Appendix 11

CLIMATE CHANGE

INTRODUCTION

The purpose of this appendix is to provide a summary of previous analyses of potential impacts of climate change on City Light operations and lay the foundation for examining adaptation strategies. The objectives are to assess how changes in regional temperature, precipitation, and hydrology patterns affect:

1. Electricity generation at the Skagit Hydroelectric Project on the Skagit River and the Boundary Project on the Pend Oreille River,
2. Electricity distribution, and
3. Future demand.

This appendix briefly summarizes the information presented in the 2010 IRP and incorporates newly published information relevant to climate change effects. While the 2010 IRP analyzed extensive studies by the Northwest Power Conservation Council (NPCC), and the University of Washington's Climate Impact Group (CIG) and modeled City Light hydroelectric project operations under climate change scenarios, there were information gaps identified that we continue to work to address. Therefore, this appendix includes discussion of:

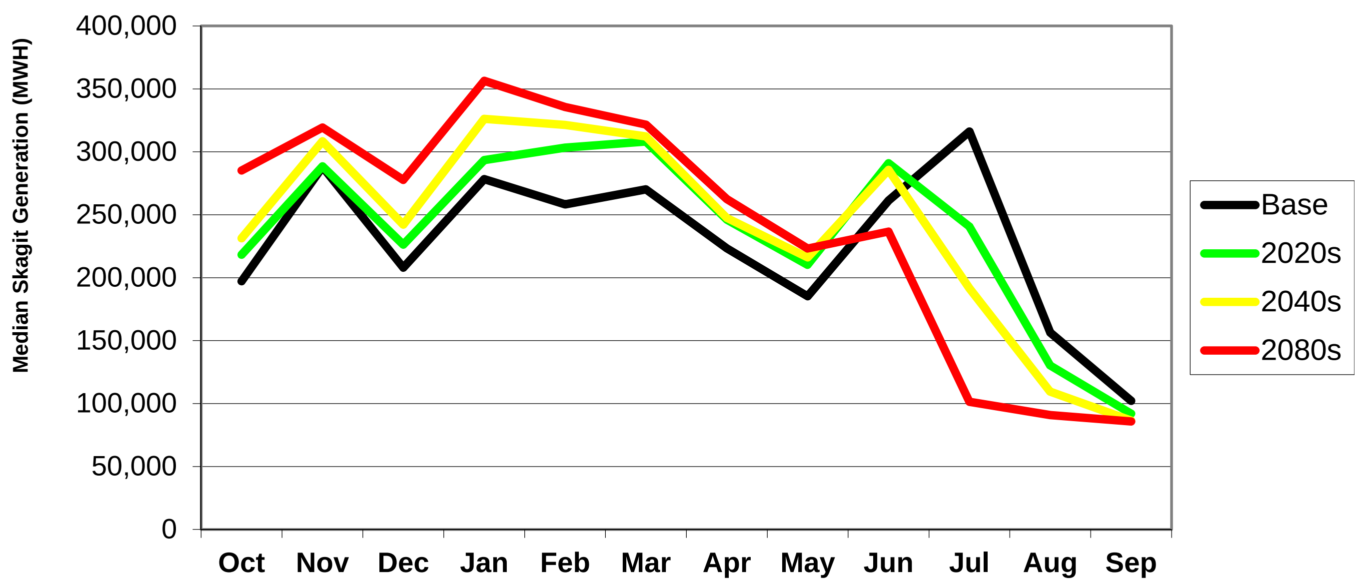
1. Projected temperature impacts on electricity demand;
2. Recent research on extreme precipitation;
3. New information on glacier, snowpack, and hydrology in the Skagit basin; and
4. Recent projections of sea level rise.

Readers are referred to the 2010 IRP Appendix L for more detail on previous analysis.

It is important to note that the graphs and tabular information presented in this appendix represent model output that are projections, not forecasts. Actual future conditions will likely vary from the averages presented here. Numerous sources of uncertainty are inherent in the complex modeling, so the models should not be viewed as predictive, but rather as a relative measure of deviation from past conditions. In many cases, strong annual and decadal cycles in weather patterns will continue to be a major factor driving short-term weather patterns.

Figure 1: Effect of Climate Change on Skagit Generation

Model Ensemble Median Values



SUMMARY OF 2010 IRP CLIMATE CHANGE INFORMATION

The main findings of the climate change analysis presented in the 2010 IRP are the following:

- During the 21st century, climate change is likely to result in changes to Skagit Hydroelectric Project inflows and result in operational modifications to maximize generation and meet recreation, fisheries, and flood control obligations. Over the short-term, operational changes will not be noticeable and within the ranges of normal variability experienced at the project. However, in the long-term, operational adaptation will likely include less winter reservoir drawdown and changes in seasonal water release patterns.

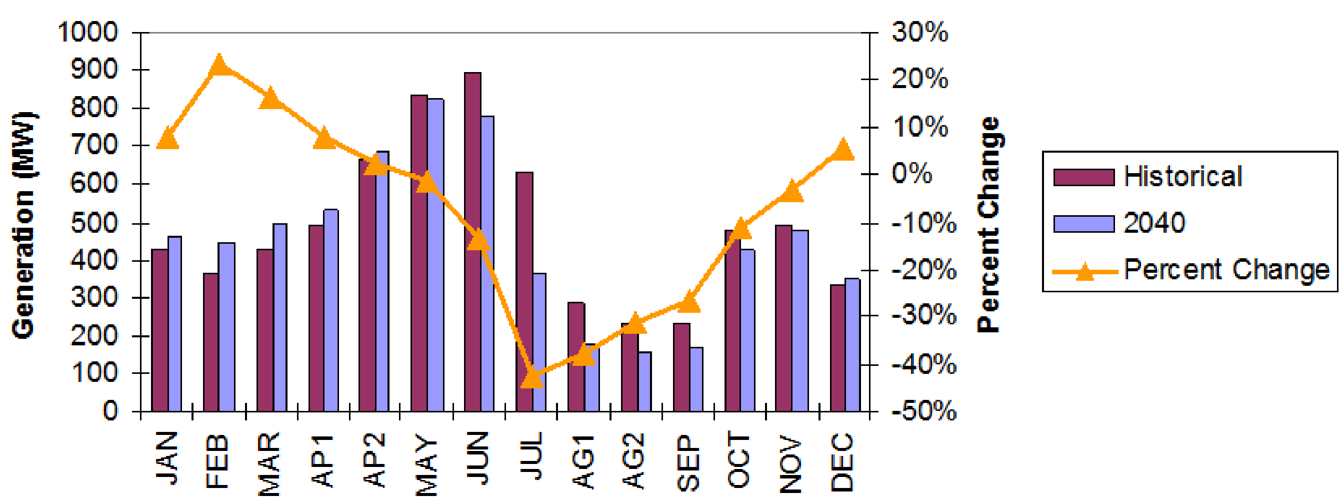
- With future climate change, the estimated median annual generation for the Skagit Project is projected to increase by approximately three percent under the climate of the 2020s, five percent by the 2040s, and nine percent by the 2080s. In general, more precipitation and runoff during the fall and winter under future climatic conditions may make it possible to achieve approximately 20 percent increases in Skagit generation during the typical peak demand period (Figure 1). However, because more precipitation is projected to fall as rain rather than snow and because of the high degree of uncertainty about frequency and intensity of storms, it is also possible that more water might be spilled, reducing generation.

- Under the 2040s climate, optimized operation of the Skagit Project will require an average of 40 feet less drawdown of Ross Reservoir during the fall-spring time period to ensure refill by July.

- Generation at Boundary is dependent on upstream operations and is more difficult to project under future climate conditions. Current modeling indicates that annual Boundary generation would decline by approximately seven percent under the 2040s climate. There will be substantial declines in June-September, with July and August being most severe in the projections (Figure 2). This decline will be partially offset by moderate generation increases in January-April.

Figure 2: Comparison of Boundary Project Generation Under Historical and 2040 Simulated Climate Conditions

Emission Scenario A1B Model Ensemble Average



Source: NPCC unpublished data

- In addition to the uncertainty inherent in climate model projections, there remain major issues that must be better understood for long-term operational adaptation. If the relative snowpack and glacier contribution decrease significantly, electricity generation could be impacted more than currently estimated. Reduced glacial input in the Skagit watershed could also increase water temperatures and impact our ability to protect fisheries resources downstream of the dams. There is also the possibility that in the future, the Federal Energy Regulatory Commission (FERC) and state and federal fisheries regulatory agencies could mandate different flows for fish protection, which would affect the project operation optimization. Also, there is a possibility of the Army Corps of Engineers changing flood control management because peak flows in the lower Skagit Valley are anticipated to dramatically increase.

DEMAND

The amount of electricity used in the City Light service area is sensitive to the local weather. In this section we investigate changes in the observed weather, the future weather changes projected by climate modeling, and the impact of these changes on load.

Electric load is usually forecasted assuming normal weather conditions. For short- and long-term planning purposes, actual electric load values are often converted to the weather-adjusted load, the expected amount of load had the weather been normal. These weather-adjusted load values and forecasts are sensitive to the definition of normal weather. City Light adjusts the load values to reflect normal weather using a weather adjustment. This weather adjustment is based on the average daily temperature, percent sunshine, average wind speed, and hours of darkness on each day. Using the weather adjustment relationship we can calculate the difference in load when the normal temperatures shift. The rate of electricity use increases non-linearly as temperatures decrease below about 65° F because more electricity is needed to heat buildings to room temperature during colder weather. The rate of electricity use also increases as air temperatures exceed about 65° F to cool buildings. City Light peak loads are associated with cold weather in the winter months. In Seattle, changes in temperature cause larger changes in load in the winter than in the summer.

The World Meteorological Organization recommends computing 30-year averages of meteorological station data, known as climate normals. In 2011, the 30-year normal from 1981- 2010 became available from the National Climatic Data Center. The previous normal was from the period 1971-2000. The observations from the weather station at Sea-Tac airport are used to describe the weather conditions in the City Light service area. The observed average annual temperature was 0.3° F warmer in the 1981-2010 period than during the 1971-2000 period, indicating the decade from 2001-2010 was warmer than the decade from 1971-1980 at Sea-Tac. These decades are 30 years apart and the temperature increase of 0.3° F is consistent with a temperature trend of 0.1° F per decade. In terms of monthly data, the average temperature increased at least one half degree Fahrenheit in January, July and August. The daily minimum temperature increased more than one degree Fahrenheit in January. The daily maximum temperature increased at least one half degree Fahrenheit in January, March, July and August. The above changes result in load changes of less than two aMW in the May-September period. These months have average temperatures more than 55° F, and the load is not as sensitive to temperature when the temperatures are close to room temperature. The 1.2° degree F increase in January decreases the load projection by 18 aMW. The 0.7° degree F increase in August doesn't impact the load, since the average temperature is close to room temperature. The load decrease on average from November-April is four aMW per month. On average, the load decreases two aMW due to the changes in climate normal temperatures. The detailed values for each month are found in Table 1. Figure 3 shows the monthly average temperatures for each set of climate normals.

Global climate models provide the main guidance in assessing future climate impacts, but these models cannot adequately simulate the weather, terrain, and land-surface processes that produce local extremes of temperature. Therefore, City Light contracted the University of Washington's Climate Impacts Group to use regional climate model simulations to provide more realistic simulations of extreme events under future climate change scenarios. (CIG 2010)

The simulations use the Weather Research and Forecasting (WRF) model using boundary conditions from 1.) the Max Plank Institute, Hamburg, global model (ECHAM) and 2.) the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM3). (CIG 2010)

The WRF model is run at a grid spacing that resolves the important mountain ranges of the state of Washington (grid cells are 36 km and 20 km on a side for the ECHAM and CCSM3 simulations, respectively).

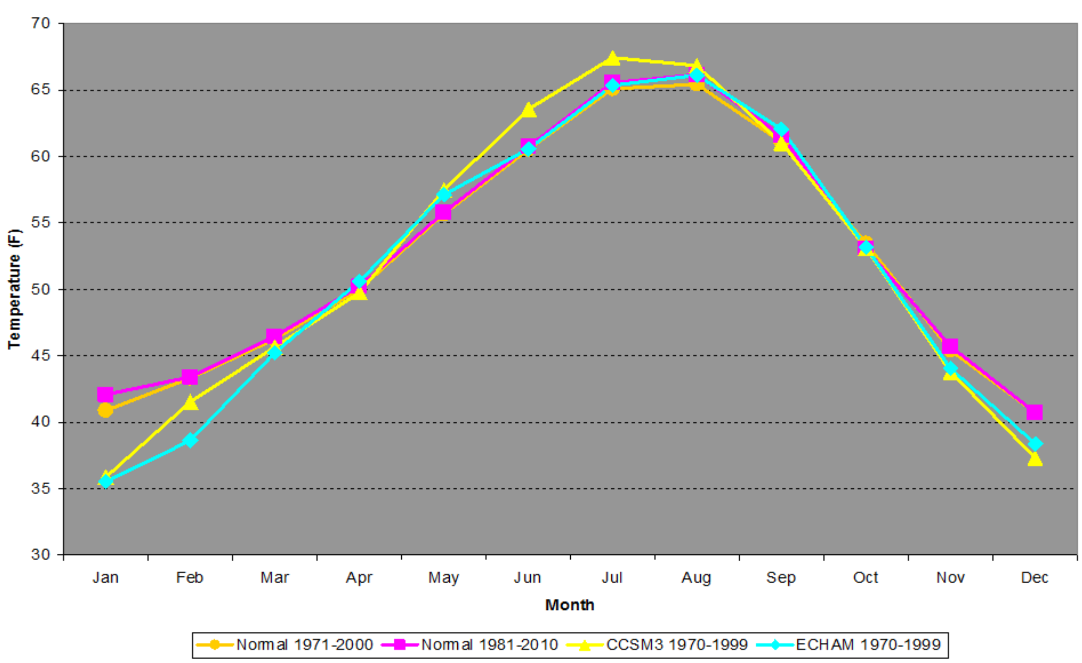
Table 1: Average temperatures, Temperature Differences and Load Impacts

	Observed Climate Normals				Climate Change Model (CCSM3)				Climate Change Model (ECHAM)			
Month	1971-2000[1]	1981-2010[1]	Temp Diff.	Impact on Load	1970-1999[2]	2020-2049[2]	Temp Diff	Impact on Load	1970-1999[3]	2030-2059[3]	Temp Diff.	Impact on Load
Jan	40.9	42.1	1.2	-17.9	35.8	39.1	3.3	-43.6	35.5	38.0	2.4	-32.6
Feb	43.3	43.4	0.1	-1.3	41.5	43.0	1.5	-18.7	38.6	40.9	2.3	-26.6
Mar	46.2	46.4	0.2	-2.9	45.7	47.6	2.0	-20.0	45.2	46.8	1.5	-16.1
Apr	50.0	50.2	0.2	-3.4	49.7	52.0	2.3	-17.9	50.6	52.9	2.3	-18.9
May	55.7	55.8	0.1	-1.2	57.5	59.2	1.7	-6.3	57.1	59.3	2.1	-8.3
Jun	60.6	60.7	0.2	-0.5	63.6	67.8	4.2	-0.7	60.6	63.6	3.1	-2.3
Jul	65.1	65.6	0.5	0.6	67.4	71.3	3.9	8.0	65.4	67.6	2.3	3.5
Aug	65.5	66.2	0.7	0.0	66.8	71.3	4.5	6.2	66.1	68.3	2.2	1.2
Sep	61.1	61.5	0.4	-0.2	61.0	64.0	3.0	-5.2	62.1	64.7	2.6	-5.4
Oct	53.4	53.0	-0.4	5.1	53.1	53.9	0.7	-5.4	53.2	55.9	2.7	-19.8
Nov	45.4	45.7	0.3	-0.6	43.8	46.9	3.1	-34.3	44.0	47.5	3.4	-38.7
Dec	40.7	40.7	0.0	1.1	37.3	39.1	1.8	-23.8	38.4	41.3	3.0	-39.3
Total	52.3	52.6	0.3	-1.8	51.9	54.6	2.7	-13.47	51.4	53.9	2.5	-16.9
Summer total	60.2	60.5	0.3	0.6	61.6	64.6	3.0	-0.6	60.7	63.2	2.5	-5.2
Winter total	44.4	44.7	0.3	-4.17	42.3	44.6	2.3	-26.4	42.1	44.6	2.5	-28.7

1. National Climatic Data Center: http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html
2. University of Washington Climate Impacts Group, 2010
3. University of Washington Climate Impacts Group, 2010

ADDITIONAL NOTES: *Temperature values are in degrees Fahrenheit and load impacts are given in average megawatts. Summer is the months May to October and winter is the months November to April*

Figure 3. Monthly Average Temperatures
(climate normals from historical data at Sea-Tac Airport, and modeled simulations from ECHAM and CCSM3 regional climate models)



The performance of both global climate models in simulating the climate of the north Pacific region is highly ranked among the full set of IPCC models; the El Niño cycle, in particular, is well represented by ECHAM. The simulations span the 100 year period from 1970 to 2069. The historic period (1970-1999) simulation is based on observed greenhouse gas forcing. Projected greenhouse gas and aerosol emissions scenarios are used for the future period (2000-2069). For the ECHAM simulation, the A1B scenario is used; for the CCSM3 simulation, the A2 scenario is used. Both scenarios project rapid greenhouse gas emissions over the early 21st century, with insignificant differences between the two until the 2050s. The A1B scenario projects stabilization of emissions in the late 21st century while the A2 scenario projects accelerated emissions.

Hourly data for several parameters was archived from the regional climate model simulations and is suitable for understanding the daily evolution of the climate. The results from both the ECHAM and CCSM3 simulations for the grid cells containing Seattle, WA, (47.62N, 122.33W) were extracted from the simulations for present and future climate periods.

Figure 3 shows the monthly average temperatures for the normal periods 1971-2000, 1981-2010, and the 1970-1999 periods for the ECHAM and CCSM3 simulations. There is a known cold bias in the WRF model which is responsible for the colder winter temperatures in the models. This will also impact the temperature sensitivity to load. The load is more sensitive to temperature at colder temperatures.

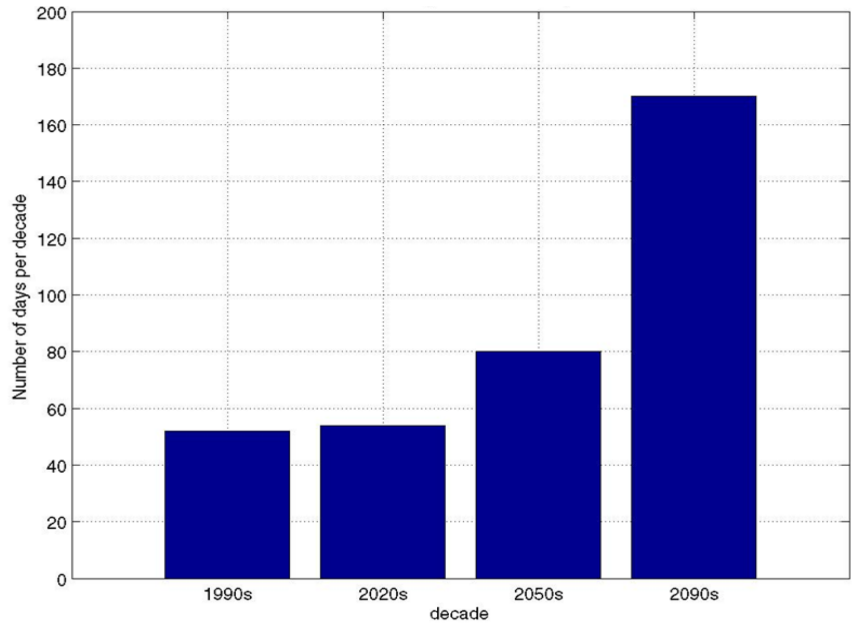
In assessing impacts of future climate change, the CCSM3 and ECHAM models project average annual temperatures in the 2020-2060 period that are 2.7° and 2.5° degrees F, respectively, above the 1970-1999 period. However, temperature increases would cause varying responses in City Light load depending on season. The average impact on the load between May and October is projected to be -2.8 aMW using these two models (-0.6 aMW for CCSM3 and -5.2 aMW for ECHAM), with July and August loads showing a small increase in load and the other months in this time period decreasing slightly (Table 1). From November to April the load is projected to decrease on average 27.6 aMW per month (26.4 aMW under CCSM3 and 28.7 aMW under ECHAM model). The winter load impact is about half of the annual average load impact. The summer load impact is much smaller than the winter load impact.

The winter load sensitivities to temperature differences in Table 1 are all equivalent to about a 0.6 aMW annual load decrease when the winter temperature increases 0.1° F. The long term observed average temperature change for Seattle is about 0.1° F per decade. This translates to about a 0.6 aMW decrease in the annual load in a decade. The City Light average annual load is about 1100 aMW, and the long term load growth rate is about 0.6 percent. The load is forecasted to grow about 66 aMW in a decade due to long term growth. This temperature effect would decrease the growth 0.6 MW, to about 65 aMW. These increasing temperature impacts on load are not significant. The changing climate has a proportionally larger change on City Light's generation facilities, than on the City Light average annual load.

The load is sensitive to many other factors in addition to the weather. It may be that future sensitivity of load to changes in temperature changes may be less than in the past because the residential sector proportion of City Light service area load is decreasing and the industrial and commercial sectors are not as sensitive to weather as the residential sector. Also the residential sector is becoming less sensitive to temperature due to the increasing efficiency of homes, and the trend towards increasing numbers of multi-family homes. This sensitivity reduction would further decrease the impact of temperature changes on load. Mass et al. (2008) modeled Sea-Tac future temperatures under climate change using the ECHAM global simulation and an earlier version of the WRF regional climate model and reported that the projected number of days with temperatures above 90° F will not change much between now and the 2020s but that by the 2050s and especially during the latter part of the century, the frequency of hot days will increase greatly (Figure 4).

The summer peak loads, associated with warm temperatures, have been increasing over time at about the same rate that the average annual load has been growing (six to nine aMW per year). As an example of how summer peak events can affect peak load, Figure 5 shows City Light load on July 29th, 2009, the day the record temperature at Sea-Tac was recorded in comparison with more typical temperatures. The average load on July 29th, 2009 was 1280 MW; July 22nd and August 5th, the previous and subsequent Wednesdays, both have average loads less than 1100 MW. The amount and efficiency of air conditioning affects the load response to extreme warm temperatures. Recent trends in peak loads suggest that summer peak loads are increasing faster than winter peak loads. The peak load for the months April, June, July, August and September occurred in the last five years.

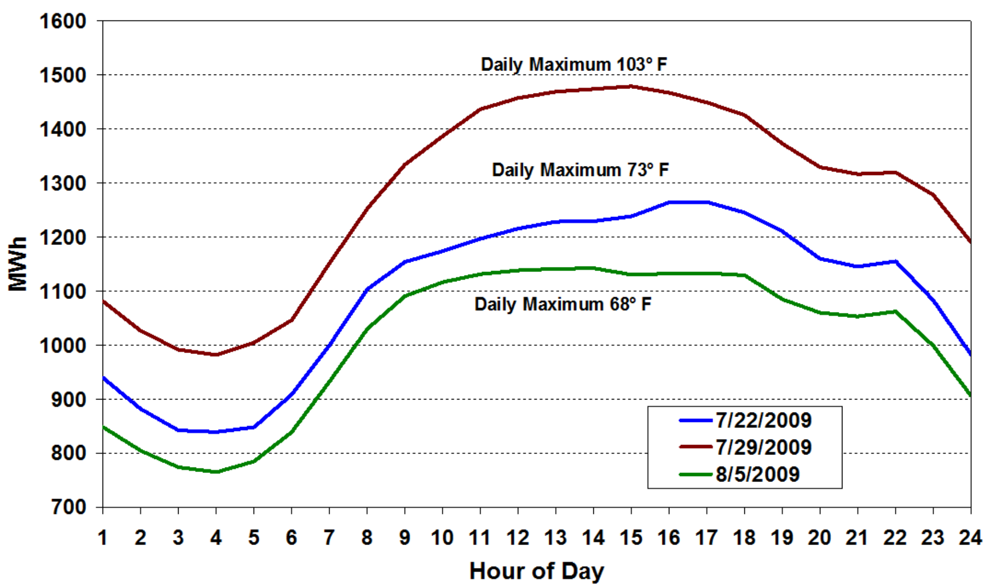
Figure 4: Number of Summertime Days With Maximum Temperature Greater than 90° F in ECHAM5-MM5 regional simulations for four different decades.



Source: Mass et al.,2008

Figure 5: City Light Load on July 29th, on July 22nd, and August 5th, 2009.

Temperature at Sea-Tac reached 103, the highest on record, on July 29th.



EXTREME PRECIPITATION

In this section recent research pertaining to heavy precipitation events in Washington is summarized.

Atmospheric River (AR) events (sometimes called the "Pineapple Express") are associated with a deep upper-level trough in the central Pacific Ocean, a plume of anomalously high amounts of integrated water vapor stretching from the tropics to the west coast of North America, and unseasonably warm temperatures (Neiman et al. 2008, Warner et al. 2012).

The heavy precipitation of these events affect the Skagit River watershed during the late-fall and winter when, upon landfall, the high water vapor content interacts with complex terrain and existing winter conditions of the coastal mountain ranges. These storm events result in very high peak flows and often cause City Light to spill water at the Skagit River project.

Over the past several decades, there has been a clear trend toward increased heavy precipitation in Washington (Duliere et al. 2010; Mass et al. 2011). According to daily station precipitation (two-day events) and unregulated river streamflow, during the past 60 years there has been a substantial increase in major precipitation events over Washington. The increasing trend in unregulated streamflow has been documented in USGS data for the Sauk River in the Skagit River watershed over the last 60 years (Schick, 2009). Nevertheless, positive trends are far from universal, and there is considerable uncertainty whether local changes are related to global climate change and will persist over the next few decades. In fact, natural variability is likely to continue to be a primary driver of local changes in the near term.

Recent studies have documented the important role that ‘‘atmospheric rivers’’ of concentrated near-surface water vapor above the Pacific Ocean play in the storms and floods in Washington and specifically on the Skagit River (Warner et al. 2012; Schick 2009). By delivering large masses of warm, moist air (sometimes directly from the tropics), ARs establish conditions for the kinds of high snowlines and copious orographic rainfall that have caused the largest historical storms. Atmospheric conditions associated with major storms and floods in Washington, in particular “pineapple express” or AR storms, were assessed in the context of recent projections of 21st Century climate change. Generally climate models with increasing greenhouse gas emissions scenarios show inconsistent responses in total precipitation across models and the region, and a robust increase in rainy days.

Climate models project an increased risk for more frequent extreme precipitation in the Northwest by the second half of the 21st century (Salathé 2006; Tebaldi et al. 2006).

Furthermore, the peak season within which most ARs occur is commonly projected to lengthen, extending the flood-hazard season (Dettinger 2012). There are strong theoretical reasons to expect increases in heavy precipitation in a warming climate, since warmer air will be able to transport more water vapor into storm systems, making it available for precipitation in extreme events and would tend to increase the intensity of both wet and dry extremes. However, on average, changes in the large-scale circulation associated with climate variability (e.g. El Niño, Pacific Decadal Oscillation) control the total annual precipitation. These circulation changes are less consistent across the various models, which suggests they are less closely controlled by anthropogenic climate change and will likely continue as in the past, yielding little change in annual total precipitation.

Thus, over the next few decades there are several climatic processes that could increase the frequency or intensity of extreme hydrologic events, with a range of uncertainty and potential impacts. More extreme storms and a longer storm season could cause very high peak flows and more spilled water at the Skagit River project.

GLACIERS

As City Light documented in Appendix N of the 2010 IRP, an important consideration that cannot yet be fully-incorporated into the analysis of climate change impacts on hydroelectricity generation and adaptation is the consequence of melting glaciers in the Skagit River watershed. Many glaciers in the North Cascades have already disappeared and most of the remaining glaciers are receding and thinning, with total glacier loss estimated to be approximately 50 percent in the last 100 years. A recent report by the National Park Service (NPS) in the North Cascades National Park which surrounds the Skagit Hydroelectric Project (Reidel 2011) reported that glaciers provided about 44 percent of total summer runoff in 2009 in the Thunder Creek drainage - a major tributary to Diablo Reservoir, whereas in the Ross Lake basin which has many fewer glaciers, the glacial contribution was about seven percent. The NPS also reported that between 1993 and 2009, the average annual melt rate for monitored glaciers had increased by about 10 percent. The high rates of summer melt have led to significant glacial contribution to streamflow. A concern going forward is that as glaciers disappear, glacier-dependent tributaries feeding City Light’s hydroelectric project and those that provide important salmonid habitat will experience significant declines in summer flows.

Not only will flows be reduced but without the contribution of melting ice, the water will be warmer, with potential important consequences for fish. Additional glaciological information is being collected by the NPS and other researchers and will be incorporated into future assessments. Improved modeling of glaciers and tributary hydrology is needed to refine our assessment of climate change impacts on hydrology of the Skagit River over the next century.

SEA LEVEL RISE

Sea level rise (SLR) is a concern to City Light due to risk of inundation of low-lying areas and increased shoreline erosion that can affect electrical distribution infrastructure (towers, underground vaults, etc.). During the 20th century, global sea levels increased at an average rate of 1.74 mm (0.07 inches) per year (Holgate 2007). At Seattle, the mean sea level increased 2.06 mm (0.08 inches) per year between 1898 and 2006 (Zervas 2009). Sea level along the Pacific coast is expected to continue to increase throughout the 21st century due to climate change because ocean water expands as it warms and water from melting glaciers and ice sheets in Greenland and Antarctica is flowing into the ocean. Seasonal changes in atmospheric circulation in the Pacific, and vertical land deformation (subsidence) also affect the Pacific coast sea level. Mote et al. (2008) estimated that under low, moderate, and high greenhouse gas emission scenarios sea-levels in the Puget Sound region would rise three, six and 22 inches by 2050, respectively, and six, 13, and 50 inches by 2100. A more recent report released by the National Academy of Science "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future" (NAS 2012) projects average Seattle sea level rise (SLR) of 16.6 cm (6.5 inches) with a standard deviation 10.5 cm (4.1 inches) in 2050 and 61.8 cm (24.3 inches) average SLR in 2100 with a standard deviation of 29.3 cm (11.5 inches). However, other studies have indicated that global SLR could be 29-75 inches by the end of the century if ice sheets melt more quickly (Vermeer and Rahmstorf 2009).

SLR impacts are further compounded by El Niño events that affect winds and ocean circulation, resulting in temporary local surges of 10 to 30 cm (3.9 to 11.8 inches) (NAS 2012). Large storms can raise coastal sea level for several hours and are particularly problematic when they coincide with extremely high tides, which can result in localized water levels that are up to 38 inches above the normal higher high water. This estimate is based on the highest observed water level recorded in Seattle (Coleman Dock NOAA gage) that occurred on January 27, 1983 (Zervas 2005). Thus, an episodic event in the late 21st century could result in water levels that are 88 inches above the current normal sea level.

FUTURE EFFORTS

The following future efforts will be the focus for improving our understanding of climate change impacts to City Light operations.

Sea Level Rise

City Light needs to incorporate climate change induced impacts on SLR into capital project planning and assessment management to inform decisions on proper citing and design of facilities (e.g., transmission and distribution assets such as towers and underground vaults) in areas susceptible to SLR impacts. City Light is coordinating with Seattle Public Utilities and the City of Seattle Office of Sustainability and Environment to assess SLR adaptation strategies.

Skagit Fisheries Downstream of Newhalem

Operation of the Skagit River Hydroelectric Project includes significant measures to provide spawning and rearing habitat in the Skagit River for salmon, steelhead, and bull trout. As climate conditions change, City Light will need to adapt operations to maximize generation while still protecting fisheries. City Light will continue to research the relationships between hydrology and fisheries populations, reproduction, and survival and will incorporate that information into long-term operational planning. Data from ongoing monitoring of salmonid populations will be used to evaluate flow management options for meeting life cycle requirements. In particular, it will be very important to gain more information on the hydrology of tributaries between Newhalem and Marblemount. City Light is participating with researchers in the Skagit Climate Science Consortium (http://www.skagitclimatescience.org/) to evaluate ecological impacts of climate change and identify ways to protect salmonid habitat.

Climate and Operational Model Improvements

City Light will monitor the continuing evolution of climate science models that may improve resolution and reduce uncertainty of future climate change projections. New climate models will attempt to incorporate decadal prediction simulations that may help evaluate the interaction between long-term climate changes and the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) climatic cycles that play such a major role in snowpack in the North Cascades. The Intergovernmental Panel on Climate

Change (IPCC) will be releasing new climate change modeling output data in fall 2012 and will publish the Fifth Assessment Report in fall of 2013. It is important that project operations be flexible to hourly, daily, monthly, and yearly electricity demands under future climatic conditions.

To test assumptions and operational options, and improve the assessment of risk and adaptation, City Light plans to evaluate making the following refinements:

- Incorporate the new IPCC climate change projections downscaled for Skagit watershed;
- Ability to use daily data to assess episodic floods and summer low-flow conditions; and
- Incorporate glacier runoff and salmon protection elements into the model.

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