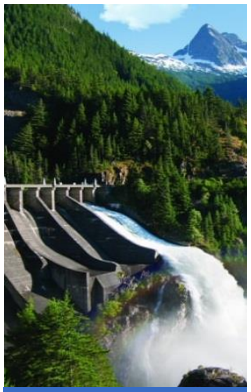
Seattle City Light
Climate Change Vulnerability Assessment and Adaptation Plan


Shoreline Infrastructure


Electricity Demand


Transmission and Distribution


Hydroelectric Project Operations


Fish Habitat Restoration

Prepared by Crystal Raymond
Climate Adaptation Strategic Advisor
Environmental Affairs and Real Estate Division
For more information contact: Crystal.Raymond@Seattle.gov | (206)-386-1620

Seattle City Light

Executive Summary

Goals and Objectives

In 2013, Seattle City Light's Strategic Plan established a Climate Initiative with two primary objectives: (1) research the impacts of climate change on the utility and (2) develop an adaptation plan with strategic actions to minimize these impacts. City Light's Climate Change Vulnerability Assessment and Adaptation Plan summarizes the impacts of climate change on the utility and identifies potential actions to reduce vulnerability and increase resilience.

The goal of adapting or preparing for a changing climate is to ensure that Seattle City Light can continue to meet its mission to produce and deliver environmentally responsible, safe, low-cost, and reliable power as the climate changes. A changing climate is one consideration in designing the electric utility of the future. Therefore, a second goal of adaptation planning is to increase institutional knowledge of the risks of climate change, as well as actions that can reduce these risks, so that the utility and its employees can make informed decisions regarding the need to prepare.

What is adaptation planning and why plan for climate change now?

Climate change adaptation, also referred to as *preparedness*, *readiness*, and *resilience*, is the process of identifying and implementing actions that reduce vulnerability to the expected impacts of climate change. To some people, climate change may seem like a far-off risk that will not affect the utility in the near-term. It can be tempting to label climate change as only a "challenge for future generations," but this is not the case for several reasons:

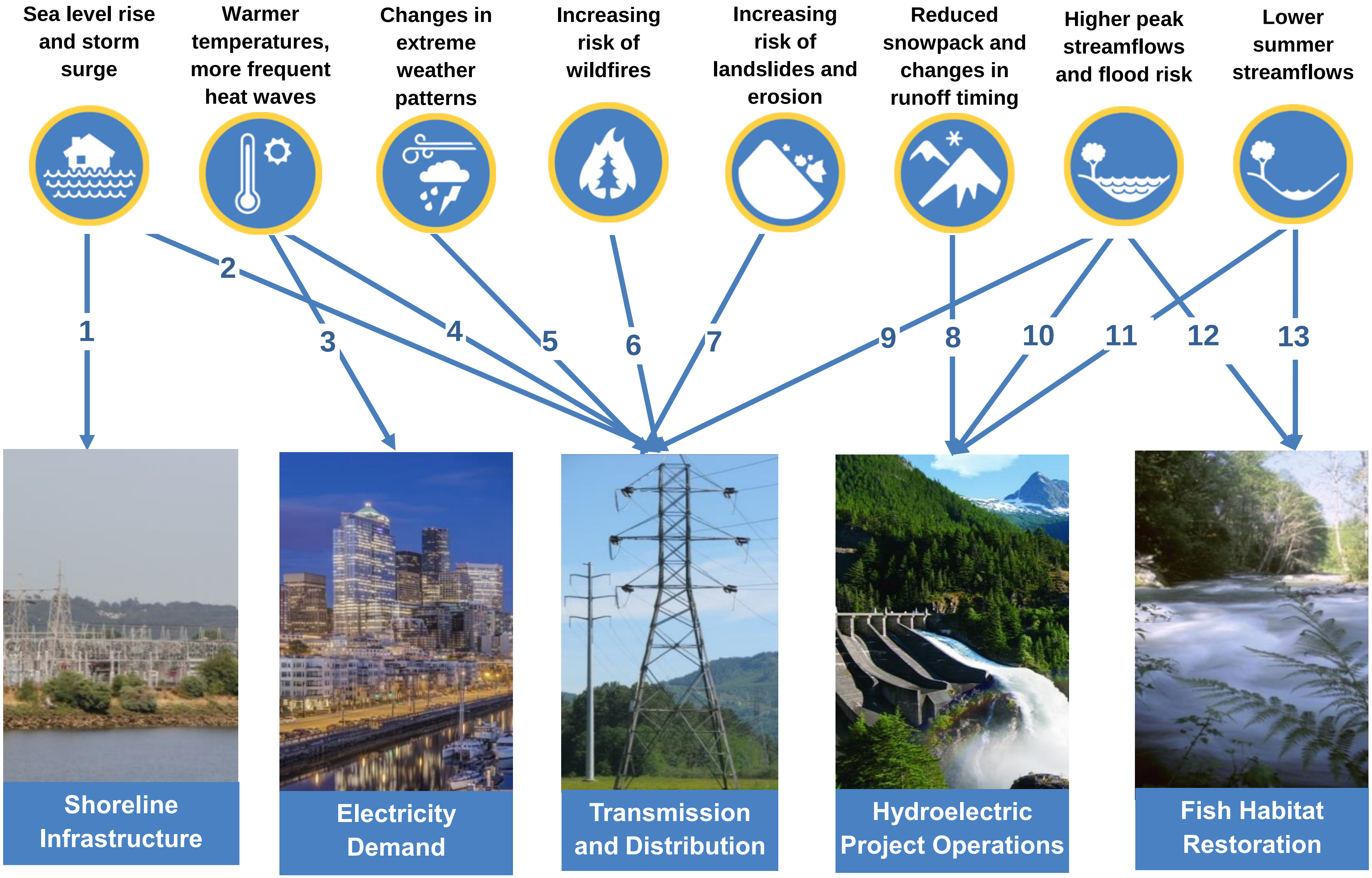
1. Climate change is happening now. Temperatures have warmed and the effects of these warmer temperatures on snowpack, heat waves, and extreme weather have been detected globally, nationally, and locally in Washington.
2. Impacts are expected to intensify and new impacts will emerge over the 21st century, regardless of reductions in emissions of greenhouse gases that cause global warming.
3. Decisions are being made today that will shape the resources and infrastructure of the utility for decades into the future when the impacts of climate change will intensify.
4. It will be easier and more cost-effective to consider the impacts of climate change in the planning and design of new infrastructure and power resources now than it will be to retrofit infrastructure or replace resources once the impacts of climate change intensify.

How does adaptation planning differ from climate change mitigation?

In the context of climate change, mitigation is the reduction of greenhouse gas emissions that cause global warming. Mitigation actions focuses on slowing and reducing the magnitude of change in the climate. Mitigation has the potential to reduce changes in the climate in the latter half of the 21st century, but for the next few decades, adaptation is necessary to prepare for the inevitable impacts of climate change.

Climate Change Vulnerability Assessment

This vulnerability assessment describes eight changes in the climate, and resulting changes in natural hazards and streamflow that could affect five aspects of City Light's operations and infrastructure. Together they create thirteen impact pathways through which the utility could experience climate-related risks to its mission.



Sea level rise and storm surge

Warmer temperatures, more frequent heat waves

Changes in extreme weather patterns

Increasing risk of wildfires

Increasing risk of landslides and erosion

Reduced snowpack and changes in runoff timing

Higher peak streamflows and flood risk

Lower summer streamflows

Shoreline Infrastructure

Electricity Demand

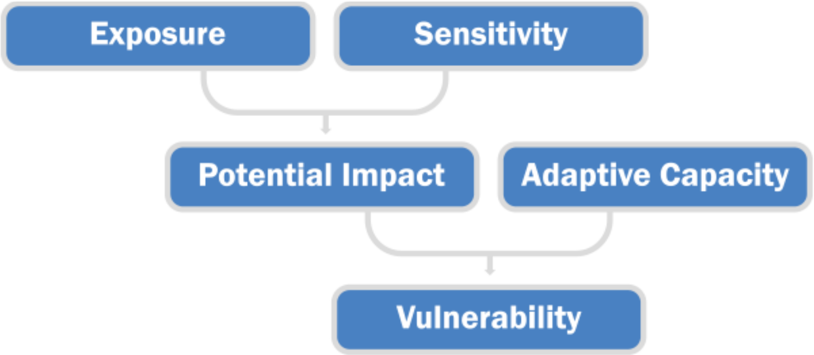
Transmission and Distribution

Hydroelectric Project Operations

Fish Habitat Restoration

For each of the thirteen impact pathways, this assessment describes (1) exposure to expected changes in the climate, (2) inherent system sensitivity to these changes, and (3) existing policies and operations that increase the utility's capacity to adapt to a changing climate. The list of impacts is not exhaustive and some impacts could interact to compound consequences.

The components of a climate change vulnerability assessment.



Results of the vulnerability assessment are summarized in Table 1. For exposure, red and yellow circles indicate impacts with higher exposure. Exposure can increase as climate change intensifies with time, therefore exposure is ranked for the near future (2030s) and far future (2050s). For sensitivity and capacity to adapt, red and yellow circles indicate impacts for which City Light has can reduce sensitivity or enhance the organizations capacity to prepare for impacts. The goal of implementing adaptation actions is to shift sensitivity and adaptive capacity from yellow or red to green.

Potential Adaptation Actions

This plan describes potential adaptation actions that could be implemented to prepare for the impacts of climate change. Adaptation actions are intentional changes in policies and operations, or upgrades to infrastructure designed specifically to reduce vulnerability and increase resilience. Preparing for climate change be accomplished through four general strategies: (1) enhancing capacity to adapt, (2) hardening infrastructure, (3) increasing resilience, or (4) retreating from exposed locations or resources. This plan describes potential adaptation strategies to reduce the consequences of the thirteen impacts described previously. Most adaptation strategies identified in this plan will need to be refined in more detail for specific projects, plans, or decision. Some actions involve conducting more detailed assessments of the impacts of climate change on specific assets and resources to better determine the most appropriate and cost-effective adaptation actions.

Photo: The Goodell Fire burning near the town of Newhalem, Washington in August 2015. Actions by Seattle City Light, the National Park Service, and others were required to protect transmission lines, generation facilities, and people living and working in the Seattle City Light towns of Newhalem and Diablo.

Table 1. Summary of vulnerability and potential magnitude of climate change impacts to Seattle City Light

Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability			Potential Magnitude** of Impact to				Ref. Pages
			Exposure	Sensitivity	Capacity to Adapt	Financial Cost	Safety	Reliability	Environmental Responsibility	
Coastal properties	Tidal flooding due to higher storm surge and sea level rise	2030	○	🟡	🔴	Low	–	–	Low	18-24
		2050	🟡			Mod	–	–	Low	
Transmission and distribution	Tidal flooding and salt water corrosion due to higher storm surge and sea level rise	2030	○	○	🟡	Low	–	Low	–	18-24
		2050	🟡			Low	–	Low	–	
	Reduced transmission capacity due to warmer temperatures	2030	🟡	○	○	Low	–	Low	–	34-39
		2050	🟡			Low	–	Low	–	
	More frequent outages and damage to transmission and distribution equipment due to changes in extreme weather	2030	○	🟡	🟡	Low	Low	Low	–	40-46
		2050	○			Low	Low	Low	–	
	More damage and interruptions of transmission and generation due to wildfire risk	2030	🟡	🔴	🟡	High	High	Med	–	47-53
		2050	🔴			High	High	Med	–	
	More damage to transmission lines and access roads due to landslide risk	2030	🟡	🟡	🟡	Med	Low	Med	–	54-58
		2050	🟡			Med	Low	Med	–	
	More damage and reduced access to transmission lines due to more frequent river flooding and erosion	2030	🟡	🟡	🔴	Med	–	Low	–	71-74
		2050	🔴			High	–	Low	–	
Energy Demand	Reduced electricity demand for heating in winter due to warmer temperatures	2030	🟡	🟡	🔴	Med	–	Low	–	25-33
		2050	🔴			High	–	Low	–	
	Increased electricity demand for cooling in summer due to warmer temperatures	2030	○	○	🔴	Low	–	Low	–	25-33
		2050	🟡			Med	–	Med	–	

*The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.

**Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

Table 1 cont. Summary of vulnerability and potential magnitude of climate change impacts to Seattle City Light

Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability			Potential Magnitude** of Impact to				Ref. Pages
			Exposure	Sensitivity	Capacity to Adapt	Financial Cost	Safety	Reliability	Environmental Responsibility	
Hydroelectric Project Operations	Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (snow-dominated watersheds)	2030	🟡	🔴	🟡	Low	—	—	Low	59-70
		2050	🔴			High	—	—	Med	
	Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (mixed-rain-snow watersheds)	2030	🔴	🔴	🟡	Low	—	—	Med	59-70
		2050	🔴			Med	—	—	Med	
	More frequent spilling at hydroelectric projects due to higher peak streamflows (snow-dominated watersheds)	2030	○	🟡	○	Low	—	—	Med	75-79
		2050	🟡			Low	—	—	Med	
	More frequent spilling at hydroelectric projects due to higher peak streamflows (mixed-rain-and-snow watersheds)	2030	🟡	🟡	🟡	Low	—	—	Med	75-79
		2050	🔴			Med	—	—	Med	
	Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (snow-dominated watersheds)	2030	🟡	🟡	🟡	Med	—	—	Low	83-87
		2050	🔴			High	—	—	Mod	
	Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (mixed-rain-and-snow watersheds)	2030	🔴	🔴	🟡	Med	—	—	Med	83-87
		2050	🔴			High	—	—	Med	
Fish Habitat Restoration	Increased difficulty meeting objectives for restoring habitat for fish species due to lower low flows.	2030	🟡	🟡	🟡	Low	—	—	Med	88-90
		2050	🔴			Low	—	—	High	
	Increased difficulty meeting objectives for restoring habitat for fish species due to higher peak flows.	2030	🟡	🟡	🟡	Low	—	—	Med	80-82
		2050	🔴			Low	—	—	High	

*The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.
**Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

Shoreline Infrastructure

Shoreline Infrastructure

The city of Seattle is located along Puget Sound, which has experienced tidal flooding in the past associated with high tides and is exposed to sea level rise. City Light owns several properties near Puget Sound and is a "potentially responsible party" in the Duwamish Superfund Site located on the Duwamish Waterway in an area exposed to sea level rise.

Summary of Impacts

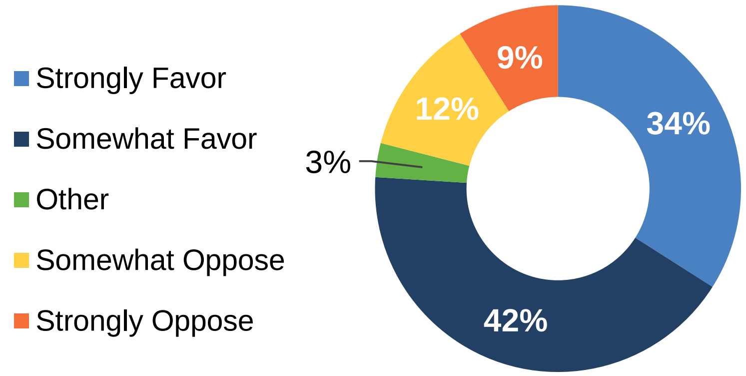
More frequent tidal flooding of coastal properties, which could damage facilities, interrupt operations, and have financial consequences for the utility.

Potential Adaptation Actions

- Make spatial information on projected sea level rise and storm surge readily available to all divisions in City Light. Use this information to identify and plan for current facilities and equipment located in areas that will be exposed to sea level rise and more frequent tidal flooding within the life expectancy of the equipment or facility.
- Consider establishing a utility-wide policy to identify future impacts of tidal flooding in the design of new proposed capital improvement projects located in areas that are projected to be exposed to sea level rise and more frequent tidal flooding.

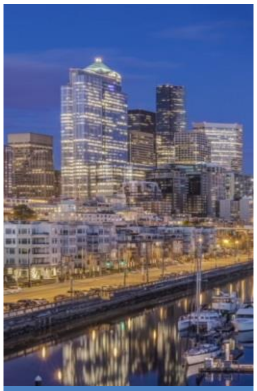
Seattle City Light's customers strongly support preparing for the impacts of climate change

Harstad Strategic Research Inc. conducted a survey for the city of Seattle in June 2013. They asked Seattle voters (603 respondents) if they favored the city doing more to prepare for the impacts of climate change (adaptation).



Electricity Demand

Seattle City Light provides power to over 360,000 residential customers and 40,000 non-residential customers. Customer load (i.e. demand) is grouped into three sectors: industrial (10 percent), commercial (56 percent), and residential (34 percent); each sector's load could respond differently to climate change. The utility is winter-peaking, meaning more power is used by retail customers in winter than in summer and the highest hourly peaks in electricity use occur with cold temperatures in winter. The commercial sector has higher load in summer because of heating, cooling, and ventilation systems, whereas the residential sector currently has low use of air conditioning.



Electricity Demand

Summary of Impacts

An increase in electricity demand for cooling in summer, which could cause summer peaks to approach winter peaks in localized areas of the distribution system with high commercial loads.

A decrease in electricity demand for heating in winter, which could cause lower retails sales and financial consequences for the utility.

Potential Adaptation Actions

- Expand Seattle City Light's analysis of the relationship between warming temperatures, seasonal base and peak load, and air conditioning use in the residential and commercial sectors. Include an evaluation of potential ways to address any revenue loss from warmer temperatures.
- Identify and evaluate potential co-benefits of existing energy-efficiency programs to reduce electricity demand for cooling in summer, in addition to current efforts focused on electricity use for heating.
- Assess the potential of demand response for reducing peak commercial load on the hottest days in summer for localized areas of the distribution system that currently have limited capacity and experience high peak loads during hot temperatures.

Are other electric utilities adapting to climate change?

Seattle City Light is one of 18 electric utilities in the nation participating in the U.S. Department of Energy *Partnership for Energy Sector Climate Resilience.* The partnership agreement signed by the utilities expresses a commitment to increasing resilience to climate change. The companies in this partnership collectively represent about 20 percent of the nation's generating capacity and 25 percent of customers. Seattle City Light's Climate Change Vulnerability Assessment and Adaptation Plan is the most comprehensive effort by an electric utility to assess and prepare for the impacts of climate change and it represents a decade of progressive action by the utility on this issue.

Transmission and Distribution


Transmission and Distribution

Seattle City Light owns and operates a transmission system consisting of over 650 miles of transmission lines and towers connected to the utility's five hydroelectric generation facilities. The utility also owns and operates a distribution system in the Seattle area consisting of 14 distribution substations, 2,337 distribution circuit miles (1,763 overhead and 574 underground circuit miles), and a downtown network system of 220 underground circuit miles. Many miles of transmission lines pass through rural, forested areas in Western Washington with steep, rugged topography. Transmission to and from City Light's distribution system also depends on the western regional transmission system, particularly for transmission from the Boundary hydroelectric project in northeast Washington and wholesale market purchases and sales.

Summary of Impacts

More frequent tidal flooding and salt water corrosion of distribution equipment could reduce the life expectancy of equipment, increasing costs for maintenance, repair, and replacement.

Warmer air temperatures could reduce the capacity of transmission lines.

Warmer air temperatures and less nighttime cooling could reduce the life expectancy of insulated transmission and distribution equipment, increasing costs for maintenance, repair, and replacement.

Warmer temperatures and drier soils could increase damage and failure of underground cables.

More intense precipitation could slow outage restoration times following major storms, particularly when inadequate drainage creates areas of standing water that prevent safe access to repair storm-related outages.

Extreme weather events such as windstorms and lighting will continue to cause distribution outages, despite limited information on changes in due to climate change.

More frequent wildfires could increase damage to transmission lines and interruptions of transmission and generation at hydroelectric facilities.

More frequent landslides and erosion could increase damage to transmission lines and access roads, increasing maintenance and repair costs, and impeding access to infrastructure.

More frequent river flooding in Western Washington could increase damage to transmission towers, erosion near towers, and damage to access roads, impeding access to transmission lines and increasing repair and maintenance costs.

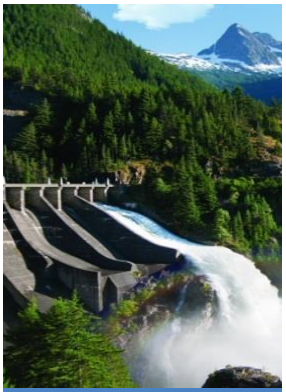
Potential Adaptation Actions

- Monitor and consider replacing equipment in the transmission and distribution system that is more sensitive to corrosion by salt water in areas that are projected to experience more frequent tidal flooding or will be inundated by sea water within the life expectancy of the equipment.
- Monitor failures of and damage to underground cables associated with warmer temperatures and drier soils to determine if alternative fill materials are needed to reduce heat-related failures.
- Expand the use of the Outage Management System (OMS) to quantify trends in the impacts of extreme weather on outages by specifically documenting additional weather-related causes of outages. This information can be used in cost-benefit analysis of infrastructure upgrades to increase resilience to extreme weather.
- Increase the capacity of employees to prepare for and respond to increasing wildfire risk through additional wildfire training, upgrading infrastructure with fire-resistant materials, and maintaining defensible space around critical infrastructure.
- Collaborate with adjacent land owners to reduce flammable vegetation and wildfire hazard along transmission lines and near critical infrastructure at the hydroelectric projects.
- Collaborate with state resource management agencies and academic institutions to map landslide risk along City Light's transmission line rights-of-way.
- Upgrade current transmission infrastructure to be resilient to higher peak flows and flood hazard in locations that currently experience flood-related damage. Consider projected increases in flooding in the design of new transmission projects located in or near historical floodplains.

Photo: A steel tower of Seattle City Light's Skagit transmission line and debris deposited by the landslide near Oso, Washington in March 2014. The debris caused minor damage to a tower.

Hydroelectric Project Operations

Seattle City Light's power resources are 90 percent hydropower, 50 percent of which is supplied by five hydroelectric projects owned and operated by the utility. The remaining hydropower is purchased from Bonneville Power Administration's Columbia River hydropower system. In addition to hydropower, City Light operates hydroelectric projects for flood control, instream flows for fish, reservoir recreation, and coordinates the operation of two projects with Seattle Public Utilities for municipal water supply. All these objectives depend on snowpack and the seasonal timing of streamflow. The Boundary and Skagit Projects (49 percent of power resources) and the BPA hydropower resources (40 percent) are located in high-elevation, snow-dominated watersheds for which impacts will be slower to emerge but significant by mid-century. The Cedar Falls and South Fork Tolt Projects (1.5 percent) are located in mid-elevation, mixed-rain-and-snow watersheds that will be more exposed to changes in snowpack and streamflow timing in the near-term.



Hydroelectric Project Operations

Summary of Impacts

Less snowpack and earlier snowmelt could challenge seasonal operations of hydroelectric projects that are based on historical conditions of water storage in snowpack and snowmelt timing in spring.

Higher peak flows could increase the frequency of spilling at hydroelectric projects in fall and winter for flood control, which could have financial consequences associated with lost revenue.

Higher peak flows could challenge operations to protect fish because more frequent spilling directly causes fish mortality and higher flows scour fish eggs and damage fish habitat downstream of the projects.

Lower streamflow in summer will decrease water availability for reservoir recreation, instream flows for fish protection, and hydropower generation, leading to financial consequences for the utility associated with lost revenue from surplus sales and more wholesale purchases to meet summer demand.

Potential Adaptation Actions

- Update and expand the utility's analyses of how operations of the Skagit and Boundary Projects could be adapted to reduce impacts associated with less snowpack, changes in the seasonal timing of streamflow, lower streamflow in summer, and higher peak flows in fall and winter.
- Collaborate with Seattle Public Utilities to evaluate the effects of changes in snowpack and streamflow timing on operations of the South Fork Tolt and Cedar Falls Projects.
- Consider further diversification of Seattle City Light's power resources by increasing non-hydro renewable energy sources that have a seasonal pattern of generation complementary to expected changes in seasonal hydropower generation.

Fish Habitat Restoration

Background

As part of Seattle City Light’s environmentally responsible operations, the utility restores and protects fish habitat to mitigate any adverse effects of the hydroelectric projects on populations of fish species. City Light acquires and restores habitat mitigation lands as part of the utility’s FERC licenses and through the ESA Early Action Program. Habitat mitigation lands are located in the Lower Skagit, Sauk, Tolt, and South Fork Tolt Rivers, all of which are mid-elevation, mixed-rain-and-snow watersheds that are projected to experience large changes in snowpack and the seasonal timing of streamflow.


Fish Habitat Restoration

Summary of Impacts

Higher peak flows and more frequent flooding in fall and winter may adversely affect fish populations and challenge City Light’s ability to meet objectives for restoring and protecting habitat for fish species.

Lower low flows in summer and warmer stream temperatures could adversely affect fish populations and challenge City Light’s ability to meet objectives for restoring and protecting fish species and habitat.

Potential Adaptation Actions

- Consider increases in peak flows and lower summer flows directly in prioritizing acquisitions of habitat mitigation lands by selecting habitats that provide refuge for fish or increase resilience to more extreme low and high flows.
- Focus objectives and design of restoration projects on ameliorating the impacts of lower summer flows, warmer stream temperatures, and higher peak flows on fish populations and habitat quality.

Implementation and Next Steps

Seattle City Light's Climate Change Vulnerability Assessment and Adaptation Plan will be used to guide the implementation of adaptation actions throughout the utility. The objective of conducting a vulnerability assessment is to ask the climate change question: will there be impacts and are they likely enough and consequential enough to warrant adaptation actions? The answer to the question depends on the planning timeframe and the utility's level of risk tolerance.

Some impacts require action now, whereas others impacts can be monitored and addressed as they emerge based on lower exposure in the near-term or lower magnitude of impacts. However, it is important to consider that effectively preparing for the impacts of a changing climate requires a long-term planning timeframe, because it may be too late to implement some adaptation actions if the utility waits until the impacts intensify. Many adaptation actions identified in this plan can be implemented through existing policies or operations of the utility; others may require additional resources.

Recommended steps for implementation are as follows:

- Establish an interdisciplinary team with representatives from relevant divisions. Solicit further feedback on the feasibility and priorities of adaptation actions identified in the plan.
- The interdisciplinary team will identify specific capital projects, long-term plans, or decisions for which climate impacts identified in the vulnerability assessment could affect the project design or decision.
- Develop methods and processes for conducting cost-benefit analysis of changes in operations or upgrades to infrastructure to harden and increase resilience to the impacts of climate change.
- Develop metrics for measuring the success of adaptation actions for reducing vulnerability, increasing resilience, and enhancing the utility's capacity to prepare for a changing climate.
- Update this plan in 2018 to include: (1) additional research findings from internal or external studies on climate change impacts, (2) results of internal assessments to better understand the consequences of impacts to the utility, and (3) benefits gained from adaptation.

Contents

List of Figures

List of Tables

List of Reviewers

Environmental Affairs and Real Estate Division
- Lynn Best, Director
- Gary Voerman, Science Policy Manager (retired)
- Kate Engel, Science Policy Manager
- Denise Krownbell, Senior Environmental Analyst, ESA lands
- Elizabeth Ablow, Senior Environmental Analyst, Cedar and South Fork Tolt

Power Management Division
- Wayne Morter, Director
- Steve Dadashi, Power Marketer
- Robert Downes, Strategic Advisor, Load Forecasting

Power Production Division
- Mike Haynes, Director

Security & Emergency Management Division
- Jerry Koenig, Strategic Advisor, Emergency Management

Energy Delivery Engineering Division
- John Nierenberg, Distribution Manager
- Bob Risch, Transmission Engineering
- Darrin Kinney, System Planning

Accounting Division
- Mike Simmonds, Accounting Director

Conservation Resources Division
- Michael Little, Energy Planning Supervisor
- Brendan O’Donnell, Energy Planning Analyst

List of Acronyms

BPA	Bonneville Power Administration
CDD	Cooling Degree Days
DEM	Digital Elevation Model
DOE	Department of Energy
DNR	Department of Natural Resources
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse Gases
HCP	Habitat Conservation Plan
HDD	Heating Degree Days
HVAC	Heating ventilation and air conditioning
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resources Plan
kV	kilovolt
MHHW	Mean High Higher Water
MW	megawatts
NERC	National Electric Reliability Commission
NTDE	National Tidal Datum Epoch
OMS	Outage Management System
PDO	Pacific Decadal Oscillation
PNW	Pacific Northwest
PRP	Potentially Responsible Party
RCP	Representative Concentration Pathway
RMJOC II	River Management Joint Operating Committee II
ROW	Right-of-Way
RSA	Rate Stabilization Account
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SHIVA	Seattle Hazard Identification Vulnerability Analysis
SLR	Sea Level Rise
SPU	Seattle Public Utilities
USGS	United States Geological Survey

1. Introduction

1.1 Objectives

The goal of this Climate Change Vulnerability Assessment and Adaptation Plan is to provide information to help ensure that Seattle City Light can continue to meet its mission as the climate changes.

This assessment describes the impacts of climate change on all four aspects of the utility's mission (environmentally responsible, safe, low-cost, and reliable power) and identifies potential actions the utility could take to prepare for a changing climate. This document is intended to be a living document that can be updated as new information emerges on climate change and its potential impacts to the utility. Beyond this initial assessment, the long-term goal of preparing for climate change is to incorporate climate change information into the policies, plans, and operations of the utility so that it becomes a regular part of decision-making. Implementation of the actions identified in this plan will most likely be successful if they are integrated into existing operations, polices, and planning processes of the utility. However, some actions may require larger changes including new policies or operations and these changes could require additional resources and time.

Seattle City Light Mission Statement:
Seattle City Light is dedicated to exceeding our customers' expectations in producing and delivering environmentally responsible, safe, low-cost, and reliable power.

1.2 What is Climate Change Adaptation?

Adaptation in the context of climate change is the process of identifying and implementing actions to reduce vulnerability to the potential or expected impacts of climate change[1]. Climate adaptation has many synonyms including preparedness, readiness, resilience, or climate risk reduction. Regardless of terminology, adaptation planning has three critical features:

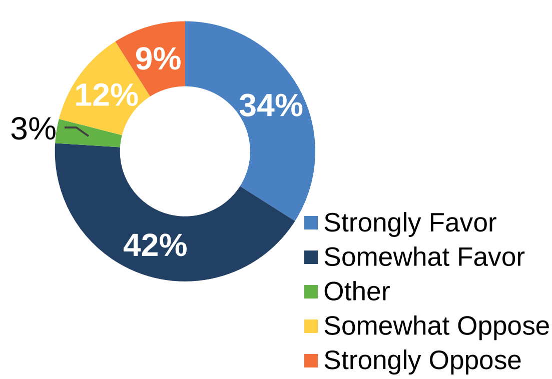
1. It is based on an understanding that the climate of the future will be different from the climate of the past.
2. It relies on a vulnerability assessment that identifies which aspects of the system will be most affected by changes in the climate.
3. It requires *intentional* actions to change policies, operations, and infrastructure design to prepare for the impacts of climate change.

In the context of emergency management, adaptation planning is similar to hazard mitigation, that is, actions to prevent or prepare for future hazards. However, adaptation planning differs from hazard mitigation because it addresses potential new hazards or changes in the likelihood and magnitude of existing hazards that could not be anticipated based on past events alone. For example, hazard mitigation may consider the impacts of storm surge, but adaptation planning assesses how future sea level rise will exacerbate the magnitude of current tidal flooding. Projections from climate models provide useful information on the direction and magnitude of future changes and can be used as tools for planning. Some hazards may intensify and others may lessen in magnitude. Thus, effective adaptation planning depends on an assessment of which changes in the climate are likely to have consequences for the utility.

Adaptation planning also differs from climate change mitigation. In the context of climate change, mitigation consists of efforts to reduce the emissions of greenhouse gases (GHG) that contribute to global warming. Mitigation actions focus on slowing and reducing the magnitude of changes in the climate, whereas adaptation planning focuses on preparing for the impacts of climate change. Both mitigation and adaptation planning are necessary actions to effectively respond to the challenge of climate change. Mitigation has the potential to greatly reduce the magnitude of changes in the climate in the latter half of the 21st century. City Light's commitment to carbon neutrality through reducing emissions, increasing energy efficiency, and purchasing GHG offsets will continue to be an important action for addressing climate change. However, adaptation planning is also necessary to prepare for the now inevitable impacts of climate change.

Seattle City Light's customers strongly support preparing for the impacts of climate change

Harstad Strategic Research Inc. conducted a survey for the City of Seattle in June 2013. They asked Seattle voters (603 respondents) if they favored the city doing more to prepare for the impacts of climate change (adaptation).



1.3 Why Prepare for Climate Change Now?

To some people, climate change may seem like a far-off risk that will not affect the utility in the near-term, especially compared to other more visible challenges facing the energy sector today. It can be tempting to label climate change as a "challenge for future generations", but this simply not the case for several reasons:

1. **Climate change is happening now, globally and here in the Pacific Northwest.** Temperatures have warmed and the effects of these warmer temperatures on snowpack, heat waves, and extreme weather have been detected globally, nationally, and locally.
2. **These impacts are expected to intensify and new impacts will emerge over the 21st century, regardless of reductions in the emissions of greenhouse gasses that cause the earth to warm.** Mitigation to reduce emissions is critical to reducing the long-term magnitude of climate change impacts. However, some impacts are now inevitable because the greenhouses gases that have already been emitted to the atmosphere will remain for decades to centuries. Even if the world stopped all emissions today, the earth would continue to warm based on previous emissions.
3. **Decisions are being made today that will shape the utility for decades into the future when the impacts of climate change will be more intense**. Decisions are currently underway regarding the location and design of buildings, the location and design of transmission lines, the conditions for operating hydroelectric projects, and the acquisition of power resources and fish habitat lands. The effects of these decisions will still be in place for decades, so it is important to consider the increasing risk of climate

impacts for the life expectancy of the decision (Figure 1.1).

4. **It is likely to be easier and more cost-effective to consider the impacts of climate change in the planning and design phases for new infrastructure than to retrofit infrastructure or replace power resources once the impacts of climate change are more apparent.** City Light is adapting to climate change now because being proactive in preparing for climate impacts can reduce the costs and consequences to the utility, its customers, and the natural environment.

Although there is uncertainty in the projected changes in future climate, similar to the uncertainty in any future projections including economic development and population growth, some impacts are certain enough now to be integrated into decision-making processes that will have long-term consequences.

1.4 Background on Climate Change Adaptation at Seattle City Light

This adaptation plan is a product of the Climate Research Initiative in the utility's 2013-2018 Strategic Plan. The initiative has three objectives:

1. Develop a utility-wide climate adaptation plan
2. Support research on the impacts of climate change to the utility's operations, resources, and infrastructure (projects supported to date are listed in Appendix A)
3. Increase the utility's capacity to prepare for a changing climate

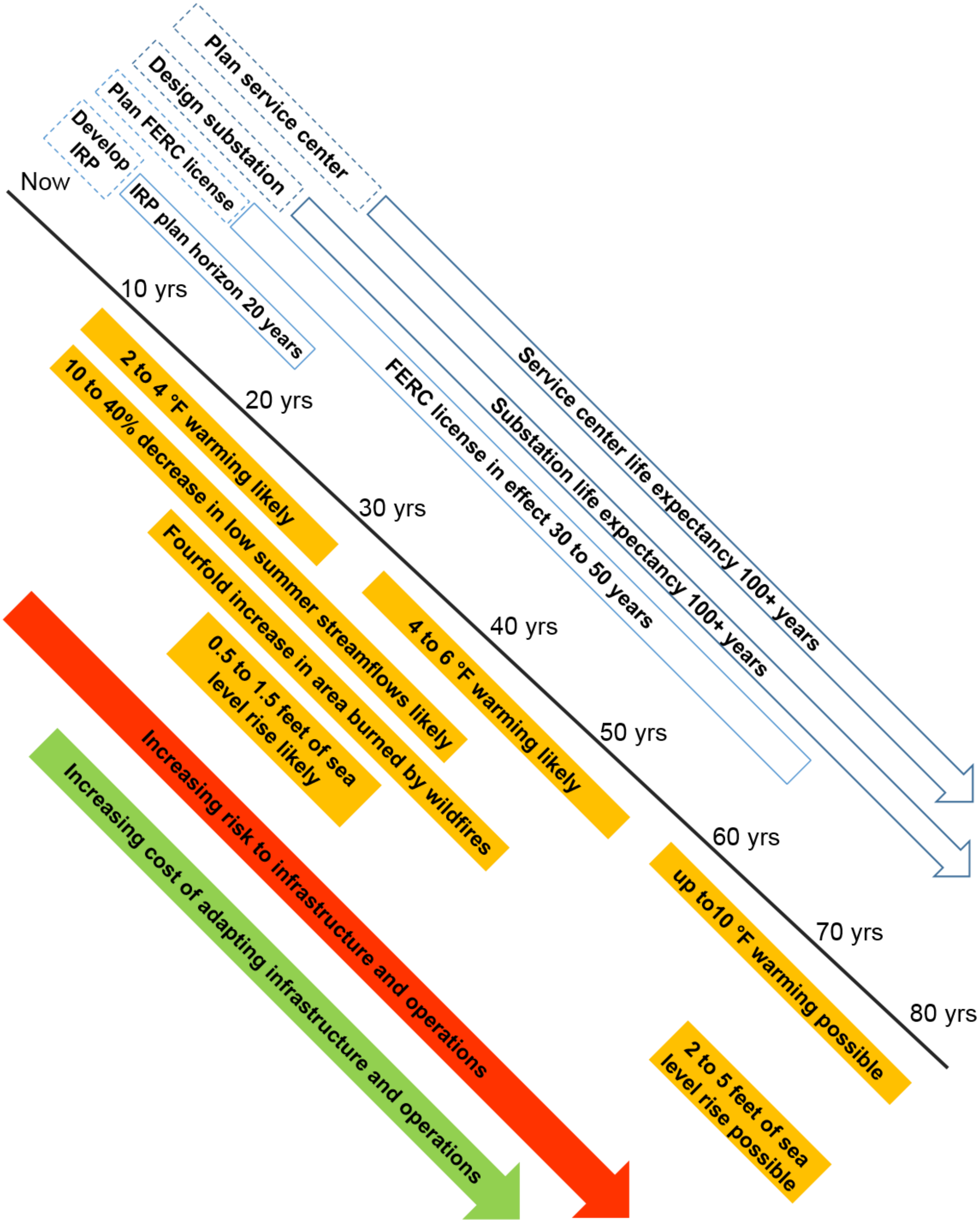
The Climate Research Initiative and this plan are a continuation of efforts at City Light to assess vulnerability and prepare for the impacts of climate change. In 2010**,** City Light supported an assessment of changes in snowpack, streamflow, and stream temperature by the Climate Impacts Group at the University of Washington[2]. Information from the 2010 assessment was included in City Light's 2010 and 2012 Integrated Resource Plans (IRP). The 2012 IRP also included an assessment of temperature impacts on load (i.e. demand). This assessment builds on the capacity to address climate change that was created by these previous efforts.

City Light also has many procedures and operations designed to manage Washington State's highly variable climate, particularly year to year variability in precipitation and snowpack that affects reservoir inflows, hydropower generation, and instream flows for fish protection. Despite the trends for changes in climate, the utility will continue to experience a highly variable climate from year to year and these practices will continue to be necessary to reduce the impacts associated with this variability. This assessment highlights these existing procedures and operations because they can also increase City Light's capacity to adapt to future changes in the climate. Current practices to manage climatic variability also may be effective for managing for long-term changes in the climate. In other cases, these practices can be leveraged to implement additional actions to reduce vulnerability and increase resilience to climate change.

This plan expands City Light's efforts to address climate change in two ways:

1. The vulnerability assessment is expanded to include other City Light functions not previously assessed, additional climate impacts, and the most recent climate projections for the Seattle area and the Pacific Northwest.
2. The plan identifies potential adaptation actions that the utility could take to reduce vulnerability and increase resilience to the impacts of climate change.

Figure 1.1. The timing of climate impacts relative to the planning horizon of major decisions made by Seattle City Light. Resource plans, FERC licenses, and new infrastructure designs being considered now will need to be robust to a wide range of changes in the climate that are expected within their lifetimes, increasing the urgency of preparing now.



1.5 Are Other Electric Utilities Adapting to Climate Change?

In the energy sector, concerns about the impacts of climate change have greatly increased in the last few years as demonstrated by a recent report from the World Energy Council on the risks of climate change and extreme weather[3]. Electric utilities throughout the nation are beginning the process of assessing vulnerability and developing adaptation strategies. Seattle City Light's Vulnerability Assessment and Adaptation Plan is the most comprehensive assessment of the impacts of climate change on an electric utility.

Many other actions are underway in the energy sector. Electric companies in the Northeastern U.S. are assessing vulnerability to extreme weather in response to Superstorm Sandy and other recent events. Electric utilities in California, including Sacramento Municipal Utility District, Pacific Gas and Electric, and San Diego Gas and Electric, are assessing the impacts of recent droughts, wildfires, and other climate-related natural hazards on operations and infrastructure. These three California utilities, along with City Light, and fourteen other utilities from around the nation, are collaborating with the U.S. Department of Energy to assess vulnerability and develop adaptation strategies through the Partnership for Energy Sector Climate Resilience[4]. The companies in the partnership collectively represent 20% of the nation's generating capacity and 25% of customers. The Partnership Agreement signed by the utilities expresses a commitment to increasing resilience to climate change.

1.6 How is this Document Organized?

This report describes eight changes in climate, and related changes in natural hazards, streamflow, and extreme weather that could significantly affect five aspects of City Light's operations and infrastructure. Together these changes and the utility functions they affect make up thirteen impact pathways through which the utility could experience risks as the climate changes (Figure 4.1, Table 4.1). For each of these thirteen impacts, this report describes:

1. **exposure** to projected changes in the climate
2. **sensitivity** to projected changes in the climate
3. **adaptive capacity** or existing practices and operations that can be leveraged to increase the utility's capacity to adapt to climate change
4. **potential adaptation actions** that could be implemented to reduce vulnerability and increase resilience in a changing climate.

System vulnerability informs which changes are likely to have the greatest consequences and therefore warrant the focus of adaptation actions. Identifying existing capacity to adapt within the utility highlights current practices that are successfully addressing the challenges associated with weather and climatic variability. Current capacity to adapt provides a starting point for identifying additional actions to prepare for more long-term changes in the climate. Potential adaptation actions listed for the thirteen impact pathways are grouped into two categories: near-term/existing capacity and long-term/expanded capacity. The first category is actions that could be taken within existing budgets and capacity, whereas the second category is actions that may require additional funding, capacity, or policy changes to implement the action.

1.7 What is a Vulnerability Assessment?

Vulnerability to climate change includes three aspects of City Light's systems and their relationship to climatic variability and change: sensitivity, exposure, and adaptive capacity[5]. When both sensitivity and exposure are high, the impact of climate change on a system is likely to be high (Figure 1.2)[6]. Adaptive capacity acts in the opposite direction by reducing vulnerability. When an organization has high capacity to adapt, the impacts of climate change are likely to be lower because the organization already has some process or procedures in place that can help prepare for the changes.

Exposure is the degree to which functions of the utility will be exposed to climate change, including the magnitude and rate of change. Exposure varies with time and location and depends on the climate variable of interest. For example, shorelines will be more exposed to sea level rise, but inland locations have limited or no exposure. Hydroelectric generation facilities located in high-elevation, snow-dominated watersheds will have less exposure to decrease in snowpack than warmer, mid-elevation watersheds that will experience a greater loss of snowpack.

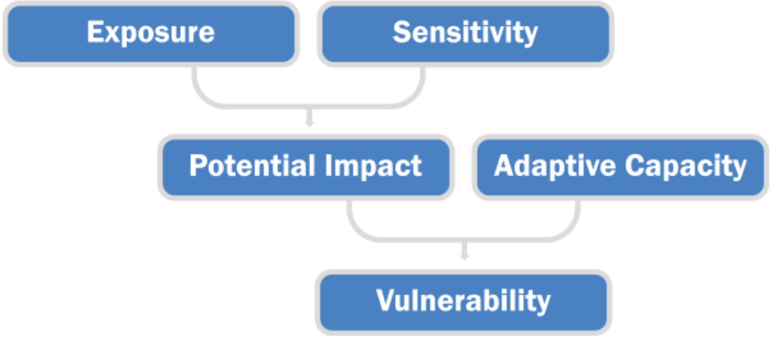


Figure 1.2 The components of a climate change vulnerability assessment. Exposure and sensitivity combine to define a potential impact of climate change. Adaptive capacity can reduce vulnerability to that impact.

Sensitivity is an inherent quality of the utility's functions (i.e. infrastructure, operations, or resources) indicating the degree to which they could be affected by climate change, regardless of exposure to those changes. For example, a summer-peaking electric utility may be more *sensitive* to warmer summer temperatures compared to a winter-peaking utility. Features of City Light's infrastructure and operations that *increase* sensitivity to climate include aging infrastructure, outdated design standards, a lack of redundancy, or a lack of flexibility in operations to manage for climatic variability. Examples of features that *reduce* sensitivity include conservative design standards, functional redundancy, and geographic diversity of resources.

Adaptive capacity is the ability of people, infrastructure, or operations to respond and adjust to climate change. For example, regulated rivers with a reservoir and dam typically have *greater capacity to adapt* and respond to changes in drought and flood risk because of the potential to store water and regulate streamflow during times of peak or low flows. Operations that are more flexible, rather than based on fixed policies and procedures, may have greater capacity to adapt and respond to changes in the climate. Use of climate and weather forecasting tools can also increase a utility's capacity to plan and prepare for extreme events.

1.8 What are Adaptation Actions?

Adaptation actions are intentional changes in policies, programs, operations, or infrastructure to reduce vulnerability and increase resilience to climate change. This can be accomplished by four general strategies: (1) enhance adaptive capacity, (2) harden infrastructure, (3) increase resilience, or (4) retreating from exposed locations or resources. Many of these adaptation strategies are being considered or implemented by electric utilities across the nation. Each strategy may be useful depending on the magnitude of the impacts and the criticality of the objectives or infrastructure.

1. Enhance Adaptive Capacity: Actions to enhance adaptive capacity increase the ability of the utility to respond to extreme weather and climatic variability or change. Actions taken by electric utilities to increase adaptive capacity include employing meteorologists, investing in weather or wildfire monitoring as well as forecasting systems, and supporting research on the impacts of climate change.

2. Harden Infrastructure: Hardening involves protecting infrastructure in place by constructing new reinforced infrastructure or retrofitting existing infrastructure[7]. Examples of hardening include installing submersible saltwater-resistant equipment, elevating infrastructure, or building flood barriers around substations to protect against sea level rise and storm water flooding. In wildfire prone areas, utilities are hardening by converting from wood to steel poles. Hardening may be the preferred adaptation action in the near term or when critical assets cannot be moved. However, as climate impacts intensify, hardening may be difficult to sustain over the long term.

3. Increase Resilience: Increasing resilience is taking action to enhance the ability of the system to respond or recover from disruptions associated with extreme weather or climate change. Increasing resilience reduces the consequences of impacts in terms of recovery time and cost. Examples of actions by utilities to increase resilience include enhancing vegetation management programs, contracting resources to be readily available for wildfire response, increasing energy efficiency to reduce electricity demand, and diversifying resource portfolios to minimize risk from impacts to any one resource.

4. Retreat: Retreating involves relocating a facility from an exposed location. Retreating can also be applied to objectives or power resources. Objectives could be abandoned if they are unlikely to be achievable given climate impacts. Resources could be sold if they are unlikely to provide sufficient benefits in a changing climate. Retreating is potentially the most extreme action and it is typically considered as a long-term solution, in response to an extreme event, or if other actions are unlikely to sufficiently reduce vulnerability. Retreating can be less politically or socially acceptable, so it may be feasible only in extreme cases. An example of a retreat action by electric utilities is to sell coastal property and move infrastructure out of flood plains in areas with high exposure to sea level rise.

1.9 How was this Plan Developed?

The development of this document relied on the expertise of City Light staff from multiple divisions of the utility. Staff were consulted through interviews and meetings and provided information on the current sensitivity of the systems to extreme weather and climate. They identified current and future vulnerabilities to climate change, as well as existing programs (adaptive capacity) that have been designed to reduce the detrimental impacts of weather and climatic variability. This information was incorporated into the sections describing sensitivity and the current adaptive capacity of the utility.

Several sources of climate change information were used to inform the sections on exposure. Information on projected changes in climate were drawn from Pacific Northwest and Washington state assessments, published literature on climate projections and impacts, and customized research studies supported by City Light's Climate Change Research Program and the Climate Resiliency Group at Seattle Public Utilities. Effort was made to keep climate change data consistent in terms of the timeframe and area covered by the projections, but given the variety of resources used to inform exposure, this was not always possible.

Adaptation actions were identified based on the vulnerability assessment, recommendations from City Light staff, published literature on adaptation, and a review of actions being considered by other companies in the DOE partnership. The actions are labeled as "potential" because this is an initial list of actions the utility could consider and does not imply that the utility will implement all the listed actions. This Vulnerability Assessment and Adaptation Plan was reviewed by utility staff from all relevant divisions, but the potential adaptation actions will be reviewed further and prioritized by utility staff during the implementation phase.

---

[1] Intergovernmental Panel on Climate Change [IPCC]. 2007. Summary for policymakers. In: Parry, M.L.; Canzianai, O.F.; Palutikof, J.P. [et al.], eds. Climate change 2007: impacts, adaptation and vulnerability: a contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press: 7–22.

[2] Snover, A.K., A.F. Hamlet, S-Y. Lee, N.J. Mantua, E.P. Salathé, R. Steed, and I. Tohver. 2010. Seattle City Light Climate Change Analysis: Climate Change Impacts on Regional Climate, Climate Extremes, Streamflow, Water Temperature, and Hydrologic Extremes. Prepared for The City of Seattle, Seattle City Light by The Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington.

[3] World Energy Perspective. The road to resilience – managing and financing extreme weather risks. The World Energy Council. http://www.worldenergy.org/wp-content/uploads/2015/09/The-Road-to-Resilience-Managing-and-Financing-Extreme-Weather-Risk.pdf

[4] U.S. Department of Energy Partnership for Energy Sector Climate Resilience http://energy.gov/epsa/partnership-energy-sector-climate-resilience

[5] Intergovernmental Panel on Climate Change [IPCC]. 2007. Summary for policymakers. In: Parry, M.L.; Canzianai, O.F.; Palutikof, J.P. [et al.], eds. Climate change 2007: impacts, adaptation and vulnerability: a contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press: 7–22.

[6] Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the Conservation Horizon:

A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

[7] Nierop, S. 2014. Envisioning resilient electrical infrastructure: A policy framework for incorporating future climate change into electricity sector planning. Climatic Change 40:78-84.

2. Seattle City Light Resources and Infrastructure

Seattle City Light owns and operates generation, transmission, and distribution systems. The municipal utility distributes power to over 360,000 residential customers and 40,000 non-residential customers within the city of Seattle and neighboring areas to the north and south, an area of 131 square miles (Figure 2.1). City Light is the largest public utility in the nation in terms of customers served. The customer load (i.e. demand) is grouped into three categories: industrial, commercial, and residential sectors. The residential sector uses about 23% of City Light's power, whereas the industrial and commercial sectors combined use 45%. City Light is a surplus utility, meaning the utility has more power than is needed by its retail customers, so approximately 27% of power resources are sold on the wholesale market.

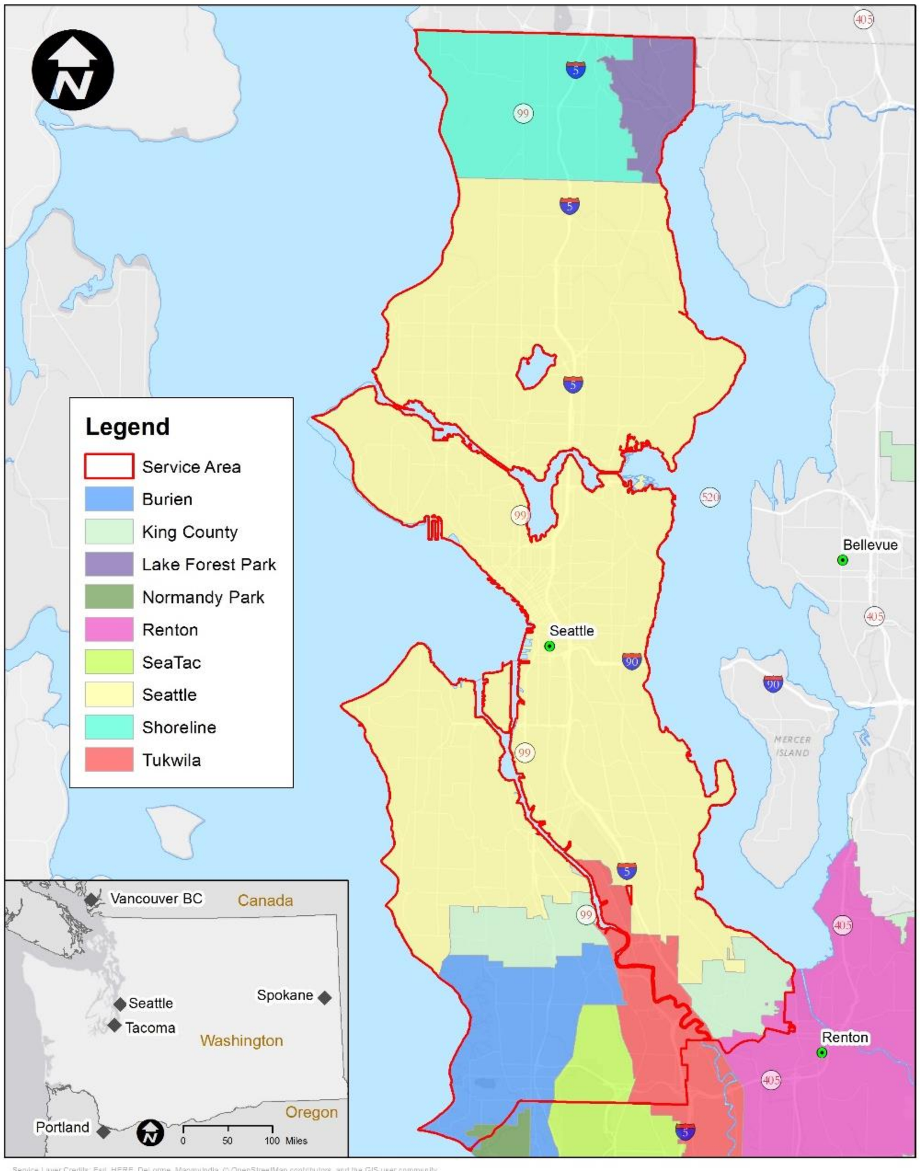


Figure 2.1 Seattle City Light's service area. City Light serves over 400,000 residential, commercial, and industrial customers over a 131 square miles area.

2.1 Generation

City Light's sources of power are 90 percent hydropower, 50 percent of which is supplied by hydroelectric facilities owned and operated by the utility. Total system generation capacity is 1,806.8 MW.

- Boundary, Pend Oreille River (1,078.4 MW)
- Ross, Skagit River (450.0 MW)
- Diablo, Skagit River (190.4 MW)
- Gorge, Skagit River (207.5 MW
- Cedar Falls, Cedar River (30.0 MW)
- South Fork Tolt, South Fork Tolt River (16.8 MW)
- Newhalem, Newhalem Creek (2.0 MW)

City Light also receives power through contracts and agreements. City Light purchases power from Bonneville Power Administration (BPA) through two contracts, Block and Slice (2011 – 2028). The Block Power purchase is for 251 MW shaped to meet City Light's load. The Slice Power Purchase is based on a percentage of BPA's system capacity and averages 253 MW per year. During low water years, the cost is higher than in high water years. City Light receives 36 MW from BC Hydro through the High Ross Treaty Agreement between British Columbia and the city of Seattle, which lasts through 2066. City Light has a contract (1988 – 2038) with four irrigation districts to purchase 39 MW from the Lucky Peak Hydroelectric Project on the Snake River. City Light's contracts for renewable resources include a contract for 28 MW from a biomass cogeneration facility and 175 MW of wind generation from the Stateline Wind Project.

2.2 Transmission

City Light owns and operates transmission lines that bring power from the hydroelectric facilities to substations within the service area.

- 230 kV transmission lines: 500 miles of overhead lines and ten miles of underground lines, most of which connect the Skagit project to the Bothell transmission substation
- 115 kV transmission lines: 137 miles of overhead and 13 miles of underground
- Four Transmission Substations
- Primarily steel (Skagit) and wood poles (Cedar Falls and Tolt) and some concrete

2.3 Distribution

City Light owns and operates distribution to about 400,000 customers in the city of Seattle and surrounding areas (130 square miles) with a population of over 780,000.

- 14 distribution substations
- Loped radial system: 2337 distribution circuit miles (1763 overhead circuit miles and 574 underground circuit miles including 34 kV, 26kV, and 4 kV systems)
- Network System: 220 distribution circuit miles (all underground, 26 kV and 13 kV systems to the downtown core, First Hill, and University)
- Transformers (pole-mounted, pad-mounted, and submersible)
- Primarily wood poles and some steel poles

3. Observed and Projected Changes in Temperature and Precipitation for Washington State

Observed changes in past climate and projections of future climate in the Pacific Northwest (PNW) are summarized below. Details of these projections and the processes used to generate them are available in the report *Climate Change Impacts and Adaptation in Washington State*[1]. These projections use the most current climate model output and scenarios for global emissions of greenhouse gasses (GHG) developed in support of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report,[2] released in 2014. For each climate variable described below, ranges are given for multiple climate models and scenarios of GHG emissions. All scenarios are considered by the IPCC to be equally plausible future climates, thus, any value in the range is equally likely. However, when multiple climate models project a similar outcome, confidence in the likelihood of that outcome is greater.

When summarizing observed changes in climate, it is important to look at regional trends that are based on observations from multiple locations, rather than trends from only one or a few locations. Observed trends in climate at a single location may represent local anomalies due to microclimates and may not be indicative of climate change. In contrast, regionally consistent trends from observations at multiple locations provide greater confidence in the significance of the trend. Regional trends are also more likely to be caused by large-scale changes in the climate.

Regional trends in future climate projections are presented below. When available, projections of climate variables for specific weather stations of interest to City Light are included. These data more directly convey how the utility could be affected by climate change, but they are less certain than regional projections because of uncertainty associated with downscaling to locations of individual weather stations.

Timeframes for Climate Projections

Projected changes in the climate are typically presented for 30-year periods in the future. These 30-year periods are used because the goal is to present the long-term *trend* associated with climate change and 30 years is the standard time needed to show a trend that is not affected by climatic variability on annual or decadal time scales. In this document, all climate projections are the average for 30 years and these periods are labeled by the middle decade. Time periods are used based on the availability of data.

2020s = 2010 – 2039
2030s = 2020 – 2049
2040s = 2030 – 2059
2050s = 2040 – 2069
2080s = 2070 – 2099

3.1 Observed Changes in Temperature

The Pacific Northwest has warmed during the 20th century, including an increase in mean annual temperature and more frequent night time heat waves.

- The Pacific Northwest warmed by about 1.3°F between 1895 and 2011. Warming was significant in all seasons except spring and the largest warming trend was observed in winter.
- There is a significant positive trend in the frequency of night time heat waves between 1901 and 2009 in western Oregon and Washington[3].

3.2 Projected Changes in Temperature

All climate models project that warming will continue in the Pacific Northwest in the 21st century, and warming is expected in all seasons.

Climate model projections differ only in the magnitude of warming, not the direction of temperature change. All models project that the PNW will be warmer. Despite differences in the magnitude of warming, warming temperatures *are the most certain and direct effect of climate change*. By the middle of the century, average annual temperatures will be outside the range of what Washington has experienced in the past (Table 3.1). The region is also likely to experience more frequent extreme heat waves and less frequent extreme cold events.

Table 3.1. Projected changes in Pacific Northwest temperature for the 2050s relative to the 1950-1999 average.

Season	Emissions Scenario*	Mean	Range
Winter (Dec. – Feb.)	Low	+4.5°F	1.6 – 7.2°F
	High	+5.8°F	2.3 – 9.2°F
Spring (May – March)	Low	+4.3°F	0.9 – 7.4°F
	High	+5.4°F	1.8 – 8.3°F
Summer (June – Aug.)	Low	+4.7°F	2.3 – 7.4°F
	High	+6.5°F	3.4 – 9.4°F
Fall (Sept. – Nov.)	Low	+4.0°F	1.4 – 5.8°F
	High	+5.6°F	2.9 – 8.3°F

*Under the low warning scenario (RCP 4.5), GHG emissions stabilize by mid-century and fall sharply thereafter. Under the high warming scenario (RCP 8.5), GHG emissions continue to increase until the end of the 21st century. RCP 8.5 is considered a business as usual scenario and current emissions follow this trajectory without mitigation.

Extreme temperatures are also projected to change. Below are projected changes in the likelihood of exceeding temperature thresholds that are relevant to City Light's operations, as well as heating and cooling degree days (indicators of electricity demand). Changes are for the 2050s relative to the 1950 to 2006 average. Data were downscaled to show changes at the SeaTac weather station for a high warming scenario.

- An increase in days with a maximum temperature above 86°F by 18 (± 6) days.
- A decrease in days with minimum temperature below 32°F by 24 (± 5) days.
- An increase in cooling degrees days of 67 (± 36) degree days (metric of electricity demand for cooling that is the annual sum of degrees above 75°F).
- A decrease in heating degree days of 1143 (± 292) degree days (metric of energy demand for heating that is the annual sum of degrees below 65°F).

3.3 Observed Changes in Precipitation

In the PNW, climate records show no significant trends in annual precipitation for the period of 1895 to 2011.

Precipitation in the PNW is strongly influenced by natural climatic variability, which causes fluctuations between wet and dry years or wet and dry multi-year periods. A portion of this variability is cyclical and can be explained by natural fluctuations in Pacific Ocean sea surface temperatures (e.g. the El Nino Southern Oscillation and the Pacific Decadal Oscillation) that affect the climate in the PNW, especially in winter. Patterns in the historical record of precipitation are dominated by this climatic variability.

3.4 Projected Changes in Precipitation

Climate models project *only small changes in annual precipitation* that will be difficult to detect above the background of the high variability typical of the PNW. However, most climate models consistently project *changes in seasonal precipitation*, which can have important implications for snowpack and streamflow.

Most climate models project increases in precipitation in winter, spring, and fall for the 2050s (relative to 1950-1999), but decreases in summer precipitation.

- For all emissions scenarios and seasons, some models project wetter conditions but other models project drier conditions, making projected changes in precipitation less certain than projected changes in temperature.
- Projected decreases in summer precipitation are more common among models with an average decrease of six percent to eight percent by the 2050s.
- Some models project a decrease in summer precipitation of more than 30 percent, although precipitation in the summer is already minimal in the PNW.

Potentially of greater importance in the PNW are projected changes in precipitation extremes, including more frequent short-term heavy rain events. Short-term heavy rain events, such as atmospheric rivers, have the greatest consequences for flooding in Washington.

Projected changes in precipitation extremes for the PNW in the 2050s (relative to 1971-2000) for a high emissions scenario include:

- A 13 percent (±7 percent) increase in the number of days with rain > 1 inch.
- A 22 percent (±22 percent) increase in the number of days with rain > 3 inches.

3.5 Projected Changes in Snowpack, Streamflow, and Natural Hazards

In addition to the changes in temperature and precipitation, Washington is projected to experience changes in some extreme weather conditions, including the frequency of convective storms and lightning (**Section 4.3)**. Warmer temperatures are projected to increase the area burned by wildfires (**Section 4.4**), whereas more intense precipitation and higher winter soil saturation may lead to more frequent landslides (**Section 4.5**). In the watersheds where City Light operates hydroelectric projects, changes in temperature and precipitation are also expected to reduce snowpack (**Section 4.6**), increase peak streamflows in fall and winter (**Section 4.7**), and reduce low streamflows in summer (**Section 4.8**).

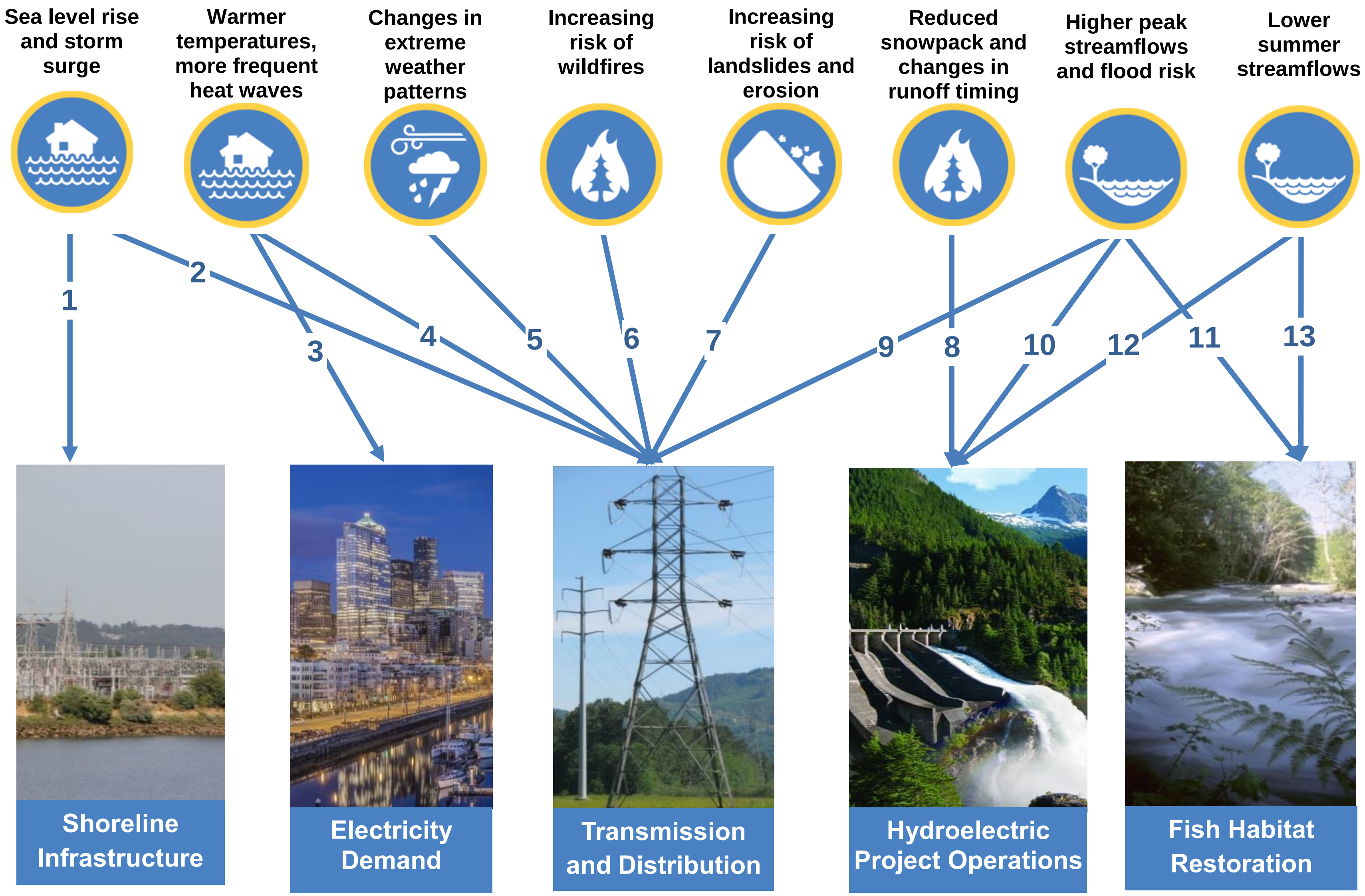
---

[1] Snover, A.K [.et al]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[2] IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F. et al, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[3] Bumbaco, K.A. [.et al] 2013. History of Pacific Northwest Heat Waves: Synoptic Pattern and Trends. *Journal of Applied Meteorology and Climatology* 52: 1618-1631.

Projected changes in climate, and affected natural hazards and hydrologic conditions



Components of Seattle City Light's Infrastructure and Operations

4. Climate Change Impacts and Potential Adaptation Actions

This plan describes eight changes in the climate, and resulting changes in natural hazards, hydrologic conditions, and extreme weather that could affect five aspects of City Light's operations and infrastructure, creating thirteen impact pathways through which the utility could experience climate-related risks to its mission (Table 4.1).

Table 4.1 Projected impacts of climate change on City Light and risks to the utility's mission.

Projected changes	Potential impacts of climate change on infrastructure and operations	Risks to
Sea level rise and storm surge	1. More frequent inundation and flooding of properties and facilities near Puget Sound	financial cost, environmental responsibility
	2. More frequent flooding and salt water corrosion of transmission and distribution equipment near Puget Sound	financial costs, reliability
Warmer temperatures and more frequent heat waves	3. Increased electricity demand for cooling in summer and decreased electricity demand for heating winter	financial cost
	4. Reduced transmission and distribution capacity and life expectancy of insulated equipment	financial cost, reliability
Changes in extreme weather patterns	5. More frequent outages and damage to transmission and distribution equipment	financial cost, reliability, safety
Increasing risk of wildfires	6. Increased risk of wildfires causing damage and interruptions to transmission lines, generation facilities, and putting employee safety at risk	financial cost, reliability, safety
Increasing risk of landslides	7. Increased damage to transmission lines and access roads and reduced access	financial cost, safety, reliability
Reduced snowpack and changes in the seasonal timing of streamflow	8. Seasonal operations of hydroelectric projects may no longer be aligned with seasonal stream flow, challenging multiple seasonal objectives for project operations	financial cost, environmental responsibility
Higher peak streamflows and more frequent river flooding	9. Increased damage and reduced access to transmission lines located in floodplains	financial cost, reliability
	10. More frequent spilling at hydroelectric projects to ensure adequate flood control in fall and winter	financial cost, environmental responsibility
	11. Increased impacts on fish populations and difficulty meeting objectives for restoring habitat for fish species	environmental responsibility
Lower low stream flows in summer	12. Increased difficulty balancing reservoir operations for power generation, instream flows for fish protection, and reservoir levels for recreation in summer	financial cost, environmental responsibility
	13. Increased impacts on fish populations and difficulty meeting objectives for restoring habitat for fish species	financial cost, environmental responsibility

For each of the thirteen impact pathways listed in Table 4.1, this plan describes (1) vulnerability in a changing climate, (2) existing operations that increase the utility's capacity to adapt, and (3) potential adaptation actions for reducing impacts and increasing resilience to climate change. This list is not exhaustive and other impacts may emerge. Furthermore, this assessment describes these impacts independently, but several impacts could interact or happen at the same time increasing the consequences for the utility. For example, in the summer of 2015, the utility experienced the combined impacts of lower than average streamflows, warmer than average temperatures, and a wildfire at the Skagit Hydroelectric Project.

4.1 Sea Level Rise and Coastal Flooding

Impact 1: Shoreline Properties and Infrastructure

Seattle City Light's property and facilities along the shoreline of Puget Sound and the Duwamish River may experience more frequent flooding and inundation associated with storm surge, sea level rise, and heavy precipitation.

Mission Objectives at Risk: Financial Cost, Environmental Responsibility

Shoreline Infrastructure

City Light's facilities could experience additional damage, maintenance costs, and loss of access due to inundation from sea level rise and episodic flooding caused by increased tidal reach, storm surge, and heavy precipitation. Most of City Light's properties and facilities, including substations and service centers, are located at high enough elevations not to be exposed to increases in tidal flooding. However, some facilities are located within areas expected to experience more frequent tidal flooding, and this may require changes to infrastructure to minimize damage and disruption of operations.

Sea level rise and storm surge can have consequences for environmental compliance if increased coastal flooding mobilizes hazardous materials from contaminated sites. The City of Seattle is a Potentially Responsible Party (PRP) for the Lower Duwamish Waterway Superfund Site. City Light and Seattle Public Utilities are the main City departments involved in the assessment and clean up. The EPA requires that sea level rise be considered in the cleanup strategy for all Superfund sites and this could be an important consideration for this site due to its proximity to Puget Sound.

Impact 2: Transmission and Distribution Infrastructure

Transmission and distribution infrastructure in low-lying areas near Puget Sound could experience more frequent flooding and salt water corrosion caused by a combination of sea level rise and storm surge.

Mission Objectives at Risk: Financial Cost, Reliability

Transmission and Distribution

Transmission and distribution equipment near the shoreline will be exposed to sea level rise and more frequent tidal flooding with higher tides, heavy precipitation, and storm surge. More frequent inundation could expose equipment to more corrosion by salt water, reducing equipment life expectancies and leading to higher costs for equipment repair and replacement. However, most of City Light's distribution and transmission equipment is located at high enough elevations not to be exposed to sea level rise. Furthermore, distribution and transmission equipment is designed to be water tight and the estimates of the life-expectancies of equipment are conservative, so further reductions in life expectancy due to sea level rise will likely be manageable through the regular repair and replacement schedules of the utility.

Shoreline areas could also experience loss of access to transmission and distribution equipment during high storm surge events, with consequences for restoration times and distribution reliability if there are power outages. During Superstorm Sandy on the East Coast, a cascading effect of coastal flooding was lack of access, which greatly slowed the response time of utilities, leading to extended outages.

Exposure

Sea level rise in specific locations can differ from global projections because of local vertical land movement and topography. The city of Seattle was the focus of a national study[4] on sea level rise that provided local projections for the Seattle area. During the 20th century, sea level in Seattle rose about 0.8 inches per decade due to a combination of warming effects and vertical land movement[1]. Sea level in Seattle is projected to continue to rise at an accelerating rate in the 21st century. The mean projection for a moderate warming scenario is an increase of 2.6 inches by 2030, 6.5 inches by 2050, and 24.3 inches by 2100 (Table 4.2, Figure 4.1). The mean for a high warming scenario is as much as 8.9 inches by 2030, 18.8 inches by 2050, and 56.3 inches by 2100. The projected range of sea level rise is large because of the high uncertainty in some factors that cause sea level rise, including ice loss from Greenland, Antarctica, and Alaska, as well as vertical land movement.

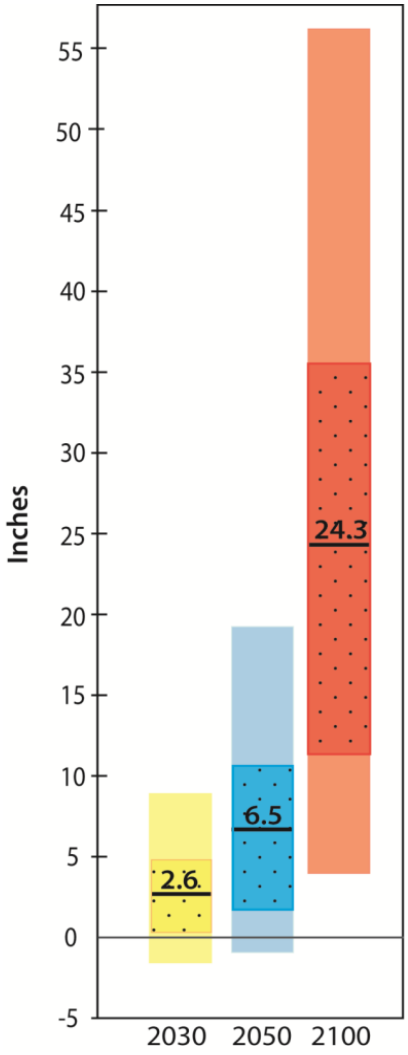


Figure 4.1. The range of projections of sea level rise for Seattle[1]. The black line is the mean for a moderate emissions scenario (A1B) and the shaded areas are standard deviations. The full bar height is for the range of projections based on multiple emissions scenarios. The top of the bar is the mean for the high scenario.

Table 4.2 Projected sea level rise for Seattle in the 21st century[1].

Time Frame	Moderate* (in)	High** (in)	Full Range*** (in)
2030	+2.6	+8.9	-1.5 to +8.9
2050	+6.5	+18.8	-1.0 to +18.8
2100	+24.3	+56.3	+3.9 to +56.3

*The moderate scenario is the mean for a moderate GHG emissions scenario (A1B).
**The high SLR scenario is the mean for a high GHG emissions scenario (A1F1).
**The low end of the full range is mean for the lowest GHG emissions scenario (B1).

Projections of sea level are most useful when put in the context of current tidal flooding during high tides or king tides. The effects of sea level rise will initially be experienced through episodic flooding during high-tide events in winter, rather than simply as a gradual increase in water levels. The Climate Resiliency Group at Seattle Public Utilities combined the historical frequency of storm surge events with projections of future sea level rise to estimate the change in the frequency of tidal flooding, assuming a maximum storm surge of 3.1 feet (Table 4.3).

Seattle's existing shoreline is defined as MHHW, which is 9.01 feet above 0.0 feet NAVD88, the official city of Seattle Vertical Datum. Under the current climate, flooding of the shoreline up to 10 feet (1 feet above MHHW) is an average *monthly event*, 11 feet (2 feet above MHHW) is an average *annual event* and flooding to12.1 feet (3.1 feet above MHHW) is a *100-year event* (an event with 1 percent probability of occurring each year). The highest water level ever observed for Seattle's shoreline was a king tide event in December 2012 that had 3.1 feet of storm surge, equivalent to a water level of 12.1 feet above MHHW.

Table 4.3 Projected change in the frequency of tidal flooding in Seattle. Values for each time period and scenario are projections of sea level rise added to the current episodic storm surge heights for each return interval.

Time Frame	Return Period	Moderate scenario (feet above MHHW)	High scenario (feet above MHHW)
Current	100-year	3.1 ft	3.1 ft
	annual	2.0 ft	2.0 ft
	monthly	1.0 ft	1.0 ft
	daily	na	na
2030	100-year	3.3 ft	3.9 ft
	annual	2.2 ft	2.8 ft
	monthly	1.2 ft	1.8 ft
	daily	0.2 ft	0.8 ft
2050	100-year	3.5 ft	4.7 ft
	annual	2.5 ft	3.6 ft
	monthly	1.5 ft	2.6 ft
	daily	0.5 ft	1.6 ft
2100	100-year	5.1 ft	7.8 ft
	annual	4.0 ft	6.7 ft
	monthly	3.0 ft	5.7 ft
	daily	2.0 ft	4.7 ft

*The moderate scenario is the mean projection for a moderate GHG emissions scenario (A1B) and the high scenario is the mean projection for a high GHG emissions scenario (A1F1).

Combining the sea level rise projections with the current frequency of coastal flooding provides information on the future frequency of coastal flooding. For example, with a high scenario of sea level rise in the year 2030, Seattle is projected to experience coastal flooding up to 1.8 feet above MHHW as a monthly event, 2.8 feet as an annual event, and 3.9 feet becomes the new

100-year event. In other words, by 2030, what is currently an annual event becomes almost a monthly event and what is currently a 100-year event becomes almost an annual event.

Most of City Light's facilities and equipment are located at high enough elevations to be unaffected by sea level rise and storm surge within the next 40 years, even for a high scenario of sea level rise, because of Seattle's relatively steep shoreline topography. However, some equipment is located in areas that are projected to flood more frequently under both moderate and high scenarios (Table 4.4).

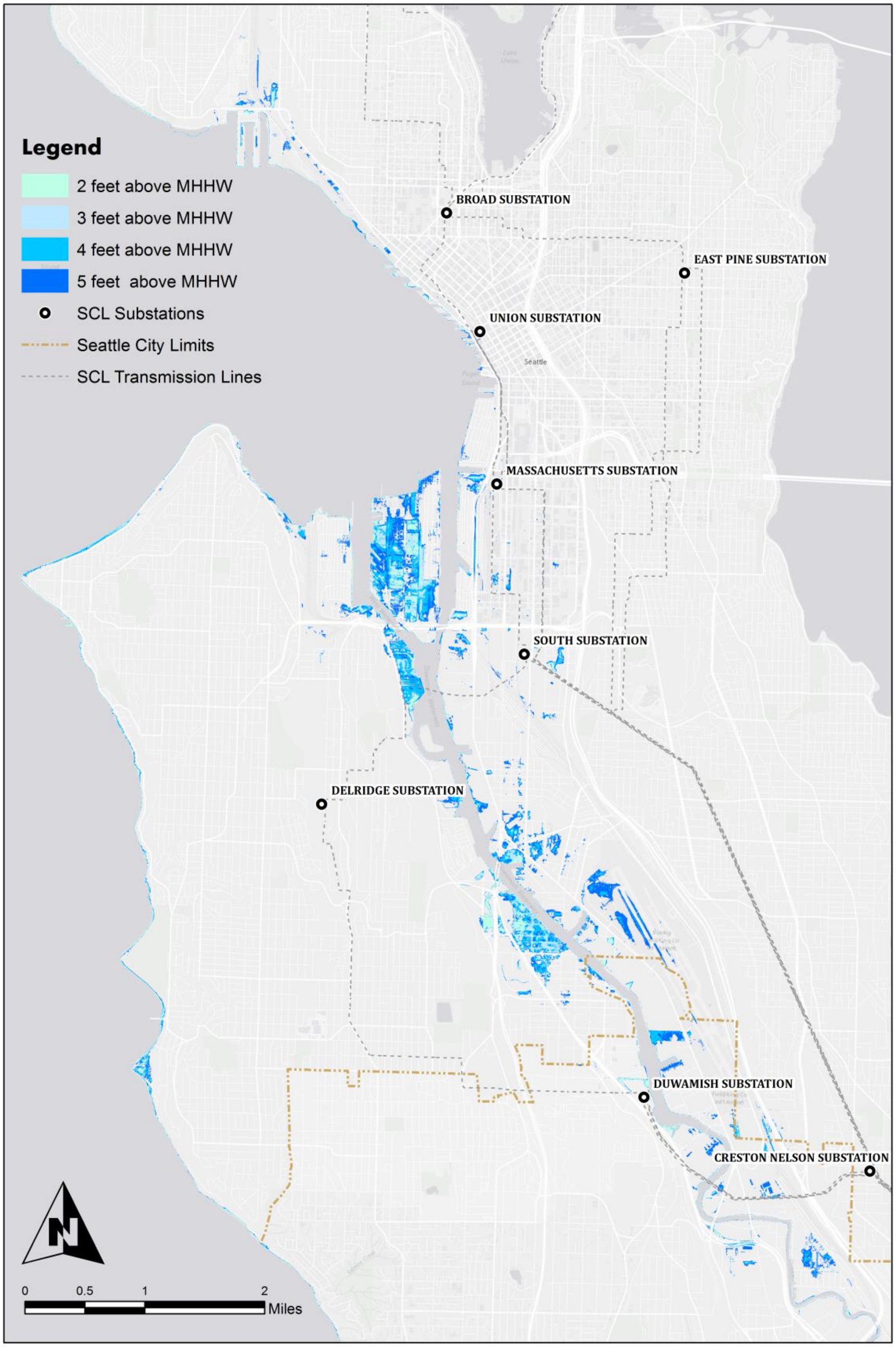
The most at risk areas of the city include infrastructure near Shilshole marina, Harbor Island and West Marginal Way, and the South Park neighborhood (Figure 4.1).The equipment listed in Table 4.4 corresponds to the areas mapped in Figure 4.2. For example, the equipment listed for 4 feet above current MHHW (12 feet NAVD88), corresponds to the area mapped as 4 feet above MHHW in Figure 4. This area and equipment does not experience coastal flooding currently but is projected to experience flooding as a 100-year event by 2030 and almost an annual event by 2050 for a high scenario of sea level rise (Table 4.3).

Table 4.4. Estimates of transmission and distribution equipment by type that could be flooded by sea water for four different elevations above MHHW as shown in Figure 4.2.

Feet Above MHHW	Support structures	Transformers Pole-Mounted	Transformers Ground Level	Transformers Submersible	Vaults	Sub-stations
2	88 (0.1%)	32 (0.1%)	0 (0%)	4 (<0.1%)	4 (0.04%)	0
3	214 (0.2%)	103 (0.2%)	4 (0.4%)	8 (0.1%)	9 (0.1%)	0
4	446 (0.4%)	196 (0.4%)	15 (1.6%)	13 (0.1%)	27 (0.3%)	0
5	783 (0.6%)	278 (0.7%)	26 (2.8%)	32 (0.3%)	50 (0.5%)	0

Note: Locations of some equipment are not precise, so values should be taken as estimates only. Locations or equipment of concern can be evaluated in more detail.

Figure 4.2. Elevations above mean high higher water (MHHW) in Seattle City Light's service area that are projected to be flooded by sea level rise and storm surge. Table 4.3 shows the frequency of flooding at these elevations for future time periods. Methods and analysis were developed by the Climate Resiliency Group at Seattle Public Utilities. Projections are based on the 2012 National Research Council report ("Sea-Level rise for the Coasts of California, Oregon, and Washington: Past Present and Future"). Sea Level Rise (SLR) information is prepared for use by the city of Seattle for its internal purposes only, and is not designed or intended for use by members of the public. Water levels account for the National Tidal Datum Epoch 1983-2001 (NTDE 83-01). The base digital elevation model (DEM) used in the analysis was produced using a 2001 Puget Sound LiDAR Consortium study, which notes a vertical accuracy, or margin of error, of 1 foot (NAVD88). Some objects such as piers may not be accurately depicted because "breaklines" were not applied[2].



Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Sensitivity

Shoreline Infrastructure

Additional factors to elevation and proximity to the shoreline, can increase the sensitivity of City Light's facilities to sea level rise and coastal flooding. Older infrastructure is less likely to be resilient to flooding and corrosion by salt water. The substrate on which facilities are built can affect soil saturation and drainage, potentially exacerbating flood impacts in some areas. Limitations in the drainage system in some areas of the city may also exacerbate the effects of sea level rise and storm surge. In addition to flooding over land, water can back up through the drainage system or through the ground during high tides.

Structures along the shoreline, such as the sea wall, provide some protection against episodic tidal flooding and sea level rise, but these areas may not be fully protected in the latter part of the 21st century depending on the magnitude of sea level rise. Furthermore, during high tide events, water can flow around protective structures. Tidal flooding in winter often coincides with heavy precipitation and areas of standing water can reduce access to City Light's facilities, slowing restoration and recovery times, as well as creating a safety risk for employees.

Tidal flooding can cause additional environmental compliance risks when storm surge floods properties or equipment that contain hazardous materials. Water from flooded equipment, such as underground vaults, must be removed and disposed of properly, which can be difficult and costly given the contaminants that can be contained in flood waters.

Transmission and Distribution

Seattle has experienced tidal flooding events in the past and frequently experiences heavy precipitation that causes localized flooding within the city, so most components of City Light's transmission and distribution system are water resistant and designed to be flooded. Salt water is more corrosive than fresh water, so more frequent tidal flooding could increase damage to transmission and distribution equipment due to corrosion. However, overall corrosion of equipment in the past is very low and Seattle's shoreline along Puget Sound does not experience sea spray and salt air to the extent of shorelines along the ocean. Flooding with salt water can decrease the life expectancy of transmission and distribution equipment, but the life expectancy of most equipment is estimated conservatively and much of City Light's equipment is already lasting longer than expected, so additional damage to equipment caused by coastal flooding can likely be absorbed in regular replacement schedules.

Adaptive Capacity

City Light's long-term facility master planning process provides an opportunity to assess and plan for the impacts of sea level rise and storm surge. Maps of sea level rise customized to the utility's service area can be used to assess the risks and costs of hardening equipment during this process. The city of Seattle is acquiring additional Light Detection and Ranging (LiDAR) data that can be used to improve the precision of the elevation resolution in current maps of sea-level rise projections. City Light's regular processes of replacing distribution equipment as needed or in response to damage provides opportunities to upgrade equipment to reduce impacts of salt water corrosion if it is observed that damage is intensifying with sea level rise and more frequent storm surge.

Potential Adaptation Actions

Near-term/ Existing Capacity

1. **Map projections of sea level rise for City Light's service area and make this information readily available to all relevant divisions in the utility. Use these maps to identify current facilities and equipment that are located within areas expected to be inundated by sea level rise and storm surge within the equipment life expectancy.** For each major asset located in exposed areas, an assessment could be conducted to determine whether the projected exposure is sufficient within the life expectancy of the infrastructure to warrant moving or hardening the equipment against coastal flooding. To increase City Light's capacity to adapt to sea level rise, maps of sea level rise should be readily available to all divisions for use in decision-making processes regarding new infrastructure along the shoreline. These maps should be updated regularly as sea level rise projections improve or LiDAR data increases the precision of elevation measurements. Where properties are designated as having coastal flood risks, infrastructure can be hardened by elevating critical equipment, installing flood barriers, or pump systems to remove water during storm surge events.

2. **Establish a utility-wide policy to consider future tidal flooding impacts in the design of proposed capital improvement projects located in areas that are projected to be more frequently affected by sea level rise and storm surge.** The assessment should include an evaluation of the timeframe of sea level rise relative to the life expectancy of the new infrastructure or upgrade. Any new facilities or upgrades built within inundation areas should consider in the design how the structure will be able to withstand sea level rise or episodic flooding with salt water. Changes to designs could include elevating or protecting components of the infrastructure that would be highly sensitive to flooding or exposure to salt water.

Long-term/Expanded Capacity

3. **Monitor and consider replacing equipment in the distribution system that is more sensitive to corrosion by salt water in areas that are projected to be inundated.** Replacements should focus on equipment in areas that are already experiencing tidal flooding during high tides or are projected to be flooded more frequently within the life expectancy of the current equipment. This process should include a cost-benefit analysis of replacing, upgrading, or hardening equipment relative to the frequency of flooding and corrosion by salt water. For equipment that is not vulnerable in the near-term, replacements or hardening can be made as part of regular repair and replacement schedules.

---

[1] National Research Council 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. The National Academies Press, Washington DC. 275 p.

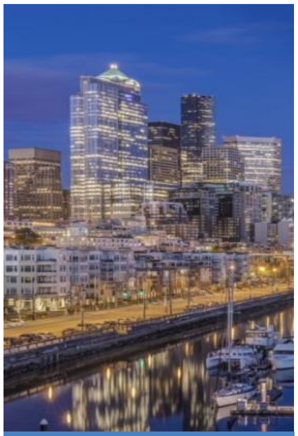
[2] http://www.seattle.gov/util/EnvironmentConservation/ClimateChangeProgram/ProjectedChanges/Sea-LevelRiseMap/index.htm

4.2 Warmer Temperatures and More Frequent Heat Waves

Impact 3: Electricity Demand

Warmer temperatures and more frequent heat waves are likely to increase electricity demand for cooling in summer and decrease electricity demand for heating in winter.

Mission Objectives at Risk: Financial Cost



Electricity Demand

Seattle City Light may need to adapt infrastructure and operations to accommodate changes in the seasonality of electricity demand as temperatures warm. The utility is likely to experience an increase in load (i.e. demand) for cooling in summer, and a decrease in load for heating in winter, flattening the current seasonal demand profile. For example, record warm temperatures in the winter of 2014/2015 (4 to 6 °F above normal) likely contributed to lower electricity demand and a decrease in City Light's retail electricity sales. These seasonal changes in electricity demand for heating and cooling will be superimposed on other changes in load associated with population growth, economic development, and improvements in energy efficiency.

Change in the seasonality of demand could have financial consequences for City Light by affecting retail sales, the timing and amount of surplus power available to sell, and additional wholesale power purchases in summer. However, this change is unlikely to have consequences for resource adequacy because City Light currently has surplus power to sell in most years. These seasonal changes in electricity demand are also unlikely to affect reliability because City Light has greater demand for electricity in winter than in summer throughout most of the service area.

Changes in demand for City Light's service area will need to be considered within the regional context of greater summer electricity demand throughout the Pacific Northwest[1] and along the West Coast, especially in California[2] where electricity demand is more sensitive to warming temperatures because of greater air conditioning use in the residential sector. Rapidly changing electricity technology, energy efficiency, electrification of transportation, and carbon mitigation policies are also likely to greatly affect electricity demand in the coming decades.

Exposure

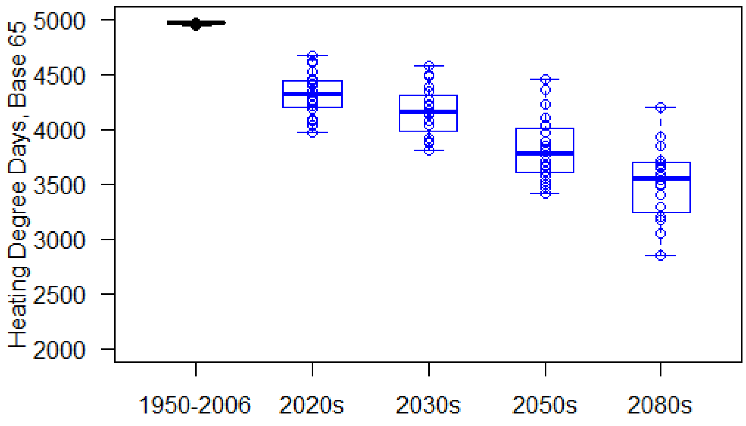
Heating and Cooling Degree Days

As described in **Section 3.2**, average temperatures are expected to warm in all seasons with more warming projected for summer. The direction of change is consistent for all climate models, but the magnitude of change varies among models.

Heating degree days (HDD) are calculated as the sum of the degrees that the daily mean temperature is below 65°F for all days of the year. HDD below a daily mean of 65°F indicate a need for electricity for heating. With a moderate warming scenario, average annual HDD are projected to *decrease* by a mean of 810 (± 227) by the 2030s and 1143 (± 292) by the 2050s, a

16 percent and 23 percent reduction respectively (Figure 4.3). With a high warming scenario, the reduction in HDD increases to 19 percent by the 2030s and 29 percent by the 2050s (Figure 4.3). Greater decreases are projected for the latter half of the 21st century and for the higher scenario of GHG emissions as warming accelerates.

Annual Heating Degree Days at SeaTac for a Moderate Scenario



Annual Heating Degree Days at SeaTac for a High Scenario

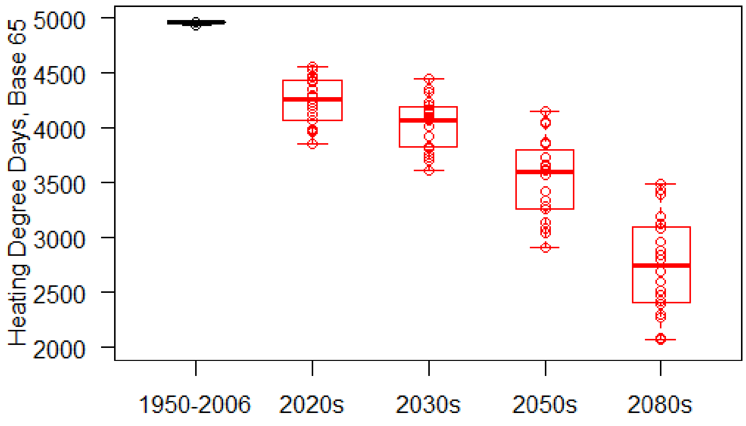


Figure 4.3. Projected changes in heating degree days (base 65°F) at the SeaTac airport weather station. Heating degree days are an indication of energy demand for heating. In City Light's service area, about 18 percent of heating systems in single-family residences[3] and 98 percent of heating systems in multifamily residences[4] are fueled by electricity. Climate data were downscaled from 20 climate models (circles) and two scenarios of GHG emissions (moderate and high). Differences between emissions scenarios are greater in the latter half of the century. Circles indicate projections for each of the 20 models and the box indicates the interquartile range for each 30-year time period.

Cooling degree days (CDD) are calculated as the sum of the degrees that the daily mean temperature is above 75°F for all days in the year. CDD above a daily mean of 75°F indicate a need for electricity for air conditioning[A]. For the historical period (1950 – 2006) CDD at SeaTac have been very low (< 20 CDD per year). With a moderate warming scenario, average annual CDD are projected to increase by a mean of 18 (± 10) by the 2030s and 38 (± 21) by the 2050s, a 288 percent and 588 percent increase respectively (Figure 4.4). With a *high* warming scenario, the increase in CDD increases to a mean of 24 (± 11) by the 2030s and 67(± 36) by the 2050s (Figure 4.4). Despite the large percentage increases, the projected future CDD remain below almost all other metropolitan areas in the U.S.

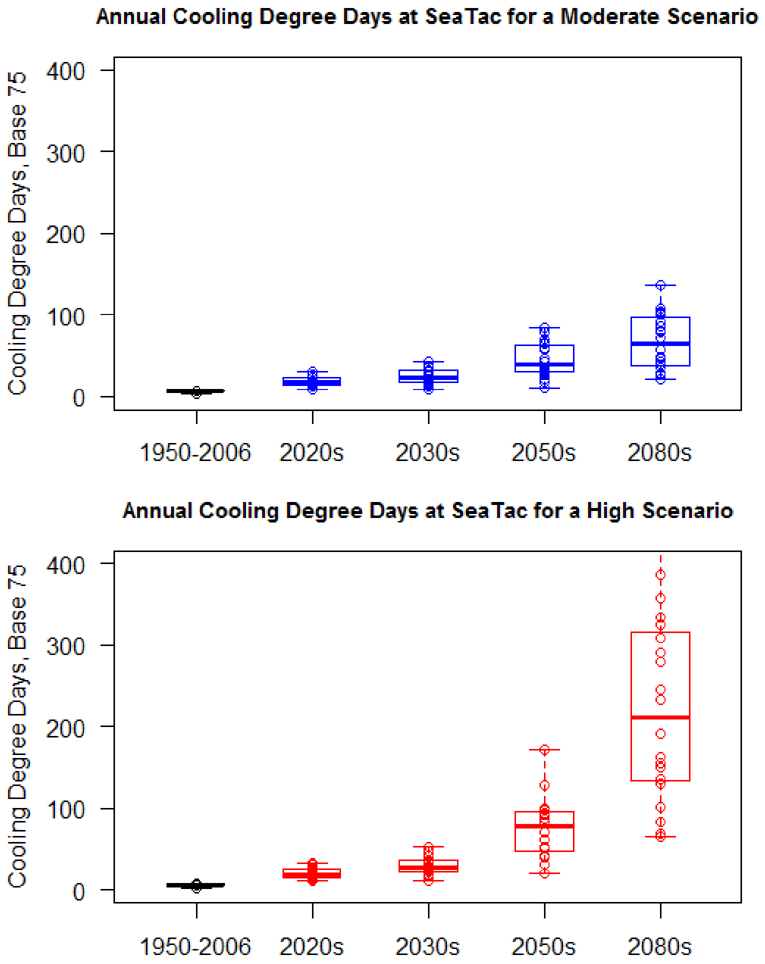


Figure 4.4. Projected changes in cooling degree days (base 75°F) at the SeaTac airport weather station. Cooling degree days indicate energy demand for cooling, most of which is met with electricity in Seattle. Data were downscaled from 20 climate models (circles) and two scenarios of GHG emissions (moderate and high). Differences between emissions scenarios are greater in the latter half of the century. Circles indicate projections for each of the 20 models and the box indicates the interquartile range for each 30-year time period.

[A] Cooling degree days are often calculate for a base temperature of 65°F similar to heating degree days, but 75°F was used because it is more indicative of air conditioning needs in the Seattle area. Using a base of 65°F would further increase the change in cooling degree days but the same general pattern would stay the same.

Extreme Temperatures

In the next 20 years, warming will likely cause more frequent extreme hot days and heat waves for which there are historical analogues, but as warming continues, average summer temperatures are projected *to* exceed the range of historical variability by the middle of the 21st century. Washington is projected to experience an increase in extreme hot temperatures but a decrease in extreme cold temperatures[5]. City Light had adequate supply and capacity to manage for extreme heat events in the recent past, such as the hot summers of 2009 (record high temperature at SeaTac of 103°F) and 2015 (record number of days over 90°F), with negligible impacts on reliability. As extreme hot days increase in frequency and intensity, the system's sensitivity to more extreme hot days will need to be assessed. The impact is likely to be localized to sections of the distribution system that already experience higher loads associated with cooling in summer, which is primarily in the downtown commercial core.

Daily Minimum Temperatures

In Washington, daily minimum temperatures are increasing faster than daily maximum temperatures and this trend is expected to continue. These changes could affect the shape of City Light's daily load profile and these effects will differ for the commercial sector vs. the residential sector. Warmer minimum (i.e. night time) temperatures will have less of an effect on the commercial sector load compared to warmer maximum (i.e. day time) temperatures because daily peak commercial load occurs during the day and decreases at night. Warmer minimum temperatures may disproportionately affect residential electricity demand for cooling because minimum temperatures occur at night when people are home and therefore may use more electricity for residential air conditioning or less for heating.

Sensitivity

Temperature is only one factor that affects load. City Light's load forecast has recently been revised downwards. Annual load is now projected to increase in City Light's service area by about 0.5 percent per year for the 2014 to 2034 period as a function of population growth and economic development[6]. City Light's preliminary analysis of the effects of warming temperatures on load indicated that annual load is more sensitive to the drivers of economic development and population growth than to warming temperatures[7]. However, as temperatures continue to warm, it will be increasingly important to consider the additional effect of warming temperatures in load forecasting and planning. Warming temperatures are likely to reduce the rate of load growth in the winter but increase the rate of load growth in summer. A more thorough analysis is necessary to understand the relative impacts of these drivers, including potential non-gradual changes in residential air conditioning use.

The sensitivity of electricity demand to temperature depends on several factors including annual and daily temperature ranges in the current climate, air conditioning use, differences in electricity use between the commercial and residential sectors, and sources of energy for heating and cooling.

Current Climate and Load Patterns

Due to its proximity to the Pacific Ocean, Seattle has a mild climate in both winter and summer. Currently, Seattle has an average July and August daily maximum temperature of 76°F, and heat waves are rare with only three days per year on average with maximum temperatures exceeding 90°F. Average daily minimum temperatures in December and January are 36°F and 37°F respectively, and only about 25 days per year drop below freezing temperatures. Furthermore, Seattle's mild climate causes low variability in temperatures within a day. This lack of temperature variability both annually and daily results in less variability and more consistent electricity load among seasons and during a day compared to most other U.S. cities that experience hotter summers, colder winters, and a larger range between daily high and low temperatures. These mild temperatures and low variability decrease the sensitivity of City Light's electricity demand to warming temperatures. However, warming temperatures are expected to change historical seasonal demand patterns and these changes will require planning and preparation.

Seattle's mild summer temperatures cause City Light's demand for electricity to be greater in winter than summer and the utility experiences its highest hourly peak loads in winter due to electricity demand for lighting and heating. Smaller peaks occur in summer associated with the hottest days. For the service area as a whole, hourly peak load is about 20 percent higher on cold, dark days in winter than on the hottest days in summer.

Air Conditioning Use by Sector

The mild summer climate also results in low air conditioning use in single-family residences (less than four units) throughout the service area. Currently, use of air-conditioning in single-family residences is only about 5 percent of residences for all types of air conditioners including central and portable systems[8]. Increases in load for cooling in this part of the residential sector will depend on increases in the use of air conditioners, which may not be gradual and could occur quickly in response to extreme temperatures or heat waves. The utility currently lacks information on potential increases in air conditioning use and its implications for summer load in the single-family portion of the residential sector.

The commercial sector uses more electricity for heating ventilation and air conditioning (HVAC) systems in commercial buildings and multi-family residences (more than four units) compared to single-family residences. The electricity required to operate HVAC systems throughout the summer results in energy consumption and peak demand for the commercial sector to be less variable among the seasons when compared to the residential sector The three substations that serve the downtown commercial core already experience summer hourly peak loads near that of winter hourly peak loads. The use of HVAC systems in the commercial sector is already high, so electricity loads in this sector are likely to be more sensitive to gradually warming temperatures because these systems can respond immediately

Public Health Impacts from Warmer Temperatures

Despite relatively mild temperatures and infrequent heat waves in Seattle, warmer temperatures could have detrimental effects on public health. The city is less well adapted to extreme temperatures and heat waves because of Seattle's historically mild climate, limiting peoples' tolerance and capacity to respond. Furthermore, public health impacts are likely to be disproportionately felt by vulnerable populations including the elderly, sick, and low-income populations who may be more sensitive to heat waves and have less access to resources for cooling. Public health impacts could have indirect effects on electricity demand by accelerating the use of air conditioning and increasing the demand for electricity by hospitals.

as temperatures warm. For these localized areas, warmer temperatures could cause summer peaks to exceed winter peaks in the near-term.

Sources of Energy for Cooling and Heating

Electricity demand for cooling is generally more sensitive to warming temperatures than electricity demand for heating because cooling systems are typically powered by electricity, whereas heating systems are often powered by other sources of energy including oil and natural gas. Greater use of non-electric energy sources for heating will further decrease City Light's electricity load in winter.

Power Resource Portfolio

The resources in City Light's power portfolio affect the utility's sensitivity to increasing summer load. City Light's resource portfolio is primarily hydropower from the Pacific Northwest for which generation is typically highest in May and June with runoff from snowmelt and lowest in August and September when streamflow is lowest. With warming temperatures and loss of snowpack, hydropower generation is projected to increase in winter, peak earlier in spring, and decrease in summer (**Section 4.7, Impact 10**). This projected change in the seasonal pattern of generation better aligns with City Light's *current* seasonal load profile, but projected decreases in summer hydropower generation will increase City Light's sensitivity to increasing summer loads. In contrast to hydropower, renewable energy sources such as solar photovoltaic are projected to have higher generation potential in summer and can decrease sensitivity to increases in summer load.[9]

Indirect Climate Change Effects on Electricity Demand

Climate Change Migration to Seattle

Climate change may affect City Light's load indirectly by increasing population growth in the Puget Sound region. The relatively mild climate of the area may attract people from other regions of the nation or the world that are projected to experience even greater warming, more frequent droughts, or other severe impacts of climate change. Climate-related migration to the region could further increase City Light's load growth in all seasons. However, it is unclear if this population growth would be detectable relative to the rapid growth already underway as a result of growth in the economy. The indirect effect of climate-related population growth on electricity demand is highly uncertain and an active area of climate change impacts research[A].

Climate Change Mitigation Policy

Another indirect effect of climate change on load growth is changes in load associated with GHG reduction policies such as the EPA Clean Power Plan and Washington State's carbon cap policies. These regulations and policies are currently under development and their effects on electricity demand are highly uncertain, but they could be significant. For example, electrification of the transportation sector in the region could increase load, but further efforts to increase energy efficiency in the building sector could decrease load.

Adaptive Capacity

Integrated Resource Planning

City Light's Integrated Resource Planning (IRP) process increases the utility's capacity for long-term planning of changes in seasonal load patterns. The IRP process forecasts demand for the next 20 years and evaluates the potential for different power resources to effectively meet demand. The IRP is updated every two years, creating a process to evaluate factors that affect load as they emerge. However, current load forecasting for the IRP relies on historical temperature normals and does not consider projected temperature increases. Furthermore, the temperature sensitive portion of load forecasting is based on heating degree days only and does not include a factor for cooling degree days. Within the 20-year IRP planning horizon, projected changes in temperature are significantly different from historical normals and could affect seasonal load.

The IRP process focuses on resource adequacy and uses peak hourly demand in December and January as the highest load for which to ensure adequate resources. Warming temperatures will likely reduce the temperature sensitive component of this peak (making current resource adequacy calculations conservative), but increases in load based on population growth and economic development are likely to further increase this peak. This sensitivity of peak load to temperature has not been fully evaluated by the utility.

Energy Conservation

City Light's current conservation programs provide capacity that can be leveraged to increase the utility's resilience to higher electricity demand in summer for cooling. The programs incentivize the purchase and installation of energy efficient equipment that address every end-use, including lighting, appliances, space conditioning, and water heating. These measures provide demand and energy savings during the summer, as well as winter.

City Light co-sponsors two programs focused on energy efficiency for heating in the residential sector. The Community Power Works Program provides rebates to customers that heat their homes with electricity, including rebates for weatherization and ductless heat pumps that can provide co-benefits of reducing electricity demand for cooling. The Homewise Program helps low-income customers weatherize their homes for heating efficiency, and specifically addresses the hardship of electricity costs on low-income populations. Weatherization provides the co-benefit of keeping homes cooler in summer, so this program also can address the disproportionate effects that warmer temperatures and more heat waves could have on low-income populations.

Potential Adaptation Actions

Near-term/Existing Capacity

1. **Expand Seattle City Light's analysis of the relationship between warming temperatures, seasonal base and peak load, and use of air conditioning in the residential sector.**
   City Light's previous analysis of the effects of warming temperatures on load could be expanded to include a larger range of future climate projections (the initial analysis included only two scenarios that do not capture the range of projected increases in temperature), a

multiple model mean, and the most recent CMIP5 climate model projections (available in 2012). The initial analysis assumed a constant relationship between temperature and load, which was derived from the historical relationship between these two factors. The analysis did not consider that this relationship could change when temperatures exceed the range of historical observations because of increases in the use of air conditioning in the residential sector or changes in the shape of the daily load profile. The analysis could be used to determine how much warming would shift peak load from winter to summer in the residential and commercial sectors and the timeframe in which this could occur based on future temperature projections. This assessment should also include an analysis of how changes in seasonal load could affect revenue, including an evaluation of how to address any revenue loss.

2. **Identify and evaluate potential co-benefits of existing energy-efficiency programs to reduce electricity demand for cooling in summer, as well as for heating in winter.**
   City Light could increase resilience to changes in seasonal load profiles by emphasizing the co-benefits of energy-efficiency programs for reducing load for cooling in summer, as well as winter. For example, City Light's Conservation program could consider new programs that facilitate a more efficient transition to greater residential air conditioning. City Light could also support energy efficiency for cooling by developing education and incentive programs that encourage customers to use the most efficient methods for air conditioning.

3. **Coordinate with the Public Health Department and Office of Emergency Management to increase the city's capacity to prepare for and respond to heat waves.**
   The Public Health Department will likely need to increase resources and preparedness for heat waves as they become more common. City Light's emergency management could coordinate with other departments to help the utility anticipate and prepare for any additional load associated with efforts by the city to provide cooling centers for vulnerable populations during heatwaves. Distribution planning should consider the potential of higher electricity demand for cooling in specific locations that are used for emergency response.

Long Term/Expanded Capacity

4. **Explore the potential of demand response programs for reducing peak commercial load on the hottest days in summer.**
   Demand response is a voluntary and temporary change in a customer's use of electricity during a load peak when the system is stressed[10]. Demand response has the potential to prevent the need for additional generation resources, wholesale power purchases, or distribution system upgrades to accommodate higher summer peak loads for parts of the system that are stressed during summer peaks. An increase in peak summer loads are more likely in the commercial sector because of HVAC systems, so demand response programs focused on the commercial sector are more likely to effectively reduce potential for summer peaks. Advanced metering facilitates demand response programs and City Light is beginning an initiative to move to advanced metering. Demand response programs in the commercial sector can include controls on central and room air conditioning and lighting. Demand respond programs require installation of new technologies to communicate with the utility and signal interruptions to the equipment.

---

[1] Hamlet, A.F., S-Y. Lee, K.E.B. Mickelson, and M.M. Elsner. 2010. Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. Climatic Change 102(1-2): 103-128.

[2] Franco, G.F, and A.H. Sanstad. 2008. Climate change and electricity demand in California. Climatic Change 87 (Suppl 1): S139-S151.

[3] Seattle City Light Residential Building Stock Assessment: single-family characteristics and energy use. Prepared by Ecotope Inc. 2014.

[4] Seattle City Light Residential Building Stock Assessment: multifamily characteristics and energy use. Prepared by Ecotope Inc. 2014.

[5] Snover, A.K [.et al]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[6] Seattle City Light, 2014 Integrated Resource Plan, http://www.seattle.gov/light/news/issues/irp/

[7] Seattle City Light, 2012 Integrated Resource Plan, http://www.seattle.gov/light/news/issues/irp/

[8] Seattle City Light Residential Building Stock Assessment: single-family characteristics and energy use. Prepared by Ecotope Inc. 2014.

[9] Bartos, M.D. and M. V. Chester. 2015. Impacts of climate change on electric power supply in the Western United States. Nature Climate Change (1-5).

[10] The Northwest Power and Conservation Council Seventh Power plan. Chapter 14: Demand Response.

Impact 4: Transmission and Distribution Capacity

Warmer temperatures and more frequent heat waves could reduce transmission and distribution capacity and the life expectancy of insulated transmission and distribution equipment.

Mission Objectives at Risk: Financial Cost, Reliability

Warmer temperatures have the potential to reduce transmission capacity. Transmission line ratings, which set the limits on the amount of power that can be transmitted through a line, partially depend on ambient air temperature. When temperature thresholds for ratings are reached or exceeded, transmission capacity may need to be reduced to prevent damage or sag of the lines that could reduce clearance above structures and vegetation.

Transmission and Distribution

Peak summer loads are likely to coincide with higher temperatures that could require this reduction in transmission capacity, further stressing the system. However, as described in **Section 4.2, Impact 3**, City Light experiences highest loads in winter when air temperatures are low. However, the coincidence of higher summer peak loads and higher air temperatures may be of concern for localized areas of the distribution system that currently have summer peaks that are closer to winter peaks because of high energy demand for HVAC systems.

Warmer temperatures could also reduce the life expectancy of insulated transmission and distribution equipment, such as transformers and underground cables, when the equipment is operated near temperature limits more frequently. This could increase maintenance and replacement costs for equipment.

Exposure

Overhead conductors, underground cables, and transformers will be exposed to higher ambient air temperatures in all seasons as temperatures warm. In addition to increases in average temperatures, Seattle is projected to experience an increase in the number of extreme hot days and a decrease in the number of extreme cold days. The frequency of extreme hot and cold temperatures is a better indicator of the exposure of transmission and distribution equipment to changes in temperatures than are average temperatures because equipment is stressed by temperature extremes.

Currently, Seattle only experiences six days per year on average with a maximum temperature exceeding 86°F (1950 to 2006 average at SeaTac weather station). For a moderate warming scenario, this is projected to increase to 13 (± 1.6) days per year by the 2030s and 18 (± 2.5) days per year by the 2050s, a 107 percent and 187 percent increase respectively (Figure 4.5)[1]. For a high warming scenario, this is projected to increase to 14 (± 2.2) days per year by the 2030s and 24 (± 5.5) days per year by the 2050s, a 121 percent and 276 percent increase respectively. Despite the large percentage increases in the number of hot days, the number of hot days is still relatively low compared to most other major metropolitan areas in the nation.

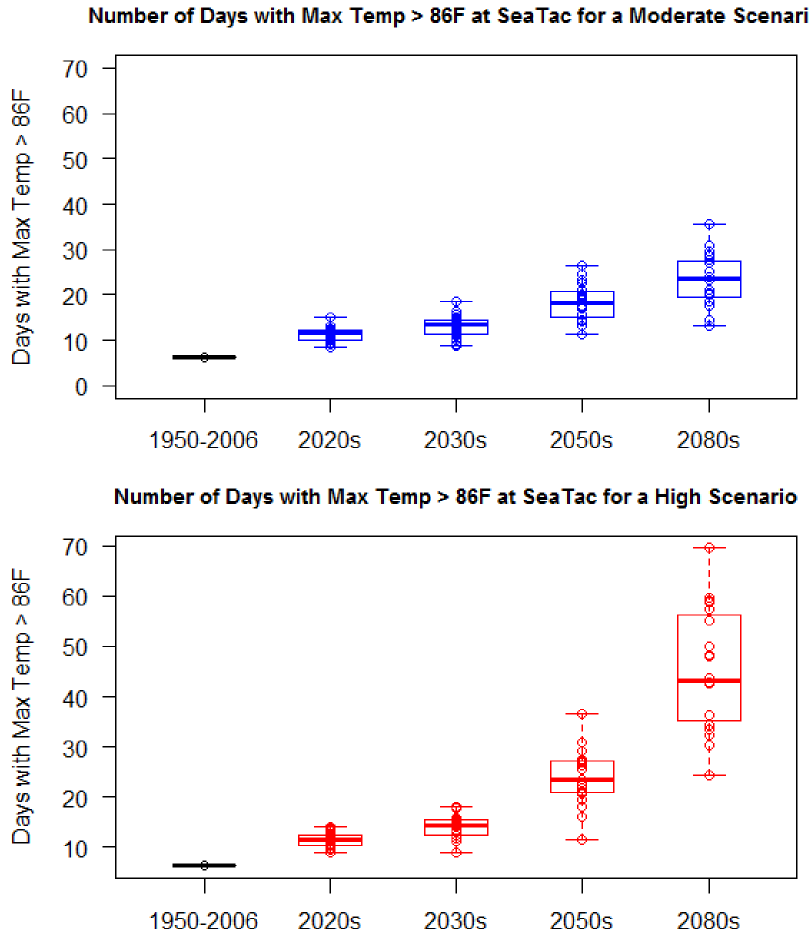


Figure 4.5. Projected changes in the number of days that summer ambient air temperature values (86°F) for transmission line ratings will be exceeded. Changes are projected for the SeaTac airport weather station. Days with a maximum temperature greater than 86°F increases significantly for all time periods and both emissions scenarios. Increases are greater for the latter part of the 21st century and for the higher emissions scenario. City Light experiences peak summer loads when air temperatures are high, but peak summer loads are less than peak winter loads.

A similar pattern is expected for the decrease in days below freezing. Seattle experiences 33 days per year on average with a *minimum* temperature below 32°F (1950 to 2006 average at SeaTac weather station). For a low warming scenario, this is projected to decrease to a mean of 17 (± 4.7) days per year by the 2030s and 12 (± 4.3) days per year by the 2050s, a 50 percent and 64 percent decrease respectively (Figure 4.6). For a high warming scenario, this is projected to decrease to a mean of 14 (± 4.9) days per year by the 2030s and 9 (± 4.5) days per year by the 2050s, a 60 percent and 72 percent decrease respectively.

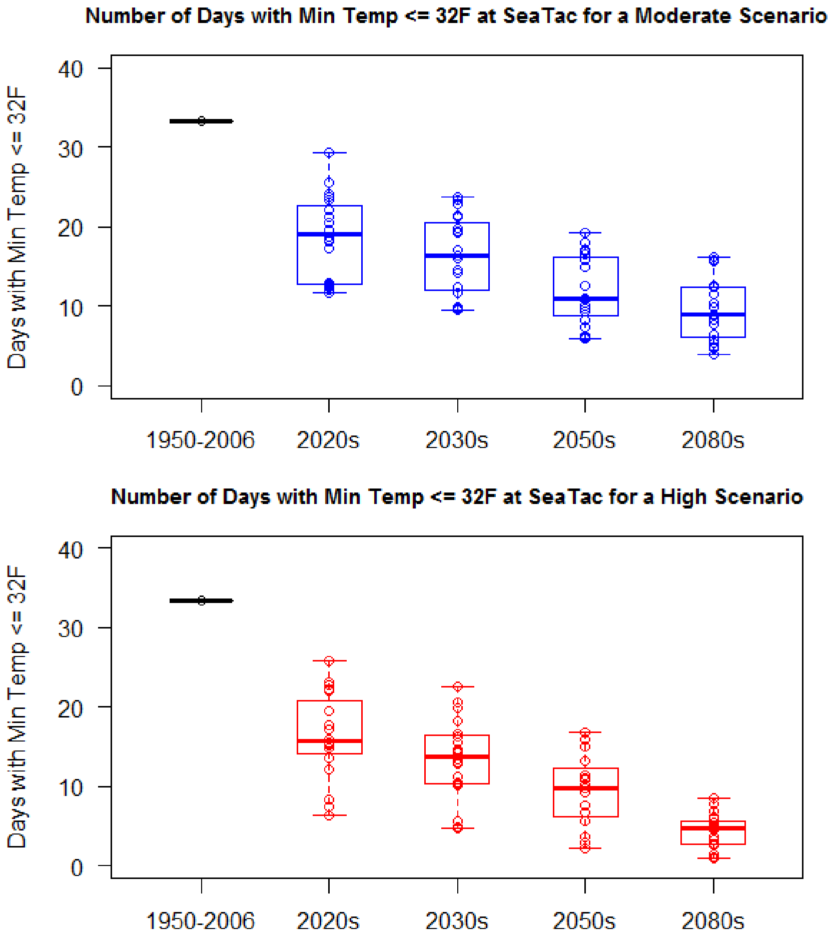


Figure 4.6. Projected change in the number of days that winter ambient air temperature (32 °F) values for transmission line ratings will be exceeded. Changes are projected for the SeaTac airport weather station. Days with a minimum temperature less than 32°F decreases significantly for all the time periods and both emissions scenarios. Increases are greater for the latter part of the 21st century and for the higher emissions scenario. City Light experiences peak loads in winter when air temperatures are lowest.

Sensitivity

Overhead Conductors

The maximum limits for power that can be transmitted through overhead conductors are set by line ratings, which are partially a function of ambient environmental conditions (wind speed, solar radiation, and air temperature). When power flows exceed the limits set by these ratings, the strength of overhead conductors can be reduced causing damage and a shorter life expectancy. Overhead conductors that get too hot can also sag more, increasing the potential to come in contact with vegetation or structures underneath the lines. When temperatures are high, load may need to be reduced to prevent overloading if lines are operating at full capacity.

Several aspects of City Light’s transmission and distribution system reduce its sensitivity to warming temperatures. First, line ratings for overhead conductors are set by the National Electric Safety Code and are designed to be conservative. Line ratings for City Light’s 230 kV transmission lines are based on an ambient air temperature of 86°F from June 1 to October 31. In winter, line ratings are based on an ambient air temperature of 32°F to reduce impacts associated with high load. Increases in ambient air temperature could theoretically decrease line ratings with an approximate 0.4 percent decrease in current per 1°F increase in temperature for a standard line. However, ambient air temperature is only one environmental factor that affects ratings. Ratings are more sensitive to wind speed than temperature. Higher wind speeds effectively cool transmission lines by moving heat away from the lines. The standard wind speed used for line ratings is only 0.7 miles per hour, but average wind speeds in the Seattle area exceed this most of the time, keeping lines below the ratings.

Second, line ratings are national standards that are designed to function in regions that have much warmer and colder temperatures. As with electricity demand (**Section 4.2**, **Impact 3**) the relatively mild summer and winter temperatures in Seattle reduce the sensitivity of the transmission and distribution system to warming temperatures. Lastly, City Light’s transmission system is rarely operated at full capacity currently, so the system has excess capacity that can be used to accommodate the impacts of warmer temperatures. Operating at lower capacity ensures that the lines are rarely near the ratings.

Transformers

The operating capability of transformers is primarily based on temperature and high ambient air temperatures can damage equipment if the current is not reduced. An important operating assumption for transformers in City Light’s service area is that they are able to cool at night with Seattle’s relatively low night time minimum temperatures. Increases in night time minimum temperatures could increase damage to transformers or require capacity to be reduced, or both. Transformers are designed to sustain high ambient air temperatures for short periods of time, but high temperatures for several consecutive days are a critical factor that can damage transformers because they are unable to cool. Climate projections for an increase in the number of days above 86°F suggests that the number of consecutive hot days will also increase, but daily sequencing of maximum temperature is beyond the scope or current climate models.

Underground Cables

Underground cables are rated based on the maximum operating temperature for the insulation materials. Excess heat produced when operating at higher temperatures can reduce the life expectancy of the cables. Both the moisture content and temperature of the soil affect the operating temperature of underground cables by reducing the amount of heat that is conducted away from the cable. Both of these soil factors are affected by air temperature. Warmer temperatures in summer are expected to increase evaporation and reduce soil moisture. Historically, underground cables have not experienced damage associated with heating in Seattle, so no specific materials are used around underground cables to prevent heat damage. Warmer, drier soils could cause greater damage and failure of underground cables, leading to a need for other fill materials besides soil around cables to prevent damage from overheating.

Adaptive Capacity

Redundancy and Contingency Planning

Based on the reliability standards set by the National Electric Reliability Cooperation (NERC), City Light's transmission system is built with redundancy to ensure that the loss of any single component of the system can be compensated for by shifting load to other components, a process known as N-1 or N-2 contingency analysis. Redundancy in the system is achieved with multiple transmission lines from the same generation facility or by operating at reduced capacity to accommodate shifting loads if a failure occurs. Furthermore, the western bulk transmission system is highly connected throughout the Northwest region providing effective redundancy. The regional system is operated with greater capacity than is needed at any one time to ensure reliability of the system as a whole. These reliability standards provide high capacity to adapt to the impacts of warmer temperatures and higher summer loads on transmission capacity.

Vegetation Management

City Light's vegetation management program (**Section 4.3, Impact 5**) increases the utility's capacity to reduce compliance violations associated with sag of overhead transmission lines. For 230 kV transmission lines, vegetation is managed in the rights-of-way (ROWs) under the lines to maintain clearances as required by NERC. Vegetation is also maintained under lower capacity transmission lines, although NERC standards are not required. Clearance standards are designed to be conservative and minimize failures by accounting for extreme scenarios of high temperature and electricity load. However, these extremes scenarios are based on *historical ranges* of temperature and load, and thus may not have the capacity to adapt to warming temperatures with climate change.

Potential Adaptation Actions

Long-term/Expanded Capacity

1. **Analyze the effect of warming temperatures on transmission capacity under current and potential alternative operating procedures for City Light's transmission lines.**
   This vulnerability assessment includes projected changes in the number of days that exceed temperature thresholds for line ratings and average changes in air temperature, as well as the range and uncertainty of these projections. This information could be used to conduct a quantitative assessment of the effects of more consecutive extreme warm days, warmer average maximum and minimum temperatures, and higher summer loads on transmission, distribution, and transformer capacity. The analysis could address the financial impacts to the utility associated with reduced capacity or more heat-related damage to insulated equipment. This analysis would also need to consider the combination of impacts that could happen simultaneously to reduce capacity, including higher summer electricity demand, warmer temperatures, and outages that are also related to warm temperatures such as wildfires.

2. **Monitor failures and damage to underground cables associated with warmer temperatures and drier soils to determine if alternative fill materials are needed to reduce heat-related failures.**
   Failures of underground cables due to heat should be monitored to determine if these failures are becoming more frequent as temperatures warm. Gradual increases in failures could likely be absorbed in current operations and would not have a significant financial impact on the utility. However, if trends are observed to be related to warmer temperatures and failures become more frequent, additional actions should be evaluated to reduce heat damage to underground cables and associated power outages.

---

[1] Dalton, M. 2014. Technical Memo #6. Future Projections of Climate Metrics of Operational Relevance. Climate Impacts Research Consortium, Oregon State University. Prepared for Seattle Public Utilities.

4.3 Changes in Extreme Weather Patterns

Impact 5: Transmission and Distribution Infrastructure

Changes in the seasonality, type, and frequency of extreme weather could increase damage to transmission and distribution equipment and increase power outages for customers.

Mission Objectives at Risk: Reliability, Financial Cost, Safety


Transmission and Distribution

More frequent and intense extreme weather events are a commonly cited concern for the energy sector[1] in a changing climate based on several recent extreme events, including hurricanes Katrina (2005), Irene (2011) and Sandy (2012). These hurricanes caused extensive power outages across the Southeast and Northeast U.S., some lasting weeks to months.

Washington is not at risk of hurricanes, but changes in other extreme weather patterns (lightning, windstorms, and heavy precipitation) could pose additional risks to the reliability of the transmission and distribution system. The most common weather-related cause of outages in City Light's distribution system is windstorms that bring trees and branches down on lines, especially when combined with heavy precipitation, ice, or snow. Lightning strikes to overhead lines and transformers can also cause outages when the equipment is not equipped with protective devices.

Preliminary climate projections do not indicate significant changes in windstorms and only slight increases in the potential for lightning in the Cascade Mountains and Eastern Washington. Increases in heavy precipitation events are projected for Western Washington and could increase damage to distribution infrastructure and slow restoration times, particularly when water exceeds the city's drainage capacity and creates area of standing water that prevent safe access for repairing storm-related outages.

Exposure

Windstorms

Little information is available on how climate change may affect windstorms, making the future exposure of City Light's transmission and distribution system uncertain. Commonly cited increases in "storm intensity" refer to increases in *hurricane* intensity in the Eastern U.S. and *precipitation* intensity in the Northwest[2]. The climate mechanisms that increase hurricane and precipitation intensity do not also increase wind intensity, despite the fact that wind and rain often come together in winter storms in Western Washington.

Given the limited information on climate change and windstorms, City Light's Climate Research Initiative funded a study to quantify projected changes in the frequency and seasonal timing of high winds, which cause the most weather-related outages to City Light's system[3]. The study used three global climate model scenarios and a regional climate model that captures local storm patterns and their interactions with the topography. Projections showed a slight increase in the number of fall days with high winds (> 25 mph) by the end of the 21st century (relative to 1970 to 2000) in Western Washington and offshore, but results were not significant. For Eastern Washington, the three climate scenarios did not show consistent projections for increases or decreases in the number of days with high winds. Results also indicated a one week earlier onset of high-wind events in fall, but this result was not significant. However, these results are preliminary because only three climate scenarios were considered and more scenarios are needed to understand the uncertainty in future projections.

Despite the lack of evidence for changes in high winds, Western Washington is likely to experience greater exposure to some other weather factors that can increase damage during windstorms, including heavy precipitation and soil saturation. Windstorms can cause more damage to the distribution system when they coincide with heavy precipitation and high soil moisture because tree limbs are more likely to break with heavy rain and tree roots are less stable when soils are saturated. Rapid freezing and thawing of soil or vegetation can increase broken limbs and downed trees; however, rapid freeze-thaw cycles are rare in Western Washington and few outages are associated with ice and freezing temperatures.

Heavy Precipitation

The intensity of short-term (daily or hourly) precipitation events is expected to increase throughout Western Washington as the climate changes[4]. Precipitation intensity increases when annual precipitation increases more than the number of rainy days. More rain must fall on the same number of rainy days. Precipitation intensity is projected to increase because warmer temperatures increase the water holding capacity of the air, causing storms to release more rain. The orographic effect of the Cascade Mountains further enhances precipitation intensity in Western Washington.

The heaviest precipitation events in Western Washington are often associated with atmospheric rivers which bring substantial moisture from the tropical Pacific and deposit it in a narrow band somewhere along the West Coast. It is during these events that Puget Sound has experienced some of the greatest flooding consequences in recent decades[5]. The frequency and intensity of these atmospheric rivers are also projected to increase as the climate changes[6].

Exposure to Snow and Ice as the Climate Changes

The frequency of snow and ice storms at low elevations in Western Washington is likely to decrease as temperatures warm with climate change. The likelihood of days near or below freezing is projected to decrease. Therefore, the frequency of outages associated with snow or ice may also decrease. However, it is important to recognize that Seattle will continue to experience climatic variability that could include freezing temperatures and snow, so snow and ice will continue to be possible. Furthermore, an increase in precipitation intensity could lead to more snow in a storm when one does occur in the Puget Sound lowlands.

Lightning

Lightning strikes specifically cannot be simulated by climate models, but the models can simulate the atmospheric conditions associated with convective storms that cause lightning. These atmospheric conditions are expected to be more common in many areas of the U.S., suggesting more frequent lightning[7]. Western Washington has some of the lowest rates of lightning of any region in the nation, yet in recent decades City Light has experienced variability in lightning frequency and associated power outages, with some years having significant lightning-related outages in the distribution system.

City Light's Climate Research Initiative funded a study to use a regional climate model to project changes in the frequency of atmospheric conditions that bring convective storms and lightning to Washington[8]. Results of the study showed that convective potential in spring is projected to increase over the Cascade Mountains, especially in the North Cascades and Northeastern Washington where City Light's hydroelectric projects are located. Results also indicated slight decreases in convective potential in spring in the Puget Sound lowlands and in summer across the state. As with wind, results are preliminary because of the limited number of climate scenarios used in the study.

Sensitivity

Wind

City Light's distribution system is very sensitive to high winds and windstorms. Threshold wind speeds that typically cause damage and outages in the distribution system are greater than 30 mph (high winds) and 40 mph (very high winds). Wind, including downed wires, trees, and limbs, is the largest weather-related cause of outages and therefore the largest weather-related contributor to the utility's annual metrics of reliability, System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). Outages caused by wind can be dispersed throughout the service area, increasing restoration times relative to larger but more consolidated mechanical outages.

The sensitivity of the system to wind depends on the timing of the event and other weather-related factors that interact with wind. Similar wind speeds can cause more outages when they occur early in fall when leaves are still on trees, making limbs more susceptible to breakage. The first significant windstorm in fall often causes the most outages because trees have experienced little wind in summer and susceptible branches have accumulated.

Many miles of City Light's transmission lines, including lines from the Skagit, Cedar Falls, and South Fork Tolt Projects, are more sensitive to wind-related outages because they pass through rural forested land. Landowners include local, state, and federal natural resource agencies, as well as private timber companies. Land use includes municipal water, forestry, recreation, and conservation, so forests cover much of the area and are managed for timber or natural conditions. The sensitivity of City Light's transmission system is also higher because these areas can be more difficult to access when weather-related outages occur, slowing restoration times and increasing the cost of restoration. Sections of the transmission line that pass through more urban, suburban, or agriculture areas are less sensitive to wind-related outages and are typically easier to access and restore.

The type of vegetation near the distribution and transmission systems also affects sensitivity to wind-related outages. For example, faster growing vegetation (e.g. cottonwood and alders) and vegetation more susceptible to wind breakage (e.g. Douglas-fir trees) can increase sensitivity to wind-related outages. In contrast, low- and slow-growing shrubs can reduce sensitivity.

Lightning

Components of City Light's distribution, transmission, and generation systems are sensitive to lightning. All three systems have experienced outages or interruptions caused by lightning in recent years, but the total impact on transmission and distribution reliability is much less than that of wind-related outages. Exterior equipment and equipment connected to overhead lines and buried cables can be damaged, but overhead lines and transformers are especially susceptible to lightning strikes. Lightning-caused outages in the distribution system are typically less than 5 percent of annual SAIDI, although this is highly variable from year to year. A few severe lightning storms can significantly contribute to annual SAIDI. In 1999 and 2005, lightning-caused outages were 27 percent and 10 percent of SAIDI respectively. The transmission system and generation facilities have also experienced outages caused by lightning, such as a lightning strike at the Gorge power plant in 2014 that interrupted power generation and significantly altered streamflow.

The sensitivity of distribution to lightning partially depends on the extent to which it is designed and engineered to be resistant to lightning. Design requirements for lightning protection by NERC depend on the expected frequency of lightning in a region (the isokeraunic level). The isokeraunic level is the expected number of thunderstorm days per year and is based on historical observations. Designing for lightning resilience is recommended by NERC for locations with an isokeraunic level of 20 or greater. The isokeraunic level for coastal Washington is 5, the lowest of any region in the nation. Given this low isokeraunic level, City Light's distribution system has been built with only limited lightning protection, increasing its sensitivity to current lightning frequency and any future increase. However, the utility has installed lightning arrestors in key locations. The downtown network distribution system is also less sensitive to lightning because it is predominantly underground.

City Light's Skagit and Boundary generation facilities are more sensitive to lightning than the distribution system because they are located in regions with higher isokeraunic levels. The Skagit project is located in an area with an isokeraunic level twice that of the service area and the Boundary project is located in a region with an isokeraunic level four times that of the service area. Infrastructure at the Boundary project has been designed with lightning protection.

If lightning frequency increases, initial impacts are likely to be minimal and the higher costs associated with equipment replacement and more labor could be absorbed in current operating budgets. However, if increases are significant in the long-term, then hardening equipment with lightning protection devices (e.g. lightning arrestors) may be more cost effective and improve reliability. However, lightning arrestors can also fail causing outages, so lightning frequency would need to increase significantly to justify additional lightning arrestors.

Heavy Precipitation

City Light's transmission and distribution equipment is designed to be water tight and is generally not sensitive to heavy precipitation. However, access to equipment during heavy rain storms could be reduced in places where standing water accumulates more with increases in precipitation intensity. Reduced access could increase restoration times and prolong power outages. Heavy precipitation and standing water also increase safety risks to City Light line crews working to repair damages to the distribution system during major storms.

Adaptive Capacity

City Light has several programs that increase capacity to manage extreme weather. These programs increase the utility's ability to prevent or reduce damage and more quickly and effectively respond to outages caused by extreme weather. In some cases, this capacity can be leveraged to make the system more resilient to long-term changes in extreme weather.

WindWatch – City Light increased capacity to prepare for and respond to windstorms by supporting the development of WindWatch. WindWatch is an online tool developed and maintained by the University of Washington's Department of Atmospheric Sciences. The tool provides real-time forecasts of high winds in Western Washington up to 72 hours in advance and alerts staff when wind gusts are forecasted to exceed the 30 or 40 mph thresholds. WindWatch has increased the utility's capacity to plan and prepare for the impacts of windstorms by providing more accurate local wind forecasts that enable City Light to mobilize appropriate levels of personnel to respond to events and communicate with customers about potential outages. The study of changes in windstorm frequency using regional climate models was designed based on WindWatch, providing an example of how this capacity can be leveraged to prepare for climate change.

Winter storm outreach – City Light participates in the city interagency winter storm preparedness program, *Take Winter by Storm*, which enables City Light to communicate with customers about safe and effective ways to prepare for and respond to power outages caused by extreme weather.

Vegetation management – City Light's vegetation management program maintains all vegetation along 230kV transmission lines for compliance with NERC requirements for clearances of overhead lines and to reduce the likelihood of trees and branches falling on equipment during storms. Vegetation is also managed similarly along 115 kV transmission lines, although not required by NERC. Within the distribution, trees are trimmed to protect distribution equipment. Vegetation is primarily managed within the ROWs to meet clearance standards, but hazard trees (trees at risk of falling onto the lines) outside the ROWs are regularly inventoried and removed as necessary.

Lightning protection equipment – City Light has installed some equipment to harden the system against lightning strikes. The Outage Management System tracks outages caused by lightning, providing the capacity to quantify and track the impact of lightning on reliability indices over time. Tracking these data would allow system upgrades to be considered if trends in lightning-related outages increase.

All-Hazard Response and Restoration Plan – City Light's capacity to respond to outages related to extreme weather is increased by having an emergency response plan that outlines policies and procedures for restoration following major outages, regardless of the cause. In this plan, many extreme weather events have been identified as trigger points for which staff begin to monitor events including forecasted lightning, ice, snow, and wind speeds greater than 25 mph. City Light's Hazard Mitigation Plan increases the utility's capacity to reduce future weather-related outages by identifying actions that could reduce vulnerability to extreme weather.

Potential Adaptation Actions

Near-term/Existing Capacity

1. **Expand the use of the Outage Management System (OMS) to quantify trends in the impacts of extreme weather on outages and system reliability.**
   Outages by cause are documented in the OMS database. Data are sufficient to track some weather-related impacts such as lightning, but the outage data are insufficient to track the impacts of other causes related to extreme weather. Additional secondary causes or categories for wind (rather than only tree/wire down), high air temperatures, flooding, landslide, and wildfire could improve City Light's capacity to quantify the impacts of climate change and extreme weather on reliability. These data could be used to assess trends in climate-related impacts and conduct cost/benefit analysis of upgrades to increase resilience or harden the system against extreme weather.

2. **Consider potential changes in future lightning frequency in the cost/benefit analysis of lightning protection equipment if a trend towards more lightning-related outages is observed.**
   National lightning protection standards are currently based on historical rates of lightning strikes, which may underestimate the risk to equipment and therefore the benefits of lightning protection for reducing outages. Technology has improved to detect lightning strikes, and the isokeurnatic maps of lightning risk zones, which are based on audible thunder, may not reflect actual rates of lightning strikes. Recent research indicates that climate change is likely to increase lightning frequency nationally[9] and local research supported by City Light suggests the potential for slight increases in the Cascade Mountains and Eastern Washington. Given the potential for more frequent lightning, lightning-related outages should be monitored more closely to identify any increasing trend.

3. **Collaborate with Seattle Public Utilities and King County to identify areas that may experience more frequent flooding or standing water because of limited capacity in the storm water drainage system.**
   Identifying areas that may be more exposed to flooding during heavy precipitation can help the utility plan for access in these areas when restoration work is needed. This can facilitate a faster response and recovery during major winter storms that include heavy precipitation. Many locations that have drainage problems are likely known based on past events, but other areas may be of concern with heavier precipitation, sea level rise, and storm surge.

Long-term/Expanded Capacity

4. **Support research on changes in extreme weather patterns associated with changes in the climate.**
   Changes in extreme precipitation have been well studied, but less information is available on other extreme weather events that cause outages. These events are influenced by regional weather and topography, so they will be modeled most effectively with regional climate models that can represent local weather dynamics and topographic features. Results of this research could be related to wind, precipitation, and lightning thresholds that are known to cause outages in City Light's transmission and distribution system.

5. **Increase capacity to prepare for windstorms through expanded forecasts and seasonal outlooks**.
   WindWatch is an effective tool for short-term (three-day) forecasting of high winds, but it provides little capacity for more long-term preparation and planning. Recent improvements in weather forecasting systems are showing skill for longer lead times (weeks to months). These forecasts could be used to expand WindWatch and increase lead times for preparing for major windstorms. Seasonal forecasting of windstorm severity (the likelihood of windstorms in a given season) is an active area of research[10] that could be supported by City Light to expand windstorm preparedness at seasonal time scales. City Light could use this information to assess the need for additional measures to prepare for a windstorm season that is forecasted to be more severe than average.

---

[1] U.S. Department of Energy 2013. U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather. DOE/PI-0013

[2] Salathé, E.P. [et al.]. 2010. Regional climate model projections for the State of Washington. Climatic Change 102(1-2): 51-75

[3] Salathe et al. 2015. Final Project Report: Regional Modeling for Windstorms and Lightning. Provided to Seattle City Light.

[4] Salathé, E.P. [et al.]. 2010. Regional climate model projections for the State of Washington. Climatic Change 102(1-2): 51-75

[5] Warner, M. D., C. F. Mass, and E. P. Salathe Jr., 2012: Wintertime extreme precipitation events along the Pacific Northwest coast: Climatology and synoptic evolution. *Monthly Weather Review* 140: 2021–2043.

[6] Warner, M. D., C. F. Mass, and E. P. Salathe Jr., 2012: Wintertime extreme precipitation events along the Pacific Northwest coast: Climatology and synoptic evolution. *Monthly Weather Review* 140: 2021–2043.

[7] Romps, D.M. [et al.] 2014. Projected increase in lightning strikes in the United States due to global warming. Science 346: 851 -854.

[8] Salathe et al. 2015. Final Project Report: Regional Modeling for Windstorms and Lightning. Provided to Seattle City Light.

[9] Romps, D.M. [et al.] 2014. Projected increase in lightning strikes in the United States due to global warming. Science 346: 851 -854

[10] Cauthers, A.L [et al.] WA Windstorms: Seasonality and Relationship to ENSO. Office of the WA State Climatologist, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA.

4.4 Increasing Wildfire Hazard

Impact 6: Transmission and Generation Infrastructure

Seattle City Light's transmission lines and hydroelectric projects will be at greater risk from wildfires that can damage equipment, interrupt electricity transmission and generation, and put the safety of employees at risk.

Mission Objectives at Risk: Safety, Financial Cost, Reliability

Transmission and Distribution

Wildfires can interrupt hydropower generation and transmission when infrastructure is threatened or directly damaged, but also when smoke from wildfires is the vicinity of lines because it can cause arcing. When exposed to high temperatures or smoke, transmission lines can also sag and become an additional source of ignitions if they come in contact with vegetation. De-energizing transmission lines when wildfires are near has financial impacts on the utility associated with wholesale power purchases to meet load and lost revenue from wholesale power sales.

Infrastructure in the City Light towns of Diablo and Newhalem at the Skagit Hydroelectric Project are at greater risk of damage from wildfires, including structures with historical designations and archeological sites. Greater wildfire risk near these communities increases safety concerns for employees, residents, and the public.

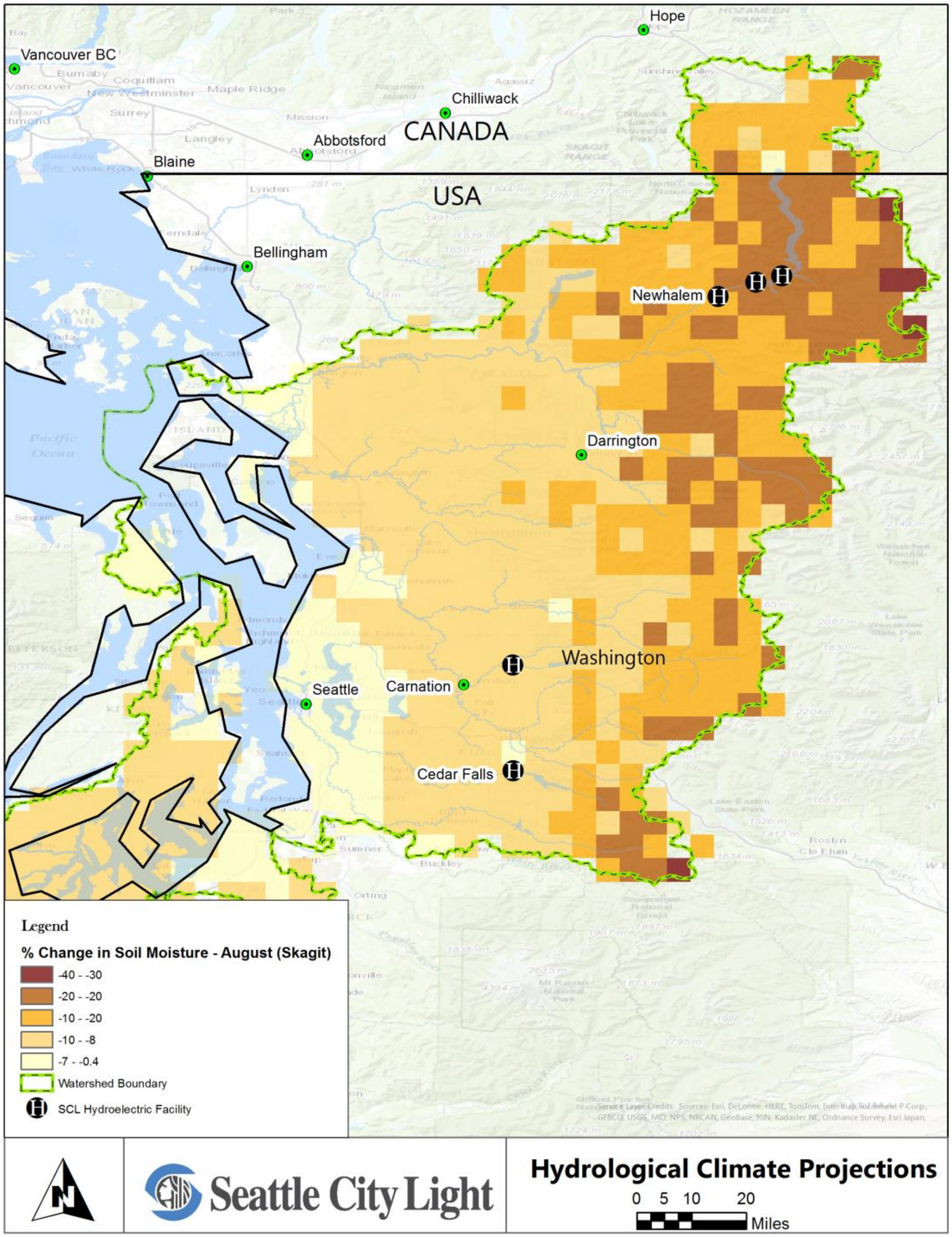
Exposure

Relative to drier regions in Eastern Washington, wildfires have been infrequent in the maritime climate of Western Washington where most of City Light's transmission and generation infrastructure is located. However, summer drought and dense forest vegetation create conditions that are conducive to the spread of wildfires when ignitions do occur. Wildfire hazard in Western Washington is an important example of why using the past as a predictor of the future can underestimate the risk as the climate changes. Historical fire risk for Western Washington is less relevant as temperatures warm, and fire risk will be better assessed based on current seasonal conditions and future climate projections.

The wildfire season in Western Washington is expected to lengthen and the area burned by wildfires is expected to increase fourfold by the mid-21st century[1]. All of City Light's hydroelectric projects and several hundred miles of overhead 230 and 110 kV transmission lines are located in rural forested areas that will be exposed to greater wildfire risk as the climate changes. Wildfires are projected to increase because of three changes in the climate that make forests more susceptible to fire:

1. Warmer temperatures and lower snowpack will cause snow to melt earlier in spring, lengthening the fire season at higher elevations.
2. Warmer temperatures in summer will dry soils (Figure 4.7) and vegetation, creating vegetation conditions that enable wildfires to spread.
3. Greater tree mortality caused by drought and insects will likely increase the amount of dead vegetation that is available as fuel to support fire spread.

Figure 4.7. Projected changes in August soil moisture in Western Washington shown as the percentage change from historical (1916 – 2006 mean) to conditions of the 2040s[2]. Negative values indicate a decrease in soil moisture. Areas with lower summer soil moisture are expected to have drier vegetation conditions that could facilitate the spread of wildfires. Future projections are the mean for an ensemble of 10 climate models and a high scenario of GHG emissions.



Warmer summer temperatures throughout the western U.S. could cause simultaneously high fire hazard across the region. This could limit the suppression resources that are available to respond to a fire and slow response times. Limited resources are a particular concern in Western Washington and the North Cascades where the fire season starts later in the year relative to the rest of the West. Once fires begin in Washington, resources are often already deployed to fires elsewhere.

Sensitivity

Hydroelectric Generation Facilities

The Skagit Hydroelectric Project (including the communities of Newhalem and Diablo) is located within a National Recreation Area that is surrounded by National Park Service forested wilderness. The towns of Diablo and Newhalem and the Skagit project facilities are classic examples of the wildland-urban interface that is most at risk of impacts associated with increasing wildfire hazard. The forests surrounding the Skagit project and extending north to Hozomeen along the east side of Ross Lake have a moderate fire regime with a more frequent fire return interval (50 to 100 years)[3] than the maritime forests west of Ross Lake. Washington State Highway 20 through the National Recreation Area is a popular corridor for summer recreation, increasing the potential for human-caused ignitions.

This area also has frequent lightning ignitions that have sparked several wildfires in recent history, including the Goodell fire that started with a lighting strike near Newhalem in August 2015. The Goodell fire required City Light to evacuate non-essential personnel from Diablo and Nehalem and de-energize the transmission lines for several days. The total cost to the utility was $2.2 million in damages, response, and labor, and additional $900K for power purchases and lost generation. The low snowpack, early snowmelt, and abnormally warm temperatures in the spring and summer of 2015 likely contributed to the spread of the fire, and this weather pattern is consistent with projected changes in climate for the Skagit area.

Photo: The Goodell Creek Fire burning near the town of Newhalem, Washington in August 2015. Actions by Seattle City Light and the National Park Service were required to ensure the protection of the transmission lines, generation facilities, and people living and working in the communities of Newhalem and Diablo.

The Boundary Hydroelectric Project is located within National Forest Service land and surrounded by forests that burn with shorter fire return intervals than forests in Northwestern Washington. The hot, dry summers in this region are conducive to the start and spread of wildfires. These forests have adapted to be resilient to fire, but a legacy of forest management and fire exclusion by humans in this region has contributed to greater fire hazard, causing fires to burn with higher severity and over larger areas when they occur.

The Cedar Falls and South Fork Tolt Hydroelectric Projects are located in wet, maritime forests with long fire return intervals (> 250 years), but large wildfires have occurred in these forests in the past. Wildfires typically burn under extreme weather conditions, with warm and dry east winds, and during periods of extended drought, so fires are large when they do occur. These watersheds are owned and managed by Seattle Public Utilities. These watersheds are heavily monitored for wildfire by SPU because of the potential detrimental impacts of wildfire on drinking water quality. SPU maintains an active and highly trained wildfire suppression crew and monitors conditions throughout the summer. Furthermore, public access to the watershed is restricted to protect water quality, but also to reduce the potential for human-caused wildfires. Lightning is less common in this region compared to the North Cascades and Eastern Washington. Thus the potential for wildfires to start near these projects is lower and the likelihood of suppressing them quickly is greater compared to the wilderness areas surrounding the Skagit Project.

Transmission Infrastructure

The location of the transmission lines from the Skagit project to Bothell, Wash. increases sensitivity to wildfire because these lines pass through areas that include rural forested land owned by state and federal natural resource agencies and private timber companies. These land uses have abundant vegetation, rugged topography, and limited access, making fire protection more challenging relative to urban or agricultural areas. Furthermore, the ROWs for the transmission lines were established long ago and are narrow, limiting the area adjacent to the lines in which City Light can manage vegetation. This increases the amount of vegetation that can support fire spread from surrounding ownerships.

Overhead transmission lines are highly sensitive to direct damage from wildfires or associated smoke and heat. Lines must be de-energized when wildfires and smoke are in the vicinity, or to ensure the safety of fire fighters. The materials used in the construction of transmission towers are an important factor affecting sensitivity. The 230 kV transmission line from the Skagit Project is primarily steel poles, decreasing sensitivity to wildfire relative to wooden poles. The 115 kV transmission lines contain more wooden poles and are therefore more sensitive to fire. Electric utilities in the western U.S. that have been heavily affected by wildfires are replacing wooden poles with steel poles as a critical action for increasing resilience.

Redundancy in the transmission system reduces the extent to which reliability is sensitive to wildfire. As part of the western bulk power system, City Light's 230 kV transmission lines are designed to be redundant and with more capacity than is needed, decreasing overall system sensitivity. If wildfire interrupts transmission and damages sections of the transmission line in one location, reliability can be maintained in most situations by redirecting transmission elsewhere in the western grid and using other facilities or power purchases to compensate. For example, the four 230 kV transmission lines (two tower lines) from the Skagit Project are located in close proximity and all have been affected in a single fire, reducing reliability in that portion of the system. However, redundancy comes from the ability to meet load through wholesale power purchases transmitted through alternate routes. These alternative transmission arrangements can have significant financial consequences for the utility, but wildfires will cause power outages or consequences for reliability only in severe cases of extended or widespread interruptions of transmission. Fire-related outages of the local distribution system at the hydroelectric projects can have consequences for reliability locally if power is not available to support the facilities.

Adaptive Capacity

Vegetation Management Program

City Light's vegetation management program for the transmission line ROWs increases the utility's capacity to reduce wildfire hazard. As described previously in **Section 4.3, Impact 5**, vegetation in the ROWs is managed primarily to maintain clearances below overhead lines and to reduce the risk of trees and branches falling on lines. Vegetation management also has the potential to reduce wildfire spread and severity by reducing fuels that can facilitate fire spread and removing more flammable vegetation types such as invasive Scotch broom. The city owns some of the land under transmission lines, but City Light mostly manages the vegetation through easements and rights-of-way (ROWs) on property owned by other government or private landowners. Many of the rights-of-way were established long ago and the widths are narrow, ranging from 40 to 300 feet wide, which limits the area of influence for vegetation management to reduce fire hazard.

Fire Hazard Risk Assessments

City Light partnered with the Skagit and Whatcom Conservation Districts to complete wildfire hazard risk assessments for the communities of Newhalem and Diablo. In response to the hazards identified in these assessments, City Light developed action plans to reduce the likelihood and consequences of wildfire for infrastructure damage and employee safety. Through this process, the towns were recognized as a Firewise community, which raises the awareness of wildfire hazard and increases coordination among City Light and the local, state, and federal agencies responsible for wildfire response. These assessments increase the utility's capacity to adapt to increasing wildfire risk in the future by identifying at-risk infrastructure and actions that can be taken now to reduce future wildfire risk. Actions include removing vegetation near buildings to increase defensible space, removing invasive and flammable vegetation, and assessing evacuation potential. The utility also increased capacity to manage wildfire risk by hiring a fire chief to oversee these efforts and other wildfire-related safety concerns.

Geographic Diversity in Owned and Contracted Power Resources

City Light's portfolio of power resources is diverse with respect to location of hydropower resources and the inclusion of power contracts and utility-owned generation. Geographic diversity increases resilience to natural hazards, such as wildfire, that affect resources in a specific place. Overall risk to reliability of the system in one location can be compensated for with resources elsewhere. Therefore, reliability in terms of outages experienced by City Light's customers is unlikely to be at risk from wildfires, but reliability of the western grid throughout the region may be at risk with more frequent wildfires that affect several locations and require multiple contingency actions. Even without direct impacts to reliability, higher wildfire hazard could affect retail costs through lost revenue from surplus power sales and costs associated with power purchases, equipment repair and replacement, loss of infrastructure, and labor.

Potential Adaptation Actions

Near-term/Existing Capacity

1. **Recognize the increasing risk of wildfire to the hydroelectric projects and transmission lines and include wildfire hazard reduction as co-benefit in City Light's vegetation management program.**
   Vegetation management practices that are focused on historical conditions lack recognition of the current and increasing risk of wildfire. Vegetation management practices could be modified to include co-benefits for reducing wildfire fuels and more flammable vegetation types. LiDAR data from transmission line ROWs can be used to identify specific areas with the highest fuels to prioritize vegetation management actions for the reduction of fire hazard. Reducing fuels in the narrow ROWs is unlikely to completely stop the spread of wildfires, but it can reduce damage and aid fire suppression efforts, thereby reducing response and recovery times.
2. **Increase the capacity of employees at the hydroelectric projects to prepare for and respond to wildfire.**
   Employees could receive additional training in wildfire response to help prepare for and respond to wildfires in coordination with local, state, and federal agencies. This increased capacity will be especially important in summers when wildfire hazard is high throughout the western U.S. and fewer resources are available to respond to wildfires in Washington. Capacity building could also include improved access to weather data and seasonal forecasts that provide specific information on fire hazard. A fire weather monitoring station could be established in Newhalem or Diablo to track fire hazard through the season.

Long-term/Expanded Capacity

3. **Collaborate with adjacent land owners to reduce hazardous fuels and wildfire hazard around critical infrastructure at the hydroelectric projects.**
   Most of Western Washington has a moderate to high-severity fire regime in which wildfires are infrequent but severe when they do occur, so it is unlikely that hazardous fuel reduction treatments can stop the spread of a wildfire if fire weather conditions are severe. However, these treatments may reduce the severity of the fire and damage to the infrastructure when they are strategically implemented around infrastructure. Fuel treatments can also increase the safety and success of fire suppression efforts.
4. **Incorporate post-fire response into vegetation management plans for transmission line ROWs.**
   After a wildfire burns, strategic vegetation management practices can reduce the adverse effects of a wildfire, such as the spread of invasive species or erosion and landslides in areas depleted of vegetation cover. These effects can make future vegetation management more difficult and create new hazards to infrastructure. Post-fire landslides and erosion can damage transmission towers and buildings, and increase sediment in waterways degrading fish habitat and reducing reservoir storage capacity. Incorporating post-fire vegetation management practices into existing management plans requires a shift from viewing fire hazard as unlikely to recognizing that climate change is increasing fire hazard making it an issue of *when* a fire will occur rather than *if* a fire will occur.

---

[1] Littell, J.S. [et al.] 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change 102: 129-158.

[2] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[3] Agee, J.K. [et al.] 1990. Forest fire history of Desolation Peak, Washington. Canadian Journal of Forest Research 20: 350-356.

4.5 Increasing Landslide and Erosion Hazard

Impact 7: Transmission Infrastructure

More frequent landslides and erosion could increase damage to transmission lines and access roads, and reduce access to infrastructure.

Mission Objectives at Risk: Financial Cost, Reliability

Transmission and Distribution

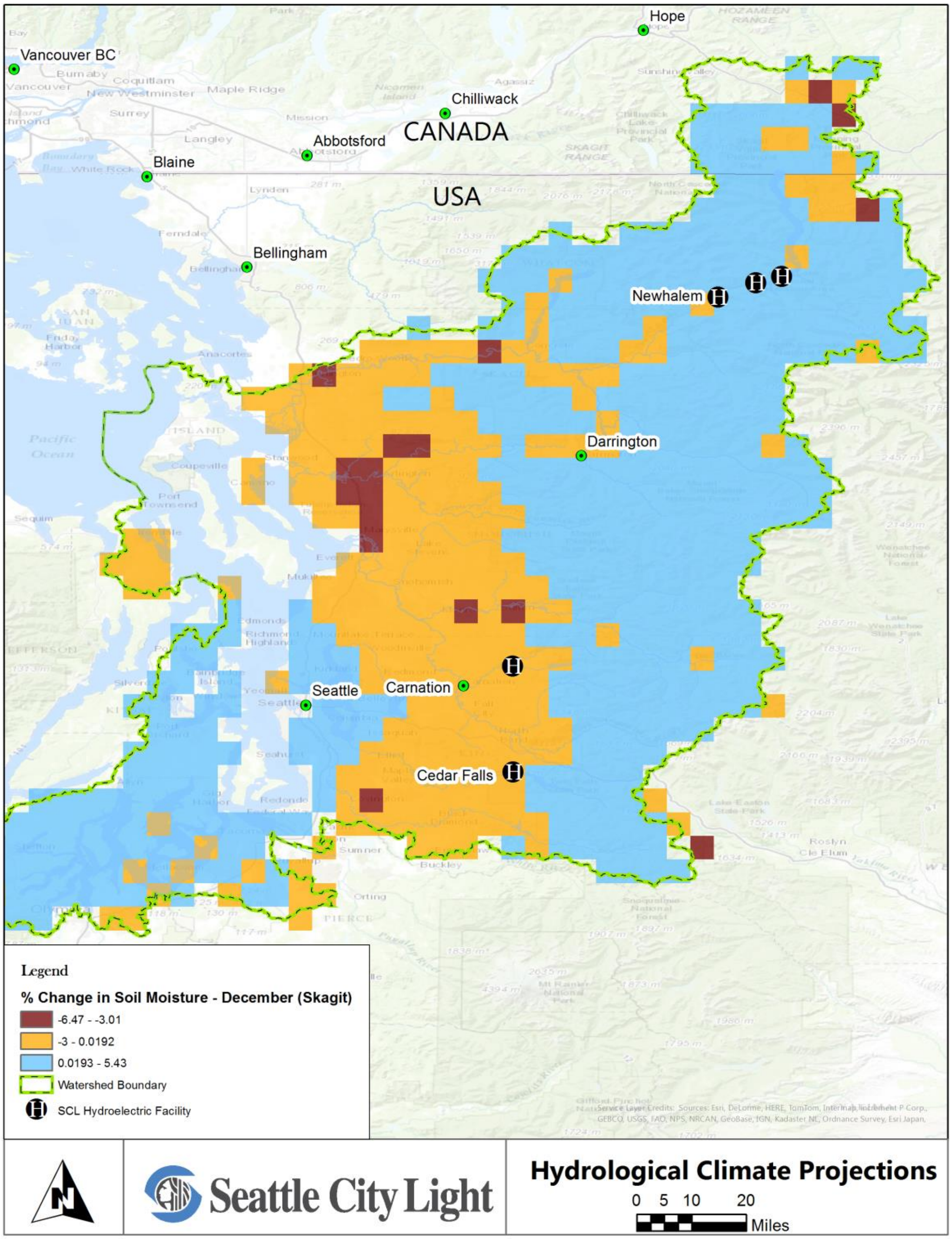
Increases in winter precipitation, soil moisture, and the intensity of short-term precipitation events will increase the risk of landslides in Western Washington. This could increase physical damage to distribution and transmission equipment, as well as access roads. Financial impacts could include greater maintenance and repair costs for damaged equipment and roads, as well as, higher costs of purchasing wholesale power associated with interrupted transmission if landslides are large enough to take a transmission line out of service. Damage to access roads could reduce reliability if access is restricted during natural disasters when it is critical for restoring and maintaining operations. Within the distribution system, landslides and erosion could directly affect more poles and lines, potentially increasing customer outages in landslide prone areas.

Exposure

The occurrence of landslides in any one place is a function of many factors, including land use, topography, geology, vegetation, and climate. Most of these factors are inherent site characteristics that change only slowly over time, but precipitation and soil saturation are critical triggering factors that change daily and are directly influenced by climate. The USGS cumulative precipitation threshold for monitoring and issuing landslide hazard warnings for the Seattle area is based on three-day and fifteen-day cumulative precipitation. Precipitation triggered landslides are more likely to occur in the Seattle area on days when precipitation has exceeded 3.5 to 5.2 inches of total precipitation over the prior eighteen-day period[1].

Four projected changes in precipitation patterns are likely to increase landslide hazard in Western Washington. Increases in short-term (<24-hour) precipitation intensity could contribute to the three-day cumulative precipitation that triggers landslides. Projected changes in total annual precipitation are uncertain and difficult to distinguish from natural variability, but most models project increases in fall, winter, and spring precipitation.[2] More precipitation in these seasons would increases soil moisture and contribute to the fifteen-day antecedent moisture conditions that contributes to landslides. Both of these change would increase the number of days per year that the USGS precipitation threshold for landslide hazard is exceeded[3]. The Cascade foothills also may experience an increase in soil moisture in fall and winter as warmer temperatures cause more precipitation to be rain rather than snow (Figure 4.8). These factors can contribute to local areas of greater erosion, as well as large landslide events.

Figure 4.8. Projected changes in December soil moisture in Western Washington shown as the percentage change from historical (1916 – 2006 mean) to 2040s conditions[4]. Projections are the mean for an ensemble of 10 climate models and a high GHG emissions scenario. Positive values indicate an increase in soil moisture. Areas with higher winter soil moisture will have conditions that are more conducive to landslides, especially when combined with an increase in short-term rain intensity that can trigger landslides when soil moisture is high.



Sensitivity

The location of City Light's transmission lines and towers affects their sensitivity to landslides.

- Several hundred miles of 230 kV and 115 kV transmission lines pass through areas with rugged topography, steep slopes, and glacial till soils that are susceptible to landslides.
- Some sections of the transmission lines are located near unregulated rivers that periodically flood, contributing to slope instability.
- Land use along the transmission lines is highly variable, but includes sections of state, federal, and private forest land where vegetation removal can change patterns of water interception and runoff. This contributes to the potential for landslides from outside of the ROWs to extend into the ROWs if they are large enough.

Several aspects of the design and materials used in City Light's transmission lines can affect the sensitivity to landslides.

- City Light's 230 kV and 115 kV transmission towers and poles are primarily steel and concrete, which hardens the system against damage form landslides and erosion. However, some of the transmission towers for the Skagit and Cedar Falls hydroelectric projects and along the South Fork Tolt and Cedar Falls transmission lines are wood.
- City Light's 230 kV transmission lines that are part of the western bulk electric grid are built with greater redundancy to increase reliability, including multiple transmission lines between generation facilities and substations.
- City Light's transmission system is also engineered to carry more load than is needed at any time. This abundance of capacity enables the system to operate under contingencies of N-1 or N-2, which allows for load to be transferred to fewer lines when there is an interruption to any one line.
- Redundancy is also gained through the ability to purchase power from the wholesale market and transmit through alternative pathways during emergencies, but this has financial consequences for the utility.

These factors can prevent damage and loss of transmission capacity caused by most landslides, but Western Washington has experienced very large landslides in the recent past, including the landslide in Oso, Wash. in March 2014 that covered a long distance and caused minor damage to a tower. The redundancy in the current transmission system may not be sufficient to protect against damage and loss of transmission capacity for low likelihood, high consequence landslides that cover large areas. The economic impacts of these events to City Light could be large, but the cost of the engineering required to build for these contingencies would also be large.

A steel tower of City Light's Skagit transmission line and debris deposited by the landslide near Oso, Wash. in March 2014. The debris caused minor damage to a tower.

Adaptive Capacity

The Seattle Hazard Identification and Vulnerability Analysis (SHIVA)[5] developed by the city's Office of Emergency Management recognizes the likelihood and consequences of landslides for the Seattle area. The city has mapped areas of landslide susceptibility within the city limits as part of the emergency management process. This provides some capacity to understand the areas of the distribution system that are most at risk of damage and outages associated with landslides.

City Light's Continuity of Operations and related Emergency Response and Hazard Mitigation plans build on the city's vulnerability analysis and specifically recognize risks to City Light associated with landslides, ranking it the 4th highest hazard for the utility[6]. Soil saturation levels that can trigger landslides are monitored and included as a trigger point for initiating the emergency response process. City Light's Hazard Mitigation Plan identifies one mitigation actions to reduce risks associated with landslides, transmission tower dead-end upgrades. Identifying these mitigation actions enables City Light to qualify for FEMA mitigation funding to reduce landslide risk in a FEMA disaster declaration. Implementing these upgrades can harden the system against the increasing risk of landslides as the climate changes.

Potential Adaptation Options

Near-term/Existing Capacity

1. **Consider the higher likelihood of landslides due to climate change in the vulnerability assessment and hazard mitigation process as part of emergency management.** Vulnerability assessment and hazard mitigation planning in emergency management focuses on assessing the likelihood and consequence of hazards based on current and historical events, assuming the risk of these hazards is static over time. A critical difference for adaptation planning is that the risk of some hazards can no longer be considered static. Therefore risk will be underestimated when based on historical events alone. City Light's emergency management planning process should consider an increased likelihood of landslides in ranking hazards and prioritizing mitigation actions. Mitigation projects designed to reduce landslide risk should consider higher likelihood in project design to ensure that the project objectives of reducing landslide risk will still be met in the future. Projected changes in total annual precipitation are uncertain and difficult to distinguish from natural variability, but most models project increases in fall, winter, and spring precipitation, increasing the likelihood that landslides could be triggered. An analysis of the costs and benefits of hazard mitigation projects should also include future likelihood of landslides to ensure that the benefits of infrastructure upgrades are sufficiently quantified.

Long-term/Expanded Capacity

2. **Collaborate with resource management agencies and academic institutions to map landslide hazard along City Light's transmission line ROWs, including a buffer to account for landslides from adjacent land.** Mapping landslide hazard typically focuses on the geology, soil, vegetation, and slope characteristics that affect landslide potential, rather than the triggering effects of precipitation. However, an understanding of these components of landslide risk can identify areas to monitor during heavy rains and potential priority areas to implement hazard

mitigation actions. LiDAR data previously acquired for the transmission line ROWs is a valuable source of data for mapping slope and vegetation characteristics that affect landslide hazard. The Washington Department of Natural Resources (DNR) is acquiring additional LiDAR data for the purpose of mapping landslides. This provides an opportunity for City Light to coordinate with DNR to acquire LiDAR data that can be used to identify past landslides and landslide prone areas along the transmission lines.

3. **Collaborate with researchers to support research and mapping of the spatial variability in the effects of climate change on existing landslide hazard.** Landslide hazard mapping has typically been conducted independent of the precipitation and soil saturation factors that trigger landslides. Variability in exposure to increases in precipitation and winter soil moisture can be combined with maps of existing topographic features, soils, geology, and landslide hazard to identify specific areas and infrastructure that are likely to experience the greatest climate-driven increase in landslide hazard.

---

[1] Chleborad, A. E., Baum, R. L., Godt, J.W. 2006. Rainfall Thresholds for Forecasting Landslides in the Seattle, Washington, Area—Exceedance and Probability. USDOI USGS Open-File Report 2006-1064

[2] Snover, A.K [et al.]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[3] Dalton, M 2014 Technical Memo#6: Future Projections of Climate Metrics of Operational Relevance.

[4] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[5] City of Seattle, Office of Emergency Management 2014. SHIVA- The Seattle Hazard Identification & Vulnerability Analysis. http://www.seattle.gov/emergency

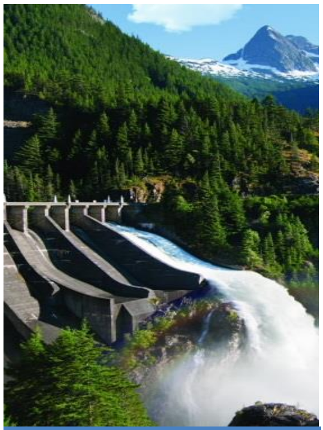
[6] Seattle City Light 2015. Seattle City Light Continuity of Operations Plan, Mitigation Plan

4.6 Reduced Snowpack and Changes in Seasonal Timing of Streamflow

Impact 8: Hydroelectric Project Operations

Seasonal operations of hydroelectric projects may no longer be aligned with seasonal streamflow, challenging management for the multiple objectives of hydropower generation, flood control, instream flows for fish protection, and reservoir levels for recreation.

Mission objectives at Risk: Financial Cost, Environmental Responsibility



Hydroelectric Project Operations

The most critical impact of less snow for the operation of City Light's hydroelectric projects will be changes in the seasonal timing of snowmelt, runoff, and streamflow. Total annual streamflow is not expected to change significantly because annual precipitation is not projected to change significantly relative to high year to year variability[1]. Other projected changes in hydrologic conditions that could affect hydropower generation and the operations of the project, including higher peak flows in fall and winter and lower low flows in summer are discussed in **Sections 4.7** and **4.8**.

City Light operates hydroelectric projects for the multiple objectives of flood control, instream flows for fish protection, hydropower, and recreation. City Light does not operate projects for municipal water supply directly, but two projects from which City Light receives hydropower are managed for water supply by Seattle Public Utilities. These objectives vary by project and season, affecting the sensitivity and potential impacts of climate change for each project. Less snowpack and earlier snowmelt could require changes in operations because the current operations were developed based on assumptions about historical conditions of water storage in snowpack and snowmelt timing. The amount of snowpack and timing of snowmelt will become moving targets that will require greater consideration of current conditions, seasonal forecasts, and future projections. Current operations are designed to manage high variability in daily and annual streamflow, but the critical difference in a changing climate is there is now a directional shift towards lower snowpack and earlier runoff, rather than simply variability around the historical average.

Exposure

Snowpack has declined across the Pacific Northwest during the 20th century and is projected to continue to decline with accelerated warming in the 21st century. In the Cascade Mountains of Washington, snowpack (measured as April 1 snow water equivalent[2]) decreased by about 25 percent between the mid-20th century and 2006, with a range of 15 to 35 percent depending on the starting year for measuring the trend between 1930 and 1970[3]. About 10 to 60 percent of the observed decline in snowpack can be attributed to natural climatic variability associated with the El Niño Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO)[4]. The remainder of the decline is likely influenced by the trend in warmer temperatures in the region, which is unrelated to climatic variability. Furthermore, during the late 20th century, hydrographs of many snow-fed rivers throughout the western U.S. showed trends towards early runoff in spring associated with earlier snowmelt[5].

With accelerated warming, snowpack is projected to continue to decline in watersheds in Washington, with earlier and less runoff in spring. The magnitude of snowpack decline varies based on the projected increases in temperature among climate models and GHG emission scenarios. In watersheds in the Cascade Mountains, snowpack is projected to decrease 38 to 46 percent by the 2040s (relative to 1916-2006) and 56 to 70 percent by the 2080s.[6] All climate models project a decrease in snowpack because it is driven primarily by *warming temperatures*, not changes in winter precipitation, which are more variable among models.

Loss of snowpack will vary by watershed based on elevation with the largest declines (50 to 100 percent by the 2040s) projected for mid-elevation watersheds that currently receive cool-season precipitation as a mix of rain and snow (Figure 4.9)[7]. Mid-elevation watersheds where City Light operates projects or owns land include the Cedar, South Fork Tolt, Sauk, and Lower Skagit. In these watersheds, much of the snow currently falls at relatively warm temperatures, so only a small amount of warming is needed to shift precipitation from snow to rain. These mid-elevation watersheds currently experience two monthly peaks in streamflow, one in fall associated with heavy rain and a second in spring associated with snowmelt. Reductions in snowpack will cause a significant change in the hydrograph by the 2040s to a single monthly peak in fall or winter associated with rain.

Snowpack is also projected to decline in higher elevation watersheds that are currently snow-dominated (i.e. receive most cool-season precipitation as snow rather than rain), but the magnitude of projected declines in these watersheds is less by the 2040s and will be slower to emerge (0 to 50 percent decline the 2040s)[8]. This pattern of change is projected for both the Upper Skagit River and the Pend Oreille River upstream of the Boundary Project (Figure 4.10). Currently, these watersheds have one monthly peak in streamflow in spring caused by snowmelt. As temperatures warm, the size of the peak streamflow in spring will decrease and shift earlier in spring. By the 2040s, the hydrograph of the Upper Skagit River could resemble the current hydrographs of the lower elevation, mixed-rain-and-snow watersheds that have both a fall and spring peak. In contrast, more moderate changes are expected for the Pend Oreille River, which is projected to continue to have a single monthly peak in spring, but the peak will decrease and streamflow will increase in fall/winter (Figure 4.11).

Similar projections for changes in the hydrograph are not yet available for the Cedar and South Fork Tolt Rivers. Both of these are mixed-rain-and-snow watersheds that are expected to experience significant changes in the hydrograph from both a fall/winter and spring peak to a single peak in winter. The Climate Resilience Group at Seattle Public Utilities is modeling changes in hydrology for the Cedar and South Fork Tolt Rivers using 40 scenarios for future climate, which will provide information on changes in streamflow amount and timing.

It is important to note that even with these projected *directional trends* in streamflow timing, annual climatic *variability* will continue to be high; some years will still have above average snowpack or lower than average snowmelt.

Figure 4.9. Projected changes in snowpack in Western Washington shown as the percentage change from historical (1916 – 2006 mean) conditions to the 2040s[9]. Snowpack is defined as April 1 snow water equivalent. Projections are the mean for an ensemble of ten climate models and a high scenario of GHG emissions. Negative values indicate a loss of snowpack.

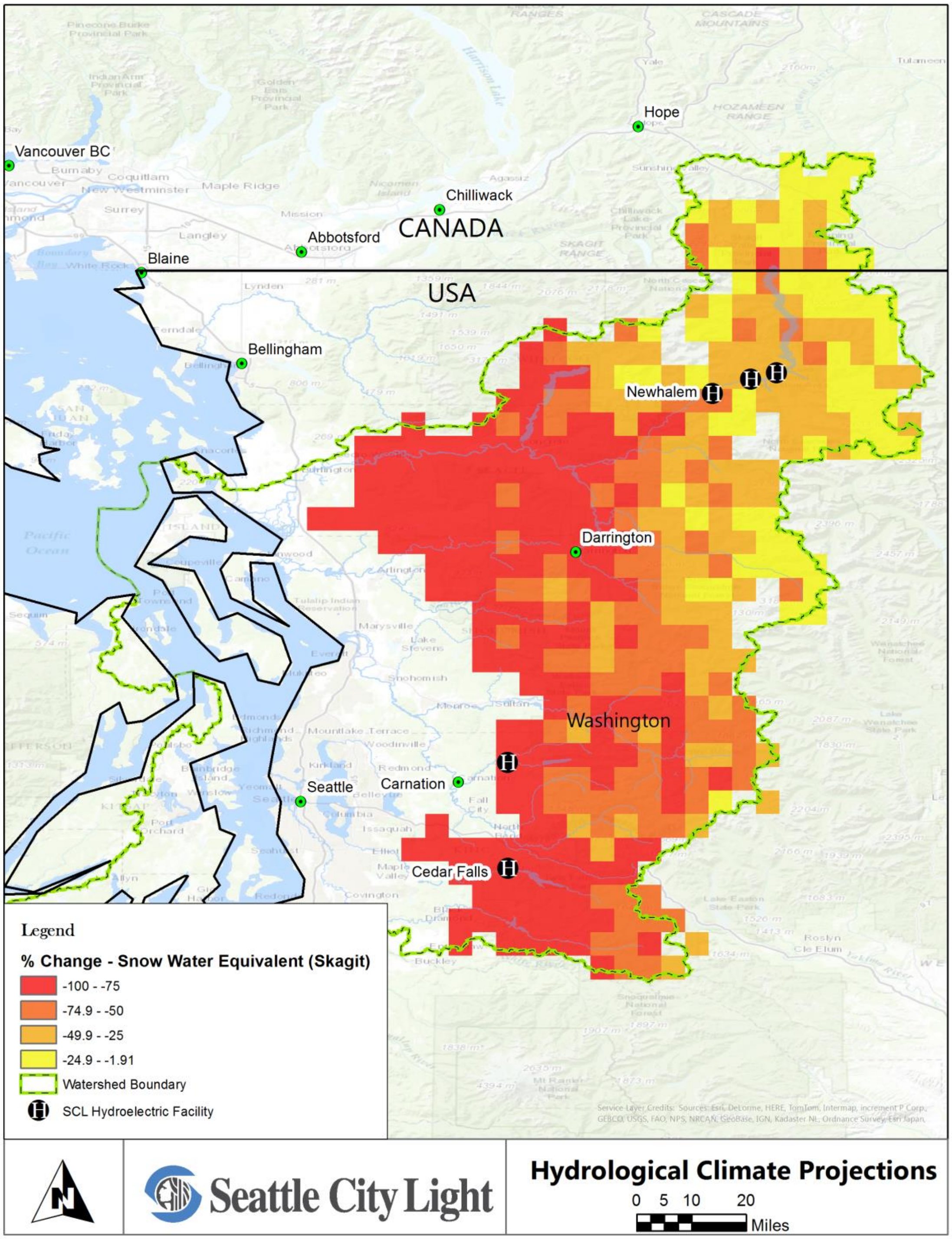
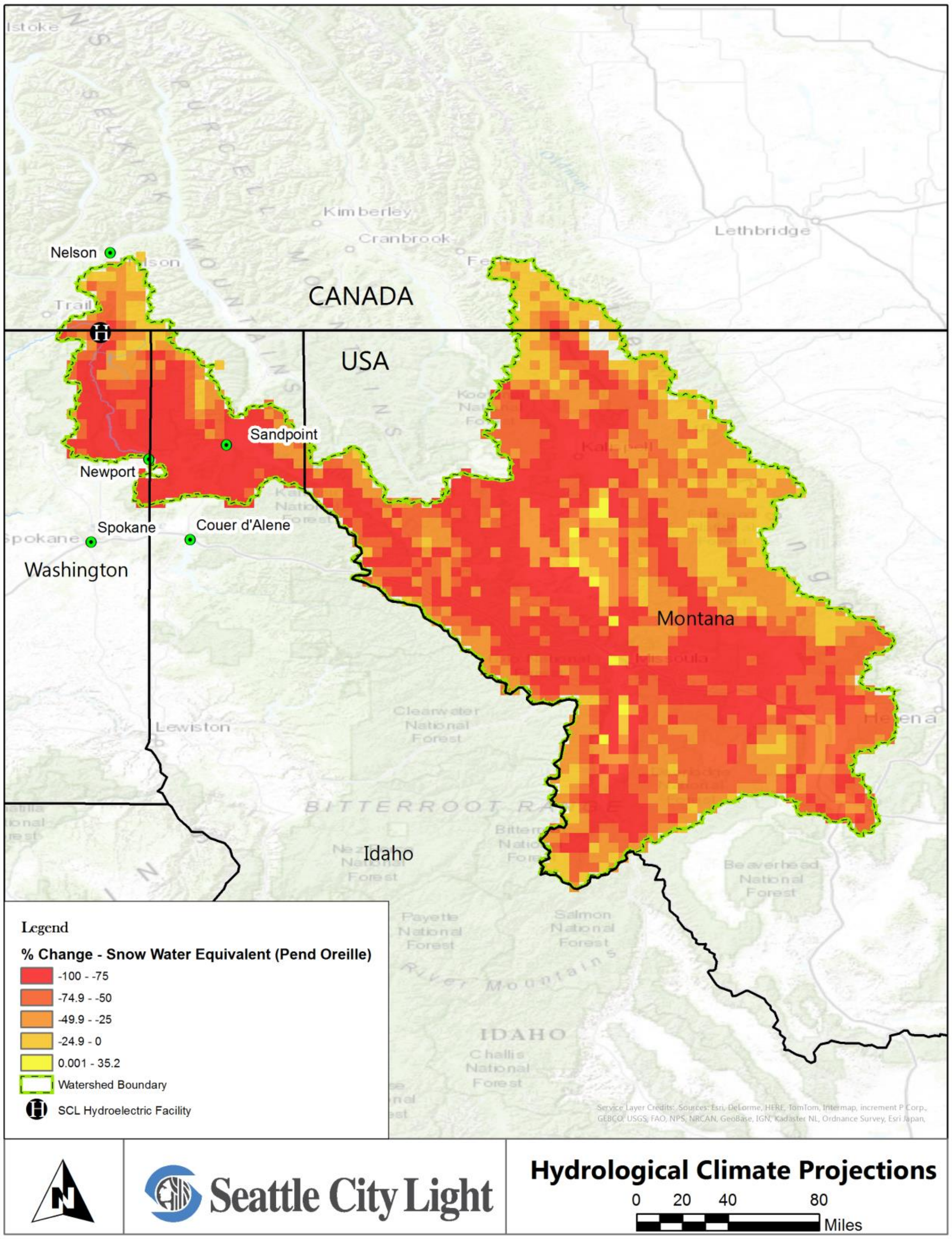


Figure 4.10. Projected changes in snowpack in watersheds in northern Idaho and western Montana that flow into the Pend Oreille watershed[10]. Snowpack is defined as April 1 snow water equivalent. Values are shown as the percentage change from historical conditions (1916 – 2006 mean) to the 2040s. Future projections are the mean for an ensemble of 10 climate models and a high scenario of GHG emissions. Negative values indicate loss of snowpack. Only small areas at high elevations in the watershed (in yellow) are projected to have increases in snowpack.



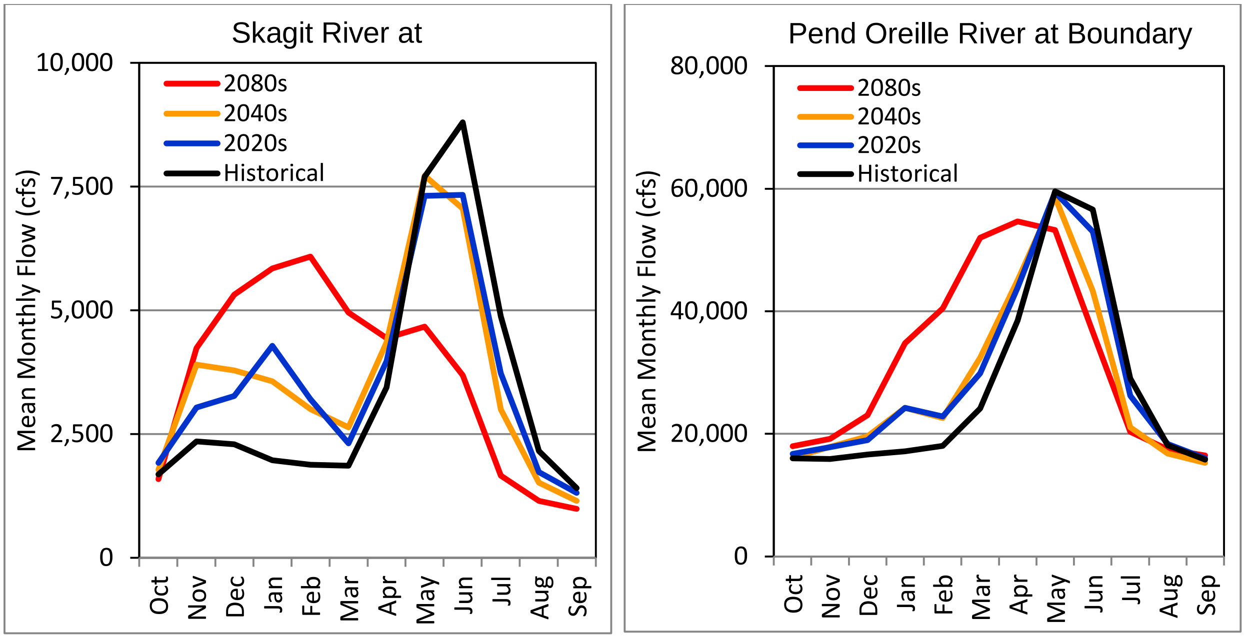


Figure 4.11. Projected change in mean monthly streamflow (cfs) at the Skagit and Boundary Hydroelectric Projects owned and operated by Seattle City Light. Projections are for three future time periods (2020s, 2040s, and 2080s) and a high warming scenario compared to historical conditions (1916 to 2006)[11]

Sensitivity

Resource Portfolio

In general, City Light's power resources are highly sensitive to changes in snowpack and streamflow timing because they are 90 percent hydropower, generated at facilities that are all likely to be affected to some degree by declining snowpack. Only 10 percent of City Light's power resources are from wholesale power purchases and non-hydro renewable energy including wind, biomass, and landfill gases. These non-hydro renewable energy sources are generally less sensitive to projected changes in climate[12].

The sensitivity of City Light's hydropower resources in the near term (2030s) is lowered by their location in high-elevation, snow-dominated watersheds where impacts are projected to be more moderate early in the 21st century and slower to emerge. Hydropower purchased through contracts with BPA and BC Hydro provides additional geographic diversification of watersheds. The hydropower purchased through these agreements is also generated at facilities in high-elevation, snow-dominated watersheds in the northern PNW.

Geographic diversity of hydropower resources reduces sensitivity because smaller scale local droughts may not affect all watersheds in the PNW simultaneously. Through the 2030s there will continue to be years when watersheds are not all exposed similarly. By the 2050s, the impacts will be more consistent across the region with a greater likelihood of regional snowpack-related droughts affecting all watersheds simultaneously.

Hydropower Generation

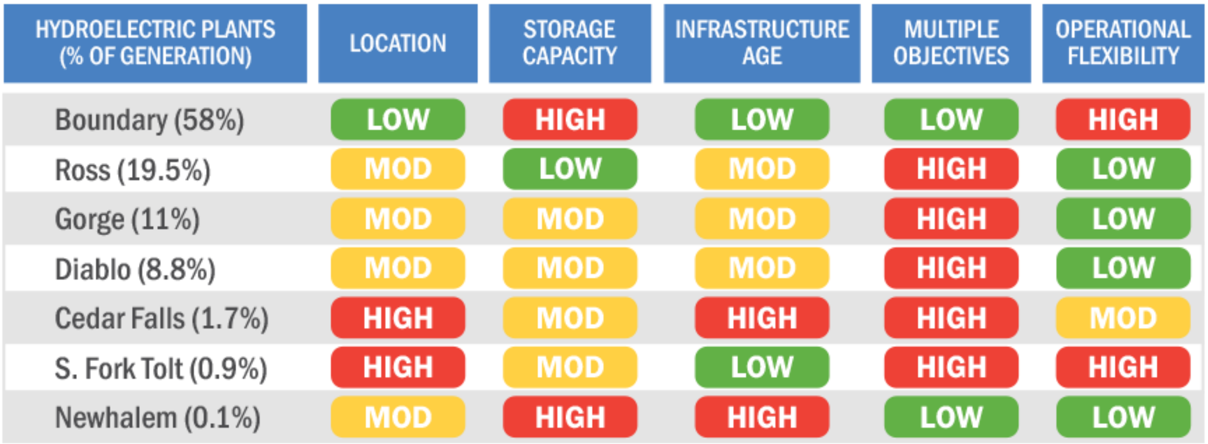
Hydropower generation is generally directly proportional to total streamflow, subject to the capacity of the facility and operational constraints for other objectives. Thus changes in the seasonal timing of power generation will follow changes in the seasonal timing of streamflow with increases in winter generation and decreases in spring and summer generation. Initial studies of the Skagit and Boundary projects identified this impact,[13] but additional analysis is underway for all facilities to better quantify impacts on generation. Streamflow projections show little or no change in total annual streamflow, but the effect on total annual hydropower generation depends on the characteristics of individual generating facilities and the interaction of power generation with the other objectives such as flood control and fish protection.

City Light's highest load months are December and January, so the increase in generation in these months could help meet load; however, the seasonal pattern of load is also projected to change in the opposite direction with lower load in winter and higher load in summer (**Section 4.2, Impact 3**). The combination of these two impacts has not been quantified.

Hydropower Generation Facilities

The potential to adapt to changes in seasonal streamflow depends on several aspects of the individual hydroelectric facilities, including location, storage capacity, infrastructure age, operational objectives, and operational flexibility (Table 4.5).

Table 4.5. Characteristics of hydropower generation facilities owned by Seattle City Light and their influence on sensitivity to reduced snowpack and changes in streamflow timing. *Low* indicates that the factor generally *lowers sensitivity* and *high* indicates that the factor *causes higher sensitivity* for that facility.



HYDROELECTRIC PLANTS (% OF GENERATION)	LOCATION	STORAGE CAPACITY	INFRASTRUCTURE AGE	MULTIPLE OBJECTIVES	OPERATIONAL FLEXIBILITY
Boundary (58%)	LOW	HIGH	LOW	LOW	HIGH
Ross (19.5%)	MOD	LOW	MOD	HIGH	LOW
Gorge (11%)	MOD	MOD	MOD	HIGH	LOW
Diablo (8.8%)	MOD	MOD	MOD	HIGH	LOW
Cedar Falls (1.7%)	HIGH	MOD	HIGH	HIGH	MOD
S. Fork Tolt (0.9%)	HIGH	MOD	LOW	HIGH	HIGH
Newhalem (0.1%)	MOD	HIGH	HIGH	LOW	LOW

Boundary Hydroelectric Project

Storage at the Boundary Project is negligible and inflows are dependent on the operations of other projects upstream. The Boundary Project is operated primarily for hydropower generation with the additional objective of maintaining reservoir levels for recreation between Memorial Day and Labor Day. This project is operated to generate power consistent with Seattle's daily load shape of higher load during the day and less at night. Historically, peak inflow occurred in May and June resulting in the highest generation in May, June, and July. The project is not operated for flood control because of minimal storage capacity. Therefore when inflows exceed capacity excess water must be spilled. There are no seasonal minimum or maximum flow requirements for fish protection, except mitigation to reduce the impact of spilling on water quality. Managing for fewer objectives decreases the sensitivity of this project to changes in streamflow timing, but the lack of storage and flexibility to manage inflows increases the sensitivity of power generation.

Limited storage capacity and operational flexibility increases sensitivity to changes in snowpack and streamflow timing because reservoir storage cannot be used to regulate inflows and compensate in years when less water is stored in the snowpack. Hydropower generation at the Boundary Project is more sensitive to the seasonality of streamflow because inflows are dependent on the operation of projects upstream, and the extent to which the operations of those projects are adapted.

Cedar Falls Project

Operations of the Cedar Falls Project are highly sensitive to seasonal changes in snowpack and streamflow because of its location in a mid-elevation watershed, but also because of the age of its infrastructure and moderate storage capacity. As an older facility (the dam was completed in 1914 and the powerhouse in 1904), Cedar Falls is sensitive to changes in streamflow because it was not designed for current flow management requirements, creating a system that is already stressed under current operations. Adapting operations to manage for future changes in streamflow will be more difficult relative to a modern facility with newer design standards. Cedar Falls is primarily operated for municipal water supply and instream flows for fish protection as required by a Habitat Conservation Plan, so flexibility to adapt operations for hydropower generation is constrained by these two objectives. Adaptation actions must first consider seasonal requirements for municipal water supply and instream flows for fish, before addressing impacts to hydropower generation.

South Fork Tolt Project

Similarly, operations of the South Fork Tolt Project are highly sensitive because of its location in a mid-elevation basin, but also because it is operated for multiple objectives. The Tolt River reservoir is primarily used for municipal water supply. Most of the year power is generated based on needs for municipal water, except at times when releasing additional water to maintain a flood pocket in the reservoir provides surplus discharge for generation. Current seasonal timing of operations for hydropower, municipal water, instream flows for fish, and flood management are based on historical conditions. Reservoir refill depends on protracted inflows as snow melts in spring. In most years, rain during fall and winter along with snowmelt in spring have produced sufficient inflow to refill the reservoir, meet municipal water demands, and provide minimum flows for fish year round.

Normal refill begins May 1 and is marked by raising the reservoir crest. The reservoir crest must be lowered by September 30 to prepare for rain in fall and flood management. Both the raising and lowering of the reservoir crest are tied to operating procedures that are part of a FERC license and therefore have little flexibility. Depending on hydrologic conditions, refill can begin as early as March 1, but less seasonal snowpack could require adapting refill strategies and the timing for raising and lowering the reservoir crest.

Skagit Hydroelectric Project (Ross, Gorge, and Diablo)

The Skagit Project has high storage capacity and greater operational flexibility because the project is comprised of three dams and reservoirs (Ross, Diablo, and Gorge). The operational flexibility provided by the three consecutive dams decreases sensitivity because it can be used to manage streamflow timing and instream flows for fish protection. The Ross reservoir has substantial storage capacity that can be used to mitigate low snowpack conditions. However, the Skagit Project is operated for multiple objectives that will all be affected differently, which increases the overall sensitivity of the project because adapting operations to meet one objective could have consequences for others.

The current seasonal timing of operations for hydropower, flood control, instream flows for fish, and reservoir levels for recreation are based on historical conditions that include a substantial snowpack that stores water, reducing runoff in fall and winter and augmenting runoff in spring. Historically, inflows peaked in May and June coinciding with the reservoir refill period between April 15 and July 1. In most years, snowmelt and spring precipitation have produced sufficient inflow to refill the reservoir by July 1 to meet objectives for recreation. A shift towards earlier snowmelt and less runoff in May to July will make it increasingly difficult to refill the reservoir.

City Light’s initial analysis of climate change impacts on operations of the Skagit Project indicated that the refill period may need to shift earlier in the season to capture sufficient snowmelt runoff to refill the reservoir[14]. However, between September and April 15, flood control is the priority objective for operating the project. The reservoir is drawn down and maintained below the flood control elevation set by the Army Corps of Engineers to provide sufficient flood storage capacity. Therefore, shifting towards an earlier refill period would cause the refill period to overlap with flood control period and increase the risk of spilling for flood control **(Section 4.7, Impact 10)**.

An important objective for operating the Skagit Project in an environmentally responsible manner is to manage instream flows for protecting fish. Discharge from the project is carefully regulated to consider streamflow requirements for each fish species at different life stages throughout the year. The life stages of anadromous fish species are also synchronized with the seasonal timing of streamflow and snowmelt. For example, steelhead spawn between March 15 and June 15 when there is spring runoff from snowmelt. High streamflows early in the spring runoff determine how high redds are placed in the river and therefore the discharge that must be released through June 15 to protect redds from dewatering. Operations to protect steelhead during spring will be sensitive to changes in the timing of snowmelt. Higher streamflow earlier in spring could result in higher redd placement and the need to maintain these flows throughout the spring, even as runoff from snowmelt declines. Adapting instream flow requirements will need to be balanced with objectives for flood control and reservoir refill during the same time period.

Adaptive Capacity

Rate Stabilization Account – Since 2001, City Light has implemented several policies that increase the utility’s capacity to manage for streamflow variability, particularly dry years with low hydropower generation or years in which wholesale market prices are high. The Rate Stabilization Account (RSA) buffers customer rates against the inherent variability in hydropower generation and wholesale market prices. The RSA can be drawn down to supplement revenue when revenue from surplus power sales is low, preventing the need to increase electricity rates for customers. This fund provides capacity for City Light to reduce the financial impacts of low hydropower generation in drought years or years with low snowpack, but it may not provide a sufficient buffer against multi-year droughts or long-term trends in declining summer hydropower generation associated with less snowpack and changes in the streamflow timing.

Resource Portfolio – City Light has increased its capacity to manage for variability in climate and hydropower generation by diversifying power resources. In 2012, City Light established a contract for wind energy, increasing wind to about 5 percent of power resources. Power resources also include smaller percentages of biomass and landfill gases. City Light has one of the longest and most active Conservation Programs of any electric utility in the nation and considers conservation through energy efficiency as a resource for meeting projected load growth. These renewable energy resources are not directly affected by declining snowpack and are generally expected to be less affected by climate change[15].

Integrated Resource Planning – City Light develops an Integrated Resource Plan every two years to compare alternatives for meeting anticipated energy demand over the next 20 years. Engaging in a long-term planning process provides City Light with an opportunity to assess long-term changes in hydropower generation associated with climate change. Updating the plan every two years also allows for updating information regarding the effects of climate change on hydropower generation as new information emerges. However, a 20-year planning horizon with a two-year evaluation may not be sufficient lead time to identify impacts that could require substantial changes in resources or operations. Longer lead times may be necessary to implement some adaptation measures, such as major structural upgrades or the acquisition of new resources.

Operational Flexibility – As described previously, flexibility in operating hydropower facilities increases the capacity to modify operations in response to changes in snowpack and streamflow timing. The flexibility with which the Skagit Project is operated allows for greater consideration of actual precipitation, snowpack, and streamflow in a given year, rather than fixed streamflow targets that do not account for variability. Streamflow required for fish protection is determined through real-time monitoring of fish populations to determine the current timing of spawning, egg incubation, emergence, and rearing. Regulating flows based on actual conditions, rather than average historical conditions, facilitates adaptation to annual variability in snowpack, runoff timing, and streamflow. Similarly, Cedar Falls is managed with a dynamic rule curve that adjusts depending on the hydrologic conditions, allowing operations to change to earlier refill if snowpack and spring runoff are limited.

Weather Monitoring and Forecasting – Operations of the hydroelectric projects and planning for hydropower generation are also based on real-time monitoring of the snowpack throughout the year. This enables the rate and timing of reservoir refill to be managed based on the precipitation and snowpack in any one year, rather than average conditions. Snowpack monitoring is augmented with weather and streamflow forecasts up to two years in advance, which are used for resource planning for the two-year timeframe. The two-year streamflow forecasts consider projections of seasonal conditions, but these forecasts still rely on the historical range of variability and may not capture changes in streamflow that are outside the range of past observations, which will be increasingly common as the climate changes.

Potential Adaptation Actions

Near-term/Existing Capacity

1. **Update the previous analyses of how objectives and operations of the Skagit and Boundary Hydroelectric Projects could be affected by reduced snowpack and changes in streamflow timing.**
   Since City Light's initial assessment, new climate projections have been released and advancements have been made in hydro-climate modeling that can fill gaps and improve the previous analysis. Advancements include a model of glacier runoff and the capability to conduct hydrologic modeling with daily resolution. Climate projections now include daily (rather than only monthly) variability in temperature and precipitation that can be used to drive hydrologic models. Based on these advancements, an updated analysis will provide additional information on how climate change will affect operations. The Climate Research Initiative is supporting research to model climate-driven changes in streamflow in the Skagit basin and inflow to the Skagit Project. These inflow and streamflow projections can be used as input to City Light's reservoir and fish habitat models to determine the sensitivity and magnitude of potential impacts to operations. Scenarios could be developed to determine how flood control curves or fish flow requirements could be adapted to manage for changes in snowpack and streamflow timing. This information could be considered with historical streamflow data and be used to inform specific adaptation actions for project operations.

2. **Collaborate with Seattle Public Utilities to evaluate the effects of changes in snowpack and streamflow on the South Fork Tolt and Cedar Falls Projects.**
   SPU is conducting research in collaboration with the Climate Impacts Research Consortium at Oregon State University to model the impacts of climate change on the Cedar Falls and South Fork Tolt Projects. This information will be used to identify adaptation actions for these projects so that they continue to meet the objectives for municipal water supply and fish protection. Through collaboration with SPU, City Light can use this information to assess long-term impacts on hydropower generation from both the direct changes in streamflow and adaptation actions implemented by SPU in response to these changes.

3. **Use data and research on climate change impacts to hydropower operations on the Columbia River Basin currently being funded by the River Management Joint Operating Committee** (**RMJOC II)**.
   The RMJOC II (comprised of BPA, Bureau of Reclamation, and Army Corps of Engineers) is supporting research to model the effects of climate change on snowpack and streamflow in the Columbia River Basin http://www.bpa.gov/news/newsroom/Pages/BPA-prepares-for-a-changing-climate.aspx. Results from this research will provide information on how streamflow and inflows to specific projects are expected to change in the Columbia River Basin. This information will be used to inform the Columbia River Treaty and Biological Opinion. These data can also be used to assess potential impacts to generation at the Boundary Project, as well as generation for the sections of the Columbia River system that provide power for City Light's contracts with BPA. All data will be available to the public upon completion of the research project in 2017.

Long-term/Additional Capacity

4. **Consider increasing capacity within City Light to model and assess changing hydrologic conditions.**
   City Light's adaptive capacity is limited because of a lack of expertise and capacity to conduct long-term hydrologic modeling internally. Currently research regarding the effects of climate change on streamflow requires external expertise for hydrologic modeling that can provide the input data for internal models of reservoir operations and resource adequacy. As rivers become more dynamic with climate change, it will be increasingly important to build the internal capacity to model and project short- and long-term changes in streamflow.

5. **Consider further diversifying City Light's power resources by increasing renewable energy sources that have a seasonal pattern of generation different from that of hydropower.**
   As described previously, City Light's resources have some diversity with respect to location of hydropower facilities and inclusion of non-hydropower renewable resources, but a 90 percent hydropower resource portfolio makes the utility sensitive to regional changes in streamflow that will affect hydropower generation. City Light could consider further diversifying its resource portfolio with additional renewable resources, including wind and solar photovoltaic consistent with the current approach to reviewing these resources. Projections of regional changes in hydropower generation, including the timeframe of these changes, could provide useful information to determine the timeframe for when diversifying will be most important. In the near-term diversifying resources can reduce the impact of year to year variability in regional hydropower generation.

6. **Assess the effectiveness of the rate stabilization account to provide a buffer against the potential magnitude of future changes in hydropower with climate change.**
   The rate stabilization account provides an important buffer during dry years or years with below average snowpack when hydropower generation is below average. With climate change, the frequency of snowpack drought years (as experienced in 2015) are projected to increase. Therefore, it will be important to assess the effectiveness of this policy as climate changes and years with a low snowpack and earlier runoff become more frequent.

7. **Consider projected changes in snowpack and streamflow in the design and cost-benefit analysis of proposed upgrades in efficiency or generation capacity of hydroelectric projects.**
   As City Light considers efficiency upgrades to hydroelectric projects, the project design phase should include a consideration of the potential effects of climate change on the proposed upgrade. This will be especially critical for projects with a life expectancy of more than 30 years, the timeframe for substantial changes in City Light's major hydropower producing watersheds. The actual costs and benefits of upgrades are unlikely to be determined accurately if only historical streamflow is considered in the analysis. For example, City Light analyzed the potential benefits of constructing a second tunnel at Gorge Dam with and without changes in streamflow under climate change[16]. The analysis showed that when future projections of streamflow were considered, the benefits of the project increased relative to the benefits based on only the historical range of streamflow.

---

[1] Snover, A.K [.et .al]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[2] The amount of snowpack on April 1st is commonly used for comparison because this date has been used historically as an indicator of the amount of water stored in the snow for the upcoming dry season.

[3] Stoelinga, M.T. [et al.], 2009. A new look at snowpack trends in the Cascade Mountains. *Journal of Climate*

[4] Mote, P.W. 2006. Climate-driven variability and trends in the snowpack in western North America. *Journal of Climate* 19: 6209-6220.

[5] Stewart, I. [et al.], 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18: 1136-1155.

[6] Snover, A.K [.et al]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[7] Elsner, M.M. [et al.], 2010. Implications of 21st century climate change for the hydrology of Washington State. *Climatic Change* 102(1-2): 225-260.

[8] Elsner, M.M. [et al.], 2010. Implications of 21st century climate change for the hydrology of Washington State. *Climatic Change* 102(1-2): 225-260.

[9] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[10] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[11] Snover, A.K., A.F. Hamlet, S-Y. Lee, N.J. Mantua, E.P. Salathé, R. Steed, and I. Tohver. 2010. Seattle City Light Climate Change Analysis: Climate Change Impacts on Regional Climate, Climate Extremes, Streamflow, Water Temperature, and Hydrologic Extremes. Prepared for The City of Seattle, Seattle City Light by The Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington

[12] Bartos, M.D. and M. V. Chester. 2015. Impacts of climate change on electric power supply in the Western United States. Nature Climate Change (1-5)

[13] Seattle City Light, 2010 Integrated Resource Plan Appendix N Climate Change, http://www.seattle.gov/light/news/issues/irp/

[14] Seattle City Light, 2010 Integrated Resource Plan Appendix N Climate Change, http://www.seattle.gov/light/news/issues/irp/

[15] Bartos, M.D. and M. V. Chester. 2015. Impacts of climate change on electric power supply in the Western United States. Nature Climate Change (1-5).

[16] Cheng, W. and Kilduff. 2008. Performance of Hydroelectric Projects in the Face of Climate Change A Case Study. Seattle City Light.

4.7 Higher Peak Flows and More Frequent River Flooding

Impact 9: Transmission Infrastructure

More frequent and larger river flooding in Western Washington could increase damage to transmission towers, erosion near towers, and damage to roads that could impede access to transmission lines.

Mission Objectives at Risk: Financial Cost, Reliability

Transmission and Distribution

Sections of City Light's transmission lines run parallel to or across rivers in Western Washington that are susceptible to periodic flooding. Flooding can directly damage transmission towers or contribute to erosion and landslides that destabilize slopes near towers. For example, high flows and dynamic movement of the Stillaguamish River contributed to the large landslide in Oso, Wash. in 2014, which occurred during the wettest March on record. The devastating slide deposited debris into City Light's transmission line ROW and caused minor damage to the foundation of a tower.

Flooding and associated erosion can also damage access roads, reducing access for maintenance and thereby increasing response time and costs during an event. Although flooding could affect reliability in extreme situations of damage to transmission lines, in most flooding situations the loss of transmission capacity if the lines are de-energized can be compensated for through the purchase of wholesale power and contingency plans that route transmission through alternative pathways. Thus, most impacts to City Light would be financial associated with repair costs and power purchases to compensate for lost transmission.

Exposure

Rivers throughout Western Washington are projected to experience increases in peak flows and more frequent flooding[1] because of three changes in the climate that contribute to higher peak flows: (1) an increase in precipitation intensity, (2) more precipitation in fall and winter, and (3) a greater proportion of fall and winter precipitation falling as rain rather than snow. The contribution of these three changes relative to each other depends on the elevation of the watershed and the proportion of cool-season precipitation that falls as rain vs. snow in the current climate.

Historically, watersheds at low elevations in Western Washington have received most cool-season precipitation as rain rather than snow causing peak flows to occur in fall and winter associated with heavy rain events. The Stillaguamish and Snohomish are two watersheds that fit this pattern and have City Light transmission infrastructure. In these watersheds, higher peak flows will be driven primarily by increases in precipitation intensity and increases in fall and winter precipitation[2]. Extreme rain events, such as atmospheric rivers or "pineapple express" storms that bring heavy precipitation to Western Washington are also expected to increase in frequency and intensity[3]. Furthermore, atmospheric rivers may occur earlier in fall, causing peak flows to shift earlier in the season in these watersheds[4].

Table 4.6 shows projected increases in streamflow for two flood return periods (20- and 100-year floods) in two low-elevation, rain-dominated watersheds and one mixed-rain-and snow watershed (Sauk) in which City Light owns and operates transmission lines. For example, for the Sauk River at Sauk, the historical peak streamflow with a 20-year return is 28,300 cfs. By the 2020s that volume is projected to increase by 26 percent to 35,700 cfs on average, but it could increase by as much as 32 percent (37,400 cfs) or as little as 17 percent (33,100 cfs). The Sauk River is projected to have a greater increase in flood magnitude than the other two because the Sauk River will also experience more precipitation falling as rain rather than snow in fall and winter. The other two rivers already receive most precipitation as rain in winter.

Table 4.6. Projected percentage increases in streamflow for two flood return periods and two watersheds in Western Washington where City Light transmission infrastructure is located.

		2020s		2040s		2080s	
River (Location)	Flood Return Period	Mean	Range (25 - 75 %tile)	Mean	Range (25 - 75 %tile)	Mean	Range (25 - 75 %tile)
Sauk (at Sauk)	20 yr	26%	17 – 32%	41%	30 – 51%	63%	43 – 73%
	100 yr	22%	12 – 25%	36%	26 – 42%	51%	29 – 63%
Stillaguamish (at Arlington)	20 yr	13%	6 – 16%	18%	10 – 22%	25%	11 – 30%
	100 yr	13%	5 – 14%	20%	8 – 24%	26%	13 – 29%
Snohomish (at Monroe)	20 yr	16%	9 – 22%	24%	14 – 32%	35%	24 – 45%
	100 yr	12%	5 – 16%	20%	10 – 26%	30%	19 – 38%

The range is the 25th and 75th percentile of the values projected with 10 climate models. The mean is the mean of projections from 20 climate models.

These projected increases in flood magnitudes likely underestimate potential increases because they are modeled using a process that does not fully capture increases in daily precipitation intensity or the orographic enhancement of precipitation on the west slopes of the Cascade Mountains, which can be important contributors to peak flows in these low-elevation, rain-dominated watersheds. The availability of regional climate modeling that can represent these processes is improving and initial studies indicate that when these two factors are included, peak flows are projected to increase more.[5]

Sensitivity

The reliability of City Light's transmission system generally has low sensitivity to higher peak flows because of designed redundancy. The transmission system is designed with some physical redundancy in the form of multiple transmission lines between generation facilities and substations, but redundancy is also designed into the system by building more capacity than is needed at any one time.

In the event of flood-related interruptions to transmission lines running from generation facilities owned by City Light, the utility can compensate by purchasing wholesale power to meet load and other obligations and transmitting this power through alternative pathways. However, flood hazard is expected to increase primarily in late fall and winter when load is also greatest. It could be more difficult and costly to make alternative arrangements for purchasing and transmitting power if a major flood-related failure occurs during these higher capacity times. The costs associated with power purchases and alternative transmission arrangements would depend on the time required to repair the system, which would be higher if flooding damages multiple locations, affects a large area, or reduces access to damaged sites.

More frequent but less costly impacts could also be associated with more frequent smaller floods that cause damage to equipment, erosion of access roads, or both. These impacts could cause gradual increases in the costs for replacing and repairing equipment and roads, which would need to be accounted for in operating budgets.

Adaptation Options

Near-term/Existing Capacity

1. **Implement projects to reduce soil erosion and saturation in areas where infrastructure and access is currently vulnerable.**
   Areas of known erosion or soil saturation along rivers will likely be exacerbated with higher peak flows and precipitation intensity. Climate change increases the importance of managing for slope stability and drainage to prevent worsening conditions that could cause damage or loss of access. The benefits of these projects are likely to increase as flood risk increases.

Long-term/Expanded Capacity

2. **Upgrade current transmission infrastructure to be resilient to higher peak flows and flood hazard in locations that currently experience flood-related damage.**
   Infrastructure that already experiences flooding and erosion during peak flows is likely to experience greater damage with climate change, making it a priority for flood protection. Options for adapting to higher flood hazard include budgeting for higher repair and maintenance costs, relocating equipment higher in the floodplain, elevating equipment, installing protective barriers, or replacing equipment with more water resistant or submersible materials. For example, in response to higher flood hazard, ConEdison, Inc. upgraded a vulnerable steam generation plant with flood gates and built protective barriers around vulnerable substations. Upgrades should be designed for projected future, rather than historical, flood magnitudes. Given that flood hazard is projected to increase over time, upgrades could be made as part of regular replacement schedules.

3. **Consider higher peak flows (e.g. 100-year flood magnitudes) and flood hazard in the design of new projects on transmission lines located in or near floodplains.**
   Designs for new infrastructure near floodplains should consider that current floodplains are calculated based on historical flood magnitudes at any return period and do not consider projected increases in flood magnitudes. The design of new projects should consider changes in flood hazard relative to the life expectancy of the infrastructure. For example, infrastructure with a life expectancy of 25 to 40 years should consider the flood magnitudes associated with projected flows for the 2040s. Designs can use specific projected peak flows or add a buffer in the design to compensate for higher flows. For example, some electric utilities in the eastern U.S. are upgrading infrastructure in response to flooding by using a buffer of the 100-year FEMA floodplain plus one to three feet or designing for the 300-year flood.

---

[1] Tohver, I., A.F. Hamlet, and S-Y. Lee. 2014. Impacts of 21st century climate change on hydrologic extremes in the Pacific Northwest region of North America*. Journal of the American Water Works Association* 1-16.

[2] Salathé Jr., E.P. [et. al.]. 2014. Estimates of Twenty-First-Century flood risk in the Pacific Northwest based on regional climate model simulations. J. Hydrometeor 15: 1881–1899

[3] Warner, M. D., C. F. Mass, and E. P. Salathe Jr., 2012: Wintertime extreme precipitation events along the Pacific Northwest coast: Climatology and synoptic evolution. *Monthly Weather Review* 140: 2021–2043.

[4] Dalton, M. 2014. Technical Memo #5. The future of atmospheric rivers: a review of the recent literature. Climate Impacts Research Consortium, Oregon State University. Prepared for Seattle Public Utilities.

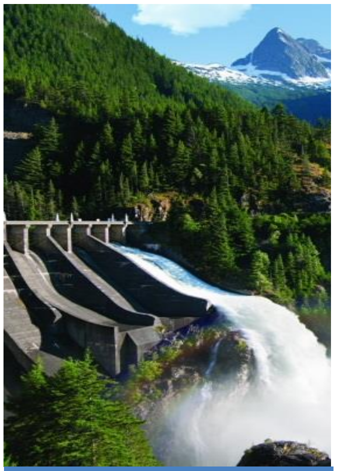
[5] Salathé Jr., E.P. [et. al.]. 2014. Estimates of Twenty-First-Century flood risk in the Pacific Northwest based on regional climate model simulations. J. Hydrometeor 15(5): 1881–1899

Impact 10: Hydroelectric Project Operations

Higher peak flows could increase the frequency of spilling at hydroelectric projects to ensure adequate flood control in fall and winter.

Mission Objectives at Risk: Financial Cost, Environmental Responsibility

High peak flows caused by heavy rain or rapid snowmelt can lead to spilling at City Light's hydroelectric projects when inflow exceeds storage and generation capacity or when additional storage is needed in anticipation of a major flood event. Power is not generated from spilled water causing lost revenue opportunities from retail and wholesale power sales. Higher peak flows in fall and winter are expected to increase the frequency of spilling at City Light's hydroelectric projects, which could lead to more lost revenue and make flood control objectives more difficult to achieve.



Hydroelectric Project Operations

Under its FERC licenses and the Endangered Species Act (ESA), City Light is obligated to protect fish species in the rivers where the utility operates hydroelectric projects. Reducing peak flows to protect salmon and steelhead is a priority for operations. Higher peak flows and frequent more spilling could challenge current operating procedures to protect fish. Spilling can directly cause fish mortality and higher flows downstream can scour redds and increase mortality of juvenile fish.

Exposure

The Upper Skagit and Pend Oreille watersheds are projected to experience large increases in peak flows by the 2080s, and more moderate changes by the 2020s and 2030s. Changes are expected to be slower to emerge relative to the lower elevation, mixed-rain-and-snow or rain-dominated watersheds described in **Impact 9**. The Upper Skagit River is projected to have a 30 to 60 percent increase in peak flows (20-year and 100-year flow magnitudes) by the 2080s, but initial increases are projected to be moderate with a 4 to 23 percent increase by the 2020s and a 5 to 26 percent increase by the 2040s (Table 4.7).

The season of peak flows in the Upper Skagit may also change. Historically, peak flows were primarily driven by rapid and abundant snowmelt in June and July. As winter precipitation shifts from snow to rain and snowpack declines, peak flows will be more frequently associated with heavy rain in fall and winter. The projections in Table 4.7 likely underestimate the contribution of short-term heavy rain events to peak flows in fall and winter in the Upper Skagit watershed[1].

Increases in peak flows are projected to be more modest and slower to emerge for the Pend Oreille watershed because of the relatively cold winter climate in this region. For the Pend Oreille River, flows associated with the 20- and 100-year return periods are not projected to increase significantly until the 2080s when peak flows are projected to be 18 to 26 percent higher than historical flood magnitudes on average (Table 7). Initially peaks flows in the Pend Oreille may decrease because they are currently associated with snowmelt in spring, which will decrease as snowpack decreases.

Table 4.7. Percentage change in peak flows for two flood return periods for the Upper Skagit and Pend Oreille Rivers (snow-dominated watersheds) where Seattle City Light's two largest hydroelectric projects are located.[2] Negative signs before the percentage change indicate a decrease in the streamflow for the flood return periods.

		2020s		2040s		2080s	
River (Location)	**Flood Return Period**	**Mean (%)**	**Range 25 to 75 %tile**	**Mean (%)**	**Range 25 to 75 %tile**	**Mean (%)**	**Range 25 to 75%tile**
Skagit (Ross)	20 yr	4%	-1 – 10%	11%	2 – 15%	30%	9 – 44%
	100 yr	7%	1 – 12%	18%	7 – 21%	49%	15 – 70%
Skagit (Diablo)	20 yr	14%	4 – 17%	5%	1 – 11%	36%	13 – 50%
	100 yr	23%	11 – 28%	8%	1 – 14%	57%	22 – 79%
Skagit (Gorge)	20 yr	6%	0 – 12%	15%	5 – 18%	38%	15 – 53%
	100 yr	9%	1 – 15%	26%	13 – 31%	61%	25 – 82%
Pend Oreille (Boundary)	20 yr	0%	-3 – 4%	3%	-4 – 8%	18%	4 – 21%
	100 yr	2%	-1 – 6%	6%	-2 – 14%	26%	7 – 28%

The range is the 25th and 75th percentile of the values projected by 10 climate models. Ranges that include a negative value include 0 in the range, indicated that no change is included in the range of future changes.

Despite the consistent trend of projected increases in peak flows, it is important to note that year to year climatic variability will continue to influence peak flows. Through the 2040s, flows associated with these flood return periods will likely be within the range of historical variability, but as warming increases in the latter part of the 21st century, the magnitude of peak flows will shift outside the range of what has been experienced in the past.

Sensitivity

Flood Control

Flood control objectives for City Light's hydroelectric projects are sensitive to higher peak flows. At the Skagit Project, the amount and timing of reservoir storage for flood control is determined by the Army Corp of Engineers and set by the FERC license. Drawdown of Ross reservoir begins after Labor Day with the goal of reaching the flood control elevation by November 15 and maintaining it through April 15. Between April 15 and July 1 the reservoir is refilled. In most years, Ross reservoir is drawn down below the required flood control elevation, providing additional flood storage to protect against the need to spill water in anticipation of major rain events.

Currently, spilling at the Skagit Project is most common in June or July when reservoir levels are high after refill has started and snow is still melting rapidly. However, intentional preemptive spilling is occasionally necessary during heavy rain events in fall. Flood control objectives will be most sensitive to higher peak flows in early fall during the period of drawdown between early September and November 15. Higher peak flows during this time are more likely to require spilling water in anticipation of major rain events because reservoir levels are still high.

The frequency of spilling is likely to increase in October through December at the Skagit Project as peak flows increase with climate change. In contrast, the frequency of spilling in May through July is likely to decrease as snowpack declines and melts earlier in spring. The substantial storage capacity of Ross reservoir and the ability to coordinate the operations of the three dams reduces sensitivity of the system to higher peak flows and the need to spill. Diablo and Gorge have little storage capacity making spilling from these reservoirs more common, but this can reduce the need to spill from Ross. However, even under the current climate, peak flows can be sufficient to require spilling a few times per year on average.

The Boundary Project is not operated for flood control because of its limited storage capacity, so the frequency of spilling is directly related to streamflow and the operations of dams upstream. Spilling at Boundary is most common with rapid snowmelt in spring. As the climate changes, spilling is likely to continue to be common in spring, but the frequency and magnitude may decrease with less snowmelt and the timing may shift earlier in the spring as snow melts earlier. The frequency and magnitude of spilling at the Boundary Project is less sensitive to changes in climate because the facility is located in a snow-dominated watershed where significant increases in peak flows are not projected until the latter part of the 21st century.

Streamflow Regulation for Fish Protection

Streamflow regulation for fish protection is sensitive to increases in peak flows above and below the projects. At the Skagit Project, flow regulation for fish protection is determined by the Anadromous Fish Flow Plan as part of the FERC license. Currently the Skagit Project is operated to reduce high flows that can adversely impact salmon and steelhead populations by scouring redds. However, during times of extreme high flows, flood control becomes the dominant objective for operating the project and discharges required for flood control can adversely affect fish survival downstream.

Higher peak flows in fall will also challenge operations of the Skagit Project to reduce maximum flows during fall spawning periods. Salmon and steelhead redds are sensitive to extreme high flows, which can cause gravel movement and scouring of eggs during incubation. During spawning periods, high flows cause salmon and steelhead to build redds at higher elevations in the river, which puts the redds at greater risk of dewatering when flows subside. If streamflows are high during fall spawning periods, higher flows must be maintained throughout the winter to prevent dewatering of redds during incubation. Maintaining these higher flows for incubation throughout the winter reduces flexibility in project operations for generation and can drawdown the reservoir further making it more difficult to refill in spring.

The Boundary Project is not operated to regulate high flows for the protection of fish species on the mainstem of the Pend Oreille River. However, spilling at the project affects the total dissolved gas levels downstream, which have adverse consequences for fish. A reduction in the frequency and magnitude of spilling could reduce the levels of total dissolved gas and improve fish habitat quality.

The South Fork Tolt and Cedar Falls Projects are operated to maintain peak flows below certain thresholds to reduce scouring of salmon and steelhead redds. The flow threshold for scouring for the Cedar River was determined by a study conducted by the HCP Instream Flow Commission. For the South Fork Tolt Project, a study is being implemented by the Tolt Fish Advisory Committee as part of the FERC license to refine the flow threshold to prevent scouring.

Adaptive Capacity

Streamflow for fish protection at the Skagit Project is managed using a dynamic process of shaping flows during spawning periods that considers the current hydrological conditions in any year. This process allows for greater flexibility and capacity to adapt to hydrologic variability than would be possible with static requirements for minimum flows. City Light implements this dynamic process by conducting extensive modeling and monitoring of fish downstream of the project to determine flow requirements throughout spawning, incubation, and rearing.

Currently, this process is effective at reducing peak flows during the spawning period to limit scour. Discharge from the project is increased before natural peak flows and reduced during peak flows. This process will likely provide some adaptive capacity for responding to higher and more frequent peak flows. However, as peak flows increase, it will become more difficult to balance objectives for flood control and limit flows during spawning to meet objectives for fish protection. The greatest conflicts are likely in October and November.

The Skagit Project Flow Agreement established the Skagit Flow Committee, a stakeholder group that can authorize modifications to the flow requirements as necessary to respond to conditions in a given year. This increases the utility's capacity to regulate streamflow variability and may also provide a means to adapt to higher peak flows, but as peak flows increase beyond the historical range of variability, additional measures to adapt operations will likely be necessary. Similarly, the Cedar Instream Flow Commission can modify flow requirements to respond to particular conditions in a given year providing flexibility to manage streamflow variability.

Adaptation Options

Near-term/Existing Capacity

1. **Update the previous analysis of how projected changes in streamflow would affect the frequency of spilling at the Skagit and Boundary Projects[3] and model potential changes in operations to reduce the impacts of higher peak flows.**
   City Light's Climate Initiative is supporting research to update streamflow projections for the Skagit watershed which will provide information that can be used to assess changes in the frequency, magnitude, and seasonal timing of spilling at the project. The RMJOC II research project (**Section 4.6, Impact 8**) is providing similar projections of streamflow for the Columbia River Basin. These research projects will include the latest climate change projections from the 5th IPCC, climate projections with daily resolution, and higher resolution hydrology models. Daily climate data will improve the precision of streamflow projections, providing better information to determine potential increases in the frequency of spilling and changes in the seasonal timing of spills. Using these streamflow projections in reservoir operation models can identify potential actions to adapt current operations to reduce the need to spill water.

Long-term/Expanded Capacity

2. **Support research on the effects of climate change on the frequency of extreme precipitation events and atmospheric rivers in the watersheds where City Light operates.**

Regional climate models coupled with weather forecasting models are a powerful tool for capturing the dynamics of extreme precipitation in Western Washington. The capability of these tools is improving and they have the potential to provide more locally specific information on changes in the intensity, seasonal timing, and location of extreme precipitation. A key difference between this approach and the current streamflow modeling research is the ability to capture feedbacks between storms and the topography of the Cascades Mountains that can amplify precipitation and causes the largest events that lead to spilling and flooding.

3. **Invest in long-range weather and seasonal forecasting tools that could increase the utility's capacity to plan and prepare for extreme precipitation events and peak flows.** Seasonal and long-range weather forecasting technology is improving and probabilistic forecasts can now be made for two weeks to nine months in advance (with uncertainty increasing as the lead time increases). Long-range weather forecasting is still experimental, yet it has the potential to expand the current weather forecasting information used by the utility to plan daily to monthly operations. Improved forecasting of daily precipitation intensity could improve operations for flood control and reduce the frequency of spilling.
4. **Modify Skagit Project operations to reduce the incidence of spill associated with higher peak flows during the fall drawdown period.** Storage capacity to accommodate heavy precipitation in fall could be increased with more rapid drawdown of Ross reservoir between Labor Day and November 15, subject to constraints on maximum flows for fish protection and generator capacity. Operational adjustments to accommodate higher peak flows will need to be balanced with changes to accommodate less and earlier runoff in spring. For example, keeping Ross reservoir more full in winter would exacerbate problems with fall and winter spilling.

---

[1] Salathé Jr., E.P. [et. al.]. 2014. Estimates of Twenty-First-Century flood risk in the Pacific Northwest based on regional climate model simulations. J. Hydrometeor 15: 1881–1899

[2] Hamlet, A.F., P. Carrasco, J. Deems, M.M. Elsner, T. Kamstra, C. Lee, S-Y Lee, G. Mauger, E. P. Salathe, I. Tohver, L. Whitely Binder, 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[3] Seattle City Light, 2010. Integrated Resource Plan, Appendix N Climate Change, http://www.seattle.gov/light/news/issues/irp/

Impact 11: Fish Habitat Restoration and Protection

Higher peak flows and more frequent flooding may adversely affect fish and challenge City Light's ability to meet objectives for protecting fish species.

Mission Objectives at Risk: Financial Cost, Environmental Responsibility

Fish Habitat Restoration

In addition to operating hydroelectric projects to regulate streamflow for fish protection, the utility also restores and protects fish habitat to mitigate any adverse effects of the project operations. City Light purchases habitat mitigation lands as part of the FERC licenses and purchases additional habitat lands through the ESA Early Action Program to mitigate impacts on ESA-listed species and other salmonids. The utility protects and restores fish habitat in the Skagit, Sauk, Tolt, and South Fork Tolt Rivers.

The success of these protection and restoration efforts could be adversely affected by higher peak flows that reduce fish survival and physically damage habitat and restoration projects. The continued viability of habitat in some locations also may be at risk. Funding for land acquisitions and habitat restoration will be spent most effectively if lands are prioritized and restoration projects are designed with explicit consideration of higher peak flows. Land acquisitions and restoration projects are long-term investments, so a long-term planning horizon is important for considering the impacts of climate change.

Exposure

Most lands purchased for fish habitat are located in mixed-rain-and-snow watersheds (Sauk, Lower Skagit, Tolt, and South Fork Tolt) where peak flows are more sensitive to warming compared to the snow-dominated Upper Skagit or Pend Oreille watersheds. These watersheds are likely to experience increases in peak flows earlier in the 21st century because only a small amount of warming is necessary to raise the elevation of the freezing level, causing precipitation to fall as rain rather than snow. Warming effectively causes an increase in the area of the watershed that contributes runoff during peak flows[1]. Unlike rain-dominated watersheds, increases in peak flows in these watersheds will be driven primarily by warming rather than increases in rain intensity, but increases in winter precipitation and rain intensity will also contribute to higher peak flows.

The Sauk and Lower Skagit Rivers are projected to have large increases in peak flows that will continue to increase with accelerated warming through the 21st century. For the Sauk River, the magnitude of the 100-year flood is projected to increase by a mean of 22 percent by the 2020s and 36 percent by the 2040s (Table 4.8)[2]. For the Lower Skagit River, the magnitude of the 100-year flood is projected to increase by a mean of 20 percent by the 2020s and 36 percent by the 2040s (Table 4.8). Historically, peak flows in these watersheds have occurred in spring and fall, but as the climate changes, peak flows will be more common in fall and winter and less common in spring. When peak flows do occur in spring, they are likely to be earlier in the season. In the

Lower Skagit River, peak flows associated with snowmelt typically occur in May and June and this is expected to shift as early as March and April.

Table 4.8. Percentage change in streamflow for two flood return periods in two mixed-rain-and-snow watersheds (Lower Skagit and Sauk) where Seattle City Light's fish habitat mitigation and ESA Early Action lands are located[3].

		2020s		**2040s**		**2080s**	
River (Location)	Flood Return Period	Mean	Range 25 – 75 %tile	Mean	Range 25 – 75 %tile	Mean	Range 25 – 75 %tile
Skagit (Mt Vernon)	20 yr	22%	15 – 28%	38%	29 – 46%	61%	39 – 70%
	100 yr	20%	10 – 22%	36%	26 – 37%	53%	29 – 69%
Sauk (Sauk)	20 yr	26%	17 – 32%	41%	30 – 51%	63%	43 – 73%
	100 yr	22%	12 – 25%	36%	26 – 42%	51%	29 – 63%

The range is the 25th and 75th percentile of the values projected by 10 climate models.

Sensitivity

City Light's objectives for contributing to the recovery of ESA-listed species in these watersheds are sensitive to peak flows because of the direct effect of these flows on fish populations. The sensitivity of ESA-listed species (Chinook salmon, steelhead, and bull trout) varies by species and depends on how the seasonality of different life stages aligns with the seasonality of peak flows. Peak flows can scour redds and reduce the survival of juvenile species. Thus impacts will be greatest for species that are in these life stages during fall and winter when peak flows are projected to increase.

City Light's efforts to protect and restore habitat on mitigation lands along the Sauk, Lower Skagit, and South Fork Tolt rivers are also sensitive to higher peak flows. Habitat restoration projects will be subject to higher peak flows that can physically damage habitat structures and woody debris that is installed to improve habitat.

However, it is important to note that peak flows can have both beneficial and detrimental effects on salmon habitat. Peak flows contribute to restructuring of the channel and habitat forming processes, but they can also remove woody debris that is critical for habitat structures and fish carcasses that are important nutrient inputs to the stream[4]. Both factors can affect long-term fish survival.

Potential Adaptation Options

Near-term/Existing Capacity

1. **Consider increases in peak flows in priorities for land acquisitions and objectives of habitat restoration projects on fish habitat lands throughout the Sauk, Skagit, and South Fork Tolt watersheds.**
   Reducing the impact of peak flows on fish and habitat is already a consideration of restoration projects, but project designs may need to be adapted to accommodate even higher peak flows. Habitat restoration can be specifically designed to reduce the impacts of higher peak flows by reconnecting side channels and sloughs, removing or setting back levees or dikes, and re-meandering channels[5]. These restoration practices ameliorate higher peak flows by storing more water and providing areas of slower moving water that serve as refuges for fish during peak flows. Restoring incised streams can prevent peak flows from concentrating by enabling water to disperse into the floodplain. Restoring incised channels can also increase access for fish to slower moving water during peak flows. Decreasing the impact of peak flows on fish populations on City Light's mitigation lands can contribute to greater overall population resilience in the watershed, offsetting adverse impacts of high flows on populations elsewhere.

2. **The design of restoration projects on fish habitat lands should consider higher peak flows in the design of restoration structures that could be damaged by these flows.**
   Structures that are installed to restore channels, such as log jams, can be damaged by peak flows. Project designs should consider projected future flows for any flood return period used in the project design to ensure that the restoration objectives of the project can still be achieved with higher flows. The timeframe for future peak flows considered in the design should be a function of the life expectancy of the restoration project.

---

[1] Tohver, I., A.F. Hamlet, and S-Y. Lee. 2014. Impacts of 21st century climate change on hydrologic extremes in the Pacific Northwest region of North America. *Journal of the American Water Works Association* 1-16.

[2] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[3] Hamlet, A.F., P. Carrasco, J. Deems, M.M. Elsner, T. Kamstra, C. Lee, S-Y Lee, G. Mauger, E. P. Salathe, I. Tohver, L. Whitely Binder, 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[4] Beechie, T. [et al.]. 2012 Restoring Salmon Habitat for a Changing Climate. *River Research and Applications*

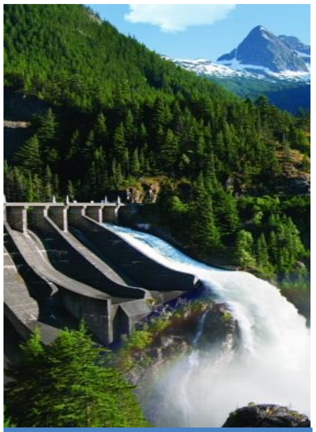
[5] Beechie, T. [et al.]. 2012 Restoring Salmon Habitat for a Changing Climate. *River Research and Applications*

4.8 Lower Low Flows in Summer

Impact 12: Hydroelectric Project Operations

Lower low flows could challenge City Light’s ability to meet hydroelectric project objectives for recreation, hydropower generation, and instream flows for fish protection in summer.

Mission Objectives at Risk: Environmental Responsibility, Financial Cost



Hydroelectric Project Operations

In summer, City Light operates hydroelectric projects to balance objectives for hydropower generation, instream flows for fish protection, reservoir levels for recreation, as well as collaborating with Seattle Public Utilities to manage projects for municipal water supplies. As streamflow declines in summer, less water will be available to balance these objectives.

Less water availability in summer is likely to reduce hydropower generation at the same time that electricity demand for cooling is expected to increase in City Light’s service area and to a greater extent in other regions in the western U.S. **(Impact 3).** Less hydropower generation in summer is unlikely to have widespread consequences for reliability because the utility has surplus power in most years and electricity demand is greater in winter than summer, even with increases in summer demand. Less hydropower generation in summer could have financial consequences for the utility due to lost revenue from surplus power sales and additional costs associated with purchasing wholesale power to meet demand in low water years. Financial impacts in summer may be partially offset by more power generation in winter, but the balance will depend on total annual generation, any increase in spilling due to higher streamflows in winter, and the energy market in any one year.

Lower inflows in summer may make it more difficult to maintain reservoir elevations for summer recreation, while simultaneously providing sufficient minimum flows to protect fish. For the hydroelectric projects that are operated to maintain minimum flows for fish, lower streamflow in the tributaries below the dams could require greater discharges from reservoirs to augment flows. This could result in more frequent drafting of the reservoirs below the levels ideal for recreation in summer. For projects that are operated for water supply, reservoir drawdown rates may also increase as water consumption demands increase with warmer temperatures.

Exposure

Low Summer Streamflow

Most rivers in Western Washington currently experience lowest streamflow in August and September when the seasonal snowpack has melted, rain is minimal, and air temperatures are high. Low flows during this time are projected to decrease significantly for most rivers in Western Washington.[1] Warmer air temperatures are expected to increase evaporation from land and vegetation, decreasing the water available for runoff. Projections of precipitation are less certain, but most climate models consistently project decreases in summer precipitation[2].

Low flows (measured as 7Q10, the seven-day average low flow magnitude with a ten-year return period) are projected to decrease for the Upper Skagit and Pend Oreille watersheds above the hydroelectric projects. For the Skagit River at the three dams, low flows are projected to decrease by a mean of 11 to 15 percent by the 2020s and 18 to 21 percent by the 2040s (Table 4.9). Periods of low streamflow are also projected to shift earlier in the summer and last longer.

City Light's Climate Research Initiative is supporting research to model changes in inflows to the three reservoirs of the Skagit Project to determine how water availability in summer will change for multiple climate change scenarios. This modeling for the Upper Skagit River will also show how tributary inflows below the project will change in summer. This research will inform whether changes in summer operations will be necessary to balance objectives for fish protection and recreation. The inflow projections will also be used to model the range of potential changes in summer hydropower generation.

At the Boundary Project, decreases in low flows are projected to be more moderate (a mean of 5 percent by the 2040s) and impacts will be slower to emerge. The Pend Oreille River is projected to have only modest decreases in low flows because the snowpack is less sensitive to warming, but the duration of low flow periods may increase with warmer temperatures[3]. The streamflow projections for the Columbia River Basin supported by the River Management Joint Operation Committee will be completed in fall 2016. These projections and any adaptation actions as a result of them can be used to inform how changes in summer streamflow may affect hydropower generation at the Boundary Project.

Table 4.9. Percentage change in low flows (7Q10, 7-day mean low flow magnitude with a 10-year return period) at the Skagit and Boundary Hydroelectric Projects[4].

	2020s		2040s		2080s	
River (Location)	Mean	Range 25 to 75 %tile	Mean	Range 25 to 75 %tile	Mean	Range 25 to 75 %tile
Skagit (at Ross)	-11%	-14 – -8%	-18%	-20 – -14%	-25%	-26 – -23%
Skagit (at Diablo)	-14%	-17 – -11%	-20%	-23 – -17%	-28%	-29 – -26%
Skagit (at Gorge)	-15%	-17 – -11%	-21%	-24 – -17%	-28%	-30 – -26%
Pend Oreille (at Boundary)	-4%	-6 – -4%	-5%	-6 – -4%	-7%	-9 – -7%

The range is the 25th and 75th percentile of values projected by 10 climate models.

Glacier Recession

The projected decreases in low flows in Table 4.9 do not include glacial runoff or projected changes in glacial runoff with climate change. Melting water from glaciers is an important source of water for summer operations of the Skagit Project and projects on the Upper Columbia River. The Upper Skagit is the most heavily glaciated watershed in the coterminous U.S. with over 396 glaciers covering a total area of 138 km^2 and contributing 100 billion gallons of water to streamflow annually[5].In glaciated watersheds, glacial meltwater is the primary source of streamflow in late summer after seasonal snow has melted. For example, in Thunder Creek, the largest tributary to the Diablo reservoir, glacial runoff provides up to 100 percent of the streamflow in late August and early September of hot dry years.

Monitoring of glaciers indicates that the area of glaciers in the Skagit watershed has declined 19 percent since 1959 and the rate of glacier recession is accelerating with most of this decline occurring after 1970[6]. As the volume and area of ice declines, the contribution of glacial runoff to summer streamflow also declines. In warm, dry years with low snowpack, the contribution of glacial runoff to the Upper Skagit River has decreased about 22 percent. Warmer temperatures and less snowpack are expected to accelerate glacier recession in the 21st century, further reducing summer inflow to the Skagit Project and tributaries downstream of the project where glacial runoff is a significant component of summer streamflow.

Sensitivity

Skagit Project

Operations of the Skagit Project in August and September are sensitive to lower low flows that reduce inflow to the reservoirs and tributary inflows to the mainstem Skagit River downstream of the project. The three primary objectives for the Skagit project in summer are to provide minimum instream flows for fish, keep Ross reservoir full from July 1 to Labor Day for recreation, and generate hydropower. Discharges from the project to meet instream flow requirements for fish depend on the tributary inflows below the project. Therefore lower tributary inflows will require greater discharges to meet the minimum flows targets. When inflows to Gorge and Diablo reservoirs are also low, the required discharges must come from Ross reservoir, causing the reservoir to be drafted below the recreation elevation.

Under low streamflow conditions when the Skagit project is discharging just enough water to meet minimum flows and drafting the reservoirs to lower elevations, the lower discharge and head[A] results in less summer power generation. Therefore, in years with low water availability in summer, reservoir levels for recreation cannot always be met and hydropower generation is reduced, but instream flow requirements for fish protection are maintained. Lower hydropower generation has financial consequences through lost revenue from surplus power sales and/or increased costs associated with power purchases to meet demand and contract obligations. Low wholesale revenue and higher costs trigger automatic rate surcharges when the balance of the Rate Stabilization Account goes below specific thresholds.

[A] Head is the difference in height between the reservoir elevation and the water outflow. More head when the reservoir elevation is high increases the amount of power generated by the same volume of water.

Adaptive Capacity

The Anadromous Fish Flow Plan for the Skagit Project establishes a flexible process for managing instream flows providing the utility with substantial capacity to manage annual variability in streamflow. As described previously for peak flow impacts, the plan uses a dynamic process to set minimum flows for fish protection that can respond to the actual flows in any year and the timing of fish spawning, incubation, and emergence. The flow plan is implemented with careful monitoring of the life stages of salmon and steelhead to time streamflow accordingly. The plan includes procedures to follow in years with insufficient flows to meet all objectives and calls for convening a flow committee to review solutions to manage below average flows.

This plan provides substantial flexibility and capacity to manage for short-term variability in climate and streamflow, but it relies on historical conditions in a way that may underestimate the potential impacts and challenges associated with a shift toward lower low flows and less water availability in summer. For example, tributary inflows below the project are calculated based on historical flows. Values are updated every five years by including in the average the most recent five years of observations. This practice was adopted to accommodate emerging trends in monthly tributary inflows. It likely improves tributary inflow estimates relative to focusing on a specific historical time period, but using this historical range of variability will underestimate the magnitude and frequency of extreme low flows moving into the future.

Potential Adaptation Options

Near-term/Existing Capacity

1. **Consider the updated analysis of changes in streamflow at the Skagit project to determine changes in operations that could increase discharge in summer while balancing reservoir levels for recreation under lower summer water conditions.** This report and City Light's previous analysis identified summer operations as particularly vulnerable to reductions in streamflows[7]. Updated streamflow projections that include the most recent climate projections and glacial runoff can be used to refine these analyses. Reservoir modeling with projected future flows can be used to identify potential operational changes to adapt to lower streamflow in summer.

Long-term/Expanded Capacity

2. **Reduce dependence on historical streamflow observations to set flow requirements for fish protection on the Skagit River.** Operations that are based on average historical hydrologic conditions may not be effective in managing lower low flows with climate change. For example, the tributary inflows on the Skagit River between Newhalem and Marblemount are modeled each year based on historical conditions. Using historical data is likely to overestimate low flow periods in summer as climate changes. Similarly, historical observations of tributary flows into the Skagit project from tributaries that receive substantial glacial runoff will likely overestimate summer flows as glacier recession accelerates and reduces runoff.

3. **Identify ways for the communities of Newhalem and Diablo to reduce water withdrawals for consumptive use.** Water to support the communities of Diablo and Newhalem is withdrawn from the tributaries of the Skagit River and ground water. During low flow periods even small diversions can

significantly reduce flows. Water conservation and decreasing withdrawals during periods of extreme high temperatures or critical low flows in late summer could augment tributary inflows, providing more instream flows for fish protection.

4. **Collaborate with stakeholders to increase flexibility in the needs for recreation on the Skagit reservoirs.**
   The required reservoir elevation levels for recreation on Ross reservoir will become more difficult to maintain as years with low water availability in summer become more frequent. City Light could collaborate with partners and stakeholders to support a more dynamic recreation system on the reservoirs that can accommodate lower reservoir elevations, such as boat docks that can function for a larger range of reservoir elevations. City Light could also increase communication and planning with the recreation stakeholders to prepare for lower lake levels as they become more common.

---

[1] Mantua, N, Tohver, Hamlet, A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for fresh water salmon habitat in Washington State. Climatic Change 102:187-223.

[2] Snover, A.K [et .al]. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle. http://cses.washington.edu/db/pdf/snoveretalsok816.pdf

[3] Mantua, N, Tohver, Hamlet, A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for fresh water salmon habitat in Washington State. Climatic Change 102:187-223.

[4] Hamlet, A.F. [et al.]. 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[5] Riedel, J.L., Larrabee, M.A. *In Review.* Impact of recent glacial recession on summer streamflow in the Skagit River. Northwest Science.

[6] Riedel, J.L., Larrabee, M.A. *In Review.* Impact of recent glacial recession on summer streamflow in the Skagit River. Northwest Science

[7] Seattle City Light, 2010 Integrated Resource Plan Appendix N Climate Change, http://www.seattle.gov/light/news/issues/irp/

Impact 13: Fish Habitat Restoration and Protection

Lower low flows in summer could challenge City Light's ability to meet objectives for restoring and protecting habitat for fish species.

Mission Objectives at Risk: Environmental Responsibility

Fish Habitat Restoration

As with higher peak flows, lower low flows could affect the success of habitat protection and restoration projects on City Light's habitat mitigation and ESA Early Action Program lands. Explicitly considering projected decreases in low flows in the acquisition of habitat mitigation lands and the design of restoration projects will help ensure the success of restoration objectives for these lands. Not considering changes in low flows could lead to the protection of habitats that may no longer be viable in a future climate or inability to meet restoration objectives.

Lower low flows in summer can have direct impacts on the health and viability of fish populations. Lower low flows can reduce the availability of spawning habitat by creating physical and thermal barriers to migration. Lower streamflow in summer also contributes to warmer water temperatures that cause thermal stress for cold-water fish and thermal barriers to migration.

Exposure

Most habitat mitigation lands and ESA-Early Action lands are located on the South Fork Tolt, Tolt, Lower Skagit, and Sauk Rivers. The Skagit River at Mount Vernon and the Sauk River are projected to have decreases in the volume of low flows of 21 percent and 25 percent on average respectively for the 2020s and 32 percent and 40 percent by the 2040s (Table 4.10). Similar data is not available for the South Fork Tolt, but a similar pattern is expected for this watershed.

Table 4.10. Percentage change in low flows (7Q10, 7-day mean low flow magnitude with a 10-year return period) for the Lower Skagit and Sauk watersheds where many of Seattle City Light's fish habitat mitigation lands are located[1].

	2020s		**2040s**		**2080s**	
River (Location)	Mean	Range 25 to 75%tile	Mean	Range 25 to 75%tile	Mean	Range 25 to 75%tile
Skagit (at Mt. Vernon)	-21%	-24 to -17%	-32%	-36 to -28%	-40%	-43 to -39%
Sauk (at Sauk)	-25%	-28 to -20%	-40%	-46 to -36%	-50%	-53 to -49%

The range is the 25th and 75th percentile of the values projected by 10 climate models.

Relative to the snow-dominated watersheds where the projects are located, low flows are projected to decrease more in these warmer, mixed-rain-and-snow watersheds because snowpack and snowmelt timing are more sensitive to warming[2]. Low flows in these watersheds are also more affected by warmer spring and summer temperatures that increase evaporation and water withdrawals. Decreases in low flows are projected to intensify in the 2080s with continued warming, reduced snowpack, and earlier snowmelt.

Sensitivity

The quality and viability of fish habitat is sensitive to the frequency and magnitude of low flows in summer. In addition to dewatering redds, lower low flows can create barriers for adult fish migrating upstream to spawn. Lower low flows can also increase water temperatures. Warmer stream temperatures can cause changes in migration and spawning behaviors, incubation durations, and thermal stress for cold-water fish that can become fatal if stream temperatures are too high[3].

The design and success of restoration projects are also highly sensitive to changes in low flows. During extreme low flow periods, restored habitat can have insufficient water or become isolated. Warmer water temperatures associated with low flows can reduce the quality of restored habitat or make it no longer suitable.

Adaptive Capacity

Habitat protection and restoration of mitigation land and lands purchased for the ESA Early Action Program provide capacity and opportunities to reduce the impact of lower low flows on fish populations and habitats. Restoration projects for this program are designed to reduce non-climatic stressors and increase the resilience of salmon populations in the lower Skagit, Sauk, and South Fork Tolt watersheds. Reducing existing stressors is one adaptation strategy for increasing overall salmon population resilience, which can help populations withstand and adapt to the additional stresses posed by climate change.

Land acquisitions and restorations as part of this program are not currently targeted to lower low flows in summer, but the program provides an opportunity to purchase habitat lands and implement restoration techniques specifically targeted to reducing the impacts of lower low flows on populations of ESA-listed species and other salmonids.

Potential Adaptation Actions

Near-term/ Existing Capacity

1. **Focus the objectives and design of restoration projects on ameliorating the impacts of lower low flows and warmer stream temperatures on fish populations and habitat quality.**
   Some habitat restoration practices are likely to have greater benefits than others for ameliorating low flows. Restoration actions that increase sediment storage and aggradation of incised channels can ameliorate low flows and increase water storage. Restoration projects that involve protection or reintroduction of beavers can also increase water storage and augment low flows. Restoring streamflow regimes that reduce runoff and peak flows

can also ameliorate low flows by slowing runoff and increasing water storage in spring that will be available during summer low flow periods. Increasing vegetation cover can reduce water temperatures during low flow periods.

Aspects of the design of restoration projects that depend on low flow volumes should consider projected decreases in these volumes in the project design. Although City Light primarily relies on partners and contractors to implement restoration projects, restoration techniques to ameliorate low flows can be emphasized in the review and criteria for project design in contracts for restoration projects.

2. **Consider lower low flows directly in the acquisition of mitigation and ESA early action habitat lands by selecting habitats that can reduce impacts or increase resilience to climate change.**
   Land acquisitions could be targeted to locations with cold-water refugia, ground water seeps and opportunities for stream recharge, or locations that provide access to side-channel habitat, which is critical rearing habitat that allows fish to escape low flow and higher warmer temperatures on the wider mainstems of rivers. Land acquisitions should avoid habitat that is already marginal in terms of stream temperature or low summer flows, unless there is significant potential to restore these habitats. These marginal habitats may not be able to sustain fish populations as the climate changes, and therefore may not be the best targets for limited restoration funds.

---

[1] Hamlet, A.F., P. Carrasco, J. Deems, M.M. Elsner, T. Kamstra, C. Lee, S-Y Lee, G. Mauger, E. P. Salathe, I. Tohver, L. Whitely Binder, 2010, Final Project Report for the Columbia Basin Climate Change Scenarios Project, http://warm.atmos.washington.edu/2860/report/.

[2] Mantua, N, Tohver, Hamlet, A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for fresh water salmon habitat in Washington State. Climatic Change 102:187-223.

[3] Mantua, N, Tohver, Hamlet, A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for fresh water salmon habitat in Washington State. Climatic Change 102:187-223.

5. Summary of Vulnerability and Magnitude of Impacts

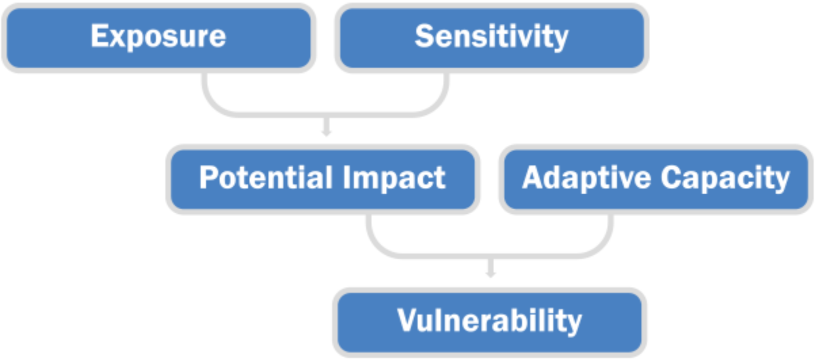
Vulnerability Assessment Summary

Table 5.2 summarizes the three components of vulnerability (exposure, sensitivity, and adaptive capacity) for each of the impacts described in this assessment and ranks them relative to each other. Table 5.1 describes the relative rankings for each component.

Table 5.1. Definition of vulnerability rankings for impacts caused by climate change

Component of Vulnerability	Rank	Description
Exposure (the expected change in the climate)	○	Projected change in the climate is small within the timeframe and unlikely to be distinguishable from historical variability.
	🟡	Projected change in the climate is moderate and more likely to be distinguished from historical variability.
	🔴	Projected change in the climate is significant and likely to be distinguishable from historical variability.
Sensitivity (the susceptibility of the system to the change)	○	Current conditions greatly reduce sensitivity to the expected change.
	🟡	Current conditions provide some buffer to the expected change.
	🔴	Current conditions are highly sensitive to the expected change if no action is taken.
Capacity to Adapt (current processes or procedures that provide capacity to adapt)	○	Existing capacity to prepare is high and can significantly reduce vulnerability.
	🟡	Some capacity exists that can be leveraged to reduce vulnerability.
	🔴	Limited capacity exists that can leveraged to reduce vulnerability, there is significant room for enhancing capacity.

Adaptation actions are designed to *reduce the sensitivity* of the utility to climate change impacts or *increase the utility's capacity to adapt* and prepare for the changes. In other words, the goal of implementing adaptation actions is to move sensitivity or adaptive capacity to green, making the utility less vulnerable and more prepared for impacts caused by climate change.



Exposure describes the change in the climate (or related natural hazard and hydrologic conditions) and cannot be directly affected by adaptation actions. Exposure does change (typically increasing) as climate change intensifies in the future with greater warming. Greater exposure can also increase the magnitude of the impacts to financial cost, reliability, safety, or environmental responsibility.

Potential Magnitude of Impact to Mission Objectives

Table 5.2 summarizes the potential magnitude of the impacts caused by climate change to Seattle City Light's mission objectives. The impacts are compared based on the effect they could have on each part of the mission: financial cost, safety, reliability, and environmental responsibility as described in the previous sections. This is a relative estimate based on current knowledge of potential impacts and could be refined with additional information from the assessments that are identified under the potential adaptation actions for each impact. The magnitude of the impacts described in Table 5.2 is the magnitude assuming no action is taken by the utility to adapt or prepare.

Table 5.2 can be used to prioritize adaptation actions and develop an implementation plan. Priorities will likely depend on several factors. It may be more important to prioritize impacts that have a high degree of exposure in the near-term. An alternative approach would be to prioritize impacts for which the magnitude could be high, yet the utility currently has limited capacity to adapt or prepare for that impact.

Timeframe of Impacts

As described throughout this document, the effects of climate change are expected to intensify over time, so the impacts to the utility are also expected to increase if no action is taken. Therefore the impacts are summarized for the projected changes in the climate that are expected for the 2030s (2020 – 2049) and the 2050s (2040 – 2069). For some of the thirteen impacts, there are significant differences in the exposure and magnitude of the impact based on different locations of the hydroelectric projects or different aspects of the system that would be affected. Therefore, these impacts are described separately. For example, hydroelectric projects in warmer, low elevation watersheds will experience changes in snowpack and streamflow sooner and to a greater extent than hydroelectric projects located in colder, high-elevation watersheds that receive more snow.

When considering adaptation actions in decisions that have long-term consequences (such as the design of infrastructure with long life-expectancies or hydropower licenses that last for decades) it is more important to consider the longer-term impacts projected for the 2050s in current designs and decisions in order to avoid the need for costly upgrades or modifications when the impacts become more apparent. For short-term planning or equipment that is replaced frequently, it may be sufficient to consider the more near-term impacts expected for the 2030s.

Table 5.2 Summary of vulnerability and potential magnitude of climate change impacts to Seattle City Light

Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability			Potential Magnitude** of Impact to				Ref. Pages
			Exposure	Sensitivity	Capacity to Adapt	Financial Cost	Safety	Reliability	Environmental Responsibility	
Coastal properties	1. Tidal flooding due to higher storm surge and sea level rise	2030	○	🟡	🔴	Low	–	–	Low	18-24
		2050	🟡			Mod	–	–	Low	
Transmission and distribution	2. Tidal flooding and salt water corrosion due to higher storm surge and sea level rise	2030	○	○	🟡	Low	–	Low	–	18-24
		2050	🟡			Low	–	Low	–	
	4. Reduced transmission capacity due to warmer temperatures	2030	🟡	○	○	Low	–	Low	–	34-39
		2050	🟡			Low	–	Low	–	
	5. More frequent outages and damage to transmission and distribution equipment due to changes in extreme weather**	2030	○	🟡	🟡	Low	Low	Low	–	40-46
		2050	○			Low	Low	Low	–	
	6. More damage and interruptions of transmission and generation due to wildfire risk	2030	🟡	🔴	🟡	High	High	Med	–	47-53
		2050	🔴			High	High	Med	–	
	7. More damage to transmission lines and access roads due to landslide risk	2030	🟡	🟡	🟡	Med	Low	Med	–	54-58
		2050	🟡			Med	Low	Med	–	
	9. More damage and reduced access to transmission lines due to more frequent river flooding and erosion	2030	🟡	🟡	🔴	Med	–	Low	–	71-74
		2050	🔴			High	–	Low	–	
Energy Demand	3a. Reduced electricity demand for heating in winter due to warmer temperatures	2030	🟡	🟡	🔴	Med	–	Low	–	25-33
		2050	🔴			High	–	Low	–	
	3b. Increased electricity demand for cooling in summer due to warmer temperatures	2030	○	○	🔴	Low	–	Low	–	25-33
		2050	🟡			Med	–	Med	–	

**The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.
*Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

Table 5.2 cont. Summary of vulnerability and potential magnitude of climate change impacts to Seattle City Light

Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability			Potential Magnitude** of Impact to				Ref. Pages
			Exposure	Sensitivity	Capacity to Adapt	Financial Cost	Safety	Reliability	Environmental Responsibility	
Hydroelectric Project Operations	8a. Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (snow-dominated watersheds)	2030	🟡	🔴	🟡	Low	—	—	Low	59-70
		2050	🔴			High	—	—	Med	
	8b. Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (mixed-rain-and-snow watersheds)	2030	🔴	🔴	🟡	Low	—	—	Med	59-70
		2050	🔴			Med	—	—	Med	
	10a. More frequent spilling at hydroelectric projects due to higher peak streamflows (snow-dominated watersheds)	2030	○	🟡	○	Low	—	—	Med	75-79
		2050	🟡			Low	—	—	Med	
	10b. More frequent spilling at hydroelectric projects due to higher peak streamflows (mixed-rain-and-snow watersheds)	2030	🟡	🟡	🟡	Low	—	—	Med	75-79
		2050	🔴			Med	—	—	Med	
	12a. Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (snow-dominated watersheds)	2030	🟡	🟡	🟡	Med	—	—	Low	83-87
		2050	🔴			High	—	—	Mod	
	12b. Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (mixed-rain-snow watersheds)	2030	🔴	🔴	🟡	Med	—	—	Med	83-87
		2050	🔴			High	—	—	Med	
Fish Habitat Restoration	11. Increased difficulty meeting objectives for restoring habitat for fish species due to lower low flows.	2030	🟡	🟡	🟡	Low	—	—	Med	88-90
		2050	🔴			Low	—	—	High	
	13. Increased difficulty meeting objectives for restoring habitat for fish species due to higher peak flows.	2030	🟡	🟡	🟡	Low	—	—	Med	80-82
		2050	🔴			Low	—	—	High	

**The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.
*Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

6. Conclusion: Information Gaps and Implementation

This vulnerability assessment and adaptation plan will be used to guide the implementation of adaptation actions throughout the utility, but the long-term goal of adaptation planning is to “mainstream” climate change thinking into existing operations policies, and decision-making processes. The objective of conducting a vulnerability assessment is to ask the climate change question: will there be impacts and are they likely enough and consequential enough to warrant intentional adaptation actions?

The answer to the question depends on the planning timeframe and the utility’s level of risk tolerance. As shown by the relative ranking, some impacts could require action sooner, whereas others impacts can be monitored and addressed as they emerge based on lower exposure in the near-term or lower sensitivity to the impacts if they occur. However, it is important to note that for decision-making to effectively account for the impacts of climate change, it requires a long-term planning horizon because it may be too late to implement some adaptation actions if the utility waits until the impacts emerge. This is particularly important for long-lived infrastructure, operating licenses, and long-term resource contracts (Figure 1.1).

Electric utilities are facing a highly uncertain future, and a changing climate is one consideration in designing the utility of the future. A second goal of this adaptation planning process is to increase institutional knowledge of climatic vulnerability and potential actions for reducing this vulnerability, so that employees can make informed decisions regarding the need to adapt. Ideally, this greater level of institutional capacity will lead to climate change becoming a regular consideration in decision-making processes.

Information Gaps

This Climate Change Vulnerability Assessment and Adaptation Plan is intended to be a living document. Completing this process has already revealed several important information gaps that will be addressed in future updates. The science of climate modeling and impacts assessment is rapidly evolving; it will continue to be important to support research on the impacts of climate change and evaluate the consequences of these impacts for City Light’s operations and infrastructure. Reviews of this assessment identified several information gaps that will be addressed in future updates.

Water Quality – An important impact not directly addressed in this assessment is the effects of climate change on water quality. Warmer water temperatures and lower streamflows in summer are likely to affect water quality, which could have consequences for the operation of hydroelectric projects, the protection of fish, and restoration of fish habitat. Furthermore, operational changes at hydroelectric projects implemented by the utility to adapt to lower streamflows could also have consequences for turbidity, water temperatures, and other aspects of water quality.

Safety – Throughout the assessment, the potential impacts of climate change on employee safety are mentioned for several impacts, including increasing wildfire risk and the impact of heavy precipitation and flooding on the safety of line workers during post-storm restoration. However, a more rigorous assessment of the potential effects of climate change on employee safety is warranted given the importance of safety to City Light's mission. Safety is a primary value at City Light and should be a driving force behind daily decisions.

Equity – The impacts of climate change are likely to disproportionally affect the low-income, elderly, and other vulnerable populations that have fewer resources to adapt to more frequent power outages or higher electricity rates associated with climate change impacts. As the consequences of climate change to the utility are assessed in more detail, it will be important to review potential adaptation actions through an equity lens. Equity is a focus of the city of Seattle's climate change adaptation plan, and City Light participates in the city's process of evaluating the disproportionate effects of climate change on vulnerable populations in Seattle. City Light recently initiated an environmental justice program that will be an important asset for evaluating the equitable implementation of adaptation actions by City Light.

Implementation

Many adaptation actions identified in this assessment can be implemented through existing policies, programs, or operations of the utility. Most of the adaptation actions are strategic approaches that will need to be refined in more detail to fit specific projects and decisions. Recommended steps for implementation are as follows:

- Establish an interdisciplinary team with representatives from all relevant divisions within the utility. Solicit further review and feedback on the feasibility and priority of the potential adaptation actions identified in this plan. The interdisciplinary team will further refine and prioritize adaptation actions based on the risk of the impacts and the risk tolerance of the utility.
- The interdisciplinary team will identify specific capital projects, long-term plans, or decisions in which the climate impacts identified in the vulnerability assessment could affect the project design or decision.
- Develop methods and processes for conducting cost-benefit analysis of changes in operations or infrastructure upgrades for hardening and increasing resilience to the impacts of climate change.
- Develop metrics for measuring the success of adaptation actions for reducing vulnerability, increasing resilience, and enhancing institutional capacity to manage a changing climate.
- Update this plan in 2018 to include: 1) additional research findings from internal or external studies on climate change impacts, 2) results of assessments to better understand the consequences of impacts to the utility, and 3) the benefits gained from implementing adaptation actions.

Appendix A. Research Funded by the Climate Research Initiative

Research Project Description	Partners	Expected Completion	Impacts Addressed
Regional climate modeling projections of changes in high winds and the atmospheric conditions that lead to convective storms and lightning in Western Washington for future climate change scenarios.	University of Washington Climate Impacts Group	February 2015	Impact 5
Glacier inventory and empirical estimates of historical glacier recession and associated changes in glacial runoff in the Skagit River watershed for hot, dry vs. cold, wet years.	North Cascades National Park	April 2015	Impact 12 Impact 13
Development of a glacier simulation model within a hydrologic model. The model will be used to simulate past and future changes in glacier volume and glacial runoff in the Thunder Creek tributary to Diablo reservoir.	University of Washington Civil and Environmental Engineering	March 2015	Impact 12 Impact 13
Multiple simulations of future streamflow in the Skagit river watershed using the most recent down-scaled meteorological data from 10 global climate models and two scenarios for future GHG emissions. Modelling will provide a range of future changes in streamflow that can be used as input to the Skagit reservoir model to assess the impacts on project operations for multiple objectives.	Skagit Climate Science Consortium, University of Washington Civil and Environmental Engineering	December 2016	Impact 8 Impact 10 Impact 11 Impact 12 Impact 13