Appendix G – Climate Change in the 2008 IRP

While much climate change research to-date has focused on global impacts, the 2008 Integrated Resource Plan (IRP) contains a preliminary analysis of potential climate change impacts on Pacific Northwest hydro operations. New research efforts to analyze climate change impacts on the region include work at the University of Washington's Climate Impacts Group (CIG) to combine the latest versions of global climate models with new regional models and detailed sophisticated local watershed models. Results of this new work were not available for the 2008 IRP but are expected to be for later IRPs.

Using 2004 estimates of climate change impacts from the CIG and the Northwest Power and Conservation Council (NPCC), City Light examined potential effects on its hydro system and power purchase agreements with other hydroelectric generators, most notably the Bonneville Power Administration. How warming temperatures affect electricity demand was also evaluated. With limited downscaling data available at this time, predicting the full financial impacts of climate change on City Light's hydro system was not possible. Important information gaps in existing research were identified during analysis, however, and will guide future efforts to more fully understand climate change impacts on City Light operations. Work continues with the CIG and other climate change researchers to examine these questions. Future integrated resource plans will likely have better information available at the watershed level.

Climate change is expected to alter both the seasonal demand for power and its availability. Temperatures have been increasing, and this trend will continue. Greater warming is forecasted for the summer months. Evidence regarding changes in precipitation has yet to lead to any firm conclusions.

Climate change modeling in the 2008 IRP is based on work done by the Northwest Power and Conservation Council (NPCC) and the University of Washington (UW) for the NPCC's Fifth Power Plan (2005). The UW modeled changes in flows associated with climate change for the 2020s and the 2040s, and the NPCC converted those changes in flows to changes in generation capability. The UW/NPCC work focused primarily on the Columbia River System, but also included Skagit watershed dams. City Light obtained data from the NPCC.

Results are derived from models of future global climate patterns, downscaled so that results can be incorporated into watershed models. Global models have been growing in sophistication by incorporating more climate-related processes with a smaller scale of resolution at the local level. Large uncertainties remain even in present-day models, however, such as the rate of melting of land-based ice, ocean processes, atmospheric water vapor and cloud formation, and the future amount of anthropogenic greenhouse gases. Model results differ, especially with regard to a particular region. Additional downscaling and bias-correction is needed to apply to a watershed, along with additional data collection - with associated difficulties of data availability - and the need to use averages in diverse geographic areas. Each step of the way introduces additional uncertainty.

Warming is expected to alter the timing of hydroelectric generation both on the federal Columbia River power system and on the City Light system. Increasing temperatures will cause more winter precipitation to fall as rain rather than snow, causing runoff to occur earlier rather than be stored in the snow-pack until spring. The results will be more water available in the winter and an earlier, smaller spring runoff.

Four major uncertainties are associated with the analysis of changes and implications for this IRP. These uncertainties render the climate change scenario inappropriate to make precise differentiations between candidate resource portfolios in the 2008 IRP.

1. There is considerable concern over the possibility that climate change will cause - or is already causing – greater variability in weather and increased magnitude and frequency of storms, which can also affect hydro

management practices and resource adequacy needs. We were not able to incorporate analysis of storm patterns into this IRP.

2. As glaciers melt, they initially contribute more summer flows and buffer the impact of warming on water temperatures throughout the summer. As the glaciers become progressively smaller, flows from the glaciers will eventually decline. The glaciers that contribute to the Skagit flows are sufficiently high in elevation that they are not expected to completely disappear for some time. More work on glacial modeling and integration of glacial modeling with watershed models needs to be done to determine consequences for the Skagit over the next century, and the consequence of melting glaciers has not been included in this year's analysis.
3. The melting of North Cascades glaciers and warmer ambient air temperatures are both expected to affect average water temperatures in the Skagit River. Relatively small changes in water temperature can have significant consequences for bull trout and salmon populations. In turn, this may affect regulations for the operation of City Light's hydro projects on the Skagit River. These potential impacts could not be modeled for the 2008 IRP.
4. The Skagit watershed presents special challenges in modeling because of the mountainous terrain, which causes rain shadows, variability in the timing of snowmelt by elevation, and the challenge of integrating glacier models. It has not been possible to do this modeling for this IRP. The ability of climate models to forecast at regional levels and the ability to integrate regional forecasts with more detailed watershed models is advancing, and City Light hopes to have better information available for the next IRP.

Impacts to the Boundary and Skagit Hydro Projects

For the climate change scenario, City Light used estimates of how climate change would affect generation at the Skagit and Boundary. Graphs represent averages. It is the nature of modeling that actual results can differ from model outcomes, and also the nature of climate that a given climate incorporates substantial annual variation.

Boundary

Boundary, City Light's largest source of power, is located on the Pend Oreille River, a tributary on the Columbia River system. Water flowing into the Boundary project comes from other dams and powerhouses upstream, and the water leaving Boundary goes to dams and powerhouses downstream. Climate effects on Boundary cannot be analyzed in isolation from the other Columbia River system projects.

The University of Washington (UW) Climate Impacts Group (CIG) is currently preparing a new analysis of the Columbia River system with changed climate. This analysis was not completed in time for this IRP, and we have used results of analysis conducted in 2004 for the Northwest Power and Conservation Council (NPCC) for their Fifth Power Plan. The UW determined how climate would affect flows, and the NPCC translated changes in flows into changes in generation at each of the dams on the Columbia River system. The historical period used for the analysis was 1930-1978.

The results for Boundary are shown in the two graphs below. These preliminary findings do not take the place of further analysis that may be required in the context of federal relicensing of the Boundary project.

Figure 1: Boundary Generation with Changed Climate (aMW)

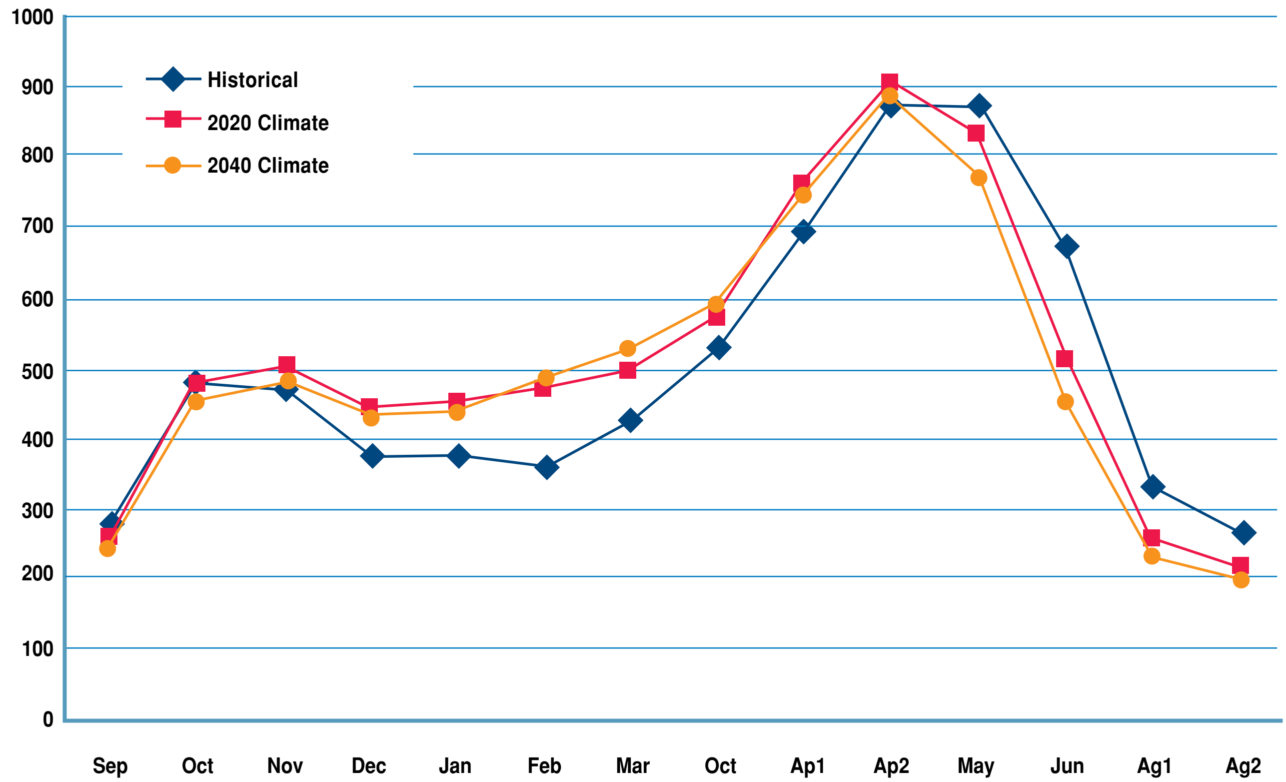
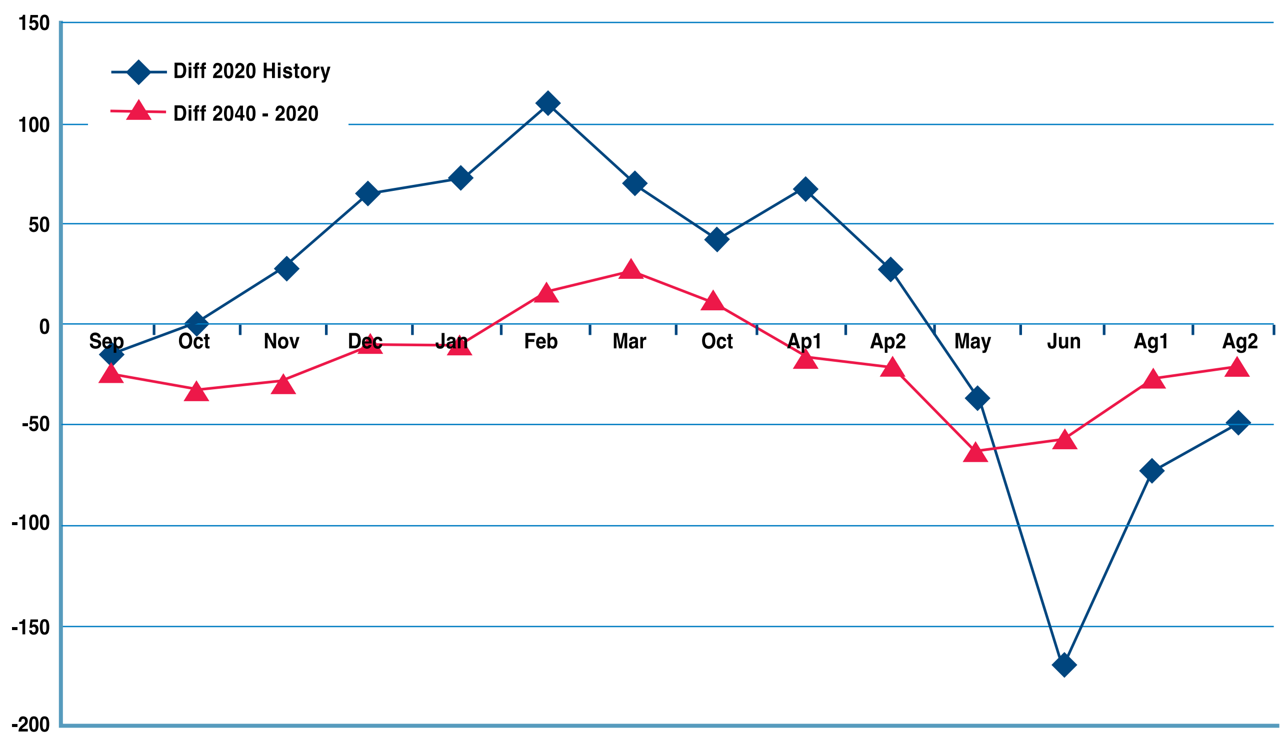


Figure 2: Changes to Boundary Generation with Changed Climate (aMW)

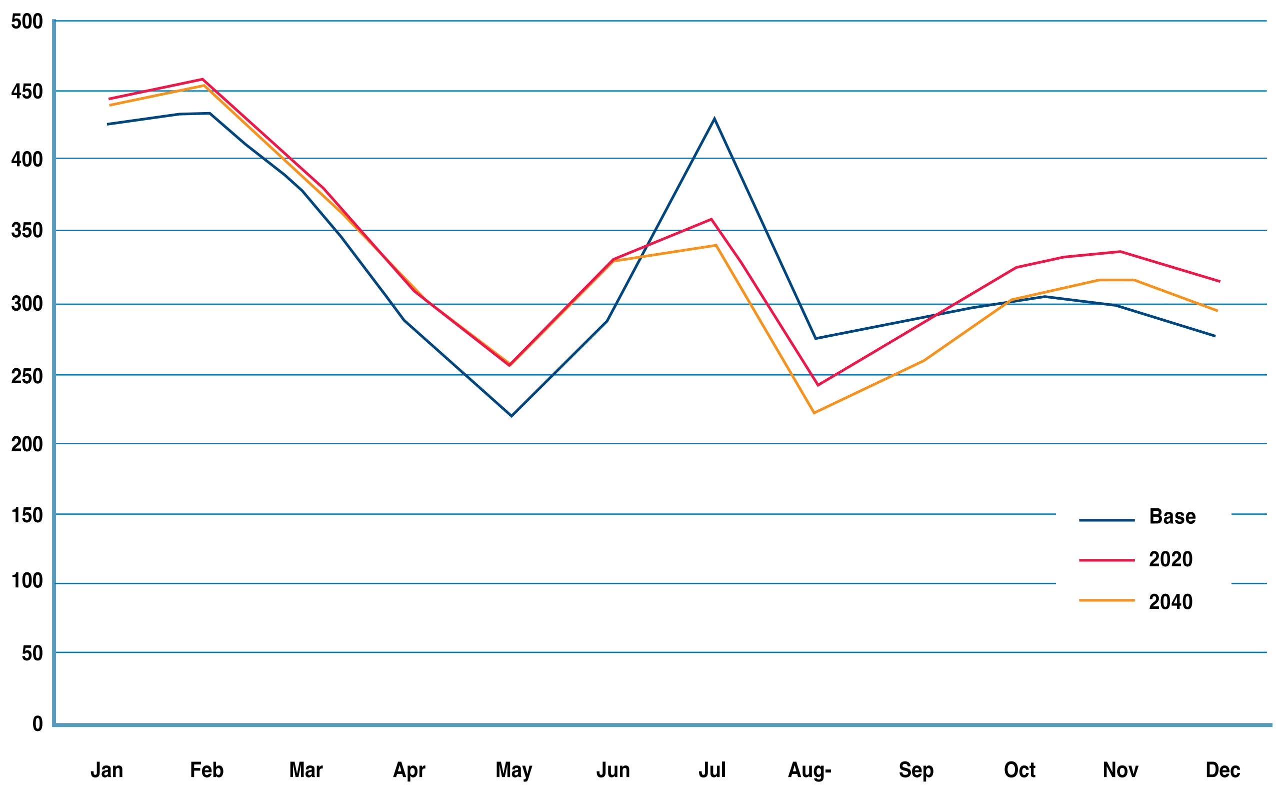


The effects of climate appear to be more dramatic before 2020 than 2020-2040. However the midpoint of the historical period was 1954, so the difference between 2020 and the historical period represents 66 years of climate change, while the difference between 2040 and 2020 represents only 20 years. In general, flows (and therefore generation) will be greater in winter and less in summer.

Skagit

For this IRP, City Light's Power Management staff translated future forecasts of Skagit flows into generation rather than using estimates of future generation from NPCC work. City Light prefers in-house estimates because they more fully incorporate all the constraints involved in operation of the three dams at this project. The expected impact of climate change on combined average monthly generation from all three dams is shown in the graph below.

Figure 3: Change in Average Skagit Generation (average Monthly Megawatts)



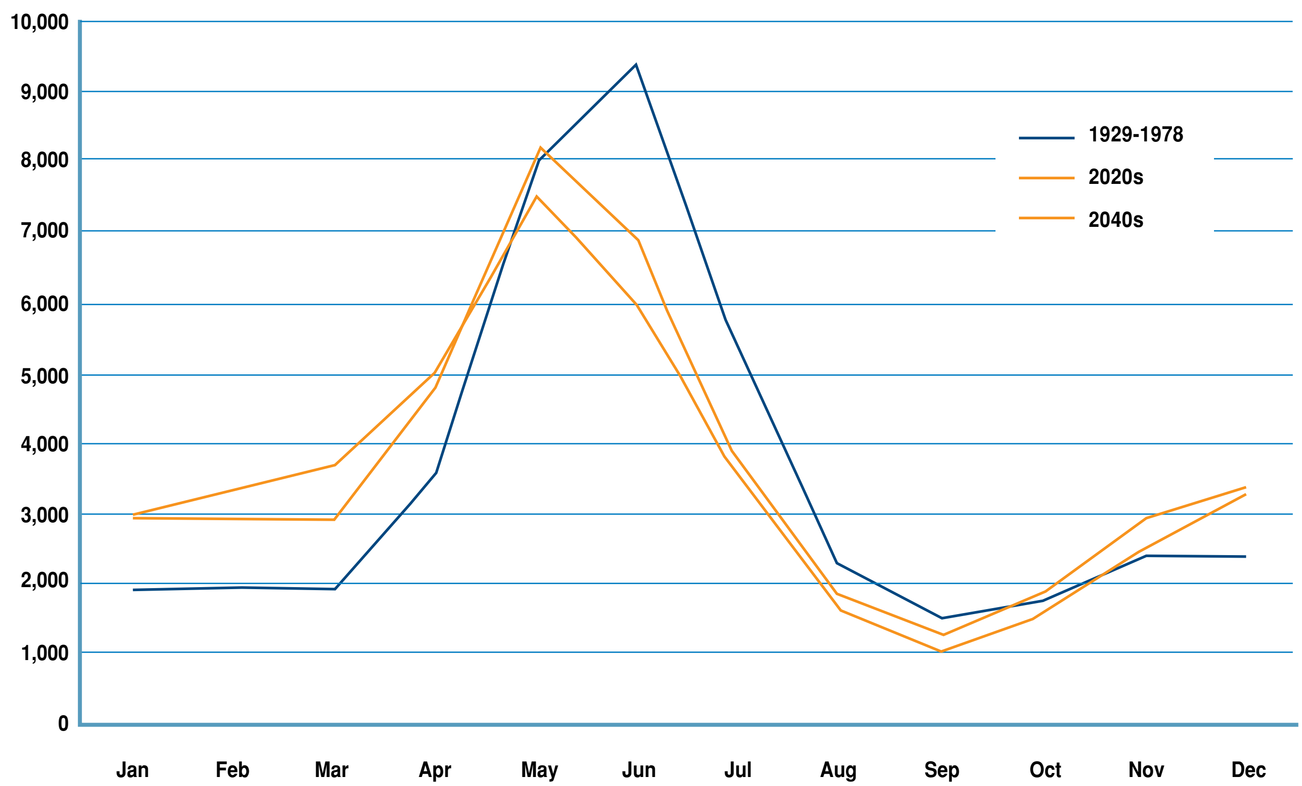
As the graph demonstrates, generation is higher in the winter and spring but does not peak as high in the summer. Total annual generation is not significantly changed. These results reflect the changes in the pattern of flows that are a consequence of climate change.

Monthly average natural inflows for Ross, Diablo and Gorge under climate conditions of the 2020s and 2040s were also obtained from work done in 2004 by the UW CIG for the NPCC. Hydroelectric generation varies from year to year depending on the weather. Therefore, instead of providing a single 12-month forecast of flows for each year, the UW estimated what monthly flows for 1929 to 1978 would have been under future climate scenarios of temperature and precipitation. Historical natural inflows were provided by Power Management and derived from records of changes to the level of Ross Lake and releases at each powerhouse.

With warmer temperatures, precipitation is more likely to fall as rain instead of snow. The result is higher flows in winter and a reduced snow-pack. Spring runoff will start earlier and have a smaller peak. The UW forecasted a small overall increase in precipitation causing somewhat greater total annual flows in the 2020s but returning to the historical level in the 2040s. Forecasts of future warming and whether total rainfall will increase or decrease involve substantial uncertainty. As better methods of forecasting weather and Skagit hydrology become available, City Light intends to follow such information closely and incorporate changes into future IRPs.

Average forecasted Ross inflows under future climate conditions are compared to the actual average for 1929 to 1978 in the graph below:

Figure 4: Effects of Climate Change on Ross Average Monthly Inflows (cubic feet per second)



Power Management derived changes in generation based on changes in natural flows by using a program called the "RefillEngine." It simulates Skagit operations, which must meet regulatory constraints regarding fish, flood control and recreation as well as the objective of providing power for Seattle. In particular, the RefillEngine attempts to maximize the value of power production while satisfying the recreation requirement of achieving refill of Ross Lake by July 1 and keeping it full through August; the flood-control requirement of keeping Ross Lake below a level set by the Army Corps in winter months; and an approximation of fisheries requirements. Fisheries requirements are adjusted from day to day depending on consultation between fisheries biologists and power managers, so that it is difficult to anticipate these requirements and include them accurately in a model.

With climate change, Skagit operation would likely be operated to modified objectives. If winter flows are higher, flood-control curves would likely be altered to accommodate this. If temperatures are higher, spawning times would be shifted. Higher stream temperatures might also trigger higher flow requirements to mitigate high temperatures for fish. These potential changes are too speculative to be included in the scope of this study, and no changes to the RefillEngine were made to reflect these possible changes. We did, however, attempt to address the question of how fisheries requirements would be altered by changes in downstream flows.

Fisheries requirements depend not just on flows coming into the project but also on side stream inflows downstream of the project, especially those between Newhalem and

Marblemount, including the Cascade River. City Light adjusts its water releases at Gorge during the spring and summer as the contribution to the Skagit River from tributaries below Gorge changes, providing better total main stream flows for fish that spawn below the project. The UW did not provide estimates for the impact of climate change on flows from downstream tributaries.

Power management staff synthesized the data by multiplying existing data times the monthly ratios between the future climate and base case natural flows at Ross. These flows were fed into the models prepared for each of the six Skagit salmon and steelhead species to arrive at tables relating spawning flows to incubation flows for pink, chum and Chinook as well as March, April, and May-June spawning segments of the steelhead population. As the greatest part of flow change occurs between the base case and 2020, new fisheries flows for 2020 were used for 2040 as well. The new sideflows for June and July were then fed into the RefillEngine that processed the 2020 and 2040 flows.

The RefillEngine was run with and without estimated changes in downstream tributaries for base case inflows. Operation during any given year will produce flow constraints for the first part of a subsequent year. These subsequent year flow constraints were then used as starting constraints for the subject year and the subject year was rerun.

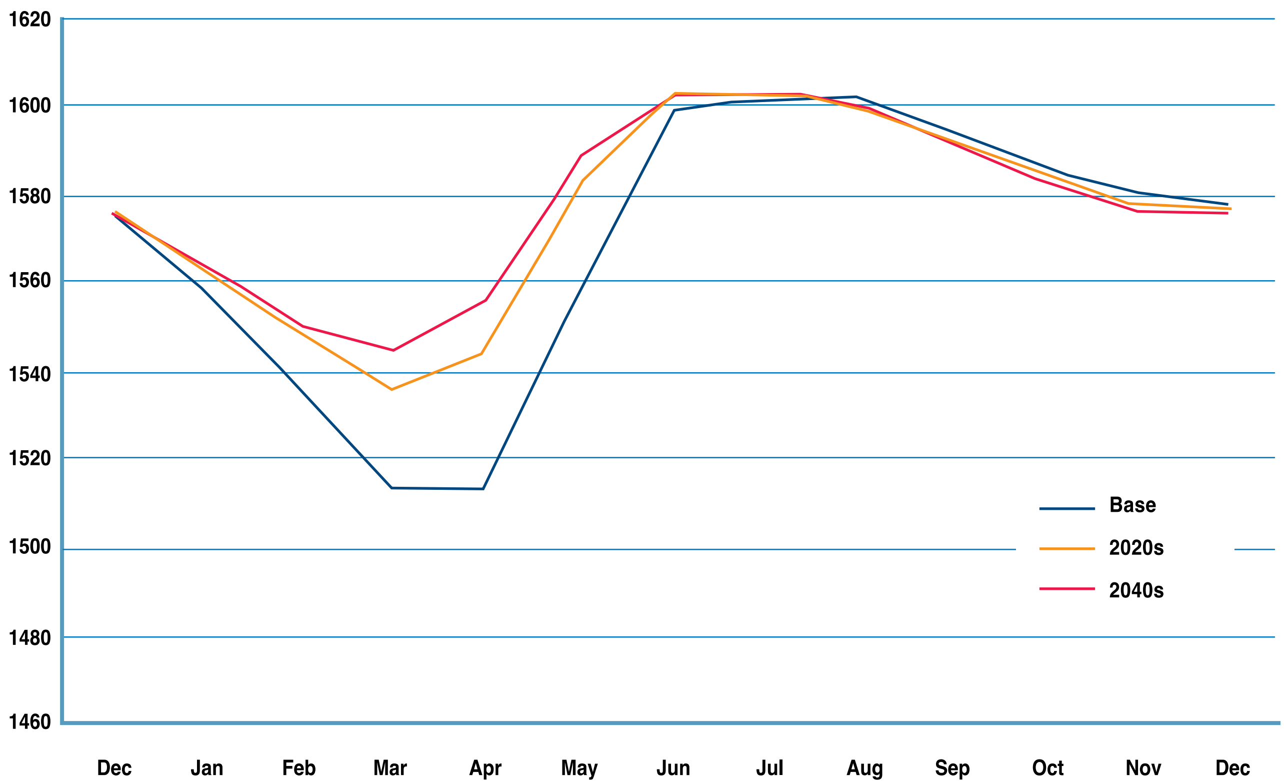
The effects of just changing tributary flows between Newhalem and Marblemount are shown in the table below. Because natural flows between Newhalem and Marblemount are forecasted to decrease so much in June and July, Gorge discharges have to be increased to compensate. This results in lower average Ross elevations during June through September and higher generation in June and July followed by reduced generation in August through October. Only the months with changes are shown. These changes are due to changes in fish-flow constraints alone and do not include changes in operation directly due to changes in inflow patterns.

Table 1: Effect of Changes to Downstream Tributaries on Skagit Operation

	Jun	Jul	Aug	Sep	Oct
Ross end-of-month elevation (feet above sea level)					
2020 constraints	-0.5	-0.5	-0.4	-0.1	0.0
2040 constraints	-0.5	-0.6	-0.5	-0.2	0.0
Generation (aMW)					
2020 constraints	+7	+1	-2	-4	-2
2040 constraints	+9	+1	-2	-5	-3

When all flow changes are included in the analysis, including inflows to the project as well as downstream tributary changes, the resulting Ross Lake elevation is expected to be as shown in the following graph:

Figure 5: Effects of Climate Change on Ross Lake Elevation (feet above mean sea level)



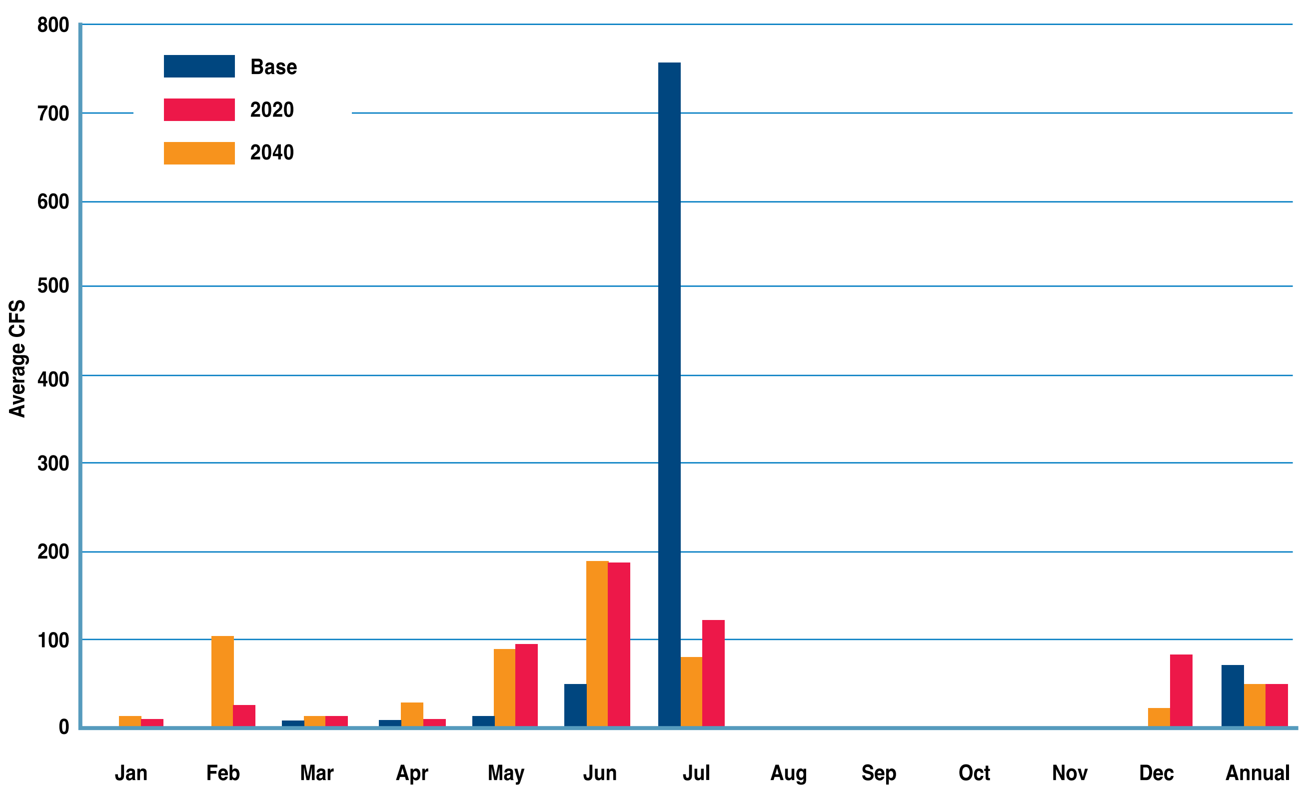
It will not be necessary to draw Ross Lake down so much in the spring, because there will not be as much snow in the mountains to melt and run into Ross Lake. Ross Lake is more likely to fill by the end of June and a little less likely to stay full through August. Table 2 shows the frequency of not meeting the license recreation requirements. The overall average lake elevation for July and August is 1601.5 in the base case, 1601.7 in the 2020s and 1601.8 in the 2040s.

Table 2: Frequency of Ross Lake Below Full Elevation (1602) at start and end of Recreation Season

	End of June			End of August		
	% < 1602	Avg. Elev.	Worst Case	% < 1602	Avg. Elev.	Worst Case
1930-1979	46	1599.8	1594.0	77	1601.2	1598.5
2020s	21	1601.6	1595.3	85	1600.2	1594.8
2040s	19	1601.9	1596.6	85	1600.3	1595.1

Spill occurs when the amount of water coming down the river exceeds the capacity of the powerhouse, and water cannot be held back until another day because the reservoir behind the dam is already full. It is difficult to produce accurate estimates of spill by analysis of average monthly flows, but estimates can be obtained. These show that the pattern of spill would probably be altered. This is illustrated by the following graph. Since there will be less of a summer peak in flows, there will also be less summer spill. However, the chance of spill increases in the winter months. Winter is the season of the most precipitation, and if that precipitation falls as rain rather than snow, it is more likely to produce high flows that lead to spill

Figure 6: Effect of Climate Change on Spill at Gorge



The above findings are subject to considerable uncertainly. Changes in climate are likely to lead to changes in fish behavior (such as the timing of fish runs) and changes in regulations that would alter the above results. Further, the effects of climate on flow are uncertain. One consideration that has been completely omitted from this analysis is the consequence of melting glaciers. Some glaciers in the North Cascades have already disappeared and most are getting smaller. As they shrink in size, their contribution to summer flows will decrease. There is not a large glacial contribution to inflows at Ross, but glaciers are important sources of flow for Thunder Creek, a tributary to Diablo Lake, and the Cascade, a tributary at Marblemount. Not only will flows be reduced, but without the contribution of melting ice, the water will be warmer, with potential negative consequences for salmon and bull trout habitat and populations.

Uncertainty about the timing and extent of changes for North Cascades glaciers, fish populations, and reservoir management practices has potentially larger impacts than the factors which we can model. This suggests the climate change scenario is inappropriate for use as a measure of small distinctions between 2008 IRP portfolios.

Estimating Power Market Impacts of Climate Change

City Light is presently able to model only a portion of the expected impacts from climate change, since as noted earlier, important information is largely unknown.

University of Washington (UW) climate research suggests that warming in the Pacific Northwest may occur at a rate of approximately 1 degree centigrade per decade, with greater warming occurring during the summer months (especially July and August) than in the rest of the year.

City Light used the temperature changes associated with the UW and Northwest Power & Conservation Council (NPCC) forecasts to estimate changes in load. Hotter summer temperatures will cause greater use of air conditioning. Although air-conditioning is not used heavily by Seattle residential customers, it is already used for a large part of the year by large commercial buildings, a growing portion of Seattle's load. City Light has analyzed how this load changes on increasingly hot summer days.

The combination of lower winter loads and greater winter availability of power could reduce the need for new resources to meet January loads and cause market prices to be lower in January. On the other hand, the combination of an earlier spring/early-summer snowmelt and higher demand for air-conditioning could cause more shortages of energy and higher prices in late summer. Traditionally, California utilities have been short in summer, and City Light has provided summer energy in exchange for winter energy. The value of long-term exchange agreements could be reduced in the future. City Light will need to track changes in natural flows not only in terms of generation capability but also in combination with our commitment to maintain flows for fish and to regulate reservoir levels for recreation and flood control.

The analysis is based upon early UW Climate Impacts Group (CIG) forecasts of changes in temperature effects. An update to this forecast is scheduled to be completed later in 2008 and should provide more specific information. However, downscaling global climate change models to estimate detailed climate impacts at specific watersheds is a complex and time-consuming process. Many questions are likely to remain unanswered for years to come.

The approach used in the analysis was to use the capabilities of the Aurora XMP market simulation model to capture the expected effects on the changes in the electric energy market and the resulting impact on Seattle's net power costs. Some of the modeling results may appear counter-intuitive, but close examination of the analysis provides valuable insights. The results are unique to City Light, including its ability to buy and sell in the electric energy market and the contracts and resources in City Light's resource portfolio and are very sensitive to City Light's overall position in the electric energy market.

Preliminary information was obtained by the Northwest Power Planning and Conservation Council, incorporating information provided by the Climate Impacts Group in Washington state. Information included the potential changes in temperature and precipitation which was used as input to forecast changes in electric energy demand and hydro electric energy in the Pacific Northwest.

Load was differentiated by monthly average for both the east and west side regions (Cascade Mountain division) for the year 2020. The change in load was input to change in a linear manner between now and the year 2020 and continuing to change at the same rate beyond this period to year 2027. Load changes (decreases) were included that averaged around 3 percent for most winter heating months, obtaining levels of approximately 4.5 percent. Loads increased in the summer periods due to increased air-conditioning, peaking at approximately 1.7 percent. This forecast does not explicitly take into effect the likelihood of a growing saturation of customers with air-conditioning.

Further, Seattle City Light forecasted changes in loads specific to its service territory. As compared with much of the inland Pacific Northwest, the electricity demand impacts of climate change for the Seattle area are expected to be moderated by a strong marine influence, arising from Seattle's location on the Puget Sound. Loads in the Seattle region were assumed to change by as much as 3.9 percent, but averaged slightly less than 1 percent change for the winter heating months. In the remaining discussion, this is called the "moderated temperature change" case.

Loads in the Desert Southwest were assumed to be affected by climate change, particularly in the summer. In these regions, load was assumed to increase in June and continue through the September cooling period, increasing monthly average loads by as much as 3 percent by 2020 in the most southern regions. Other western regions were also affected, but to a lesser extent.

Hydro data was provided by the NPCC by specific projects. In the database used in the Aurora XMP model, non-City Light hydro energy is aggregated for all hydro projects, applying the same energy shape to all hydro generation within an area to obtain an hourly energy representation. City Light projects are separately identified, providing unique input for each. For generalized hydro shaping, the change in energy for all projects was combined to establish an overall all change in energy that could be represented within each of the 24 areas modeled.

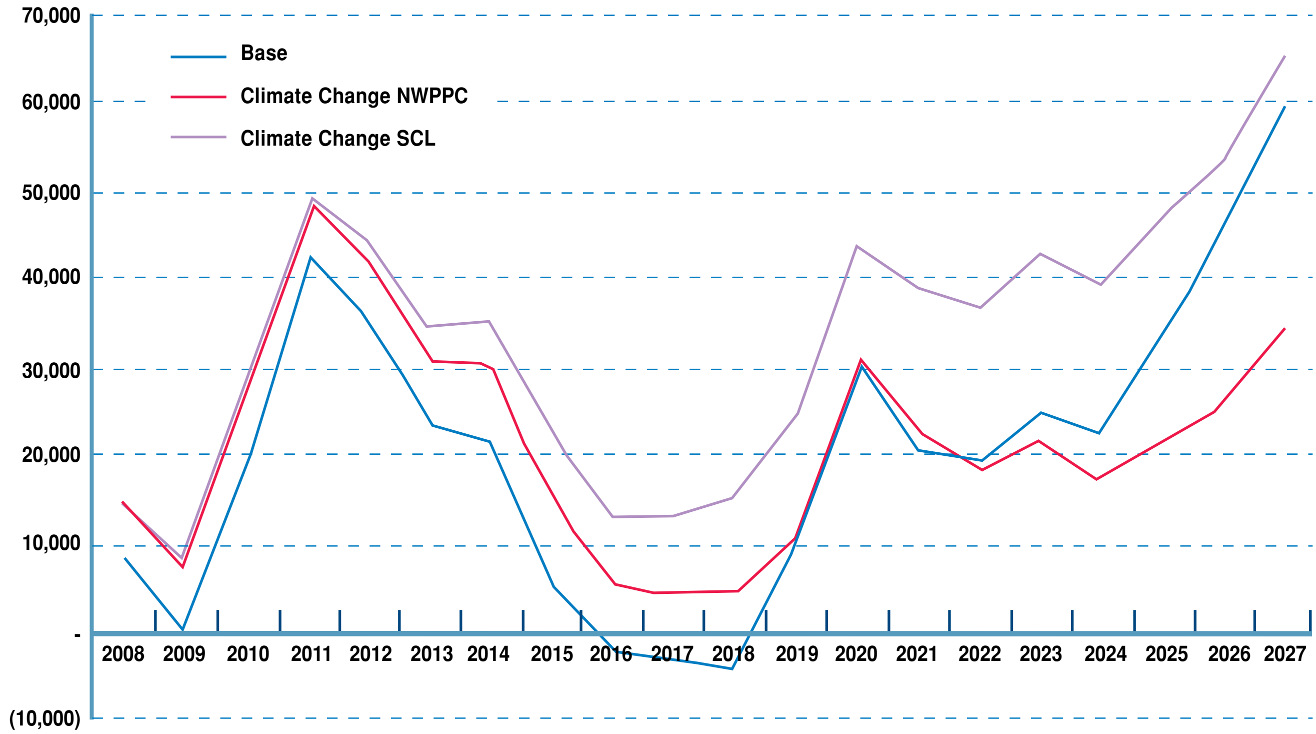
City Light's net power cost position was modeled over a 20-year period. Many factors have an influence in City Light's net power cost position. Some climate change-related factors have opposing influences, increasing the level of uncertainty for the net power cost position.

As described above, electricity demand is reduced in the winter heating months and increased during the summer cooling months. Winter loads decline due to an increase in average winter temperatures; and hydro run-off increases earlier due to increased temperatures and declining storage in snow-pack during the winter months. All other things being equal, this results in lower winter prices in the Pacific Northwest. Summer prices see an opposite effect however, they rise instead of fall. In the analysis, summer loads are increased for all areas in the West and there is reduced summer hydroelectric generation, since much less water was stored in the form of snow-pack for a late spring run-off.

Under average water conditions today, City Light is in a net power sales position. In the Climate Change scenario, the value of wholesale power sales is reduced by lower wholesale market prices for power during the winter months. In the moderated temperature change case, the reduction in wholesale market prices results in lower wholesale market revenues, which translates to higher net power costs for the winter. In the summer season, both load and market prices rise for City Light, when City Light has less hydropower resources available and must make more seasonal power purchases from the market than before. This causes summer net power costs to rise noticeably from the base case.

The dip in net power costs from 2014 to 2018 in Figure 7 is not a climate-related effect. It is caused by changes in forecasted natural gas prices through the period, which in turn affect wholesale power market prices.

Figure 7: Net Power Costs with Climate Change: Two Cases



Summary

As explained above, City Light is modeling only the partial financial impacts of climate change in this scenario. The impacts to City Light are particularly sensitive to assumptions about future resource acquisition, future demand growth, City Light's specific position in the wholesale power market, and the four unknowns previously identified.

The results of this initial scenario analysis generally match the hypothesized impacts of climate change for a winter peaking system. However, in the moderated temperature change case, the relative rate of change in winter loads and winter wholesale power market prices played an unanticipated role. As winter wholesale prices for the region fall at a proportionately faster pace than City Light's winter retail loads fall, there is a net reduction in winter wholesale revenues for City Light under average water conditions. This effect would increase City Light's winter net power costs above the Pacific Northwest average temperature change case.

The modeling results for the summer season more closely matched expectations. Summer loads increased; less hydropower was available to serve retail load; more summer market purchases were made to satisfy City Light demand; and regional wholesale market prices increased. These effects combined to increase net power costs in the summer for Seattle City Light. When combined, the winter and summer effects in the scenario resulted in an annual increase in net power costs for Seattle City Light in both the cases modeled.

This scenario is useful in identifying the magnitude and timing of potential financial impacts from climate change for a particular strategy; however, it involves an unlikely assumption. It assumes that despite the growing impacts of climate change, City Light does not ever adjust its acquisition plans for new resources for winter, nor does it adjust the seasonal shaping of resources to better match specific climate change impacts to its system. Both of these actions are options if the predicted changes occur.

In summary, this preliminary analysis provides a better understanding of the direction of local changes. The downscaling data that we relied on gives us a better sense of temperature changes than precipitation changes. We also have identified important information gaps in existing research. So far, the CIG analysis does not incorporate changes in glaciers and the impact of those changes on flows and water temperature. Further scientific research is needed on the pace of melting of North Cascade glaciers. Nor does the current research predict how potential impacts may change the habitat for critical species, like salmon and bull trout, which, in turn, may change how City Light and others manage watersheds to meeting federal and state stewardship responsibilities. City Light's preliminary analysis of this for the Skagit indicates that the climate impacts on fish species has the potential to alter flow requirements. Finally, the research does not predict the possible changes in the frequency of severe storms and flooding. All of these changes could affect hydroelectric generation potential.

In evaluating climate change impacts on City Light, the scenario highlights the importance of looking at impacts within the broader context of the western region. It is important to consider changes in seasonal hydro resource position, demand impacts, and market prices. As described above, climate change impacts to net power costs may be more complex than first envisioned. Not only was the direction of change in demand important, but also the rate of change in City Light's demand relative to western regional demand and the resultant implications for western wholesale market prices.

For the next IRP, City Light staff will continue to work with researchers in this field at the University of Washington and the Lawrence Livermore National Lab to improve the availability of information on the impacts of climate change to Seattle City Light's power system.