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Prepared for the  
Tillamook Estuaries Partnership

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This Vulnerability Assessment was developed with the expert input and guidance from Tillamook Estuaries Partnership staff and stakeholders, as well as numerous local experts who participated in phone calls, interviews, consultations, and a workshop. We want to thank all of the stakeholders and other participants for their expertise and insights.

Names and affiliations of those who guided and contributed are listed at the end of this report.

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# Executive Summary

The Tillamook Estuaries Partnership (TEP) is working to conserve and restore Tillamook County's estuaries and watersheds. Under future climate conditions, the work that the organization conducts will become even more vital than it is already. The priority topics identified in TEP's 1999 Comprehensive Conservation and Management Plan (CCMP) included key habitat loss, water quality, erosion and sedimentation, and flooding. These are expected to remain highly relevant under projected future conditions.

Changing conditions within the Tillamook region have been documented and are expected to accelerate over time with continued greenhouse gas emissions. Due to coastal influences, this region has experienced less warming than the rest of the state and nation. On average, temperatures in Tillamook County have increased 1° F and precipitation has declined 1.8 inches since 1901. Most notably, changes in ocean acidity are already affecting shell formation in marine organisms along this portion of the Oregon coast.

Future projected changes include continued warming of 4-7° F by the 2080s, with more warming in the summer than the winter. Winters are expected to become wetter while summers become drier, with lower streamflow. Both flooding and erosion could increase from larger storms, higher sea level, and bigger waves. Ocean acidification is expected to worsen and rise above a critical threshold needed for calcification and larval development of bivalves by 2030.

These climate stressors and others will interact with existing stressors (such as pollution, land conversion, sedimentation, etc.) to further impact vital resources throughout the Tillamook region. Following the EPA's Vulnerability Assessment framework, specific vulnerabilities to TEP's goals, as set out in the CCMP, were identified and ranked based on their likelihood and the seriousness of their consequences. The timeframe for impacts was also considered.

TEP stakeholders and other local experts provided input on the potential vulnerabilities to TEP's goals. A total of 74 risks were identified and assessed. By far, most risks were related to Water Quality and Key Habitat goals, specifically those to assess, protect and enhance specific types of habitat (riparian, instream, wetland, and estuary and tidal), as well as promoting the beneficial uses of bays and rivers. Risks to improving farm management practices were also identified and assessed.

The most severe near-term climate risks, ranking highest in both likelihood and consequence to the ability of TEP to meet its goals, included the following:

- Potential salmonid declines from warmer water
- Potential salmonid declines due to larger storms that scour redds and displace juveniles
- Salmonids and other native species potentially affected by increased incidence of disease
- Changes in distribution and lower survival of numerous native aquatic organisms
- Negative impacts to shellfish, crabbing, and fishing from ocean acidification
- Broadening and contraction of pools in streams, leading to stranded fish
- Lower survival of newly planted riparian vegetation and failure of restoration efforts
- TEP and partners requiring more funds to keep up with increasing stressors

- Increased water demand leading to exacerbated stress to fish populations
- Negative impacts to conservation efforts from increased installation of erosion control measures in response to larger waves and higher storm surge

Over longer time frames, additional risks are expected to further threaten TEP's ability meet its goals. These included overall changes in species composition and distribution, changes in the extent and distribution of tidal habitats, more runoff and sedimentation of streams, increasing landslides, greater flood damage, and difficulty for agricultural producers to meet water temperature requirements.

In addition to specific risks to TEP's goals, this assessment provides an overview of the expected changes and impacts to forests, water, fish, and wildlife. Climate change was not considered during the development of the initial CCMP in 1996, so the goals that were developed do not necessarily reflect some the greatest threats to the resources of the region. The risks and vulnerabilities identified in this report will allow TEP to incorporate climate change trends and impacts into its current CCMP.

The natural resources of the Tillamook estuaries and watersheds are central to the social and economic well-being of the communities scattered throughout this region. While these resources have always been dynamic, the rate of change is expected to accelerate in coming years and much can be done to increase the overall resilience of the natural systems in this region. This Vulnerability Assessment provides the foundation needed to develop strategies that promote resilience and sustainability of Tillamook County's estuaries and watersheds in the face of ongoing change.



Don Best / Tillamook Estuaries Partnership

# Introduction

Tillamook County is dynamic and diverse, with rivers, bays, and forests that are constantly changing and contributing to the vitality of the region. Healthy and productive forests, estuaries, rivers and pastures are all vital resources for industry, recreation, and conservation. The five bays along this portion of the northern Oregon coast are important resources for local communities. The region supports dairy farming, timber harvest, and oyster production, as well as recreation, fishing, and other tourism. Local residents work collaboratively to maintain functioning ecosystems and biodiversity and sustain local economies and quality of life.

The five bays in Tillamook County include Nehalem, Tillamook, Netarts, Sand Lake, and Nestucca. While all five estuaries share some similar challenges and opportunities, they also retain their unique character because of their natural differences and the distinct communities at the heart of each. Features of each bay, its watershed, and current issues can be found in the State of the Bays Report.<sup>1</sup>



## Tillamook Estuaries Partnership

Tillamook Estuaries Partnership (TEP) works with partners and stakeholders throughout the estuarine watersheds of Tillamook County to address issues such as flooding, wetland restoration, salmon recovery, climate change impacts, water quality, and environmental education. Diverse partnerships are critical to balancing the needs and resources that sustain both people and nature in the region.

The National Estuary Program first designated Tillamook Bay as a “Bay of National Significance” in 1994. In 1999, the Comprehensive Conservation Management Plan (CCMP) was developed, and in 2002, the geographic scope of the Tillamook Estuaries Partnership (TEP) was expanded to include all of Tillamook County’s estuaries and watersheds, from the highest peaks to the estuarine and near shore habitats. The CCMP was organized around four “priority problems” and applied throughout the study area. The four priority problems included Key Habitat, Water Quality, Erosion and Sedimentation, and Flooding.

With a wide array of partners, TEP is working to influence stewardship throughout the watershed, thereby improving water and habitat quality. Voluntary participation and collaboration are the cornerstone of TEP’s ability to meet its goals. TEP collaborates with partners on a variety of project types including habitat restoration, water quality monitoring, and environmental education. TEP, and Tillamook County as a whole, is recognized for positive collaborations that benefit the community overall.

## COMMUNITY and COLLABORATION

### Tillamook’s Shared Values

TEP Stakeholders were asked what they valued most about where they live. Their answers tell the story of what Tillamook County is all about — it’s about people working together. We heard again and again that local residents value their community’s dedication to collaboration. In 1992, when the governor first nominated Tillamook Bay to the National Estuary Program, DEQ Administrator Fred Hanson recognized the region’s history of “working together to take action to address its problems.”

Some of Tillamook County’s shared values include:

- Recreational opportunities (kayaking, hiking, mountain biking, fishing...)
- Wild coastline and un-crowded beaches
- Pristine forests, clean water, and healthy ecosystems
- Sustainable agricultural and forestry industries
- Wild fish
- Rainy winters and drier summers
- Dedication and commitment of people to working together
- Balance between working lands and environmental concerns
- High quality people, with great kids
- Real connection between people and natural resources

These values give us hope. While Tillamook County communities may be facing impacts and changes, some of which are happening quickly, there is a long history of people working together to solve difficult problems and make positive change.

## About This Project

Climate change is already impacting natural ecosystems and human communities around the world. Changes to the Earth's systems are being tracked and documented, and those changes are expected to accelerate over time, especially if greenhouse gas emissions continue to rise. The Oregon Climate Change Research Institute (OCCRI) recently analyzed historical and projected future trends and

impacts for Tillamook County.<sup>2</sup> The OCCRI report shows that changes in temperature have already been documented in the region and warming is expected to continue throughout the century. In addition, the region could receive more precipitation in the form of larger storms, worsening ocean acidification, and sea level rise causing inundation of coastal areas and important ecosystems.<sup>2</sup>

**Figure 1** Map of the Study Area for the Tillamook Estuaries Partnership, including all five estuaries in Tillamook County and their watersheds (image from the Tillamook Estuaries *State of the Bays* report).



Climate impacts are already being felt at the local level. In 2007, the Whiskey Creek Shellfish Hatchery experienced increased mortality among its oyster seed stock, which was attributed to increasing ocean acidity. Large concentrations of warm seawater off the coast are affecting ocean food chains and valuable fisheries. Water temperatures in some streams are nearing those known to be lethal to salmon. Examples like these are expected to continue and worsen over time, unless measures are taken to reduce the impacts.

Coastal communities in Tillamook County are increasingly being threatened by coastal erosion, landslides, larger waves, and ocean flooding. The beach in Neskowin, for example, has receded 150 feet, and property owners are affected by larger waves overtopping revetments.<sup>3</sup> The *Tillamook County Coastal Erosion Hazards Framework Plan* addresses many of the threats to the immediate coastline and local infrastructure, while this report addresses the vulnerabilities of Tillamook County's vital natural resources.

Estuaries around the nation are experiencing similar climate impacts as Tillamook County's estuaries. Thus, the U.S. Environmental Protection Agency (EPA) developed guidance on conducting climate change vulnerability assessments and adaptation strategy development for the National Estuaries Program (NEP). The EPA's Climate Ready Estuaries (CRE) Program released its *Being Prepared for Climate Change* workbook,<sup>4</sup> as well as small grants to support its implementation. TEP received funding for this project from EPA's CRE and the US Bureau of Land Management.

The purpose of this project is to develop a risk-based vulnerability assessment and adaptation strategy for the TEP. This vulnerability assessment report is the first of two reports. It is focused specifically on the goals and objectives of TEP, which are documented in the organization's Comprehensive Conservation and Management Plan (CCMP).<sup>5</sup> The companion report is the climate change strategy report, which lays out specific actions for reducing overall impacts to TEP's goals and the region's vital resources.

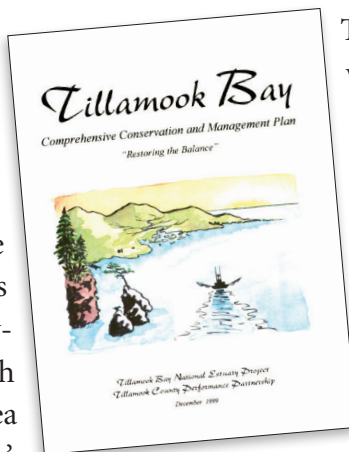




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## History of TEP's Comprehensive Conservation and Management Plan (CCMP)

Completion of a Comprehensive Conservation and Management Plan (CCMP) is the cornerstone of the National Estuary Program and a requirement for the 28 National Estuary Projects. The original Tillamook Bay CCMP was completed in 1999 and initially covered Tillamook Bay. In 2002, with the expansion of TEP's study area to include all of Tillamook County's estuaries and watershed, the CCMP was applied across the broader landscape. With the 2018 revision to the CCMP, the priorities and actions have been updated and reflect their impacts upon all of the estuaries.



The timing of the Vulnerability Assessment was concurrent with the revision of the CCMP and as such references the original CCMP. However, this report and the resulting adaptation strategies are incorporated into the 2018 CCMP and aligned with key habitat, water quality (which now includes erosion and sedimentation), natural hazards (which now includes flooding) and community engagement.

This report focuses on the climate risks associated with the overall goals and action items within the main priority areas (Table 1) recognizing that the CCMP has evolved over the last 19 years.

**Table 1** Specific goals and actions based on the four priority areas identified in the 1999 CCMP. Priority actions are listed in bold. These goals and actions were the focus of the vulnerability assessment.

Priority Area: Key Habitats	Priority Area: Water Quality
<b>GOALS:</b>	<b>GOALS:</b>
<ul style="list-style-type: none"> <li>Assess, protect, and enhance riparian habitat</li> <li>Assess, protect and enhance instream habitat</li> <li>Assess, protect and enhance wetland habitat</li> <li>Assess, protect and enhance estuary and tidal habitats</li> <li>Assess health of salmonid, shellfish, and other aquatic species stocks</li> </ul>	<ul style="list-style-type: none"> <li>Promote beneficial uses of the bays and rivers</li> <li>Improve farm management practices</li> <li>Assess and upgrade wastewater treatment infrastructure</li> <li>Assess and upgrade urban non-point treatment infrastructure</li> <li>Reduce instream temperatures to meet salmonid requirements</li> <li>Reduce instream suspended sediments to meet salmonid requirements</li> </ul>
<b>ACTIONS:</b>	<b>ACTIONS:</b>
<p>HAB-01 Characterize Riparian and Instream Habitat</p> <p>HAB-02 Assess and Map Riparian and Wetland Habitat</p> <p>HAB-03 Prioritize Upland Protection and Enhancement Sites</p> <p>HAB-04 Prioritize Floodplain/Lowland Protection and Enhancement Sites</p> <p><b>HAB-05</b> Protect and Enhance Upland Riparian Areas</p> <p>HAB-06 Protect and Enhance Lowland Riparian Areas</p> <p><b>HAB-07</b> Protect and Enhance Instream Habitat</p> <p>HAB-08 Protect and Enhance Freshwater Wetland Habitat</p> <p><b>HAB-09</b> Control Livestock Access to Streams</p> <p><b>HAB-10</b> Stabilize Streambanks Using Alternatives to Riprap</p> <p><b>HAB-11</b> Encourage Protection and Enhancement on Private Lands</p> <p>HAB-12 Sponsor a Native Vegetation Planting Day</p> <p><b>HAB-13</b> Increase Incentive Program Payments</p> <p><b>HAB-14</b> Ensure Minimum Streamflows</p> <p><b>HAB-15</b> Revise Local Ordinances to Increase Protection of Riparian Areas, Wetlands, and Instream Habitat</p> <p>HAB-16 Effectively Enforce Laws and Regulations</p> <p><b>HAB-17</b> Characterize Estuarine and Tidal Habitats</p> <p><b>HAB-18</b> Prioritize Tidal Sites for Protection and Enhancement</p> <p><b>HAB-19</b> Protect and Enhance Tidal Marsh</p> <p><b>HAB-20</b> Protect and Enhance Eelgrass Habitats</p> <p><b>HAB-21</b> Remove or Modify Ineffective Tide Gates and Floodplain/Lowland Culverts</p> <p>HAB-22 Enhance Large Wood in Estuary</p> <p>HAB-23 Update the Estuary Plan and Zoning</p> <p>HAB-24 Reconnect Sloughs and Rivers to Improve Water Flow</p> <p>HAB-25 Control Burrowing Shrimp Populations</p> <p>HAB-26 Prevent Introduction and Control Exotic Species</p> <p>HAB-27 Effectively Enforce Fishing Regulations</p> <p>HAB-28 Evaluate Commercial and Sport-Fishing Practices</p> <p>HAB-29 Implement Essential Fish Habitat Mandates</p> <p>HAB-30 Support the Oregon Plan for Salmon and Watersheds</p>	<p><b>WAQ-01</b> Define, Implement, and Enforce Pollution Prevention and Control Measures on Agricultural Lands</p> <p><b>WAQ-02</b> Implement Voluntary Farm Management Plans</p> <p><b>WAQ-03</b> Implement Revised Confined Animal Feeding Operation (CAFO) Inspection Procedure</p> <p><b>WAQ-04</b> Use Farm-Specific Agronomic Rates for Nutrient Management</p> <p><b>WAQ-05</b> Provide Farm Management Training Programs</p> <p>WAQ-06 Ensure Adequate Wastewater Treatment Capacity</p> <p>WAQ-07 Expand Sewer Network</p> <p>WAQ-08 Ensure Adequate Urban Runoff Treatment and Retention</p> <p><b>WAQ-09</b> Ensure Properly Functioning On-Site Sewage Disposal Systems</p> <p><b>WAQ-10</b> Implement Temperature Management Strategies</p> <p>WAQ-11 Implement Suspended Sediments Management Strategies</p> <p>WAQ-12 Evaluate Shellfish Growing Area Classifications</p> <p>WAQ-13 Update Shellfish Management Plan Closure Criteria</p>

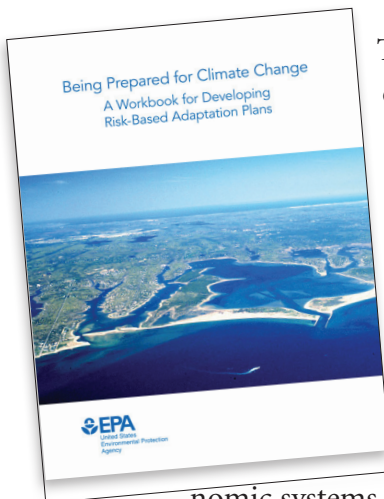
Priority Area: Erosion and Sedimentation	Priority Area: Flooding
<b>GOALS:</b> <ul style="list-style-type: none"> <li>Reduce Sediment Risks from Forest Management Roads</li> <li>Reduce the Adverse Impacts of Rapidly Moving Landslides</li> <li>Improve Channel Features to Improve Sediment Storage and Routing</li> <li>Reduce the Adverse Impacts of Erosion and Sedimentation from Developed and Developing Areas</li> <li>Reduce the Adverse Impacts of Erosion and Sedimentation from Agricultural Areas</li> </ul>	<b>GOALS:</b> <ul style="list-style-type: none"> <li>Improve Floodplain Condition</li> <li>Develop and Maintain a Comprehensive Floodplain Management Plan</li> </ul>
<b>ACTIONS:</b> <p><b>SED-01</b> Implement Road Erosion and Risk Reduction Projects</p> <p><b>SED-02</b> Implement Practices That Will Improve Sediment Storage and Routing</p> <p>SED-03 Reduce Risks in Landslide-Prone Areas</p> <p><b>SED-04</b> Ensure Sufficient Resources to Enforce Forest Practices Act</p> <p>SED-05 Reduce Sedimentation from Non-Forest Management Roads</p> <p>SED-06 Develop, Implement, and Enforce a Stormwater Management Ordinance</p>	<b>ACTIONS:</b> <p><b>FLD-01</b> Develop a GIS-Based, Unsteady State Hydrodynamic Model</p> <p><b>FLD-02</b> Implement Watershed Drainage Modification Projects</p> <p>FLD-03 Elevate and/or Relocate Structures, Livestock and Equipment</p> <p><b>FLD-04</b> Update Existing Floodplain Map</p> <p><b>FLD-05</b> Regulate New Construction and Development in the Floodplain</p> <p>FLD-06 Effectively Clear Mapped Lowland Floodways and Floodplains of Hazardous Materials</p>





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# Methods



This Vulnerability Assessment was conducted following the steps of the EPA's *Being Prepared for Climate Change* workbook. This workbook was developed specifically for the Climate Ready Estuaries program, for resource and watershed managers. The workbook follows a series of steps to lead resource managers to prepare a broad, risk-based vulnerability assessment.

Similar to many other frameworks for climate change vulnerability assessment, the EPA's workbook brings the most up-to-date and robust scientific understanding of climate change together with local expertise of the natural and socioeconomic systems of interest. This allows managers to assess climate change risks and begin to develop strategies to reduce the impacts. Consideration of climate change must be included in all planning processes in order to ensure successful goals and strategies.

This Vulnerability Assessment provides results from Steps 2-5 in the EPA's framework (see below).

## The steps in the EPA's framework are as follows:

1. Communication and Consultation
2. Vulnerability Assessment – Establishing the Context
3. Vulnerability Assessment – Risk Identification
4. Vulnerability Assessment – Risk Analysis
5. Vulnerability Assessment – Risk Evaluation
6. Strategy Development – Establishing the Context
7. Strategy Development – Risk Evaluation: Deciding on a Course
8. Strategy Development – Finding and Selecting Adaptation Options
9. Preparing an Action Plan
10. Monitoring and Review

**Step 1** – The “Communication and Consultation” step is an important component of the process, which is carried out throughout the effort as more people become engaged. A separate report was issued by Climate Access on the outreach and communications strategies for local communities and TEP stakeholders.

**Step 2** – The “Establishing the Context” step involved identifying the specific goals and actions that were to be addressed in the plan. This step limits the scope of the project to only those issues directly pertinent to TEP. Other climate impacts could be relevant to the area, but unless they are directly linked to the goals and actions of TEP, they were not assessed in this effort.



**Figure 2** Vulnerability assessment and adaptation strategy development steps following the EPA's planning framework.

**Step 3** – The “Identifying Risks” step started with a review of “climate stressors.” This review involved the compilation of relevant climate change projections and information to provide an overview of the primary risks to the region. Once the climate stressors were identified, we worked with small groups of experts to brainstorm how those stressors and future climate trends would affect specific goals and actions from TEP’s CCMP. In addition to these experts, a larger group of local stakeholders and experts reviewed and amended the list during the first workshop.

**Step 4** – The “Risk Analysis” step involved assessing each “risk” that was identified in the previous step and characterizing it based on: (1) consequence, (2) likelihood, (3) spatial extent of the

impact, (4) time horizon until the problem begins, and (5) habitat type. During the workshop, stakeholders were asked to work in groups of 6-8 to develop consensus around the risks themselves, as well as their rankings for the evaluation step.

**Step 5** – The “Risk Evaluation” step results in a ranking of risks as High, Medium, or Low, based on the information gathered in the previous step. The risks are organized in a matrix to provide information on the relative roles of consequence and likelihood in their ranking.

The results from this process (Steps 2-5) are the subject of this report. The resulting risk matrix will be used in the development of Adaptation Strategies for TEP (Steps 6-9).







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# Overview of Climate Change Stressors

Identification and evaluation of climate change risks are dependent on a sound understanding of climate trends (both historical and future) and associated impacts. Climate-related impacts were identified and referred to as “climate change stressors.” The climate change stressors were then used as the basis of the Vulnerability Assessment, in order to determine the likely impacts of each stressor on TEP’s goals and objectives in the CCMP.

Research and modeling of climate trends have been conducted for the Tillamook region. A short summary of the available research and information on a variety of climate change trends and impacts was developed into a *Climate Change Primer: Tillamook Estuaries Trends and Projections*. This primer provides an assessment of the projected future trends and level of uncertainty associated with different variables of interest, including temperature, precipitation, extreme events, sea level rise, ocean acidification, and others.

Based on this summary, and informed by the climate change stressors evaluated in the *Regional Framework for Climate Adaptation for Clatsop and Tillamook Counties*, the following list of climate change stressors was used to guide the identification of risks to TEP’s goals and objectives.

**Table 2** Overview of climate change trends for the Tillamook region, from the Climate Change Primer.<sup>7</sup>

## Historical Trends

- Temp. ↑ 1° F from 1901–2009
- Precip. ↓ 1.8 in. since 1901
- Large storms ↑ more frequent
- Sea level ↓ 1 inch since 1925  
(note – sea level rise has been balanced out by local upward land movement)
- Ocean acidification ↑ since pre-industrial levels

## Likely Future Trends

- Temp. ↑ 4–7° F by 2080s
- Summer temp. ↑ 5–8° F by 2080s
- Number of days above 90° F ↑
- Precipitation ↑ 5% by 2080s
- Wetter winters ↑, drier summers ↓
- ↑ flooding and ↑ drought
- Sea level rise ↑ 2–5 ft. by 2100
- Ocean acidification ↑ doubled
- Higher winter ↑ and lower summer ↓ streamflow

- **Warmer summers** – By the end of the century, summer temperatures are expected to increase 5–8° F along the coast and 5–9° F inland.<sup>2</sup>
- **Warmer winters** – By the end of the century, winter temperatures are expected to increase 4–7° F throughout the region.<sup>2</sup>
- **Increased likelihood of extreme heat** – The hottest day of the year could increase by 2–8° F along the coast and 5–9° F inland. The number of days per year above 90° F is expected to increase from close to zero to 3–10 days per year.<sup>2</sup>
- **Increased likelihood of drought** – Precipitation is expected to decline by 3–4% in the spring and 14–19% in the summer. The combination of increasing temperatures and declines in precipitation indicate much drier summer conditions. Greater variability is also a potential problem, leading to more extreme conditions and increased likelihood of drought.
- **Changes in hydrology related to timing** – Stream flow is expected to peak earlier and have larger pulses in winter, potentially increasing erosion and sedimentation. Summer flows are expected to be lower than historical low flows.<sup>6</sup>
- **Changes in hydrology related to water temperature** – Historical monitoring of stream temperatures in the TEP study area show increasing temperatures in recent decades. Continued warming is expected based on projected future lower summer flows,<sup>7</sup> although modeling information specific to water temperature is not available.
- **Increased likelihood of extreme precipitation and floods** – Winter precipitation is expected to increase by 7–13%.<sup>2</sup> The number of days per year with precipitation over 2 inches, as well as the amount of precipitation on the wettest day of the year, are both projected to increase throughout the century.<sup>2</sup>

- **Increased coastal storm surge, wind, and wave height** – Wave heights are increasing about 3 inches/yr.<sup>8</sup> throughout the region. Sea level rise and stronger storms could lead to increased coastal storm surge, wind, and wave heights, but future changes are highly uncertain.
  - **Coastal erosion, landslides, and inundation from sea level rise** – During the last century, global sea levels have risen by about 8 inches, but Oregon’s coastline has been rising due to plate tectonics. In the future, global rates of sea level rise are expected to overwhelm local tectonic trends. Sea level rise in the Tillamook area is expected to increase 2-9 feet by the end of the century, which could also cause inundation of important infrastructure and habitats, as well as erosion and landslides.
  - **Increasing ocean acidification and change in ocean chemistry** – Changes in ocean chemistry have already affected the Oregon coast and will continue to worsen, with ocean acidity roughly doubling by the end of the century. Some shellfish, such as oysters at the Whiskey Creek hatchery are already being affected. An important threshold disrupting calcification and larval development of bivalves is expected to be reached by 2030.<sup>9</sup>
  - **Increase in wildfire frequency and intensity** – Fire return intervals west of the Cascades are expected to decrease by about half (from 80 years to about 47 years), while the total area burned is expected to increase by about 140%.<sup>6</sup>
  - **Change in abundance and distribution of habitat for aquatic and terrestrial wildlife** – Most species are closely linked to a specific “climate envelope” or suite of climatic conditions for which they are well adapted. As those climatic conditions shift on the landscape or within aquatic habitats, species are expected to experience population increases or declines, as well as dispersal to new areas.
  - **Increases in pests, diseases, and invasive species** – Warmer temperatures can lead to increases in pests, diseases, and invasive species. New strains or species are expected to move into the area. Existing pests, diseases, and invasive species may become even more prevalent as conditions become more favorable and native species are less able to compete.
  - **Loss of wetlands and ecosystem services** – Higher temperatures, lower spring/summer precipitation, and inundation from sea level rise could result in loss of important wetlands and their associated ecosystem services. Wetlands act to filter pollutants, reduce downstream flood risk, and provide important habitat for biodiversity.
- \*Note – the last three “stressors” are more accurately considered climate change impacts or responses, yet they are included on this list because of their ubiquitous nature. Range shifts; increasing pests, disease, and invasive species; and loss of wetlands and ecosystem services are largely predicted across regions and ecosystems, in all landscapes.<sup>10</sup>





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# Climate Impacts to Water, Forests, Fish, and Wildlife

The impacts of climate change on the Tillamook estuaries and watersheds were explored specific to four main sectors. These included water resources, forests, wildlife, and fisheries. While climate impacts to all of these sectors are listed below, only a subset of those impacts are relevant to TEP's goals as outlined in the CCMP. This section provides a review of the climate impacts and risks to the four natural resource sectors. In the following section, risks that are relevant to TEP and its primary goals are specifically identified.

## Water Resources

Water resources are the central focus of TEP and its partners. Local communities have close links to both freshwater and brackish waters for their livelihoods (including for transportation and shipping, irrigation, commercial and recreational aquatic species, and tourism, among others) and for quality of life. Inclusion of the five estuaries into TEP's study area has created a focus on collaborative management for functioning ecosystems. Managing water resources for long-term sustainability is vital to the future of the region.

## Existing Stressors to Water Resources

Climate change threatens to exacerbate existing stressors and results in new ones. Existing stressors to water resources in the Tillamook estuaries and their watersheds include:

- algal blooms
- contamination from pollutants, waste, nutrients, or toxins during large storms
- excess sediment deposition from storms and land use
- low river flows due to competing demands
- warmer water temperatures lethal to fish
- bacteria concentrations that affect health and shellfish safety
- dissolved oxygen levels that are often too low to support aquatic life

Climate change poses a serious risk to water resources in the region. Climate impacts to waterways are numerous, including projected changes in timing of flows, variability of flows, water temperature, water chemistry, and extreme events that increase sedimentation. In addition to those direct impacts, climate change threatens to exacerbate existing stressors to water resources (see box).

As temperatures increase and low river and stream flows further exacerbate warming, the protection and enhancement of cooler waters will be vital. Forest cover and riparian vegetation provide shading that maintains lower temperatures. Retaining forest canopies near waterways, identifying areas with deep pools and maintaining flows from higher elevations as long as possible into summer months will all be needed.

**Freshwater** – Tillamook County communities rely heavily on surface water for municipal and agricultural use. Hotter air temperatures are expected to substantially increase the demand for

water in both sectors. Crops and yards alike will need more water for irrigation as evapotranspiration increases. Hotter inland temperatures could also bring more tourism to the coast, at times when stream flow is low, waters are warm, and excess water is not available. Because of the limited storage opportunities in the region, new off-channel storage may need to be considered.

Many streams are currently not meeting the temperature standards for a portion of the summer-time periods. The number of days above temperature targets has been increasing in some reaches of Tillamook, Nehalem, and Nestucca watersheds.<sup>1</sup> This trend is expected to continue unless there are significant efforts to reduce water temperature as the climate warms. All of Oregon's salmonids are affected by warming, but the southern range of chum salmon (*Oncorhynchus keta*) distribution could be most vulnerable, as more variable flows are already starting to affect chum habitat and weaker populations could disappear. Spring chinook (*O. tshawytscha*) are most affected by warmer summer water temperatures.

**Estuaries** – The estuaries of Tillamook County are prized resources in the region. The five estuaries encompass extensive tidal wetlands, open water, mudflats, and other important habitats. The diverse aquatic resources supported by these estuaries are vital for the local and regional economies, as well as overall culture and quality of life for residents.

Climate change impacts to Tillamook County's estuaries include warmer waters, which can lead to increases in disease, parasites, bacteria, and invasive species. Many of the impacts of warmer water are already being felt and are expected to worsen over time. Warmer waters act to exacerbate existing stressors to water quality in estuaries, by allowing bacteria, algae, and invasive species to flourish and by stressing native species that rely on cold and oxygen-rich waters. In addition, warm



Don Best / Tillamook Estuaries Partnership

waters favor the occurrence and spread of wasting disease, which leads to the widespread loss of eelgrass.<sup>11</sup> Eelgrass provides important estuarine habitat for fish, crabs, mollusks, and other wildlife species

Sea level rise impacts include changes in both vertical and horizontal distribution of salt water in estuaries, with deeper tidal channels and inundation of important marsh habitats (vertical), as well as salt water intrusion further into freshwater systems (horizontal), thereby changing the types of plants that are able to grow there. More brackish conditions are expected to develop, while freshwater wetlands become more rare. This affects the types of fish and wildlife that are found in the area. Each estuary is expected to respond differently to sea level rise due to geological and topographical complexity.

## Forests

Tillamook watersheds are dominated by mixed-age forests in the western hemlock zone. Douglas-fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Tsuga pilcata*) are the main species in this type of forest. Other species include big leaf maple (*Acer macrophyllum*), cascara buckthorn (*Rhamnus purshiana*), and red alder (*Alnus rubra*). Wildfire is rare in Oregon's coastal forests (300+ year return intervals), but is characterized by large, stand replacing fires when they do occur. Root diseases like Phellinus, laminated root rot and black stain are the most common causes of tree mortality in the coast range. Swiss needle cast (*Phaeocryptopus gaeumannii*), a prevalent pathogen, and bark beetles can cause smaller scale die-off events.<sup>13</sup>

Some expected impacts of climate change to these forests include increased probability of summer drought, causing reduced tree growth and productivity, more frequent wildfire, and increased disturbance from pathogens, insects, and disease. All of these impacts are exacerbated by human activities that also reduce forest resilience and spread invasive species and pathogens. Invasive species could outcompete native species as warmer temperatures and changes in precipitation patterns cause native species to become stressed. Overall, the region is expected to lose some common species of conifers<sup>14</sup> while deciduous species are expected to expand.

Mature forests are more resistant to climate change as they have an insulating effect.<sup>15</sup> Many older forests, and especially coastal older forests, are likely to experience fewer impacts and a lower rate of change than other forests. These areas could be especially important for providing intact climate refuges, which act to maintain biodiversity as other areas experience accelerated die-off or change. In fact, maximum temperatures in old-growth forests were found to be, on average, 4.5° F cooler than simplified stands.<sup>15</sup>

Many impacts of climate change to the region are poorly understood. For example, summer fog frequency along northern California's coast has declined by about 30% in recent decades.<sup>16</sup> Similar changes in fog along Oregon's coast could reduce the suitability of the coastline for Sitka spruce and hemlock. Douglas fir could expand throughout the coastal zone, but Douglas fir is often limited in the area by pathogens such as Swiss Needle Cast. Foresters may need to plant different species than they have before, such as Coast Redwood along the Oregon coast as its range contracts further south.<sup>14</sup>

## Fisheries

The Tillamook estuaries and rivers that feed them provide vital habitat for numerous species of fish, molluscs, and crustaceans, in many different life stages. Some of the species that are found in the five estuaries of Tillamook County include Dungeness crab (*Cancer magister*), bay clams (numerous species), razor clams (*Silqua patula*), steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), Pacific coast chum salmon (*Oncorhynchus keta*) and Chinook salmon (*O. tshawytscha*). Chinook salmon are especially sensitive to estuarine impacts,<sup>17</sup> but all species rely heavily on a healthy estuary for sustaining populations.<sup>17</sup> Many impacts to estuaries, in addition to climate change, include habitat loss, pesticides, species invasions, and hypoxia from eutrophication. Compared to the rest of the nation, estuaries in northern Oregon have relatively low levels of stressors.<sup>18</sup>

Due to their federal and state listing, as well as their sensitivity to stressors, salmon are a main focus of restoration activities in the Tillamook estuaries and watersheds. Salmon are an iconic species of the region, and have been returning to Tillamook streams and estuaries for millennia. Once thought inexhaustible due to the sheer number of fish, stocks of salmonids began to decline in the early 20th century due to over-harvest and a loss of stream, estuary, and ocean habitat. Current management focuses on restoring key variables of salmonid life history in order to restore and stabilize populations. TEP plays a key role in salmonid assessments, habitat restoration, and fish passage restoration.

Numerous species of salmonids are found in the study area, including Oregon Coast coho, Chinook, Pacific coast chum, steelhead, and coastal cutthroat trout. In the Tillamook, Nestucca, and Nehalem watersheds, coho and Chinook salmon show significant year-to-year variation in spawn-



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ing individuals, but their overall trend appears to be stable or potentially increasing in number.<sup>1</sup>

Salmon are affected by conditions and resources in the open ocean, rivers, and estuaries, giving them high potential exposure to serious climate impacts on numerous fronts.<sup>19</sup> In the ocean, for example, salmon could be affected by declines in preferred foods (juvenile sand lance and smelts, for example) due to warmer waters, harmful algal blooms, or expansion of the dead zone (hypoxia areas).

In rivers and streams, salmon are highly sensitive to water temperature, with many native species found primarily in waters cooler than 63° F.<sup>20</sup> Models indicate that trout habitat in the Pacific Northwest could decline by 8-33% and salmon habitat by 40%, by late century.<sup>20</sup> The State of Oregon has reviewed temperature tolerances and set temperature standards under the Clean Water Act. When temperatures exceed the standards, salmon experience an increased susceptibility to disease, inability to spawn, reduced egg survival, reduced juvenile growth and survival, increased

competition for habitat and food, and inability to compete with species that are better adapted to higher temperatures (often introduced species). Higher temperatures also mean higher metabolic rates in fish (more food needed), and the potential for earlier emergence of juveniles from gravel, with the risk of being flushed down to the bay. Many of the rivers in TEP's study area are not meeting the temperature targets for "core cold water" streams set by the state, and trends show continued warming.<sup>11,1</sup>

In estuarine habitats, climate impacts to salmonids include warmer waters, increases in disease and parasites, changing salinity, and loss of wetlands to sea level rise. In addition, warmer waters may lead to greater occurrence and spread of wasting disease, impacting eelgrass beds, which provide critical nursery habitat for juvenile fish and crustaceans.<sup>11</sup>

Shellfish are also increasingly vulnerable to climate impacts. They are affected by warmer water temperatures, tideflat temperatures, changes in water

depth (area of intertidal zone), changes in salinity, sedimentation, hypoxia, and possibly changes in seagrass distribution. Ocean acidification is also expected to have serious impacts to shellfish. The ocean has absorbed about 25% of anthropogenic CO<sub>2</sub> emissions, which steadily increases the acidity of the water column. Eutrophication, upwelling, and river discharge act to further exacerbate localized acidity levels, which, off the Oregon and Washington coasts, are among some of the highest worldwide.<sup>21</sup>

Impacts of ocean acidification to Pacific oyster fisheries have already cost the shellfisheries of the Pacific Northwest nearly \$110 million. The Oregon and Washington coasts are more vulner-

able than other coastlines due to upwelling of acidic waters that exacerbate acidification caused by climate change.<sup>21</sup>

Impacts of acidification to native shellfisheries (bay clams, Dungeness crabs) are poorly understood, and it is possible that estuarine populations are relatively resilient to acidification. The larval stage could be most vulnerable, but effects of acidification to adult shellfish are poorly known. Human consumption of native shellfish could also become more risky as the virulence and abundance of marine pathogens, such as *Vibrio parahaemolyticus*, increase with warmer temperatures.<sup>22</sup>

In addition to the numerous negative impacts to Tillamook's fisheries, climate change could have some positive impacts. For instance, higher salinity in the lower estuary could lead to expanded size of bay clam and Dungeness crab habitat and greater opportunities for recreational and commercial harvest, yet this benefit is highly speculative.

## Ocean acidification already affecting shellfish industry

The world's largest shellfish hatchery, the Whiskey Creek Shellfish Hatchery, is located on Netart's Bay and provides oyster, clam, and mussel seed for commercial and restoration efforts. In 2007, Whiskey Creek noticed a dramatic increase in oyster larvae mortality and further investigation led to the discovery that incoming seawater was so acidic that shell development was disrupted.

Oyster growers can, to a limited extent, buffer the water with the addition of sodium carbonate, increasing shell development and survivorship of farmed shellfish. In the wild, however, such options are not feasible. As acidity continues to increase, seawater off the coast of Oregon is expected to become so acidic by 2030 that the process of calcification and development in larval mollusks will be disrupted.<sup>22</sup> This could affect the marine food chain in the region.

## Wildlife

Wildlife throughout the globe, and specifically in Oregon, is already responding to climate change and associated impacts. Frogs, for example, are reproducing earlier in the year and many are becoming infected with emergent diseases. Insect development is occurring earlier in the year as well. Land birds are shifting their ranges northwards and migrating earlier. Small mammals have contracted their ranges in some areas, in response to warming temperatures.<sup>20</sup>

The Tillamook estuaries and their watersheds are home to a diversity of fish and wildlife. Natural ecosystems in the study area include coastal rainforests, wetlands (tidal, brackish, freshwater, etc.), estuaries, rivers, grasslands, meadows, and other types. The predicted declines in wetlands and ecosystem services could be devastating to local bio-



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diversity, due to the disproportionate importance of such systems for a wide diversity of species.

Some taxa were identified as more vulnerable than others. Salamanders, for example, have low dispersal capabilities and are heavily impacted by changes in moisture and temperature. The study area is home to both Columbia and Southern Torrent Salamanders (*Rhyacotriton kezeri* and *R. variegatus*). Torrent salamanders are found in coastal coniferous forests and rely on aquatic environments during their larval stage. They have extremely low tolerance for desiccation or warm water, and have been identified as “extremely vulnerable” to climate change in the University of Washington’s Climate Change Sensitivity Database. Torrent salamanders are expected to experience severe climate impacts, including decreased fitness, reduced dispersal, increased

moisture stress, disruption of their lifecycle, and increased exposure to predators.<sup>13</sup>

The Oregon silverspot butterfly (*Speryeria zerene zippolyta*), a state listed species that is limited to only five localities, could be at risk due from climate change and its effects on changing habitats and life history timing. Increases in invasive species with climate change pose a significant risk to the silverspot due to potential displacement of its preferred host plant, the early blue violet (*Viola adunca*). Phenology, or the timing of life history stages, could become misaligned with climate change, as the developmental stages are timed to occur in synchrony with other biological events that are closely linked to climate.<sup>20</sup>

Additional rare and poorly understood species of the coast range are likely to be impacted by



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climate change, but without close monitoring many impacts could go undetected. Changes in small mammal populations could affect Northern Spotted Owls (*Strix occidentalis caurina*) in the region. Neotropical songbirds are expected to change in abundance and distribution with climate change, with some species losing important specialized habitats over time.

In the 2010 State of the Birds report, Oregon's coastal birds were shown to be most vulnerable to climate change, including Marbled Murrelet (*Brachyramphus marmoratus*) and Black Oystercatchers (*Haematopus bachmani*).<sup>23</sup> While Black Oystercatchers are threatened by sea level rise and ocean acidification, Marbled Murrelets are at risk from a loss of important mature coastal rainforest habitat. Fog-dependent spruce hem-

lock forests could be affected by a contraction of the fog belt, which would limit their distribution. Increasing forest pests and disease, such as Swiss needle cast, are expected to increasingly affect stressed trees throughout the region, causing a potential risk to species dependent on mature forests in the area.

Numerous species of wildlife are expected to expand or increase with climate change, especially those that prefer burned, disturbed or more open habitats, such as mule deer (*Odocoileus hemionus*) and Roosevelt elk (*Cervus canadensis roosevelti*). Increases in human-wildlife conflicts could occur if deer and elk are displaced from their natural habitats by fire or other disturbances, and become more common near agricultural areas.



# Vulnerability Assessment

The vulnerability assessment was conducted specific to the goals listed in the TEP's CCMP (see Table 1), which are organized under the four Priority Problems. For each goal, there were often numerous diverse climate change risks that were identified. **While many individual risks may seem similar, they each have a unique “risk pathway,” or chain of events leading up to the risk.** Any point within the “risk pathway” could provide an intervention point, or an opportunity to change the trajectory or outcome by implementing an adaptation action. In order to keep the risk pathways intact, the list of risks provided in this report (Tables 4, 5, and 6) has not been condensed further at this time, even where they overlap considerably, but many will be consolidated for the final Adaptation Strategy report.

## Key to terms

**Risk** = Possibility or threat that a specific goal will not be met due to impacts related to climate change

**Near-term** = impacts or trends already happening or likely to occur by 2020

**Mid-term** = impacts or trends likely to occur 2020-2050

**Long-term** = impacts or trends likely to occur 2050 and beyond

**Likelihood** (which could also be considered *confidence*) is a combination of the level of certainty associated with the model projections (both climate mod-

els and ecological models) and an understanding of the ecological response described by those projections. Model projections for warming, for instance, are more certain than those for precipitation. In addition, the ecological impacts of warmer temperatures on salmonids are well understood compared to some other ecological relationships. Thus, the likelihood assigned to impacts associated with warming is listed as “high.”

**Consequence** is the assessment of the ability of TEP to meet its goal if the projected impact occurs. *High* indicates that the goal will be difficult or impossible to obtain given the projected conditions. *Medium* indicates that the goal will be more difficult to reach, but still achievable. *Low* means that the efforts to reach the goal could be affected, but only in minor ways.

**Spatial extent** is the overall distribution of the projected or anticipated impact or trend across the study area. This is meant to measure how big of a problem a specific risk may pose. If it is confined to a small area, it may be easier to mitigate than if it spans the entire watershed, for instance.

TEP stakeholders and other local experts provided input on the potential vulnerabilities to TEP’s goals. A total of 74 individual risks were identified and assessed to determine vulnerabilities. By far, most risks were related to goals within the priority topics of Water Quality and Key Habitats (Table 3), specifically those to assess, protect, and enhance specific types of habitat (riparian, instream, wetland, and estuary and tidal), as well as promoting the beneficial uses of bays and rivers. Quite a few risks to improving farm management practices were also identified and assessed. Risks to TEP’s ability to meet its goals were organized into a vulnerability matrix based on the time frame, likelihood, and consequence of each risk (Fig. 3).

Further, one of four general management approaches were identified for each risk: Mitigate, Transfer, Accept, or Avoid. Some risks may be able

to be mitigated through the types of activities and actions that TEP already does, or by developing new adaptation actions that address the risk. Others may need to be transferred to other organizations or agencies, even if TEP provides assistance. In many instances, risks may simply be accepted and accommodated with little change to TEP’s overall mission or goals. Finally, risks can be avoided by changing or abandoning specific goals that are associated with those risks, if mitigation is not feasible or practical. The Advisory Committee and TEP staff decided, for each risk, the appropriate approach. Those that were assigned to the “Mitigate” approach are the focus of Tillamook Estuaries Partnership’s Adaptation Strategy report.

The most severe near-term climate risks, ranking highest in both likelihood and consequence to the ability of TEP to meet its goals included the following:

- Potential salmonid declines from warmer water
- Potential salmonid declines due to larger storms that scour redds and displace juveniles
- Salmonids and other native species potentially affected by increased incidence of disease
- Changes in distribution and lower survival of numerous native aquatic organisms
- Negative impacts to shellfish, crabbing, and fishing from ocean acidification
- Broadening and contraction of pools in streams, leading to stranded fish
- Lower survival of newly planted riparian vegetation and failure of restoration efforts
- TEP and partners requiring more funds to keep up with increasing stressors
- Increased water demand leading to exacerbated stress to fish populations
- Negative impacts to conservation efforts from increased installation of erosion control mea-

asures in response to larger waves and higher storm surge

## Priority Problem #1:

### Key Habitats

Much of TEP's work focuses on maintaining and enhancing key habitats throughout the five watersheds. Maintaining a diverse array of healthy, high-quality habitats is essential for local livelihoods and quality of life. TEP and its partners

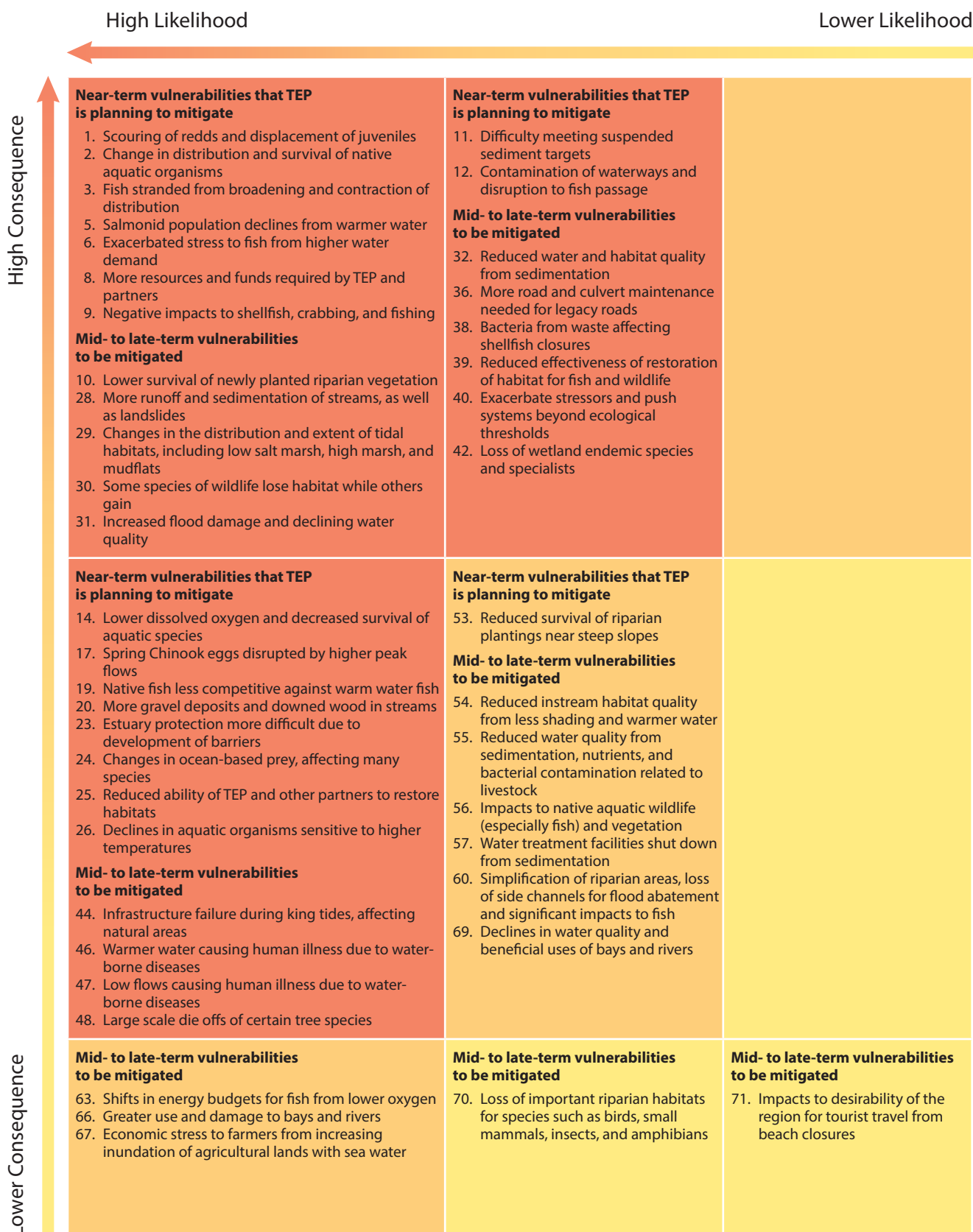
recognize the immense importance of natural resources to the local economy and culture. TEP works with diverse partners to identify, prioritize, conserve, and enhance or restore vital areas and ensure their sustainability over time.

### GOAL: *Assess, protect, and enhance riparian habitat*

Riparian habitats have been heavily modified by forestry practices, fire, agricultural activities, road construction, and urban development. Protecting

**Table 3** The number of identified risks to each of TEP's goals, under each of the four priority topic areas (Key Habitats, Water Quality, Erosion and Sedimentation, and Flooding). A total of 74 risks were identified and assessed. Each risk was ranked as High, Medium or Low based on the likelihood of the risk and the consequence to TEP's ability to meet its goals. The near-term time frame is shown because it could affect the prioritization for developing adaptation actions.

	Higher Risk	Medium Risk	Lower Risk	Near Term
<b>Key Habitats</b>	<b>20</b>	<b>5</b>	<b>1</b>	<b>14</b>
Assess, protect, and enhance riparian habitat	3	0	1	3
Assess, protect and enhance instream habitat	6	2	0	5
Assess, protect and enhance wetland habitat	5	0	0	1
Assess, protect and enhance estuary and tidal habitats	5	1	0	4
Assess health of salmonid, shellfish, and other aquatic species stocks	1	2	0	1
<b>Water Quality</b>	<b>21</b>	<b>12</b>	<b>4</b>	<b>12</b>
Promote beneficial uses of the bays and rivers	10	7	3	5
Improve farm management practices	4	4	1	2
Assess and upgrade wastewater treatment infrastructure	0	0	0	0
Assess and upgrade urban non-point treatment infrastructure	0	1	0	0
Reduce instream temperatures to meet salmonid requirements	4	0	0	3
Reduce instream suspended sediments to meet salmonid requirements	3	0	0	2
<b>Erosion and Sedimentation</b>	<b>7</b>	<b>1</b>	<b>0</b>	<b>4</b>
Reduce sediment risks from forest management roads	3	0	0	0
Reduce the adverse impacts of rapidly moving landslides	1	1	0	1
Improve channel features to improve sediment storage and routing	1	0	0	1
Reduce the adverse impacts of erosion and sedimentation from developed and developing areas	2	0	0	2
Reduce the adverse impacts of erosion and sedimentation from agricultural areas	0	0	0	0
<b>Flooding</b>	<b>1</b>	<b>1</b>	<b>0</b>	<b>0</b>
Improve floodplain condition	1	1	0	0
Develop and maintain a comprehensive floodplain management plan	0	0	0	0



**FIGURE 3** Vulnerabilities of TEP's goals to climate change are evaluated based on the likelihood of each risk and the severity of the consequence. More details on each risk can be found in Tables 4, 5, and 6.



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and enhancing riparian habitat along perennial and seasonal streams throughout the study area is one of TEP's primary approaches for reducing sediment loading and improving water quality and habitats.

Risks to TEP's restoration and habitat management activities were identified based on numerous climate change stressors. The greatest risks include changes in hydrology and the timing of stream flow. Model projections indicate wetter winters and drier summers, leading to potentially higher runoff in the winter, but longer low flow periods and lower base flows in the summertime. These periods of low flows are expected to stress newly planted vegetation as well as established vegetation, thereby reducing overall success.

In addition, changes in the types of plants that can be established and naturally occurring vegetation could lead to a loss of important riparian habitat,

while extreme heat and drought will further stress riparian vegetation and reduce the effectiveness of restoration activities. These impacts could lead to an increase in the level of management and cost required to maintain important riparian habitats. Increased likelihood of wildfire and extreme precipitation and flooding are also expected to reduce the success of restoration activities.

**GOAL:** *Assess, protect, and enhance instream habitat*

Instream habitats for salmonids and other aquatic species have been degraded by numerous human activities throughout the study area. Protecting and enhancing instream habitats is a top priority for TEP throughout the five watersheds. TEP and partners conduct instream enhancement projects with landowners to restore habitat structure, woody debris, fish passage, and stream flow.

Risks to instream habitats were identified based on numerous climate change stressors. Precipitation projections indicate the potential for larger storms and higher precipitation in the winter, although model projections for precipitation are associated with greater uncertainty (more variation among models, with some indicating lower precipitation and others indicating higher precipitation, on average) than those for temperature. Greater winter precipitation and bigger storms could lead to risks to aquatic species, including salmonids, while warmer waters during longer periods of low flow in the summer could increase disease, invasive species and algal blooms, while reducing dissolved oxygen and overall water quality. Overall changes in vegetation, as well as wildfire, are also expected to lead to warmer waters and increased sedimentation.

**GOAL:** *Assess, protect, and enhance wetland habitat*

Wetland conversion to agricultural, urban, road, and other land uses has reduced off-channel rearing habitat for salmonids and altered water tables and stream flow in the floodplains and tidelands. Protecting and enhancing wetlands provides habitat for salmonids and diverse aquatic species, helps reduce flood and sediment impacts, and improves water quality.

Risks to wetland protection and enhancement activities were identified and all fell within the “Higher Risk” category. These included the impacts to the important services that wetlands provide, including flood abatement and specialized habitats. Warmer temperatures are likely to cause declines in many aquatic organisms, while wildfire could damage specialized habitats. Finally, wildlife species composition could change as freshwater wetlands decline and brackish wetlands expand.



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**GOAL:** *Assess, protect, and enhance estuary and tidal habitat*

Estuary and tidal habitats are vital for a variety of species of fish, wildlife, plants, and invertebrates. Large acreages of tidal habitat have been filled, diked and/or drained for various human uses. These activities have significantly reduced rearing habitat for salmonids, and heavy sediment loads have impacted estuary and floodplain/lowland habitat. Protecting and enhancing estuary and slough habitats helps to restore viable populations of salmonids and other species. TEP and numerous partner organizations and landowners work to restore ecological function throughout the watersheds that feed into the five estuaries. From 2010-2015, restoration projects were carried out on more than 1,500 acres of land and in 150 miles of rivers and streams.<sup>1</sup> Extensive restoration efforts have begun to pay off, with improvements to water quality, riparian and tidal wetlands, and likely some native fish and shellfish populations.<sup>1</sup>

Risks to TEP’s continued success in meeting its goals of protecting and enhancing estuary and tidal habitats were assessed. Climate stressors to the estuaries and tidal habitats are extensive and diverse. All identified risks to TEP’s goal for protecting and enhancing estuary and tidal habi-

tats fell into the “Higher Risk” category. They include warming waters that threaten water quality enhancement projects, changes in salinity and nutrients, affecting species distribution and use, sea level rise, leading to higher tides and inundation of important habitats as well as shifts to marine species. Finally, storms and flooding could lead to increases in toxic contamination, or further armoring of coastlines, making it harder to protect estuaries near developed areas.

**GOAL:** *Assess health of salmonid, shellfish, and other aquatic species stocks*

Historically, populations of salmon returning to Tillamook County watersheds were so plentiful that they seemed inexhaustible. In the early 20th century, however, harvest practices combined with rapid loss of stream, estuary, and ocean habitats led to quickly declining numbers of salmon. As our understanding of the complex life history requirements of salmon has increased, efforts to protect and restore habitats has become more targeted and effective. TEP and partners dedicate significant resources to restoration and monitoring efforts that target salmonid populations and habitats.

Both Tillamook and Netart’s bays have significant shellfish industries, and good water quality is a vital component for their success and for human health. In fact, the shellfish fishery is shut down when fecal coliform bacteria exceeds the standard. TEP’s role in supporting shellfish populations is primarily to improve the water quality of rivers and streams that feed the bay, thereby reducing the risk of contamination.

The risk assessment showed that risks to TEP’s goal of assessing the health of salmonids and shellfish were limited to sampling limitations from warmer temperatures, changes in distribution, and changes in timing.

## Priority Problem #2:

### Water Quality

Clean water is important for a variety of uses and natural functions throughout the watersheds of Tillamook County. Much of the drinking water for the region comes from surface water, including streams and rivers. Recreational activities in the bays and rivers also require clean water to protect people’s health and well-being. Salmon and other aquatic organisms require clean water for reproduction and survival. Pollutants, turbidity, and other impacts to water quality in the rivers and bays have been identified and are closely tracked. TEP works with diverse partners and land owners throughout the watersheds to improve water quality through restoration activities and improved land management.

Bacteria and other pathogens from both point and non-point sources present a principal water quality problem. Bacterial pollution threatens public health through the ingestion of contaminated shellfish and water, or direct water contact. It also results in frequent closure of commercial shellfish harvesting areas. Some stream reaches do not meet water quality criteria for bacteria or temperature, and exceed recommended concentrations of suspended solids. Dissolved oxygen concentrations meet water quality standards in most areas of the watersheds except in lowland sloughs, where significant oxygen depression has been observed. Nutrient concentrations do not appear to adversely impact water quality except in lowland sloughs. No acute or chronic effects from toxic substances have been observed or monitored.

TEP and its partners monitor water quality throughout the region and report on progress in the *State of the Bays* report. Many measures of water quality are improving in some or most of the study area, including bacteria levels, dissolved oxygen, and sedimentation. Stream temperatures, however, continue to rise.<sup>1</sup>



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**GOAL:** *Promote beneficial uses of the bays and rivers*

Beneficial uses of the bays and rivers are highly diverse, and include such uses as recreation, commercial harvest, industry, water for residential and agricultural use, and fish and wildlife habitat. Water quality issues affect the myriad of beneficial uses, as well as human health. Water quality issues that are tracked by TEP include bacteria, dissolved oxygen, sedimentation, and stream temperature, among others.

Much of TEP's work to promote beneficial uses of the bays and rivers is focused on improving water quality through ecosystem restoration projects, as well as working with diverse partners to reduce point-source and non-point source pollution from agriculture, development, industry, municipalities, and other land use sources. Partnerships and collaborative efforts are the key to working to reduce pollution inputs to bays and rivers.

Identified risks to promoting the beneficial uses of bays and rivers were extensive. Many climate stressors are expected to impact important economic activities of the region, as well as recreation, and human health. Local infrastructure could also be at risk from numerous climate stressors. Fish and wildlife populations are expected to experience numerous diverse risks as well.

**GOAL:** *Improve farm management practices*

Improving management practices on agricultural and rural lands enhances water and habitat quality, and in many instances, improves farm productivity. When not properly managed, storm runoff and process water from farms carries contaminants into surface water. These contaminants include pesticides, fertilizers, bacteria, pathogens, and organic matter that deplete oxygen, raise turbidity, and cause other adverse impacts on water quality.

Risks associated with TEP's efforts to improve farm management practices included risks to water availability for certain crops or fertilizer, limits to land use from flooding or sea level rise, and the inability to grow certain crops due to precipitation or temperature change. In addition, the ability of farmer to meet water quality standards could become more difficult with warmer temperatures. Wildfire may force wildlife into agricultural areas, increasing wildlife damage to crops.

**GOAL:** *Assess and upgrade wastewater treatment infrastructure*

With or without pretreatment, wastewater discharged directly into the Bay reduces water quality in the Bay. Significant sources of wastewater include treatment plants, industrial facilities, on-site disposal systems, and other sources. Assessing the treatment capacity of industrial, municipal, and residential sources will better focus resources on upgrading inadequate wastewater infrastructure.

TEP has little direct responsibility for assessing and upgrading wastewater treatment infrastructure, but risks to wastewater treatment included increased operating costs due to higher flows and more turbidity.

**GOAL:** *Assess and upgrade urban non-point treatment infrastructure*

Nonpoint source pollution from urbanized areas significantly degrades water quality. The most common water quality problems include increased bacteria, nutrients, sediments, and temperature. Upgrading the infrastructure available to control nonpoint source runoff helps to increase water quality throughout the study area.

TEP has little direct influence over urban non-point treatment infrastructure. However, TEPs work with diverse partners and stakeholders provides an opportunity to affect management in a variety of ways. With larger storms, an increase in non-point source pollution to streams is expected unless more control measures are put in place.

**GOAL:** *Reduce instream temperatures to meet salmonid requirements*

While most other water quality measures have shown improvement over the last five years, many stream reaches in the study area do not meet water quality standards for temperature. Past and present human activities and many types of land and water uses have individually and cumulatively altered the aquatic environment for salmonids.



Improving riparian buffer function and ensuring sufficient streamflow provide the most effective ways to reduce instream temperatures, and those measures will need to become even more effective to combat warming associated with climate change.

Numerous risks to the goal of reducing instream temperatures were identified. Warmer waters and lower flows are expected to be exacerbated by wildfire and higher water demands from agriculture and residential use. Warmer waters affect all ages of salmonids by impacting estuarine resting areas and freshwater, energetic demands, and competition with non-native species.

**GOAL:** *Reduce instream suspended sediments to meet salmonid requirements*

Past and present human activities and land uses have individually and cumulatively increased sediment loading in the environments used by salmon. Reducing instream sediments improves the productivity of spawning salmonids, survival of juveniles, and availability of prey.

Risks to TEPs goal of reducing instream suspended sediments come from numerous climate stressors, including more precipitation and flooding and increases in wildfire, which can affect sedimentation rates.



### Priority Problem #3:

## Erosion and Sedimentation

Erosion and sedimentation throughout the study area can adversely impact the human and natural environment. Impacts may include the loss of spawning and rearing habitat in both fresh and salt water, degradation of other estuarine habitats, changes in the bays' depths and water circulation patterns, and flooding.

### **GOAL:** *Reduce Sediment Risks from Forest Management Roads*

Many roads throughout the study area were built prior to current design standards and pose a number of sediment and other risks to salmonids. Such roads have been identified as a leading potential source of increased sediment. Road sur-

faces, cut and fill slopes, and ditches are generally chronic sediment sources, and poorly designed culverts frequently block fish passage. Failures of road crossing fills or cut and fill slopes produce episodic sediment runoff, usually related to very large precipitation events. Regular maintenance of all roads and upgrading or decommissioning older forest management roads reduce sediment loading to streams in the study area.

Very large precipitation events are projected to increase with climate change. As winters become wetter, and storms become larger, sedimentation could become exacerbated. Identified risks associated with forest management roads include landslides, erosion, and increased costs associated with culvert failure and repair, as well as road maintenance.

### **GOAL:** *Reduce the Adverse Impacts of Rapidly Moving Landslides*

Rapidly moving landslides (debris flows) are natural events that most commonly occur during high duration and intensity rainfall events on slopes steeper than 65%. Vegetation removal may impact debris flows by changing their timing, size, and composition, reducing the value of debris flow deposits in providing fish habitat. Forest practices that maintain the vegetation components that affect either the timing or structural elements of debris flows help to reduce the adverse impacts downstream.

Climate change risks to the goal of reducing the adverse impacts of landslides were based on projections of larger storms and higher frequency and intensity of wildfires, which would cause more sedimentation and increased forest management costs.



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**GOAL:** *Improve Channel Features to Improve Sediment Storage and Routing*

Historically, large wood stored and sorted sediments in streams, creating complex pools with a variety of substrate conditions. Channels also migrated across the floodplain. Dikes, roads, and other development now confine many channels, so that sediments are no longer spread across the floodplain. Rather, they are transported more rapidly through the system and may accumulate more rapidly in the lower reaches of the watersheds. Increased large wood supply and retention and floodplain connectivity improve sediment storage and routing functions.

**GOAL:** *Reduce the Adverse Impacts of Erosion and Sedimentation from Developed and Developing Areas*

Roads and other hardened surfaces contribute to surface water runoff, increasing stream power and bank erosion. Road and building construction and other activities associated with development can also increase erosion by exposing unprotected soil and disrupting natural drainage patterns. Careful erosion controls on construction and development sites reduce the contribution of sediment from urban areas.



**GOAL:** *Reduce the Adverse Impacts of Erosion and Sedimentation from Agricultural Areas*

Erosion in agricultural lowlands typically takes two forms: streambank cutting, and sheet and rill erosion. Bank erosion is commonly associated with the removal of riparian vegetation. Cattle accessing streambanks can also increase erosion when their hooves break up the soil matrix and remove vegetation. Sheet and rill erosion can contribute significant amounts of sediment, including organic material (e.g. livestock feed, bedding and manure) in localized areas. Improved riparian condition and farm management practices reduce sedimentation from agricultural areas.

**Priority Problem #4:**

**Flooding**

The interaction of human activities with dynamic natural systems has increased the magnitude, frequency, and impacts of flood events. These events affect water quality through increased erosion and co-mingling of flood waters with industrial and agricultural products and waste products. Each time a significant flood occurs, water quality and aquatic wildlife are negatively impacted as contaminants enter the system. Flooding is a significant exacerbating factor for many of the goals listed above.

Because this priority problem has few goals listed in the CCMP, few risks were identified during the Vulnerability Assessment process. It is noted, however, that many of the risks identified in the following section are linked to the priority problem of flooding as well as the goals for which they were developed. Thus, the priority problem of flooding was extensively, but somewhat indirectly addressed in this report and the companion report on adaptation strategies.

**GOAL:** *Improve Floodplain Condition*

Floodplain condition in the study area can be optimized to slow the movement of water from the uplands to the estuary, minimize conflicts with human habitation or development, and improve natural ecosystems. TEP and its partners identify, design, and implement projects that delay runoff (e.g., flatten storm hydrographs), increase floodplain storage capacity, and facilitate drainage where appropriate.

**GOAL:** *Develop and Maintain a Comprehensive Floodplain Management Plan*

To date, a comprehensive floodplain management plan has not been developed. Such a plan would facilitate large-scale, cohesive floodplain management across diverse land ownership.



Tech. Sgt. Nick Choy, Oregon National Guard Public Affairs Office

**Table 4** High Vulnerability (based on likelihood and consequence rankings) climate change risks to TEP's goals, sorted in order by time-frame (near-term to long-term) and habitat type.

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Assess, protect, and enhance instream habitat	Increase in extreme precipitation and floods	1. Multiple species, including coho and Chinook, negatively affected by increased scouring of redds (salmon spawning nests), displaced juveniles, and loss of juvenile refuge areas	Increase in large storms and flooding → multiple species, including coho and Chinook, negatively affected by increased scouring of redds (salmon spawning nests), displaced juveniles, and loss of juvenile refuge areas	Instream habitat	Near-term	High	High	Upper end of watershed to top of estuary	Mitigate
Goal – Assess, protect, and enhance instream habitat	Increase in extreme precipitation and floods	2. Change in distribution and survival of native aquatic organisms, including invertebrates, amphibians, and native fish	Larger storms, increased flooding, and increases in peak flow → changes in distribution and survival of native aquatic organisms, including invertebrates, amphibians, and native fish	Instream habitat	Near-term	High	High	Instream habitat throughout study area	Mitigate
Goal – Assess, protect, and enhance instream habitat	Increased incidence of drought, changes in hydrology (timing)	3. Broadening and subsequent contraction of fish distribution may leave fish stranded or vulnerable to predation	Changes in hydrology and the timing of streamflow → higher spring flows → broaden (expand) the distribution of adult spring Chinook and trout → fish become stranded when flows contract, especially in areas that are disconnected or have poor water quality → also more vulnerable to predation at low flows	Instream habitat	Near-term	High	High	Upper end of watershed to top of estuary	Mitigate
Goal – Assess, protect, and enhance instream habitat	Change in hydrology (water temperature)	4. Native salmonids and other aquatic species negatively affected by disease	Warmer waters → increased prevalence and/or virulence of diseases → native salmonids and other aquatic species negatively affected	Instream habitat	Near-term	High	High	Instream areas within study area	Transfer
Goal – Reduce instream temperatures to meet salmonid requirements	Change in hydrology (water temperature)	5. Impacts to all ages of salmonids, from warmer water, causing population declines	Warmer water temperatures → more difficult to meet salmonid temperature requirements → impacts to all ages → population declines	Instream habitat	Near-term	High	High	Upper end of watershed to top of estuary	Mitigate
Goal – Reduce instream temperatures to meet salmonid requirements	Warming – Warmer summers Warmer winters	6. Exacerbated stress to fish from low flows and warmer water	Warmer temperatures → increased water demand for residential and agricultural use → higher water withdrawal from the rivers and creeks → exacerbated stress to fish and other aquatic wildlife from low flows and warmer water	Instream habitat	Near-term	High	High	Upper end of watershed to top of estuary	Mitigate
Goal – Reduce the adverse impacts of erosion and sedimentation from developed and developing areas	Increase in extreme precipitation and floods	7. Greater demand for use of riprap and other measures to combat erosion	More precipitation and flooding → high streamflow → stream bank erosion and road blowouts in many areas where homes are built on the valley floor (large flat floodplains and flat fields are more susceptible to flooding and erosion) → greater demand for use of riprap and other measures to combat erosion	Instream habitat	Near-term	High	High	Instream areas within study area	Transfer
Goal – Assess, protect and enhance estuary and tidal habitats	Warming – Warmer summers Warmer winters	8. More resources and funds required by TEP and partners to enhance estuary habitats	Warmer temperatures → increased need to enhance a variety of estuarine habitats potentially including low-marsh, high-marsh, tidal swamp, eelgrass beds and others → more resources and funds required by TEP and partners to enhance estuary habitat	Estuaries and Tidal Habitats	Near-term	High	High	Estuary and tidal areas within study area	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increase in ocean acidification and change in ocean chemistry	9. Negative impacts to shellfish, crabbing, and fishing industries and recreational opportunities	Increasing ocean acidification and changing ocean chemistry exacerbates the impacts of algal blooms, loss of oxygen, and dead zones → negative impacts to shellfish, crabbing, and fishing industries and recreational opportunities	Estuaries and Tidal Habitats	Near-term	High	High	Upland estuary and near ocean	Mitigate
Goal – Assess, protect, and enhance riparian habitat	Increased incidence of drought, changes in hydrology (timing)	10. Lower survival of newly planted vegetation	Changes in hydrology → longer low flow conditions → warmer water temperature → lower survival of newly planted vegetation and negative impacts to associated fish and wildlife	Riparian habitat	Near-term	High	High	Riparian areas within study area	Mitigate

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Reduce instream suspended sediments to meet salmonid requirements	Increase in extreme precipitation and floods	11. Difficulty meeting suspended sediment targets and disruption of spawning and refuge habitat quality for juvenile fishes	Increased frequency of extreme precipitation and floods → more erosion and sedimentation, especially in areas of industrial timber extraction where slope, road use, maintenance, and timing affect sediments → difficulty meeting suspended sediment targets and disruption of spawning and refuge habitat quality for juvenile fishes	Instream habitat	Near-term	Medium	High	Upper end of watershed to top of estuary	Mitigate
Goal – Reduce instream suspended sediments to meet salmonid requirements	Increase in extreme precipitation and floods	12. Contamination of waterways and disruption to fish passage	Increased frequency of extreme precipitation and floods → infrastructure failures (culverts, holding ponds, etc.) → contamination of waterways and disruption to fish passage	Instream habitat	Near-term	Medium	High	Instream areas within study area	Mitigate
Goal – Improve farm management practices	Increase in extreme precipitation and floods	13. Changes in FEMA designations, which in turn limit land use for agriculture	Increased frequency of extreme precipitation and floods → changes in FEMA designations, which in turn limit land use for agriculture	Agriculture	Near-term	Medium	High	Agricultural lands in Study Area	Transfer
Goal – Assess, protect, and enhance instream habitat	Change in hydrology (water temperature)	14. Lower dissolved oxygen and decreased survival of aquatic species	Higher water temperatures → increased risk of algal blooms and lower dissolved oxygen → survival of aquatic species declines	Instream habitat	Near-term	High	Medium	Instream areas within study area	Mitigate
Goal – Assess health of salmonid, shellfish, and other aquatic species stocks	Change in hydrology (water temperature)	15. Reduced ability of TEP's partners to assess the health of salmonids via sampling	Warmer temperatures → increased stress in salmonids, which could be exacerbated by handling → reduced ability of TEP's partners to assess the health of salmonids via sampling	Instream habitat; Estuaries and Tidal Habitats	Near-term	High	Medium	Study Area	Transfer
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought, changes in hydrology (timing)	16. Overdraft of river water and potential shift to groundwater use during low flow periods	Changes in hydrology and the potential for more frequent and severe low flows → residential and agricultural use could be impacted especially because of a lack of water storage → overdraft of river water and potential shift to groundwater use during low flow periods	Instream habitat	Near-term	High	Medium	Study Area	Transfer
Goal – Promote beneficial uses of the bays and rivers	Increase in extreme precipitation and floods	17. Spring Chinook eggs disrupted by higher peak flows	Increased frequency of extreme precipitation and flooding → fish populations at risk, especially spring Chinook, which already have a small population → eggs disrupted by higher peak flows	Instream habitat	Near-term	High	Medium	Upper end of watershed to top of estuary	Mitigate
Goal – Improve farm management practices	Warming – Warmer summers	18. Higher water demand for grass in summer, while supplies are already limited	Warmer temperatures → higher water demand for corn and grass in summer, while lower summer flows already limit water availability	Instream habitat	Near-term	High	Medium	Agricultural lands in Study Area	Transfer
Goal – Reduce instream temperatures to meet salmonid requirements	Change in hydrology (water temperature)	19. Native fish less competitive against warm water fish such as bass, pan fish, and others	Warmer temperature → increase in invasive aquatic species, which can compete with native species for food resources → native fish less competitive against warm water fish such as bass, pan fish, and others	Instream habitat	Near-term	High	Medium	Streams and rivers throughout the study area	Mitigate
Goal – Improve channel features to improve sediment storage and routing	Increase in extreme precipitation and floods	20. More gravel deposits and downed wood, especially in areas with steep slopes, could have positive impacts to fish habitat in headwater streams, but risk in lowlands near infrastructure	More precipitation and flooding → more gravel deposits and downed wood in streams, especially in areas with steep slopes, could enhance fish habitat	Instream habitat	Near-term	High	Medium	Benefit in headwater streams; Risk in lowlands, near infrastructure	Mitigate
Goal – Reduce the adverse impacts of erosion and sedimentation from developed and developing areas	Increase in extreme precipitation and floods	21. Higher erosion on agricultural lands, requiring more cover crops	Increases in precipitation and flooding → higher erosion on agricultural lands, requiring more cover crops	Instream habitat	Near-term	High	Medium	Instream areas near agriculture	Transfer

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Assess, protect and enhance estuary and tidal habitats	Change in hydrology (timing)	22. Changes in species distribution and habitat use in estuaries (from streamflow changes)	Changes in stream flow timing → changes to the salinity profile of the bay → nutrient cycles and timing affected → changes in species distribution and habitat use	Estuaries and Tidal Habitats	Near-term	High	Medium	Estuary and tidal areas within study area	Accept
Goal – Assess, protect and enhance estuary and tidal habitats	Increased coastal storm surge, wind, and wave height	23. Estuary protection and restoration are more difficult to implement in some areas due to development of barriers	Larger storm surges, wave heights, and flooding → increased risk to residential areas → development of barriers, including dikes and levees → estuary protection more difficult to implement in some areas	Estuaries and Tidal Habitats	Near-term	High	Medium	Estuary and tidal areas near infra-structure and development	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increase in ocean acidification and change in ocean chemistry	24. Changes in ocean-based prey, affecting salmonids, birds, and other species	Increasing ocean acidification and changing ocean chemistry exacerbates the impacts of algal blooms, loss of oxygen, and dead zones → changes in ocean-based prey, affecting salmonids, birds, and other species	Estuaries and Tidal Habitats	Near-term	High	Medium	Upland estuary and near ocean	Mitigate
Goal – Assess, protect, and enhance riparian habitat	Increased incidence of extreme heat	25. Reduced ability of TEP and other partners to successfully implement restoration efforts	Increased likelihood of extreme heat and drought → reduce survival of newly planted riparian vegetation → threaten TEP's restoration efforts, as well as those of other partners and stakeholders	Riparian habitat	Near-term	High	Medium	Riparian areas within study area	Mitigate
Goal – Assess, protect, and enhance wetland habitat	Warming – Warmer summers	26. Declines in aquatic organisms sensitive to higher temperatures	Warmer summer temperatures → warmer water in freshwater wetlands and marshes → declines in aquatic organisms sensitive to higher temperatures (fishes, amphibians and semi-aquatic mollusks, among others) or low oxygenation	Wetlands	Near-term	High	Medium	Wetlands within study area	Mitigate
Goal – Improve farm management practices	Increased incidence of drought, changes in hydrology (timing)	27. Agricultural producers would need to increase restoration activities, reduce water withdrawals, and take more action to meet stream temperature requirements	Lower stream flow → warmer water → declines in water quality → agricultural producers would need to dedicate more resources to meeting water quality targets (temperature, bacteria, turbidity, etc) → increase riparian vegetation protection and restoration, reduce withdrawals, and other practices that keep water higher and/or cooler	Instream habitat	Mid-term	High	High	Agricultural lands in Study Area	Transfer
Goal – Reduce sediment risks from forest management roads	Increase in extreme precipitation and floods	28. More runoff and sedimentation of streams, as well as landslides	Larger storms and more rain on snow events, less snowpack, and more concentrated periods of rainfall, when soils are already saturated → sedimentation exacerbated by wildfire → more runoff and sedimentation of streams, as well as landslides	Instream habitat	Mid-term	High	High	Instream areas within study area	Mitigate
Goal – Assess, protect and enhance estuary and tidal habitats	Sea level rise	29. Changes in the distribution and extent of tidal habitats, including low salt marsh, high marsh, and mudflats	Sea level rise → inundation of important habitats, such as freshwater marsh, changes in the distribution and extent of tidal habitats, including low salt marsh, high marsh, and mudflats	Estuaries and Tidal Habitats	Mid-term	High	High	Estuary and tidal areas within study area	Mitigate
Goal – Assess, protect, and enhance wetland habitat	Change in abundance and distribution of habitats for aquatic and terrestrial species	30. Changes in bird species and other wildlife, with some species losing habitat while others gain habitat	Overall changes in climate conditions → large shifts in wetland types (e.g. freshwater declines and brackish expands) and associated biota → changes in bird species and other wildlife, with some species losing habitat while others gain habitat	Wetlands	Mid-term	High	High	Wetlands within study area	Mitigate
Goal – Assess, protect, and enhance wetland habitat	Loss of wetlands and ecosystem services	31. Increased flood damage and declining water quality	Increased temperatures and incidence of severe drought → loss of wetland vegetation and ecosystem function → reduced flood abatement and sediment trapping qualities in key areas → increased flood damage and declining water quality	Wetlands	Mid-term	High	High	Wetlands within study area	Mitigate
Goal – Assess, protect, and enhance instream habitat	Increase in wildfire frequency and intensity	32. Reduced water quality and instream habitat quality from sedimentation	Increased potential for catastrophic wildfire → reduced water quality and instream habitat quality from sedimentation	Instream habitat	Mid-term	Medium	High	Northern part of the study area has more state and private lands where this would apply more	Mitigate

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Reduce instream temperatures to meet salmonid requirements	Increase in wildfire frequency and intensity	33. Regulatory consequences of not meeting salmonid temperature requirements	Increase in wildfire frequency or severity → exacerbated water temperature issues, due to loss of vegetation along streams → more difficult to meet salmonid temperature requirements → regulatory consequences	Instream habitat	Mid-term	Medium	High	Instream areas within study area	Transfer
Goal – Reduce instream suspended sediments to meet salmonid requirements	Increase in wildfire frequency and intensity	34. Water quality declines and difficulty meeting targets	Increased incidence of wildfire → more sedimentation, erosion, and landslides → negative impacts to water quality → failure to meet targets	Instream habitat	Mid-term	Medium	High	Instream areas within study area	Transfer
Goal – Reduce sediment risks from forest management roads	Increase in wildfire frequency and intensity	35. Higher risk of erosion and landslides	Very dense fuels and an increase in wildfire risk → increased sedimentation of streams and rivers → erosion and landslides throughout entire watersheds	Instream habitat	Mid-term	Medium	High	Instream areas within study area (especially eastern portion, upper elevations, and close to Tillamook Bay – Wilson River, Trask Canyon, and others)	Transfer
Goal – Reduce sediment risks from forest management roads	Increase in extreme precipitation and floods	36. More culvert replacement and repair necessary, as well as more road maintenance, affecting many areas with unmaintained or legacy roads	Increased rainfall and larger storms, with rain instead of snow → higher risk of sediment discharges due to landslides, clogged culverts, erosion and logging activities → more road maintenance and culvert replacement and repair necessary, especially affecting areas with low use, unmaintained or legacy roads	Instream habitat	Mid-term	Medium	High	Instream areas within study area	Mitigate
Goal – Reduce the adverse impacts of rapidly moving landslides	Increase in wildfire frequency and intensity	37. More sedimentation from wildfires at upper elevations	Larger and more catastrophic wildfires → more sedimentation, especially when combined with more precipitation and flooding → upper elevations at higher risk	Instream habitat	Mid-term	Medium	High	Loose organic soils nearer to the coast could burn more, leaving clay, sand-stone, etc. with different erosion hazards	Transfer
Goal – Promote beneficial uses of the bays and rivers	Increase in extreme precipitation and floods	38. Bacteria from waste (esp. manure) flushed into the bays, affecting shellfish closures	Larger storms and changes in hydrology and timing of high flows → bacteria from waste (esp. manure) flushed into the bays, affecting shellfish closures (clams and other shellfish)	Estuaries and Tidal Habitats	Mid-term	Medium	High	Estuaries/ Bays EXCEPT Netarts	Mitigate
Goal – Assess, protect, and enhance riparian habitat	Increase in wildfire frequency and intensity	39. Reduced effectiveness of restoration activities in providing important habitat for fish and wildlife	Increased incidence of wildfire → less riparian vegetation → reduced stream shading → warmer water temperatures → reduced effectiveness of restoration activities in providing important habitat for fish and wildlife	Riparian habitat	Mid-term	Medium	High	Riparian areas within study area	Mitigate
Goal – Improve floodplain condition	Increase in extreme precipitation and floods	40. Exacerbate current issues and push systems beyond ecological and functional thresholds (note: risk is not specific enough)	More extreme precipitation and flooding → declines in ecosystem function → exacerbate current issues and push systems beyond ecological and functional thresholds	Riparian habitat; Wetlands	Mid-term	Medium	High	Riparian areas within study area	Mitigate
Goal – Assess, protect, and enhance wetland habitat	Increase in wildfire frequency and intensity	41. Damage to wetlands in forested areas, such as spruce swamp	Increased incidence of wildfire → damage to wetlands in forested areas, such as spruce swamp	Wetlands	Mid-term	Medium	High	Wetlands within study area	Transfer
Goal – Assess, protect, and enhance wetland habitat	Increased incidence of drought	42. Loss of wetland endemic species and specialists	Changes in temperature and increased likelihood of drought → changes in wetland size, function, and species composition → loss of endemic species and wetland specialists	Wetlands	Mid-term	Medium	High	Wetlands within study area	Mitigate
Goal – Improve farm management practices	Increased incidence of drought	43. Build up of manure due to drought	Increased incidence of drought → irrigation water limited → limitations in crops that can be grown → exacerbates existing problem of build up of manure, taxing available storage	Instream habitat	Mid-term	High	Medium	Instream areas within study area	Transfer
Goal – Assess, protect and enhance estuary and tidal habitats	Sea level rise	44. Inundated areas and habitats affected by infrastructure failure during king tides	Inundation from sea level rise (higher king tides) → dikes, culverts, and other infrastructure potentially fail → inundated areas and habitats affected	Estuaries and Tidal Habitats	Mid-term	High	Medium	All bays and tidally influenced rivers	Mitigate

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought, changes in hydrology (timing)	45. Impacts to desirability of the region for tourist travel from water shortages	Changes in hydrology and increased frequency of low flows coincide with tourist peak season → water shortages and restrictions → hurt the desirability of the region for tourist travel	Estuaries and Tidal Habitats	Mid-term	High	Medium	Estuary and tidal areas within study area	Transfer
Goal – Promote beneficial uses of the bays and rivers	Change in hydrology (water temperature)	46. Increases in algae, bacteria, and other water-borne diseases, which can cause human illness	Warmer temperatures → lower water quality in the bays → increases in algae, bacteria, and other water-borne diseases, which can cause human illness	Estuaries and Tidal Habitats	Mid-term	High	Medium	Coastal areas More agriculture near Tillamook Bay than other estuaries	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought, changes in hydrology (timing)	47. Increases in algae, bacteria, and other water-borne diseases, which can cause human illness	Lower flows and lower water quality in the rivers → increases in temperature → increases in algae, bacteria, and other water-borne diseases, which can cause human illness	Estuaries and Tidal Habitats	Mid-term	High	Medium	Coastal areas More agriculture near Tillamook Bay than other estuaries	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Change in abundance and distribution of habitats for aquatic and terrestrial species	48. Large scale die offs of certain tree species that are unfit for the new climatic conditions	Overall changes in climate conditions → tree species distributions and abundance to change over time → certain species unfit for the new climatic conditions → large scale die offs	Forests	Long-term	High	Medium	Study Area	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increase in wildfire frequency and intensity	49. Negative impacts to the forestry industry from large and catastrophic fires	Increasing frequency of wildfire → negative impacts to forestry industry from large and catastrophic fires (long fire return intervals mean substantial amount of fuels have built up)	Forests	Long-term	High	Medium	Study Area	Transfer

**Table 5** Medium Vulnerability (based on likelihood and consequence rankings) climate change risks to TEP's goals, sorted in order by time-frame (near-term to long-term) and habitat type.

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought	50. Overall loss of available fish habitat reduces angling opportunities	Increased incidence of drought → fish habitat reduced and distribution contracts → headwaters stream fish forced to move downstream → overall loss of available habitat reduces angling opportunities	Instream habitat	Near-term	Medium	Medium	Instream areas within study area	Transfer
Goal – Reduce the Adverse Impacts of Rapidly Moving Landslides	Increase in extreme precipitation and floods	51. Forest managers required to protect more area from logging that removes roots, disturbs slopes, and increases risk	More extreme storms and flooding → more landslides, especially on slopes >70% gradient with shallow soil or bed-rock with soil on top → land managers required to protect more area from logging that removes roots, disturbs slopes, and increases risk	Instream habitat	Near-term	Medium	Medium	Instream areas within study area	Transfer
Goal – Assess, protect and enhance estuary and tidal habitats	Increase in extreme precipitation and floods	52. Increased toxics from flooded contaminated sites and redistribution of toxic hotspots	Larger storms and more flooding → increased toxics from flooded contaminated sites (such as petrochemicals, pesticides, etc.) and redistribution of toxic hotspots	Estuaries and Tidal Habitats	Near-term	Medium	Medium	Estuary and tidal areas within study area	Transfer
Goal – Assess, protect, and enhance riparian habitat	Increase in extreme precipitation and floods	53. Reduced survival of riparian plantings near steep slopes	Increase in extreme precipitation and floods → restoration efforts affected → reduced survival of riparian plantings near steep slopes	Riparian habitat	Near-term	Medium	Medium	Riparian areas within study area	Mitigate
Goal – Assess, protect, and enhance instream habitat	Change in abundance and distribution of habitats for aquatic and terrestrial species	54. Less shading and warmer water, reduced instream habitat quality	Overall changes in climate → change in types of dominant vegetation naturally occurring in riparian areas, as well as those used in restoration → less shading and warmer water, reduced instream habitat quality	Instream habitat	Mid-term	Medium	Medium	Riparian areas within study area	Mitigate
Goal – Assess, protect, and enhance instream habitat	Increased incidence of extreme heat	55. Reduced water quality from sedimentation, nutrients, and bacterial contamination related to livestock	Higher temperatures → more instream use by livestock as cattle become heat stressed and need more water → reduced water quality from sedimentation, nutrients, and bacterial contamination	Instream habitat	Mid-term	Medium	Medium	Instream areas near livestock	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought	56. Impacts to native aquatic wildlife (especially fish) and vegetation	Drought → lower water availability → exacerbates already low flows and high water temperatures → impacts to native aquatic wildlife (especially fish) and vegetation	Instream habitat; Estuaries and Tidal Habitats	Mid-term	Medium	Medium	Estuaries, tidal areas, and instream habitats in the study area	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increase in extreme precipitation and floods	57. Water treatment facilities shut down from too much sedimentation in rivers and creeks	Increase in extreme precipitation and floods → increased sediments into rivers and creeks coming from (1) logged areas (2) landslides and (3) unmaintained roads → water treatment facilities and intakes need to be shut down, requiring alternative sources such as groundwater	Instream habitat	Mid-term	Medium	Medium	Instream areas within study area	Mitigate
Goal – Assess and upgrade urban non-point treatment infrastructure	Increase in extreme precipitation and floods	58. More stormwater control measures required due to non point-source pollution entering streams	Greater storm runoff → increase in the amount of non point-source pollution from fields, roads, etc. that enters streams → more stormwater control measures needed	Instream habitat	Mid-term	Medium	Medium	Study Area	Transfer
Goal – Promote beneficial uses of the bays and rivers	Increased coastal storm surge, wind, and wave height; sea level rise	59. Reduced beach and shore access for recreational opportunities and habitat restoration due to new armoring and other treatments to prevent erosion	Inundation from sea level rise, higher waves, and storm surge → increased coastal erosion → changes in sediment budget and increased engineering (armoring) to protect development → Reduced beach and shore access for recreational opportunities and habitat restoration due to new armoring and other treatments to prevent erosion	Estuaries and Tidal Habitats	Mid-term	Medium	Medium	Coastal areas in study area	Transfer
Goal – Improve floodplain condition	Increase in extreme precipitation and floods	60. Simplification of riparian areas, loss of side channels for flood abatement and significant impacts to fish	More precipitation and flooding → modification (raise heights) of dikes to prevent overtopping, as well as dredging → simplification of riparian areas and stream channels → loss of side channels for flood abatement and significant impacts to fish	Riparian; Instream habitat	Mid-term	Medium	Medium	Riparian areas within study area	Mitigate

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal – Improve farm management practices	Increased incidence of extreme heat	61. Agricultural producers may need to plant alternatives	Extreme heat → certain types of grasses may not survive → agricultural producers may need to plant alternatives	Agriculture	Mid-term	Medium	Medium	Agricultural lands in Study Area	Transfer
Goal – Improve farm management practices	Increase in extreme precipitation and floods	62. Shorter agricultural growing season due to waterlogged grasses	Increases in winter precipitation → winter waterlogged grasses → shorter growing season	Agriculture	Mid-term	Medium	Medium	Agricultural lands in Study Area	Transfer
Goal – Assess health of salmonid, shellfish, and other aquatic species stocks	Increased incidence of extreme heat	63. Higher densities and less oxygen lead to shifts in energy budgets for fish	Rising temperatures and extreme heat during summer → re-distribution of fish populations (distribution shrinks and fish in the headwaters are forced to move downstream) → increasing fish density (combined with oxygen declines) → shifts energy budgets from foraging to respiration and immune system response	Instream habitat	Mid-term	High	Low	Instream areas within study area	Mitigate
Goal – Promote beneficial uses of the bays and rivers	Increased incidence of drought, changes in hydrology (timing), increase in extreme heat	64. More angling closures in recreational fisheries	Warmer water temperatures → more angling closures in recreational fisheries, which already occur during drought and extreme heat	Instream habitat	Mid-term	High	Low	Instream areas within study area	Transfer
Goal – Assess health of salmonid, shellfish, and other aquatic species stocks	Sea level rise	65. More marine/brackish conditions favoring marine organisms in estuaries	Sea level rise → saltwater intrusion into estuaries → shift from freshwater marsh to saltwater marsh → more marine/brackish conditions favoring marine organisms	Estuaries and Tidal Habitats	Mid-term	High	Low	Estuary and tidal areas within study area	Accept
Goal – Promote beneficial uses of the bays and rivers	Warming - Warmer summers Warmer winters	66. Greater need for restoration activities for bays and rivers due to use	Warmer air temperatures → increased recreation and use of bays and rivers, especially with extreme temperatures → increased traffic, pollution, and trash → more degradation of water quality in bays and rivers → greater need for restoration activities for bays and rivers	Estuaries and Tidal Habitats	Mid-term	High	Low	Estuary and tidal areas within study area	Mitigate
Goal – Improve farm management practices	Sea level rise	67. Economic stress to farmers from increasing inundation of agricultural lands with sea water	Increasing sea level and storm surge → near-shore farming operations negatively impacted by amount of time that fields are useable (ex. Tillamook cow pastures inundated more frequently) → increasing inundation of agricultural lands with sea water → economic stress to farmers	Agriculture	Mid-term	High	Low	Coastal agricultural lands	Mitigate
Goal – Improve farm management practices	Increase in extreme precipitation and floods	68. Increased build up of manure from increased winter precipitation	Increased winter precipitation → fields too wet to plant in the spring → delayed planting → exacerbates existing problem of build up of manure, taxing available storage	Agriculture	Mid-term	High	Low	Agricultural lands in Study Area	Transfer
Goal – Promote beneficial uses of the bays and rivers	Loss of wetlands and ecosystem services	69. Declines in water quality and beneficial uses of bays and rivers	Loss of wetlands and ecosystem services such as flood abatement, sediment control, and filtration of pollutants → water quality declines, affecting all beneficial uses	Wetlands; Estuaries and Tidal Habitats	Long-term	Medium	Medium	Study Area	Mitigate

**Table 6** Low Vulnerability (based on likelihood and consequence rankings) climate change risks to TEP's goals, sorted in order by time-frame (near-term to long-term) and habitat type.

TEP CCMP Goal	Climate Stressor	Final Risk	Risk Pathway	Habitat	Time horizon	Likelihood (L, M, H)	Consequence (L, M, H)	Spatial Extent	Approach
Goal - Assess, protect, and enhance riparian habitat	Change in abundance and distribution of habitats for aquatic and terrestrial species	70. Loss of important riparian habitats for species such as birds, small mammals, insects, and amphibians	Changes in overall climate and stream conditions → change in abundance and distribution of riparian vegetation → loss of habitat for many species of wildlife (birds, amphibians, insects, etc.) dependent on specific conditions → loss of disproportionate amount of biodiversity	Riparian habitat	Mid-term	Medium	Low	Riparian areas within study area	Mitigate
Goal - Promote beneficial uses of the bays and rivers	Change in hydrology (timing)	71. Impacts to desirability of the region for tourist travel from beach closures	Low flows coincide with tourist peak season → warmer waters → bacteria outbreaks (such as E. coli) and more beach closures → hurt the desirability of the region for tourist travel	Estuaries and Tidal Habitats	Mid-term	Low	Low	Coastal areas, Rockaway, Neskowin, Oceanside, Smart sands	Mitigate
Goal - Promote beneficial uses of the bays and rivers	Increased coastal storm surge, wind, and wave height	72. More frequent limits on commercial and recreational use of bays from storms	Increase in coastal storm surge, wind, and wave height → more frequent limits on commercial and recreational use of bays from storms	Estuaries and Tidal Habitats	Mid-term	Low	Low	Bays and estuaries in the study area	Accept
Goal - Improve farm management practices	Increase in wildfire frequency and intensity	73. Increased occurrence of human-wildlife conflicts and crop damage	Increased incidence of wildfire → elk and other wildlife to move into agricultural areas → increased occurrence of human-wildlife conflicts and crop damage	Agriculture	Mid-term	Low	Low	Agricultural lands in Study Area	Transfer
Goal - Promote beneficial uses of the bays and rivers	Sea level rise	74. Saltwater intrusion impacts to residential and agricultural groundwater users	Sea level rise → saltwater intrusion into groundwater → impacts to residential and agricultural users	Agriculture; Residential	Long-term	Low	Low	Residential and agricultural lands near coast	Transfer





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## Conclusions and Next Steps

TEP works closely with many partners in the region to balance the diverse needs of the local community, including cultural, social, economic, and natural resource sectors. Healthy and functioning natural systems are a vital part of the local community across the study area, and TEP and its partners are committed to sustaining those natural systems as well as the communities that rely on them. The need for balance drives multiple organizations, businesses, and individuals to all work together to create a sustainable landscape.

Climate change poses a significant threat to the resources of Tillamook County, and fundamentally changes how they need to be managed over time. Following the EPA's *Being Prepared for Climate Change* framework, this effort included the development of specific adaptation strategies and preparation of a Climate Change Adaptation Plan for the region. Potential adaptation strategies were developed and reviewed by this project's Advisory Committee, local stakeholders and relevant experts. These strategies were evaluated based on a list of cri-

teria, including the effectiveness of the approach, feasibility, cost, potential co-benefits to community sectors (such as human health, economics, or safety), and the level of influence TEP has to implement each strategy.

This Vulnerability Assessment revealed that many of the risks to the region's forests, wildlife, water, and fish are not addressed within the EPA's framework focused on TEP's goals. This is because many climate change related threats to the region's resources were not foreseen when the CCMP was created in 1999. Other risks were addressed in the CCMP, yet their impacts have become greatly exacerbated by climate change, and the current goals may be inadequate to address them. Due to changes in the stressors that affect the region's resources, current and future impacts and trends associated with climate change are addressed in the revised CCMP.

One of the four priority problems, *Flooding*, for example, only resulted in two risks being identified even though increased frequency of large storms and flooding, as well as coastal flooding associated with larger waves and sea level rise, are projected to increase. In 1999, when the original priority problems were developed, sea level rise and increasing wave height and storms surge were not considered part of this priority problem. Flooding is already a serious issue in the region, affecting not only natural resources, but also infrastruc-

ture including roads, homes, and water treatment facilities. In the revised CCMP, TEP considered natural hazards including flooding in the development of its actions and looks at these hazards through the lens of these additional factors.

Additional threats to the region's resources that stem from climate change include ocean acidification and its impacts on a wide variety of species and associated economic and social values; increasing threats associated with pests, disease, and invasive species; and the secondary impacts associated with peoples' *response* to climate change such as increasing use of pesticides and herbicides, increased demand for renewable energy, and increasing installation of flood control structures.

Numerous climate change adaptation plans have been developed for the northern coast of Oregon. TEP's climate change adaptation plan highlights where adaptation strategies from more than one plan can work together and where new partnerships could be developed. As different sectors and organizations continue to develop strategies for climate change resilience, it is vital that they continually collaborate, reassess, and develop co-benefits across sectors and diverse community interests. Because of TEP's role as a community hub that already brings diverse partners together, it is natural to also play a role in coordinating and collaborating for overall climate change resilience.

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