the amount of carbon dioxide and other greenhouse gases emitted into the atmosphere as a result of human activities. Greenhouse gas emissions scenarios are developed by international climate modeling centers for use by the scientific community globally to study climate change and climate change impacts.

The findings summarized in this report, which are drawn from various published studies or datasets, are based on two generations of greenhouse gas scenarios: the current generation of greenhouse gas scenarios (the Representative Concentration Pathway (RCP) scenarios) and the previous generation of scenarios used primarily from 2001-2013 (the SRES scenarios). Table 10 summarizes the key characteristics of the scenarios most frequently used in climate studies, including those reported in this document. Where possible, the greenhouse gas scenario(s) associated with specific findings are noted to help the reader know the relative level of greenhouse gas "forcing" associated with a finding (i.e., low versus high level of emissions).

Table 10. Greenhouse gas emissions scenarios used in global and regional climate studies. The scenarios most commonly used in Pacific Northwest climate change studies are noted with an *. Emission scenarios are typically updated every 5-10 years for use in Intergovernmental Panel on Climate Change (IPCC) global assessment reports, which are released every 5-7 years. Table modified from Snover et al. 2013, Table 3-1.

| Representative Concentration Pathway (RCP) scenarios **(IPCC 2013)** | Scenario characteristics | Amount of carbon dioxide in the atmosphere, 2100 **[7]** | Comparable SRES scenarios **(IPCC 2001, 2007; replaced by RCPs starting in ~2012)** | Qualitative description |
|---|---|---|---|---|
| ***RCP 4.5**** | A low scenario in which greenhouse gas emissions stabilize by mid-century and fall sharply thereafter | 538 parts per million (ppm) | Very close to B1 by 2100, but higher emissions at mid-century | "Low" |
| ***RCP 6.0*** | A medium scenario in which greenhouse gas emissions increase gradually until stabilizing in the final decades of the 21st century | 670 ppm | Similar to A1B by 2100, but closer to B1 at mid-century | "Medium" |
| ***RCP 8.5**** | A high scenario that assumes continued increases in greenhouse gas emissions until the end of the 21st century | 936 ppm | Nearly identical to A1FI | "High" |

## Perspective on Recent and Projected Greenhouse Gas Trends

As shown in Table 10, the concentration of greenhouse gases in the atmosphere is projected to increase dramatically in the 21st century absent substantial reductions in greenhouse gas emissions. Prior to the start of the Industrial Revolution, the concentration of carbon dioxide in the atmosphere was 280 parts per million (ppm). By the end of 2014, the annual average concentration of carbon dioxide in the atmosphere as measured at Hawaii's Mauna Loa Observatory was 398.55 ppm, and three individual months in 2014 (April, May, and June) exceeded 400 ppm for the first time since observations at Mauna Loa began in 1958.[8] The high greenhouse gas emission scenario (RCP 8.5), often referred to as a "business as usual" scenario, has an atmospheric concentration of carbon dioxide of 936 ppm in 2100 and levels out at 1,962 ppm by the year 2250 [7]. Annual greenhouse gas emissions will vary from year to year but are generally tracking with RCP 8.5.

[8] Monthly average concentrations in carbon dioxide will vary due to seasonal and monthly variations in carbon dioxide emissions (and uptake) from human and natural sources (e.g., plant respiration). For example, monthly values in 2014 ranged between 395.26 ppm (Sept 2014) and 401.78 ppm (May 2014). The highest monthly mean value reported to date since measurements began at Mauna Loa in March 1958 is 403.94 ppm (May 2015).

## TEMPERATURE

### PACIFIC NORTHWEST

All climate models project warming in the Pacific Northwest during the 21st century as a result of rising greenhouse gas concentrations in the atmosphere. Warming is expected in all seasons with the most warming occurring in the summer. The total amount of projected warming depends on the greenhouse gas scenario and time period.

- For the 2050s, relative to 1950-1999, average annual temperature is projected to rise +4.3°F (range: +2.0 to +6.7°F) for a low emissions scenario (RCP 4.5) and +5.8°F (range: +3.1 to +8.5°F) for a high greenhouse gas scenario (RCP8.5) (Figure 4) [6].[9]
- For the 2080s, relative to 1950-1999, average annual temperature is projected to rise +5.2 (range: +2.5 to 8.5°F) for a low emissions scenario (RCP 4.5) and +8.7°F (range: +4.9 to 12.3°F) for a high greenhouse gas scenario (RCP8.5) [6].[10]

### CITY OF TACOMA

Temperature projections for the City of Tacoma were evaluated for the 2050s from a statistically downscaled dataset using global climate model data from two emissions scenarios (RCP 4.5 and RCP 8.5) [8]. The metrics analyzed are listed in Table 11.

Temperature projections for the City of Tacoma show warming under both emissions scenarios, but with greater warming projected for the higher greenhouse gas scenario (RCP 8.5). Temperatures are projected to warm more during the summer months (Jun – Aug) than the winter months (Dec-Feb) (Table 12). Warmer winter temperatures contribute to the projected increase in minimum temperatures. Maximum temperatures also increase, contributing to a greater likelihood of more intense heat waves.

[9] "2050s" refers to the 30-year average spanning from 2041 to 2070.
[10] "2080s" refers to the 30-year average spanning from 2070 to 2099.

Figure 35. Average yearly temperatures for the Pacific Northwest relative to the average for 1950-1999 (black horizontal line). The black line shows the average simulated temperature for 1950–2005, while the grey lines show individual model results for the same time period. Thin colored lines show individual model projections for two emissions scenarios (low: RCP 4.5, and high: RCP 8.5), and thick colored lines show the average among models projections for each scenario. Figure source: Climate Impacts Group, based on climate data developed for IPCC 2013.

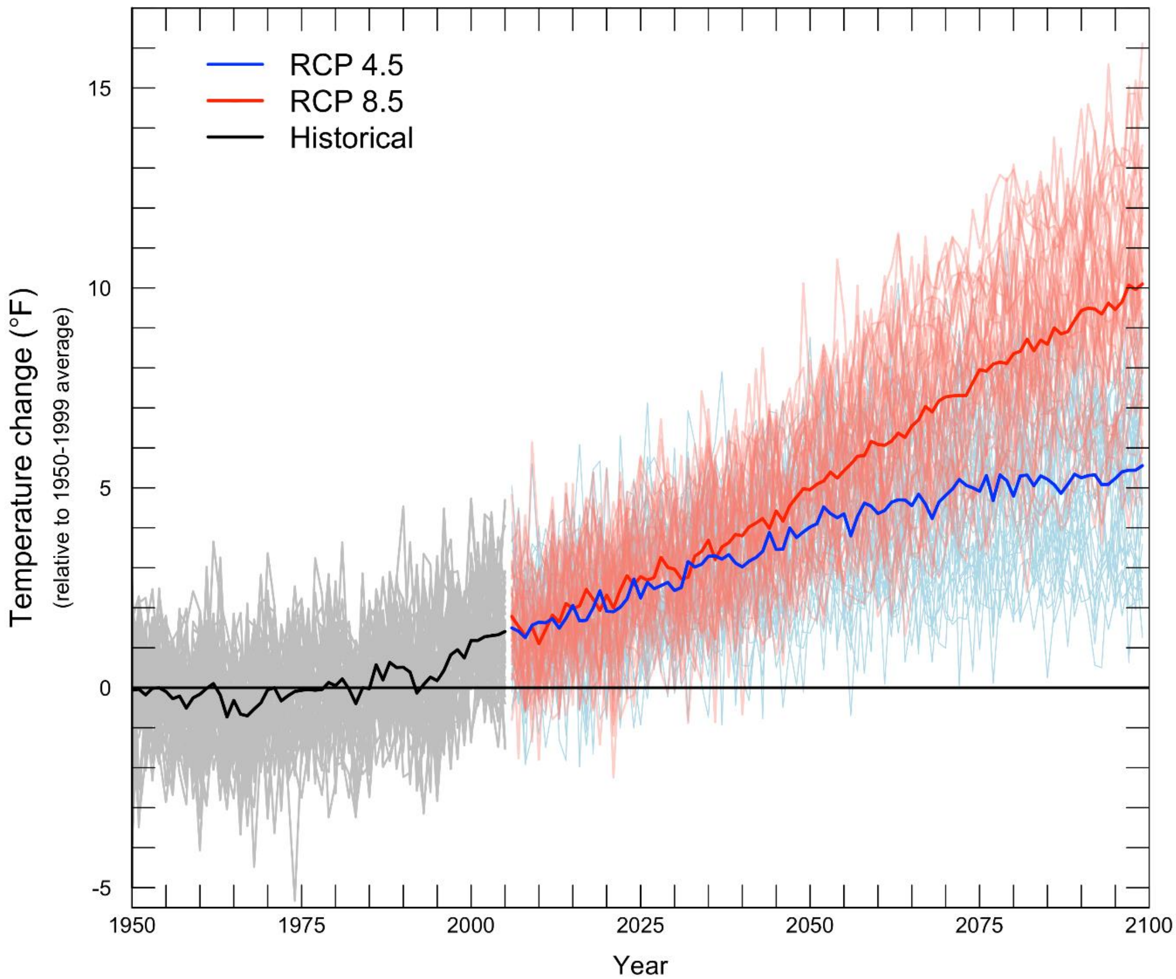


Table 11. Temperature metrics used in this study. Percentiles refer to the point where temperatures (in this case) fall below a specific temperature for a specified percentage. For example, TMIN_ p01 is the temperature at which 1% of modeled daily minimum temperatures are below the TMIN_p01 value and 99% are above that value. Conversely, TMAX_p99 is the temperature at which 99% of the modeled daily maximum temperatures are below the TMAX_p99 value and only 1% of the modeled temperatures are above that value. The specific values defining each threshold will vary by location.

| Metric ID | Definition |
|---|---|
| **TMIN_p01** | Daily minimum temperature: 1st percentile. |
| **TMIN_p05** | Daily minimum temperature: 5th percentile. |
| **TMIN_p10** | Daily minimum temperature: 10th percentile. |
| **TMAX_p90** | Daily maximum temperature: 90th percentile. |
| **TMAX_p95** | Daily maximum temperature: 95th percentile. |
| **TMAX_p99** | Daily maximum temperature: 99th percentile. |
| **TAVG_p01** | Daily average temperature: 1st percentile. |
| **TAVG_p05** | Daily average temperature: 5th percentile. |
| **TAVG_p10** | Daily average temperature: 10th percentile. |
| **TAVG_p90** | Daily average temperature: 90th percentile. |
| **TAVG_p95** | Daily average temperature: 95th percentile. |
| **TAVG_p99** | Daily average temperature: 99th percentile. |

Table 12. Modeled historical and future projected temperatures (°F) for Tacoma, WA, for the average among all 10 GCMs. Results are shown for the historical period (1970-1999) and 2050s (2041-2070) for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario. The table includes both absolute temperatures and changes relative to the modeled historical baseline, the latter showing the range among all 10 GCMs. Note that monthly average and TAVG values incorporate both day and nighttime temperatures. Data source: Integrated Scenarios of the Future Northwest Climate.

| Historical (1970-1999) and Future (2041-2070) Average Temperature – Tacoma, WA | | | | *Change Relative to Historical Mean (Range)* | |
|---|---|---|---|---|---|
| *Month* | ***Historical*** (°F) | ***RCP 4.5*** (°F) | ***RCP 8.5*** (°F) | ***RCP 4.5*** (°F) | ***RCP 8.5*** (°F) |
| **Oct** | 54.9 | 58.6 | 60.0 | +3.7 (2.0 – 5.1) | +5.1 (3.2 – 7.9) |
| **Nov** | 51.2 | 54.7 | 56.0 | +3.5 (2.3 – 5.2) | +4.8 (3.1 – 6.5) |
| **Dec** | 45.1 | 49.0 | 50.2 | +3.9 (2.2 – 5.0) | +5.1 (3.5 – 7.1) |
| **Jan** | 40.3 | 44.0 | 45.0 | +3.7 (2.5 – 5.3) | +4.7 (2.8 – 6.7) |
| **Feb** | 42.7 | 46.7 | 47.3 | +3.8 (2.7 – 5.3) | +4.6 (2.8 – 8.0) |
| **Mar** | 45.9 | 49.9 | 50.7 | +4.0 (2.4 – 6.4) | +4.8 (2.1 – 9.5) |
| **Apr** | 49.9 | 53.4 | 54.2 | +3.5 (2.2 – 4.6) | +4.3 (2.3 – 6.4) |
| **May** | 55.6 | 58.9 | 60.0 | +3.3 (2.0 – 4.2) | +4.4 (2.5 – 5.8) |
| **Jun** | 60.3 | 64.7 | 66.0 | +4.4 (2.3 – 6.2) | +5.7 (3.4 – 7.6) |
| **Jul** | 64.7 | 69.5 | 71.5 | +4.9 (2.8 – 7.1) | +6.8 (4.9 – 10.6) |
| **Aug** | 64.9 | 70.0 | 71.8 | +5.1 (3.3 – 7.7) | +7.9 (4.9 – 10.0) |
| **Sep** | 60.1 | 64.8 | 66.5 | +4.7 (3.0 – 6.2) | +6.4 (4.6 – 8.6) |
| **Annual** | 53.0 | 57.0 | 58.2 | +4.0 (2.8 – 5.3) | +5.3 (4.1 – 7.0) |
| **Dec-Feb** | 42.7 | 46.4 | 47.4 | +3.8 (3.7 – 4.6) | +4.8 (3.0 – 6.9) |
| **Jun-Aug** | 63.3 | 68.1 | 69.8 | +4.8 (3.1 – 7.0) | +6.5 (4.6 – 9.2) |
| *Metric* | ***Historical*** | ***RCP 4.5*** | ***RCP 8.5*** | ***RCP 4.5*** | ***RCP 8.5*** |
| **TMIN_p01** | 20.5 | 24.5 | 25.9 | +4.1 (1.0 – 6.5) | +5.4 (3.2 – 9.0) |
| **TMIN_p05** | 28.3 | 32.3 | 33.5 | +4.0 (2.3 – 5.5) | +5.3 (3.2 – 5.5) |
| **TMIN_p10** | 31.4 | 35.4 | 36.4 | +4.0 (2.8 – 5.2) | +5.0 (3.1 – 7.1) |
| **TMAX_p90** | 77.8 | 82.9 | 84.7 | +5.1 (3.8 – 7.2) | +7.0 (5.5 – 9.5) |
| **TMAX_p95** | 81.4 | 86.6 | 88.6 | +5.2 (3.8 – 7.0) | +7.2 (5.7 – 9.9) |
| **TMAX_p99** | 87.4 | 92.2 | 94.9 | +5.5 (3.8 – 7.0) | +7.5 (5.1 – 10.1) |
| **TAVG_p01** | 28.7 | 32.7 | 33.8 | +4.0 (1.4 – 6.2) | +5.2 (2.7 – 8.1) |
| **TAVG_p05** | 35.6 | 39.6 | 40.7 | +4.0 (2.6 – 5.2) | +5.1 (3.0 – 6.9) |
| **TAVG_p10** | 38.9 | 42.7 | 43.7 | +3.9 (2.4 – 4.7) | +4.9 (3.0 – 6.7) |
| **TAVG_p90** | 65.1 | 70.0 | 71.8 | +4.9 (3.9 – 7.0) | +6.6 (5.1 – 9.4) |
| **TAVG_p95** | 67.7 | 72.7 | 74.7 | +5.0 (3.6 – 7.0) | +7.0 (5.4 – 10.0) |
| **TAVG_p99** | 72.0 | 77.4 | 79.2 | +5.4 (3.8 – 7.5) | +7.3 (5.5 – 10.2) |

## Implications: Rising Temperatures

Increasing summer temperatures and more extreme heat events can increase the potential for heat-related illnesses and death associated with cardiovascular, respiratory, cerebrovascular (e.g., stroke) diseases [52]. Increasing summer temperatures can also contribute to more accidental deaths (e.g., drowning) and asthma in areas where rising temperatures increase ground-level ozone formation. A recent study on the effects of heat events on illness and mortality between 1980-2010 in King County found that the relative risk of death on a heat day[11] was 10% higher for all ages and all causes of mortality compared to a non-heat day [53]. The study also found increased vulnerability among diabetics. Other urban-based impacts associated with increasing temperatures include:

- Reduced winter snowpack and summer streamflows (see Section 3.3);
- Reduced water quality in rivers, lakes, ponds, and nearshore areas due to rising temperatures and the potential for more harmful algal blooms;
- Increased drought stress on urban landscaping;
- Increased demand for municipal and household irrigation;
- Increased use of cooling centers, wading pools, and spray parks (leading to higher water costs);
- Increased heat stress on electrical equipment that relies on passive ventilation or fans;
- Increased heat stress on outdoor laborers and field crews;
- Potential for pavement buckling or softening; and
- Lengthening of the construction season and opportunities for street painting.

# PRECIPITATION AND WIND EVENTS

## Average Annual and Seasonal Precipitation

Climate models project small increases in total annual precipitation for the Pacific Northwest but an enhancement of existing seasonal patterns (i.e., wetter winters and drier summers). Winter, spring, and fall precipitation is expected to increase, but those increases are small relative to the large natural year-to-year variation that characterizes Pacific Northwest precipitation. Summer precipitation is expected to decrease.

- Projected increases in winter, spring and fall precipitation range, on average, from +2% to +7% by the 2050s (2041 – 2070, relative to 1950 – 1999 [6]).
- Summer precipitation decreases -6% to -8% for RCP 4.5 and RCP 8.5, respectively, on average for the 2050s, relative to relative to 1950 – 1999 [6].
- Some individual models show a decrease in summertime precipitation up to -30% by the 2050s, relative to relative to 1950 – 1999 [6].

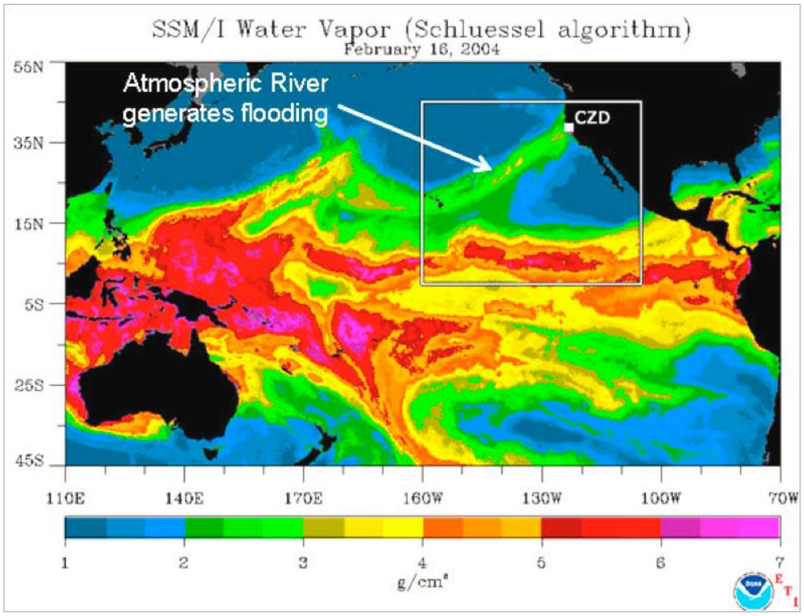
[11] A heat day was defined as the 99th percentile of the average maximum humidex value for King, Pierce, and Snohomish counties (97°F, inclusive of both temperature and humidity). There were 114 days between 1980 and 2010 that exceeded the 97°F threshold.

## Extreme Precipitation

Regionally, extreme precipitation events are primarily attributable to “atmospheric rivers,” or ARs [54]. ARs are narrow bands of water vapor transport extending from the tropical Pacific to the west coast of North America during the winter months (see Figure 36). ARs encountered in the Puget Sound are responsible for most of the major rainfall events in the fall and early winter months.

- Extreme precipitation events projected by climate models show a rise in the frequency and intensity of AR events during the winter months along the U.S. west coast [9] [10] [2]. The location of the Puget Sound convergence zone is a significant factor in where such storms strike, however any effect on the convergence zone is not yet evident in climate model simulations.
- The number of days that precipitation exceeds 1-inch in the Pacific Northwest increases by +13% (±7%) by midcentury (2041–2070) under a high emissions scenario, compared to the average over the historical period from 1950–1999 [2].
- The number of days that precipitation exceeds the historical 99$^{th}$ percentile increases by +280% by the end of the 21$^{st}$ century (2070–2099, relative to 1970–1999) under the highest emissions scenario (RCP 8.5) due to projections of more frequent AR events along the North American west coast [10].

Figure 36. Satellite image of an Atmospheric River. Source: NOAA.




## Extreme Wind Events

Preliminary research on changes in extreme wind events in western Washington found no clear trends in the frequency or intensity of extreme wind events over western Washington under moderate emission scenarios (A1B and RCP4.5) for the period 2040-2070, relative to 1970-2000 [16].

For the purposes of the study, an extreme wind event was defined as the 95$^{th}$ and 99$^{th}$ percentile events, which correspond to wind speeds of about 25 and 32 mph, respectively, at Seattle-Tacoma International Airport. There is some indication that extreme wind events could shift earlier in the fall by as much as a week, increasing the chance that events occur when more leaves are on trees. Additional research is needed assess the robustness of these findings, however.

## Implications: Changing Precipitation

More winter precipitation overall can increase ground saturation, contributing to a higher risk of landslides, seepage around retaining walls and into underground vaults or other structures, and downed trees. Higher groundwater and more exposure to moisture can also increase corrosion and reduce asset life.

More extreme precipitation can exacerbate drainage problems and lead to more urban flooding, landslides, and erosion. Where storm water and sewer systems are connected, more extreme precipitation increases the potential for combined sewer overflows. Finally, more extreme precipitation over large areas such as the Puyallup River watershed can increase flood risk. Smaller urban creeks are also likely to experience more flooding with increases in extreme precipitation.

Lower summer precipitation, combined with warmer summer temperatures, contributes to increasing drought stress for urban trees and landscaping. Additionally, lower summer precipitation will exacerbate summer low flows in urban streams and the Puyallup River. This can concentrate pollutants and lead to warmer water temperatures, both of which affect water quality and can create conditions that are more stressful for aquatic species. Discharge permits can also be affected by lower and warmer receiving waters.

# SNOWPACK AND STREAMFLOW

## Snowpack and Glaciers

Projected changes in temperature and precipitation will result in a shorter snow season as more precipitation falls as rain and snow melts earlier in spring. Projected changes in April 1st snow water equivalent (SWE)[12] show large declines, relative to the historical period, in the Washington State and the Puyallup watershed for low (B1 and RCP 4.5), moderate (A1B) and high emissions scenarios (RCP 8.5) [55] [56] [57].

- Average spring snowpack in Washington State is projected to decline by −56 to −70% by the 2080s (2070-2099, relative to 1916-2006) for a low (B1) and moderate greenhouse gas emissions scenario (A1B).13
- Under a moderate greenhouse gas scenario, RCP 4.5, SWE declines by -52% (ranging between -36% and -59%) by the 2050s, and by -58% (between -39% and -76%) by the 2080s (2070 – 2099) for the Puyallup watershed.
- Under a higher emissions scenario (RCP 8.5), SWE declines by -63% (between -53% and -78%) by the 2050s, and by -80% (between -64% and -92%) by the 2080s for the Puyallup watershed.

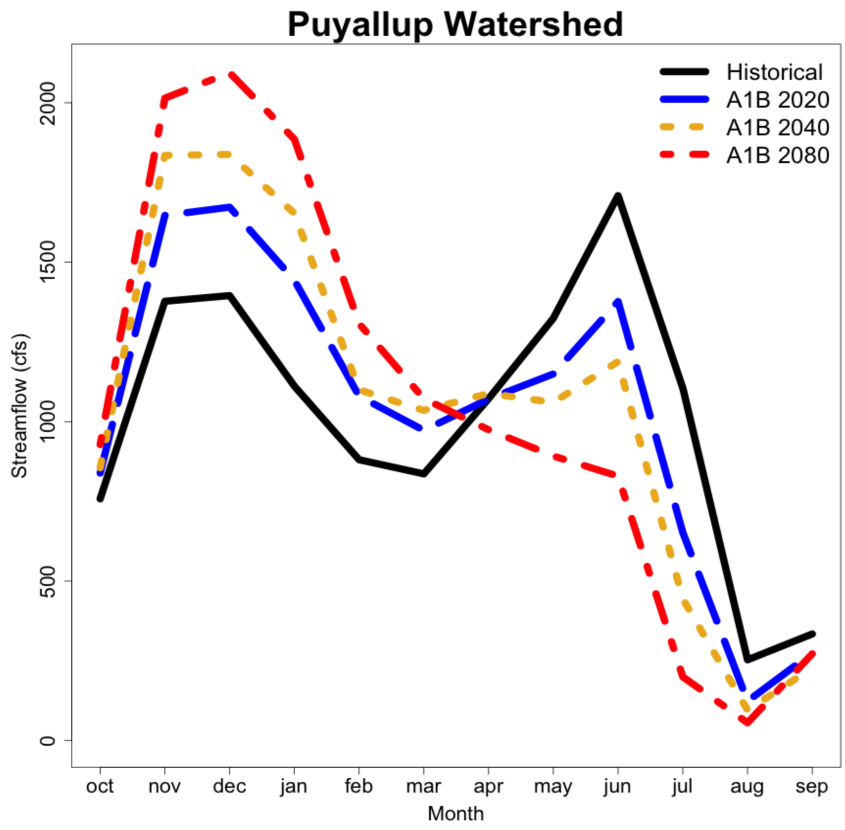
[12] SWE is a measure of the total amount of water contained in the snowpack. April 1st is the approximate current timing of peak annual snowpack in the mountains of the Northwest.
[13] These numbers indicate changes in April 1st Snow Water Equivalent (SWE).

There are no quantitative projections for glacial recession for Mt. Rainier at this time. However, current trends indicate that Mt. Rainer's glaciers, and others contributing to summertime streamflows and sedimentation in Puget Sound watersheds, will continue to melt as temperatures warm.

## Streamflow

The Puyallup River is considered a transient watershed, a classification determined primarily by the pattern of natural (i.e., absent the influence of dams) seasonal streamflow. Historically during the cool season, Puyallup streamflows undergo the first seasonal peak as rainfall contributes inputs to the lower watershed. In the upper watershed, where temperatures are cooler, water is stored as snowpack until the spring melt season when snowmelt contributes to a second period of peak monthly flows (Figure 37– black line). As temperatures warm and less precipitation is stored as snowpack, streamflows in the Puyallup watershed become more rain-dominant and less influenced by snowmelt (Figure 37– blue, red, and yellow lines). This trend is increasingly prevalent at each consecutive future time period.

Figure 37. Monthly graph of streamflow estimated for the Puyallup watershed. (Puyallup River at Puyallup) Estimates of the monthly average depth are based on the water-year, starting in October and ending in September. Changes are shown for three time periods: the 2020s (blue line), the 2040s (gold line), and the 2080s (red line) for the A1B emissions scenario. All changes are relative to average historical flows (1916–2006; black line). Figure based on data from the PNW Hydroclimate Scenarios Project (http://warm.atmos.washington.edu/2860/).



## Flood Risk

Flooding in the Puyallup watershed is also expected to shift as a result of changes in snowpack and increases in extreme precipitation events. Increasing temperatures projected for the region will force snowlines to rise in elevation, enlarging the effective basin area during storm events. Currently, there are no flood projections specific to the Puyallup watershed as a whole, however projections for a major tributary to the Puyallup, the White River at Buckley, can be assessed as a proxy for future floods in the watershed:

- The magnitude of the 100-year flood for the Puyallup River at Puyallup is projected to increase by +37% (ranging from +10% to +88%) by the end of the century (2070 – 2099) compared to historical conditions (1970 – 1999) under a moderate (A1B) emissions scenario [58].
- Recent research has shown that heavy precipitation events will increase in both frequency and intensity [10]; this would further exacerbate flood risk in the Puyallup watershed.

# LANDSLIDES AND SEDIMENT TRANSPORT

Changes in landslide frequency and sediment transport can affect water quality, aquatic and coastal habitat, flooding, and relative sea level rise. Little research has been completed on how climate change may affect sediment loads and landslides in the Puget Sound region, although past events in the Puget Sound region provide some insights.

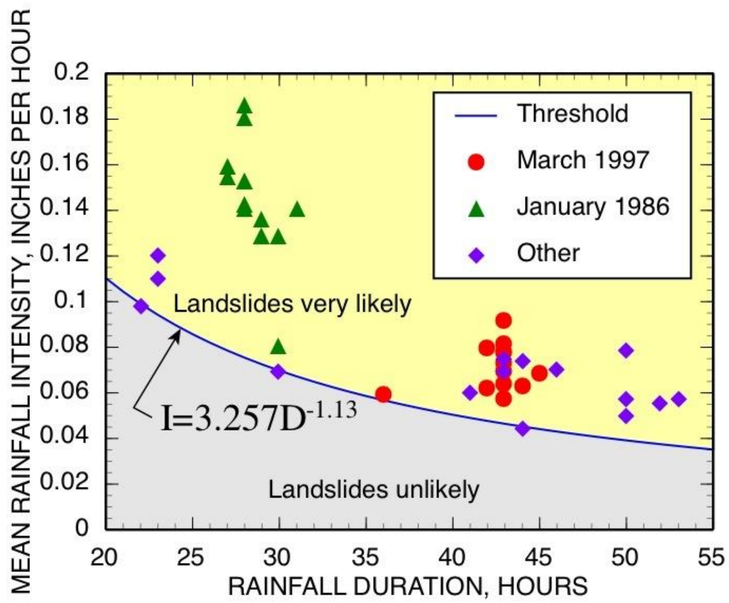
### LANDSLIDES

The topography and geography of Tacoma make the area prone to landslide events. The location and size of landslides depends on several factors, including precipitation duration and intensity, antecedent soil moisture, soil types, slope gradients, runoff patterns, land cover, and land-use [59] [60]. Most landslides in the Pacific Northwest occur on the west side of the Cascades during the rainy season (Oct – May). They are predominantly initiated by intense rain events or by lower intensity, but persistent rainfall over a prolonged period (precipitating high soil moisture content), rapid snow or ice melt, or low evaporative demand that allow soil moisture to persist [55].

The most direct mechanism by which climate change may influence future landslide risk is higher seasonal precipitation and more extreme precipitation. According to a U.S. Geological Survey assessment of landslide risk in the Seattle area from 1933 – 1997 [61], the probability of a landslide occurring increases when rainfall totals and/or intensity exceed the following thresholds:

- *Cumulative Precipitation Threshold:* the probability of a landslide occurring is approximately 10% when the region experiences between 3.5 and 5.2 inches total precipitation during any 18-day period; and/or
- *Rainfall intensity-duration threshold:* the probability of a landslide occurring is between 30–70% when the intensity-duration threshold is exceeded in a day. If soils are already wet, a storm producing at least 2-3 inches of rain over the course of 1-2 days is enough to exceed the intensity-duration threshold (Figure 38). [61].

Figure 38. U.S. Geological Survey rainfall intensity and duration curve determining landslide threshold based on observed landslides in the Seattle area from 1933 – 1997.




There are no specific projections for changes in landslide frequency or location in the City of Tacoma as a result of climate change. However, landslides are expected to become a more common occurrence due to projected increases in extreme precipitation events and increasing winter precipitation, particularly in areas most prone to present-day landslides (Figure 39).

## Sedimentation

The Puyallup, White and Carbon Rivers drain the glaciated, volcanic landscape of Mt. Rainier, delivering large amounts of sediment downstream to Commencement Bay. In the past, vast volumes of sediment were regularly dredged from the lower Puyallup basin, offsetting the immense inputs from the upper basin. However, this practice ceased in the mid-1990s to prevent the detrimental effects on aquatic habitat of ESA-listed species of salmon found in the watershed: Chinook (*Oncorrhynchus tshawytscha)* and steelhead (*O. mykiss)*. When dredging ceased, the conveyance capacity of the watershed declined as sediment increased in the lower portion of the basin, contributing to recent higher flood flows in the lowlands [62]. The USGS analyzed topographic and bathymetric data from 1984 to 2009 along transects of the lower watershed, including the reaches of the White and Carbon Rivers above the confluence with the Puyallup. The data indicate significant aggradation that during this time period: the channel elevations of the Puyallup, White and Carbon Rivers rose by 7.5 feet, 6.5 feet, and 2 feet, respectively (Figure 40). [15].

Figure 39. Landslide hazard map for the city of Tacoma as identified by the Washington Department of Ecology. Landslide hazard areas are based on slope stability and slope severity. Figure adapted from: City of Tacoma, Community and Economic Development.

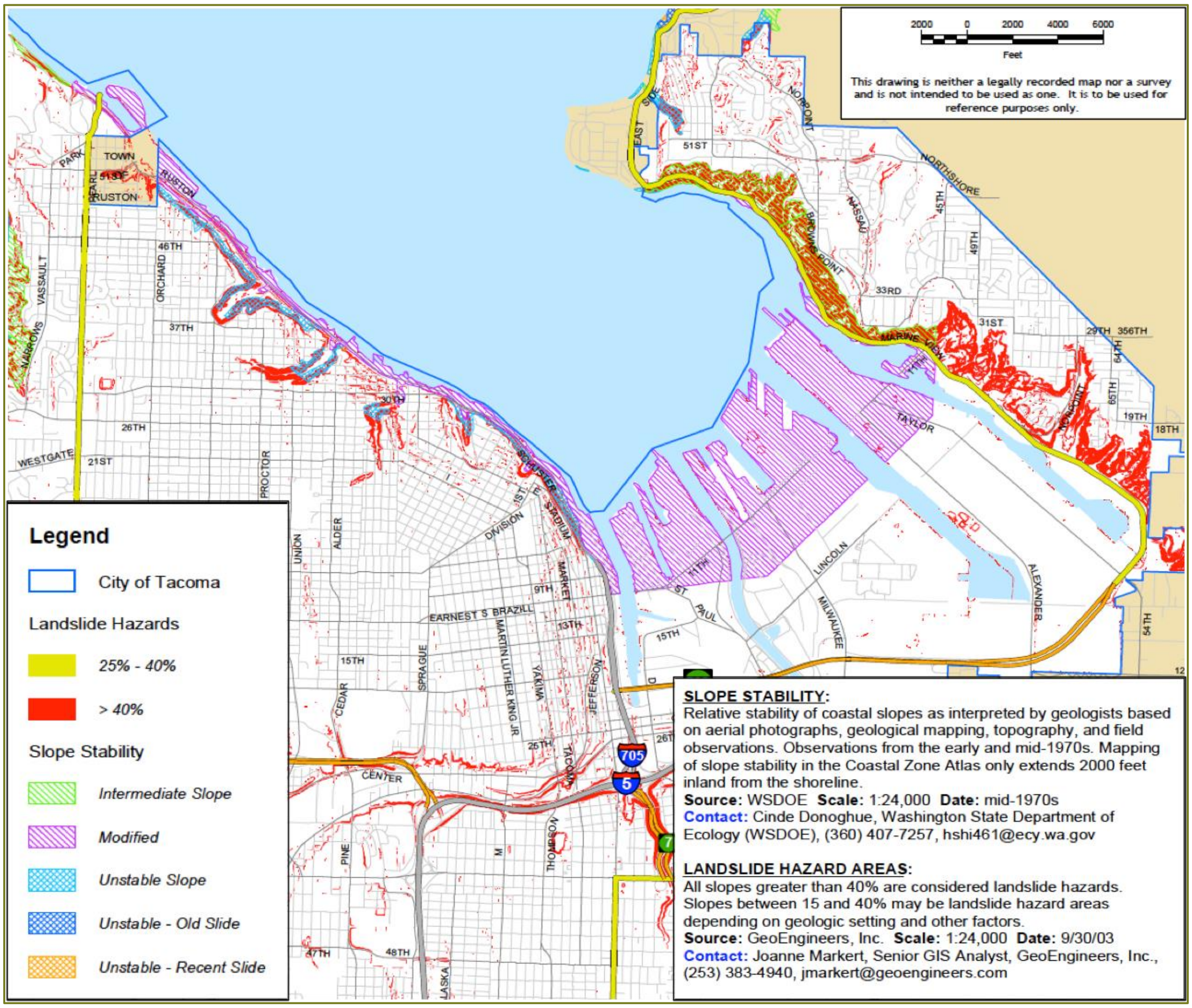
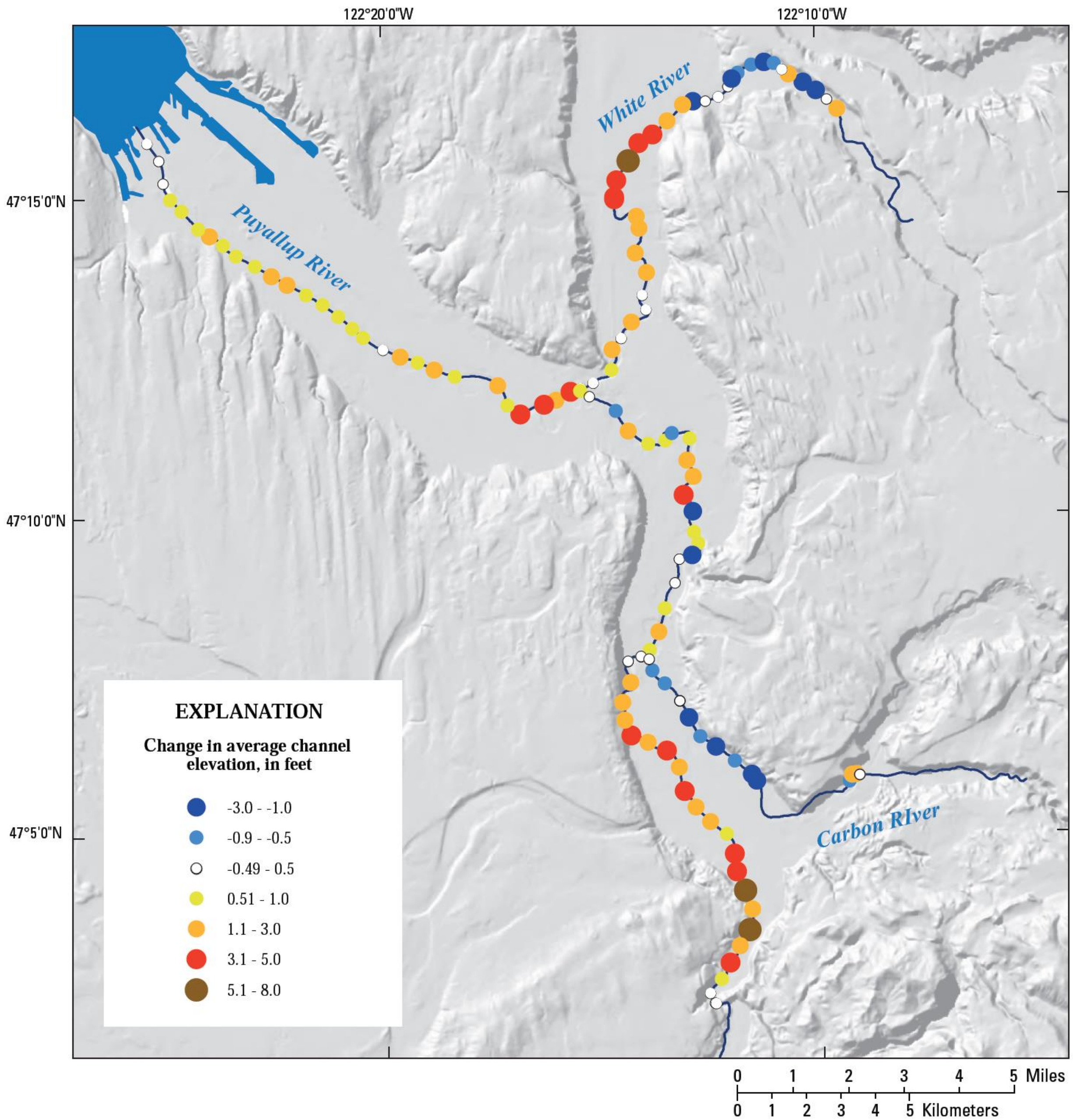


Figure 40. Change in average channel elevation, in feet, between 1984 and 2009 in the Puyallup, White, and Carbon Rivers. Figure source: Czuba, et al. 2010.



Projections of climate-induced changes to sedimentation in the Puget Sound are not available and remain a complicated dynamic to capture in modeling studies. However, sediment loads in the Puget Sound rivers are expected to increase as declining snowpack and glacial recession expose more unconsolidated soils to rain, floods, and disturbance events. [11] [13] [14]. Sediment transport in coastal areas is also likely to increase as a result of sea level rise. Projected sea level rise will increase tidal reach, potentially accelerating erosion rates and increasing landslide frequency in coastal areas. It remains uncertain if bluff erosion will mitigate sea level rise in nearshore areas or if sediment will be transported offshore by increased wave exposure due to higher water levels [63].

## STREAM TEMPERATURE

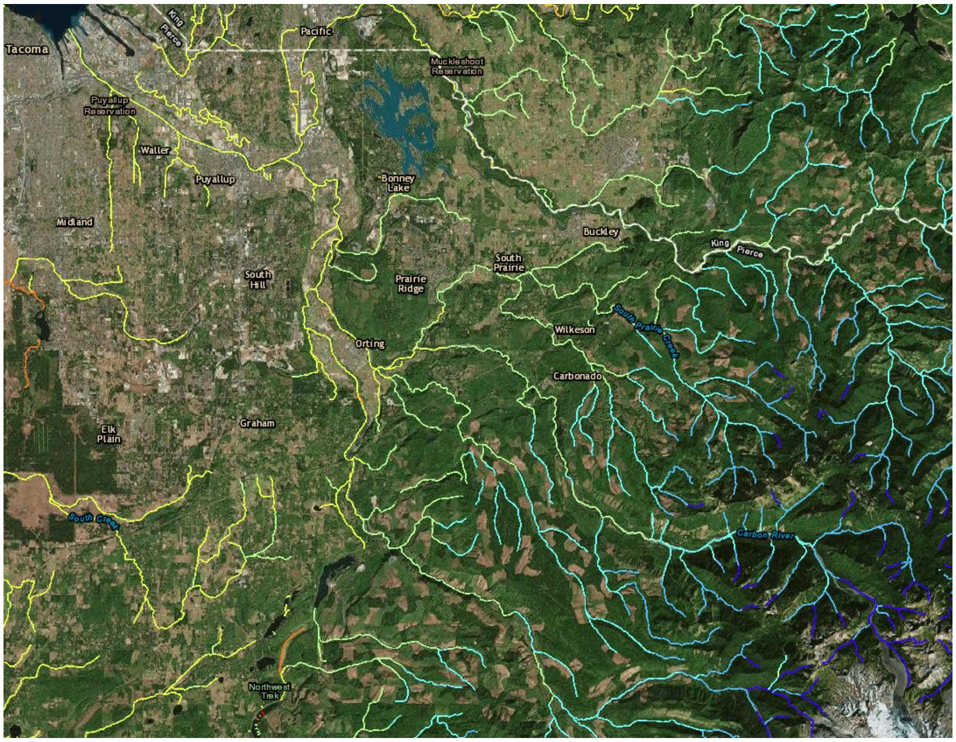
Stream temperatures are an important factor in the quality of Pacific Northwest aquatic habitat and salmon. When exposed to higher water temperatures, salmon become more susceptible to pathogens, suffer higher mortality, and stop or slow their migration. Stream temperatures are regulated by the Department of Ecology and also influence dissolved oxygen levels and other parameters regulated under state surface water quality standards.

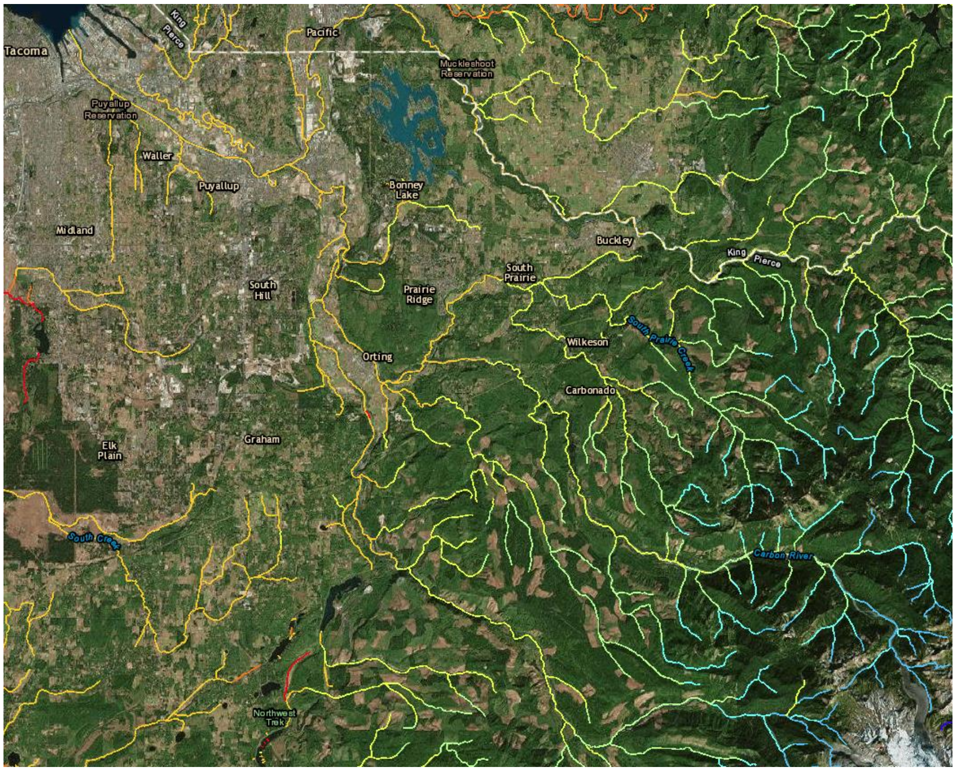
The warmer air temperatures projected as a result of climate change will increase water temperatures in watersheds throughout the Puget Sound region, including the Puyallup watershed (Figure 41) [12]. Increases are generally found in the lower elevation, downstream portions of watersheds where rivers slow, widen, and encounter warmer air temperatures. The amount of time that rivers could exceed thermal thresholds is also expected to lengthen.

- By the 2080s (2070-2099, relative to 1970-1999), 16 percent more stream locations in Western Washington are projected to experience weekly summer stream temperatures stressful to salmon (in excess of 67°F ) under a moderate (A1B) greenhouse gas scenario [12].[14]
- The number of river miles in the Puyallup River watershed that are within thermal thresholds for core summer salmonid habitat (mean August stream temperature <60°F) is projected to decline by 54 miles (-5%) by the 2040s and 120 miles (or -12%) by the 2080s under a moderate (A1B) greenhouse gas scenario, relative to 1993-2011 [64].

[14] Average projected change for 124 stream locations across Washington State. Projections are made using ten global climate models and a medium greenhouse gas scenario (A1B).

Figure 41. Maps of historical (1993 – 2011) average August stream temperatures in °C (top) and projected stream temperatures modeled for the 2080s (2070 – 2099) (bottom) using August air temperatures under a moderate (A1B) greenhouse gas scenario. Source: NorWest Stream Temp Regional Database.



# MARINE CONDITIONS AND SHORELINES

## Sea Level Rise

Most coastal areas of Washington State and the Puget Sound will be affected by sea level rise.[15] Primary impacts include inundation of low-lying areas, increased exposure to storm surge, increased coastal flooding and erosion, and shifting or loss of habitat types. The amount of sea level rise at any specific location will reflect projected global rates of rise as well as regional factors that influence local sea levels, including seasonal wind patterns, vertical land movement resulting from plate tectonics, thermal expansion and sedimentation.

- Global sea level is projected to increase by +11 to +38 inches by 2100 (relative to the 1986 – 2005 levels), depending on the amount of greenhouse gas emissions in the 21st century [65].
- Sea levels in Washington State are projected to increase by +4 to +56 inches by 2100, relative to 2000 levels (Table 13) [17].

Table 13. Sea level rise projections for Washington State and sub-regions. Projections are in inches, for 2030, 2050, and 2100 (relative to 2000), from two regionally-specific studies: Mote et al. 2008 and NRC 2012. Values shown are the central (for NRC 2012), or medium (for Mote et al. 2008) projections, with the projected range shown in parentheses.

| Domain | 2030 | 2050 | 2100 |
|---|---|---|---|
| **Washington State (NRC 2012)** | +3 inches (-2 to +9 in.) | +7 inches (-1 to +19 in.) | +24 inches (+4 to +56 in.) |
| **Puget Sound (Mote et al. 2008)** | --- | + 6 inches (+3 to +22 in.) | +13 inches (+6 to +50 in.) |

## Storm Surge

Climate change is not projected to change the overall behavior of storm surge events in the Pacific Northwest, however sea level rise is expected to increase the level of inundation along the region's coasts [66]. Higher sea level amplifies the inland reach and impact of high tides and storm surge, increasing the likelihood of today's extreme coastal events. For example:

- An increase of +6 inches in sea level in Olympia increases the probability of the occurrence of the 100-yr flood event from 1% annually to 5.5% annually (or the 18-yr event).
- With +24 inches of sea level rise, the 100-year flood event would become an annual event (Table 14) [18].

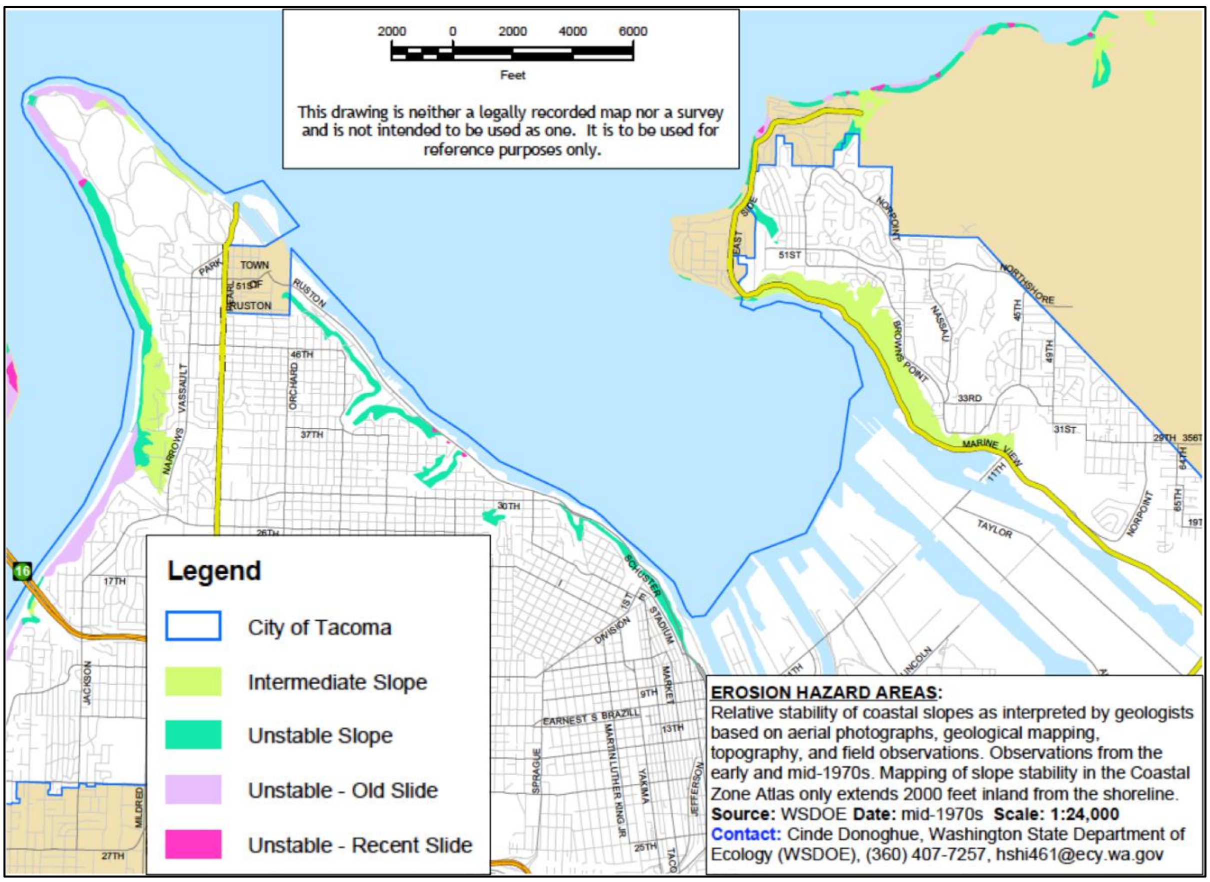
The combined effects of higher sea level projections and greater storm surge impacts in Puget Sound are likely to increase coastal erosion. There are few formal studies investigating the response of coastal erosion to climate change in the region. Existing information on erosion hazards in the City of Tacoma may be useful for identifying areas of potential risk along the city's coast (Figure 42).

[15] The northwest Olympic Peninsula is currently expected to experience sea level *fall* through the mid- to late 21st century as a result of tectonic uplift that is causing that part of the Peninsula to rise at a rate faster than the rate of global sea level rise.

Table 14. Impact of sea level rise on the probability of today's 100-year coastal flood event in Olympia, WA. The probability of today's 100-year flood event increases from a 1% annual probability to a 100% probability if sea level rises +24 inches or more. Figure and caption adapted from Simpson (2012).

| Sea level rise amount | 0 inches | +3 inches | +6 inches | +12 inches | +24 inches | +50 inches |
|---|---|---|---|---|---|---|
| Return frequency for a storm tide reaching the current 100-year flood level | 100-yr event | 40-yr event | 18-yr event | 2-yr event | < 1-yr event | << 1-yr event |
| Equivalent annual probability of occurrence | 1% | 2.5% | 5.5% | 50% | 100% | 100% |

Figure 42. Erosion hazard map for the city of Tacoma. Figure adapted from: City of Tacoma, Community and Economic Development.




## Ocean Acidification

Worldwide the oceans have absorbed about 25% of the carbon dioxide associated with human activities [19]. The added carbon dioxide has changed the ocean's chemistry by increasing its acidity (+30% relative to pre-industrial levels) and reducing the availability of carbonate ions [20]. This latter impact is particularly threatening to shellfish that require calcium carbonate as the molecular building block for shell formation.

Washington's marine waters are particularly susceptible to ocean acidification because of the influence of regional upwelling, which transports offshore, carbon-rich water to the continental shelf [21]. In urbanized estuaries and restricted inlets of Puget Sound (such as Hood Canal), runoff containing nutrients and organic carbon from land sources also influence pH levels. Added nutrients and organic carbon stimulate algal growth, ultimately increasing acidity as the algae and other associated organic matter decompose [22] [20].

Ocean acidity is expected to increase in Puget Sound as a result of these regional factors and changes in global ocean acidification resulting from human activities. The average acidity of the global oceans is projected to increase by 100–150% by the end of this century (compared to pre-industrial levels) under a high (A2) greenhouse gas scenario [21]. Research specific to Hood Canal found that ocean acidification is expected to account for 49-82% of the corrosiveness projected for Hood Canal subsurface waters (defined as depths greater than 40 meters) by the end of this century [22]. There are currently no projections for ocean acidification for Puget Sound as a whole.

# APPENDIX 3: ADDITIONAL FIGURES

Figure 43. Projected Ruston Way wastewater system exposure to sea level rise in 2050.

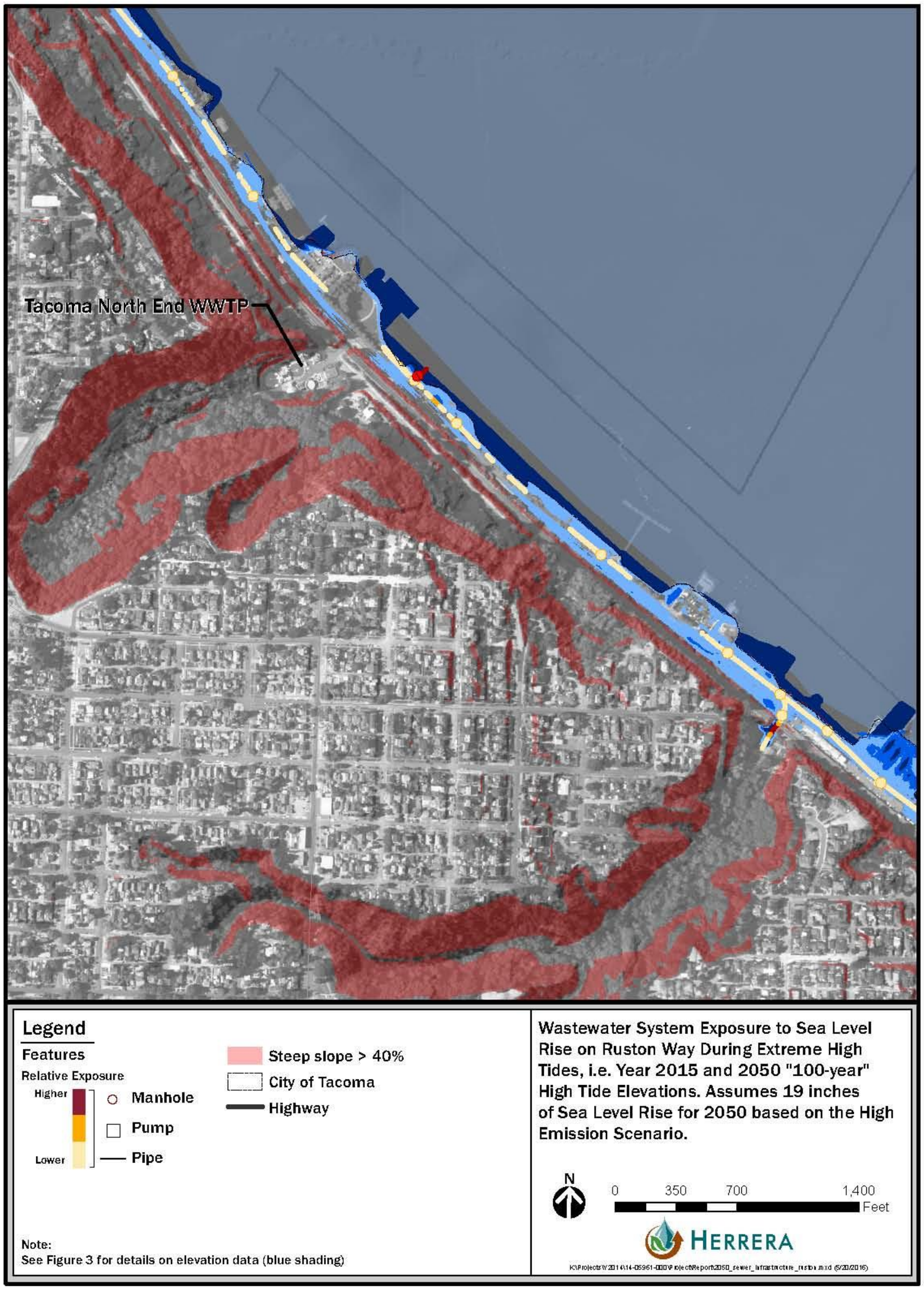


Figure 44. Projected Ruston Way surface water system exposure to sea level rise in 2050.

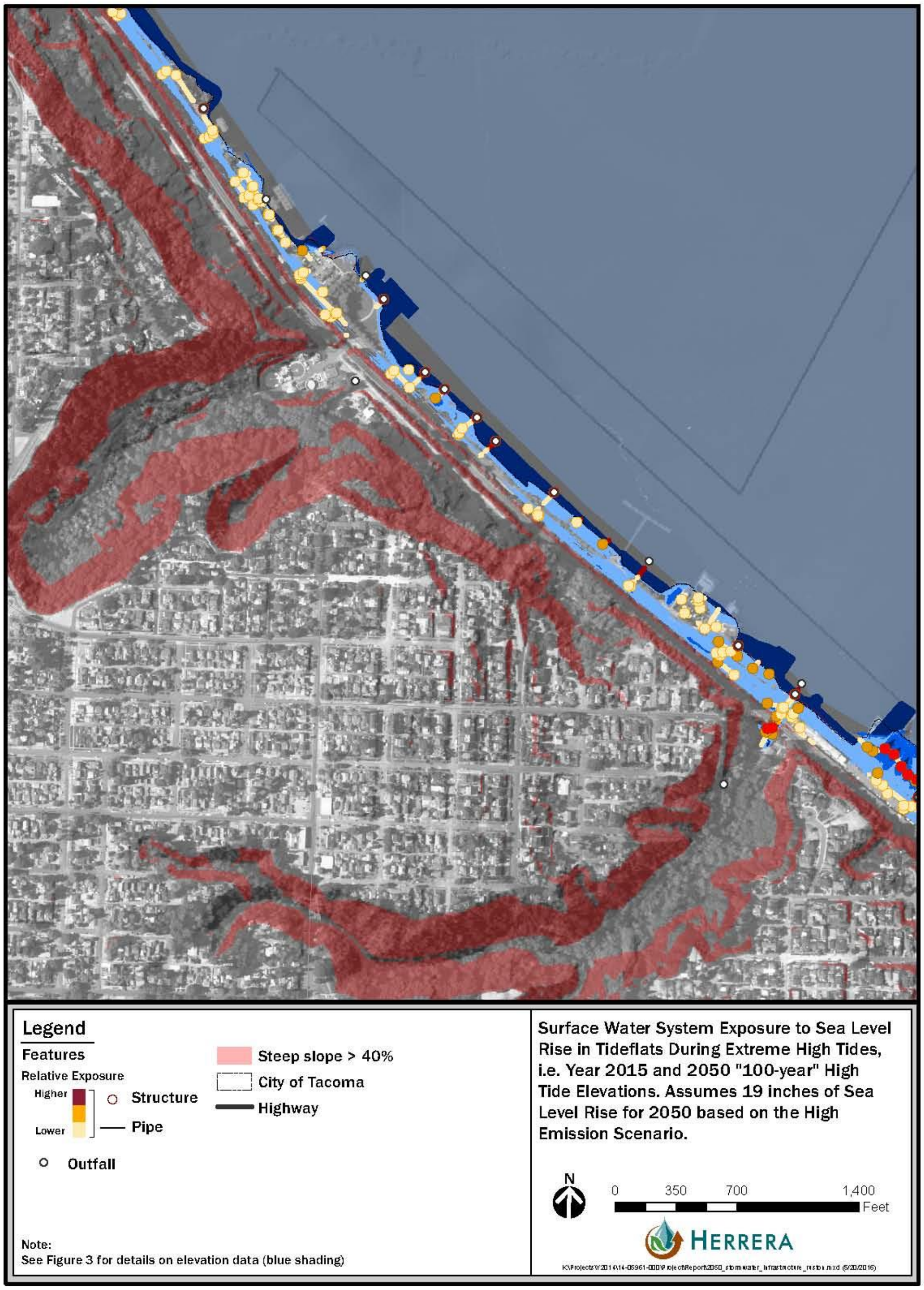
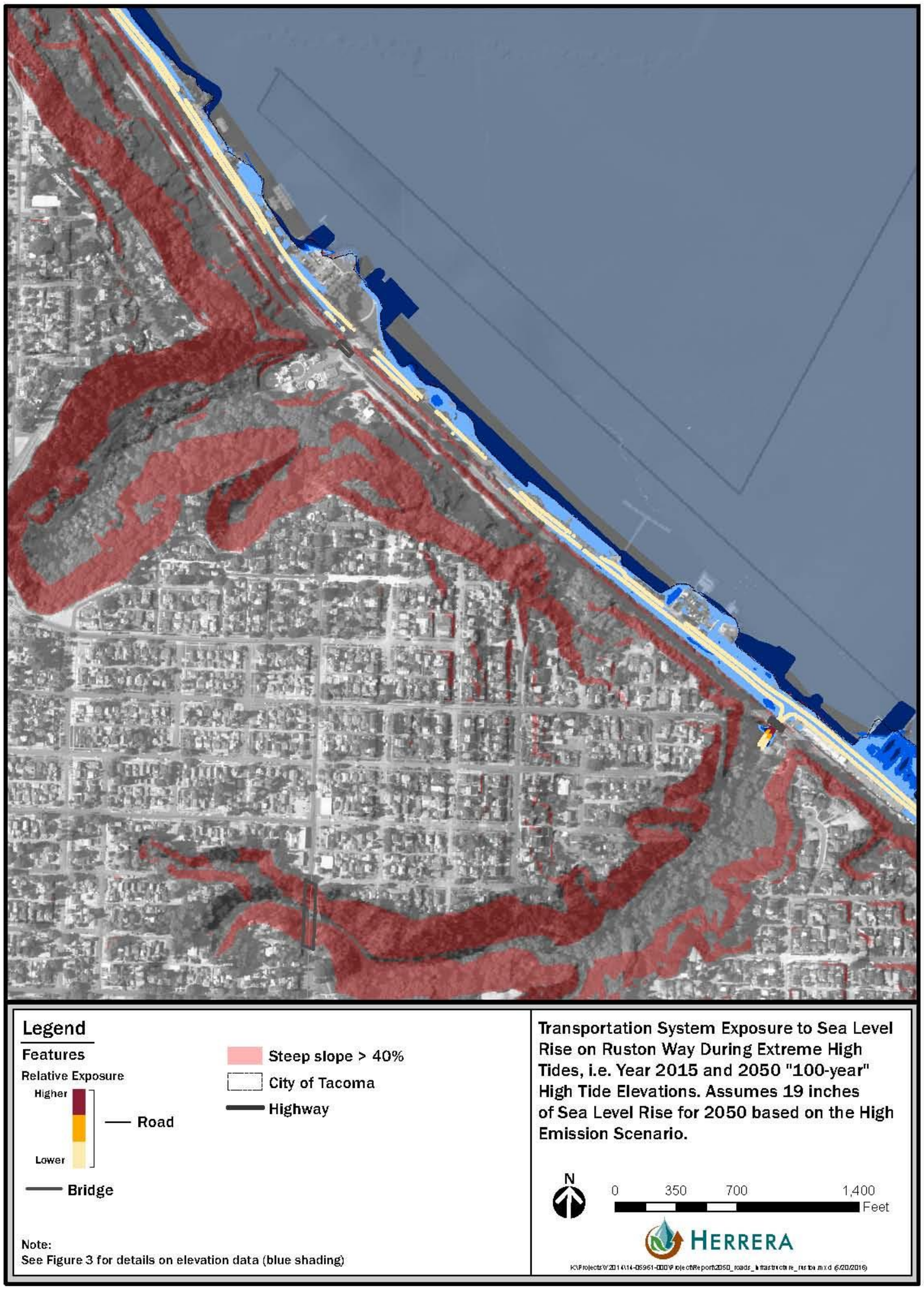


Figure 45. Projected Ruston Way road system exposure to sea level rise in 2050.



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