APPENDIX M: CLIMATE CHANGE IMPACTS TO LOADS AND RESOURCES

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KEY FINDINGS

There are at least two ways in which climate change can affect the power plan. First, long-term changes in temperature will alter electricity demand and change precipitation patterns, river flows and hydroelectric generation. Second, policies enacted to reduce greenhouse gases will affect future resource choices. While the Council is not tasked with nor does it have the resources to resolve these uncertainties, it does have the obligation to investigate possible impacts of climate change on the region's power system and to recommend actions to maintain the adequacy, reliability, efficiency and economy of the system whenever appropriate. A discussion of greenhouse gas policies and their influence on resource choices is discussed in detail in Chapters 3 and 15. This appendix addresses the potential *physical* impacts of climate change and how they may affect the power plan.

Council analysis shows that climate induced changes to loads and river flows will not affect resource choices during the action plan period (2016 through 2021). However, beyond 2026, if load growth is higher than average, resource decisions would be different under a scenario in which climate change is considered. Because of this, the Council will continue to monitor and participate in efforts to improve climate change data and analysis, as provided by the Intergovernmental Panel on Climate Change (IPCC) and regional entities that downscale that data for Northwest use.

The most recent IPCC report[1] (Assessment Report 5) indicates that future global temperatures are very likely to increase. Unfortunately, data collected from global climate modeling will not be downscaled and processed for the Northwest region until early 2017 – much too late for analysis in the Seventh plan. However, some of the IPCC data can be used in combination with existing data to analyze potential physical impacts to the Northwest power system.

From previous climate modeling downscaling efforts, the prediction for the Northwest is for less snow and more rain during winter months, resulting in a smaller spring snowpack and lower summer flows.[2] Winter electricity demands would decrease with warmer temperatures, easing generating requirements. In the summer, demands driven by air conditioning and irrigation loads would rise.

The power supplies for both 2026 and 2035, as projected by the Regional Portfolio Model under a future high-load path, were examined under two scenarios, one without climate change and one with projected climate change effects. Results show that the 2026 power supply meets the Council's

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[1] IPCC, 2013: Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh, G.J., M. Collins, J. Arblaster, J.H. Christensen, J. Marotzke, S.B. Power, M. Rummukainen and T. Zhou (eds.)]. In: 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., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] For general details and a description of projected climate change effects for the Northwest, see p. 57 in the Climate Change strategy of the Council's 2014 Columbia River Basin Fish & Wildlife Program and Appendix G of that program.

adequacy standard in both cases. Thus, up through 2026, no additional resources are required to maintain an adequate supply, even under a climate change scenario. The same is true in 2035 for the no climate change case. However, after applying the climate induced shift in river flows and load, the likelihood of a shortfall in 2035 grows to 15 percent, which is far above the Council's adequacy standard. In this case additional resources would have to be acquired to maintain adequacy.

The Council's analysis indicates that climate induced changes to river flows and loads will not alter resource acquisition strategies at least until 2026. Thus, in the near term, climate change effects do not render the system inadequate and do not require modification to the resource acquisitions identified over the next six years.

Other potential climate impacts include increased flooding concerns in fall and winter, reduced salmon migration survival due to lower streamflows combined with higher water temperatures and increased electricity prices in summer.

Though the physical effects of climate change remain imperfectly understood, the Council has examined them and recommends that research continue in this area. While no immediate actions regarding reservoir operations are indicated by this analysis of the physical impacts of climate change, the region should begin to examine and consider alternative reservoir operations that could potentially mitigate those impacts.

BACKGROUND

In 1988 the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC), which was subsequently endorsed by the United Nations General Assembly.[3] The IPCC was established to assess available scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation. The IPCC's purpose is to collect and review the most recent scientific information produced worldwide relevant to the understanding of climate change. It does not conduct any research on its own nor does it monitor climate-related data. It is open to all member countries of the United Nations and currently has 195 participating countries that review all of the scientific material to ensure an objective and complete assessment of current information.

In November of 2014 the IPCC completed its Fifth Assessment Report (AR5).[4] Most participating organizations use complex computer models, commonly known as "global circulation models" or GCMs, to forecast long-term changes in the Earth's climate. These models primarily focus on the effects of greenhouse gases on temperature and precipitation. They take into account the interaction of the atmosphere, oceans and land surfaces.[5] Each of these models has been "calibrated" to some

[3]See "IPCC Factsheet: Timeline – highlights of IPCC history" at http://www.ipcc.ch/news_and_events/docs/factsheets/FS_timeline.pdf.
[4] See link at http://www.ipcc.ch/index.htm.
[5] http://gcrio.org/CONSEQUENCES/fall95/mod.html

degree and crosschecked against other such models to provide greater confidence in their forecasting ability.

Scientists are confident about their projections of climate change for large-scale areas but are less confident about projections for smaller or regional-scale areas. This is largely because computer models used to forecast global climate change are still ill-equipped to simulate how things may change on smaller scales. Forecasts on a global level therefore are of little use to planners in the Northwest. A method to downscale the output from the global models to a regional level has been developed.[6] This downscaled data matches better with hydrological data used to simulate the operation of the Columbia River hydroelectric power system. By using forecast temperature and precipitation changes, downscaled for the Northwest, a range of climate-affected potential future water conditions and temperatures can be developed. The climate-adjusted water record is used as input to the Council's GENESYS model, which estimates impacts to hydroelectric generation, river flows and reservoir elevations. Projected temperature changes lead to adjustments in electricity demand forecasts.

There are at least 20 different global circulation models that project future changes in temperature and precipitation. Every one of these models, to varying degrees, forecasts a warming trend for the Earth. Each uses modern mathematical techniques to simulate changes in temperature as a function of atmospheric and other conditions. Like all fields of scientific study, however, there are uncertainties associated with assessing the question of global warming and, as we are often reminded, a computer model is only as good as its input assumptions. The effects of weather (in particular precipitation) and ocean conditions are still not well known and are often inadequately represented in climate models – although both play a major role in determining future climate.

Generally, results from the most relevant GCM models are downscaled for the Northwest by several groups in the region, in particular the Climate Impacts Group at the University of Washington in conjunction with the River Management Joint Operating Committee (RMJOC). The downscaled data is processed to ultimately produce two components that are necessary for the Council's analysis: 1) a set of climate-change adjusted historical natural streamflows (including an appropriate set of rule curves); and 2) a set of projected monthly and daily temperature changes for future years. As mentioned earlier, the temperature data is used to adjust future load forecasts and the streamflow data is used as input to the GENESYS model to determine the output of the region's hydroelectric system.

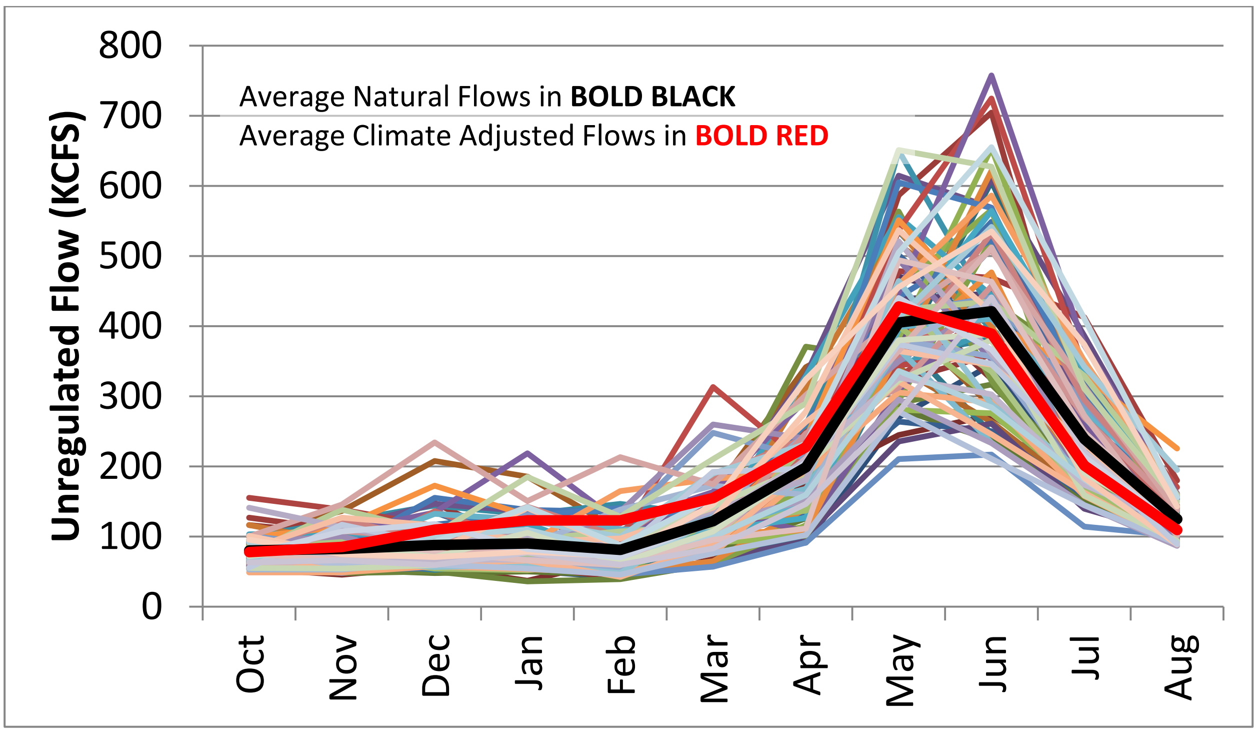
Unfortunately, data from the most recent IPCC report (AR5) GCMs is still in the process of being downscaled for Northwest use and will not be available until late 2016 or early 2017. The most recent complete set of downscaled data is based on the AR4 report, which was issued by the IPCC in 2007. That data, however, has two deficiencies; 1) is it based on scientific information that has since been updated in significant ways; and 2) streamflow adjustments were made to the older 70-

[6] Wood, A.W., Leung, L. R., Sridhar, V., Lettenmaier, Dennis P., no date: "Hydrologic implications of dynamical and statistical approaches to downscaling climate model surface temperature and precipitation fields."

year historical record, which has known errors.[7] Thus, the Council does not currently have any useable downscaled GCM data to use in its models to assess potential impacts of climate change on the Northwest power supply.

However, because climate change impacts to average monthly river flows are small relative to year-to-year streamflow variations (see Figure M - 1), the current historical streamflow record can be amended to simulate the effects of climate change. To do this, each of the 80 historical water years is given a weight based on its likelihood of occurring during a climate change future. Then, when simulating future operations for a climate change scenario, certain water years are selected more or less often depending on their respective weights. A non-climate-change future is analyzed by drawing water records with equal weights. More detail on this method is provided below.

Figure M - 1: Average vs. Year-to-Year Variation in the Historic 80-Year Water Record



[7] Natural streamflows for Canadian projects and for certain mid-Columbia River projects were amended to correct errors. The net effect of these corrections plus the addition of another ten years of flow record (from 1999 to 2008) result in an average increase in summer flows with a roughly equivalent decrease in winter flows.

TEMPERATURE AND HYDROLOGICAL CHANGES

For the Northwest, previously downscaled GCM results show that potential impacts of climate change include a shift in the timing and perhaps the quantity of precipitation for the Northwest. They also forecast less snow and more rain in the winter, thus increasing natural river flows during that period. With a smaller snowpack and warmer temperatures, spring and summer flows are projected to be lower and runoff timing is expected to peak earlier in the spring. More discussion regarding these possible impacts and their implications is provided in the next section.

Downscaled hydrologic and temperature data for the Northwest used for analysis in the Sixth Power Plan was obtained in 2009 from the Joint Institute for the Study of Atmosphere and Ocean (JISAO)[8] Climate Impacts Group (CIG)[9] at the University of Washington. This data, which was prepared for a single climate change scenario, was a composite of results from several climate models used by the CIG. This scenario roughly represented an “expected” or average climate change forecast.

A summary of forecasted annual temperature and precipitation changes from the downscaled AR4 data set is shown in Figure M - 2. In this figure, the X-axis represents changes from current conditions in annual precipitation (in millimeters) and the Y-axis represents changes in annual temperature (in degrees Centigrade). Each point in this figure represents the average precipitation and temperature change for each climate change scenario studied by the CIG. For example, the point labeled “3” indicates that the average annual precipitation in the 2020s is forecast to be about 0.5 millimeters greater and the average annual temperature is forecast to be about 1 degree Centigrade greater (than a non-climate change scenario). In spite of the fact that these data are old, three conclusions drawn from this figure are still relevant today; 1) each model shows a net temperature increase, 2) nothing definitive can be said about the change in total annual amount of precipitation and 3) there is great uncertainty in both the temperature and precipitation forecasts.

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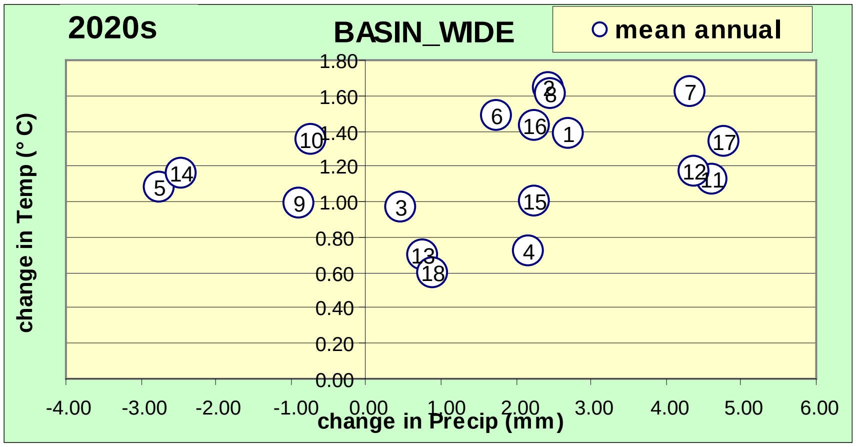
[8] http://tao.atmos.washington.edu/main.html
[9] http://tao.atmos.washington.edu/PNWimpacts/index.html

Figure M - 2: Columbia Basin Temperature and Precipitation Change Forecasts*



* Taken from the River Management Joint Operation Committee's preliminary summary of the University of Washington Climate Impacts Group's Global Climate Model analyses for the Northwest (RMJOC_Task1.2_ExploreScenariosSpread_v2.xls).

Precipitation, Snow Pack, and River Flows

Every global circulation model whose results were downscaled for the Northwest indicates that the region will become hotter across each month of the year. If this happens, less precipitation will fall as snow during fall and winter months, thus reducing the amount of snowpack in the mountains. The resulting increase in fall and winter rainfall will make unregulated stream flows higher. In the spring and summer months, unregulated runoff flows will decrease due to the smaller snowpack. The downscaled results of global models also predict that the timing of the peak spring runoff for the 2040 to 2050 time period could occur as much as a month earlier, on average, than it does now. Figure M - 3a shows the average historical unregulated monthly flows for the Columbia River at The Dalles Dam along with the average unregulated flows adjusted for climate change effects for 2045. Figure M - 4a highlights these effects by plotting the change in average flows at The Dalles Dam by month.

While some of these monthly hydrologic changes are large (i.e. an average flow reduction of almost 40,000 cubic feet per second in July), they are not expected to occur until the 2040 to 2050 decade. As will be demonstrated in a later section, annual changes to temperature and consequently river flows from today through 2045 are expected to change gradually and in a non-linear fashion (with changes growing more rapidly later in the period). In fact, climate-induced changes to monthly river flows in the near-term are difficult to detect due to the large natural variance in annual weather patterns as shown in Figure M - 1.

Figure M - 3a: Average Unregulated Flows at The Dalles
Historic vs. 2045 Climate Change

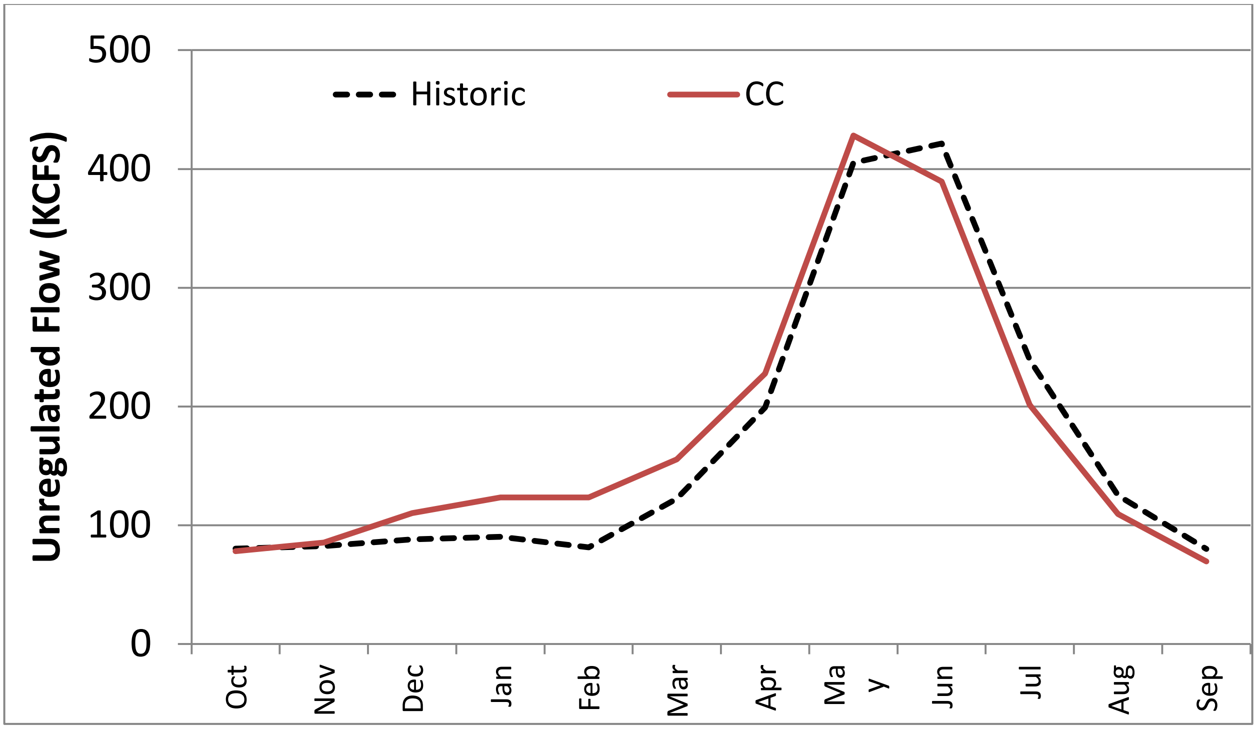
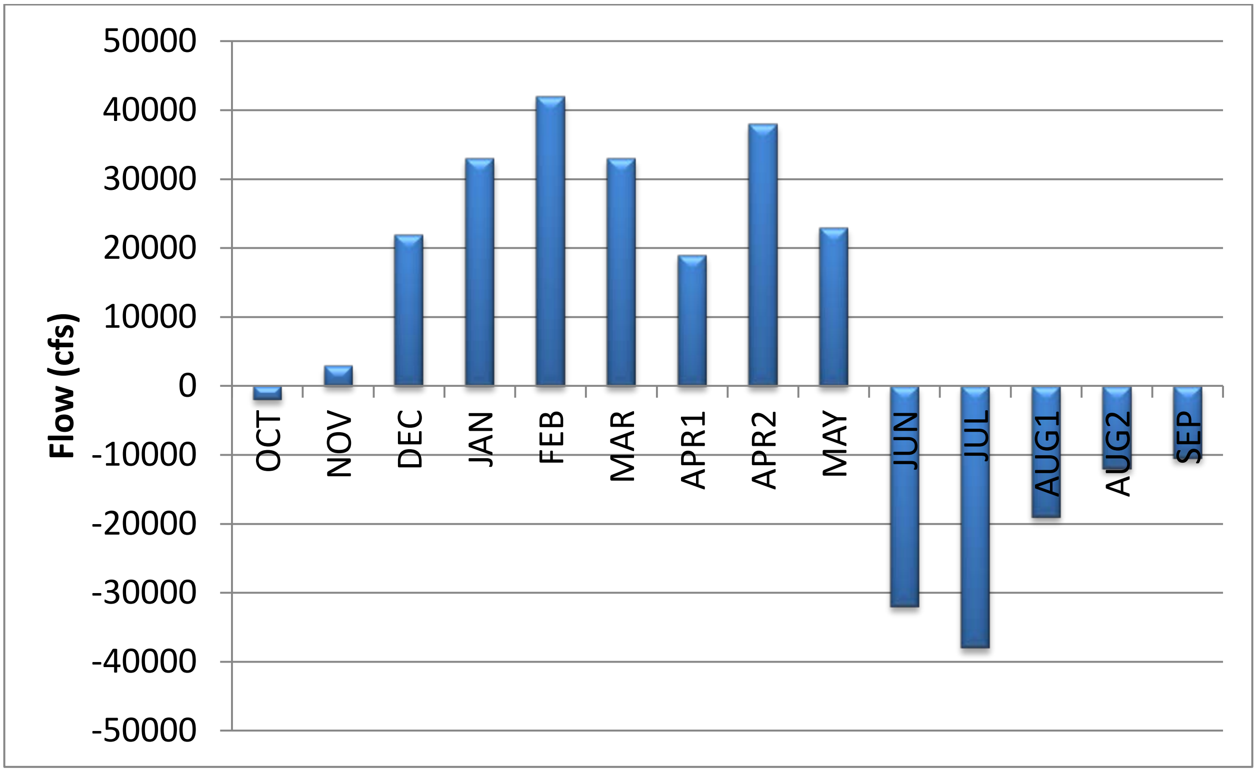


Figure M - 4a: **2045** Climate Induced Change in Unregulated Flows at The Dalles

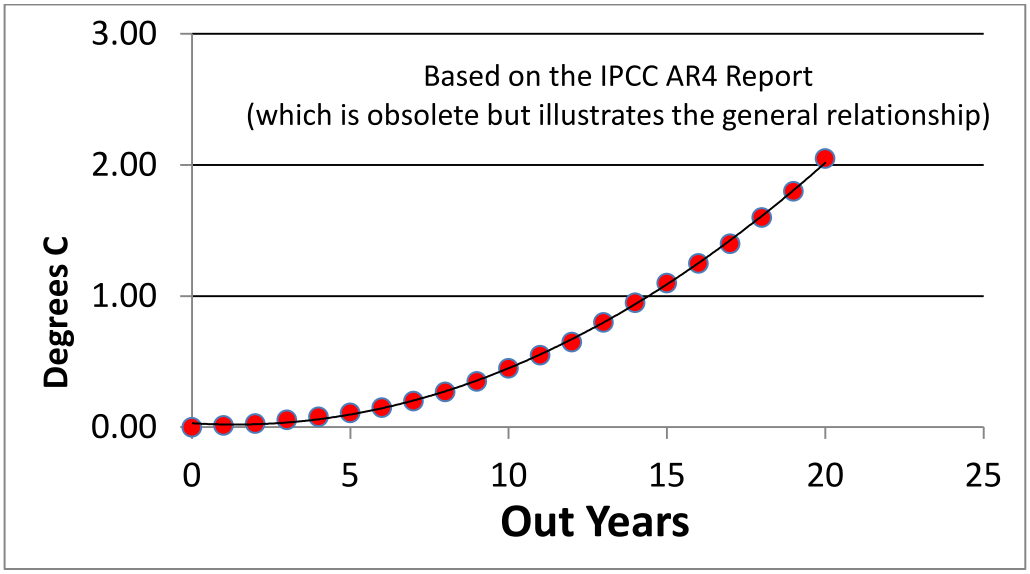


Electricity Demand

There is a clear relationship between temperature and electricity demand. For electrically heated homes, as the temperature increases in winter months, electricity use goes down. In summer months, higher temperatures translate into higher demand as the use of air conditioning units rises and as a higher percentage of air conditioning units are installed. The Council uses its long-term load forecasting model to simulate the impact of increasing temperatures.

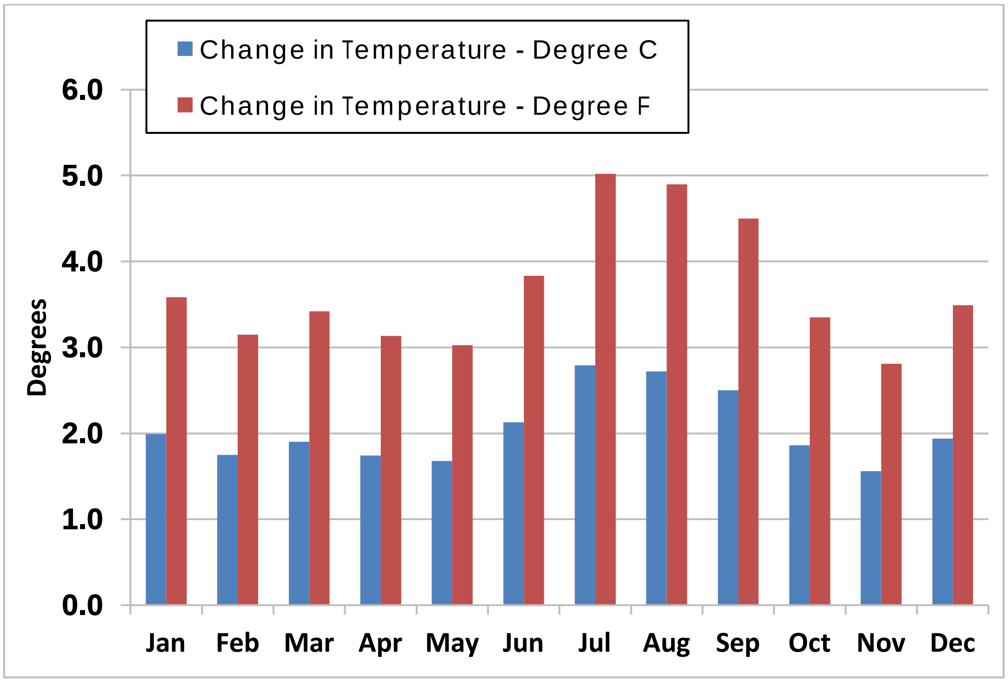
Climate-induced temperature increases are not expected to grow linearly over time. The AR4 data indicate that temperature increases should grow gradually, as illustrated in Figure M - 5. This general trend for global temperature increase was used to interpolate the projected 2045 temperature increase back to 2035. That interpolation resulted in an estimated temperature increase of 2.05 degrees Centigrade (or about 4.3 degrees Fahrenheit) by 2035. These temperature increases were used to develop a climate induced load forecast for 2035, as will be described below.

Figure M - 5: Illustration of Projected Temperature Increase (2015 to 2035)



Using historic heating and cooling degree days and their relationship to system peak load and system energy characteristics, the model estimates that by 2035 summer peak loads could be higher by about 3,500 megawatts and energy loads would be higher by about 1,200 average megawatts. Correspondingly, winter peak and energy loads could be lower by 120 megawatts and 70 average megawatts, respectively. Figure M - 6 shows the assumed increase in monthly temperature by 2035 used for this analysis. Just like the water year record, temperature year records have a great deal of variation year to year. To simplify this analysis, only the average temperate increases over time were considered when producing the climate change revised load forecast.

Figure M - 6: **2035** Climate Induced Monthly Temperature Changes



The projected increases in annual and monthly temperatures from the AR4 HADGEM1 data are converted to higher cooling and lower heating degree days for each state. The cooling and heating degree days are measured as the average of annual cooling or heating degree days for years 1985 through 2012. The cooling and heating degree days vary by state. For example, under normal conditions, the annual cooling degree day value for state of Idaho is about 482 degree days. In the preliminary climate change scenario, the normal cooling degree days is forecast to increase to 849 degrees by 2035. Each state's normal and 2035 forecast cooling and heating degree day values are shown in Table M - 1 below.

Table M - 1: Cooling/Heating Degree Days by State

	Cooling Degree Days (Normal) (1985-2012)	Cooling Degree Days (2035)	Heating Degree Days (Normal) (1985-2012)	Heating Degree Days (2035)
ID	482	849	6,755	5,931
MT	267	470	8,159	7,164
OR	229	403	5,171	4,540
WA	189	333	5,531	4,856

As with all forecasts about the future, there is uncertainty regarding whether these trends will actually materialize at the pace projected. For example, the forecast growth in summer peak loads results from the assumption that due to higher summer temperatures more residential consumers will install central air conditioning. Figure M - 7 shows the assumed market shares of air conditioning across three residential housing types. Given the historical trend towards increased air conditioning, the growth in penetration shown in Figure M - 7 is not unrealistic. Nevertheless, it is still a forecast, not a fact.

Summer loads are more sensitive to temperature than winter loads. Regional variations in summer temperatures are greater than variations in winter temperatures. Figure M - 8 shows the forecasted monthly increase for energy and peak loads. Peak load is measured at the time of system peak (coincident peak).

Figure M - 7: Increased Air-conditioning Penetration Rates (Residential)

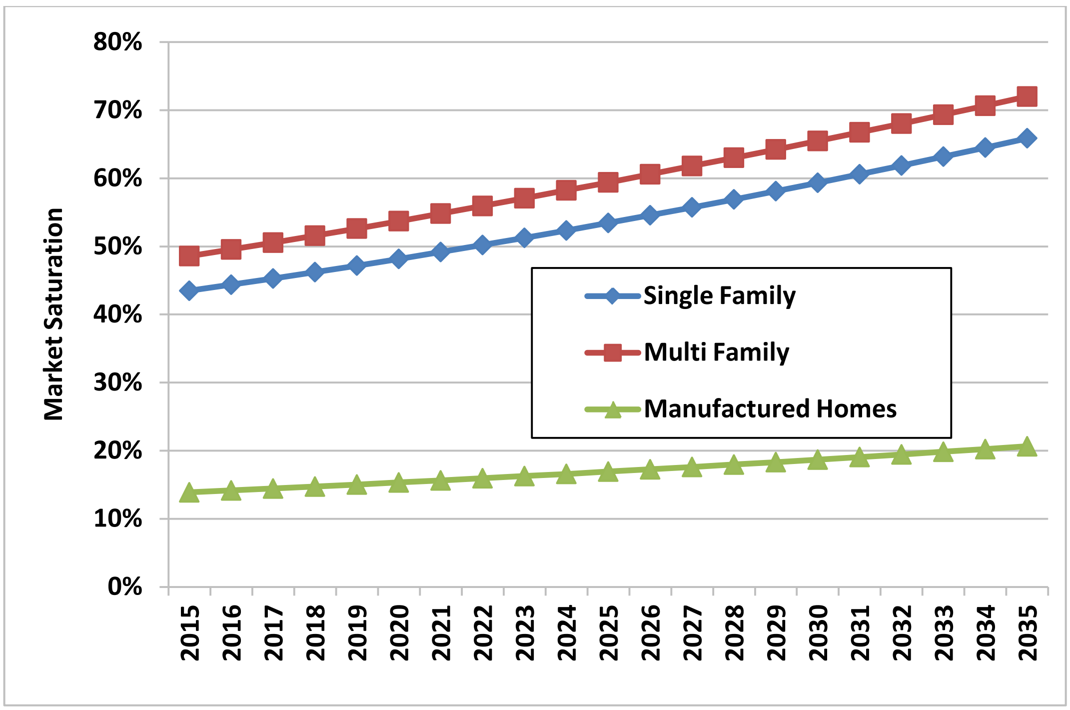
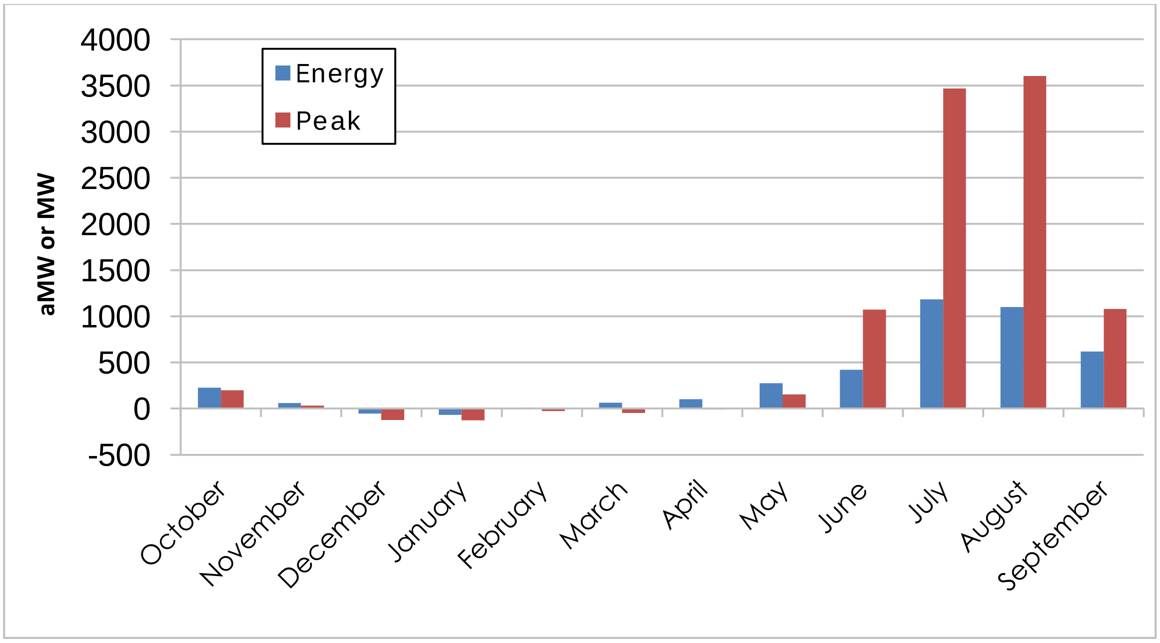


Figure M - 8: Change in Peak and Energy Loads
for a 4.3° F Annual Increase in Temperature



Figures M - 9 and M - 10 show the forecast range for peak and energy loads under the climate change scenario. The key variables for simulating climate change impacts on future energy and peak loads for this analysis were changes in the regional cooling and heating degree days and increases in the market share of residences with air conditioning. In the climate change scenario, regional peak load were projected to be between 34,000 and 38,000 megawatts by 2035. Projected annual energy use in the climate change forecast to be between 23,000 and 26,000 average megawatts by 2035. Under the climate change forecast, the Northwest region shifts from being a winter peaking system to a summer peaking system after 2028.

Figure M - 9: Peak Load Forecast under a Climate Change Scenario (MW)

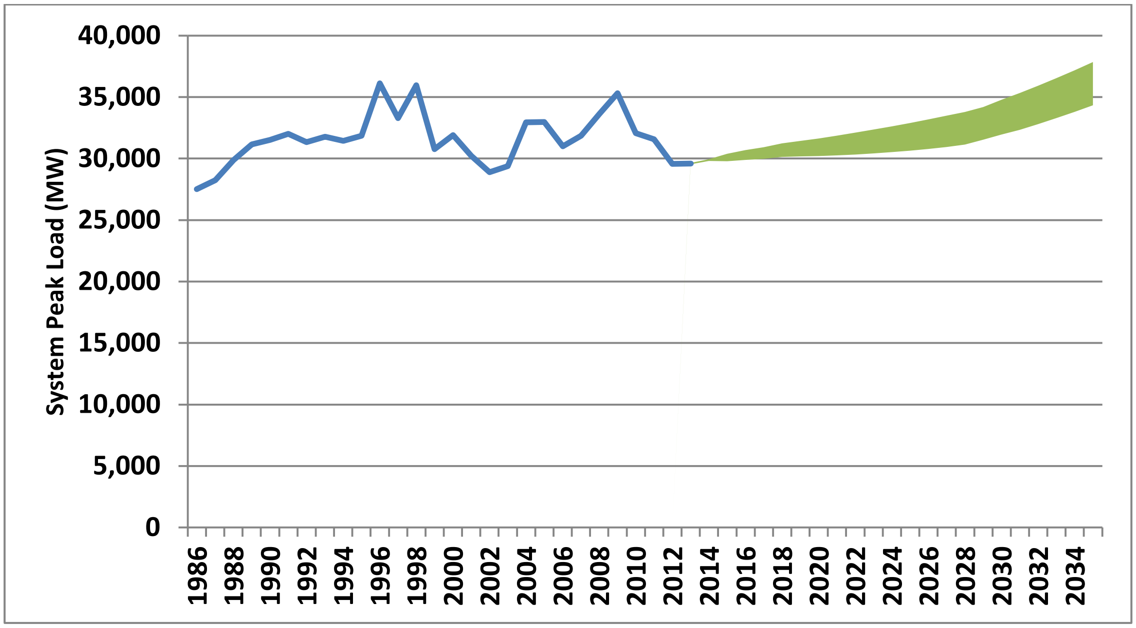
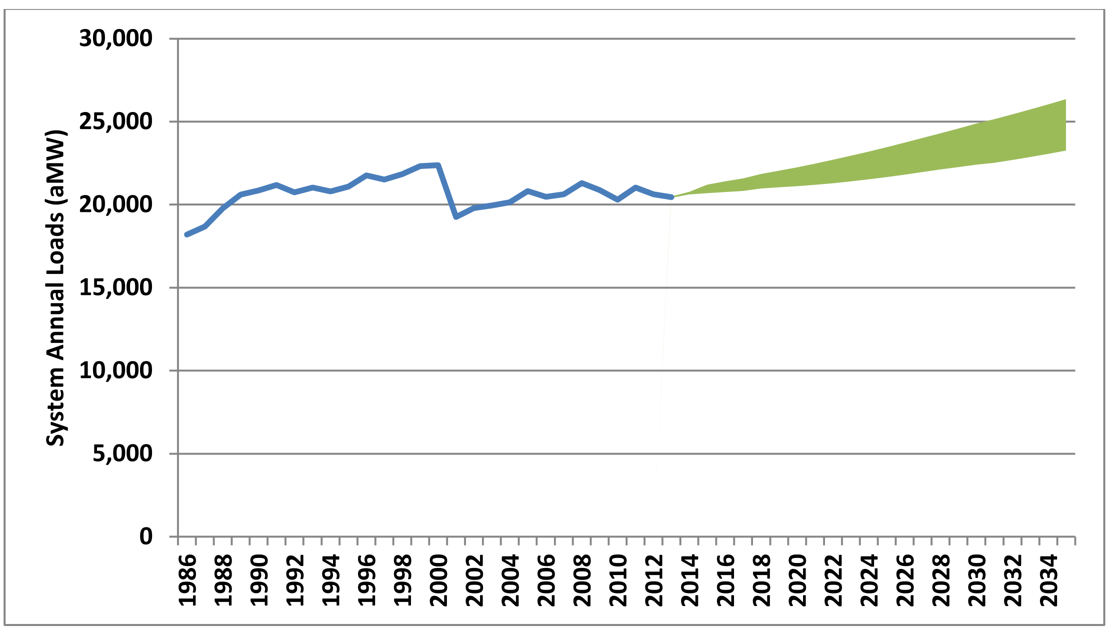


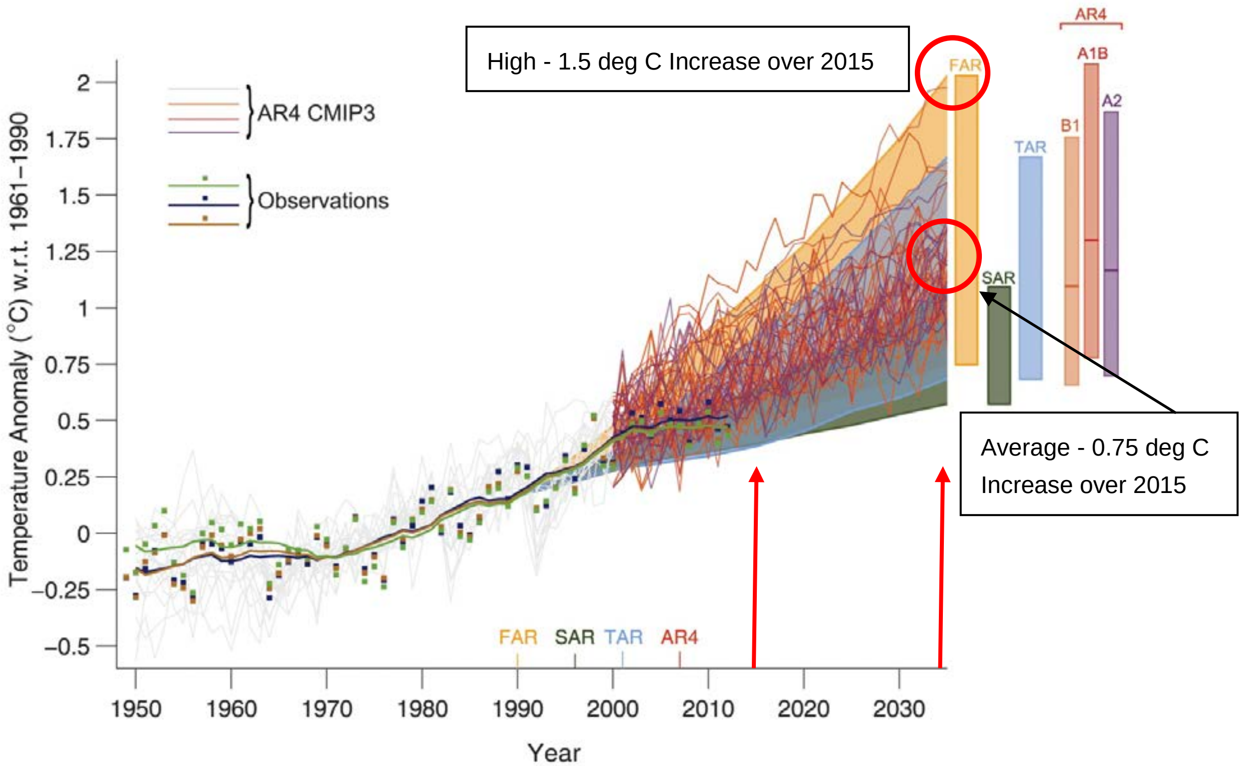
Figure M - 10: Energy Load Forecast under a Climate Change Scenario (aMW)



The more current AR5 data indicate that at a global level, the range of temperature increases by 2045 will be less than what was projected by the AR4 data. The current temperature projections globally and for Western North America are shown in Figures M - 11, M - 12a and M - 12b. Using the newer data, the projected average 2.05 degrees Centigrade increase by 2035 drops to an average of increase of about 0.75 degrees. On the high end of the AR5 data, the 2035 increase in average temperature could be as much as 1.5 degrees Centigrade. Table M - 2 shows the assumptions used for climate-induced average temperature increases for 2026 and 2035. These assumptions are based on a linear relationship between projected out-year temperature increases and current temperatures. A linear relationship was assumed because insufficient data was available to extract the non-linear relationship (as illustrated in Figure M - 5). However, by using a linear relationship, the projected temperature increases are slightly higher than would be expected, thus making this analysis more pessimistic with regard to climate-induced impacts.

The climate-induced load adjustments shown in Figure M - 8 were adjusted to reflect the lower temperature increase projections from the newer AR5 data. The loads were adjusted in a linear fashion for each month. In other words, the monthly energy and peak load change for the 2.05 degree temperature increase was modified proportionally for the 0.75 and 1.5 degree increases.

Figure M - 11: IPCC 5 Report Projected Changes in Global Temperature*



* Source: “Climate Change 2013 The Physical Science Basis,” Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change

Table M - 2: Assumed Temperature Changes using a Linear Interpolation

Year	2026	2035
High	0.75 °C	1.50 °C
Medium	0.38 °C	0.75 °C

Figure M - 12a: Projected Changes for West North America Jun-Aug

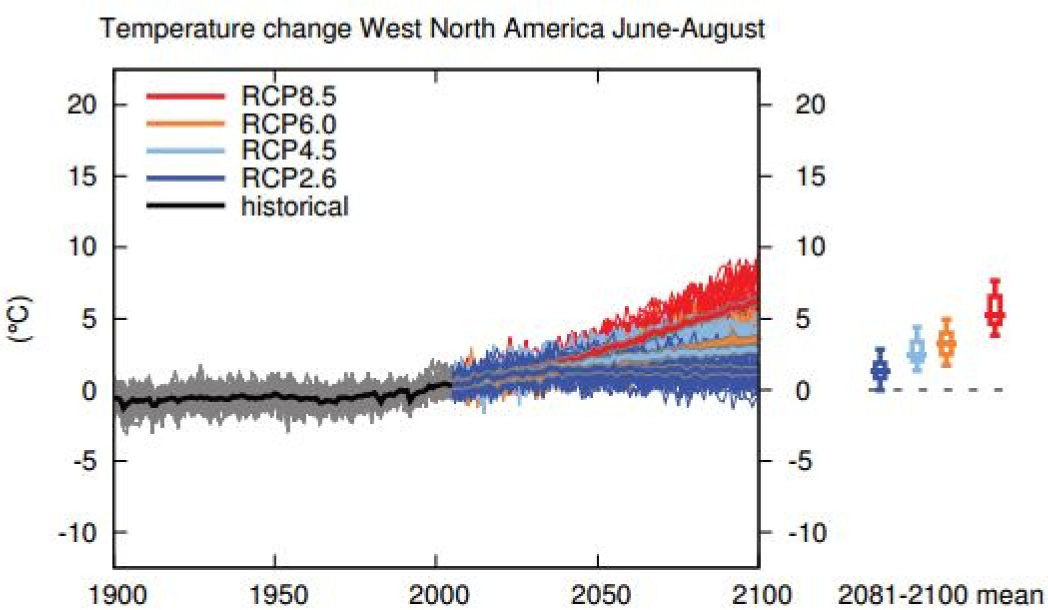
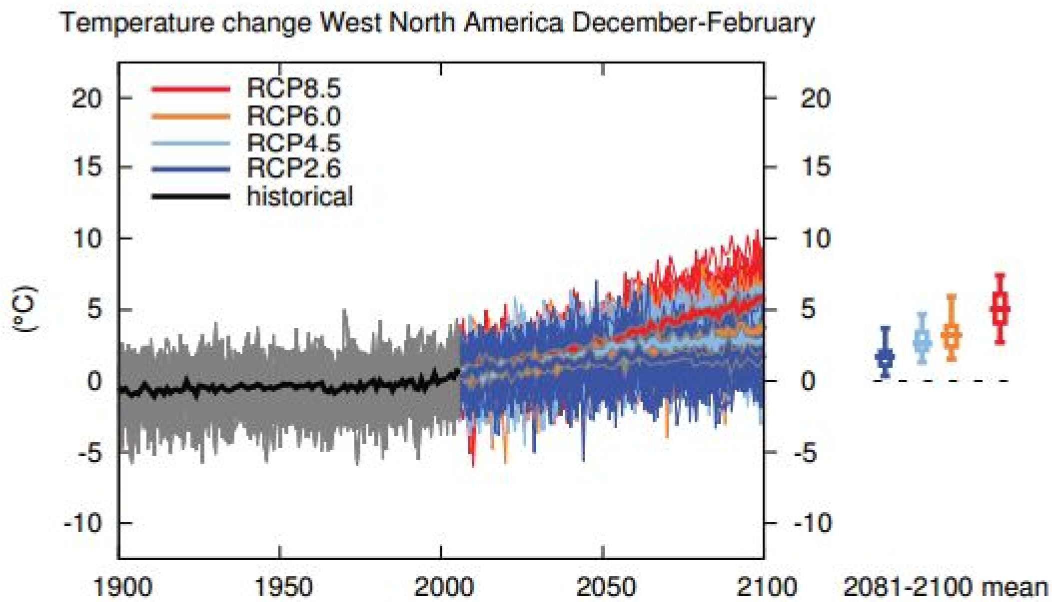


Figure M - 12b: Projected Changes for West North America Dec-Feb[10]



IMPACTS TO THE POWER SYSTEM

Methodology

To assess climate change impacts, the Council uses the GENESYS computer model, which simulates the physical operation of hydroelectric and thermal resources in the Northwest. GENESYS is a Monte Carlo program that performs an economic dispatch of resources to serve regional demand. The model splits the Northwest region into eastern and western portions to capture the possible effects of cross-Cascade transmission limits. It also accounts for available out-of-region imports, if needed, to maintain continuous service to Northwest customers. Outages on the cross-Cascade and inter-regional transmission lines are not modeled.

Important future uncertainties that are explicitly modeled include natural stream flows, temperatures (as they affect electricity loads), forced outages on thermal generating units and variability in wind generation. The model simulates the operation of the power system for a single future operating year thousands of times, with each simulation (or game) drawing randomly from the unknown parameters identified above.

[10] Source: IPCC 5, Annex I: Atlas of Global and Regional Climate Projections, Figure AI.16, page 1330, Figure AI.17, page 1331

Key outputs from the model include reservoir elevations, regulated river flows and hydroelectric system generation. The model also tracks reserve margin violations and service curtailments and assesses the adequacy of the power supply.

Assumptions

The most direct way of assessing the impact to the power system of changes in unregulated river flow is to simply replace the historical set of water conditions with a set that has been adjusted for climate change. Unfortunately, climate-adjusted unregulated flow data sets will not be available until late 2016 or early 2017. Thus, because the AR5 data have not yet been downscaled for the region and converted into a useable form for GENESYS, an alternative approach was taken to approximate what the climate-adjusted unregulated flows would be.

Because annual variations in unregulated flows are so wide (see Figure M - 1) relative to the average change due to climate effects, it seems likely that many of the historical stream flow records would also appear in a climate change future. To determine which ones and how often they may appear, an optimization program was used to assign a specific weight to each of the 80 historical water records. Then, when water records are drawn at random based on their individual weights thousands of times (i.e. the larger the weight, the more likely that record will be chosen), the resulting average monthly unregulated flows should closely match the projected average changes from the AR5 data. Figures M - 3b and M - 4b are identical to Figures M - 3a and M - 4a, with the addition of the optimally fitted curves that approximate the average climate change flows.

Figure M - 3b: Average Unregulated Flows at The Dalles

Historic, 2045 Climate and Fitted Values

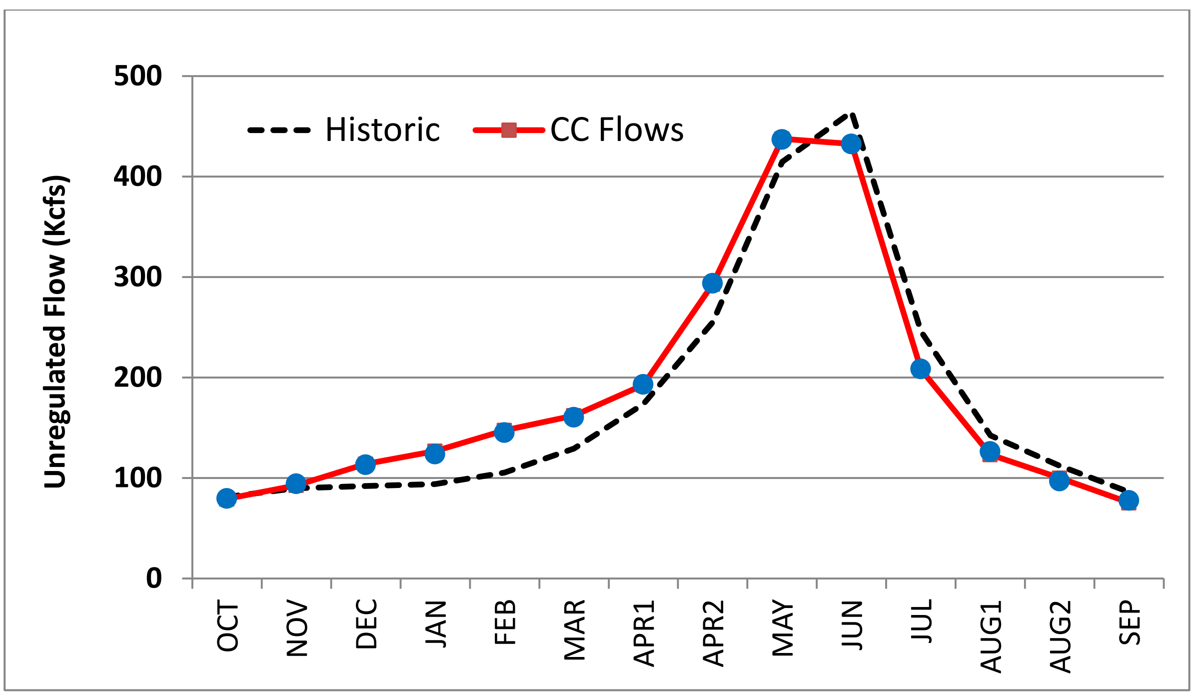
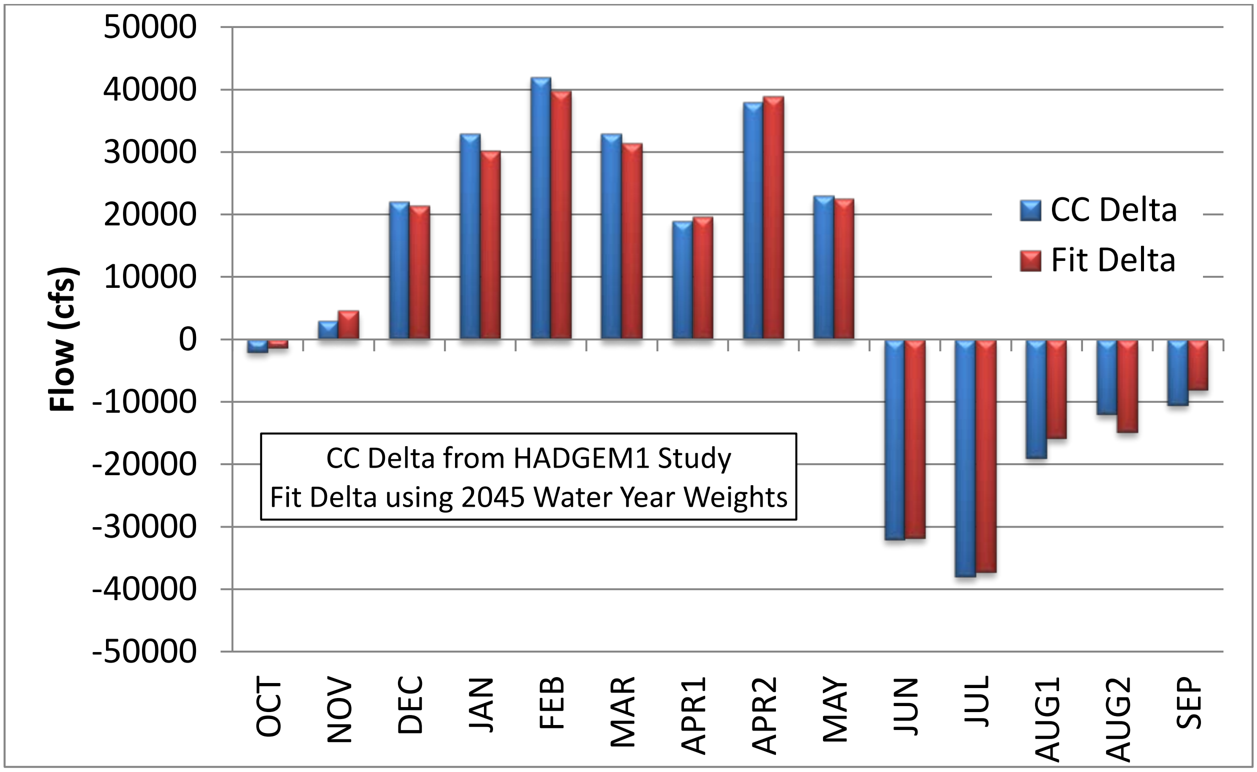


Figure M - 4b: **2045** Forecast Change in Unregulated Flows at The Dalles



The main advantage of using this method to select water years in our analysis is that each water year record already has its corresponding and appropriate operating rule curves built in.[11] The two disadvantages are that: 1) this set of water records is more limited (i.e., only a subset of the 80 year record is used); and 2) any new, as yet unseen, water conditions that would appear in a climate change future are not modeled. However, given that the AR5 data are not available; this method provides a reasonable approach to assessing climate induced impacts to the operation of the power system.

Unfortunately, when running GENESYS in random-water mode, the analysis must be done as a refill study, that is, for each game the starting contents at reservoirs in October (the beginning of the operating year) are reset to initial values. This effectively provides more water for the study and reduces the effects of back-to-back bad water years. Thus, the resulting adequacy assessment will be optimistically high. For our analysis, however, the important parameter is not the absolute value of adequacy but rather the difference in adequacy between climate-change and non-climate-change scenarios.

A further adjustment that must be made is to reduce the average change in monthly unregulated flows that are projected for 2045 (as shown in Figures M - 3b and M - 4b) to values that are

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[11] With the exception of the drafting rights rule curves that have to be adjusted for shifts in load.

appropriate for 2026 and 2035. To do this, a linear relationship was also assumed. In other words, the total change in monthly average flows from 2045 was assumed to occur in equal increments for each year from 2016 through 2045. The resulting climate-adjusted monthly average unregulated flows for 2026 and 2035 are shown in Figures M - 13a and M - 13b, along with averages when using the fitted data.

Figure M - 13a: **2026** Projected Change in Unregulated Flows at The Dalles

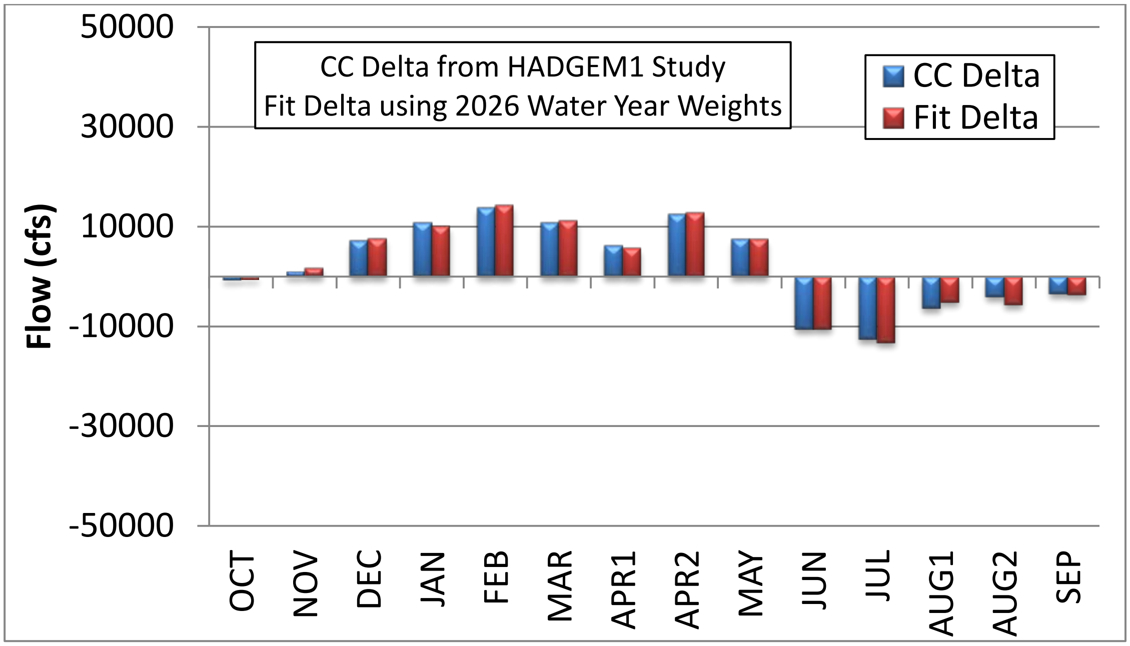


Figure M - 13b: **2035** Projected Change in Unregulated Flows at The Dalles

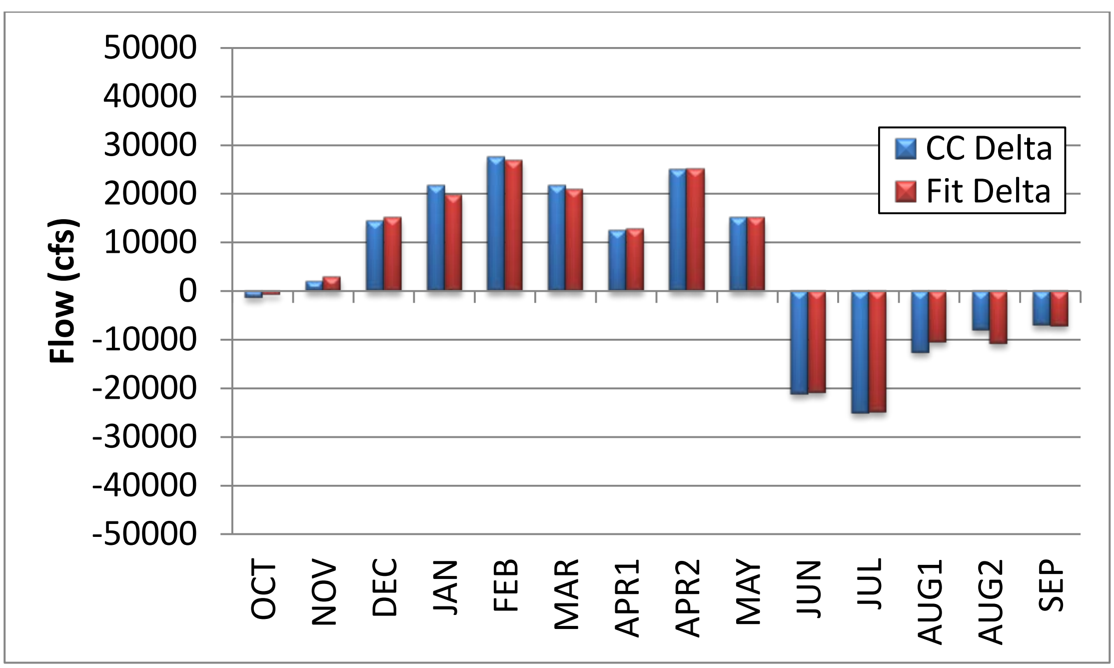


Figure M - 14a and M-14b show the climate-induced changes to average and peak monthly loads for 2026 and 2035. These values were derived from adjusting the forecast load changes for 2045 (Figure M - 8) linearly back to 2026 and 2035 for the high temperature cases. For 2026 the projected average temperature increase was assumed to be 0.75 degrees Centigrade and for 2035 the assumed temperature increase was 1.5 degrees Centigrade.

Figure M - 14a: **2026** Projected Change in Average and Peak Loads

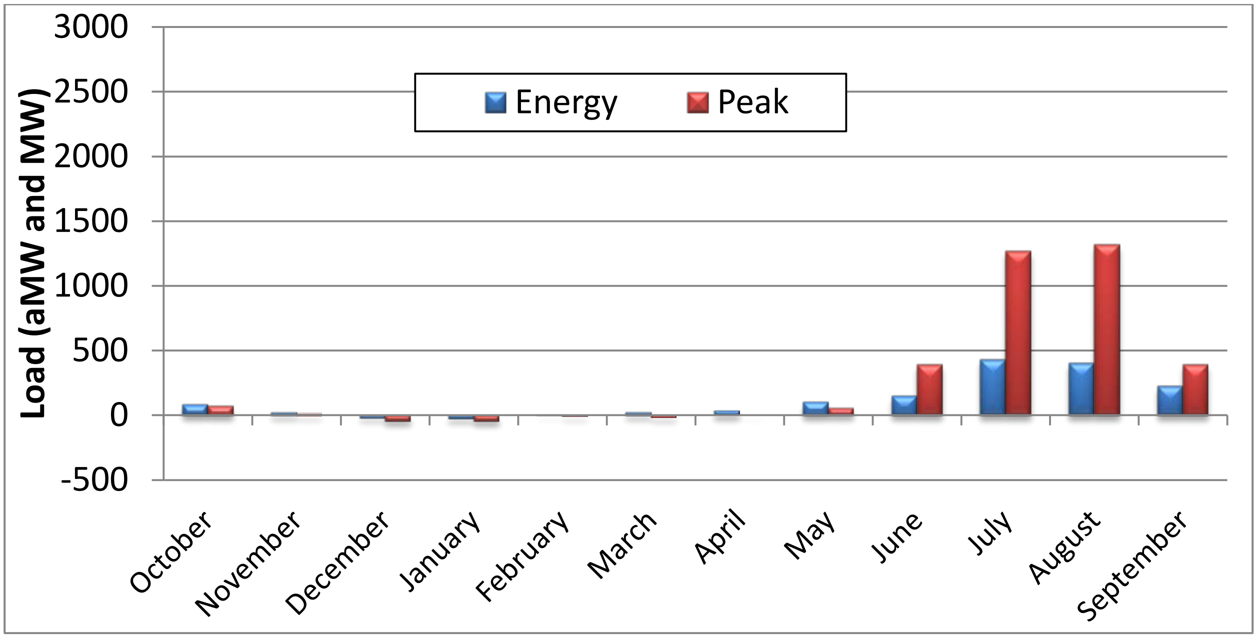
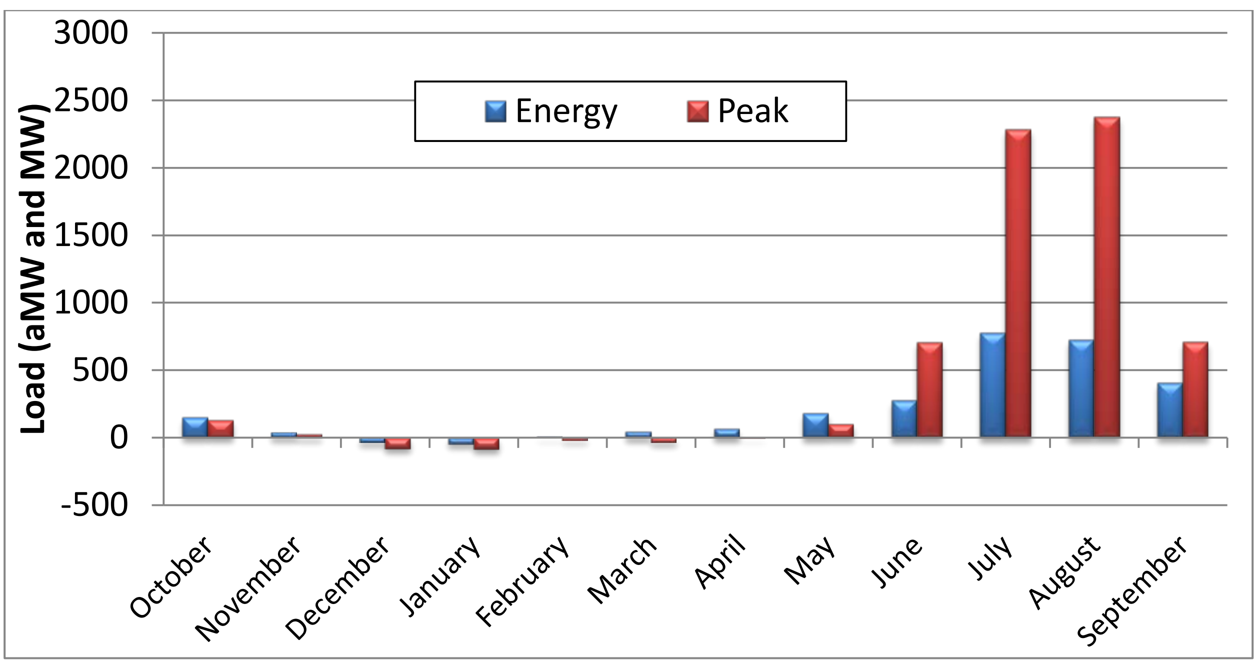


Figure M - 14b: **2035** Projected Change in Average and Peak Loads



The resulting projected load changes were applied to the base load forecast extracted from the Regional Portfolio Model futures number 781 and 70. Those specific futures generally reflect a high load growth path, which is shown in Figure M - 15. The corresponding resource acquisitions (including new energy efficiency measures) for both of these futures are shown in Figures M - 16a and M - 16b. The GENESYS model was run for both a climate-change and a non-climate-change scenario for both the 2026 and 2035 cases. The non-climate-change scenarios included the resource build out from the RPM futures and their base load forecasts. The climate-change scenario included the climate modified stream flow record and the climate modified loads – everything else was kept the same, including the resource acquisitions.

Figure M - 15 shows the Council's low and high annual energy load forecasts for the 20-year study horizon (solid black and red curves). It also shows the particular 20-year load path from RPM futures number 781 and 70, both of which show high load growth. In fact, the loads in future 781 actually slightly exceed the Council's forecast load range. The dots on Figure M - 15 represent the operating years that were analyzed with the GENESYS model. The red dot represents the load used for 2026 and the black dot reflects the load used for 2035. Figures M - 16a and M - 16b provide the RPM produced resource build outs for these two futures. The determination of the types and amounts of new resources is guided by the logic built into the RPM but also note that these resource build outs are for two different time periods. For example, future 781, which was used to assess 2026, shows 3,380 average megawatts of energy efficiency savings. Future 70, which was used to assess 2035, develops 4,167 average megawatts of savings. Since the year studied in iteration 70 comes nine years after the year studied for iteration 781, the difference in the amount of energy efficiency developed is primarily driven by these additional years, but also affected by other differences between these futures, such as natural gas and wholesale electricity prices.

The resource builds and the associated load forecasts were used in GENESYS to assess the non-climate-change scenario adequacy for 2026 and 2035. In each case, the resulting loss of load probability (LOLP) remained under 5 percent (the Council's maximum threshold). Next, these two scenarios were amended to include climate change induced load changes and streamflows. The results of the analyses are described in the sections below.

Figure M - 15: Load Paths for Two Different Futures out of RPM

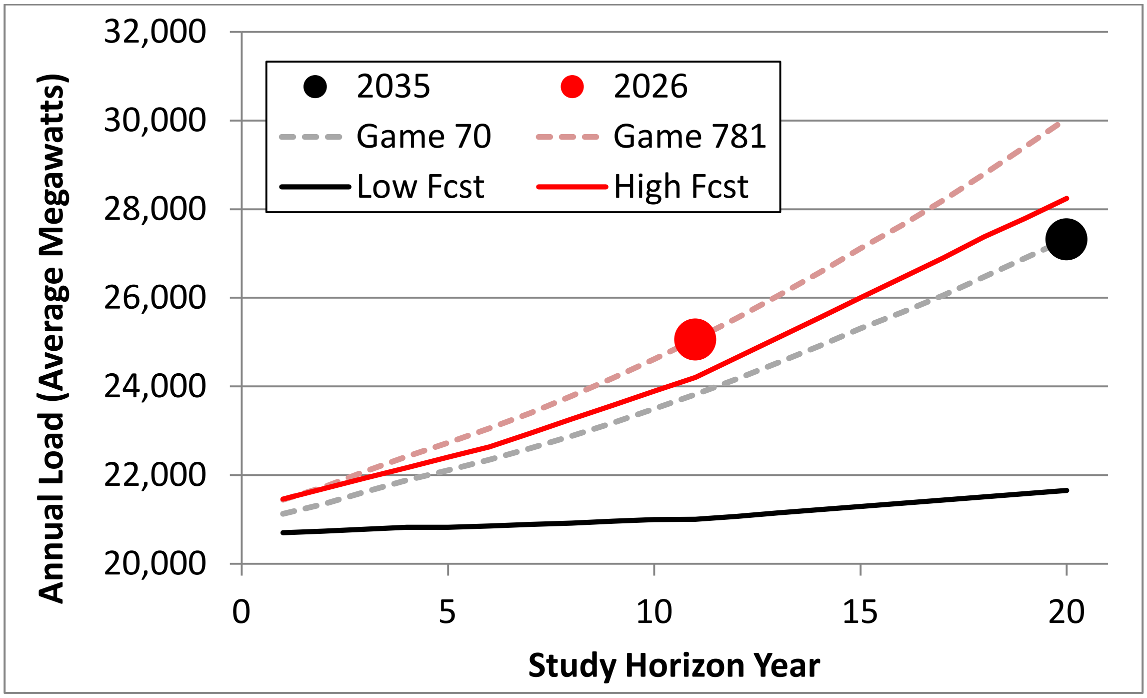


Figure M - 16a: **2026** Projected Resource Development (RPM Future 781)

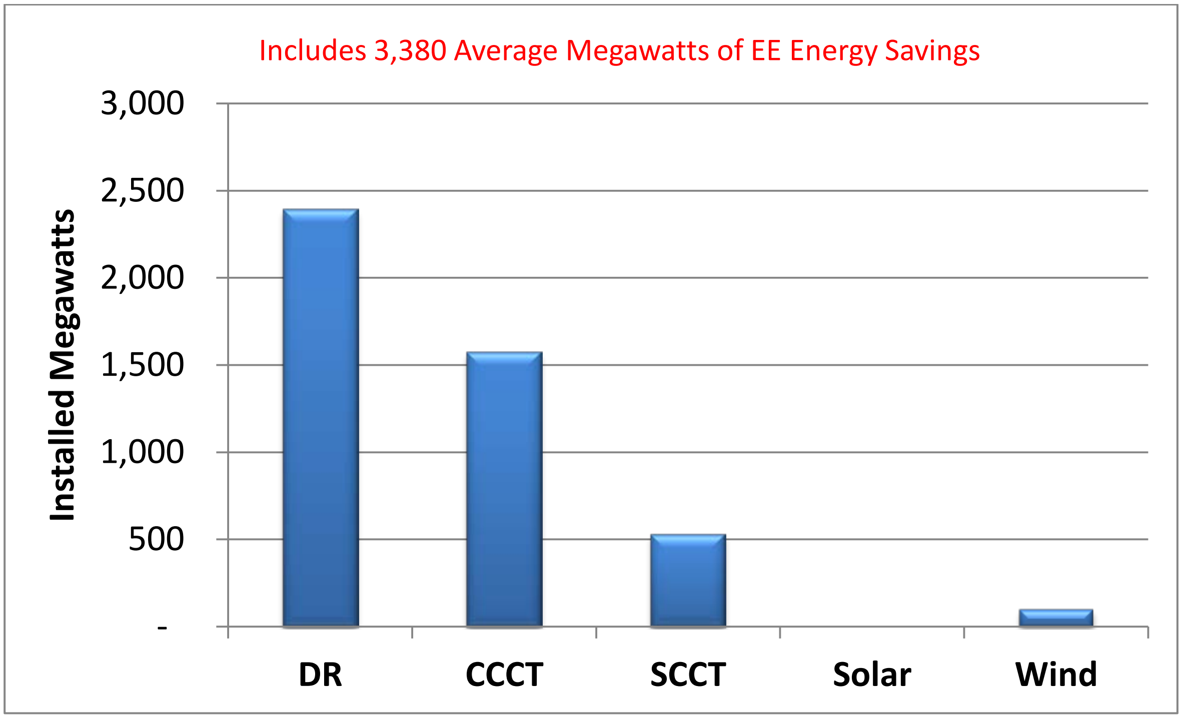
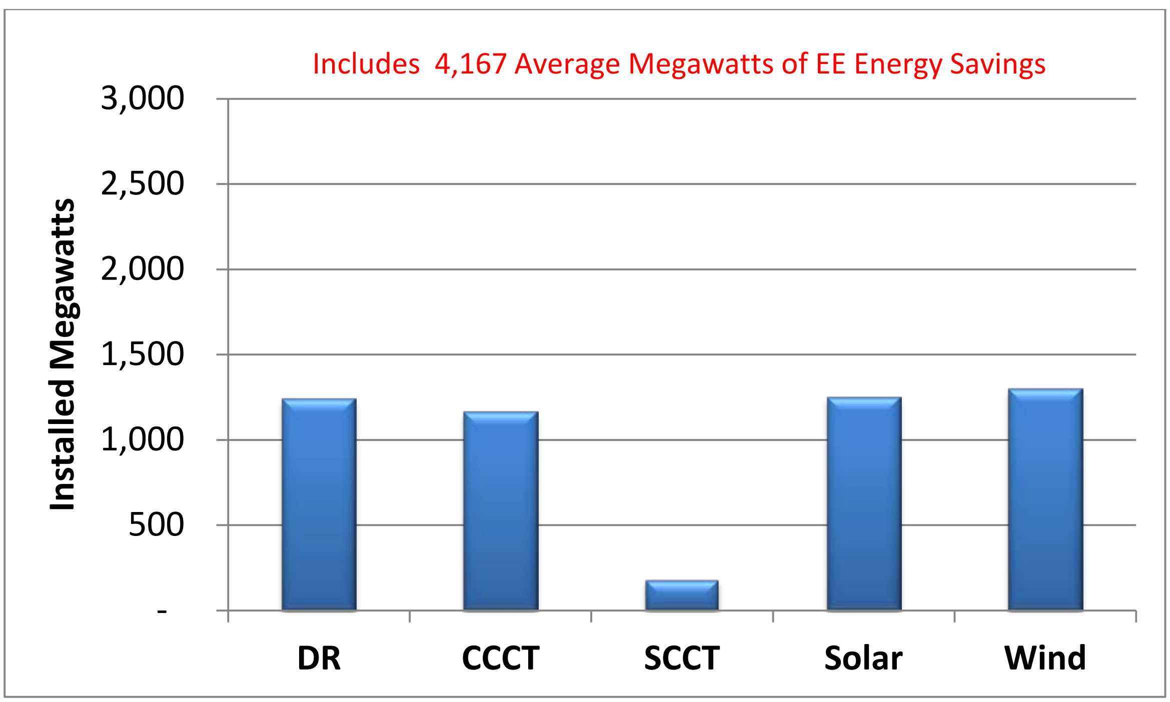


Figure M - 16b: **2035** Projected Resource Development (RPM Future 70)



Regulated Flows and Hydroelectric Generation

More rain in winter months means higher stream flows at a time when electricity demand is highest in the Northwest. This, in combination with the fact that demand for electricity is likely to decrease due to warmer temperatures, should ease the pressure on the hydroelectric system to meet electricity needs in winter months. In fact, excess water (water than cannot be stored) may be used to generate electricity that will displace higher-cost thermal resources or may be sold to out-of-region buyers.

While the future winter outlook under climate change appears to be better from a power system perspective, a more serious look at flood control operations is warranted. Some global circulation models indicate not only more fall and winter precipitation but also a higher possibility of extreme weather events, including heavy rain. This, together with warmer temperatures, should prompt the Corps of Engineers to reexamine flood risk management and the amount of its flood control releases from storage during the fall and winter period. Evacuation of water stored for flood control purposes would also add to hydroelectric generation and could further reduce the need for thermal generation during that time.

However, any winter power benefits are offset by potentially worse summer problems. With a smaller snowpack, the spring runoff volume will be correspondingly less, translating into lower river flows. On the demand side, except for the eastern portions of the Northwest, the region experiences its highest load during winter months. However, as summer temperatures increase so will electricity load due to anticipated increases in air-conditioning use. The projected increase in Northwest summer demand along with potential reductions in hydroelectric generation will force the Northwest to consider resource options for summer needs sooner rather than later.

Figure M - 17 shows the expected average regulated flow changes in 2026 and 2035 at McNary Dam due to climate impacts, which are similar to the pattern of unregulated flows shown in Figure M - 13 for The Dalles Dam.[12] The difference in summer regulated flows between the climate-change scenario and the non-climate-change scenario is small when compared to the difference in summer unregulated flows. This is because additional water is released in summer for both power and fish needs (see Figure M19 for storage content changes).

Hydroelectric generation is proportional to river flow, thus it is no surprise that the average change in hydroelectric generation for 2026 and 2035 (as shown in Figure M - 18) has the same monthly shape as the change in regulated flows. Table M - 3 summarizes the changes to winter and summer loads and the respective shifts in hydroelectric generation. The data in that table highlights the observation that under a climate change future, the winter power situation is improved while the summer situation gets much worse.

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[12] Regulated flows at McNary Dam are shown here because the Council's Fish and Wildlife Program minimum outflow requirements for smolt migration are linked to this project.

Figure M - 17: Projected Change in Regulated Flows at McNary Dam

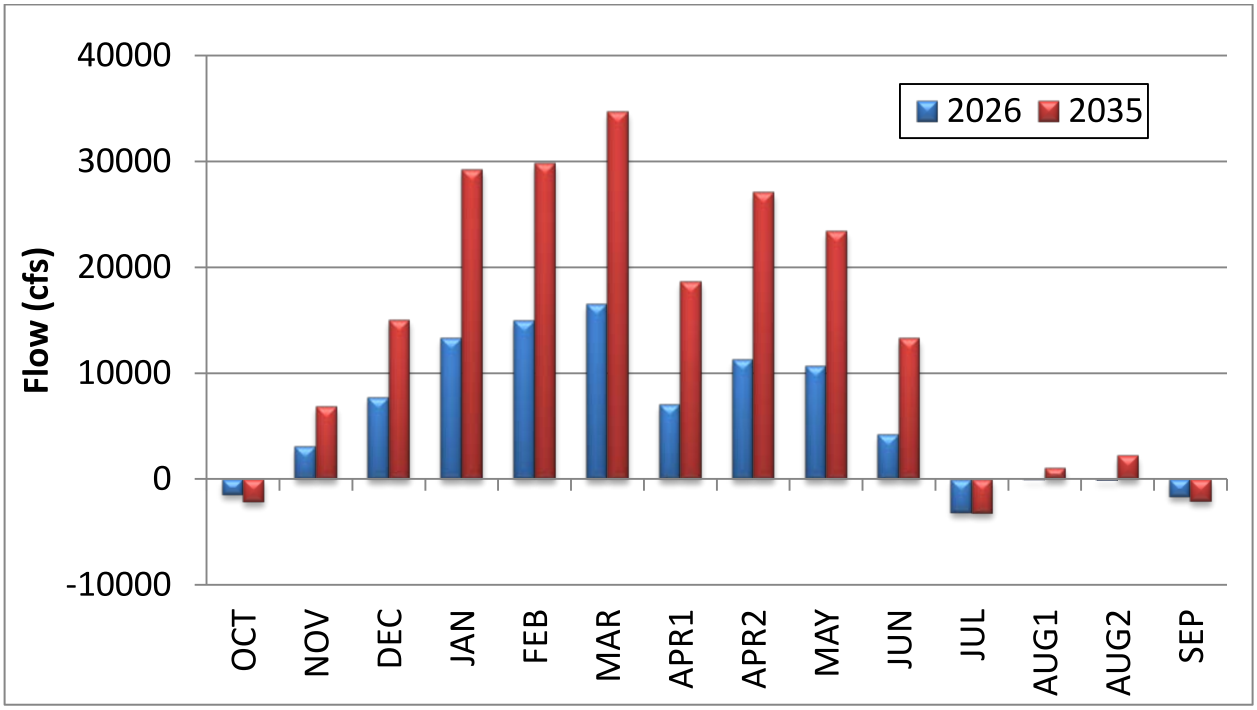


Figure M - 18: Projected Change in Hydroelectric Generation

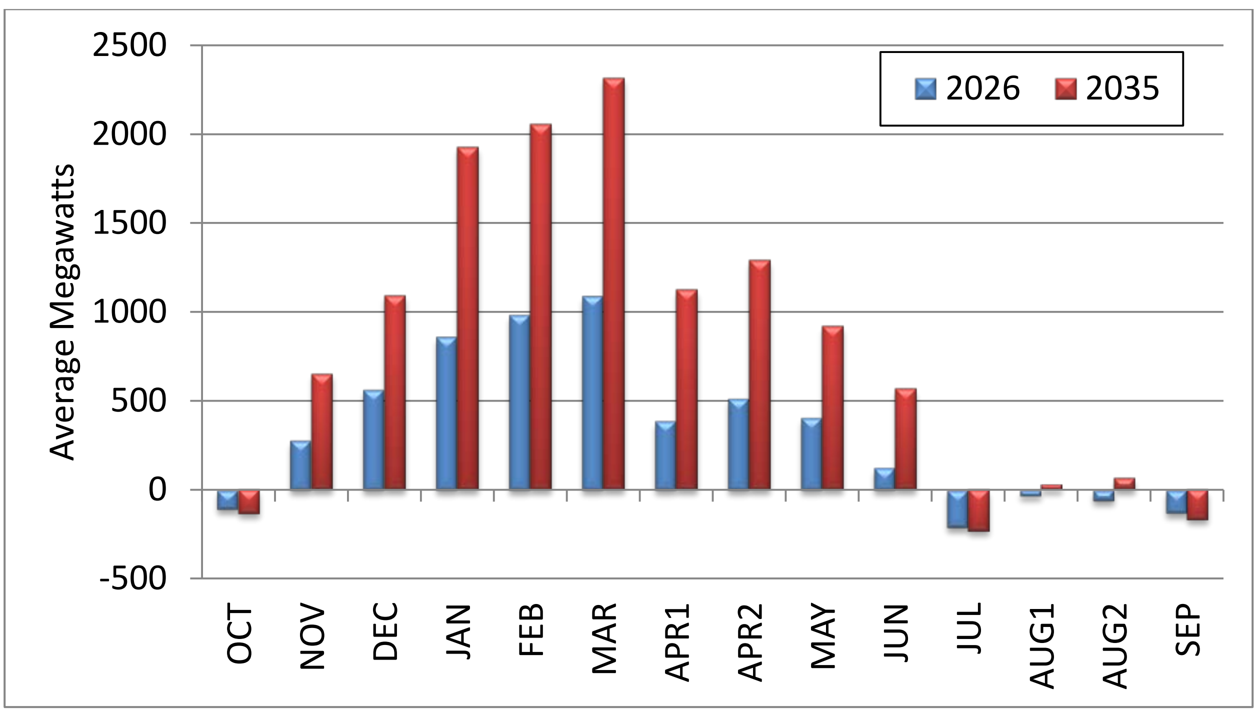


Table M - 3: Climate Induced Impacts to Energy Load/Resource Balance (aMW)

	2026		2035	
	Winter	Summer	Winter	Summer
Hydro Generation	700	-125	1,500	-140
Load	-20	400	-40	750
Net (R-L)	**720**	**-525**	**1,540**	**-890**

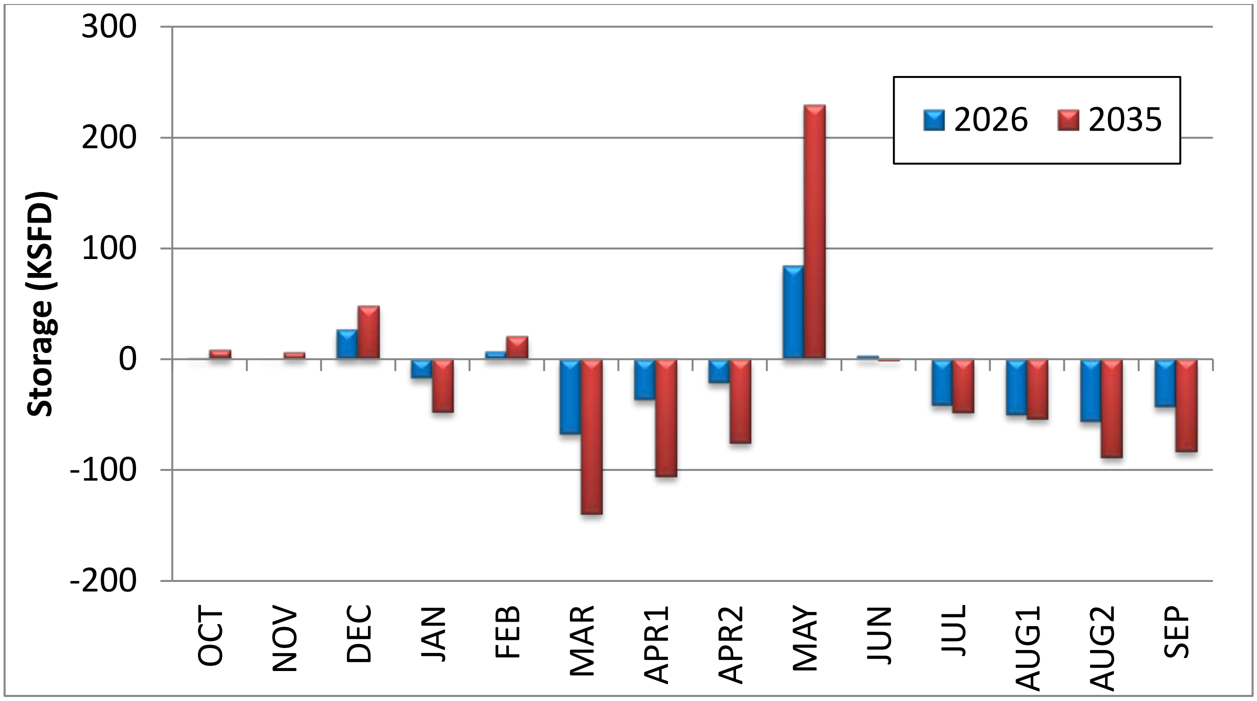
Reservoir Storage

Because of the climate-induced shift in unregulated flows and in demand for electricity, reservoirs will be used, to the extent possible, to realign the monthly pattern of hydroelectric generation to the changing monthly load shape. In fall and winter, for example, when demand should be lower, as much water as possible should be stored and held until summer when demand is expected to be higher. Due to operating constraints for non-power purposes (such as flood control and fish flow augmentation), however, it may not be possible to shift very much water from fall and winter to summer. On the positive side, because the snowpack is expected to be smaller, flood control elevations during spring months should be correspondingly higher, thus enabling more water to be stored and available for summer use.

Figure M - 19 shows the simulated change in aggregate average end-of-month storage content at Grand Coulee, Libby, Hungry Horse and Dworshak dams that would occur in 2026 and 2035 under a climate change scenario. Storage in this chart is measured in thousands of “second foot days” (KSFD). One KSFD is equivalent to roughly 2,000 acre-feet and 500 KSFD is equivalent to about one million acre-feet (MAF).

A breakdown of the results in that figure shows that, on average, the reservoir system stores water in December but that water is forced out in January. It is not clear why that occurs but it is likely due to non-power constraints. In March and April storage is down relative to a non-climate-change scenario. Again this may be due to constraints (minimum flow requirements) to keep salmon eggs and fry in the Columbia River submerged during those months. The month of May shows an increase in storage, likely due to reduced flood control requirements. Finally, in the summer months through September, the additionally stored water (and more) is released for both power and fish requirements. These storage changes are not large relative to the aggregate storage capability of these four projects, which is about 7.8 million acre-feet. It appears that, on average, the storage at these four projects will be slightly lower going into the following year. This effect was not included in the analysis because the GENESYS runs were performed as refill studies. More detailed analysis will be done once the IPCC 5 AR5 data is downscaled and prepared for hydrologic studies.

Figure M - 19: Climate Induced Change in Storage
(Coulee, Libby, Horse and Dworshak)



Power Supply Adequacy

In 2011, the Council adopted a resource adequacy standard that set the maximum likelihood of a future shortfall to be no more than 5 percent. This standard has been incorporated into the Regional Portfolio Model so that, in general, resource strategies developed by the model will produce power supplies that are adequate. Because climate change scenarios cannot, as yet, be included in Regional Portfolio Model analyses (see the section below), the purpose of this analysis is to assess whether a climate change scenario would alter any resource actions the region would take based on the power plan's recommendations.

In order to assess whether resource actions would be affected during the action plan period (first six years), expected resources acquisitions from a Regional Portfolio Model scenario can be examined for adequacy for a normal case and for a climate change case. For this comparison, scenario 1B was used to extract the resource builds for a high-load path case for the years 2026 and 2035 (see Figure M - 15). Power supply adequacy was examined for both those years for both normal and climate change scenarios.

In both cases, the 2026 power supply was deemed adequate. However, that does not mean that climate change has no impacts. Figure M - 20a illustrates the 2026 expected monthly energy shortfalls for both the normal and climate change scenarios prior to the deployment of demand response resources. (After deployment, both scenarios show very little shortfall, which makes comparing the two scenarios difficult.) Figure M - 20b shows the 2035 expected monthly energy shortfalls.

As evident in Figure M - 20a, monthly shortfalls in winter decrease somewhat in the climate change scenario while monthly shortfalls in summer greatly increase. This supports the observation made above that the region is transitioning from a winter-only peaking region to one with both winter and summer peaks. Figure M - 20b illustrates the expected monthly energy shortfalls for 2035.

Figure M - 20a: **2026** Projected Change in Expected Loss of Load

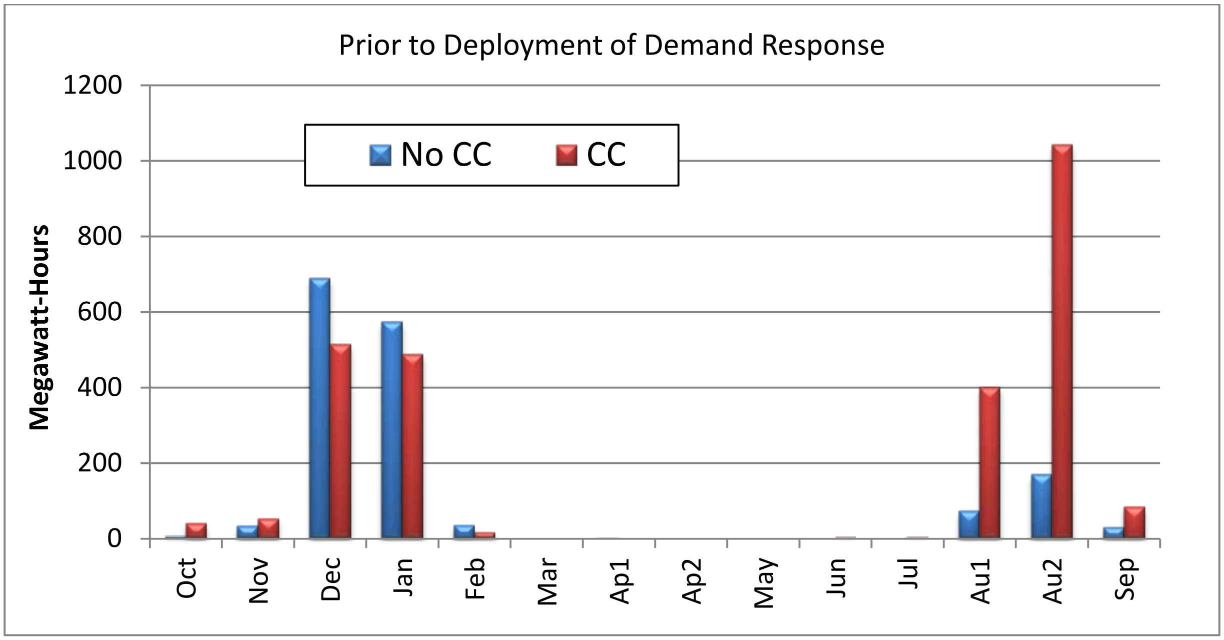
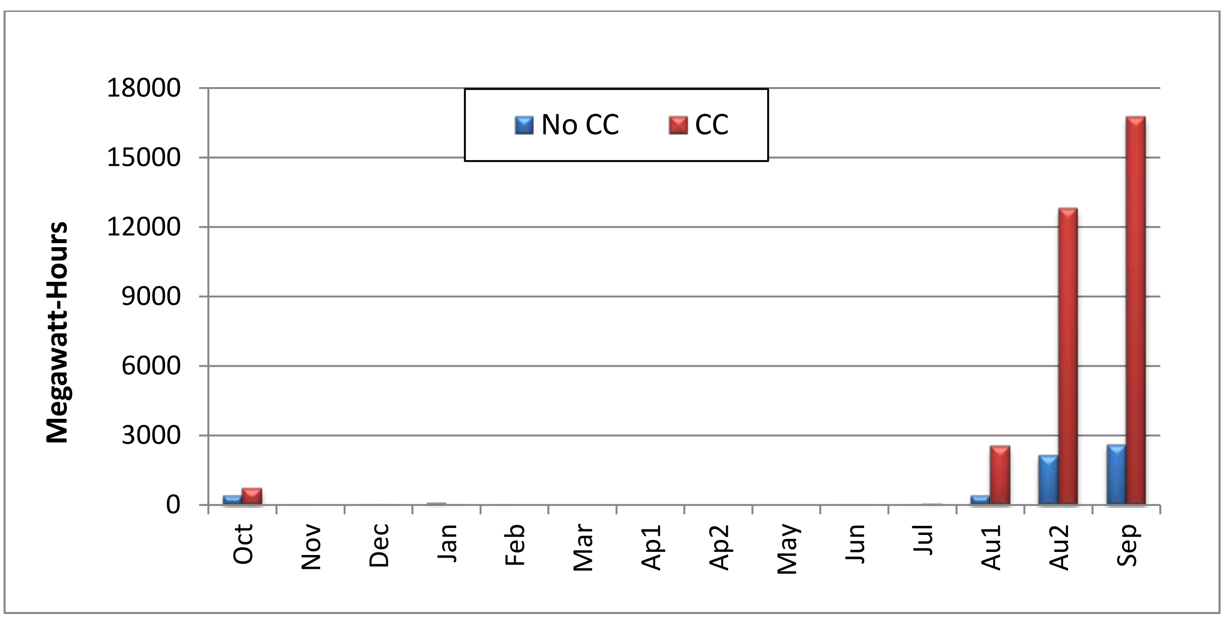


Figure M - 20b: 2035 Projected Change in Expected Loss of Load

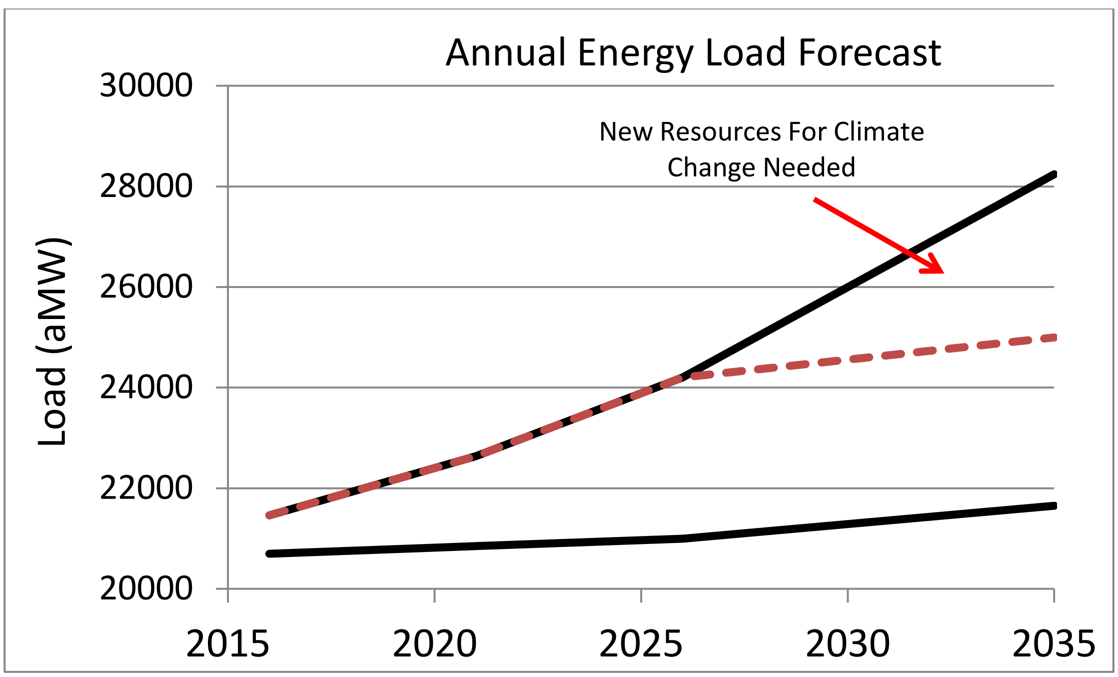


Climate Change Effects on the Seventh Plan

For the 2035 high load case, the resulting loss of load probability under the climate change scenario grew to about 15 percent, which violates the maximum standard of 5 percent established by the Council. This means that for the 2035 high load case, additional resources would be needed to offset the temperature and flow impacts of climate change. However, the 2026 high load case indicated that no new resources were required under the climate change scenario to maintain adequacy. Therefore, the Council concluded that no new resource acquisitions would be needed until at least 2026 beyond those called for in the Seventh Plan's resource strategy. This means that the climate change scenario analyzed for this appendix has no effect on this plan's six year action plan.

For a medium load path case through 2035, in which only economic energy efficiency savings were acquired, no new resources for climate change were needed, thus setting somewhat of a lower bound for climate-change required resource additions. Figure M - 21 illustrates the load conditions under which the region may need additional resources to offset the effects of climate change.

Figure M - 21: When Additional Resources may be needed to offset Climate Change



OTHER CLIMATE CHANGE IMPACTS

Because river flows are likely to decrease in spring and summer, smolt (juvenile salmon) outmigration (journey to the ocean) and adult salmon returns will be affected. Lower river flows translate into lower river velocity and longer travel times to the ocean for migrating smolts. Lower river flows combined with higher air temperatures also means that water temperatures are likely to increase, another factor contributing to salmonoid fish stress and mortality. For example, based on this year's experience, warm water appears to have been detrimental to larger sturgeon. However, other warm water species will likely fare better – possibly even thrive in warmer waters.

The projected shift in unregulated flows could:

- Put greater flood control pressure on storage reservoirs and increase the risk of late fall or winter flooding;
- Boost winter production of hydroelectric generation when Northwest demands are likely to drop due to higher average temperatures;
- Reduce the size of the spring runoff and shift its peak to an earlier time;
- Reduce late spring and summer river flows and potentially cause average water temperatures to rise, especially in the tributaries;
- Jeopardize native fish survival, particularly salmon, steelhead and possibly sturgeon, by reducing the ability of the river system to meet minimum flow and water temperature requirements during the spring, summer and fall;
- Reduce the ability of reservoirs to meet demands for irrigation water;
- Reduce summer power generation at hydroelectric dams when Northwest demands and power market values will likely be higher; and
- Affect summer and fall recreation activities.

Besides the impacts to river flows, hydroelectric generation and temperatures, climate change will affect the Northwest's electricity interactions with other regions. Currently, both the Northwest and Southwest benefit from having different peak load periods. During the winter peak demand season in the Northwest, the Southwest generally has surplus capacity, which can be imported to help with winter reliability. In the summer months, the opposite is generally true and some of the Northwest's hydroelectric capacity can be exported to help the Southwest meet its peak demand needs. This sharing of resources is cost effective for both regions.

Under a severe climate change scenario the Northwest could see increased summer demand with greatly decreased summer hydroelectric production. It is possible the Northwest could find itself having to plan for summer peak needs as well as for winter peaks. In that case, the Northwest would no longer be able to share its surplus capacity with the Southwest. This would obviously have economic impacts in the Southwest where additional generating resources may be needed to maintain summer service. This would likely raise the value of late summer energy in the West, thereby increasing the economic impact of climate change to the Northwest.

All of the impacts described above are based on an analysis of a hydroelectric system operation using current drafting and filling constraints for both power and non-power purposes. It is unclear at this time how much flexibility the system has to modify certain constraints in order to better adapt hydroelectric generation with shifts in electricity load. For example, if reservoirs were allowed to be drafted deeper by summer's end, the additional regulated flow and corresponding generation would benefit both migrating fish and electricity customers, and potentially late fall and early winter flood control. Unfortunately, making this change could affect other non-power users. However, it is prudent to review all constraints placed on the hydroelectric system operation in light of potential climate change impacts.

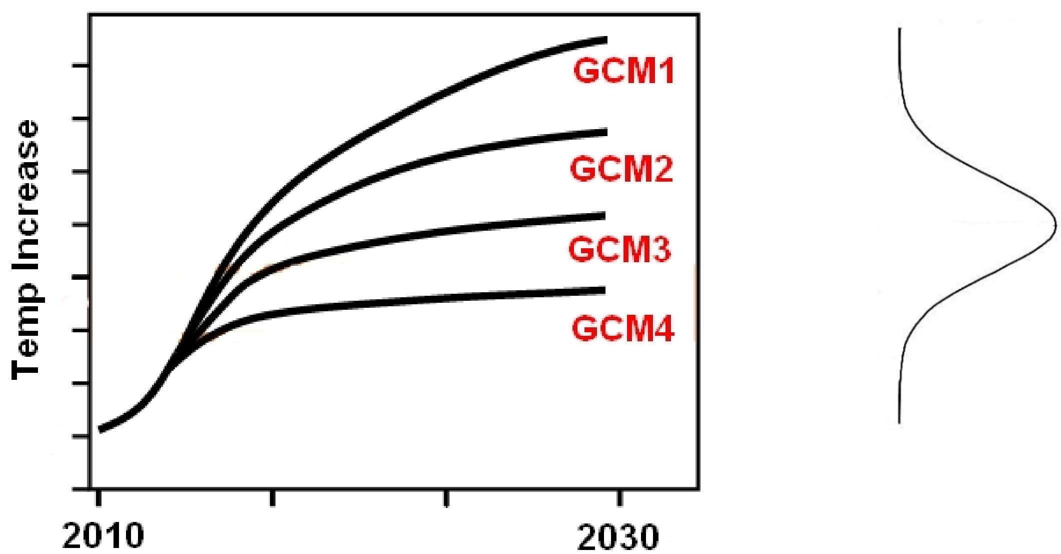
MODELING CLIMATE CHANGE IN THE REGIONAL PORTFOLIO MODEL

Ideally, climate change uncertainty and its impacts to hydroelectric generation and loads would be included as one of the random variables in the Council's Regional Portfolio Model. Unfortunately, this cannot be done at this time for several reasons. First, the data required to do so is not available. Second, even if the data were available, the Regional Portfolio Model is not equipped to accommodate it. Third, the relative likelihood of occurrence for each separate GCM climate change scenario is not known.

Figure M - 2 illustrates the mean forecasted temperature and precipitation changes in the Columbia River Basin for a number of climate change scenarios. Each point in this graph represents the result of a single GCM climate change scenario analysis. Three conclusions can be drawn from this figure; 1) each GCM result shows a net temperature increase, 2) nothing definitive can be said about the change in total annual volume of precipitation and 3) there is great uncertainty in both the temperature and precipitation forecasts.

The Regional Portfolio Model is a Monte Carlo computer program that assesses average power system cost and economic risk for many different resource plans. Each resource plan is, in essence, a potential supply curve of available new resources, including conservation, over the study horizon period. Each resource plan is examined over many different potential futures for the Northwest. Each future covers a 20-year period and draws from many random variables, including load, hydroelectric generation (water condition), electricity prices, fuel prices and carbon cost to assess costs. In order to incorporate climate change uncertainty into the model as a random variable, the relative likelihood of occurrence for each climate scenario shown in Figure M - 2 must be known. Then for each future examined, one particular climate change profile would be selected (i.e. one of the points in Figure M - 2) as one of the many random variables used for that particular future. This concept is illustrated graphically in Figure M - 22. In this figure, the mean forecasted temperature increase per year over a 20-year period is plotted for several different climate change scenarios (GCM1 through GCM4). In this example, a probability distribution is assigned to the set of scenarios, shown as the bell curve to the right of the graph. In this example, GCM2 and GCM3 are more likely to occur than GCM1 or GCM4 and thus they would be selected more often in the Monte Carlo simulation. Probability distributions for Northwest climate change scenarios, however, have not yet been developed.

Figure M - 22: Illustrative Probability Distribution for Climate Model Results



Unfortunately, this is only one problem that has to be overcome in order to incorporate climate change as a random variable into the Regional Portfolio Model. Once a climate scenario is chosen by the model, its long-term effects on load and on hydroelectric generation will have to be interpolated back into the 2015 to 2035 study horizon period. Methods for performing that interpolation have not been extensively explored, although an example of one method has already been discussed earlier in this appendix.

But in spite of these difficulties, progress is being made. The Bonneville Power Administration, the Corps of Engineers and the Bureau of Reclamation have initiated a regional process to collect, review and make available all climate change data related to river operations. This process is being developed under the auspices of the River Management Joint Operating Committee (RMJOC) and will ultimately result in a web-based database that will include climate change data needed to perform river operation analyses. Among other things, the additional data will include climate-change adjusted runoff forecasts and operating rule curves. The Council supports this work and will actively participate in its development. Currently, the RMJOC is scheduled to complete its work to translate the AR5 results into useable data by the end of 2016 or by early 2017.

CONCLUSIONS AND RECOMMENDATIONS

Global circulation models all seem to agree that future temperatures will be higher but they differ on overall levels of precipitation. Some models suggest that the Northwest will be drier while others indicate more precipitation. But all the models predict less snow and more rain during winter months, resulting in a smaller spring snowpack. Winter electricity demands would decrease with warmer temperatures, easing the Northwest's generating requirements. In the summer, demands driven by air conditioning and irrigation loads would rise and potentially force the region to compete with the Southwest for electricity resources.

The development of the Seventh plan for the Northwest incorporates actions intended to address future uncertainties and their risks to electricity supply and to the economy. Such uncertainties include fluctuations in demand, fuel prices, changes in technology and increasing environmental constraints. Uncertainties related to climate change fall into two areas; 1) physical impacts that affect electricity demand and hydroelectric generation and 2) policies directed at reducing greenhouse gas emissions that affect resource operation and cost. The effect of policy decisions is described in more detail in Chapters 3 and 15. The physical effects of climate change have no effect on the resource acquisition or actions identified in this plan over the next six year period. However, the Council will continue to monitor and participate in regional efforts to better understand potential climate change and its effects on the power supply.

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