THURSTON CLIMATE ADAPTATION PLAN

Vulnerability Assessment

Thurston Regional Planning Council

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1: Executive Summary

1.1: Approach

The Thurston Climate Adaptation Plan's vulnerability assessment uses text, tables, maps, and other tools to explain how the region's climate has changed historically, how it is projected to change during the 21st century, and how such changes affect the vulnerability of our human and natural systems.

The vulnerability assessment — the foundation of a risk assessment to be completed in 2017 — builds upon the project's *Science Summary* by describing how human health and welfare, as well as highways, municipal water systems, estuaries, and other built and natural "assets" within the project area [*Figure 1, below*] are vulnerable to the collective impacts of natural hazards (e.g., wildfires, landslides, floods) and human-caused stressors (e.g., water pollution) exacerbated by climate change.

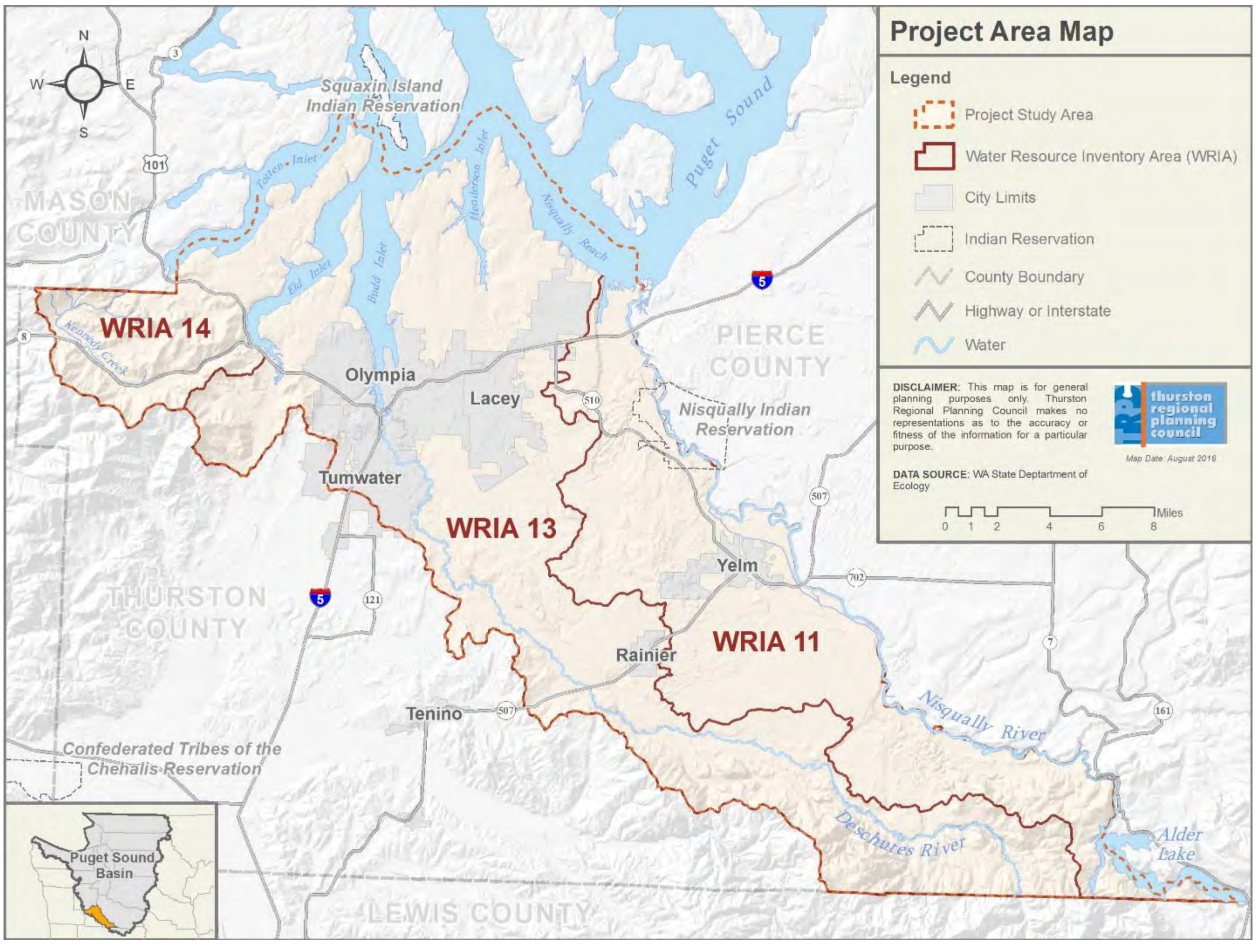

Figure 1. The Thurston Climate Adaptation Plan project area includes parts of the Puget Sound-draining Nisqually (WRIA 11), Deschutes (WRIA 13) and Kennedy-Goldsborough (WRIA 14) watersheds that are within Thurston County. The full Nisqually Watershed straddles Thurston, Pierce and Lewis counties and begins on the flanks of Mount Rainier; the Deschutes Watershed straddles Lewis and Thurston Counties and begins in the Mount Baker-Snoqualmie National Forest, southwest of Alder Lake; the Kennedy-Goldsborough Watershed (WRIA 14) straddles Mason and Thurston counties and includes Kennedy and Goldsborough creeks, as well as Totten, Hammersley and Little Skookum inlets.

1.2: Scenarios & Models

The vulnerability assessment incorporates plausible scenarios of future greenhouse gas emissions that researchers ran through global climate models to project changes in air temperature, precipitation, and other climate indicators [*Figure 2, below*]. Researchers then downscaled the global projections to Puget Sound-draining watersheds, including those that overlay most of Thurston County.

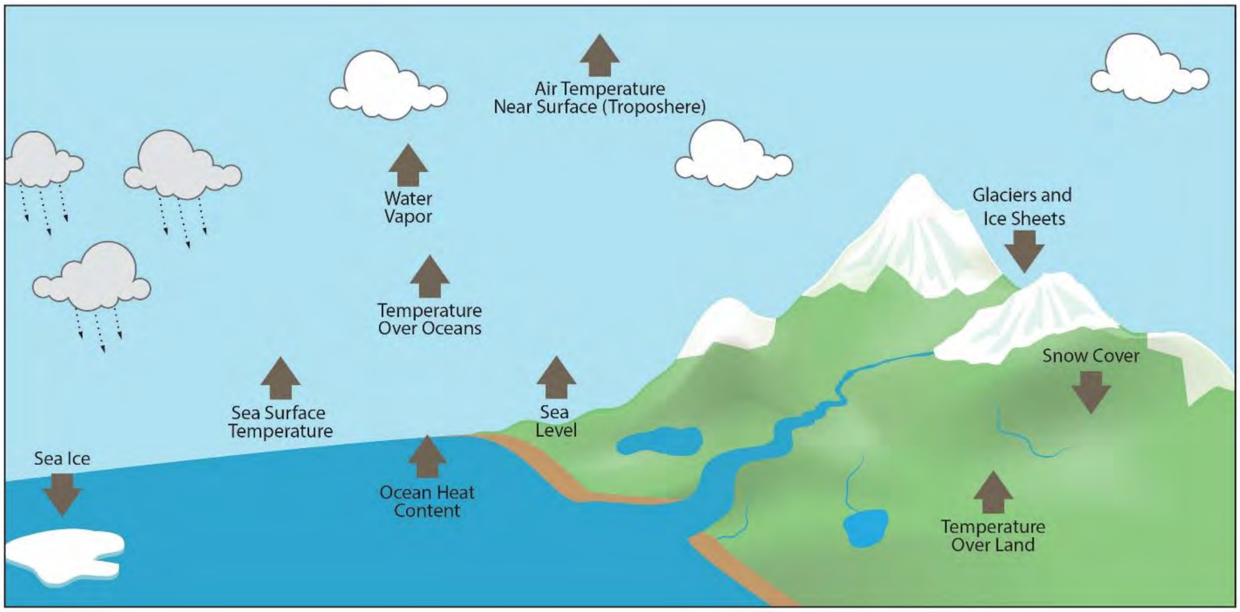

Figure 2: Pictured above are key indicators of the earth's changing climate. Arrows show increasing or decreasing trends based on global observations.
Source: *TRPC, adapted from image in U.S. Global Change Research Program's (USGCRP) 2014 National Climate Assessment*

The current set of greenhouse gas emissions scenarios used to drive global climate models were released in 2011. The scenarios, known as Representative Concentration Pathways (RCPs), were developed by an international collaboration of researchers for use by the global climate-modeling community. The scenarios reflect a range of informed assumptions about future human behaviors, energy sources, economies and technologies.

Global climate models are developed and maintained by numerous academic and governmental organizations around the world, notably the National Center for Atmospheric Research (NCAR), National Oceanic & Atmospheric Administration (NOAA), and National Aeronautics and Space Administration (NASA). The 2013 Intergovernmental Panel on Climate Change (IPCC) assessment of global climate change impacts used more than 40 global climate models; the University of Washington Climate Impacts Group (UW CIG) used ten models for its 2015 assessment of Puget Sound region impacts.

The climate change projections that emerge from the global climate models reflect the scientific community's current understanding of how complex and dynamic natural systems respond to increasing emissions of carbon dioxide (CO2) and other heat-trapping "greenhouse" gases. Understanding of these various components will continue to evolve over time, as will the climate projections developed on the basis of these components. Additionally, natural variability (e.g., the El Niño and La Niña cycles) has and will continue to play a role in shaping our region's climate. For more information about the global climate models, scenarios and projections (global, national and regional), please read this project's companion *Science Summary*, at www.trpc.org/climate.

1.3: Spatial Analysis

The UW CIG report,[1] titled *State of Knowledge: Climate Change in Puget Sound* (Mauger et al., 2015), is the main source of data used in the Thurston Climate Adaptation Plan's vulnerability assessment. Thus, most of the assessment's maps feature the same emissions scenarios (low and high), spatial extent (South Puget Sound watersheds analyzed by the CIG), and time intervals (historical, 2050s and 2080s)[2].

The South Puget Sound watersheds, as delineated by the U.S. Geological Survey (USGS), are subdivided into smaller watershed units so as to show how climate indicators such as air temperature, precipitation, snowpack and runoff vary with elevation [*Figure 3, right*]. The project area, encircled in black, shows the Thurston County extent of the Nisqually, Deschutes and Kennedy-Goldsborough Water Resource Inventory Areas (WRIAs), as delineated by the Washington State Department of Ecology. The appendix includes additional details about the watershed delineations [*See pg. 99*] and a more detailed reference map [*See pg. 101*] that shows major roads, municipalities, waterbodies and other important features that are referenced in the assessment.

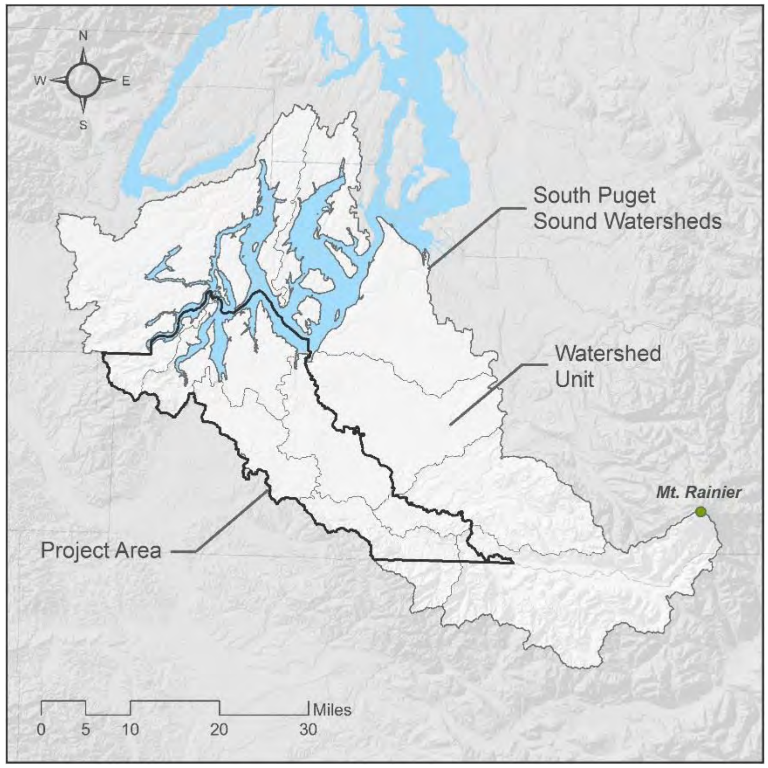

Figure 3. The image above shows the geographic delineations used in this assessment that incorporate UW CIG data. ***Source:*** *TRPC*

While diverse topographically, the project area does not exist within a bubble. Mount Rainier's glaciers and snowpack within Pierce County, for example, affect the timing and volume of the Nisqually River and the adaptive capacity of its estuary in Thurston County. So, when more local or regional detail is warranted or emissions scenarios or data differ, some assessment figures (maps, tables and graphs) focus on different time periods or geographies (e.g., the entire county or region or an individual lake or watershed).

[1] Global climate models simulate changes at spatial scales of about 50-100 miles from one grid cell to the next. Downscaling translates such coarse-resolution projections to a level of detail and resolution (~5-10 miles from one grid cell to the next) that is more relevant to local decision-making. Almost all of the projections in the UW CIG report are based on statistical downscaling, which is a well-established approach that uses relationships between weather observations and coarse global climate model weather patterns. While statistical downscaling is an effective means of translating global-scale changes to smaller scales, the approach does not fully capture some of the local-scale processes that can affect how a particular location responds to warming (Mauger, et. al, 2015). Using regional climate models — an alternative approach to statistical downscaling — better captures such local-scale processes. There are a limited number of scenarios available at this time, however, given the high computational requirements for running regional climate models.

[2] With the exception of the air temperature maps, all of this assessment's maps created with data provided by UW CIG show projected changes (relative to historical averages) in percent. Such percent ranges are more reliable figures than absolute values. For additional details, see the assessment's appendix [*pg. 99*].

1.4: Organization

Water defines both the geography and organization of the Thurston Climate Adaptation Plan and its components. Section 2 of this report — the Troposphere — focuses on air (temperature, quality) and precipitation (timing, volume and type) because they are fundamental components of the hydrologic cycle that drives our watershed processes [*Figure 4, below*].

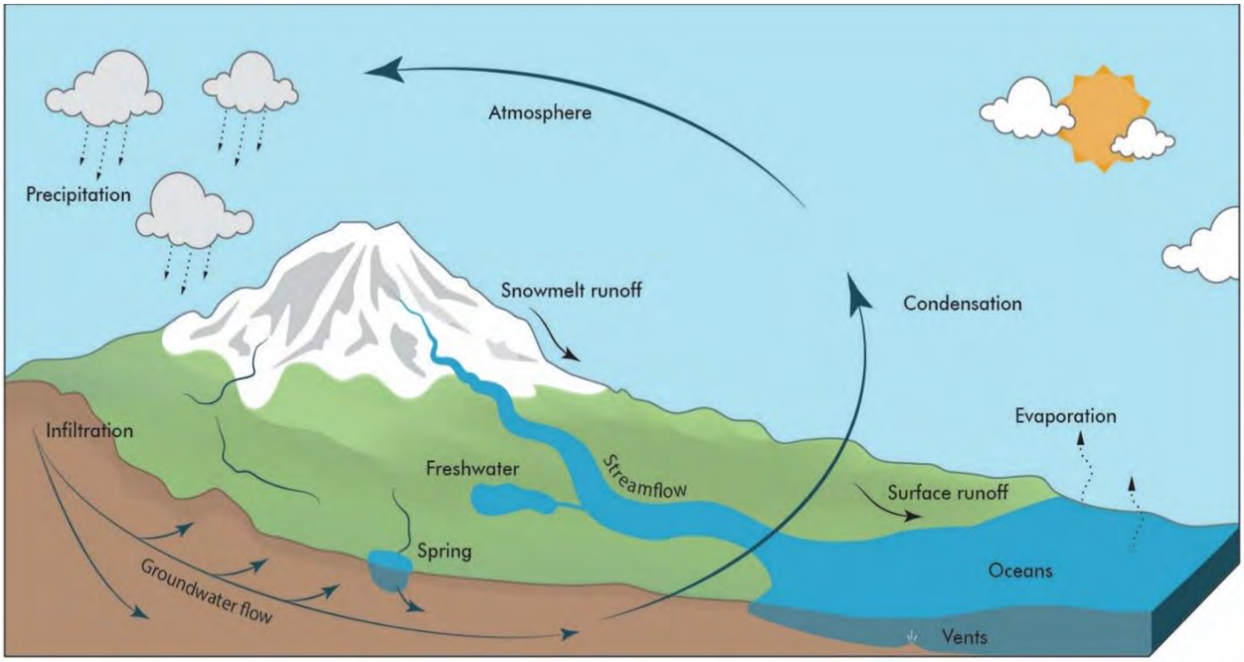

Figure 4. This illustration of the hydrologic cycle, also known as the water cycle, shows how water moves continuously in the form of liquid, vapor and ice on, above, and below the earth's surface. ***Source:*** *TRPC, adapted from USGS infographic*

Subsequent sections of the assessment — Freshwater Ecosystems [*Section 3*], Marine Ecosystems [*Section 4*], and Terrestrial Ecosystems [*Section 5*] — explore the vulnerability of our built assets (roads, seawalls and other infrastructure) and natural assets (fish, plants and animals). Climate change impacts on human health and welfare — perhaps our most precious asset — are explored throughout the report and summarized in Section 6.

This organizational approach recognizes that humans — more than any other species — affect and are affected by changes in multiple ecosystems. To help readers understand these connections, climate stressors and impacts that are referenced in multiple parts of the assessment are denoted with italicized and bracketed section titles and page numbers.

1.5: Summary Findings

The following list summarizes the observed and projected climate change impacts and vulnerabilities explored in this assessment's sections:

Section 2: Troposphere

- ***2.1: Air Temperature***: The Puget Sound region's annual average air temperature rose during the 20th century. The frost-free season lengthened, and nighttime air temperatures increased faster than daytime air temperatures in the lowlands (i.e., Lacey, Olympia and Tumwater) where most of the region's residents live *[See pg. 15]*.

    - **Extreme Temperatures:** The warming trends are projected to continue through the 21st century, intensifying heat waves and weakening cold snaps. Such changes in temperature extremes, coupled with shifts in seasonal precipitation, are expected to affect human and natural systems in many ways *[See pg. 17]*.

- ***2.2: Air Quality***: Historically, Thurston County has not struggled with air quality issues to the degree that many larger communities have. Local air quality could become a bigger threat to community health in coming decades, however, if Thurston County's population and air pollution increase with air temperature *[See pg. 22]*.

    - **Pollutants**: Air pollutants of particular concern include surface ozone (a main ingredient of urban smog) and $PM_{2.5}$ (particulate matter smaller than 2.5 micrometers in diameter). The primary sources of $PM_{2.5}$ in Thurston County today are wood burning in stoves and outdoors — and, to a lesser degree, combusting fossil fuels in automobile engines. The primary sources contributing to surface ozone are nitrogen dioxide emissions from automobiles and volatile organic compounds from industrial facilities *[See pg. 22]*.

- ***2.3: Precipitation***: There is no discernable historical trend in precipitation across the Puget Sound region, which averaged about 78 inches annually during the latter half of the 20th century. The region's annual precipitation volume is not projected to change significantly this century. Seasonal precipitation volumes are projected to change considerably, however: Models indicate generally hotter and drier summers and warmer and wetter winters. Highland forest areas of the Deschutes and Nisqually watersheds would see the biggest shifts in precipitation timing, type, and volume *[See pg. 23]*.

    - **Storm Frequency & Intensity:** The frequency of the region's heaviest 24-hour rain events (top 1 percent) is projected to increase — occurring about seven days a year by late century, compared to two days a year historically. The intensity of such events is projected to increase as well, making communities more vulnerable to floods, landslides, and water-borne pollution *[See pg. 26]*.

    - **Snowfall & Snowpack Volume:** Warmer winters are projected to result in more winter precipitation falling as rain instead of snow in Thurston County's highlands and contiguous areas of Lewis and Pierce counties. This shift is projected to reduce the extent of mountain snowpack and glaciers on Mount Rainier and alter the timing and volume of runoff that affects streamflow and groundwater levels *[See pg. 29]***.**

Section 3: Freshwater Ecosystems

- ***3.1 Streams:*** A shift to more rain-dominant conditions across Thurston County watersheds is projected to result in higher runoff and streamflow during cooler months but the opposite during warmer months *[See pg. 32]*.

    - **Water Volume Vulnerability:** Within the Nisqually and Deschutes watersheds, the higher-elevation headwater areas are projected to experience the biggest changes in snowpack and runoff, which affect streamflow timing and volume. Fish and other species that have evolved around predictable peak flows would be vulnerable to die-offs and degraded habitat *[See pg. 32]*.

        - **Hydropower Vulnerability:** Projected changes in seasonal precipitation and streamflow — generally, more water during cool months and less water during warm months — are expected to affect the productivity of hydropower dams on the Nisqually River and other Pacific Northwest rivers. Winter hydropower production is projected to increase modestly in coming decades, while summer hydropower production and overall peak energy demand would decrease more sharply. This could lead to energy blackouts and price spikes during periods of extreme heat *[See pg. 36]*.

    - **Water Temperature & Salmonid Vulnerability:** Water temperatures are projected to rise in Thurston County's highland and lowland streams over the 21st century. Juvenile salmonids that develop in streams (e.g., Chinook, Coho and chum) and ocean-going adults that swim back up streams to spawn are vulnerable to such changes because they have evolved within certain temperature parameters. Impacts could include upgradient shifts in suitable stream habitat and changes to migration timing and success *[See pg. 38]*.

    - **Water Quality Vulnerability:** Climate change could complicate local government efforts to comply with state water-quality standards — particularly with regard to lowering temperature, pollution, and sediment loading in streams. More frequent and intense storms raise the risk of runoff from impervious surfaces and erosion of riparian vegetation that provides cooling shade and stabilizes shorelines *[See pg. 43]*.

- ***3.2 Lakes:*** Shifts in the region's hydrologic cycle, compounded by nutrient loading from urban and rural lands, could make lake conditions more suitable for algal blooms that degrade water quality and pose health risks for humans, fish, and animals *[See pg. 45]*.

    - **Water Temperature & Quality Vulnerability:** Warmer, drier summers are projected to reduce lake levels and raise water temperatures, which strongly influence the growth of cyanobacteria and harmful algal blooms *[See pg. 45]*.

- ***3.3 Wetlands:*** Warmer, drier summers are projected to reduce the flow of water that replenishes and cools non-tidal marshes — which are mostly freshwater wetlands near lakes or on poorly drained soils. Such areas provide important habitat for frogs, birds, and other wildlife *[See pg. 47]*.

- ***3.4 Groundwater:*** Bigger winter storms and high groundwater flooding can result in less infiltration into the soil and aquifers, as well as more runoff into streams and Puget Sound. Summer droughts, in turn, could spur more groundwater pumping when surface water is scarce. Such direct and indirect climate impacts, coupled with sea-level rise, could make Thurston County's coastal freshwater aquifers more vulnerable to water quality and quantity risks *[See pg. 49]*.

    - **Saltwater Intrusion & Inundation Vulnerability:** The direct impacts of saltwater intrusion and inundation on groundwater are likely to be greatest in places with low topographic relief and very low hydraulic gradients between freshwater and saltwater (e.g., downtown Olympia and Nisqually Valley) *[See pg. 49]*.

    - **Pathogen & Pollution Vulnerability:** Prolonged droughts raise the risk of concentrating contaminants in private water systems' shallow wells (less than 50-100 feet deep) — especially those at risk for saltwater intrusion or those with low productivity. Conversely, greater deluges raise the risk of overwhelming wastewater, septic, and stormwater conveyance systems and causing water-borne disease outbreaks in small community or private groundwater wells or other drinking water systems where water is untreated or minimally treated. *[See pg. 51]*.

    - **Water Quantity Vulnerability:** Water quantity (supply-and-demand) vulnerability is expected to be highest in snow-influenced watersheds with existing conflicts over water resources (e.g., fully allocated watersheds with little management flexibility). Vulnerability would be lowest where hydrologic change is smallest (i.e., existing rain-dominant watersheds), where there are simple institutional arrangements, and where current water demand rarely exceeds supply *[See pg. 53]*.

Section 4: Marine Ecosystems

- ***4.1 Sea-level Rise:*** The Puget Sound region is projected to experience continued, and possibly accelerated, sea-level rise in coming decades as a result of melting ice sheets and warmer oceans. This may result in permanent inundation of some low-lying areas, and increased frequency, depth, and duration of coastal flooding due to greater reach of tides and storm surges *[See pg. 54]*.

    - **Coastal Infrastructure Vulnerability:** Downtown Olympia, part of which is built atop fill and subsiding, floods today when there is heavy precipitation and a high tide that inundates the gravity-fed stormwater drainage system. Rising sea levels are projected to exacerbate this problem and increase the vulnerability of key roads and bridges, the LOTT Budd Inlet Treatment Plant, and other important assets. Vulnerable infrastructure along other parts of Thurston County's Puget Sound shoreline include low-lying homes, seawalls, and sections of Interstate 5 and U.S. Highway 101 *[See pg. 54]*.

    - **Coastal Species Vulnerability:** Rising seas are projected to permanently inundate the Nisqually Estuary's tidal marshes and turn them into mudflats. Amphibians, birds, and other wildlife would be particularly vulnerable to such changes in habitat *[See pg. 63]*.

- ***4.2 Ocean Acidification & Pollution:*** Increased seawater absorption of atmospheric carbon dioxide is projected to increase the frequency, magnitude, and duration of harmful pH conditions throughout Puget Sound, which will make it harder for calcifying marine organisms to maintain shells. Water-filtering clams and oysters — which hold significant cultural, economic, and environmental value in the region — are particularly vulnerable to such ocean acidification. Continued pollution from land-based sources, coupled with changes in ocean temperature and pH, exacerbate health risks for people who eat raw or undercooked shellfish *[See pg. 65]*.

Section 5: Terrestrial Ecosystems

- ***5.1 Farms & Ranches:*** Puget Sound's agricultural sector is expected to be relatively resilient to climate change — and some crops may even benefit from a longer growing season and more atmospheric carbon dioxide. However, periodic drought and flood events, as well as invasive pests and plants, still pose risks for local farms and ranches *[See pg. 67]*.

    - **Drought & Flood Vulnerability:** Sustained periods of low or no precipitation could make surface water supplies scarce, forcing farmers and ranchers to rely more heavily on groundwater for irrigating agricultural crops and watering livestock. Conversely, sustained periods of heavy rain, coupled with sea-level rise, could reduce the ability of drainage ditches and other infrastructure to handle flood events in near-coastal agricultural lands *[See pg. 67]*.

    - **Crop & Livestock Vulnerability:** Climate change is expected to influence which crops Puget Sound region farmers cultivate in the decades ahead. Emitting more carbon dioxide into the atmosphere may increase the biomass productivity of some crops, such as beans and grasses, but reduce the nutritional quality of forage and pasture lands for livestock and wild animals. The largest livestock (e.g., dairy cows and horses) would be more vulnerable to heat stress during hotter, drier summers or flooding during warmer, wetter winters. Such stressors also could benefit thistle and other invasive plant species and allow them to outcompete native grasses and crops. Among other agricultural crops that have been studied specifically, berries, tree fruit, and tubers could experience a production decline, while some wine grapes could benefit from projected changes. *[See pg. 67]*.

- ***5.2 Forest & Prairies:*** Climate change is projected to affect the region's forest and prairie vegetation growth, productivity, and range, as well as the prevalence and location of diseases, insects, and invasive species *[See pg. 70]*.

    - **Vegetation Vulnerability:** Shifts in seasonal temperature and precipitation threaten to alter the timing of flowering and the abundance of insect pollinators amid prairies, which could reduce some plant species. Such shifts also threaten to alter the range of Garry oak, Douglas-fir and other important tree species, as well as threaten their survival due to pest and disease outbreaks. Increased water stress associated with such seasonal changes is expected to lead to higher forest mortality, decreased fuel moisture, and more intense fires. These disturbances may be compounded by more pest and disease outbreaks *[See pg. 71]*.

Section 6: Human Health & Welfare

- ***6.1 Wildfires:*** Hotter, drier summers threaten to increase the frequency and intensity of wildfires in Thurston County and the broader Puget Sound region. Wildfires can pose acute or long-term health and welfare risks for firefighters and residents: incurring stress as a result of property losses; suffering burns and death; and, breathing in smoke and other pollutants. Such fires may also disrupt energy transmission by downing power poles and damaging other infrastructure. Presumably, damages associated with these fires would go up if they occur in or spread to the wildland-urban interface *[See pg. 73]*.

- ***6.2 Floods & Landslides:*** Warmer, wetter winters threaten to increase the frequency and intensity of floods and landslides, which can degrade water quality and threaten property and public safety. Buildings, roads and other assets located near rivers and coastlines are most vulnerable to floods. Assets most vulnerable to landslides are located on or near steep slopes *[See pg. 78]*.

- ***6.3 Diseases & Other Health Threats:*** The shifts in temperature and precipitation noted previously are projected to exacerbate or introduce a wide range of health threats, including infectious diseases from exposure to viruses and bacteria, which would affect human health outcomes. Exposure pathways include food, water, air, soil, trees, insects, and animals *[See pg. 84]*.

    - **Tribal Vulnerability:** Members of local tribes, which are rooted in place and utilize land and waters for cultural traditions, are particularly vulnerable to climate change impacts on Puget Sound's waters and marine species. Continuing to consume traditional seafood staples such as shellfish may increase health risks from contamination, but replacing such traditional foods may involve the loss of cultural practices tied to their harvest *[See pg. 85]*.

    - **Assessing Adaptive Capacity:** The vulnerability of our region's residents will depend largely on their sensitivity and exposure to climate change-exacerbated threats and capacity to adapt. Local and state public health professionals are beginning to consider a wide range of social and behavioral factors (e.g., social isolation, physical ability, etc.) as they assess individuals' exposure to threats and resiliency *[See pg. 86]*.

- ***6.4 Population Displacement:*** Climate change-exacerbated natural hazards can lead to temporary or permanent population displacement. It's impossible to predict how many people might move to or within Thurston County, or when, as a direct result of climate change. The region can start preparing for the possibility of climate migrants, however, by analyzing census data, migration trends, and other information to assess who might move here (e.g., because of family/ethnic connections or suitable job skills) and how to accommodate population growth in a manner consistent with comprehensive plans *[See pg. 88]*.

2: Troposphere

The troposphere is the first atmospheric layer above the earth's surface and where weather occurs. Air temperature and precipitation are as fundamental to weather as they are to the broader climate, so these indicators are among the first explored in this vulnerability assessment. Subsequent sections assess in greater detail how changes in these indicators affect freshwater, marine and terrestrial (land) ecosystems.

> **Weather vs. Climate**
>
> **Weather is atmospheric conditions over the short term (e.g., minutes to days). Climate is the average of weather over longer periods of time and space (e.g., years and decades). … A good way to remember the difference is that climate is what you *expect* — like a long and hot summer; weather is what you *get* — like a dry and sunny day.**
>
> — NASA, 2005

…

2.1: Air Temperature

Rising air temperatures during the 21st century will affect human and natural systems in myriad ways — from shifting precipitation and vegetation patterns to changing the temperature and chemistry of the oceans. The following section examines past and projected changes in annual, seasonal and daily temperatures throughout the adaptation plan's project area and the broader Puget Sound region.

Annual Changes

During the past century, the air temperature rose and the frost-free season lengthened amid the Puget Sound region (Mauger et al., 2015). Nighttime air temperatures rose faster than daytime air temperatures throughout Puget Sound's lowlands — which include Thurston County's urban core of Olympia, Lacey and Tumwater. The lowlands' average temperature was 50.3°F historically[3] and increased 1.3°F (range: 0.7 to 1.9°F) between 1895 and 2014.

The broader Puget Sound region's average annual air temperature was 44°F historically and is projected to rise 4.2°F per a low global greenhouse gas emissions scenario (RCP 4.5)[4] and 5.9°F per a high scenario (RCP 8.5) for the 2050s[5] [*Figure 5, below*]. For the 2080s, the temperature is expected to rise 5.5°F per the low scenario and 9.1°F per the high scenario.

Indicator	Scenario	2050s		2080s	
		Mean	Range	Mean	Range
Average annual air temperature	Low (*RCP 4.5*)	+4.2°F	2.9°F to 5.4°F	+5.5°F	2.3°F to 11°F
	High (*RCP 8.5*)	+5.9°F	4.3°F to 7.1°F	+9.1°F	4.3°F to 17°F
Temperature of hottest days[6]	Average of RCP 4.5 and 8.5	+6.5°F	4.0°F to 10.2°F	+9.8°F	5.3°F to 15.3°F
Temperature of coolest nights[7]	Average of RCP 4.5 and 8.5	+5.4°F	1.3°F to 10.4°F	+8.3°F	3.7°F to 14.6°F

Figure 5. Projected changes in average annual air temperature and extremes for the Puget Sound region per the low (RCP 4.5) and high (RCP 8.5) global emissions scenarios. ***Source:*** *TRPC, adapted from Mauger et al., 2015*

[3] Historical average temperature for 1950-1999.
[4] These scenarios — known as Representative Concentration Pathways (RCPs) — are used in model simulations of the earth's future climate. Most of the UW CIG and TRPC assessments focus on two scenarios to show a range of potential climate impacts: RCP 4.5 — a "low" scenario that assumes greenhouse gas emissions stabilize by mid-century and fall sharply thereafter; and RCP 8.5 — a "high" scenario that assumes substantial greenhouse gas emission increases until the end of the 21st century.
[5] References to the 2050s throughout this assessment refer to the 2040-2069 period, relative to 1970-1999; references to the 2080s refer to the 2070-2099 period, relative to 1970-1999.
[6] Projected change in the top 1 percent of daily maximum temperature.
[7] Projected change in the bottom 1 percent of daily minimum temperature.

The U.S. Geological Survey (USGS) National Climate Change Viewer projects annual maximum and minimum temperatures for the two emissions scenarios over the full 21st century. The online tool shows that Thurston County's average annual maximum temperature is projected to rise from 60.9°F in 2000 to 65.1°F in 2099 per the low emissions scenario and to 69.3°F per the high scenario (Alder & Hostetler, 2013).[8] Over the same period, Thurston County's average annual minimum temperature is projected to rise from 41.4°F in 2000 to 45.9°F in 2099 per the low scenario and to 51.1°F per the high scenario.

Climate change of even a few degrees is consequential, considering that the global average temperature during the last ice age was just 7°F to 9°F colder than now (The Royal Society, 2016). Warmer air holds more moisture, so the projected increase in Thurston County's air temperature is expected to influence the timing, type and volume of precipitation. Such changes in the hydrologic cycle are also expected to affect human health and welfare, as well as native plants and fish that have evolved within certain parameters [*See subsequent sections*].

Seasonal Changes

Figures 7 and 8[9] [*See pgs. 18-19*] show that Thurston County's average winter and summer temperatures generally decrease as elevations increase. The elevation rises from sea level at Puget Sound's southern shore to almost 3,000 feet above sea level near Alder Lake area, in the county's southeastern corner. Historically, these highlands were about 6°F cooler than the lowlands during the winter and were the only part of the county that received snowpack regularly.

Per the low emissions scenario, the project area's average winter temperature is projected to increase 3°F to 4°F from an historical average of 36°F for the 2050s and 4°F to 5°F for the 2080s [*Figure 7*]. Per the high emissions scenario, the project area's average winter temperature would increase 4°F to 5°F for the 2050s and 7°F to 9°F for the 2080s. This would likely mean fewer days with freezing temperatures and more rain instead of snow.

Per the low emissions scenario, the entire project area's average summer temperature would increase 4°F to 5.5°F for the 2050s and 5.5°F to 7°F for the 2080s [*Figure 8*]. Per the high emissions scenario, the project area's average summer temperature would increase 5.5°F to 7°F for the 2050s and 8.5°F to 11.5°F for the 2080s.

Daily Changes

Across the entire Puget Sound region, daily minimum air temperatures (generally, during the nighttime) rose by 1.8°F between 1895 and 2014 (historical average); daily maximum air temperatures (generally, during the afternoon) rose by 0.8°F (Mauger et al., 2015). During roughly the same time period (1901-2009), warm nights became more frequent.

Daytime and nighttime temperatures [*Figures 9 & 10, on pgs. 20-21*] are likely to rise throughout the project area during the 21st century per both emissions scenarios. Such changes are consistent with

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[8] The National Climate Change Viewer's spatial analysis scales include the nation, regions, states and counties rather than the Watershed Resource Inventory Area (WRIA) units that define the adaptation plan's project area. The Washington Department of Ecology has divided the state into 62 WRIAs to delineate areas that drain into a river, lake or other waterbody.

[9] The South Puget Sound region maps show historical (1970-1999) and projected (2050s and 2080s) changes in air temperature across seasons (summer and winter) per the low and high emissions scenarios. Southwestern Thurston County drains into the Chehalis River, so it is not included in the National Estuary Program grant and project area (encircled in black). Hash marks overlay areas where no data are available (Squaxin, Hartstene, Anderson, McNeil and Ketron islands). Historical periods shown in the vulnerability assessment's other figures may vary due to the length of record-keeping.

those projected across the broader Puget Sound region, where heat waves are expected to intensify and cold snaps are expected to become less severe over the century (Mauger et al., 2015).

Such changes in temperature extremes, coupled with shifts in seasonal precipitation volume, are likely to affect human and natural systems in many ways. For example, projected increases in the frequency and intensity of extreme heat events are may stress plants [*Figure 6, right*], exacerbate algal blooms, and delay outdoor construction projects and increase costs. Extreme heat can also increase the urban heat island effect in the region's most densely developed areas, as well as hospitalization and emergency service calls and costs to treat heat-related physical and mental stress (Mauger et al., 2015).

Figure 6: A bald cypress tree — brown and stressed following a bone-dry summer — rises from muddy water that spills over the southern shore of Olympia's Capitol Lake following a record-breaking rainstorm in December 2015. ***Source:*** *TRPC*

Children and older adults have a higher risk of dying or becoming ill as a result of heat stress, also known as hyperthermia (USGCRP, 2016), with symptoms including cramps, loss of consciousness, weakness and stoke. Other populations especially vulnerable to extreme heat and other exposure pathways include people who work outdoors, people who are homeless, people with chronic disease (e.g., diabetes, asthma, obesity), people with mental illness, and people who are socially isolated and economically disadvantaged (Thurston County, 2010). Section 6.3 of this assessment — Human Health & Welfare — includes a table [*Figure 66, on pg. 85*] that summarizes these and other health threats exacerbated by climate change.

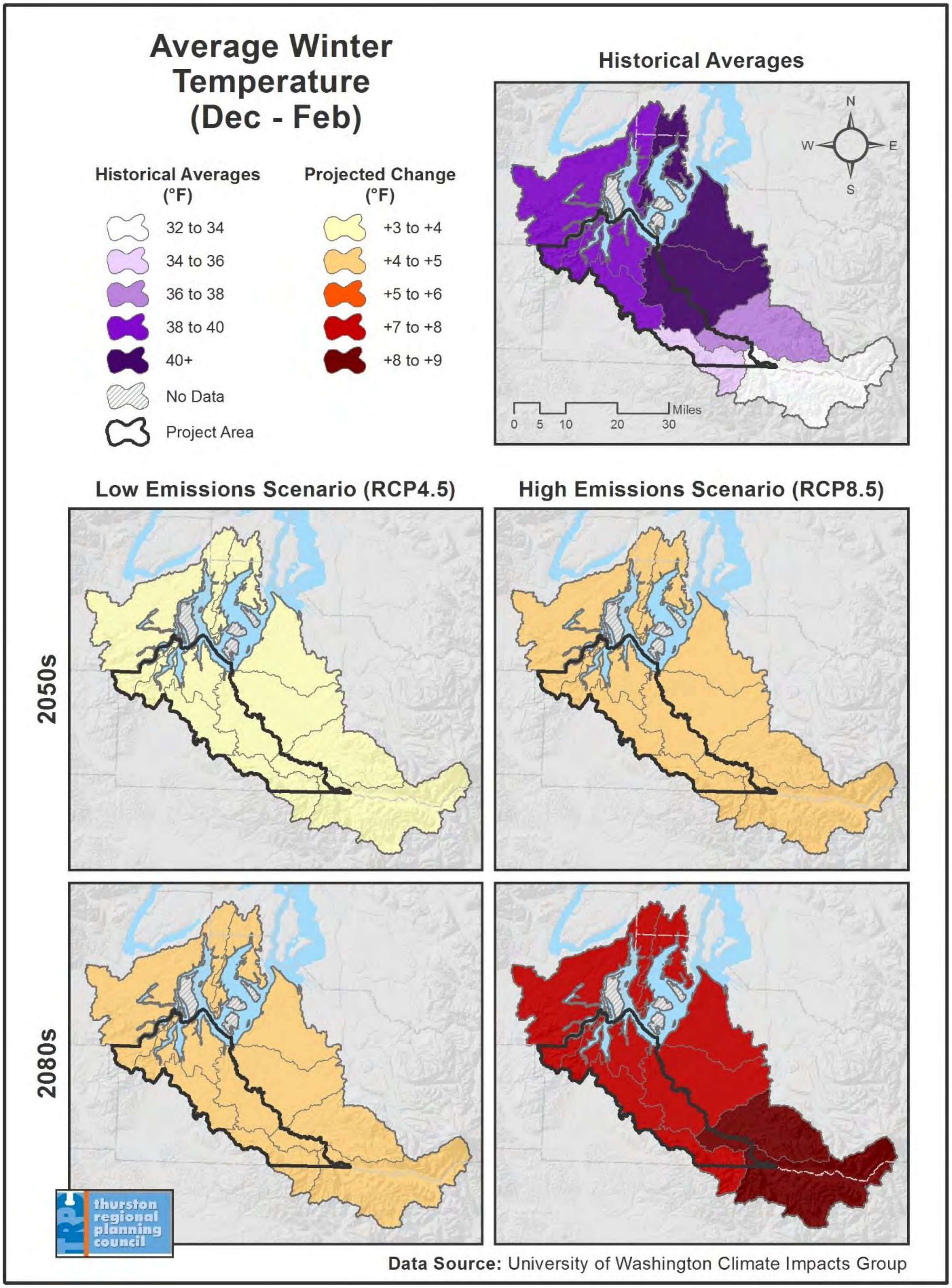

Figure 7. Projected changes in average winter temperature for South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 1b in Appendix B of Mauger et al., 2015.*

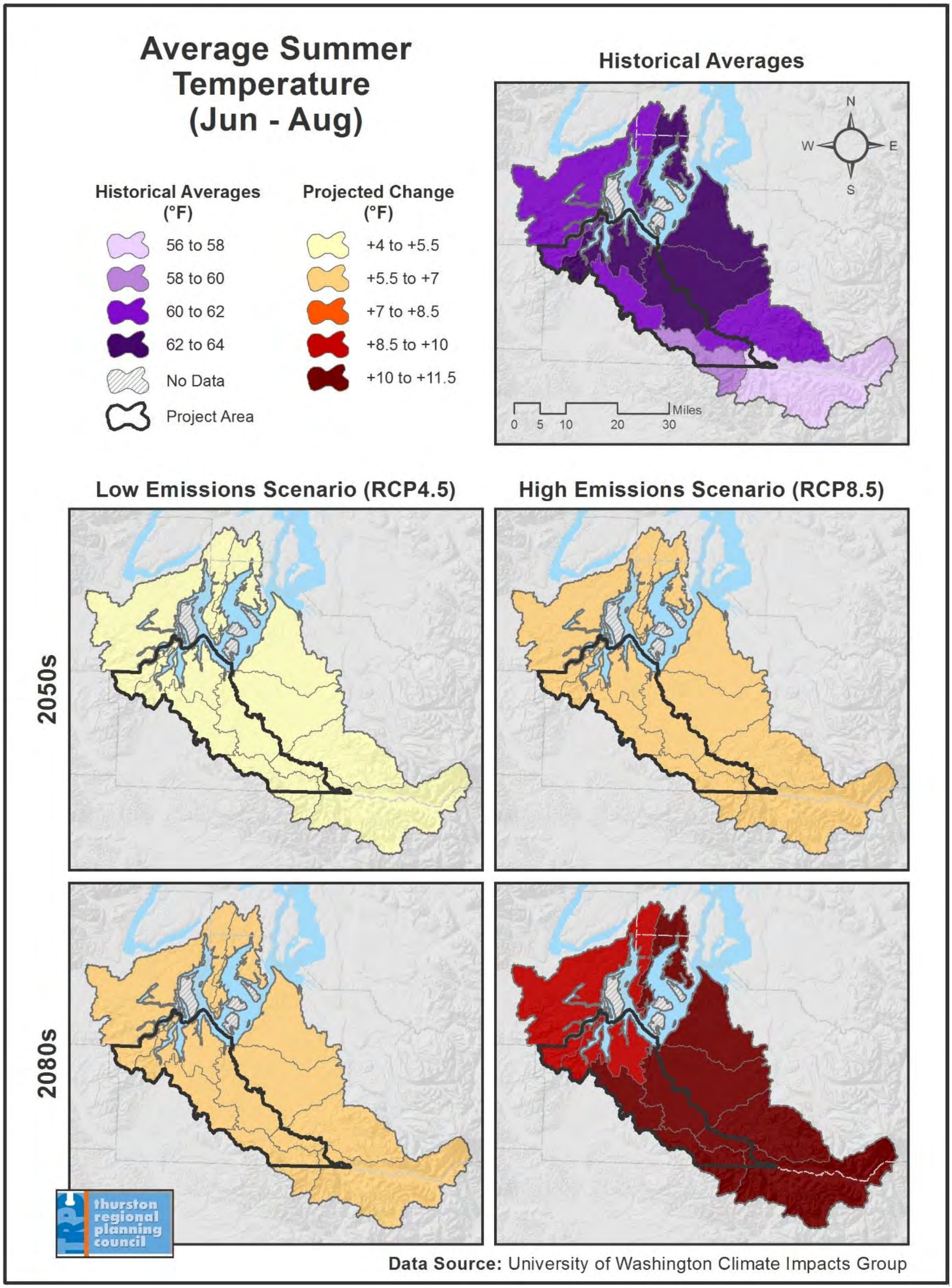

Figure 8. Projected changes in average summer temperature for South Puget Sound watersheds per emissions scenarios.
Source: *Adapted from Figure 2a in Appendix B of Mauger et al., 2015.*

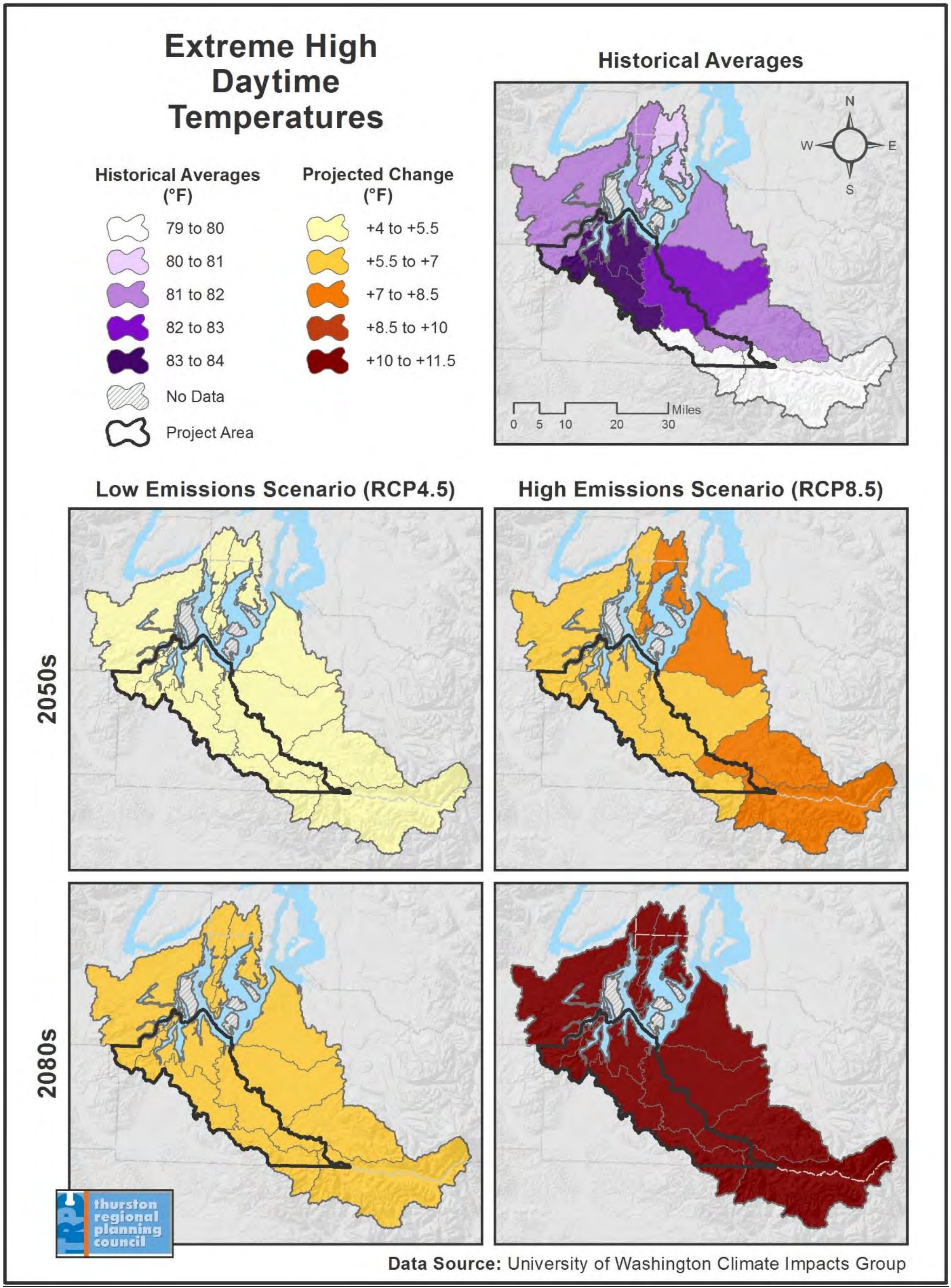

Figure 9. Projected changes in extreme high daytime temperatures for South Puget Sound watersheds per emissions scenarios. ***Note:*** *The "extreme high" temperature is the 95th percentile of daily maximum temperatures occurring annually.* ***Source:*** *Adapted from Figure 4b in Appendix B of Mauger et al., 2015.*

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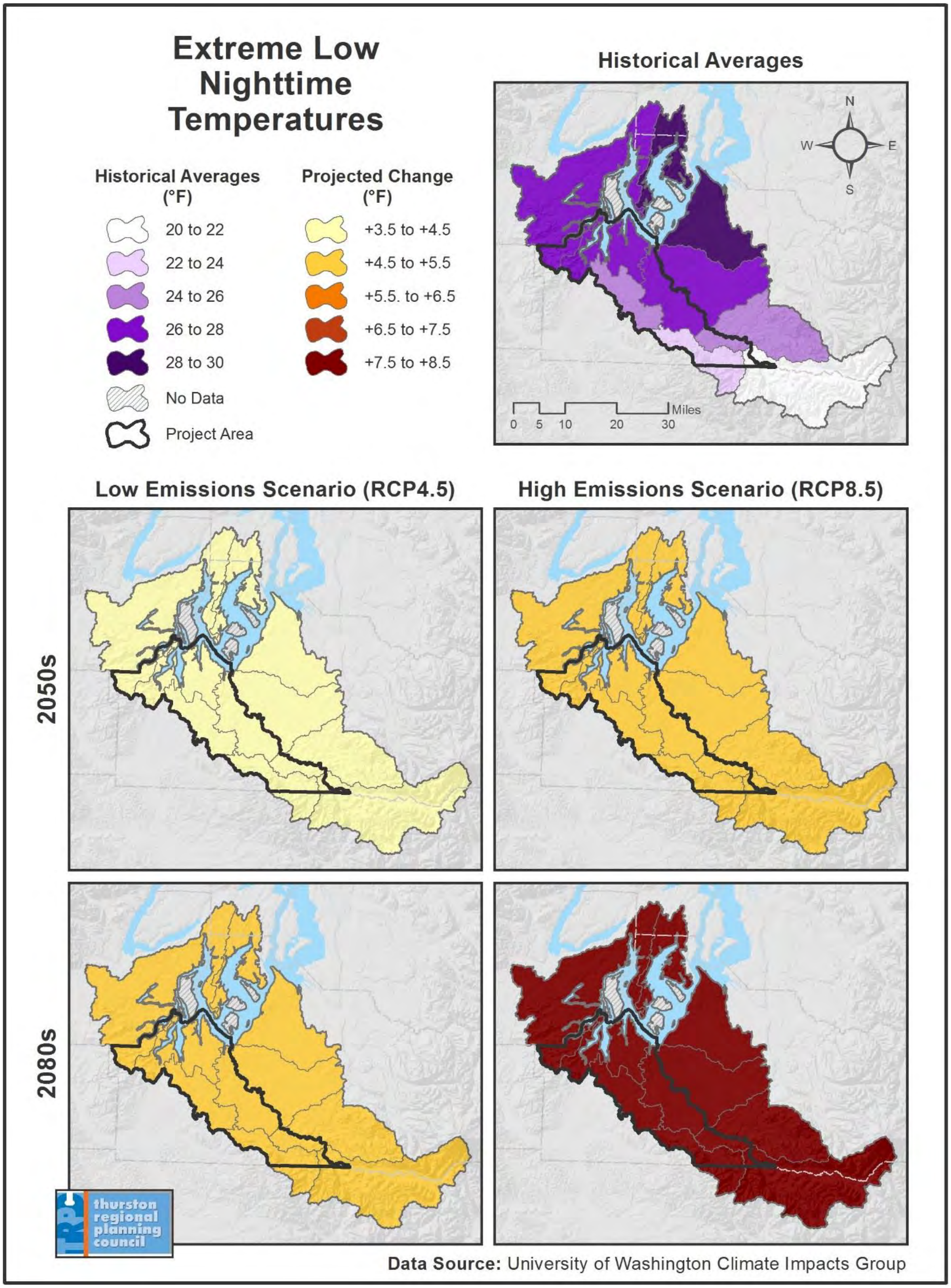

Figure 10. Projected changes in extreme low nighttime temperatures *(the 5th percentile of daily minimum temperatures occurring annually)* for South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 5b in Appendix B of Mauger et al., 2015.*

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2.2: Air Quality

Air quality changes are driven primarily by emissions and temperatures. Modeling indicates that, with locally higher surface temperatures in polluted regions, regionally triggered feedbacks in chemistry and local emissions will, with "medium confidence,"[10] (IPCC, 2013) increase peak levels of surface ozone and $PM_{2.5}$ (particulate matter smaller than 2.5 micrometers in diameter).

$PM_{2.5}$ poses a human health risk because such fine particles — about 1/30th the average width of a human hair — can be inhaled and lodge deeply in lungs (EPA, 2016). Surface ozone (tropospheric O_3), a main ingredient of urban smog, is harmful to breathe and damages vegetation (EPA, 2014). Children and older adults — as well as people of any age with preexisting heart and respiratory (cardiopulmonary) problems — are among groups that are most sensitive to these air pollutants. The primary sources of $PM_{2.5}$ in Thurston County are wood burning in stoves and outdoors (e.g., brush piles) — and, to a lesser degree, combusting fossil fuels in automobile engines (Hadley, 2016). The primary sources contributing to surface ozone are nitrogen dioxide emissions from automobiles and volatile organic compounds from industrial facilities [*Also see Section 6.3 and Figure 66, on pg. 85*].

The U.S. EPA sets national ambient air quality standards for particulate matter and ozone, as well as four other criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). Thurston County is currently meeting standards for $PM_{2.5}$ and surface ozone, according to Olympic Region Clean Air Agency data analyzed by TRPC (TRPC, 2016).

While Thurston County doesn't struggle with air quality issues to the degree that many larger communities do, the county is one of the fastest-growing in the state. Local air pollution could become more severe in coming decades — especially if Thurston County's summers are hotter and drier and its roads add more petroleum-powered cars and trucks (Hadley, 2016). Thurston County's population is projected to increase by about 47 percent between 2015 and 2040, while the county's cumulative annual vehicle miles traveled is projected to increase 37 percent, according to TRPC modeling[11].

One study, which factored in projected growth in statewide population and $PM_{2.5}$ concentrations, estimated that $PM_{2.5}$ could cause 139 more deaths annually across Washington by 2050 compared to 2001 (Tagaris et al., 2009). A separate study, which factored in projected population growth and ground-level ozone concentration in the greater Seattle area, estimated that the attributed number of "excess deaths" (expected deaths above the baseline) during summer would nearly double — from about 69 annually (1997-2006 average) to about 132 annually by 2050 (Mauger et al, 2015).

The relationship between climate change, aeroallergens (e.g., pollen and fungal spores) and health outcomes has not been studied in the Puget Sound region (Mauger et al., 2015), but studies conducted elsewhere show that pollen production in some plant species (e.g., ragweed) increases with carbon dioxide (CO_2) levels. Other research concludes that warmer temperatures could lead to a longer pollen season with increased allergenicity to some allergens (WDOE, 2007).

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[10] IPCC 2013 uses the following terms, which are based on the type, amount, quality, and consistency of evidence, to indicate the assessed likelihood of an outcome: "virtually certain," 99-100% probability; "very likely," 90-100% probability; "likely," 66-100% probability; "about as likely as not," 33-66% probability; "unlikely," 0-33% probability; "very unlikely," 0-10% probability. The IPCC report uses the following qualifiers to denote a level of confidence that is based on the degree of scientific agreement and available evidence: "very low," "low," "medium," "high," and "very high." The UW CIG assessment reports climate trends only if they are statistically significant at or above a 90% or 95% confidence level. In several cases, this vulnerability assessment modifies text from such source documents only slightly so as to ensure technical accuracy of terms.

[11] The figures, previously unpublished, are derived from TRPC's transportation and population forecast models.

2.3: Precipitation

A continued rise in average annual temperature over the 21st century is expected to shift the region's seasonal cycle of precipitation, which could affect myriad assets within our human and natural systems: For example, too much rainfall at once could scour streambeds, flood valleys, and trigger landslides that destroy property and wildlife habitat; too little rainfall over a sustained period, however, could kill fish and vegetation, cause drought, diminish hydropower production, and increase the risk of wildfire.

Annual & Seasonal Changes

There is no discernable historical trend in precipitation across the Puget Sound region, which averaged about 78 inches annually from 1950-2005 (Mauger et al., 2015). In the decades ahead, however, the region's seasonal precipitation totals [*Figure 11, below*] — and to a much lesser extent, annual precipitation totals [*Figure 12, below*] — are projected to change.

Season	Scenario	2050s		2080s	
		Mean	Range	Mean	Range
Fall	Low *(RCP 4.5)*	+5.5%	-5.7% to +13%	+12%	+1.6% to -21%
	High *(RCP 8.5)*	+6.3%	-2.4% to +19%	+10%	+1.9% to +15%
Winter	Low *(RCP 4.5)*	+9.9%	-1.6% to +21%	+11%	+1.3% to +16%
	High *(RCP 8.5)*	+11%	+1.8% to +19%	+15%	+6.2% to +23%
Spring	Low *(RCP 4.5)*	+2.8%	-9.4% to +13%	+1.6%	-3.2% to +9.3%
	High *(RCP 8.5)*	+3.8%	-7.7% to +13%	+2.5%	-6.7% to +11%
Summer	Low *(RCP 4.5)*	-22%	-45% to -6.1%	-20%	-38% to -10%
	High *(RCP 8.5)*	-22%	-50% to -1.6%	-27%	-53% to -10%

Figure 11. Projected changes in Puget Sound region seasonal precipitation for the 2050s and 2080s per the low and high scenarios. ***Source:*** *TRPC, adapted from Mauger, et al., 2015*

Time Period	Scenario	Mean	Range
2050s	Low *(RCP 4.5)*	+4.2%	+0.6% to +12%
	High *(RCP 8.5)*	+5.0%	-1.9% to +13%
2080s	Low *(RCP 4.5)*	+6.4%	-0.2% to +10%
	High *(RCP 8.5)*	+6.9%	+1.0% to +9.4%

Figure 12. Projected changes in Puget Sound region annual precipitation. ***Source:*** *TRPC, adapted from Mauger, et al., 2015*

Future Puget Sound summers are likely to be hotter and drier, with more extreme heat events; winters are likely to be warmer and wetter, with more intense heavy rain events. Summer precipitation[12] is projected to decline 22 percent for the 2050s for both scenarios (Mauger et al., 2015). Conversely, winter precipitation is projected to increase by roughly 10 percent for the 2050s for both scenarios.

Within South Puget Sound and the project area, the biggest changes in seasonal precipitation would occur in southeastern Thurston County [*Figures 13 & 14, on pgs. 24-25*]. Summer precipitation[13] is projected to decrease by 8.5-11.5 percent for the 2080s for the low emissions scenario in this area — which includes the Nisqually Indian Reservation and the growing city of Yelm; precipitation would decrease by 11.5-13 percent per the high scenario. Conversely, this area would see the biggest relative increase in winter precipitation for the high scenario.

[12] Puget Sound summer (April-September) precipitation averaged 18.66 inches historically (1970-1999); winter (October-March) precipitation averaged 56.51 inches, according to TRPC calculations using UW CIG data.
[13] South Puget Sound summer precipitation averaged 15.06 inches historically; winter precipitation averaged 48.39 inches.

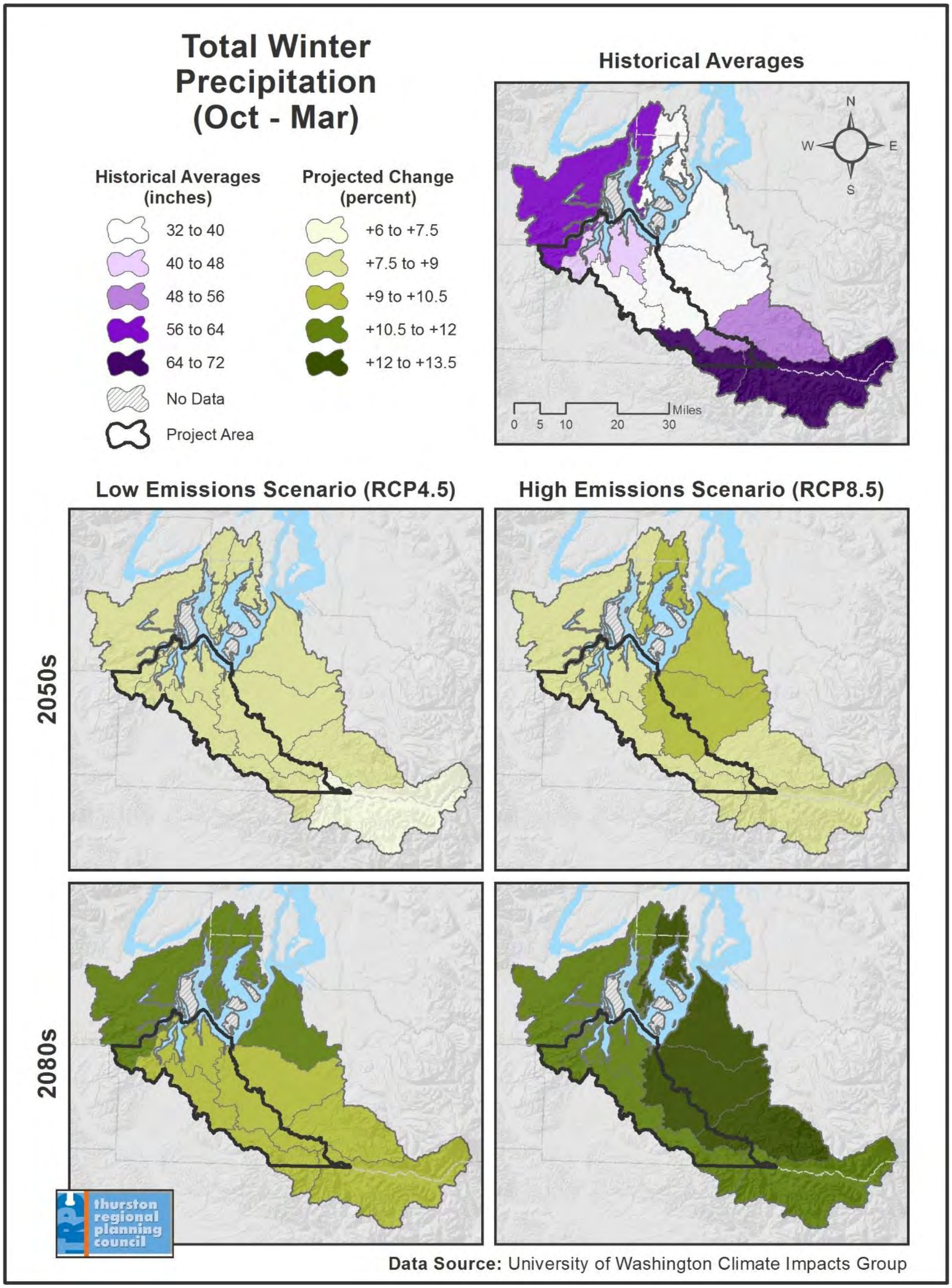

Figure 13. Projected changes in total winter precipitation for South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 6b in Appendix B of Mauger et al., 2015.*

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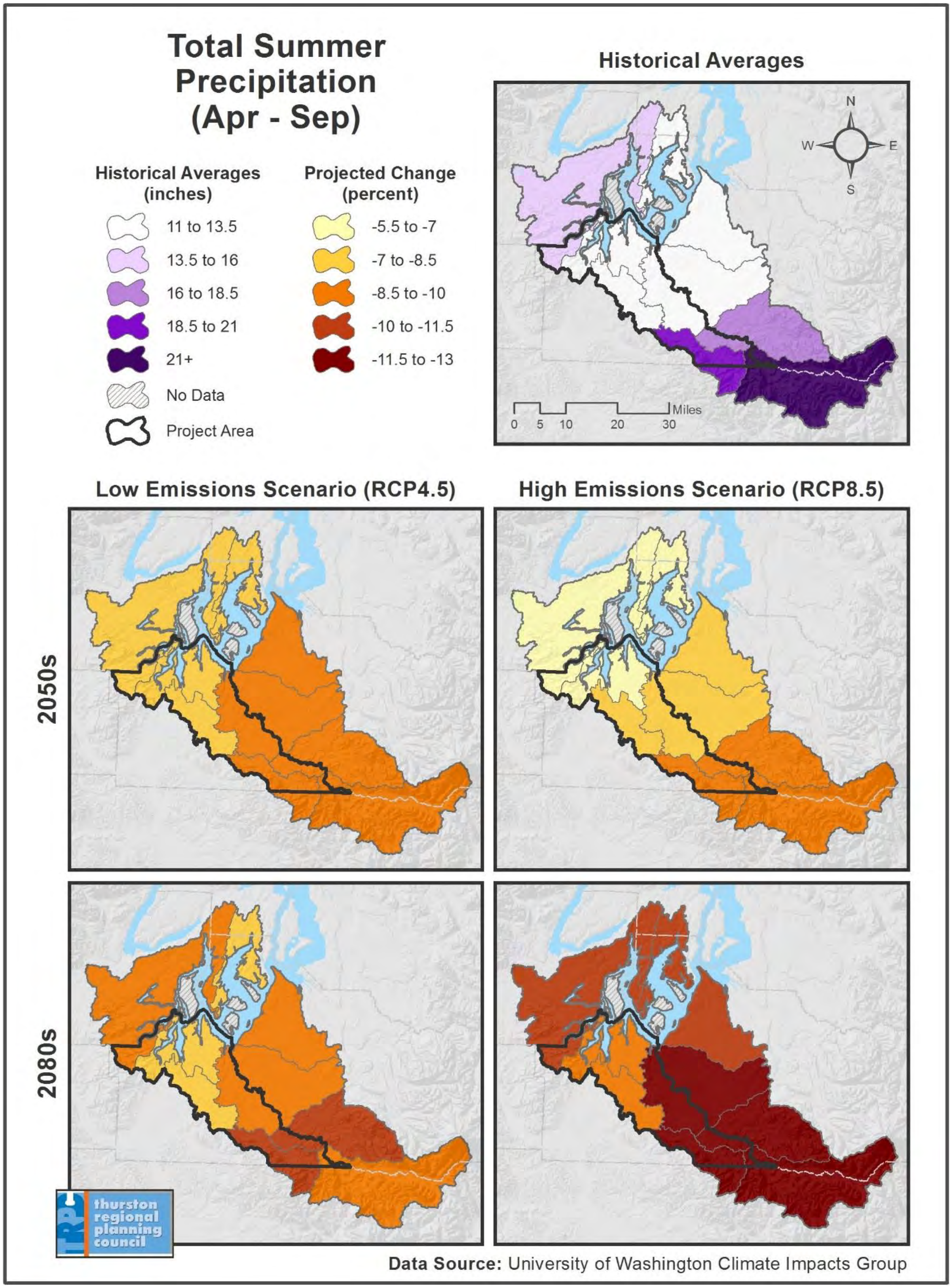

Figure 14. Projected changes in total summer precipitation for South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 7b in Appendix B of Mauger et al., 2015.*

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Storm Frequency & Intensity

The *Natural Hazards Mitigation Plan for the Thurston Region* finds that damaging rain has a "high" (38 percent) annual chance of occurrence currently, based on analysis of past storm events (TRPC, 2009). A future with warmer and wetter winters increases the likelihood that such "heavy" rainstorms will be more frequent and intense (Mauger et al., 2015), potentially resulting in flooding and other hazards that endanger human health and welfare [*Figure 15, below*].

Within the broader Puget Sound region, the frequency of today's heaviest 24-hour rain events (top 1 percent) is projected to increase — occurring about seven days per year for the 2080s, per the high greenhouse gas scenario, compared to two days per year historically (Mauger et al., 2015). Within the project area, the intensity of such events is also projected to increase; the biggest increases would be along the Deschutes River as it heads into Capitol Lake [*Figure 16, on pg. 28]*.

Figure 15: The Deschutes River overtops its banks at Tumwater Falls Park after a record-breaking storm in 2015. **Source:** TRPC

While models project more frequent and intense storm events for the region, there is no scientific consensus regarding whether climate change will affect wind speeds and patterns. Observed trends in wind speed and pattern are ambiguous, with some studies finding increases and others finding decreases (Mauger et. al, 2015).

Heavy rainfall events could cause some septic systems to fail, which would degrade water quality and pose health risks.

Added to this, the region's oldest stormwater infrastructure — the network of ponds and pipes that capture and channel runoff from streets and other impervious surfaces — would be especially vulnerable to overflows associated with such events. Stormwater runoff from downtown Olympia and surrounding neighborhoods is piped directly into Puget Sound, and runoff from many newer subdivisions and commercial developments is captured on-site in stormwater ponds that have been designed to handle historic levels of rainfall.

To protect water quality — and, as a co-benefit, reduce the risk of stormwater-related flooding — the Washington Department of Ecology's revised municipal stormwater permit requires permittees to revise their drainage manuals to require more distributed, on-site infiltration and runoff mitigation. Local permittees — including Thurston County, Olympia, Lacey and Tumwater — are also revising their codes in 2016 to make such "low-impact development" the preferred and commonly used approach to site development, where feasible.

Going forward, key challenges for Thurston County communities include identifying where LID is infeasible (e.g., areas with tightly packed soils or steep slopes), as well as designing and investing sufficiently in stormwater infrastructure (new and retrofitted) that is able mitigate the flooding and runoff associated with more frequent more frequent and intense rain events. Subsequent sections of this assessment explore how such extreme rain events will exacerbate the risks of water pollution, flooding and landslides. [*See Section 3.4, on pg. 49, and Section 6.3, on pg. 85*].

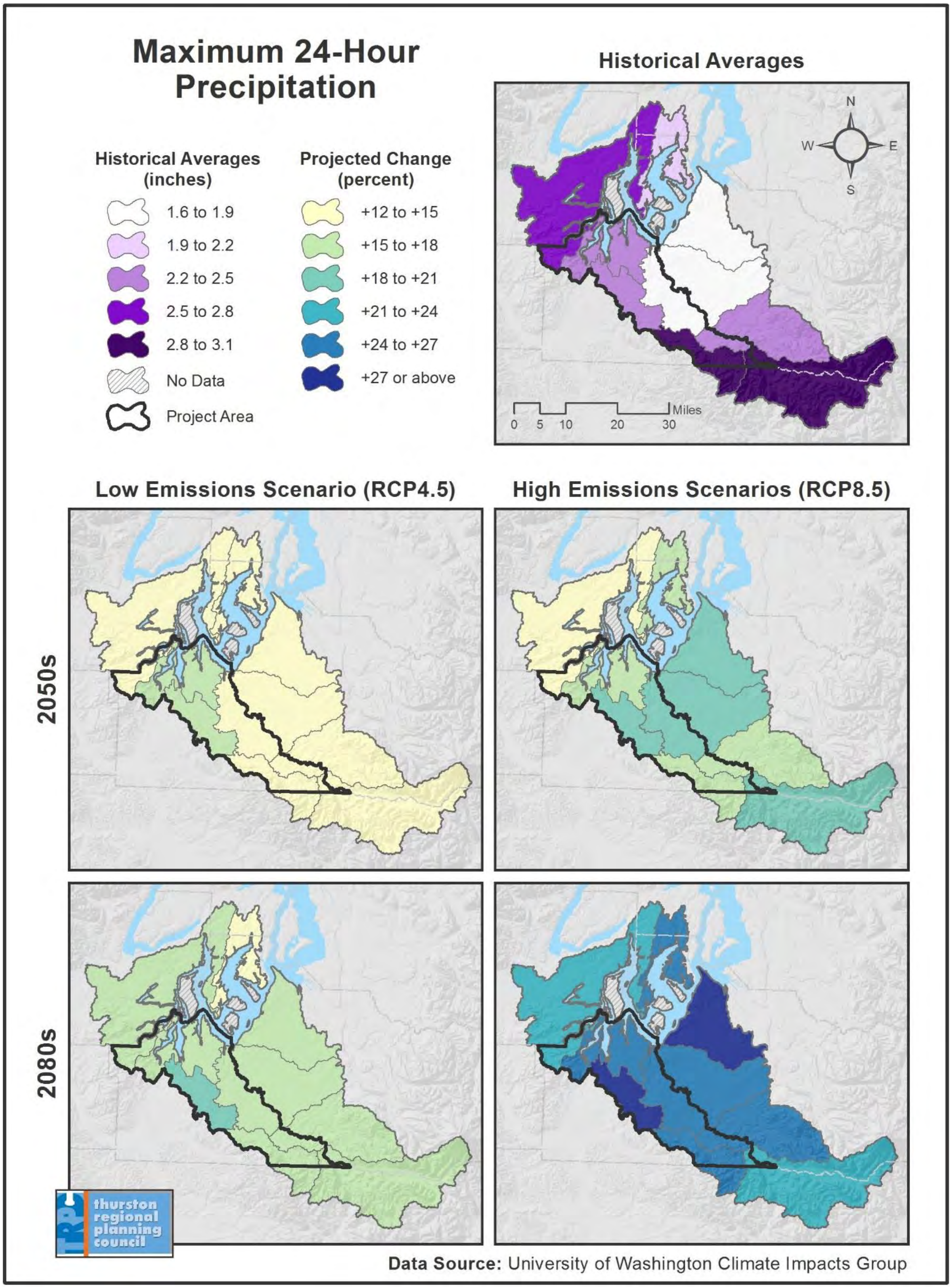

Figure 16: The intensity of the heaviest 24-hour rain events (top 1 percent) — as measured in inches of precipitation — is projected to increase amid the project area. ***Source:*** *Adapted from Figure 8b in Appendix B of Mauger et al., 2015.*

Snowfall & Snowpack Volume

A continued rise in the average annual temperature over the 21st century will result in more winter precipitation falling as rain instead of snow in the Puget Sound region. This shift would reduce the extent of mountain snowpack and glaciers and alter the timing of runoff and volume of streamflow. The potential loss of forestland — e.g., via timber harvesting, fire and disease — could degrade further the ability of highlands to retain snowpack and control streamflow (Greene and Thaler, 2014).

Thurston County's annual average snowfall is projected to decrease by just two-tenths of an inch per both the high and low emissions scenarios for the 2050s and 2080s and become virtually nonexistent by the end of the 21st century, according to the USGS National Climate Change Viewer (Alder & Hostetler, 2013). A key reason for this small figure is that all of Thurston County is less than 3,000 feet above sea level. In most years, there is little or no snowfall nor sustained snowpack outside of the county's higher-elevation forestlands (e.g., Capitol State Forest and Alder Lake area).

Snow blankets Alder Dam and southwestern Thurston County's forested highlands in December 2016. ***Source:*** *TRPC*

April 1 is considered the date of peak snowpack[14] in Pacific Northwest highlands. Historically, peak snowpack is about 20-30 inches within the watershed unit that includes Alder Lake and the southwestern flank of Mount Rainier within Lewis and Pierce counties — the headwaters of the Nisqually River [*Figure 17, on pg. 30*]. For the 2080s, peak snowpack would decline 80-90 percent in this watershed unit for the low emissions scenario and 90-100 percent for the high scenario. The length of the snow season in southeastern Thurston County and surrounding highlands also would decline significantly per both scenarios [*Figure 18, on pg. 31*].

Annual mean snowfall in Pierce County — which includes the Nisqually River's headwaters — is projected to decrease by about 43 percent over the 21st century per the low emissions scenario (from 5.8 inches historically[15] to 3.3 inches in 2099) and about 71 percent per the high scenario (from 5.8 inches to 1.7 inches) (Alder & Hostetler, 2013). Annual mean snowfall in Lewis County — which includes the Deschutes River's headwaters — is projected to decrease by about 63 percent over the century per the low scenario (from 3.8 inches historically to 1.4 inches) and about 87 percent per the high scenario.

[14] Climate models express "peak snowpack" as April 1 snow water equivalent — the total amount of water contained in the snowpack. The UW Climate Impacts Group calculated changes only for Puget Sound areas that regularly accumulate snow (historical April 1 snowpack depth of about 0.4 inches, on average).

[15] Historical figures for both counties referenced in this paragraph denote the 1950-2005 average annual mean.

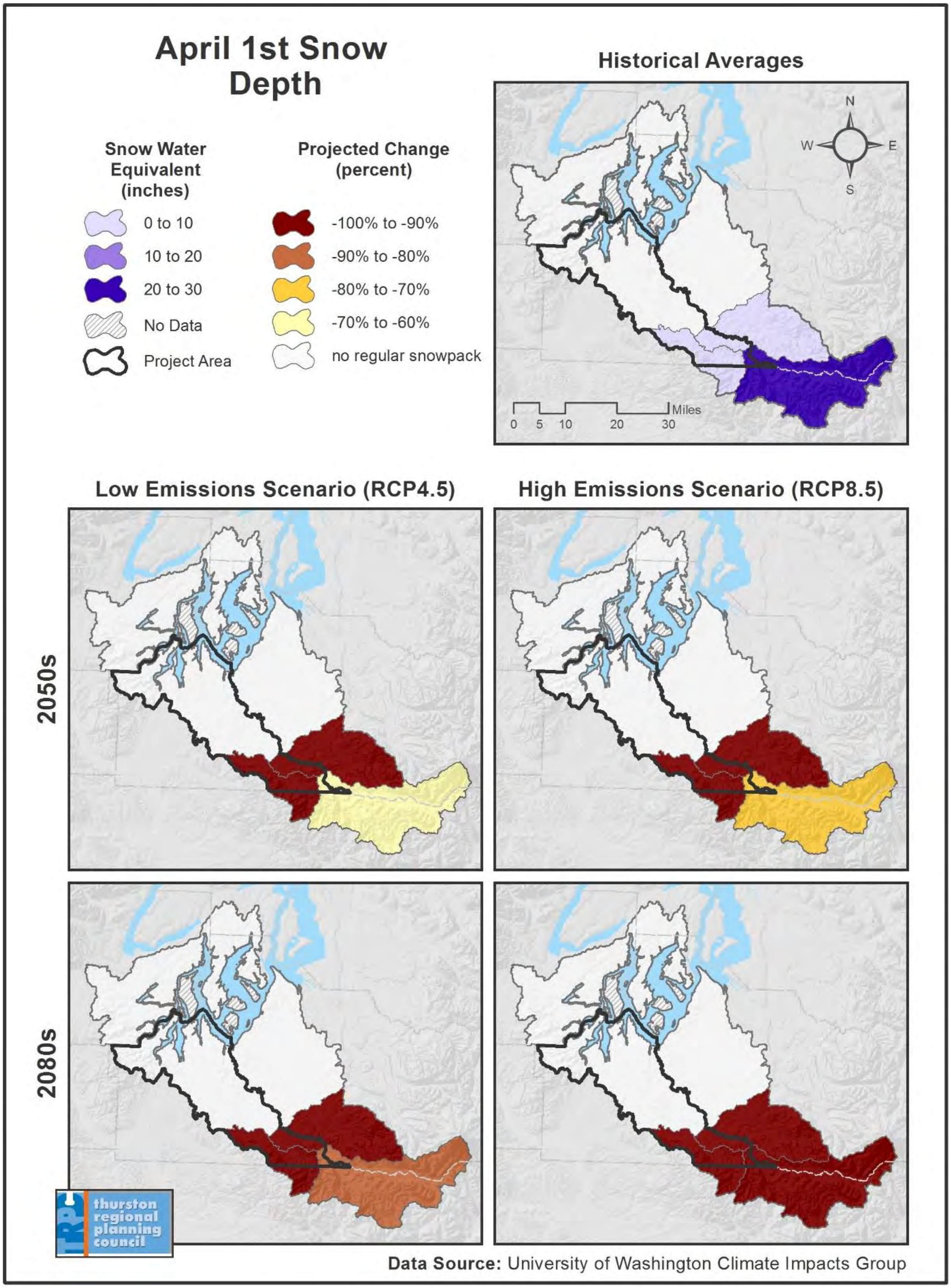

Figure 17. Projected changes in April 1st peak snowpack, expressed as snow water equivalent (measure of the total amount of water contained in snowpack) amid South Puget Sound watersheds. ***Source:*** *Adapted from Figure 11b in Appendix B of Mauger et al., 2015.*

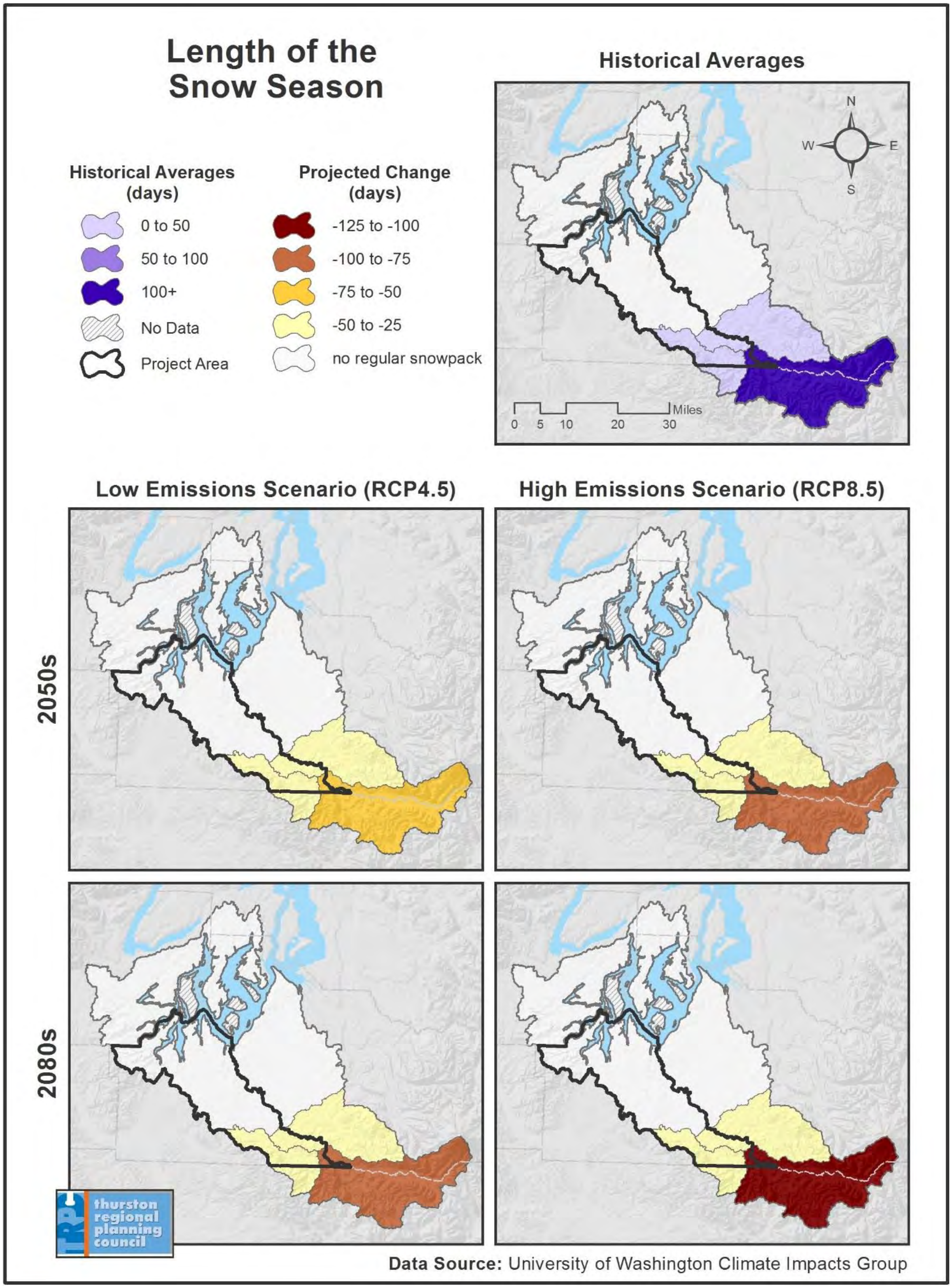

Figure 18. Projected changes in length of snow season amid South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 13b in Appendix B of Mauger et al., 2015.*

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3: Freshwater Ecosystems

As noted previously, climate models project a shift to more rain-dominant conditions across the Puget Sound region as a result of progressively warmer air temperatures during the 21st century. This would result in higher runoff and streamflow during cooler months but the opposite during warmer months. The analysis below examines the effects of such changes on surface and subsurface waters.

…

3.1: Streams

Precipitation and stream temperature, timing and volume are linked inextricably and are key indicators of a watershed's health.

Major winter rainstorms can flood streams with sediment and fast-moving runoff that degrades water quality and critical habitat [*Figure 19, right*]. Fish eggs and benthic macroinvertebrates (small organisms that cycle nutrients and occupy an important place in the food web) are especially vulnerable to scouring, sediment-laden streamflow associated with major storm events.

Conversely, dry summers can leave streams with low, slow-moving flows and high temperatures that harm freshwater organisms and increase competition for water among farms, utilities and other users. Pollution from runoff and other sources can exacerbate the effects of such changes in stream temperature and volume.

Figure 19: Fast-moving water removed riparian vegetation along a rural stretch of the Deschutes River during the winter of 2015-'16, making the streambank vulnerable to erosion. ***Source:*** *TRPC*

Water Volume Vulnerability

Across the Puget Sound region, summer streamflow volume — which is influenced by runoff — is projected to decrease by 24-30 percent, on average, for the 2080s (Mauger et al., 2015). Within South Puget Sound watersheds, changes in summer runoff will be greatest amid the headwaters of the Deschutes and Nisqually rivers — higher-elevation areas with working forests [*Figure 20, on pg. 33*]. For example, in the watershed unit that stretches from Alder Lake to Mount Rainier, summer runoff is projected to decline 40-50 percent for the 2080s per the low emissions scenario; summer runoff is projected to decline 50-60 percent per the high emissions scenario.

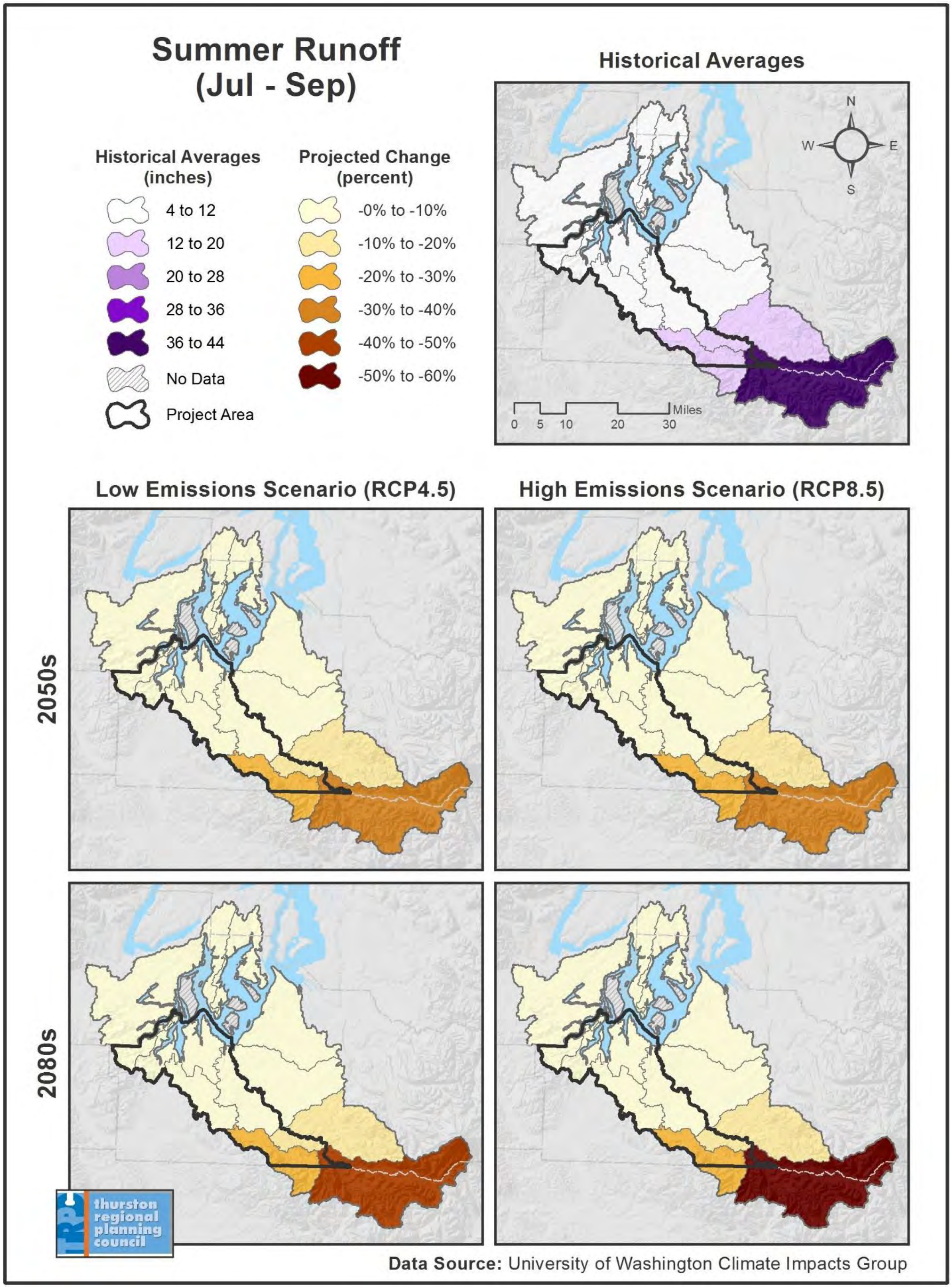

Figure 20. Projected changes summer runoff amid South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 15b in Appendix B of Mauger et al., 2015.*

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The resultant slower, warmer water could stress fish, reduce suitable spawning habitat and alter migration (Mauger et al., 2015). A shift to more winter precipitation, however, will also pose challenges (e.g., degraded habitat and die-offs) for fish and other species that have evolved around predictable spring peak flows. The table below [*Figure 21*] estimates the impact of such changes in the Nisqually Watershed, which is projected to shift from a mixed rain-and-snow watershed (i.e., a watershed that receives 10-40 percent of its precipitation as snow) to a rain-dominant watershed (i.e., a watershed that gets less than 10 percent of its precipitation as snow) for the 2080s (Mauger et al., 2015).

Nisqually Watershed	
Indicator	**Change**
River miles with August stream temperatures in excess of thermal tolerances for fish	+24 miles (*adult salmon*) +179 miles (*char*)
Streamflow volume associated with 100-year (*1 percent annual probability*) flood event	+18% (*range: -7% to +58%*)
Summer minimum streamflow volume	-27% (*range: -35% to -17%*)
Peak streamflow timing (*days earlier*)	-34 days (*range: -45 to -25 days*)

Figure 21. Projected changes in Nisqually River streamflow timing, temperature and volume for the 2080s per a "moderate" emissions scenario. ***Source:*** *Adapted from Mauger, et al., 2015*

The UW GIC did not model future streamflow for the Deschutes and Kennedy-Goldsborough watersheds individually because each is projected to remain a rain-dominant system. Historical data collected by Thurston County, however, shows that the Deschutes River's summer streamflow volume has declined gradually since the 1950s [*Figure 22, below*], which is consistent with the projected trend for Puget Sound region streams.

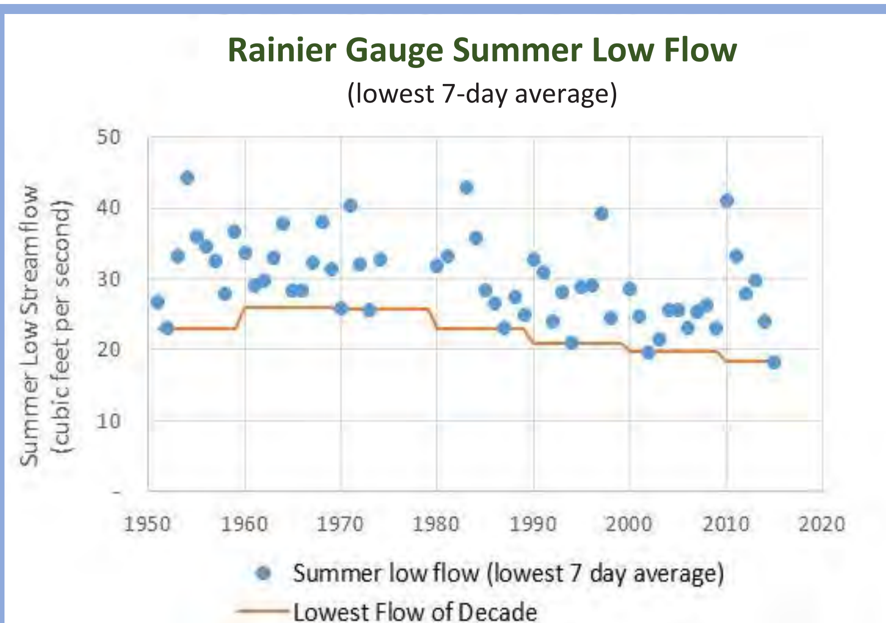


Figure 22. Where useful, this assessment uses local examples to show historical changes. The graphs below show how Deschutes River record low summer flows, as measured at Thurston County's Rainier gauge, have declined gradually since the mid-20th century. ***Source:*** *TRPC, using Thurston County data*

Looking ahead, winter runoff [*Figure 23, on pg. 35*] and streamflow in the Deschutes and Nisqually rivers would be higher as a result of more winter precipitation falling as rain amid southeastern Thurston County and surrounding highlands in Pierce and Lewis counties.

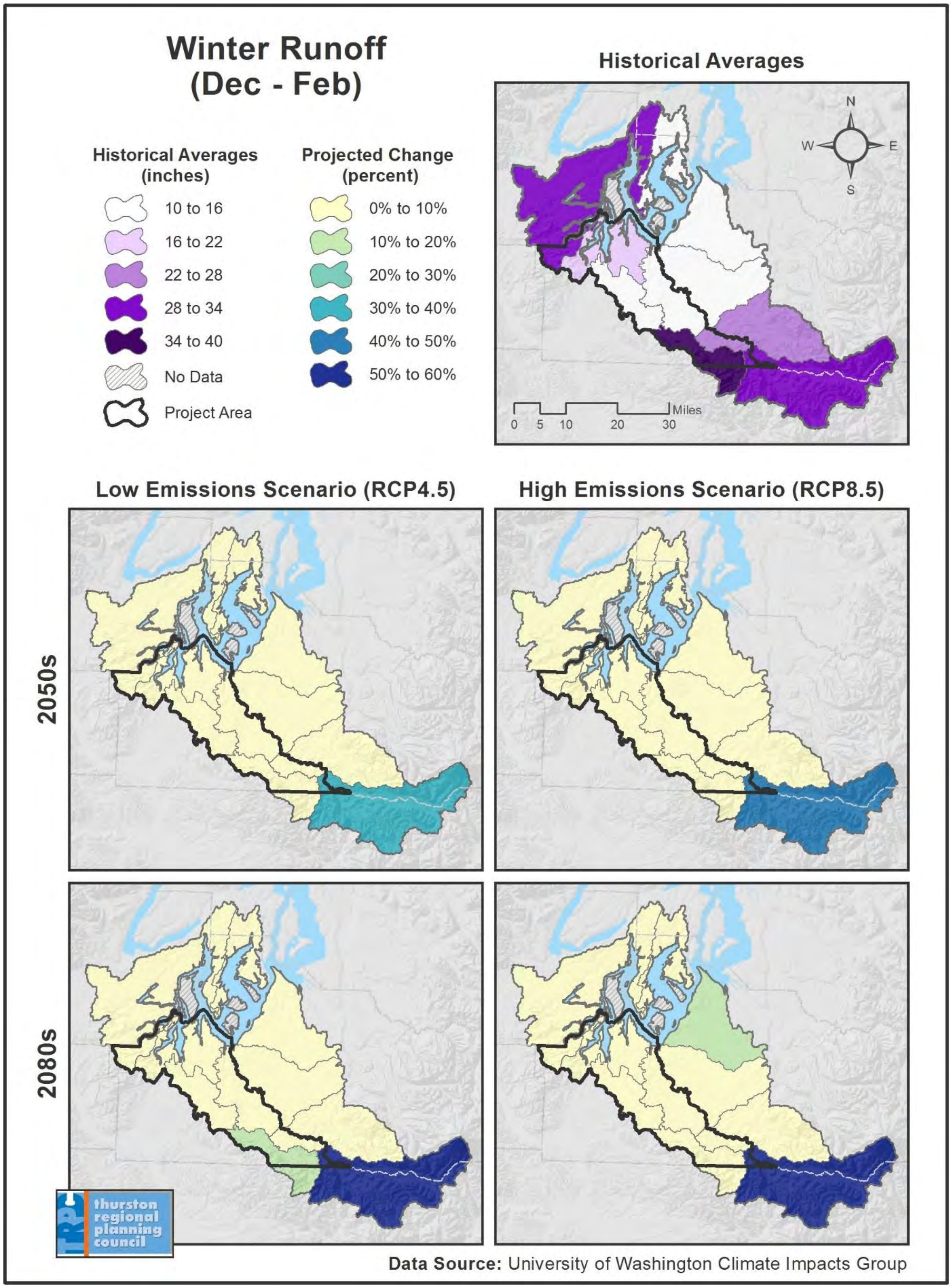


Figure 23. Projected changes winter runoff amid South Puget Sound watersheds per emissions scenarios. ***Source:*** *Adapted from Figure 14b in Appendix B of Mauger et al., 2015.*

Hydropower Vulnerability

Projected changes in precipitation and streamflow are expected to affect the extent of glaciers on Mount Rainier and productivity of hydropower dams on the Nisqually River and other Pacific Northwest rivers. Mount Rainier's glaciers declined about 14 percent in volume between 1970 and 2008 (Mauger et al., 2015). The Nisqually Glacier's retreat [*Figure 24, below*] is adding to sediment loads aggregating in the Nisqually River and increasing flooding risks. Tacoma Power's Alder and LaGrande hydropower dams ameliorate the problem by holding back sediment at the 3,000-acre Alder Lake (USGS, 2012). This build-up could become a long-term problem, however, because it diminishes water storage capacity behind the dams, which provide power to roughly 43,000 households in Pierce County (Maurer, 2016). Added to this, organic materials that aggregate and decompose in such reservoirs emit greenhouse gases (Mooney, 2016).

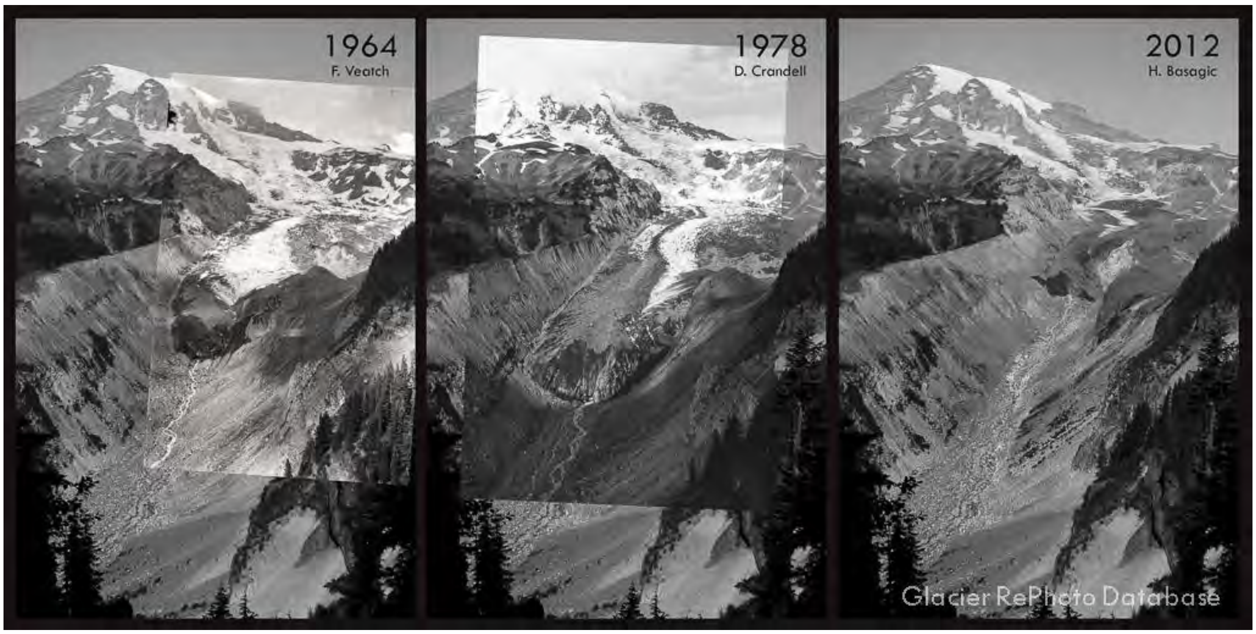


Figure 24. The Nisqually Glacier on Mount Rainier's southern flank [*pictured*] advanced slightly during the 1960s and 1970s but has retreated significantly in the decades since.
Source: *Glacier RePhoto Project Database (Basagic, 2013).*

In coming decades, the Nisqually River is expected to shift to increased early winter peak flows and decreased flows during the spring and summer, according to the UW CIG, which analyzed streamflow into Alder Lake at the request of Tacoma Power (Lee et al., 2015). The watershed is projected to shift from a rain-snow mix watershed with two periods of peak runoff (early winter and spring) to a rain-dominant watershed with peak flows in winter. In the near term, glacial melt may augment summer streamflow as temperatures warm. However, the supply of meltwater is projected to decline sharply by the end of the 21st century (Mauger et al., 2015).

Decreasing summer streamflow will make it harder to balance competing demands for water across the growing region (Hamlet et al., 2010). State law requires that Tacoma Power and other hydropower producers release enough water from behind their dams to support instream resources and uses, including fish, wildlife, recreation, aesthetics, water quality and navigation (Pacheco, 2016).

Pacific Northwest hydropower production is projected to decrease by 1-4 percent annually during the 2020s (increase by 0.5-4 percent in winter, and decrease by 9-11 percent in summer); winter increases and summer decreases for the 2040s and 2080s would be more pronounced (Hamlet et al., 2010). Meanwhile, residential cooling demand is projected to increase to 4.8-9.1 percent of Washington's total energy demand for the 2080s, relative to 1970-1999, due to the combined effects of higher air temperature, population growth, and greater use of air conditioners. Warmer winters, conversely, could lower residential heating demand and utility bills.

Climate change is also a consequential issue for Puget Sound Energy, which has 120,000 electric customers in Thurston County [*Figure 25, below*] and 1.1 million electric customers in Western Washington counties collectively. Hydropower accounts for 36 percent of the electricity PSE delivers to its customers; coal and natural gas account for 35 percent and 24 percent, respectively, while nuclear wind and other sources account for the rest of the utility's energy portfolio (Puget Sound Energy, 2016). The company owns and operates two dams — on the snowmelt-fed Baker and Snoqualmie rivers — and it purchases additional power from Central Washington public utility districts with Columbia River dams.

The investor-owned utility's 2015 Integrated Resource Plan — which uses scenarios to evaluate energy supply and demand decisions over the ensuing 20 years — projects that PSE's base peak demand[16] growth rate will average 1.6 percent annually (almost 1,000 additional megawatts, from 2015-2035) (Puget Sound Energy, 2015). The resource plan does not call for additional hydropower generation capacity. Rather, the plan targets significant investments in energy efficiency, wind power generation and other measures to meet projected demand and comply with renewable portfolio standards.[17]

Figure 25. Mount Rainer looms over transmission lines in Thurston County, where Puget Sound Energy has about 120,000 electric customers. ***Source:*** *TRPC*

[16] This term refers to the minimum amount of electricity needed when consumer demand is highest (e.g., during the hottest afternoons when air conditioner use is highest).

[17] Washington state's Renewable Portfolio Standard (RCW 19.285) requires large utilities to obtain 15 percent of their electricity from new renewable resources (e.g., solar and wind) by 2020 and to undertake cost-effective energy conservation measures.

Water Temperature & Salmonid Vulnerability

Stream temperature is a function of both flow and shading, as shallow rivers with sparse riparian vegetation are warmer than deep rivers with dense riparian vegetation. Historically, average annual stream temperatures have been warmest amid South Puget Sound's lowlands, where most of Thurston County's urban development is concentrated. Stream temperatures have been coolest in the less-developed, higher-elevation areas, where there is generally more riparian shade, steeper gradients and faster-moving water [*Figure 28, on pg. 40*].

The shifting hydrologic patterns noted above are projected to increase water temperatures in both Thurston County's highland and lowland streams during the 21st century. The average annual temperature of most streams within the project area is projected to rise roughly 5°F for the 2040s and 2080s [*Figures 29 & 30, on pgs. 41-42*] per a moderate emissions scenario[18], according to U.S. Forest Service modeling. That figure is similar to the UW CIG assessment's 4°F to 4.5°F estimate for the broader Puget Sound region, per the same scenario and time period.

Temperature is consequential for salmonids. Juveniles that develop in streams (e.g., Chinook, coho and chum salmonids) and ocean-going adults that swim back up streams to spawn [*Figure 26, right*] are vulnerable to temperature changes because they have evolved within certain parameters (Mauger et al., 2015).

Figure 26. A chum salmon swims up McLane Creek, south of Eld Inlet, to spawn in late 2013. ***Source:*** *TRPC*

Several salmon species listed under the endangered species act, including Chinook and coho, spawn in streams amid the project area. To protect these species, Washington State has defined water temperature standards of 16°C (60.8°F) for summer salmon survival and 17.5°C (63.5°F) for spawning, rearing and migrating.

Theoretically, suitable conditions for salmonids and other aquatic species would shift upstream to higher elevations as air and water temperatures warm. Some fish may even shift their migration timing earlier as stream temperature and volume conditions change.

Key challenges remain, however: Some salmonids may have lower migration success because they still must pass through warm areas to reach the cooler habitat. Added to this, projected changes in streamflow and volume may expand the range of pathogens, which could compromise the immunity of stressed fish, as well as an expand the range of warm water-adapted invasive fish that compete with or prey on salmonids (Mauger et al., 2015).

[18] The U.S. Forest Service's NorWeST database models stream temperatures for the 2040s and 2080s using the A1B scenario from a 2007 IPCC report. A1B is similar to the 2013 IPCC report's moderate RCP 6.0 scenario, in which emissions increase gradually until stabilizing during the final decades of the 21st century.

Diversity may provide an important hedge against fish species decline, as sub-populations that are more suited to warmer conditions would theoretically survive and reproduce in greater numbers (Mauger et al., 2015). Another factor critical to the survival of salmon and other organisms during warmer summer months would be the persistence of riparian vegetation and cold-water refugia — such as shade-covered side channels and deep pools — along streams that drain into Puget Sound.

Maintaining or increasing riparian shade cover [*Figure 27, below*] would help mitigate the impacts of climate change amid the Deschutes River and other waterbodies that already struggle with pollution and other development-related stressors.

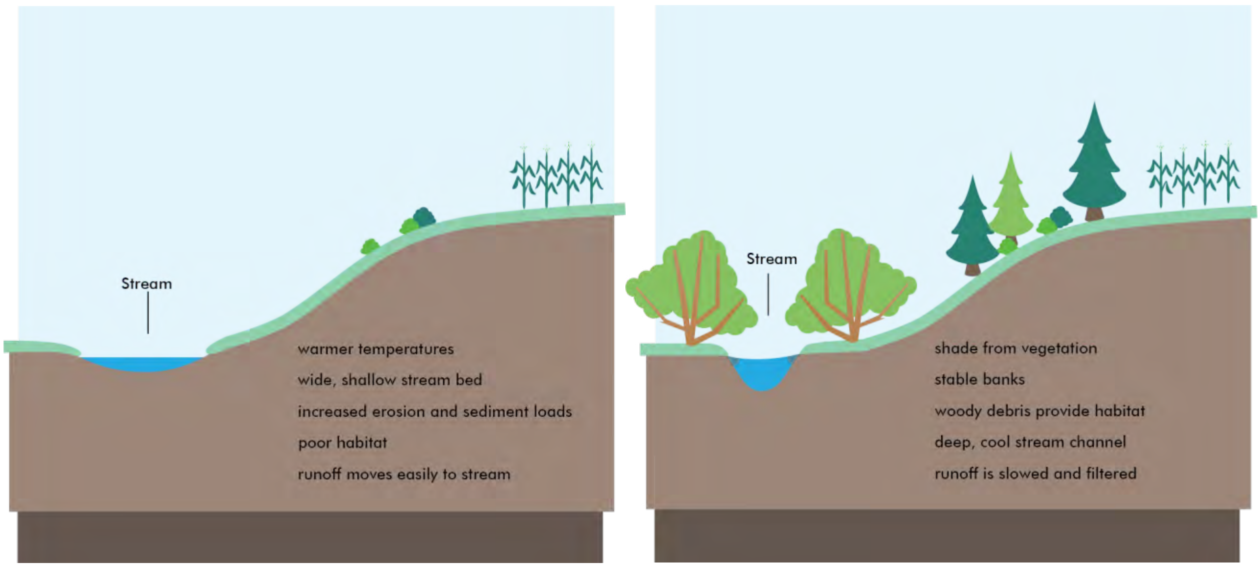


Figure 27. Maintaining or increasing riparian areas decreases stream temperature, runoff, erosion and improves overall habitat for salmon and aquatic species. ***Source:*** *TRPC*

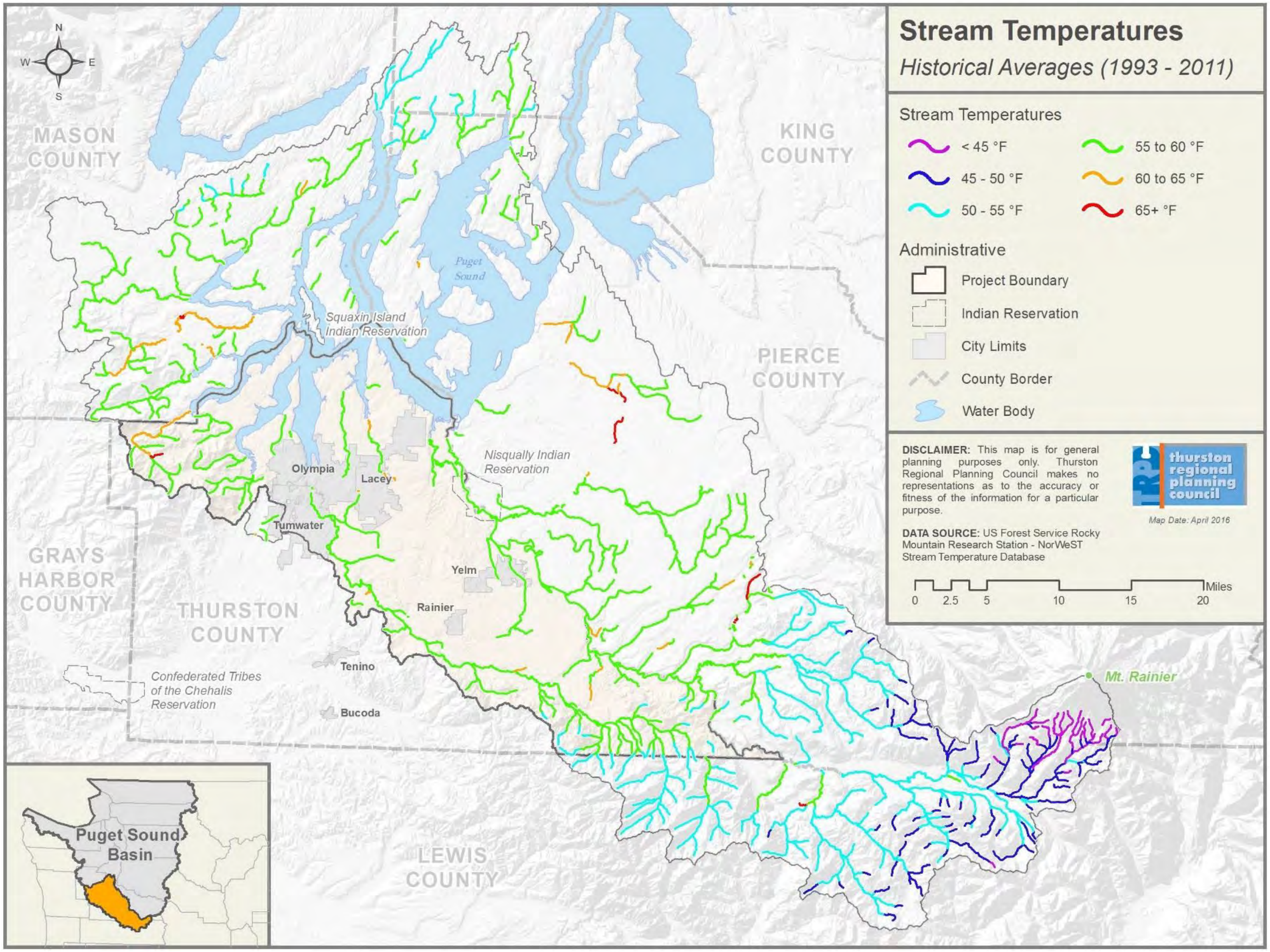


Figure 28: Historical annual average temperature amid South Puget Sound watersheds.

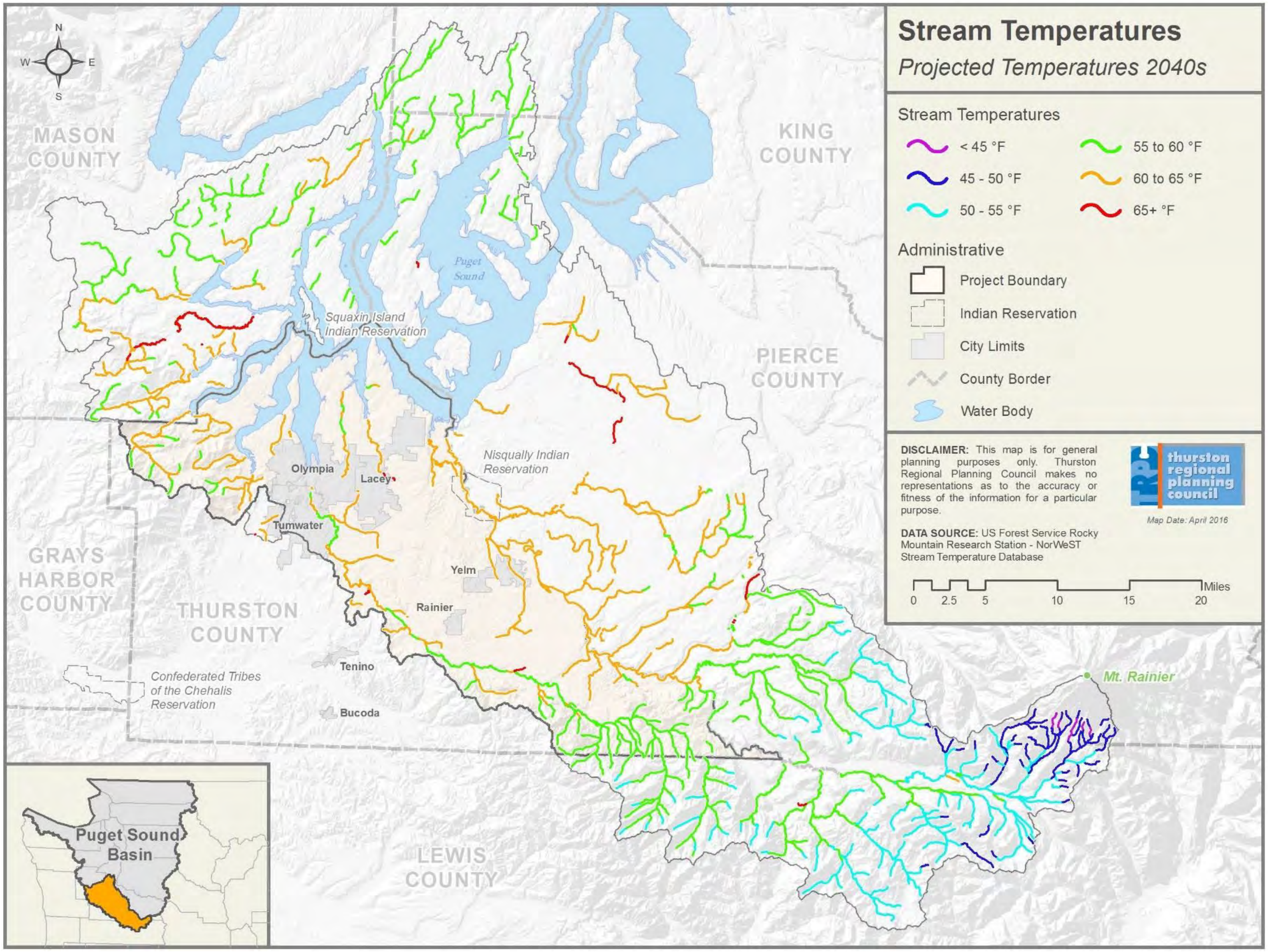


Figure 29: Projected (2040s) annual average temperature amid South Puget Sound watersheds per a moderate emissions scenario.

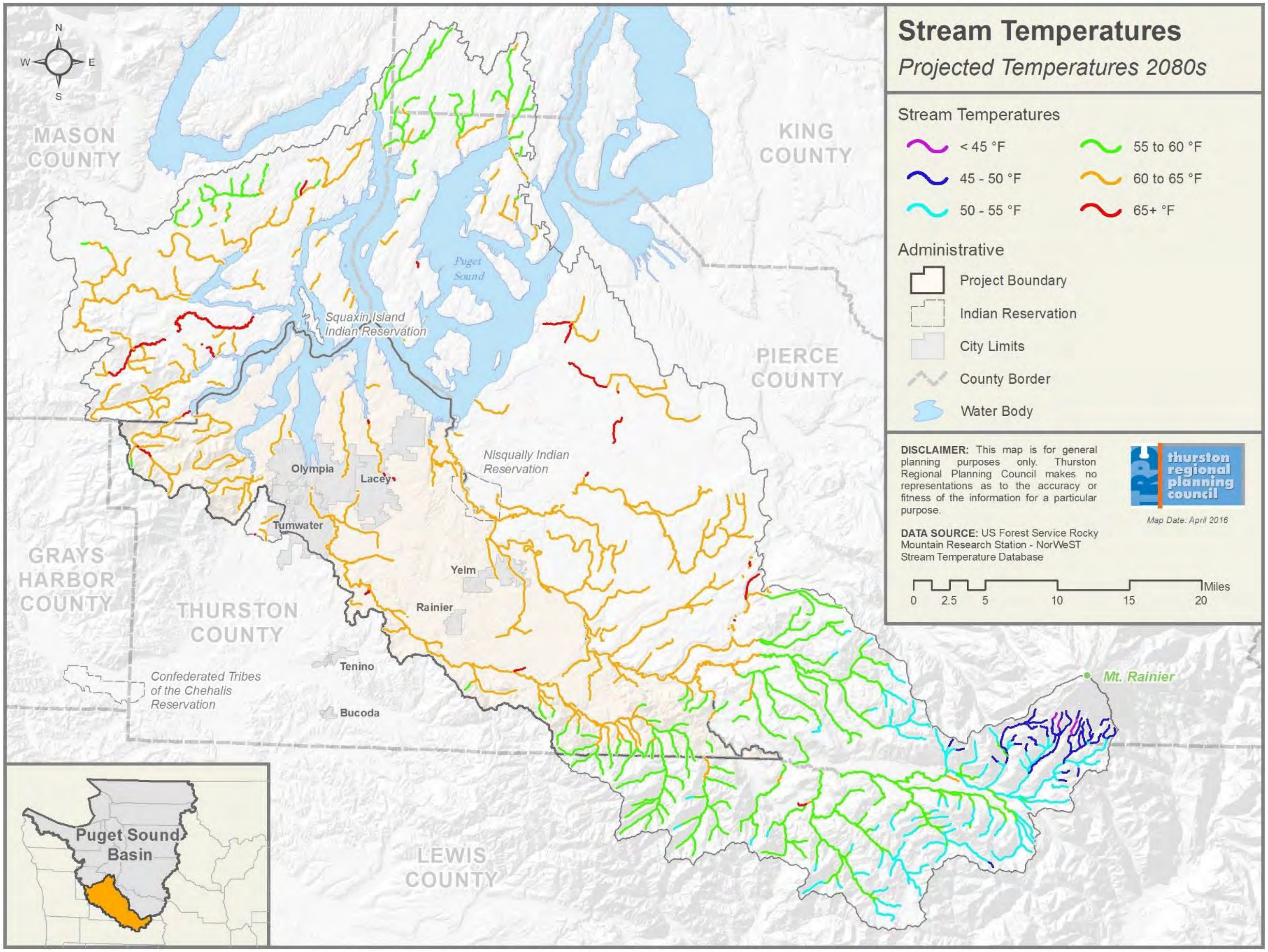


Figure 30: Projected (2080s) annual average temperature amid South Puget Sound watersheds per a moderate emissions scenario.

Water Quality Vulnerability

Shifts in the region's hydrologic cycle this century could complicate local government efforts to comply with state water-quality standards — particularly with regard to lowering water temperature, dissolved oxygen, and sediment loading in streams and other waterbodies.

The federal Clean Water Act requires that Washington develop a Total Maximum Daily Load (TMDL) — the maximum amount of pollutant (e.g., fecal coliform bacteria from human and animal waste) a surface waterbody can receive and still meet water-quality standards — for each waterbody on the state's 303(d) list.[19] The U.S. EPA has approved state implementation plans to address water-quality impairments in all three watersheds (WRIAs 11, 13 and 14) within the Thurston Climate Adaptation Plan's project area [*Figure 31, below*], and the Washington State Department of Ecology conducts monitoring to assess the effectiveness of local efforts to comply with the TMDLs.

TMDLs in Thurston County Watersheds		
Watershed	**Pollutants in Waterbodies**	**Status**
Nisqually Watershed (WRIA 11)	Nisqually River: Dissolved Oxygen; Fecal Coliform	U.S. EPA approved implementation plan
Deschutes Watershed (WRIA 13)	Deschutes River and tributaries: Dissolved Oxygen; Fecal Coliform; pH; Sediment; Temperature	State Department of Ecology submitted implementation plan to U.S. EPA for approval
	Budd Inlet and Capitol Lake: Dissolved Oxygen; Phosphorous	State Department of Ecology developing implementation plan
	Henderson Inlet: Dissolved Oxygen; Fecal Coliform; pH; Temperature	U.S. EPA approved implementation plan
Kennedy-Goldsborough Watershed (WRIA 14)	Totten/Eld Inlets: Fecal Coliform; Temperature	U.S. EPA approved implementation plan
Upper Chehalis Watershed (WRIA 23)[20]	Upper Chehalis River: Fecal Coliform; Temperature; Dissolved Oxygen; Ammonia-N; BOD (5-day)	U.S. EPA approved implementation plan

Figure 31. The table above shows polluted waterbodies within Watershed Resource Inventory Areas (WRIAs) that over lay parts of Thurston County. ***Source:*** *TRPC, adapted from Washington State Department of Ecology table (WDOE, 2016).*

[19] Washington's 303(d) list, named for a section of the federal Clean Water Act, includes lakes, streams and inlets for which drinking, aquatic habitat and other beneficial uses are impaired by pollutants such as fecal coliform and high temperature. Such waterbodies fall short of the state's water-quality standards and are not expected to improve within two years (WDOE, 2016).
[20] The Upper Chehalis Watershed (WRIA 23) covers an area of southwestern Thurston County that drains into the Pacific Ocean and is therefore not include in the Thurston Climate Adaptation Plan project area.

In 2015, Ecology released a draft Water Quality Improvement Report / Implementation Plan for the Deschutes River TMDL area with numeric load allocations for temperature, bacteria, dissolved oxygen, pH, and fine sediment. Thurston County and other partners in the watershed are currently working on ways to address the TMDL.

In terms of improving water temperature, the most important implementation actions are to conserve forested riparian buffers and establish new ones along streams that have become degraded by development (e.g., clearing land for grazing animals or building homes) (Thurston County, 2015). Additional management actions include reducing fecal coliform bacteria during the summer months, stabilizing channels that contribute sediment (e.g., with downed trees), reducing nutrient sources, and quantifying water withdrawals in the watershed.

Figure 32. Trees planted adjacent to the Deschutes River near Rainier will provide multiple ecosystem services as they mature. ***Source:*** *TRPC*

Some of these implementation actions would have climate change adaptation and mitigation co-benefits. For example, trees planted in the riparian zone along streams [*Figure 32, right*] could help reduce erosion associated with more intense winter storms, shade and cool water for fish and amphibians, and sequester carbon dioxide — the main heat-trapping gas that contributes to climate change.

Such on-the-ground projects would not be immune to natural hazards exacerbated by climate change, however. More frequent and intense storm events and associated floods and landslides [*Also see Sections 2.3, 6.2 and 6.3*] could erode shade-providing riparian areas and increase sediment loading in streams.

3.2: Lakes

The shifting hydrologic cycle, compounded by nutrient loading, could make lake conditions more suitable for algal blooms that degrade water quality and pose health risks for humans, fish and animals.

Water Temperature & Quality Vulnerability

Many Thurston County lakes struggle today with algal blooms — a rapid increase in photosynthetic algae and cyanobacteria when water temperatures are warm and nutrients such as nitrogen and phosphorous are present. In Thurston County, common sources of such pollutants include septic systems and fertilizers applied at homes and farms.

Algal blooms can be harmful when they starve a waterbody of sunlight and oxygen [*Figure 33, below*]. Some algae even produce toxins that can poison people and animals that go near the water, consume the water, or swim in the water (CDC, 2016).

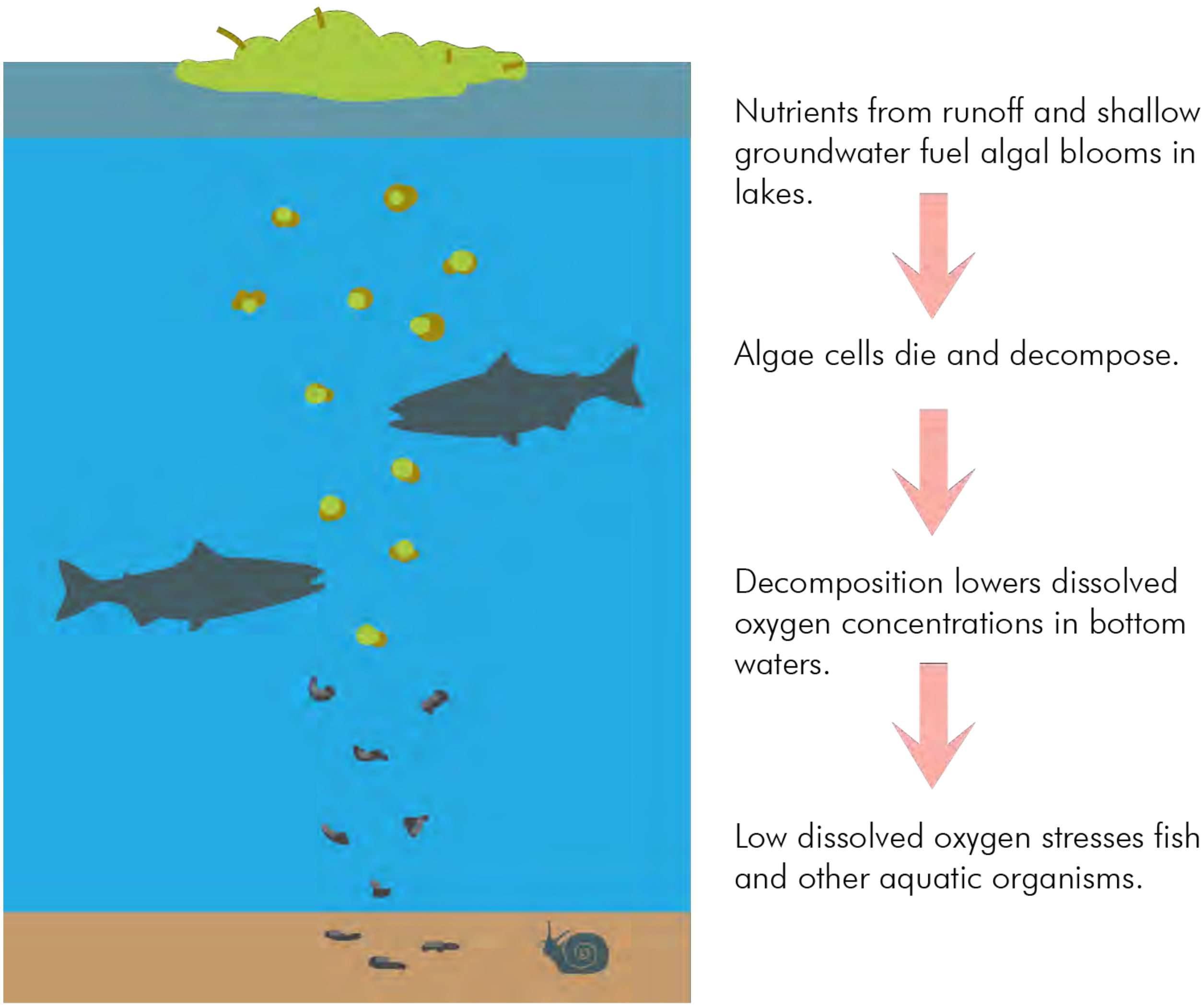


Figure 33: Algal blooms block sunlight and reduce dissolved oxygen essential for fish and other aquatic organisms.
Source: *TRPC*

Warmer surface water may shift earlier in the year lake thermal stratification and the spring plankton bloom, a critical piece of the freshwater food web (Mauger et al., 2015). Higher water temperatures may also support the growth of algae in lakes (WDFW, 2011).

Water temperature strongly influences the growth of cyanobacteria and harmful algal blooms (USGCRP, 2016). Water temperatures of at least 77°F favor cyanobacteria over less-harmful types of algae.

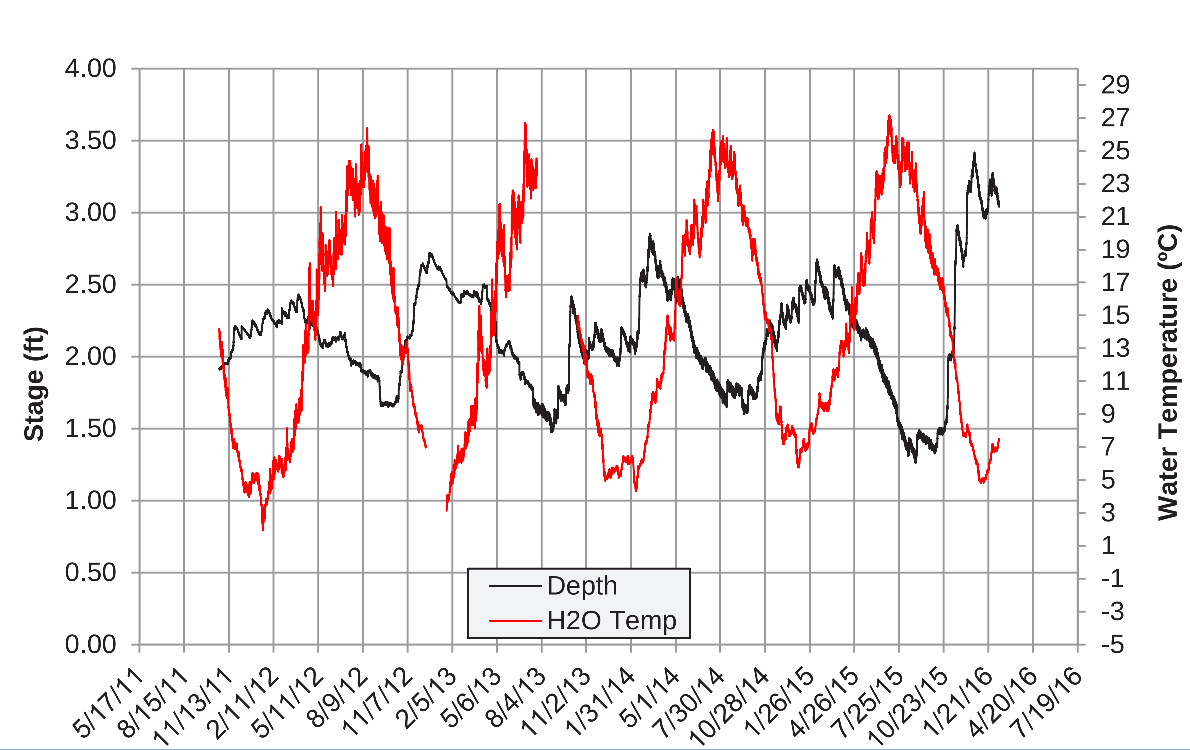
Several lakes within the project area already struggle with this issue. Toxic blue-green algal blooms occurred in 2004 and 2010/11 in Lake Lawrence, which is on Washington State's Clean Water Act Section 303(d) list of impaired water bodies for total phosphorus (Roberts et al., 2012).

Toxic blue-green algal blooms also occurred in Long and Pattison lakes, amid a stretch of unseasonably warm and dry weather last spring, prompting Thurston County to advise people to temporarily avoid the popular swimming, boating and fishing sites [*Figure 34, below*]. Lake water samples taken April 4, 2016, detected the algae toxin *Anatoxin* — which affects the nervous system — at about 20 micrograms per liter (µg/L), well above the state standard of 1 µg/L (Thurston Talk, 2016). The toxin level at Pattison Lake was 21.82 µg/L, and the level at Long Lake was 19.27 µg/L (King County, 2016).

Figure 34: Swimmers enjoy a July 2016 dip in the water at Long Lake Park, a hot spot for summer recreation activities.
Source: *TRPC*

Figure 35 [*on pg. 47*] shows that, historically, Long Lake's water temperature rises as its depth decreases. Given this relationship, the projected increase in summer temperature and decrease in summer precipitation could raise the risk of algal blooms in coming years.

Figure 35. The graph below shows the inverse relationship between the water depth and temperature amid Long Lake, as recorded at Holmes Island, during the October 2011-February 2016 period. ***Source:*** *Thurston County*



3.3: Wetlands

Wetlands — which provide critical habitat for amphibians, waterfowl and other organisms — would also be vulnerable to changes in precipitation volume, sea level, and air and water temperature in the decades ahead.

Thurston County's wetlands [*Figure 36, on pg. 48*] include tidal and non-tidal marshes that are continually or frequently inundated by surface water and/or groundwater. Non-tidal marshes are mostly freshwater wetlands on poorly drained soils or near lakes or streams (EPA, 2016); tidal marshes include freshwater, brackish and saltwater wetlands near the Puget Sound coast.

There have been very minor observed changes (within the margin of error) in wetland extent and type within the project area in the past 20 years. Thurston County was approximately 6.65 percent covered by wetlands in 1996, according to NOAA's Coastal Change Analysis Program (C-CAP) Land Cover Atlas tool, which analyzes general land cover change trends across coastal areas in the United States. By 2010, the figure dropped to approximately 6.63 percent. Of the changes observed, there was a 0.13 percent increase in freshwater (palustrine) wetlands, and a 1.22 percent decrease in saltwater (estuarine) wetlands.

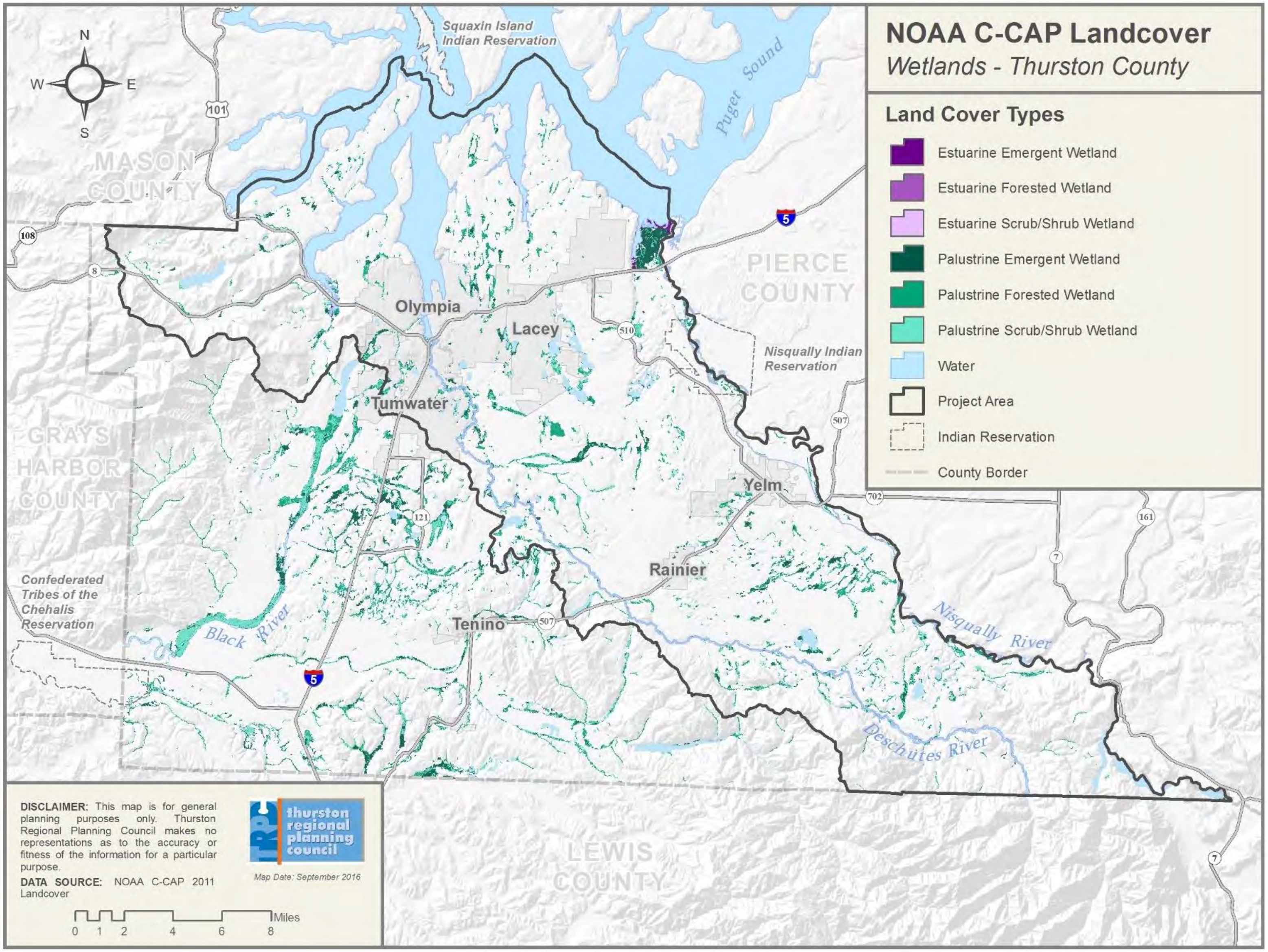


Figure 36: This map shows the current extent of freshwater (palustrine) and saltwater (estuarine) wetlands in Thurston County. ***Source:*** *TRPC, using NOAA C-CAP data*

The projected impacts of sea-level rise on Thurston County's tidal wetlands and other coastal habitat have been studied extensively and are summarized in this assessment's next section, Marine Ecosystems [*See Section 4.1, on pg. 54*]. Non-tidal wetlands farther inland are vulnerable to changes in precipitation and air temperature, which could reduce the amount of water replenishing and cooling wetlands.

If Thurston County's freshwater wetlands decrease in extent, as some models project [*Figure 47, on pg. 64*], frogs and other cold-blooded amphibians would be among species affected most. Some populations may be able to adapt to temperature changes — e.g., shifting in latitude and elevation (Mauger et al., 2015). Other populations will become too warm or dry, resulting in less growth or death.

Thurston is one of five Washington counties with the Oregon spotted frog [*Figure 37, right*], which is listed as threatened under the federal Endangered Species Act (USFWS, 2016). The amphibian prefers large marshes with abundant plants that provide opportunities for basking or taking cover.

In addition to providing frog habitat, local wetlands provide ecosystem services such as water purification, flood protection, shoreline stabilization, groundwater recharge, and streamflow maintenance (WDOE, 2016). Thurston County's nearly 34,000 acres of wetlands provide between $109 million and $3.7 billion in ecosystem service benefits to the region's economy annually (Flores, et al., 2012).

Figure 37: Oregon spotted frog
Source: *Thurston County*

3.4: Groundwater

Bigger winter storms and high groundwater flooding can result in less infiltration into the soil and aquifers, and more runoff into streams and Puget Sound. Summer droughts, in turn, could spur more groundwater pumping when surface water is scarce. Such direct and indirect climate impacts, coupled with sea-level rise, could make Thurston County's coastal freshwater aquifers more vulnerable to water quality and quantity risks. The following section examines the vulnerability of groundwater — the main source of drinking water in Thurston County — to saltwater intrusion and inundation, pathogen and pollution contamination, and drought and overconsumption.

Saltwater Intrusion & Inundation Vulnerability

The boom and bust cycle of precipitation described above could leave coastal freshwater aquifers more vulnerable to the intrusion of denser saltwater from Puget Sound as sea levels rise by an estimated 24 inches this century [*See Section 4.1, on pg. 54*]. Salty water can be unhealthy for people sensitive to sodium (e.g., those with high blood pressure) (Hayes, 2016).

The direct impacts of saltwater intrusion and inundation on groundwater are likely to be greatest in places with low topographic relief and very low hydraulic gradients between freshwater and saltwater (e.g., downtown Olympia, Nisqually Valley, Steamboat Island area) (Pitz, 2016). Increases in near-shore pumping rates when less surface water is available during summer months (an indirect response to climate change) could exacerbate the risk of saltwater intrusion in such places.

Some Thurston County municipalities and tribes have already begun adapting to climate-related threats. In 1995, Olympia applied to the state Department of Ecology to transfer its municipal water rights from McAllister Springs and Abbott Springs to a new McAllister Wellfield upgradient of the springs. Engineers had deemed McAllister Springs — the City's primary drinking water source at the time — susceptible to saltwater intrusion from nearby Puget Sound, as well as vulnerable to hazardous transportation spills and microbial contamination (City of Olympia, 2010).

In 2012, Ecology issued Olympia water rights for McAllister Wellfield, which now serves as the City's primary water source, supplemented seasonally by six Group A[21] water system wells (City of Olympia, 2015). Two of these wells, located at Allison Springs, are the City's only drinking water sources deemed at risk of saltwater intrusion due to their proximity (about 1,000 feet) to Eld Inlet (Buxton, 2016). The City characterizes the near-term risk as "low" and monitors Allison Springs' groundwater regularly, looking for changes in conductivity and chloride concentration that may indicate influence of saltwater.

The Nisqually Indian Tribe eventually intends to draw water from the McAllister Wellfield to meet future demand. Three wellfields (Cuyamaca, Leschi, and Nisqually), on the Nisqually Indian Reservation, meet the Tribe's current needs. Saltwater intrusion is not deemed a risk for these water sources (Cushman, 2016).

The Tribe plays a leadership role in resources management within the Nisqually watershed to protect water quality and quantity in the Nisqually River. The Tribe recently bought out several properties near the river and discontinued production from their shallow, low-producing wells (Cushman, 2016).

The City of Lacey has 20 wells that draw from three aquifers beneath the city and its unincorporated urban growth area. None of the wells is currently deemed vulnerable to saltwater intrusion (Rector, 2016). However, significant sea-level rise, exacerbated by high tide events, could spur seawater to inundate two of the City's shallow (100 feet deep) wells amid the Nisqually Valley, near where Old Pacific Highway crosses the Nisqually River.

Lacey also has three deep (450-550 feet) active production wells in Hawks Prairie that are screened below sea level. The City manages pumping at the wells to avoid causing saltwater intrusion of the underlying aquifer and operates a monitoring network to provide early warning detection.

While Lacey has not seen any indication of saltwater intrusion in this aquifer, a significant change (+1 foot or more) in sea level would likely affect the City's pumping strategies (Rector, 2016). Going forward, Lacey officials contend that the diversity in water supply and ability to pump water between pressure zones — coupled with demand-side strategies such as reducing water consumption — should enable the City's water system to adapt to changes in precipitation patterns and sea levels.

The City of Tumwater's primary water sources are its Palermo Wellfield — immediately west of the Tumwater Valley Municipal Golf Course and Deschutes River — and its Bush Wellfield, located just east of Interstate 5, near Bush Middle School. During the peak summer demand period, five other wells located throughout the incorporated city help meet increased water demand (Tumwater, 2016). All of the wells are comparatively shallow, averaging about 100 feet deep.

Tumwater officials consider sea-level rise a low near-term risk for the City's wells, which are several hundred feet above sea level and several miles south of Budd Inlet (Smith, 2016). However, as part of

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[21] Group A water systems include community water providers with at least 15 residential connections (e.g., the municipal-run water systems in Thurston County); Group B water systems have fewer than 15 residential connections (e.g., small homeowners' associations).

the water systems planning cycle that begins in 2017, the City will begin looking at whether saltwater intrusion could pose a greater risk if sea levels rise and affect the upper Deschutes River (Smith, 2016). The other cities within the project area, Rainier and Yelm, get their water from wells within city limits — far enough away from Puget Sound so as to not be vulnerable to saltwater intrusion or inundation as a result of sea-level rise, according to officials from both cities (Beck, 2016; Van Every, 2016).

Thurston County owns several Group A water systems near the Puget Sound shoreline, including the Tamoshan system, on the low-lying Cooper Point peninsula, and the Boston Harbor system, across Budd Inlet. The County regularly tests the water quality of the community systems' wells — which are more than 500 feet deep — and has detected no signs of saltwater intrusion (Patching, 2016). Even so, as part of a nascent drought-planning effort, County staff members have begun to consider the long-term risks of drinking water contamination associated with climate change.

The Thurston Public Utility District (PUD) also runs several Group A water systems with wells close to Puget Sound. The PUD owns the Lew's 81st well, near Boston Harbor, and tests it regularly for chloride, as required by the State. The PUD has detected no signs of saltwater intrusion (Gubbe, 2016).

The PUD does not conduct such tests for the other Group A water systems it manages near Puget Sound — including Beverly Beach, on Cooper Point; Edgewater and Olympic View, near Steamboat Island; and, Dana Passage, north of Boston Harbor (Gubbe, 2016). The PUD, which provides water to about 3,500 homes, businesses and schools, has not conducted a formal assessment of how climate change could affect its water systems, but the issue has generated interest among the PUD's elected commissioners.

The issue has also generated interest at the state level, and additional guidance to water system managers is coming. The Washington Department of Health's (DOH) Source Water Assessment Program (SWAP) assesses the vulnerability of roughly 6,800 water sources (wells, springs, surface water) operated by about 4,100 Group A water systems across the state. The DOH program looks for potential sources of contaminants, such as oil and chemicals from commercial and industrial sites, but doesn't currently assess the risks of saltwater intrusion or changes in precipitation. The agency acknowledges the risk of saltwater intrusion into the source waters of community water systems near Puget Sound, so in coming years DOH will encourage such system operators to evaluate their vulnerability and consider how they would respond to risks (Hayes, 2016).

Pathogen & Pollution Vulnerability

Prolonged drought, or even reduced seasonal streamflow, can make contaminants more concentrated in wells — the source of drinking water for many rural and urban Thurston County residents. Conversely, extreme rain events and runoff can overwhelm wastewater, septic and stormwater conveyance systems and cause problems such as sewer overflows, basement backups and localized flooding (USGCRP, 2016).

Contamination occurs when microbial pathogens (e.g., bacteria from animal and human waste) and nutrients (e.g., nitrogen and phosphorous from fertilizers) are carried from farms, ranches, suburban neighborhoods, and urban centers into surface and groundwater [*Figure 38, on pg. 52*]. Stormwater is already the leading contributor of pollution of Washington's urban waterways, and such runoff endangers sensitive species and habitats (Adelsman & Ekrem, 2012).

Concentrated contaminants are not a risk for municipal water systems that draw water from deep wells and purify it. However, private water systems that rely on shallow wells (less than 50-100 feet deep) —

especially those at risk for saltwater intrusion or those with low productivity — are likely to be more vulnerable to contamination during drought conditions (Mauger et al., 2015).

Small community or private groundwater wells or other drinking water systems where water is untreated or minimally treated are also highly susceptible to water-borne disease outbreaks in the wake of extreme precipitation events (USGCRP, 2016). For example, increased rainfall and peak streamflow during the winter months could make conditions more suitable for water-borne parasites that cause Cryptosporidiosis, a diarrheal disease that occurs when humans ingest the cysts of *Cryptosporidum parvum* or *Cryptosporidum hominis* (Mauger et al., 2015).

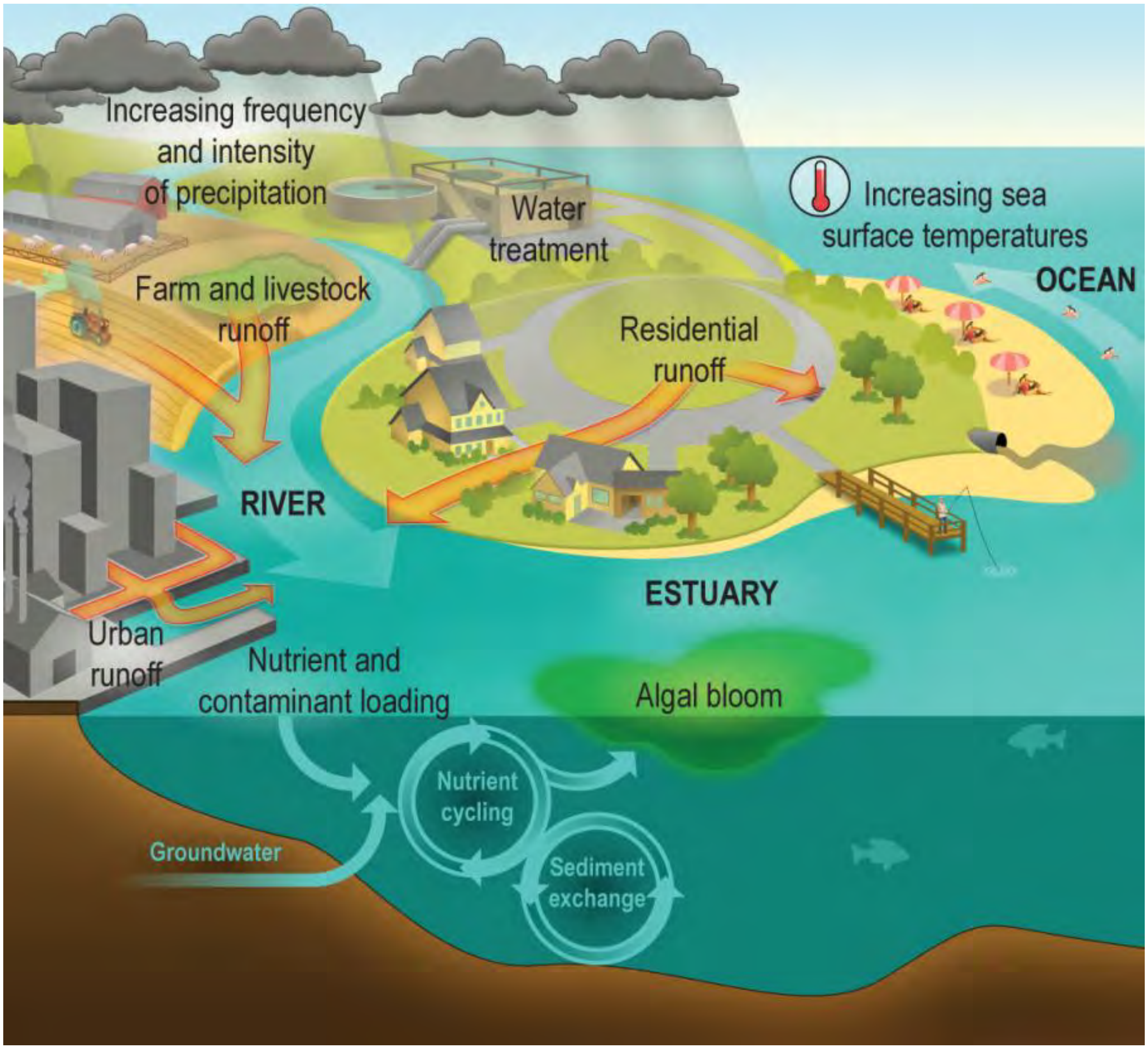

Figure 38: Precipitation and temperature changes affect fresh and marine water quantity and quality primarily through urban, rural, and agricultural runoff, which affects human exposure to water-related illnesses primarily through contamination of drinking water, recreational water, and fish and shellfish. ***Source:*** *USGCRP, 2016*

Water Quantity Vulnerability

As noted in the previous section, a future with warmer, drier summers could spur growing communities around the state to increase their groundwater withdrawals when surface water is limited (Pitz, 2016). This could exacerbate water quantity and affordability vulnerabilities.

Water quantity (supply-and-demand) vulnerability will likely to be highest in snow-influenced watersheds with existing conflicts over water resources (e.g., fully allocated watersheds with little management flexibility) (Snover et al, 2013). Vulnerability will be lowest where hydrologic change is smallest (i.e., existing rain-dominant watersheds), where there are simple institutional arrangements, and where current water demand rarely exceeds supply.

As noted previously in this assessment [*See Section 3.1, on pg. 32*], the Nisqually Watershed is projected to shift this century from a mixed rain-and-snow watershed (i.e., a watershed that receives 10-40 percent of its precipitation as snow) to a rain-dominant watershed (i.e., a watershed that gets less than 10 percent of its precipitation as snow); the Deschutes and Kennedy-Goldsborough watersheds will remain rain-dominant systems.

Studies conducted in Everett, Tacoma and Seattle and noted in UW CIG's 2015 assessment find that the reliability of municipal water supplies — that is, the probability of meeting demand in a given year — is largely unaffected by projected changes precipitation (Mauger et al., 2015). The report did not reference any Thurston County communities.

Communities and homes that rely on wells for water could see their costs rise if seasonal overconsumption lowers groundwater levels and forces wells to pump from greater depths (Pitz, 2016). A potential risk is that such a decrease in groundwater levels, coupled with an increase in energy prices, could make pumping from wells too expensive for some users. Another potential risk is there could be less water available to support new development.

4: Marine Ecosystems

Increasing greenhouse emissions and rising air temperatures over the 21st century are projected to affect the world's marine ecosystems in significant ways, from increasing ocean temperatures and acidity to melting ice sheets and raising sea levels. Such changes would impact both estuaries and residential and urban development along Thurston County's Puget Sound coastline. The following section explains how changes in the ocean's volume, acidity and temperature are expected to affect the Puget Sound region's built and natural environments.

…

4.1: Sea-Level Rise

Throughout the 21st century, the Puget Sound region is expected to experience continued, and possibly accelerated, sea-level rise as a result of melting ice sheets and warmer oceans. This may result in permanent inundation of some low-lying areas, and increased frequency, depth, and duration of coastal flooding due to increased reach of tides and storm surges (Mauger et al., 2015). Sea-level rise may also exacerbate river flooding by slowing the ability of water to drain into Puget Sound, as well as degrade drinking water sources [*See Section 3.4, on pg. 51*].

Globally, average sea level rose about 8 inches — roughly the same level recorded at the Seattle tidal gauge — during the 20th century (Mauger et al., 2015). The Puget Sound region's sea level is projected to rise another 24 inches (range: +4 to +56 inches) by the end of this century, relative to 2000 (NRC, 2012).[22] Levels could be higher or lower than this range, however, depending on the rate that the local coastline is sinking or rising due to geologic factors and the rate that polar ice is melting. The analysis below examines how built and natural assets are vulnerable to coastal flooding and erosion associated with sea-level rise.

Coastal Infrastructure Vulnerability

Most Thurston County shorelines are stable. However, Olympia City Hall in downtown is subsiding by about 2.5 millimeters (0.9 inch) per decade (Pacific Northwest Geodetic Array, 2016). Thus, City of Olympia engineers estimate that sea-level rise could be 11 inches greater amid low-lying downtown — much of which is built atop fill — than the surrounding shoreline areas (Christensen, 2016).

The City of Olympia established a policy in 2010 to protect downtown from flooding resulting from high runoff combined with a high tide [*Figure 39, right*] that inundates the gravity-fed stormwater drainage system. Downtown Olympia generally experiences nuisance

Figure 39. A March 2016 king tide event inundated downtown Olympia's Percival Landing and Sylvester Street. Sea-level rise is expected to raise the risk of coastal flooding associated with such high-tide events. ***Source:*** *TRPC*

[22] The National Research Council (NRC) projections noted in this assessment are based on global climate models and extrapolations of historical trends, as well as account for rapid changes in the behavior of ice sheets and glaciers that have been observed recently.

flooding[23] just once or twice a year — sometimes more during periodic El Niño events — but the risk rises with the sea [*Figure 41, on pg. 56*] (Christensen, 2016):

- With 1 foot of sea-level rise, Olympia could expect nuisance flooding 30 times annually, affecting approximately 261 structures and inundating up to 163 acres;
- With 2 feet of sea-level rise, Olympia could expect nuisance flooding 160 times annually; affecting approximately 328 structures and inundating up to 252 acres;
- With 4 feet of sea-level rise, Olympia could expect nuisance flooding 440 times annually or during more than half of its high-tide events, affecting approximately 402 structures and inundating up to 368 acres.

Downtown Olympia's importance to the region cannot be understated. The densely built area is the home of dozens of businesses, the Port of Olympia marine terminal, Olympia City Hall, LOTT Budd Inlet Treatment Plant, and other important facilities. Fortunately, most of the area's shoreline is owned by or under the control of local or state government agencies [*Figure 40, below*].

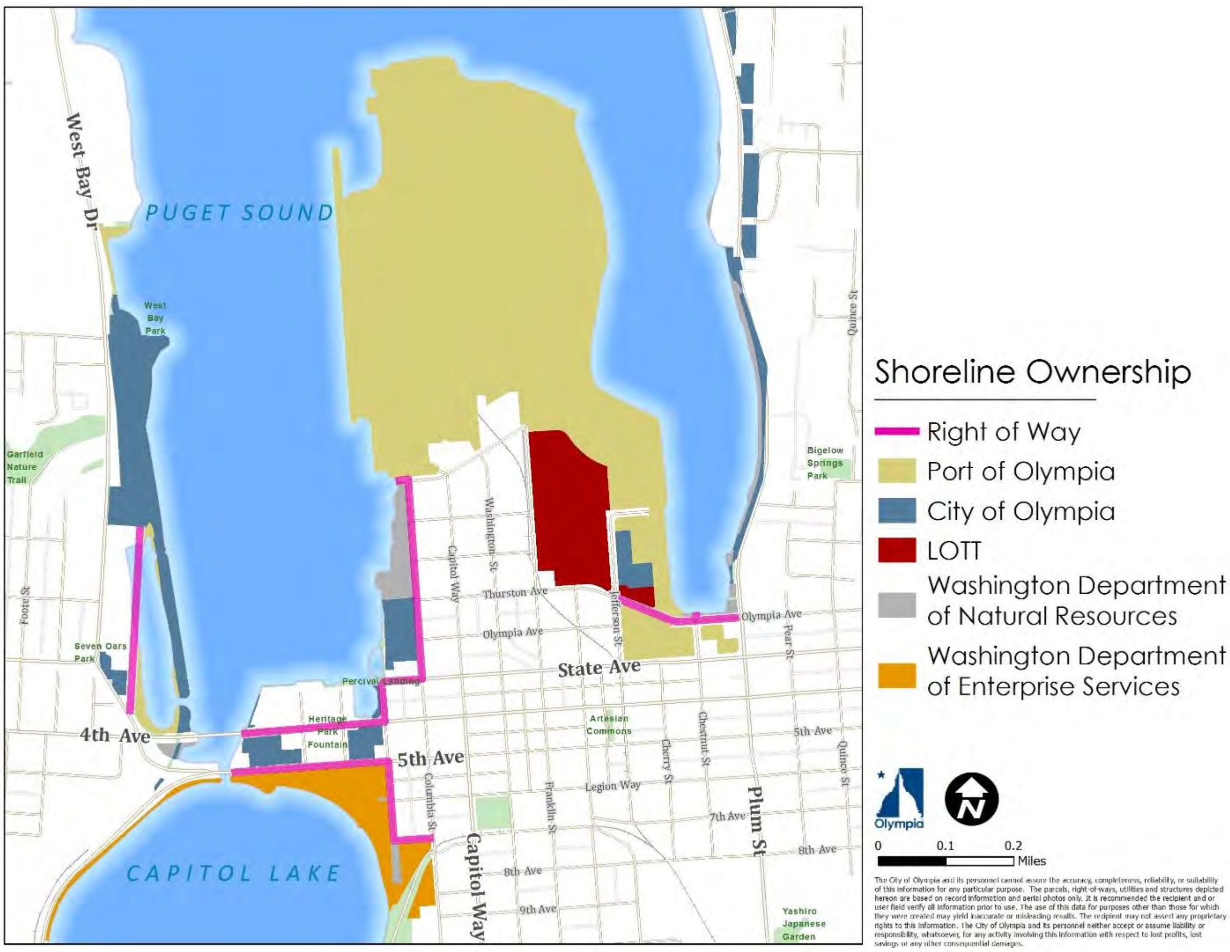

Figure 40. Most of downtown Olympia's shoreline is public ownership, which could simplify future efforts to adapt to sea-level rise. ***Source:*** *City of Olympia*

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[23] Nuisance flooding events are tides in excess of 17 feet mean lower low water (MLLW) — the average height of the lowest tide recorded at a tide station each day during a recording period. Generally, this is when downtown Olympia streets flood.

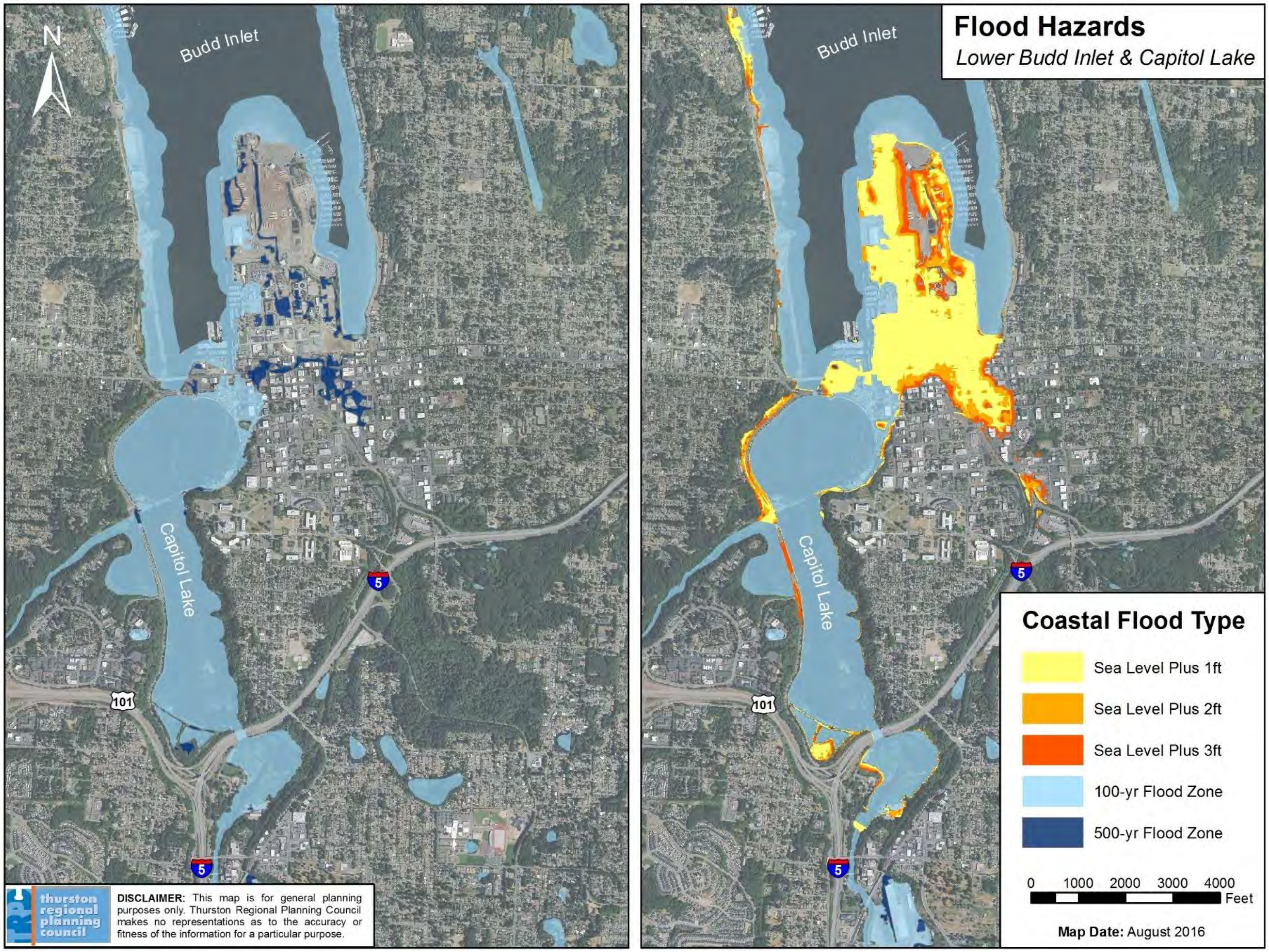

Figure 41: These maps show the extent of 100- and 500-year flood events coupled with 1-3 feet of sea-level rise throughout lower Budd Inlet and the Capitol Lake complex. ***Source:*** *Federal Emergency Management Agency (FEMA) preliminary 2016 flood data*

In addition to potentially disrupting commerce and damaging billions of dollars in public and private property, flooding amid the greater downtown Olympia area could pose temporary safety risks (e.g., inhibiting the movement of emergency service vehicles), as well as long-term health risks (e.g., mobilizing toxic chemicals amid former industrial sites and inundating sewer lines and treatment facilities). To prepare for and cope with such risks, the City will begin work in 2017 on a sea-level rise management plan and funding strategy with assistance from partners including the State of Washington, Port of Olympia, and LOTT Clean Water Alliance (Hoey, 2016).

City staff are considering a wide range of strategies (City of Olympia, 2016), including some that were identified in a 2011 technical report (Simpson, 2011).

- Require that the finished floors of new buildings accommodate 1 foot of sea level rise
- Install flood gates on stormwater outfalls that are connected to Budd Inlet and Capitol Lake and susceptible to backflow flooding; eventually, consolidate drainage systems and install pumping stations to get Moxlie Creek and stormwater runoff out of downtown
- Build barriers (e.g. floodwalls) around critical facilities and along shorelines
- Regrade low-elevation areas (e.g., Heritage Park east of Capitol Lake and Percival Landing east of Columbia Avenue)
- Elevate roadways

The LOTT Clean Water Alliance also hired a consultant to evaluate the vulnerability of its Budd Inlet Treatment Plant — a critical facility that handles wastewater from almost 90,000 residential, commercial and industrial customers served by the sewer utilities of Lacey, Olympia, and Tumwater. The 2014 assessment, prepared by the consultant firm Brown and Caldwell, used five scenarios that incorporated UW CIG sea-level rise projections — including combinations of sea-level rise, 100-year tidal flooding, and storm surge flooding — so as to identify inundation areas and high-level vulnerabilities at the treatment plant.

Under the three higher scenarios, critical infrastructure, including the effluent pump station, main utilidors (underground access tunnels), and a Puget Sound Energy substation, would be inundated (Polda & Brown and Caldwell, 2014). In the two most extreme scenarios, the headworks building, administration building, multiple substations, and backup generators would also be inundated.

Any failure of these core services would likely shut down key sections of the plant, resulting in potential backup. If shutdown or failure of the core infrastructure were to occur, flow would back up through the collection system and exacerbate flooding throughout the sewer system, downtown Olympia, and possibly areas farther upstream (Polda & Brown and Caldwell, 2014).

The assessment recommended a variety of adaptation actions, most of which focus on raising electrical distribution panels above the projected high-water line, and preparing methods to seal off critical areas from water in the event of a flood.

Low-lying sections of Interstate 5 and U.S. Route 101 also could be vulnerable to the combined effects of flooding and sea-level rise in the future [*Figure 42, on pg. 58*]. These highways are critical to ensuring that commercial trucks, commuter cars, emergency service vehicles and other automobiles are able to move within and through the Thurston County region.

McAllister Creek occasionally floods I-5 on- and off-ramps south of the Nisqually National Wildlife Refuge (area of Milepost 114), and this would be made worse by sea-level rise, according to a recent Washington Department of Transportation vulnerability assessment of transportation infrastructure

(WSDOT, 2011). The embankment atop which I-5 sits was never evaluated for open water at its toe. The levee removal at the Nisqually delta and the rising sea level means that the toe of the slope is now exposed to potential wave action (Maurer, 2016).

Similarly, along U.S. Route 101, as it crosses Mud Bay west of Olympia, water currently backs up in culverts and floods the highway's median during high tides. There is the potential for water to flood travel lanes temporarily due to sea-level rise (WSDOT, 2011).

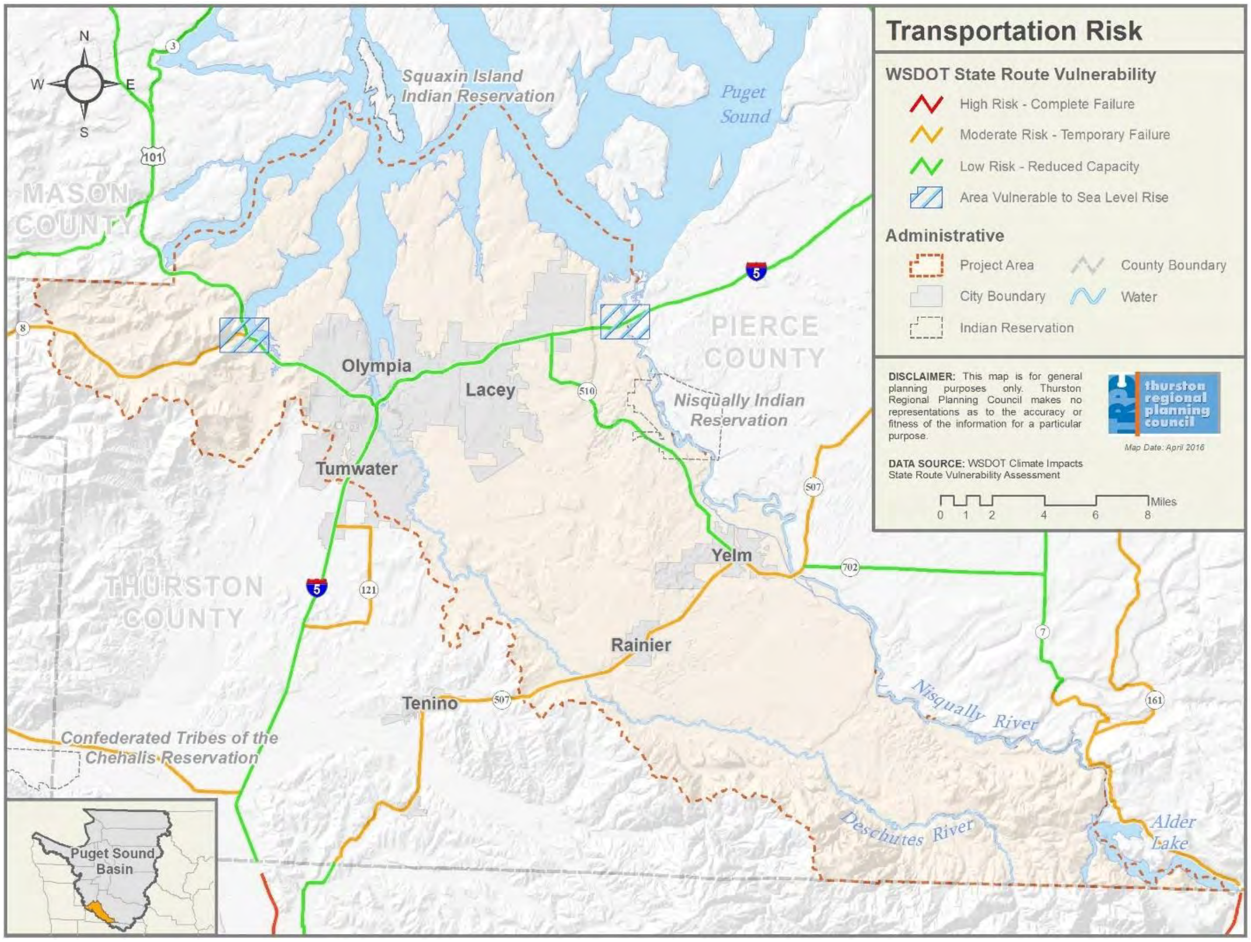

Figure 42. The map above shows sections of U.S. Route 101 and Interstate 5 that are currently vulnerable to coastal flooding, which could be exacerbated by rising sea levels. ***Source:*** *TRPC, adapted from WSDOT map*

The following maps [*Figures 43-46, on pgs., 59-62*] use preliminary Federal Emergency Management Agency (FEMA) data to show the projected reach of 100- and 500-year coastal flood events[24] compounded by sea-level rise of 1-3 feet (12-36 inches). As the draft maps show, some homes and commercial buildings near low-lying coastal areas such as the Nisqually Estuary, Henderson Inlet and Mud Bay would be vulnerable to sea-level rise.

[24] The 100-year floodplain includes lands subject to a 1% chance of flooding in a given year. The 500-year floodplain includes lands subject to a 0.2% chance of flooding in a given year.

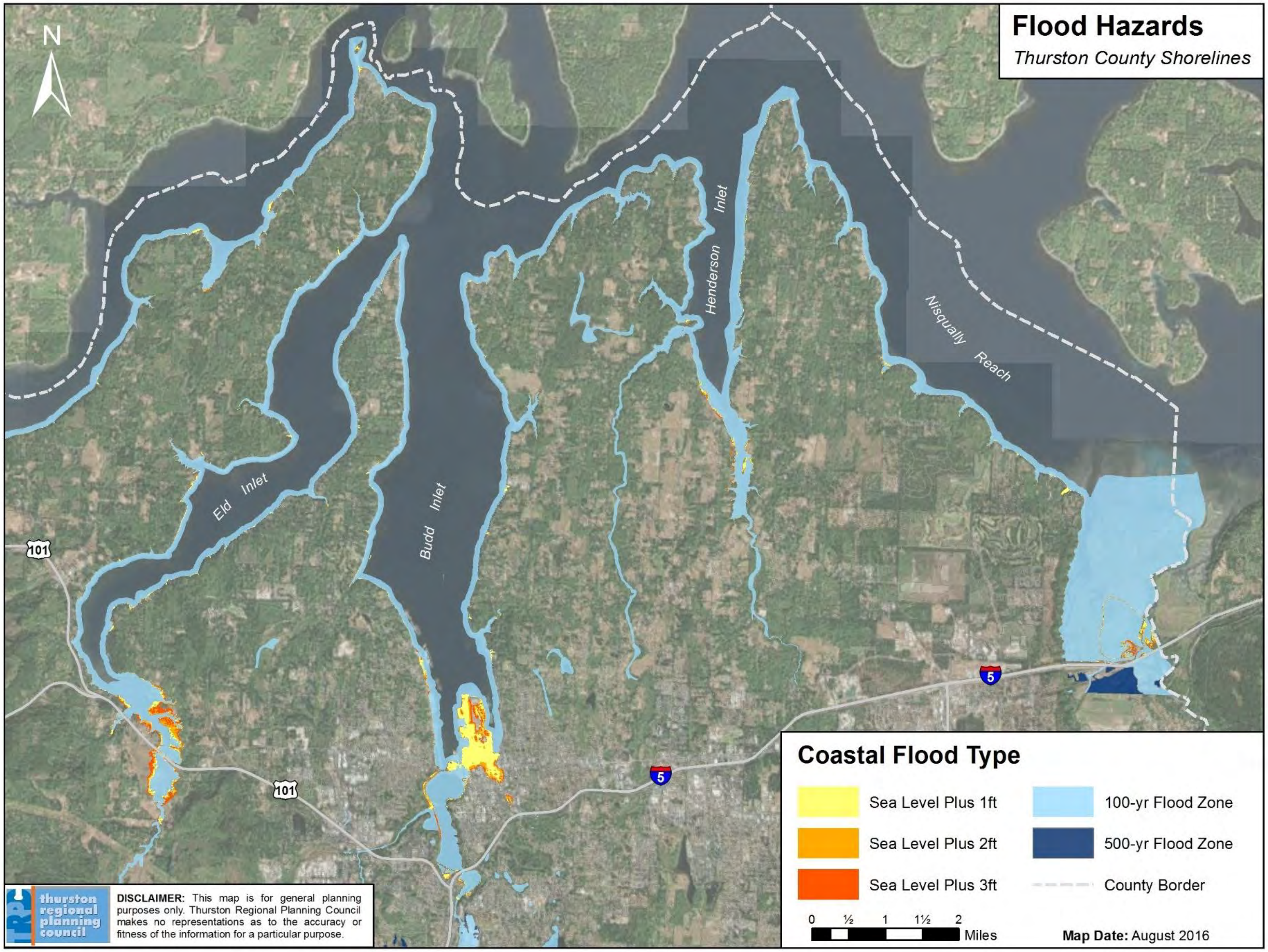

Figure 43: This map shows the extent of 100- and 500-year flood events, coupled with 1-3 feet of sea-level rise, throughout north Thurston County. ***Source:*** *Federal Emergency Management Agency (FEMA) preliminary 2016 flood data*

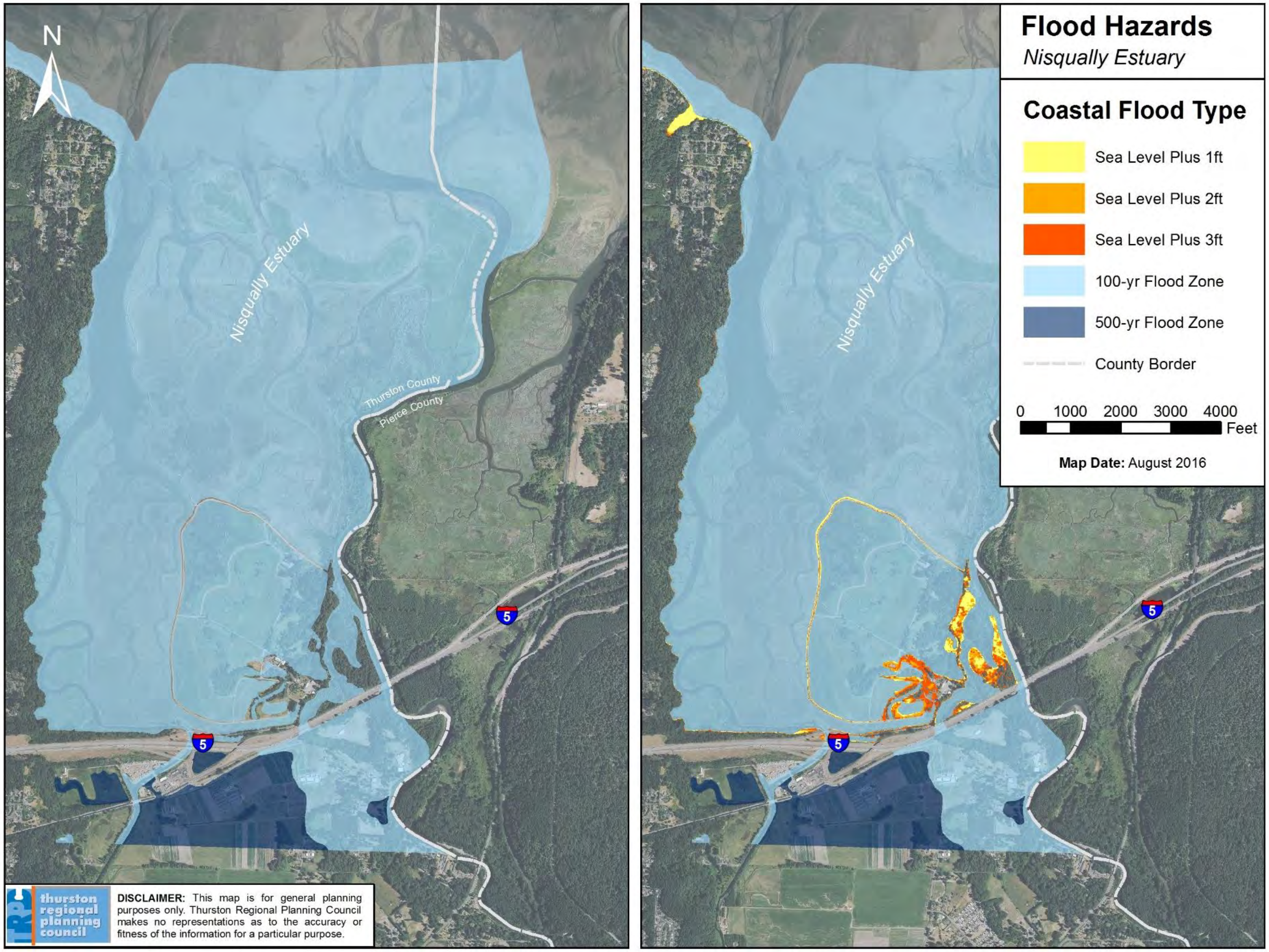

Figure 44: These maps show the extent of 100- and 500-year flood events, coupled with 1-3 feet of sea-level rise, throughout the Nisqually Estuary. ***Note:*** *Data shown only for Thurston County.* ***Source:*** *Federal Emergency Management Agency (FEMA) preliminary 2016 flood data*

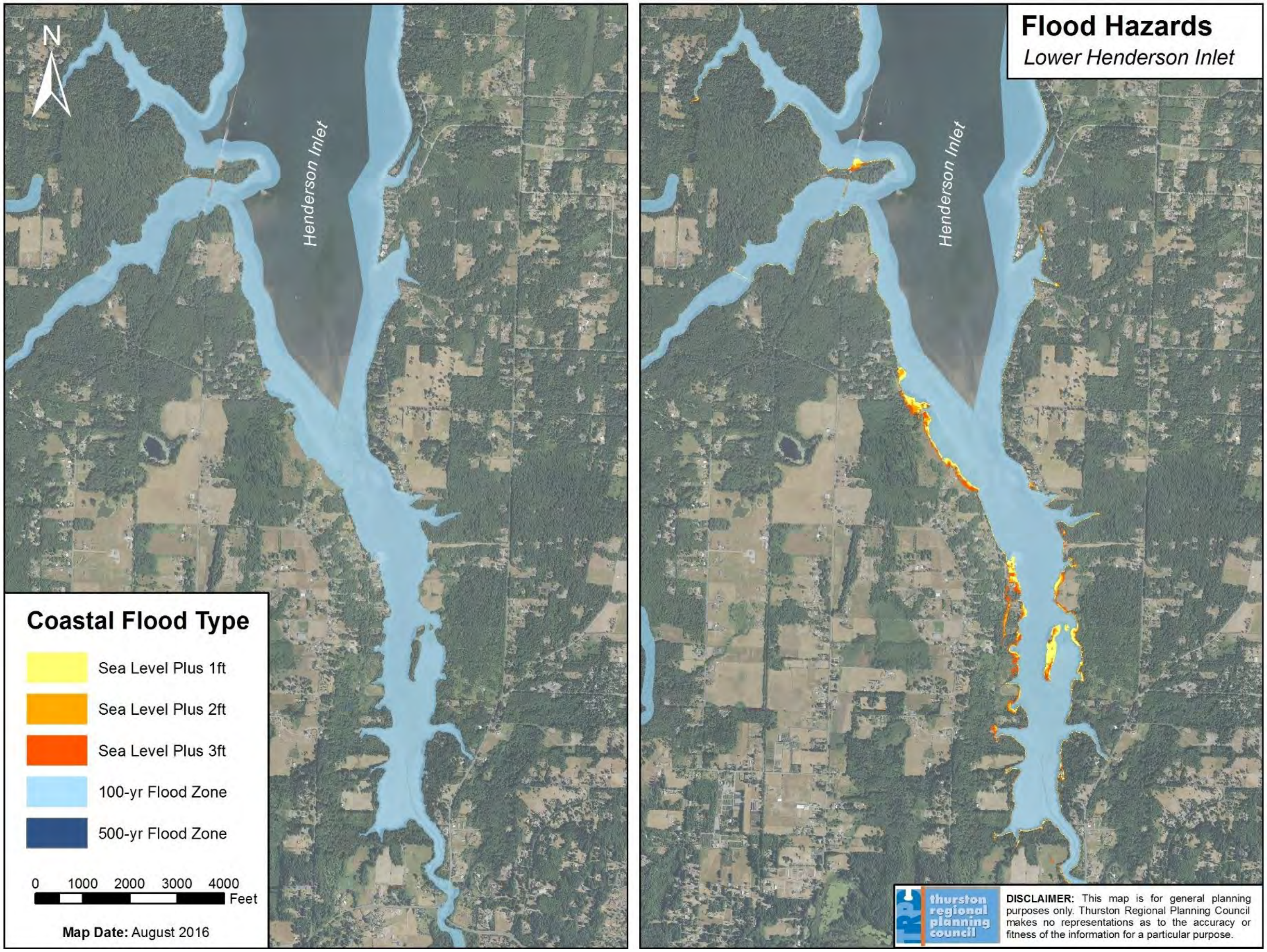

Figure 45: These maps show the extent of 100- and 500-year flood events, coupled with 1-3 feet of sea-level rise, throughout lower Henderson Inlet. ***Source:*** *Federal Emergency Management Agency (FEMA) preliminary 2016 flood data*

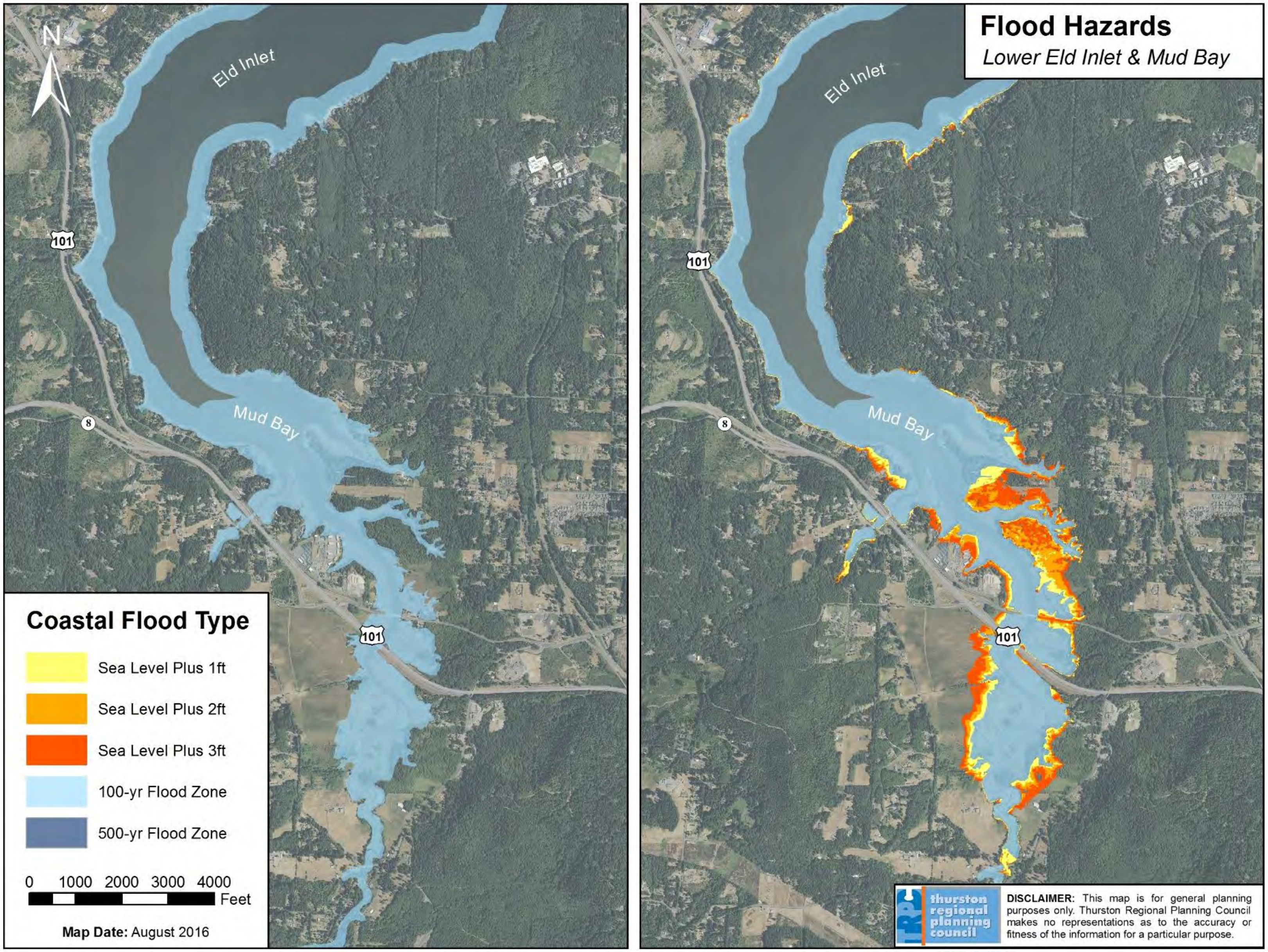

Figure 46: These maps show the extent of 100- and 500-year flood events, coupled with 1-3 feet of sea-level rise, throughout lower Eld Inlet and Mud Bay.
Source: *TRPC, using preliminary FEMA flood hazard data as of August 2016*

Increased exposure to water and wave energy as a result of sea-level rise is expected to erode unprotected coastal bluffs, which may have both detrimental and beneficial impacts: Coastal bluff erosion may threaten nearby buildings and occupants, yet this naturally occurring process also may contribute sand and gravel that would allow for down-drift shores to become higher and move landward, thereby maintaining the beach profile (Johannessen and MacLennan, 2007).

More than a quarter of Puget Sound's shoreline is armored with rock revetments, seawalls and other materials (PSP, 2016) that are built to protect homes, roads and other infrastructure. Such barriers do not guarantee that the land behind them is invulnerable to the sea's growing reach, however.

Seawalls and revetments are usually designed for a particular set of conditions. If rising sea levels continue to magnify the effects of high tides and waves, the original freeboard will be exceeded by seawater gradually and overtopping will become more frequent (NRC, 2012). This would increase the probability of structural damage.

Coastal Species Vulnerability

Increased erosion and inundation associated with sea-level rise is expected to affect the type and extent of coastal habitat (Mauger et al., 2015). This could be most acute in areas that are low-lying, with highly erodible soils, and where inland migration is hindered by bluffs for infrastructure (e.g., roads).

A 2007 National Wildlife Federation study used a model[25] to project the effects of sea-level rise on 11 Pacific Coast and Puget Sound sites — including north Thurston County, from the Nisqually Reach to the Cooper Point peninsula (NWF, 2007). Figure 47 [*below*] shows projected changes in marsh habitat amid the Thurston County study area — which included northern Olympia and Lacey, unincorporated peninsulas north of the cities and Puget Sound shorelines.

North Thurston County

Habitat Type	Baseline	Projected Change	
	2007 *(Initial Conditions)*	2100 *(+27" of sea level)*	2100 *(+59" of sea level)*
Inland Freshwater Marsh	1,614 acres	-154 acres (-10%)	-208 acres (-13%)
Tidal Freshwater Marsh	47 acres	+2 acres (+4%)	+2 acres (+4%)
Brackish Marsh	672 acres	-69 acres (-10%)	-101 acres (-15%)
Saltwater Marsh	133 acres	+574 acres (+432%)	+670 acres (+504%)

Figure 47: Projected change in north Thurston County tidal and non-tidal marsh (wetland) habitat in 2100 as a result of sea-level rise. ***Source:*** *TRPC, adapted from NWF, 2007*

A more recent study by U.S. Geological Survey and Oregon State University researchers evaluated elevation, vegetation, mineral and organic matter buildup (accretion), and water level and salinity characteristics at 60 acres of the Nisqually Estuary and eight other sites along the Oregon and Washington coasts in order to model differences in tidal marsh vulnerability to sea-level rise (Thorne, Dugger, & Takekawa, 2015). Under the "mid" sea-level rise scenario used in the study (about 25 inches by 2100), the Nisqually Estuary would lose all of its high-marsh habitat and most of its mid-marsh

[25] The NWF study's Sea Level Affecting Marshes model (SLAMM 5.0) used a projected a 27-inch and 59-inch rise in global sea level by 2100, relative to 1980-1999, per the A1B maximum greenhouse gas scenario. The AIB scenario is similar to the RCP 6.0 scenario — described as "moderate" in the UW CIG's 2015 assessment — in which greenhouse gas emissions increase gradually until stabilizing during the final decades of this century.

habitat by the end of the century. Under the "high" sea-level rise scenario (about 56 inches), however, sea-level rise would drown all of the estuary's marsh habitats and turn them into mudflats [*Figure 48, below*].

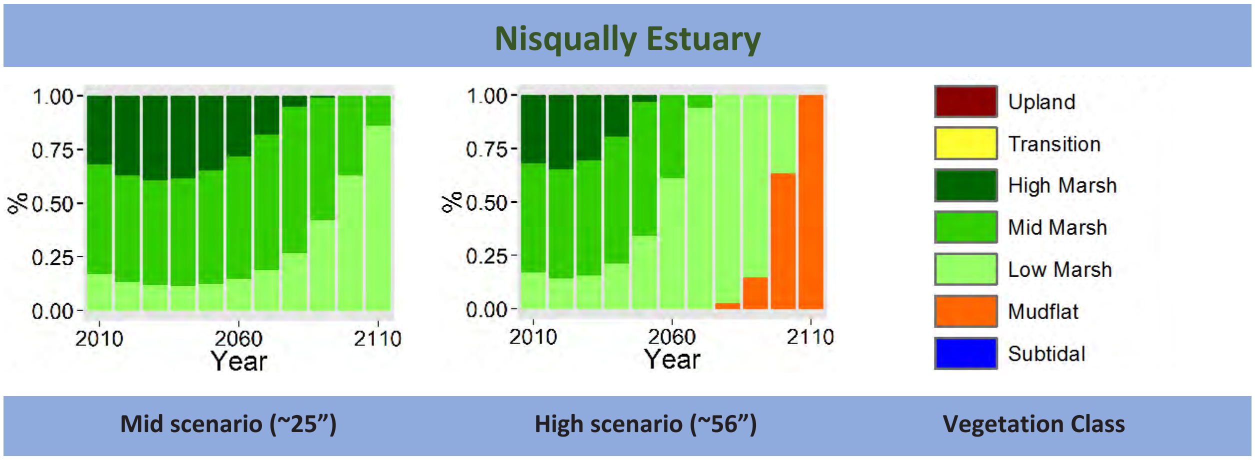

Figure 48: The figure above shows the projected percent change in vegetation class amid the Nisqually Estuary per mid and high emissions scenarios. ***Source:*** *TRPC, adapted data from USGS, 2015*

Such changes could have negative effects on birds, amphibians, and other wildlife that use less frequently inundated tidal marsh [*Figure 49, below*] for cover, foraging and nesting (Thorne, Dugger, & Takekawa, 2015). Conversely, the changes could increase habitat for marine algae, estuarine fish, and shellfish.

The Billy Frank Jr. Nisqually National Wildlife Refuge at the mouth of the river is rich in biodiversity today, attracting more than 200 species birds (and many more bird-watchers) throughout the year. Otters, clams, crabs, salmon and many other land and sea creatures also live amid the refuge's seven distinct habitats, which include riparian forest, coniferous forest, river, seasonal freshwater wetlands, permanent freshwater wetlands, estuary and open saltwater (USFWS, 2016).

Figure 49. The Nisqually delta (*pictured*) was restored in 2009 by removing dikes and reconnecting 762 acres of former farmland with Puget Sound's saltwater tides. This was the largest estuary restoration project in the Pacific Northwest (USFWS, 2016). ***Source:*** *TRPC*

The climatic ranges of more than 100 bird species across Washington are projected to decline by 50 percent or more (relative to 1971-2000) by the 2080s (Mauger et al, 2015). Such "climate-sensitive" bird species include the bald eagle and western grebe (Langham et al., 2015), which are found in the Nisqually Estuary and the broader Puget Sound region.

The persistence of tidal marshes along Puget Sound and other parts of the Pacific Northwest coast will depend largely on future sediment supply and marsh productivity (Thorne, Dugger, & Takekawa, 2015). A local barrier not noted in the report is Tacoma Power's hydroelectric dam complex at Alder Lake, which limits the movement of sediment down the Nisqually River and accretion at the Nisqually Estuary [*Also see Section 3.1, on pg. 36*]. Interstate-5 provides yet another barrier, which could limit the estuary's ability to migrate upstream as the sea level rises.

4.2: Ocean Acidification & Pollution

Ocean acidification occurs when seawater absorbs atmospheric carbon dioxide — the main greenhouse gas — causing chemical reactions that reduce the water's pH (a measure of acidity ranging from 0-14) (NOAA, 2016). As the seawater acidity increases, it becomes harder for clams, oysters, crabs and other calcifying marine organisms to make and maintain shells.

Ocean acidification is projected to increase the frequency, magnitude and duration of harmful pH conditions throughout Puget Sound (Mauger et al, 2016), which could affect the entire food web. For example, a decline in the population of plankton would reduce food available for salmon, resulting in lower growth rates in seawater with higher acidity. Fewer salmon would reduce the food available for both predatory marine mammals (e.g., resident orca whales and seals) and humans. Perhaps the biggest casualty would be water-filtering shellfish — which hold significant cultural, environmental and economic value in the region.

For centuries, Squaxin, Nisqually and other tribal peoples have harvested shellfish, including the Olympia oyster [*Figure 50, right*], for subsistence and trade. Shellfish continue to be a major income source for tribal and non-tribal communities: Washington leads the nation in production of farmed clams, oysters and mussels, and shellfish growers directly and indirectly employ more than 3,200 people and contribute $270 million to state economy (State of Washington, 2011).

Figure 50: The Olympia oyster, *Ostrea lurida*, is a native edible oyster of Puget Sound that has been harvested by generations of coastal residents. ***Source:*** *Wikimedia Commons.*

Today, fecal material, nutrients and other polluted runoff from land-based sources (e.g., farms, septic tanks, stormwater, wastewater) limit recreational and commercial shellfish growing and harvesting along many parts of the South Puget Sound shoreline [*Figure 51, on pg. 66*].

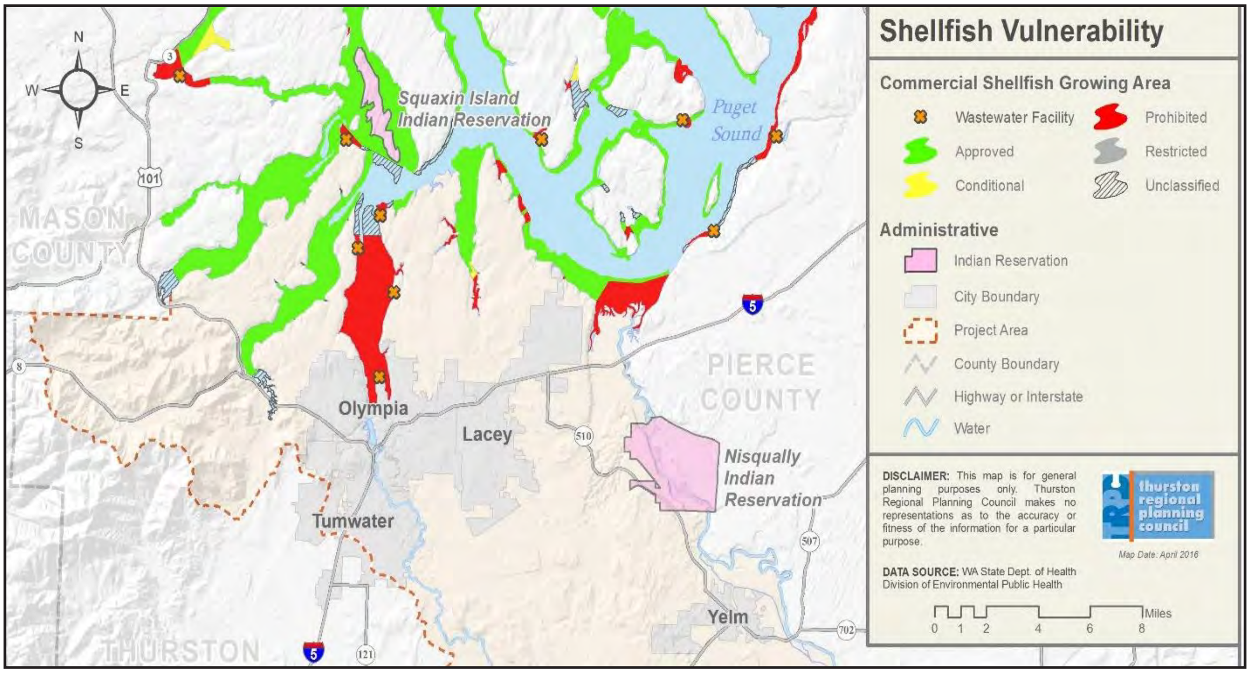

Figure 51: The Washington State Department of Health keeps a statewide database on commercial and recreational shellfish growing areas, including their overall health risk and proximity to wastewater treatment plants. The map above shows the current status of the commercial shellfish growing area within South Puget Sound. ***Source:*** *TRPC, adapted from DOH map*

Combined, changes in ocean temperature, chemistry and pollution could exacerbate risks to marine creatures and those that consume them.

For example, greater inflows of warmer freshwater — which holds less oxygen — raises the risk of marine water stratification and hypoxia and can alter the timing of spring plankton blooms that support the food web, including salmon and other economically important fish (Mauger et al., 2015). Warmer waters are also projected to increase the spread of *Vibrio parahaemolyticus* and *Vibrio vulnificus*, bacteria strains that can cause illness in people who eat raw or undercooked shellfish — specifically oysters [*See Figure 66, on pgs. 85-86*].

Precipitation will be the primary climate driver affecting the flow of enteric viruses from sewage (e.g., noroviruses and hepatitis A) to shellfish areas in coming decades (USGCRP, 2016). Heavy rainfall events could increase the load of such contaminants, organic matter (e.g., plant debris that releases CO2 as it decomposes) into South Puget Sound, increasing the persistence of enteric bacteria and viruses and contributing to acidification.

Rising air and sea temperatures are also projected to increase the magnitude and frequency of harmful algal blooms, often called “red tides,” in marine waters (Mauger et al., 2015).

Warming is projected to increase the Puget Sound seasonal window of growth for red tide-causing *Alexandrium* toxic organisms by about 30 days by 2040, enabling algal blooms to start earlier in the year and last longer (USGCRP, 2016) [*Also see Figure 66, on pgs. 85-86*]. People who swim in Puget Sound or eat fish and shellfish from its waters — particularly, children, older adults, pregnant women and immunocompromised individuals — face the highest health risks (USGCRP, 2016) [*Also See Section 6.4, on pg. 86*].

5: Terrestrial Ecosystems

The following section examines how climate change is likely to impact the Puget Sound region's terrestrial ecosystems — the land and the species that live upon it. The first half of the section looks at climate change impacts on farms and ranches, including economically important agricultural crops and livestock (e.g., berries and dairy cows); the second half of the section looks at climate change impacts on forests and prairies, including economically and environmentally important trees (e.g., Douglas fir and Garry oak). As noted previously, climate change impacts on humans are noted throughout this assessment and summarized in Section 6 — Human Health & Welfare.

…

5.1: Farms & Ranches

Puget Sound's agricultural sector is expected to be relatively resilient to climate change (warmer, wetter winters and hotter, drier summers), and some crops may even benefit from a longer growing season and more atmospheric carbon dioxide (Mauger et al., 2015). However, climate change-exacerbated drought and flood events, as well as invasive pests and plants, will still pose risks for local farms and ranches.

Drought & Flood Vulnerability

Drier summers would exacerbate temperature-driven declines in summer water availability (Mauger et al., 2015). Periodic drought is an issue that already affects the state and region — particularly the agricultural and industrial sectors — and adaptation is already taking place to protect the economy and environment.

The Department of Ecology, for example, provides emergency water permits, financial assistance and temporary transfer of water rights during a state-declared drought emergency, such as during 2015, when water supplies were below 75 percent of normal (WSU, 2016). The state agency also provides grants and loans for emergency water supply projects in declared drought areas to help irrigated crops and fisheries survive (TRPC, 2009).

Sustained periods of low or no precipitation could cause crops to wither and soil to blow away, causing economic losses and air-quality threats (e.g., PM_{10} in airborne dust) (CARB, 2009). Further, scarcer surface water could force farmers and ranchers to rely more heavily on groundwater for irrigating agricultural crops and watering livestock (Adelsman & Ekrem, 2012). As noted previously, however, consuming more groundwater during dry periods could exacerbate the risks of saltwater intrusion of coastal water supplies [*Also Section 3.4, on pg. 49*].

Conversely, heavy rain events (in any season), coupled with sea-level rise, could reduce the ability of drainage ditches and other infrastructure to handle flood events in near-coastal agricultural lands (Mauger et al., 2015). An analysis evaluating the expected annual damages from Skagit River flooding puts the estimate at roughly $1.5 million annually, with more than $86 million of farm property defined as at-risk within the Skagit River Basin (Mauger et al., 2015). Such figures provide useful context for calculating potential flood damage costs (e.g., lost or damaged agricultural crops, equipment and buildings) amid the Thurston Region's near-coastal farmlands, such those near Mud Bay and the Nisqually Estuary.

Crop & Livestock Vulnerability

Thurston County has more than 1,300 farms, spread across more than 75,000 acres, according to the U.S. Department of Agriculture's most recent census (USDA, 2012). The county's top crops, as measured in annual sales, are: nursery plants, greenhouse plants, floriculture and sod grasses ($43 million); poultry and eggs ($22 million); milk from cows ($22 million); and, aquaculture ($18 million).

Changes in precipitation and air temperature — as well as atmospheric carbon dioxide (CO_2) levels — are expected to influence which crops Puget Sound region farmers cultivate in the decades ahead. For example, emitting more carbon dioxide into the atmosphere may result in increased biomass productivity of some crops, such as beans and grasses (Korner et al., 2007). Assuming sufficient water is available during the growing season, the benefits of this process, known as "CO_2 fertilization," could outweigh the negative effects of warming temperatures (Mauger et al., 2015).

Increased CO_2, however, is also projected to reduce the nutritional quality of forage and pasture lands for livestock and wild animals, the largest of which (e.g., dairy cows and horses) would be more vulnerable to heat stress or flooding as a result of seasonal warming temperatures (Mauger et al., 2015). Such stressors could also benefit thistle and other invasive plant species and allow them to outcompete native grasses and crops (Dalton et al., 2013). Forage land used for hay, grass silage and greenchop is by far Thurston County's top-acreage crop — almost 16,000 acres (USDA, 2012).

Among other agricultural crops that have been studied specifically, berries, tree fruit, and tubers could experience a production decline due to climate change stressors — most notably, drought [*Figure 52, right*] (Mauger et al., 2015). Conversely, some types of wine grapes could thrive under the region's increasingly warm climate (Sorte et al., 2013).

Figure 52: Blueberries wilt in Thurston County's summer heat. Increasingly warmer and drier summers amid the region could cause a decline in berries and other agricultural crops in the decades ahead. ***Source:*** *TRPC*

A key cause of changes in crop vigor is that the frost-free season has been lengthening across the Puget Sound region. Added to that, the number of "growing degree days," which measures heat accumulation in plants[26], is projected to increase throughout the project area — especially in lower-elevation areas [*Figure 53, on pg. 69]*.

Too much warmth at lower elevations could be problematic for vintners, however, by eliminating the microclimate necessary for premium wine production. Growers could be forced to choose between producing lower-quality grapes or starting over with a grape that is better suited for warmer, lower-elevation conditions (Dalton et al., 2013). In addition to such direct effects on grape vines, climate may also impact grapes by affecting their pests and pathogens.

[26] Grapevine development is influenced strongly by air temperature, so average heat accumulation is often used to compare regions and vine-growing condition (WSU, 2016). Average heat accumulation is often referred to as Growing Degree Days (GDD), which is calculated by subtracting 50 from the average daily temperature (°F). If the resulting value is less than 0, then it is set to 0. Thus, daily GDD units are always positive.

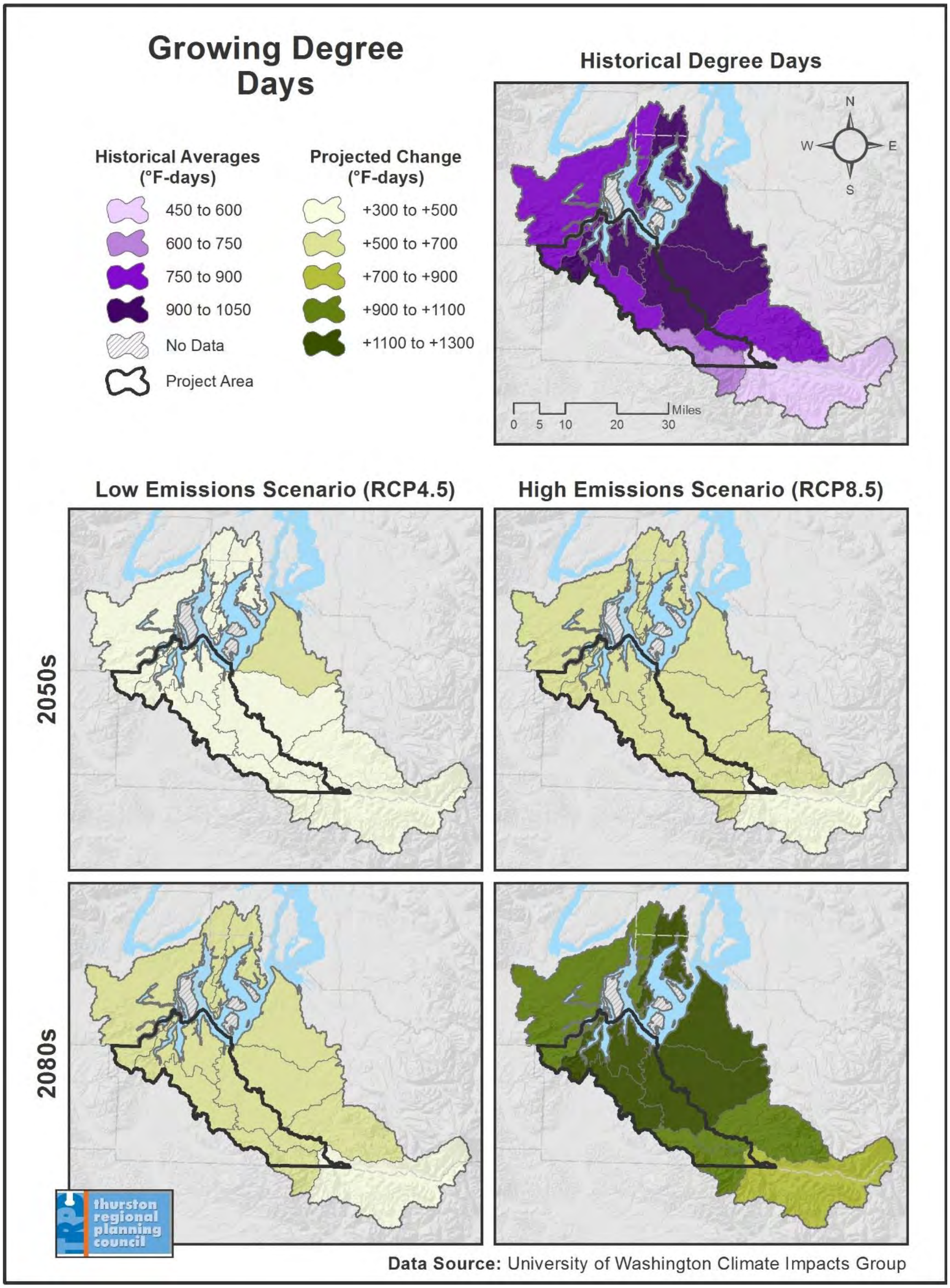

Figure 53: Projected changes in Growing Degree Days, which measures heat accumulation in plants, amid South Puget Sound watersheds. ***Source:*** *Adapted from Figure 3b in Appendix B of Mauger et al., 2015.*

Among the factors that will help the broader Puget Sound region adapt to climate change in the decades ahead are its diversity of crops, temperate climate (compared to Eastern Washington), and access to urban markets (Mauger et al., 2015). Within Thurston County specifically, other beneficial factors include comparatively small farms with more intensive agricultural practices (Kinney, 2016); the average farm size in the county is 57 acres (USDA, 2012).

Water will be a factor limiting agricultural productivity for the reasons explained above, but shifting crop irrigation practices could help local farmers adapt in the decades ahead (Mauger et al., 2015). Other limiting factors include the costs of transitioning to new agricultural practices and crops, as well as the availability of subsidies and conservation programs that may discourage such changes.

5.2: Forests & Prairies

As a whole, there will likely be continued changes in forest growth, productivity and range, greater risks of wildfire, and changes in the prevalence and location of disease, insects and invasive species (Mauger et al., 2015). The following section looks at how such changes are expected to affect lowland forest and prairie areas, Thurston County's dominant terrestrial ecosystems.

Prairie Species Vulnerability

Prairies amid South Puget Sound lowlands range from open savanna-type landscapes with flowers such as the Golden Paintbrush, White-topped Aster and Rose Checker-Mallow (CNLM, 2016) to scattered woodlands that include Garry oak [*Figure 54, right*], Douglas-fir, Oregon ash, bigleaf maple, and Pacific madrone trees (WDFW, 2011). Within Thurston County, prairies and other open areas provide important habitat for the following federal Endangered Species Act-listed wildlife: Mazama pocket gopher, Taylor's checkerspot butterfly and Streaked horned lark (Thurston County, 2016).

Figure 54: A grove of Garry oak near McAllister Creek, east of Lacey. ***Source:*** *TRPC*

Prairie ecosystems, which historically covered 10 percent of the landscape in the South Puget Sound lowlands, have been reduced by 90 percent during the past 150 years, due largely to settlement activities such as land fragmentation, construction and agriculture (WDFW, 2011). Such ecosystems have also been degraded by invasive species such as Scotch Broom, which forms dense stands and crowds out native vegetation.

Climate change is expected to result in further shifts in the composition of prairie ecosystems. For example, warmer, wetter winters may lead to an increase in the area of wetland prairies on poorly drained soils (Bachelet et al., 2011), such as the glacial till and clay common amid South Puget Sound. Climate change, as well as stressors such as invasive species and land fragmentation, will also affect the extent of Garry oak woodlands. One study, which assessed the potential impacts of climate change on the distribution Garry oak in British Columbia, Washington and Oregon, concluded that climate suitability in areas that currently support the oak will decline in coming decades (Bodtker, 2009).

The shifts in seasonal temperature and precipitation noted above may also lead to shifts in timing of flowering (phenology) and the abundance of insect pollinators amid prairies (WDFW, 2011). This, in turn, could lead to the decline of some species of flowering plants if bees and other pollinators are absent during times of peak flowering (Halofsky et al, 2011).

Thurston County's more than 25,000 acres of prairie — including oak groves and grasslands — provide $12 million-$19 million in ecosystem service benefits to the economy annually (Flores, et al., 2012).

Forests with other deciduous trees and conifers — totaling about 236,000 acres in Thurston County — provide between $448 million and $1.9 billion annually in such benefits, including erosion control, climate regulation and pollination.

Forest Species Vulnerability

More than half of Washington's 43 million acres are classified as forestlands (WDOE, 2006), which provide economic activities (e.g., revenue from timber production, hiking and camping) and ecosystem services (e.g., wildlife habitat, carbon storage). Douglas-fir, western hemlock and other softwood tree species constitute about 73 percent of the live-wood volume (about 95 billion net cubic feet of wood volume total) on these forestlands, which are presently a net sink for CO_2 (Campbell et al., 2010); hardwood species such as alder, maple, and oak constitute 7 percent of the live-tree volume. Such species are found in Thurston County, which contains the state-managed Capital State Forest in the northwest and privately-owned working forests in the southeast [*Figure 56, on pg. 72*].

Climate change is expected to impact such forestlands directly (e.g., by affecting tree growth and extent) and indirectly (e.g., through pest and fire damage). Hotter, drier summers will likely decrease the extent of suitable habitat for Douglas-fir trees, especially amid the southern Olympic Peninsula and South Puget Sound lowlands. Models project the range of Douglas-fir — one of the most commercially important tree species west of the Cascade Range — may decline by as much as 32 percent in Washington by the 2060s, relative to 1961-1990, per a medium emissions scenario (Snover et al., 2013). Conversely, western hemlock, white bark pine, and western red cedar may expand in range.

Increased water stress associated with such hotter, drier summers may in turn lead to higher tree mortality (in forests and landscaped urban areas) and more intense fires [*See Section 6.1, on pg. 73*] (Greene & Thaler, 2014). These disturbances may be compounded by more pest and disease outbreaks (Dalton et al., 2013).

Armillaria root disease, which affects conifers and hardwoods in the region, will likely have more impact due to stress induced by hotter and drier summers. Swiss needle cast, a disease caused by *Phaeocryptopus gaeumannii,* has also been associated with such temperature and precipitation changes [*Figure 55, right*]. The foliar pathogen is projected to have more capacity to affect Douglas-fir (Dalton et al., 2013).

Figure 55: Swiss needle cast, which causes Douglas-fir tree crowns to look yellow–brown in spring, now affects trees in Oregon, Washington and British Columbia. ***Source:*** *Shaw et al., 2014*

Mountain pine beetles, a significant natural disturbance in the area today, may experience a long-term decline in extent at lower elevations as air temperatures rise. However, short-term trends indicate that both lower and higher elevations are becoming more suitable for the beetles (Greene & Thaler, 2014).

Such direct and indirect climate change impacts may increase the region's volume of organic waste, as well as offset any potential economic benefits from timber yield increases associated with higher temperatures and CO2 concentrations (Dalton et al., 2013). The UW CIG assessment (Mauger et al., 2015) underscores, however, that more research is needed to determine specifically how invasive and non-native species currently within the Puget Sound region will respond to climate change, and which new species may emerge as invasive.

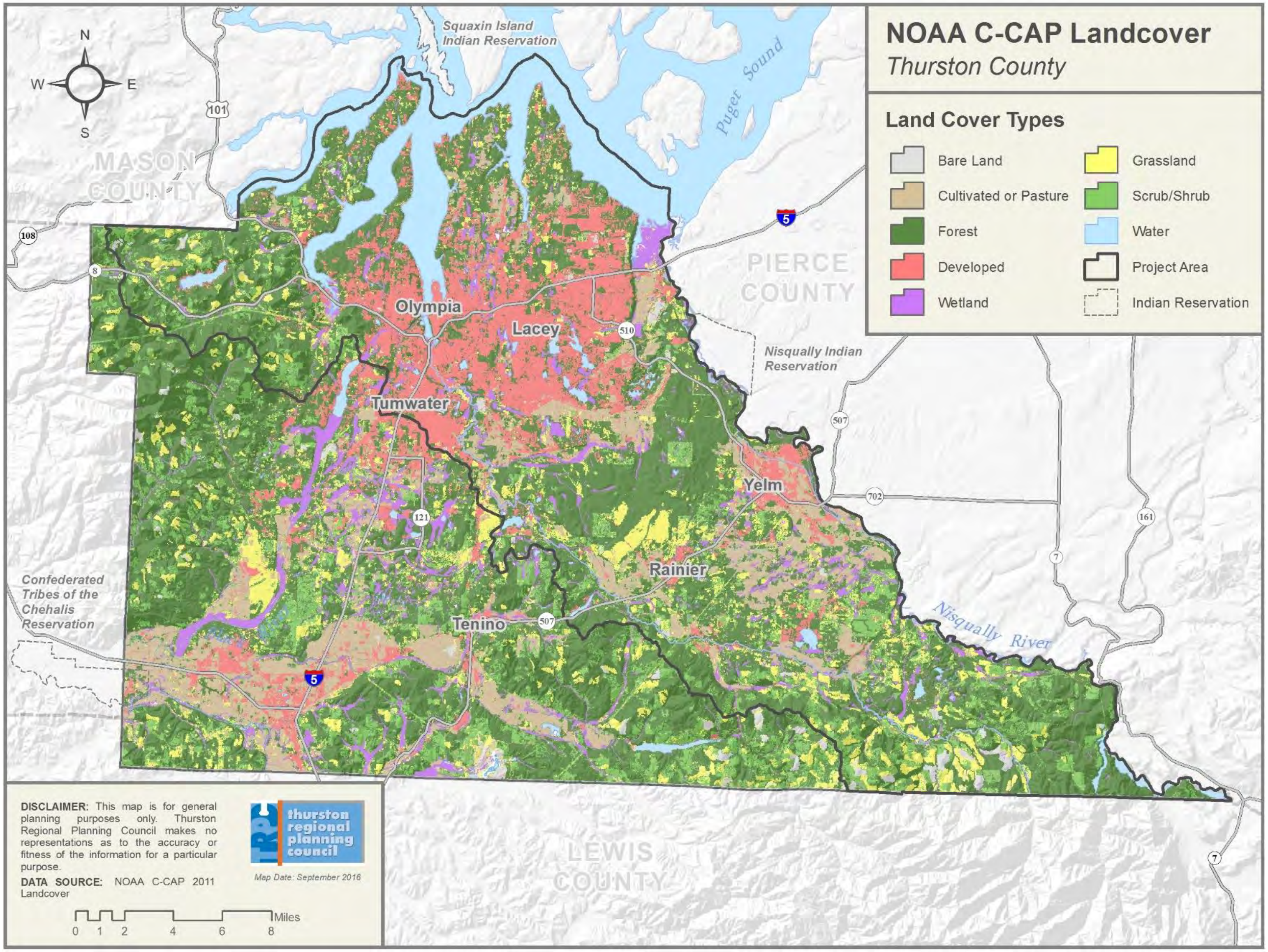

Figure 56: This map shows land cover types in Thurston County**.** ***Source:*** *TRPC, using* National Oceanic and Atmospheric Organization (NOAA) Coastal Change Analysis Program (C-CAP) data

6: Human Health & Welfare

The following section explores how climate change is expected to increase the incidence of wildfires floods and landslides — hazards that affect Thurston County's human and natural systems in myriad ways. The section concludes by exploring the projected effects of indirect climate change exposure pathways — changes in infectious disease agents and population displacement.

…

6.1 Wildfires

Over its recorded history, Thurston County has experienced comparatively small wildland fires, or "wildfires," most of which were started by human activities such as burning debris and lighting fireworks (TRPC, 2009). About two-thirds of the county's wildfires (roughly 2,500 between 1972 and 2007) were between July and September, when the climate is typically warmest and driest.

The historical frequency of local wildfires suggests that such hazards have a "high" probability of occurrence, but about 97 percent of future fires will be small — five acres or less — concluded the *Natural Hazards Mitigation Plan for the Thurston Region* (TRPC, 2009). The plan did not factor in climate change but cautioned that it may create more suitable conditions (e.g., warmer, drier summers) for bigger, more frequent wildfires.

One set of fire models for the broader Pacific Northwest projects that total area burned by wildfire could more than double — from 0.5 million acres historically (1916-2006) to 1.1 million acres for the 2040s, per a moderate emissions scenario (Littell et al., 2010). While these and other models are limited in their ability to capture unique Puget Sound conditions associated with wildfires, the region is still expected to experience greater wildfire frequency and severity associated with changes in air temperature and precipitation (Mauger et al., 2015).

Wildfires can pose acute or long-term health and welfare risks for firefighters and residents: incurring stress as a result of property losses; suffering burns and death; and, breathing in smoke and particulate matter (PM_{10}). Such fires may also disrupt energy transmission by downing power poles and damaging other infrastructure, as well as burn trees and other vegetation that prevent soil from eroding.

Presumably, damages associated with fires will go up if those fires occur in or spread to the wildland-urban interface [*Figure 58, on pg. 75*]. This is where most of the county's wildfires have occurred in recent decades (TRPC, 2009) [*Figure 59, on pg. 76*].

In 2014, there were about 30,500 residents and 12,900 dwelling units in Thurston County's wildland-urban interface area, according to TRPC data; the value of all buildings and contents was more than $2.9 billion. In 2040, about 38,100 residents and 16,200 dwelling units are expected in this area. This represents a 25 percent and 26 percent increase, respectively.

In addition to temperature and precipitation, conditions that influence the severity and extent of wildfires include soil and vegetation type, slope grade, and road access. Based on these criteria, the hazards plan deemed the following communities most vulnerable to wildland fires [*Also see Figure 60, on pg. 77*]:

- Steamboat Island Peninsula;
- Boston Harbor/Fishtrap Loop/Woodard Bay/South Bay Peninsula;
- Johnson Point Peninsula;
- Nisqually River Valley, south of Yelm
- Lake Lawrence, western shore vicinity;
- Tenino, upland vicinity south of town;
- Grand Mound/Rochester/Confederated Tribes of the Chehalis Reservation;
- Capitol State Forest vicinity.

The prospect of more frequent and intense wildfires would have economic consequences. The Washington Department of Natural Resources (DNR) projects that statewide direct costs for fire preparedness and response would rise from more than $18 million in the 2040s to $24 million in the 2040s (WDOE, 2006). The total economic impacts of wildfire — including lost timber value, lost recreational expenditures, and health and environmental costs associated with air pollution and other forest changes — could be many times higher than DNR's projected preparedness and response costs.

To reduce the risk of wildfires, Thurston County currently imposes an outdoor burn ban during summer [*Figure 57, right*]. Outdoor burning is prohibited year-round for residents within the cities of Olympia, Tumwater and Lacey, as well as for county residents within the Urban Growth Area (UGA) boundary.

Figure 57: A sign near Yelm announces that a summer burn ban is in effect. ***Source:*** *TRPC*

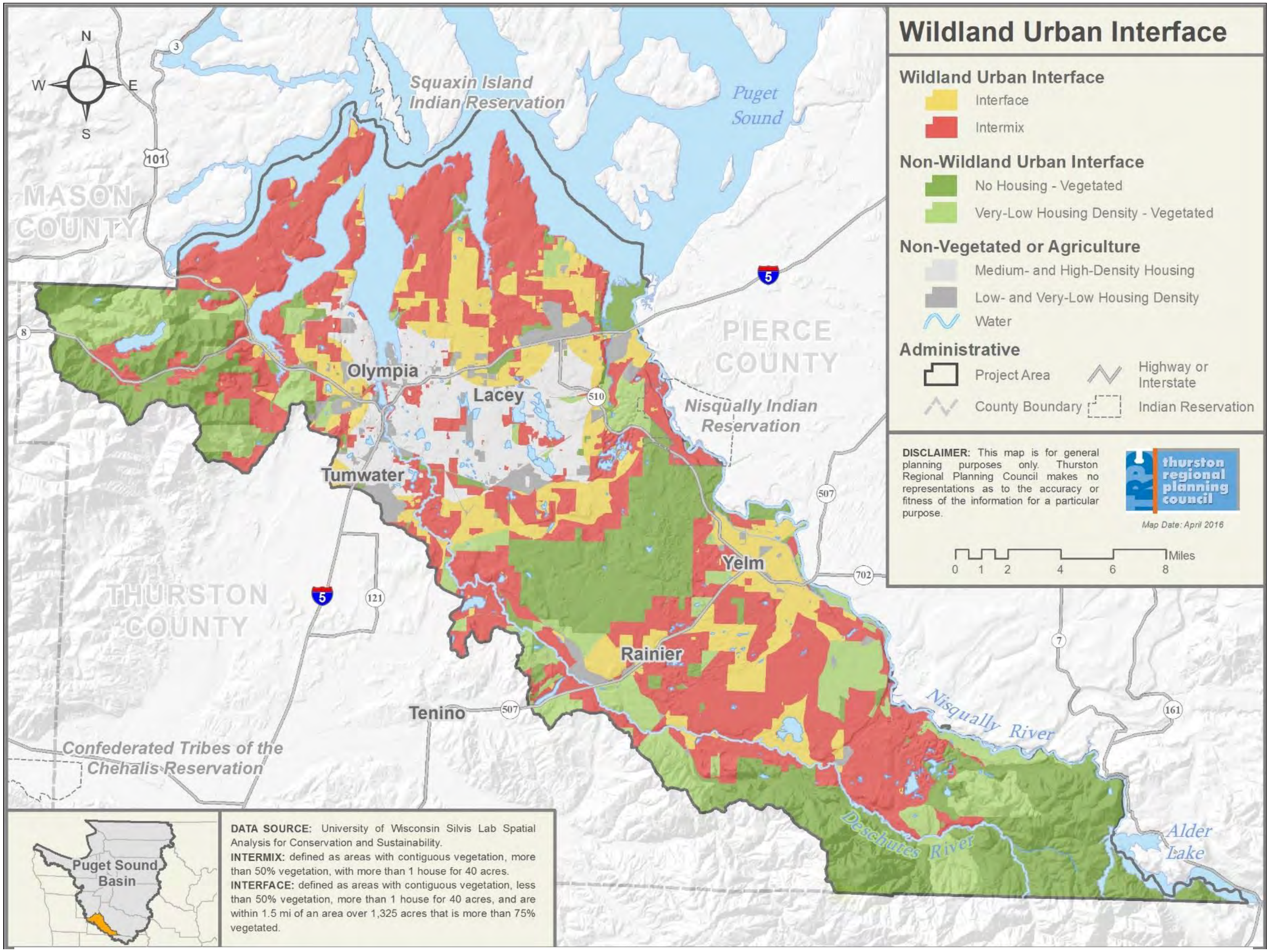

Figure 58: The project area's Wildland-Urban Interface (*shown*) is the zone of transition between unoccupied land and human development.

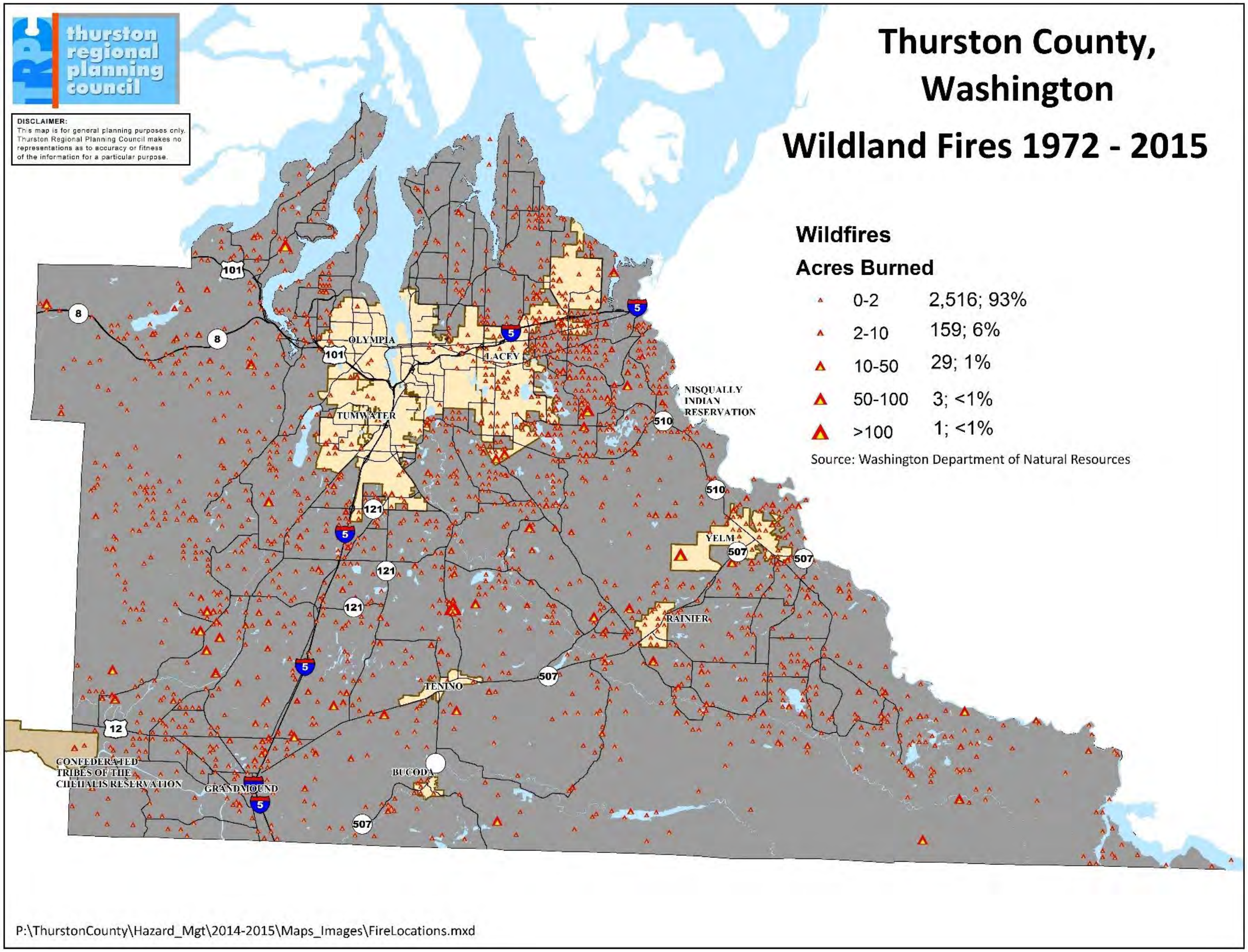

Figure 59: The map shows the location and size of wildland fires that burned in Thurston County between 1972 and 2015. As icons indicate, most of these wildfires were less than 10 acres. ***Source:*** *TRPC*

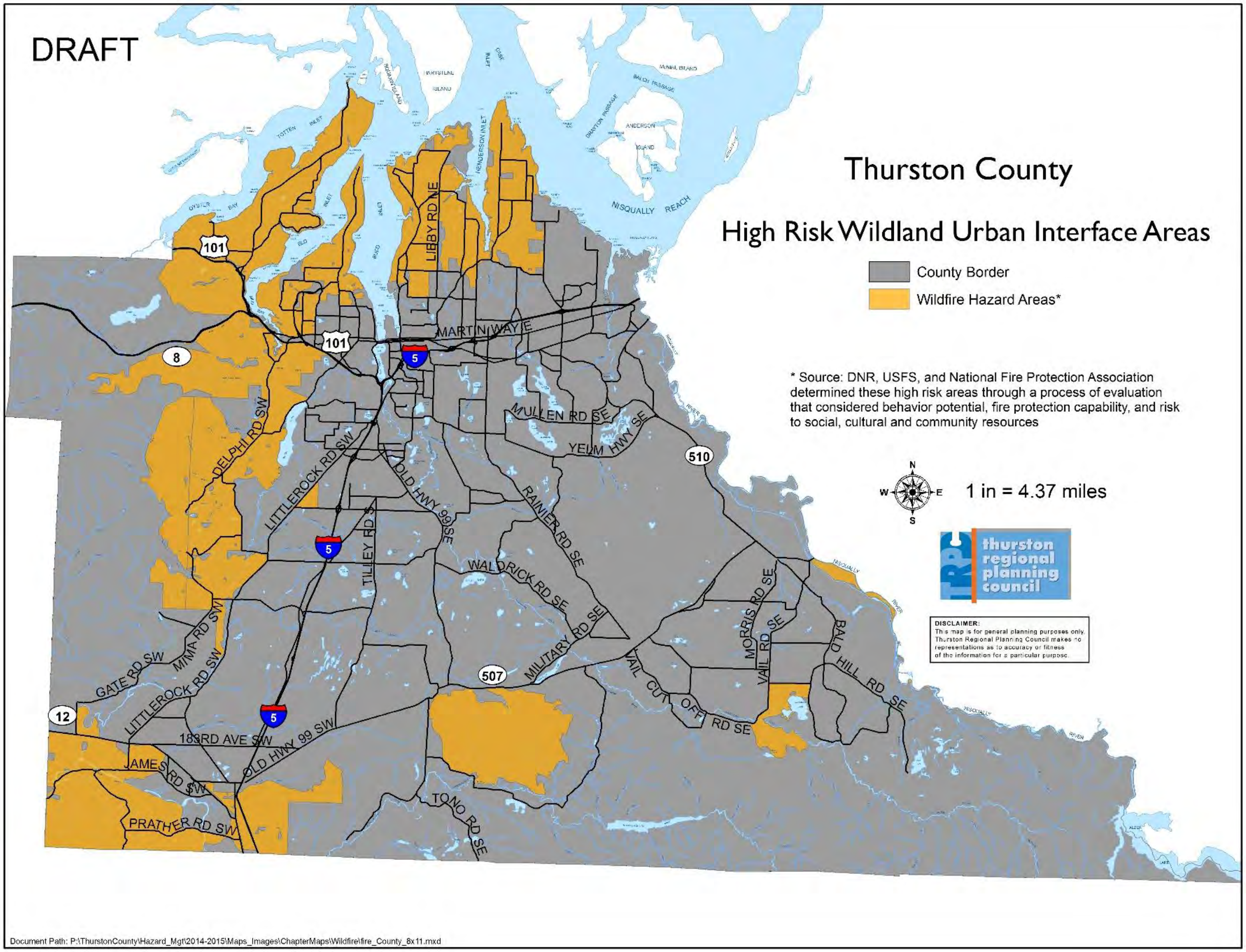

Figure 60: The map shows Thurston County wildland-urban interface areas with the highest risk of wildfires

6.2 Floods & Landslides

As noted previously in this assessment, the frequency and intensity of today's heaviest 24-hour rain events is projected to increase during the 21st century [*See Section 2.3, on pg. 23*]. An increase in these top 1 percent heavy rain events and winter precipitation would raise the risk of floods and landslides — natural hazards that degrade water quality and threaten public safety. The following section examines which Thurston County areas and assets are most vulnerable to such hazards.

Flood Vulnerability

Flooding can come from swollen rivers, high groundwater and other sources and threaten human health and welfare in several ways, ranging from drowning in rising waters, to consuming contaminated water, to breathing in mold that grows after waters recede. Swift-moving flood water, as well as the woody debris and other detritus left behind, can pose obstruction hazards for culverts, roads and bridges that are critical transportation routes for school and transit buses, fire trucks, ambulances and other vehicles (TRPC, 2009). Inundation, erosion and sediment deposits can also damage homes and businesses, as well as disrupt communication, electric, gas and water utility infrastructure.

In its *Natural Hazards Mitigation Plan for the Thurston Region*, TRPC used more than 40 years of stream gauge data to calculate the probability and frequency of flooding in local rivers. Based on this analysis of the past, the hazards plan concluded that a "major"[27] flood event occurred on at least one county river about every 2.3 years — a "high" probability of occurrence. The Nisqually River has an estimated 12 percent chance of major flooding in a given year, or about one major flood every eight years, according to the analysis (TRPC, 2009); the Deschutes River has an estimated 22 percent chance of major flooding in a given year, or about one major flood every 4.5 years.

The hazards plan also concluded that there is a "high" probability of groundwater flooding[28] associated with a high water table and persistent heavy rains. Additionally, the hazards plan concluded that there is a "moderate" probability of tidal flooding along the county's Puget Sound coastline, and a "high" probability of urban flooding associated with stormwater runoff exceeding the conveyance capacity of drainage systems. The hazard plan's assessment, which concluded that there is a "high" overall risk of all types of flooding, did not factor in projected climate change impacts.

As noted above, heavy rainfall events are projected to become more intense and result in higher peak river flows and runoff during winter months. Adding to this, rising sea levels could increase the potential for higher tidal/storm surge and coastal flooding. More than 65,000 acres and $1.5 billion in buildings and contents are currently within Thurston County's flood hazard areas (TRPC, 2009). Such lands have high groundwater or are within the 100-year or 500-year floodplains[29] [*Figure 61, on pg. 79*].

Several stretches of local roadway are within these flood hazard areas and flood on a regular basis [*Figure 58, on pg. 68*]. Regional stretches of highway have also flooded several times in recent decades, snarling traffic and endangering motorists. In 1996, for example, riverine flooding forced the temporary closure of I-5 at the border of Thurston and Lewis counties (TRPC, 2009). The Washington Department of Transportation's climate change vulnerability assessment (WDOT, 2011) deemed this low-lying stretch of I-5, adjacent to the Chehalis River in Lewis County, "high vulnerability" and at risk of "complete failure" in the event of a major flood [*See Figure 42, on pg. 58*].

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[27] The *Natural Hazards Mitigation Plan for the Thurston Region* defines "major" flooding as follows: Neighborhoods and communities are threatened and evacuation is recommended for residents living on specified streets, in specified communities or neighborhoods, or along specified stretches of river. Major thoroughfares may be closed and major damage is expected.

[28] This occurs when impermeable hard pan prevents infiltration and causes standing water on land below the water table.

[29] The 100-year floodplain includes lands subject to a 1% chance of flooding in a given year. The 500-year floodplain includes lands subject to a 0.2% chance of flooding in a given year.

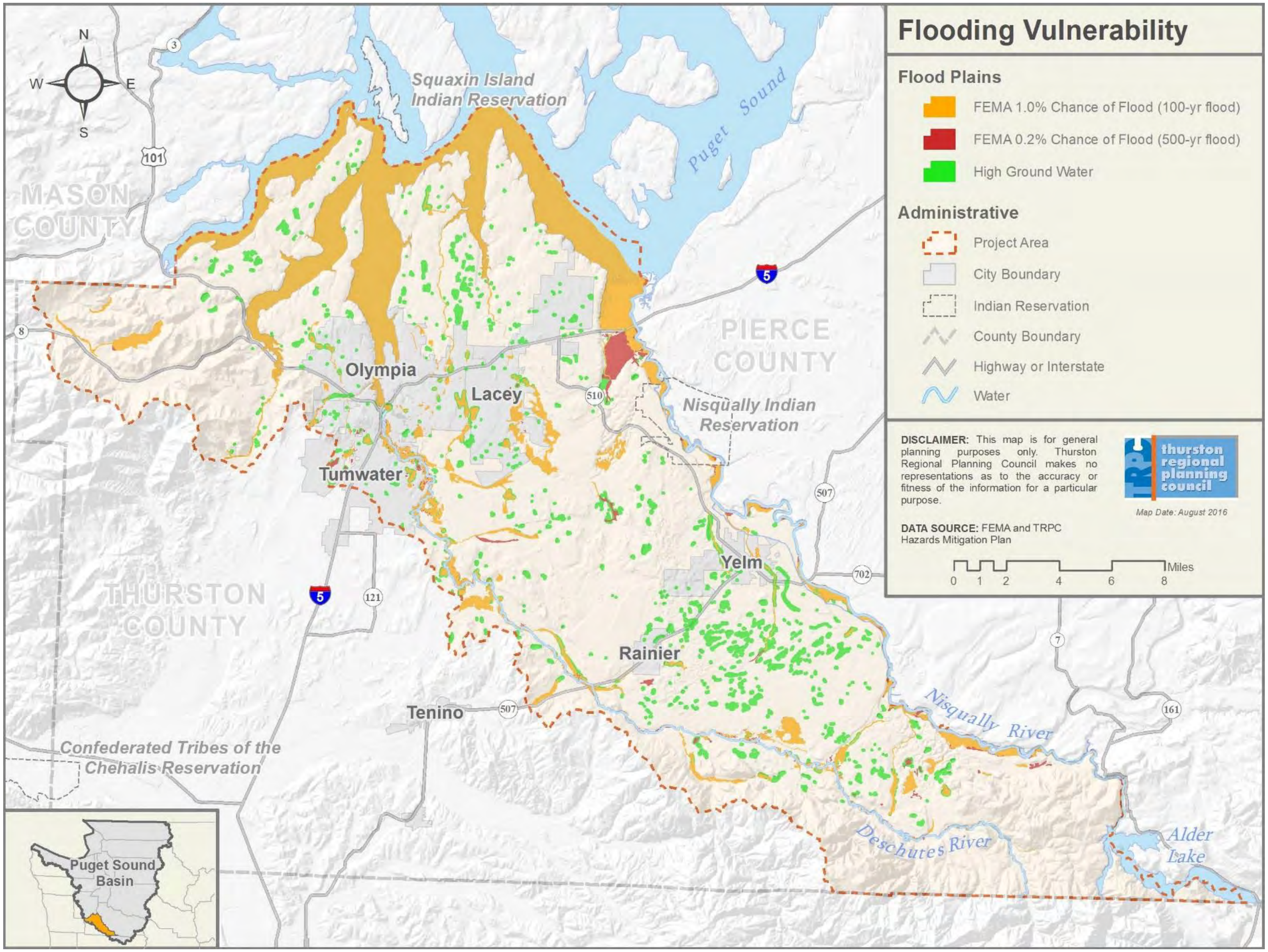

Figure 61: The map shows floodplain and high groundwater areas within the project area that are deemed most vulnerable to flooding.

Landslide Vulnerability

Heavy rain events can compromise the stability of hillsides by raising the water table quickly and boosting drainage through the soil to lower layers (Mauger et al, 2015). As explained previously in this assessment, this can cause flooding amid areas with high groundwater, as well as trigger landslides or significant sediment runoff from steep slopes where the soil is unprotected by vegetation or snow.

Such hazards can have lasting effects on salmon, which, as noted previously in this assessment, are an important part of this region's environment and cultural traditions. For example, winter storms in the 1990s, compounded by logging activity, triggered landslides in the Deschutes River and decimated the stream's Coho salmon population [*Figure 62, below*].

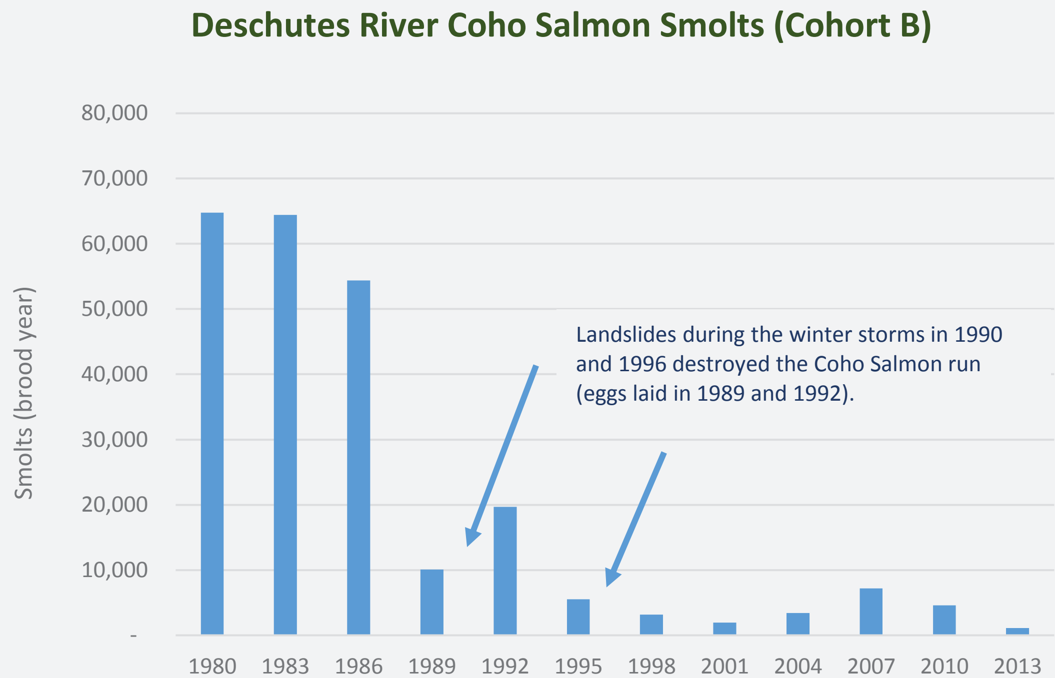

Figure 62: Coho salmon return to spawn three years after emerging. Cohort B, which includes eggs which were laid in 1980 and their descendants, has not recovered from landslides that decimated habitat in the Deschutes during the winters of 1990 and 1996. ***Source:*** *Washington Department of Fish & Wildlife*

Landslides can also topple trees and affect the transmission of electricity across the region. PSE has more than 1,500 miles of overhead distribution lines, 1,200 miles of underground cable, 30 distribution substations, and six transmission substations within Thurston County (Puget Sound Energy, 2012).

Landslides can also exact a costly toll on homes and roads built adjacent to sleep slopes. Landslides on the northeastern shore of Eld Inlet during the winter of 1998-1999, for example, resulted in $24 million in damages and response and recovery costs (TRPC, 2009). More than 30 homes amid the Carlyon Beach community, south of Hunter Point, [*Figure 63, on pg. 81*] were destroyed by the landslides, which followed three years of above-average rainfall (Slaughter, 2016).

The Thurston Region hazards plan (TRPC, 2009) assessed the risk of future landslides as "moderate," after factoring in the high probability of landslides occurring in the area, coupled with their history of destructive, but localized, impacts. The hazards plan's risk assessment did not factor in projected climate change impacts.

Currently, more than 12,000 Thurston County residents and 4,400 acres are within landslide hazard areas — locations where the slope is greater than 40 percent [*Figure 64, on pg. 82*]. The value of buildings and goods within the county's landslide hazard is more than $1.1 billion, according to TRPC data.

Figure 63: Photo of Carlyon Beach property damaged by the '98-'99 winter landslides. ***Source:*** *Slaughter, 2016*

In coming decades, shifts in Puget Sound region air temperature, precipitation and streamflow are expected to increase the frequency of landslides and rate of erosion during winter and spring but reduce such processes during summer (Mauger et al, 2015). For example, modeling projects winter soil water content — an indicator of landslide hazard — is projected to increase up to +35 percent for the 2040s (relative to the 1970-1999 period) along Cascade Range slopes.

The increase would be due, in part, to the mountains getting less snowpack, which absorbs rain and protects slopes from raindrop erosion. The UW CIG report cautioned that such quantitative projections are limited, however, because it is difficult to distinguish between impacts exacerbated by climate change and human activities such as logging and land development (Mauger et al., 2015).

In preparation for increasing frequency of these natural hazards, TRPC and its partners are creating a spatial database of road segments that have been affected by landslides and floods or are most likely to be affected by these hazards in the future [*Figure 65, on pg. 83*]. For each road segment, the database identifies potential triggers (e.g., slope grade or groundwater seepage), alternative routes, and mitigation measures taken.

The goal of this online database, which also includes road segments vulnerable to flooding, is to help catalogue and prioritize problem spots that may warrant additional actions (e.g., slope stabilization, debris containment; stormwater management, road relocation, culvert replacement) as the region's climate changes.

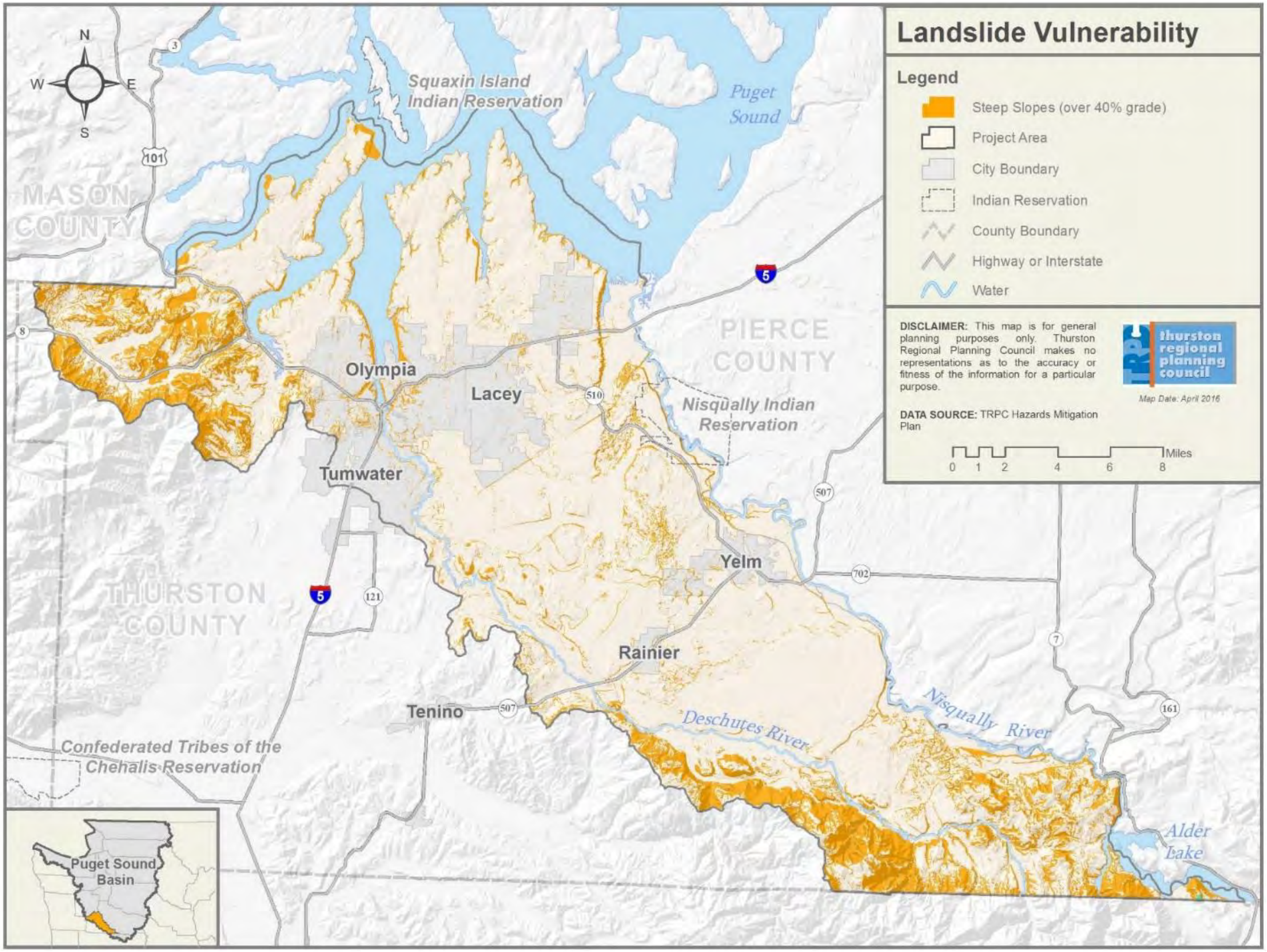

Figure 64: Coastal bluff and forested hillsides are among Thurston County lands most vulnerable to landslides.

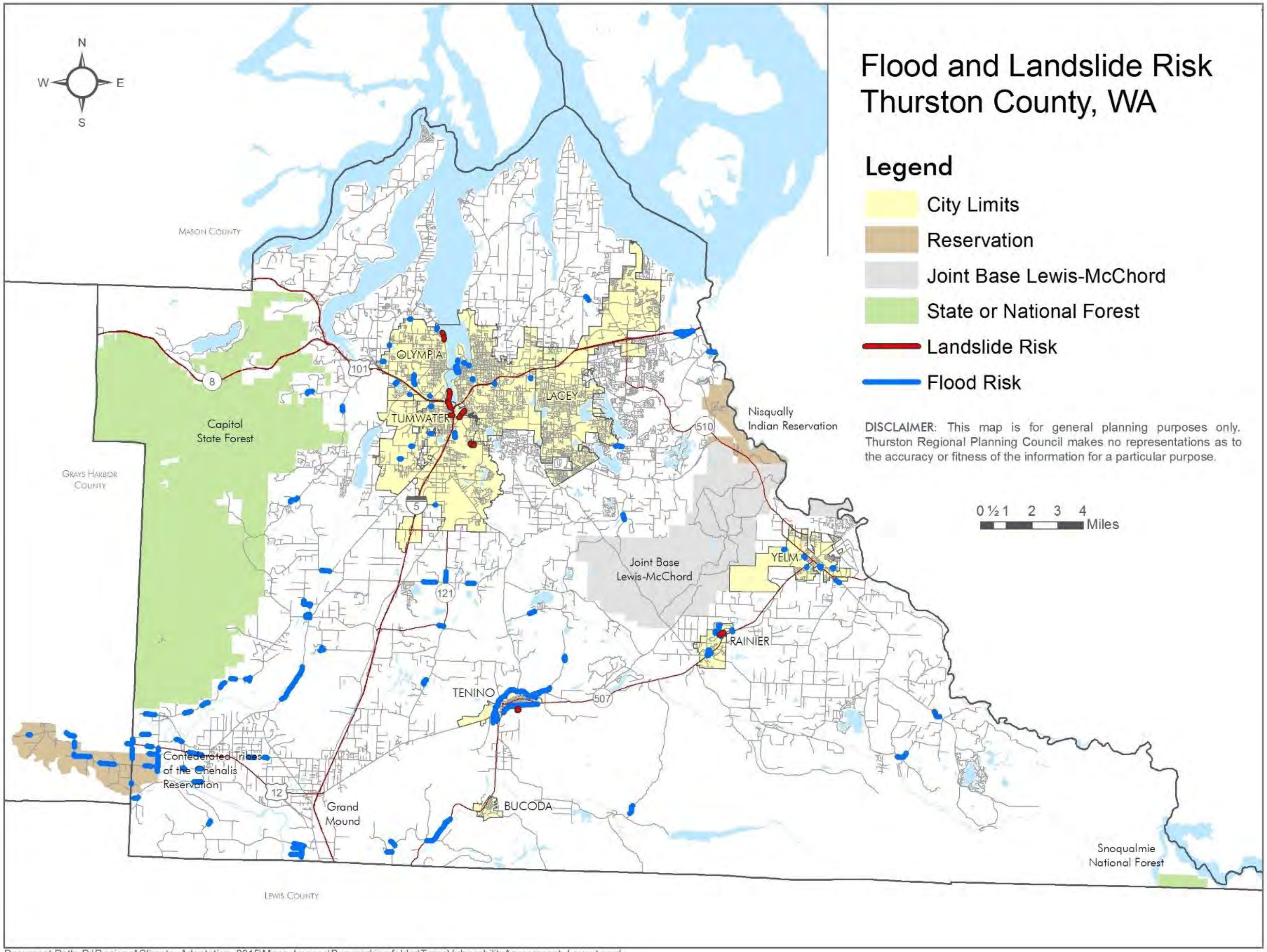

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Figure 65: This map shows the locations of road segments that have been affected by floods and landslides historically and are deemed most vulnerable to such natural hazards in the future. ***Source:*** *TRPC, using information provided by local government jurisdictions*

6.4: Diseases & Other Health Threats

As explained throughout this assessment, climate change is projected to exacerbate or introduce a wide range of health threats, including infectious diseases from exposure to viruses and bacteria, which would affect human health outcomes in Thurston County and the broader Puget Sound region. Exposure pathways include food, water, air, soil, trees, insects and animals [*Figure 66, pgs. 84 and 85].*

Human Health Threat	Exposure Pathway	Outcomes & Symptoms	Climate Driver
Algae: Toxigenic marine species of *Alexandrium, Pseudo-nitzschia, Dinophysis, Gambierdiscus; Karenia brevis*	Shellfish; Fish Recreational waters (aerosolized toxins)	Gastrointestinal and neurologic illness caused by shellfish poisoning or fish poisoning. Asthma exacerbations, eye irritations caused by contact with toxins.	Temperature (increased water temperature), ocean surface currents, ocean acidification, hurricanes [*See Section 4.2, on pg. 64*]
Cyanobacteria (multiple freshwater species producing toxins including microcystin)	Drinking water; Recreational waters	Liver and kidney damage, gastroenteritis (diarrhea and vomiting), neurological disorders, and respiratory arrest.	Temperature, precipitation patterns [*See Section 3.2, pg. 45*]
Enteric bacteria & protozoan parasites: *Salmonella enterica; Campylobacter* species; Toxigenic *Escherichia coli; Cryptosporidium*; *Giardia*	Drinking water; Recreational waters; Shellfish	Enteric pathogens generally cause gastroenteritis. Some cases may be severe and may be associated with long-term and recurring effects.	Temperature (air and water; both increase and decrease), heavy precipitation, and flooding [*See Section 3.4, on pg. 49*]
Enteric viruses: enteroviruses; rotaviruses; noroviruses; hepatitis A and E	Drinking water; Recreational waters; Shellfish	Most cases result in gastrointestinal illness. Severe outcomes may include paralysis and infection of the heart or other organs.	Heavy precipitation, flooding, and temperature (air and water; both increase and decrease) [*See Section 4.2, on pg. 65*]
Bacteria: *Vibrio* species	Recreational waters; Shellfish	Varies by species but include gastroenteritis, septicemia (bloodstream infection) through ingestion or wounds, skin, eye, and ear infections.	Temperature (increased water temperature), sea level rise, precipitation patterns (as it affects coastal salinity) [*See Section 4.2, on pg. 65*]

(Table continued on pg. 85)

Human Health Threat	Exposure Pathway	Outcomes & Symptoms	Climate Driver
Fungi: *Cryptococcus gattii*	Soil; Trees	Inhaling the tropical organism may cause cryptococcosis pulmonary disease, with symptoms such as headache, fever, cough and chest pain (CDC, 2010).	Temperature and precipitation (hotter, drier summers, and warmer, wetter winters)
Vector-borne viruses: West Nile Virus	Mosquitos	Minor symptoms such as fatigue, fever and headache; in severe cases, brain inflammation (CDC, 2015).	Temperature and precipitation (hotter, drier summers, and warmer, wetter winters)
Heat Stress (hyperthermia)	Air	Extreme heat can cause cramps, loss of consciousness, weakness and stroke — and, in extreme cases, death	Temperature (hotter, drier summers) [*See Section 2.1, on pg. 15*]
Air Pollution: surface ozone; particulate matter ($PM_{2.5}$)	Air	Surface ozone can increase allergy symptoms; fine particulate matter can enter lungs and cause symptoms including coughing, sneezing, runny nose and shortness of breath	Temperature and precipitation (hotter, drier summers, and warmer, wetter winters) [*See Section 2.2, on pg. 22*]

Figure 66: The table above shows the connections between climate change drivers (shifts in air temperature and precipitation) and exposure pathways (food, water, air, and vectors such as biting insects) for viruses, bacteria and other human health threats. ***Source:*** *TRPC, adapted from table in USGCRP, 2016*

Tribal Vulnerability

Members of local tribes, which are rooted in place and utilize the land and waters for cultural traditions, are particularly vulnerable to climate change impacts (TNC, 2016). According to one study, tribal and Asian and Pacific Islander community members consume 3-10 times the amount of fish and shellfish of average U.S. consumers (Judd et al., 2016). Continuing to consume traditional seafood staples may increase health risks from contamination (e.g., *Vibrio* in shellfish), but replacing such traditional foods may involve the loss of cultural practices tied to their harvest (USGCRP, 2016).

Squaxin Island Tribe members are already thinking about these and other climate risks and considering strategies to support current and future generations. In 2015, a team of Pacific Northwest researchers worked with the Squaxin and several other tribes to develop indicators that reflect tribal definitions of health and wellbeing. Squaxin-specific indicators included (Donatuto et al., 2015):

- Physical Health — including maintaining body strength and nutrition and being free of illness and pollution;
- Community Connection — including actively participating in community functions, such as harvesting, and looking out for family and tribal elders;
- Natural Resources Security — including having abundant and accessible land, plants, water and animals to support a healthy ecosystem and human community;
- Cultural Use — including being able to harvest local natural resources (e.g., clams and salmon) and carry forth cultural traditions;
- Education — including passing on knowledge, values and beliefs to future generations;
- Self-Determination — including maintaining the ability to exercise treaty rights and define and enact the Tribe's chosen environmental or habitat restoration programs;

- Balance — including maintaining homeland connections and ensuring that the wellbeing and health of future generations are not at risk due to environmental changes and relationships with others.

Based on interviews with Squaxin officials, the researchers summarized potential actions and opportunities. Ideas with climate change mitigation and adaptation benefits include (Donatuto et al., 2016): building river turbines and enhancing riparian buffers; removing the Fifth Avenue dam at Capitol Lake; educating people about climate change and health; repairing septic systems to protect water quality; and, working with the State of Washington to repair roads and bridges susceptible to failure associated with more extreme temperature changes.

Assessing Adaptive Capacity

New health threats may emerge and others may worsen in coming years, necessitating the need for both flexible and durable strategies in the Thurston County region. The vulnerability of the community's health and welfare will depend largely on peoples' sensitivity and exposure to threats and capacity to adapt (USGCRP, 2016). Thus, it will be important for our local and state public health professionals to consider a wide range of social and behavioral factors [*Figure 67, below*] as they assess communities' and individuals' adaptive capacity and develop strategies.

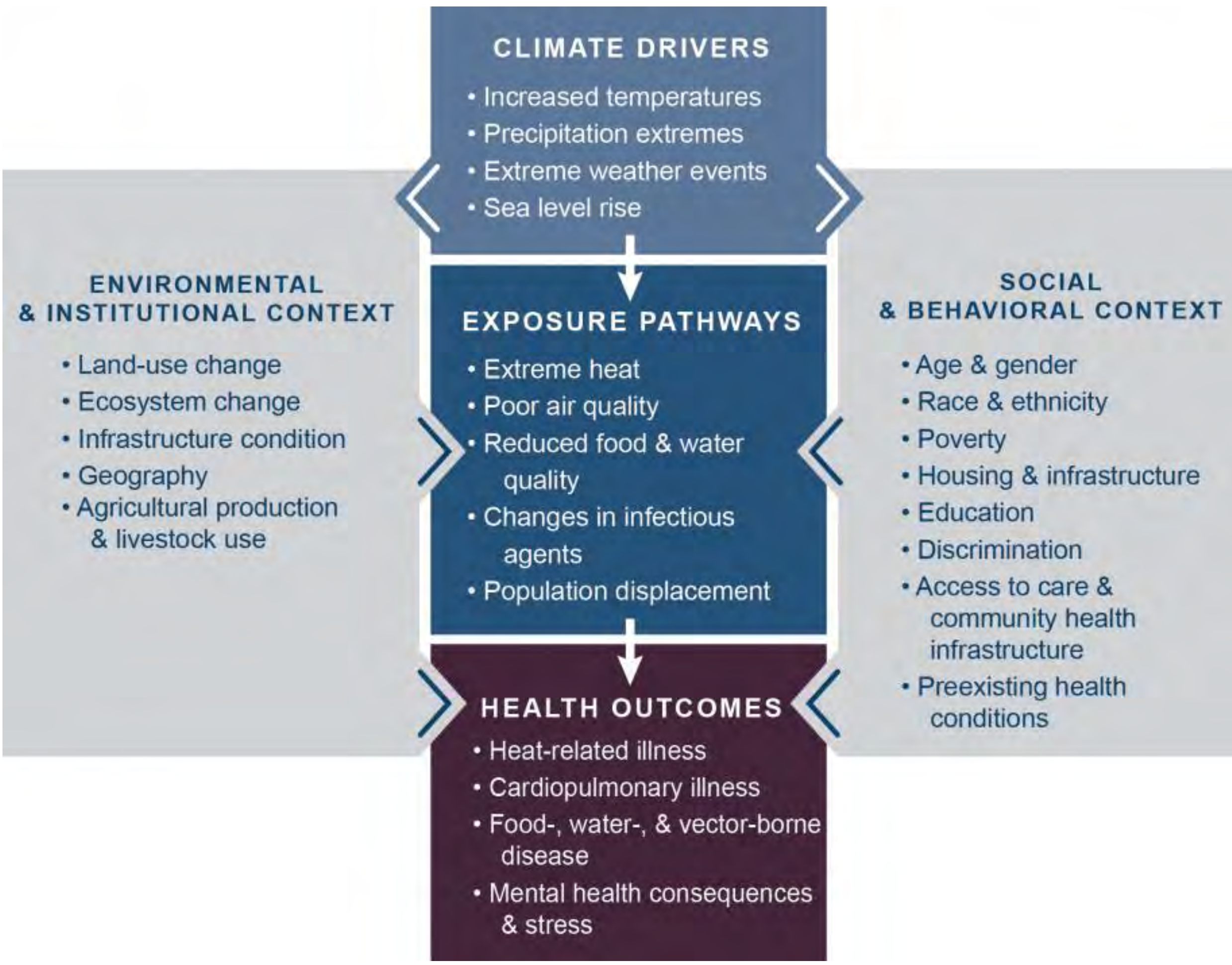

Figure 67: This diagram illustrates climate drivers and exposure pathways that affect human health outcomes. The gray boxes show factors, such as socio-economic status and land use change, which can affect a person's or a community's vulnerability and adaptive capacity. ***Source:*** *USGCRP, 2016*

Our region has a solid foundation for such efforts. The Thurston Thrives initiative, which grew out of TRPC's Sustainable Thurston project, uses a systems approach to identify priority health outcomes and implement cross-sector strategies to achieve community targets related to climate change, clean energy, food and other topics (Thurston Thrives, 2016).

Thurston Thrives' website includes strategy maps and tracks measures of progress for such topics. Similarly, the Washington State Department of Health's Washington Tracking Network website tracks indicators affected by climate change (e.g., heat stress, air quality, wildfire occurrence, flood risks).

The DOH interactive online tool's Social Vulnerability of Hazards map, for example, rates the social vulnerability of census block groups (1 = "low" social vulnerability; 10 = "high" social vulnerability) by factoring in criteria, including: educational attainment; English language proficiency; disability; age; housing type and household size; access to a private vehicle; and, unemployment and poverty rates.

Based on such criteria, the Thurston County census tracts [*Figure 68, below*] with the highest social vulnerability to hazards (rating of 9 or 10) include: 012411 (North Yelm); 012320 (Nisqually Valley); 011550 (Tanglewilde-Thompson Place); 011200 (Central Lacey/Woodland District); 011621 (South Lacey/Smith Lake); 010510 (Southwest Olympia/Capital Mall).

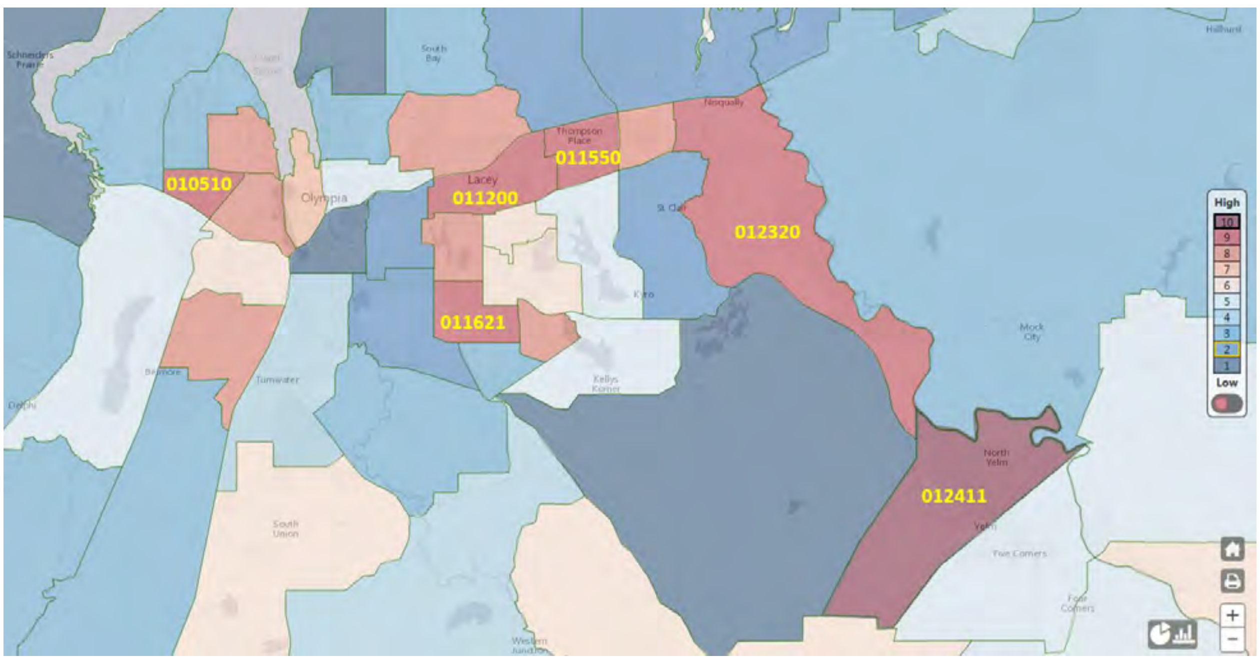

Figure 68: The map above shows the Thurston County areas (census tracts) that are most vulnerable to natural hazards, as ranked by the Washington State Department of Health's Washington Tracking Network. TRPC and its partners could use such tools to assess the adaptive capacity of communities and to develop strategies to prepare for and cope with climate change impacts. ***Source:*** *DOH; census track numbers added by TRPC*

6.5: Population Displacement

As the project's *Science Summary* explains, climate change is projected to affect other parts of the nation in myriad ways — including more frequent and intense hurricanes in the Southeast, droughts in the Southwest, and heat waves in the Northeast. This raises the provocative idea that the comparatively temperate Pacific Northwest will become a refuge from climate change in the decades ahead.

Cliff Mass, who teaches atmospheric science at the University of Washington, concluded as much after analyzing how climate change could exacerbate the effects of natural hazards on other parts of the nation. "A compelling case can be made that the Pacific Northwest will be one of the best places to live as the earth warms — a potential climate refuge," Mass wrote recently on his widely read weather blog (Mass, 2015). Others caution that adaptation is still essential amid the Puget Sound region, given the breadth and severity of projected climate change impacts.

Social scientists have already observed how environmental, social and economic stressors accompanying sudden "pulse" events (e.g., Hurricane Katrina) [*Figure 69, below*] and sustained "pressure" events (e.g., the Dust Bowl) spur people to migrate both voluntarily and involuntarily to new communities. Whether such migration is temporary or permanent depends on several factors, including a migrant's economic status, educational attainment, and social and cultural connections (Saperstein, 2015).

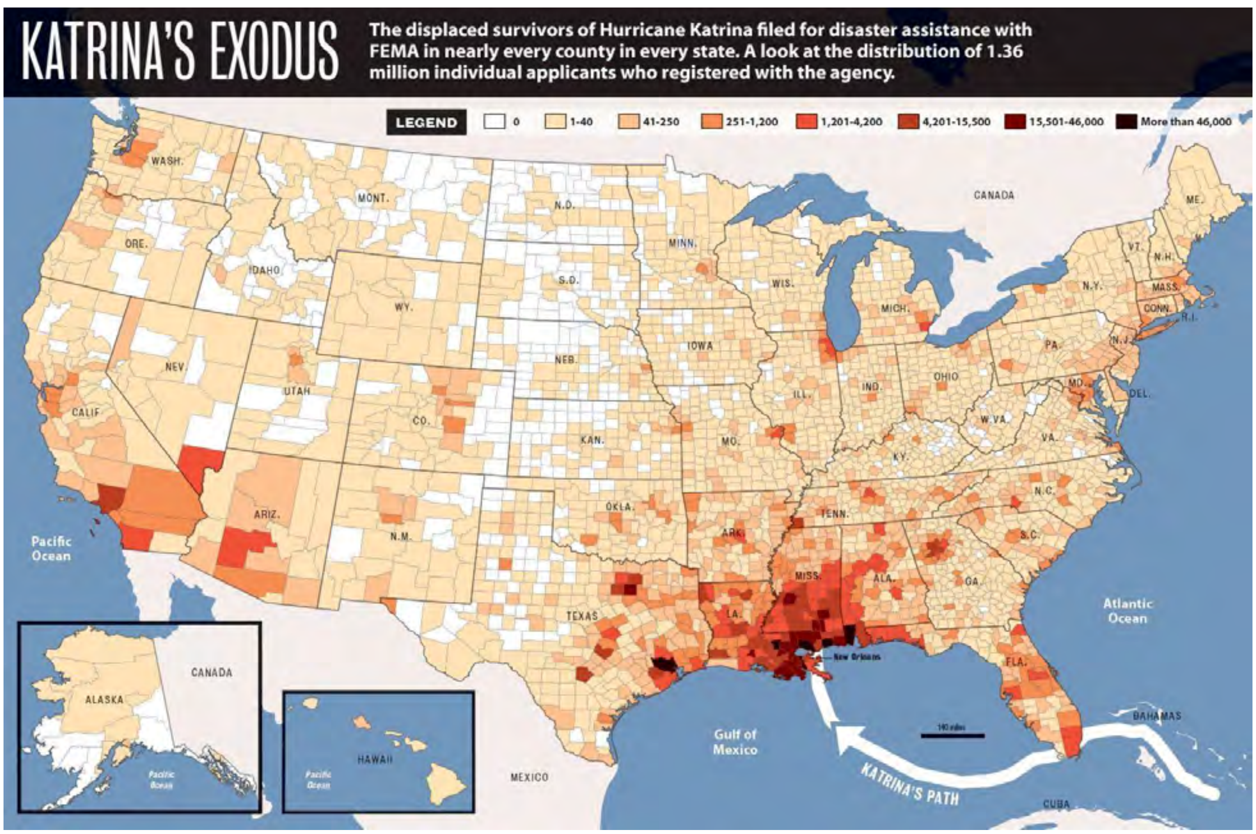

Figure 69: The map shows where Hurricane Katrina survivors moved to after the storm, as recorded by FEMA disaster-assistance applications. ***Source:*** *New Orleans Times-Picayune/NOLA.com, using information from FEMA, U.S. Census Bureau, The New York Times and Queens College*

Climate change-induced migration is the subject of a small-but-growing body of research — yet the fact remains that it is impossible to predict how many people might move to or within Thurston County — or when — as a result of climate change. This doesn't mean we can't or shouldn't begin preparing today for how climate change could shape local population growth and its impacts.

This vulnerability assessment marks a first adaptation step, as it begins to show what areas and assets of the Thurston County region are most vulnerable to climate-exacerbated threats. Subsequent assessments could take a closer look at which of the region's residents are most vulnerable to displacement (e.g., low-income or socially isolated residents who may be forced to move because of coastal or upland flooding) and what resources they might need. Depending on their circumstances, displaced residents may require shelter, food, clothing, health care, and job-placement assistance (TRPC, 2010).

Potential risks and opportunities of climate change impacts on the region's growth include:

- Increases pressure on rural lands to develop, yet also presents an opportunity to focus growth in existing urban areas, consistent with the Sustainable Thurston vision;
- Increases demand for food, water, energy and other resources;
- Increases pressure on existing parks and open spaces;
- Increases pressure on transportation infrastructure (e.g., roads, transit);
- Increases demand for local goods and services and supports job creation/demand;
- Increases cost to provide social services;
- Increases pollution related to development (e.g., more septic systems and impervious surfaces);
- Increases solid and organic waste creation;
- Increases demand on schools (e.g., unplanned influx of students)

Going forward, local government agencies and their partners could study who is most likely to move here from other parts of the state, nation and world (e.g., by studying "chain migration," the tendency of migrants to follow those of similar ethnicity or job skillset). Researchers could also assess how to accommodate potential newcomers in ways consistent with community values (e.g., by evaluating where and what type of growth should occur so that it is consistent with local comprehensive plans). A recent paper published by Portland State University provides an approach for such work using U.S. Census Bureau data analysis and collaborative planning strategies (Ahillen et al., 2011).

7: Next Steps

The following section provides a brief description of the next steps TRPC and its partners will take to craft a Thurston Climate Adaptation Plan with a vision, goals and strategies to help the region prepare for and cope with climate change impacts. As the United Nations Intergovernmental Panel on Climate Change underscored in its fourth assessment report, adaptation is "necessary to address impacts resulting from the warming that is already unavoidable" due to past emissions (Klein et al., 2007).

7.1: Overview of Plan Components

In coming months, the project team will work with its Stakeholder Advisory Committee to complete a risk assessment — modeled after a U.S. Environmental Protection Agency approach — which considers the probability and consequence of local climate change impacts identified in the vulnerability assessment. The risk assessment will help the Stakeholder Advisory Committee to develop and prioritize project-area adaptation strategies — many of which may also be applicable to others parts of Thurston County and the Puget Sound region with similar built and natural assets. For more information about the U.S. EPA risk-assessment methodology, please visit: www.epa.gov/sites/production/files/2014-09/documents/being_prepared_workbook_508.pdf.

Earth Economics will conduct a detailed benefit-cost analysis (BCA) of at least two priority strategies that are selected by the Stakeholder Advisory Committee. The Tacoma-based firm's analysis will evaluate the economics of natural ecosystems, including the ecosystem services that are produced or protected by a particular land cover type [*Figure 70, below*].

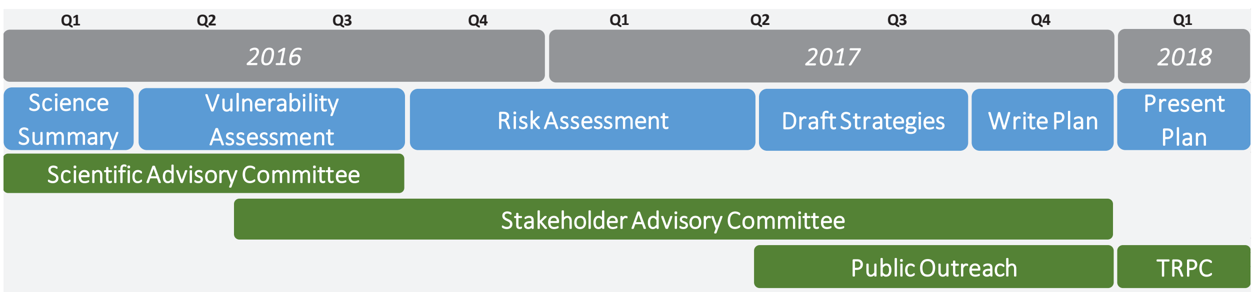

Figure 70: The process diagram above shows key Thurston Climate Adaptation Plan dates and components, including the vulnerability and risk assessments. ***Source:*** *TRPC*

As this vulnerability assessment shows, climate change is projected to exacerbate the risk of natural hazards (e.g., storms, floods, landslides, etc.) that already affect the region and may introduce new risks (e.g., disease vectors) to built and natural systems. Thus, during the final action-planning phase, the Stakeholder Advisory Committee will consider how adaptation strategies can address multiple risks or have co-benefits such as mitigating (reducing) greenhouse gas emissions or protecting air and water quality.

> **"A prudent way to cope with invisible but inevitable dangers … is to build resilience into all systems critical to our well-being. A resilient system can absorb large disturbances without changing its fundamental nature."**
>
> — Thomas Homer-Dixon, *The Upside of Down: Catastrophe, Creativity and the Renewal of Civilization*

This planning approach, which is consistent with the project's vision and guiding principles, will help the Thurston Region's built and natural environments remain resilient in the decades ahead. For more information about the project's process, vision and documents, please visit www.trpc.org/climate.

8: Appendix

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8.2: Explanation of Figures

Watershed Delineation

Per the requirements of TRPC's National Estuary Program (NEP) grant, the Thurston Climate Adaptation Plan's project area includes the extent of three Water Resource Inventory Areas (WRIAs) within Thurston County: WRIA 11 (Nisqually), WRIA 13 (Deschutes), and WRIA 14 (Kennedy-Goldsborough). WRIAs are watershed units defined by the Washington State Department of Ecology. WRIAs and HUCs are similar except for small differences in basin groupings, as well as the fact that HUCs extend beyond the state's borders into Canada, Idaho and Oregon. Both were digitized using 1:24,000 scale hydrography and topography maps and data.

Below is a list of other useful information about vulnerability assessment figures that incorporate data from UW CIG or other sources. These descriptions are adapted from the UW Climate Impacts Group's 2015 Report *State of Knowledge: Climate Change in Puget Sound* (Mauger et al, 2015).

University of Washington Climate Impacts Group Figures

In Mauger et al., 2015, the University of Washington Climate Impacts Group (CIG) used 10 global climate models and statistical downscaling to assess climate change impacts for the Puget Sound region. The models incorporate the "low" RCP 4.5 and "high" RCP 8.5 emissions scenarios used by the International Panel on Climate Change its fifth assessment report (IPCC, 2013).

UW CIG used hydraulic unit codes (HUCs), defined by the U.S. Geological Survey, to delineate the data for the Puget Sound region watersheds. The Thurston Regional Planning Council (TRPC) then used these data in a geographic information system (GIS) to spatially analyze historic and projected climate trends amid the South Puget Sound sub-region, which includes the project area.

Such maps show the historical and projected change in temperature, in Fahrenheit (°F). Such maps also compare watershed averages for historical conditions (1970-1999) and the projected change for current climate models. Projections are shown for the 2050s (2040-2069) and 2080s (2070-2099), and projections are included for two greenhouse gas scenarios: one low (RCP 4.5) and one high (RCP 8.5).

With the exception of the air temperature maps, all of the maps show projected changes (relative to historical averages) in percent ranges rather than absolute values. The UW CIG took the same approach in its Puget Sound climate impacts assessment (Mauger et al., 2015) because the percent ranges are more reliable numbers than absolute values.

The UW CIG modelers showed percent changes for variables that vary widely across the region. For example, annual precipitation varies by a factor of 10 from the driest to the wettest parts of the Puget Sound region. Absolute changes in precipitation, however, are not easily distinguishable from that pattern (Mauger, 2016).

U.S. Forest Service - NorWeST Projected Stream Temperature Figures

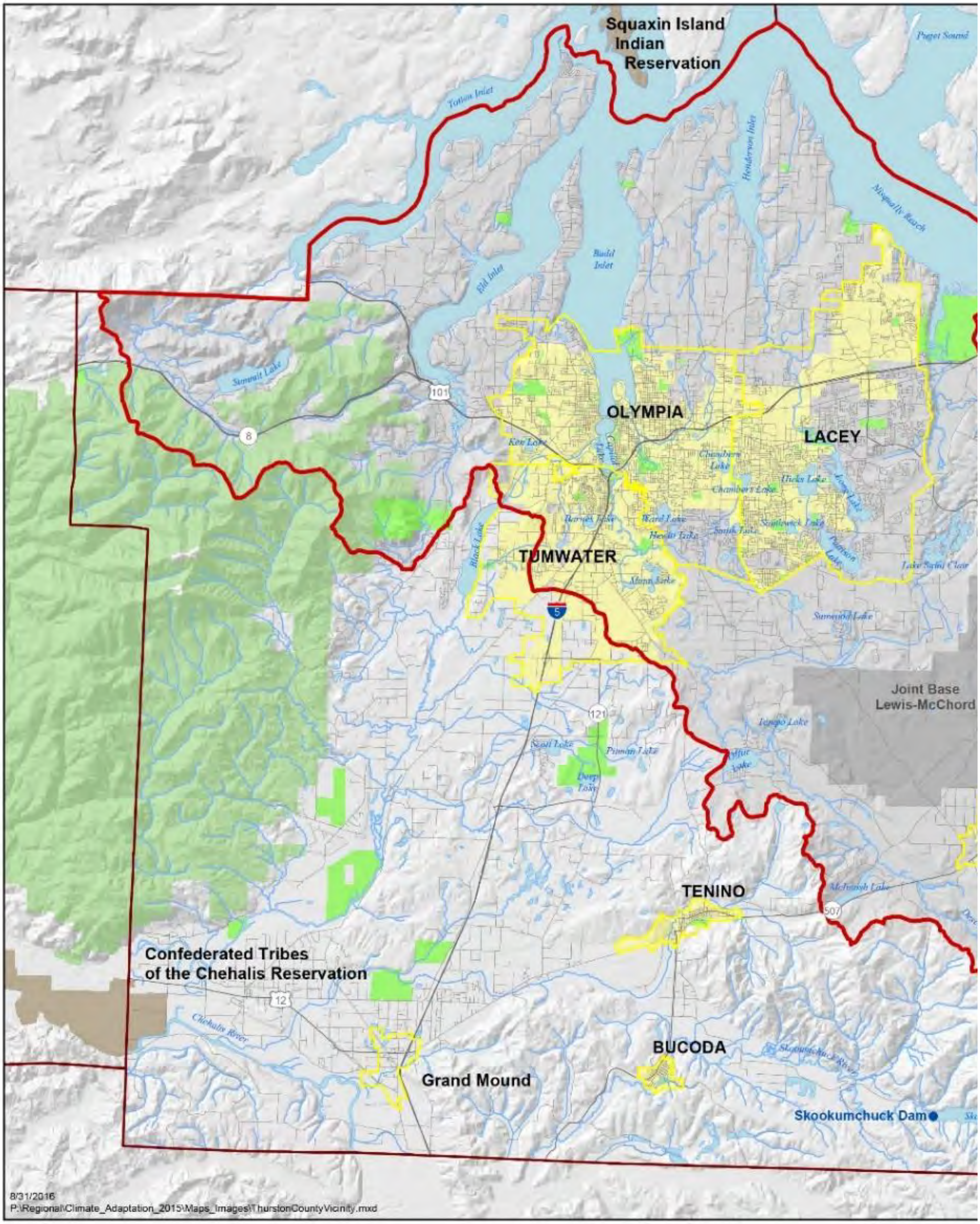
The NorWeST Stream Temperature data set contains three temporal extents based on historic and projected stream temperature data. The descriptions below are from the metadata contained within the GIS dataset. It should be noted that while the University of Washington Climate Impacts Group data utilized the most recent IPCC climate scenarios, the NorWeST dataset is based on 2007 scenarios.

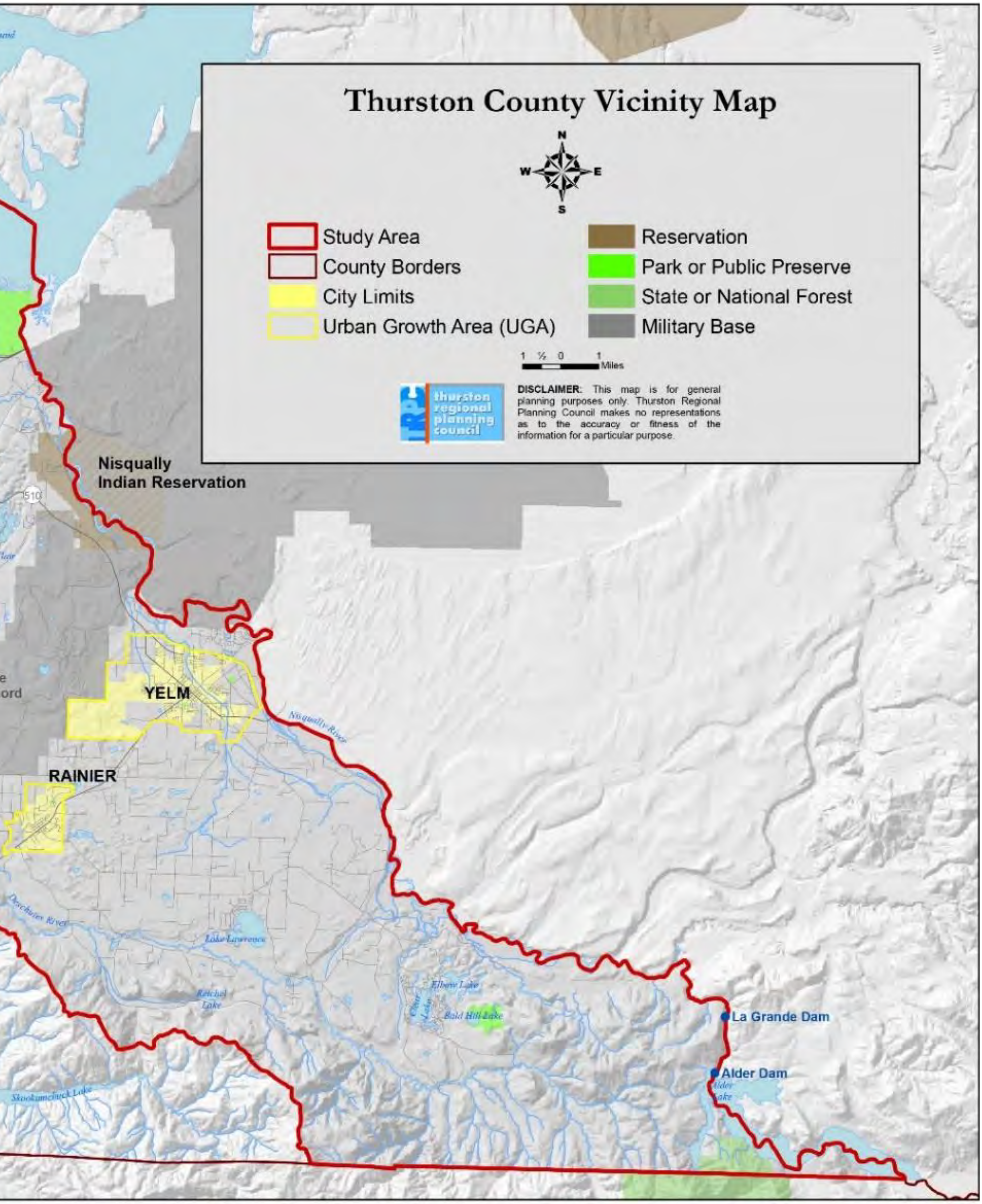
Mean August Stream Temperature - Historical composite scenario representing 19-year average of August mean stream temperatures for 1993 – 2011.

Modeled Future Scenario 2040 - Future scenario based on global climate model ensemble averages that represent the A1B warming trajectory for 2040s (2030 - 2059). Future stream deltas within a processing unit were based on similar projected changes in August air temperature and stream discharge, but also accounted for differential warming of streams by using historical temperatures to scale temperature increases so that cold streams warm less than warm streams.

Modeled Future Scenario 2080 - Future scenario based on global climate model ensemble averages that represent the A1B warming trajectory for 2080s (2070 - 2099). Future stream deltas within a processing unit were based on similar projected changes in August air temperature and stream discharge, but also accounted for differential warming of streams by using historical temperatures to scale temperature increases so that cold streams warm less than warm streams.

8.3: Reference Map




Thurston County Vicinity Map
N
W
E
S
Study Area
County Borders
City Limits
Urban Growth Area (UGA)
Reservation
Park or Public Preserve
State or National Forest
Military Base
1 ½ 0 1
Miles
thurston regional planning council
DISCLAIMER: This map is for general planning purposes only. Thurston Regional Planning Council makes no representations as to the accuracy or fitness of the information for a particular purpose.
Nisqually Indian Reservation
YELM
RAINIER
Nisqually River
Lake Lawrence
La Grande Dam
Alder Dam