Effects of Climate Change on the Hydroelectric System

SUMMARY

The Council is not tasked, nor does it have the resources to resolve existing uncertainties associated with global warming. Currently, there is still much debate surrounding the data, although a preponderance of scientific opinion asserts that the Earth is warming. The science has gotten stronger over the last 15 years and many uncertainties have been resolved. And although it appears that this trend is likely to continue, some uncertainties remain.

While the Council cannot resolve these issues, it does have the obligation to investigate potential impacts of climate change to the power system and to recommend mitigating actions whenever possible. While global warming cannot be modeled with precision for the Pacific Northwest, it is possible to make general predictions about potential changes and, as a result, recommend policies and actions that could be adopted and implemented today to prepare for potential future impacts.

Many nations and government agencies are already taking actions. Canada, for example, has signed on to the Kyoto agreement. Also, a pilot cap-and-trade system for carbon dioxide is to be implemented in Europe in 2005 with a mandatory system in place by 2008. Oregon, Massachusetts and New Hampshire require offsets for new fossil power plants and Washington legislators have recently enacted a carbon dioxide offset requirement for new power plants, similar to Oregon's.

Global climate change models all seem to agree that temperatures will be higher but they disagree somewhat on levels of precipitation. Some models suggest that the Northwest will be drier while others indicate more precipitation in the long term. 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 peak requirements. In the summer, demands driven by air conditioning and irrigation loads would rise and potentially force the region to compete with southern California for electricity resources.

All of these changes have implications for the region's major river system, the Columbia and its tributaries. More winter rain would likely result in higher winter river flows. Less snow means a smaller spring runoff volume, resulting in lower flows during summer months. This could lead to many potential impacts, such as:

- Putting greater flood control pressure on storage reservoirs and increasing the risk of winter flooding;
- Boosting winter production of hydropower when Northwest demands are likely to drop due to higher average temperatures;
- Reducing the size of the spring runoff and shifting its timing to slightly earlier in the year;

- Reducing late spring and summer river flows and potentially causing average water temperatures to rise;
- Jeopardizing fish survival, particularly salmon and steelhead, by reducing the ability of the river system to meet minimum flow and temperature requirements during spring, summer and fall migration periods;
- Reducing the ability of reservoirs to meet demands for irrigation water;
- Reducing summer power generation at hydroelectric dams when Northwest demands and power market values are likely to grow due to higher air conditioning needs in the Northwest and Southwest; and
- Affecting summer and fall recreation activities in reservoirs.

There also are potential impacts away from the river system, particularly for the electricity industry. Current scientific knowledge holds that global warming largely results from increased production of carbon dioxide and other greenhouse gasses due to human activities. Because of the widespread use of fossil fuels to produce electricity, the electricity industry worldwide is a principal contributor to the growing atmospheric concentration of carbon dioxide and would be affected by any initiatives to reduce carbon emissions.

The Council has used its resource portfolio model to look at the potential effects of control polices aimed at reducing greenhouse gas emissions on the relative cost-effectiveness of resources available to the Northwest. This involved posing different scenarios about the probability, timing and magnitude of carbon control measures and assessing their effect on different portfolios in terms of cost and risk. This analysis may also shed light on the value of various strategies to address climate change impacts.

The Council's electricity price forecasting model, AURORA©, is being used to assess the possible impact of carbon dioxide control measures on electricity prices and what changes in the composition of the generating resource mix it might induce.

The effects of the uncertainty surrounding a potential carbon tax have been incorporated into the Councils portfolio analysis and have appropriately influenced the recommended resource strategy and action plan. Further details of that analysis are provided in the main section of the power plan and in appendix M.

The potential effects of climate change on river flows and the operation of the hydroelectric system are still being refined but indications are that the region will see a slowly evolving shift in flow pattern. Analysis summarized in this appendix identifies the potential range of changes and the corresponding impacts to hydroelectric production. Some suggestions are made regarding actions that could be implemented to mitigate potential impacts to reliability and potential increases to fish mortality. However, due to the uncertainty surrounding the data and models used for climate change assessment, no actions (other than to continuing to monitor the research) are recommended in the near term.

BACKGROUND

Over the last century or so, the Earth's surface temperature has risen by about 1 degree Fahrenheit, with accelerated warming during the past two decades. The ten warmest years have all occurred in the last 15 years. Of these, 1998 was the warmest year on record. Warming has occurred in both the northern and southern hemispheres, and over the oceans. Melting glaciers and decreased snow cover further substantiate the assertion of global warming and appears to be more pronounced at higher latitudes. Figure N-1 below illustrates the warming trend, showing global temperatures from 1880 to 2000.

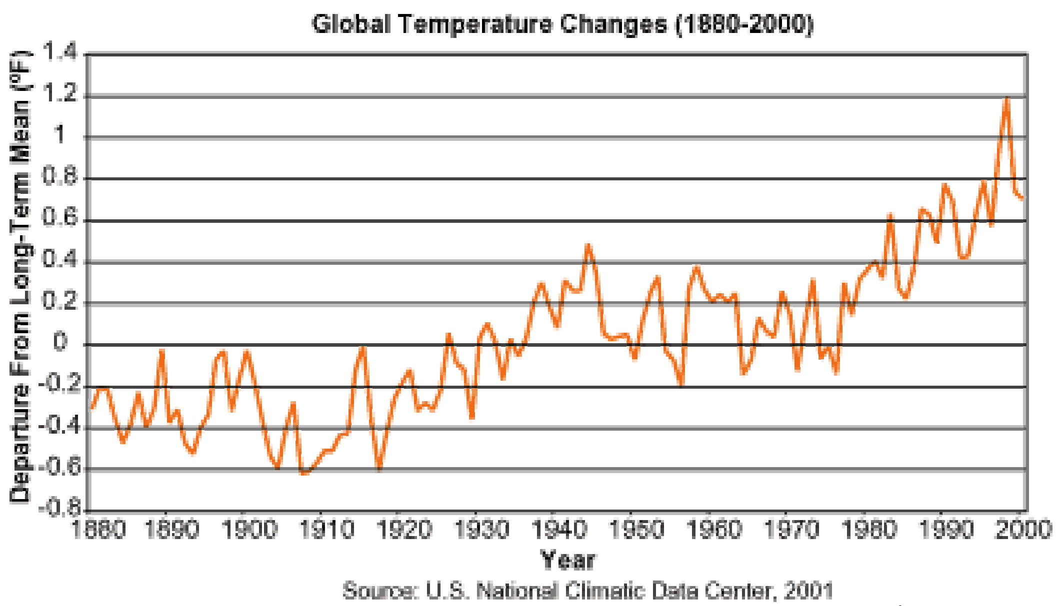

Figure N-1: Global Temperature Changes (1880-2000)[1]

Two rather obvious questions arise related to the data in Figure N-1. First, is this rise in temperature statistically significant (i.e. is the warming trend real?) and, if it is, what are its causes? Secondly, what potential impacts might global warming have and are there mitigating actions that we can take? While the first question is scientifically very interesting and is of great importance to Northwest inhabitants, the Council is not tasked to explore or debate this issue. Rather, the Council's efforts are directed toward the second question. More specifically, it must assess potential Northwest impacts of global warming and determine what mitigating actions are required to continue to protect, mitigate and enhance fish and wildlife populations, while maintaining an adequate, efficient, economic and reliable power supply for the Northwest. However, before moving on to a discussion of potential Northwest impacts and mitigating actions, the debate surrounding global warming will be briefly examined.

Is Global Warming Real?

There is much anecdotal evidence of increasing temperature. Over the last 20 years, we have observed retreating glaciers, thinning arctic ice, rising sea levels, lengthening of growing seasons (for some), and earlier arrival of migratory birds. The northern hemisphere snow cover and Arctic Ocean floating ice have decreased. Sea levels have risen 8 to 10 centimeters over the past century, as illustrated in Figure N-2. Worldwide precipitation over land has increased by about one percent and the frequency of extreme rainfall events has increased throughout much of the United States. Figure N-3 shows that in 1910 about 9 percent of the U.S. experienced extreme rainfall compared to about 11 or 12 percent by 1990.

[1]Source: U.S. National Climatic Data Center, 2001

A cursory look at the temperature data in Figure N-1 indicates that there has been a warming trend and that it appears to be accelerating. However, the average change in temperature over the last century has been about one degree Fahrenheit, which may arguably be smaller than the accuracy of early measuring devices. It is also not clear how many geographical data points were available in the early years. (Recall that the data reflects average surface temperature over the entire Earth). Other things to consider are rare natural events, such as large volcanic eruptions or serious weather events that may have increased the greenhouse effect sporadically over the years. Such events may explain (at least in part) some of the year-to-year variation in the curve in Figure N-1. But, before further discussing the uncertainties surrounding global warming, it would be beneficial to understand what scientists believe is the cause.

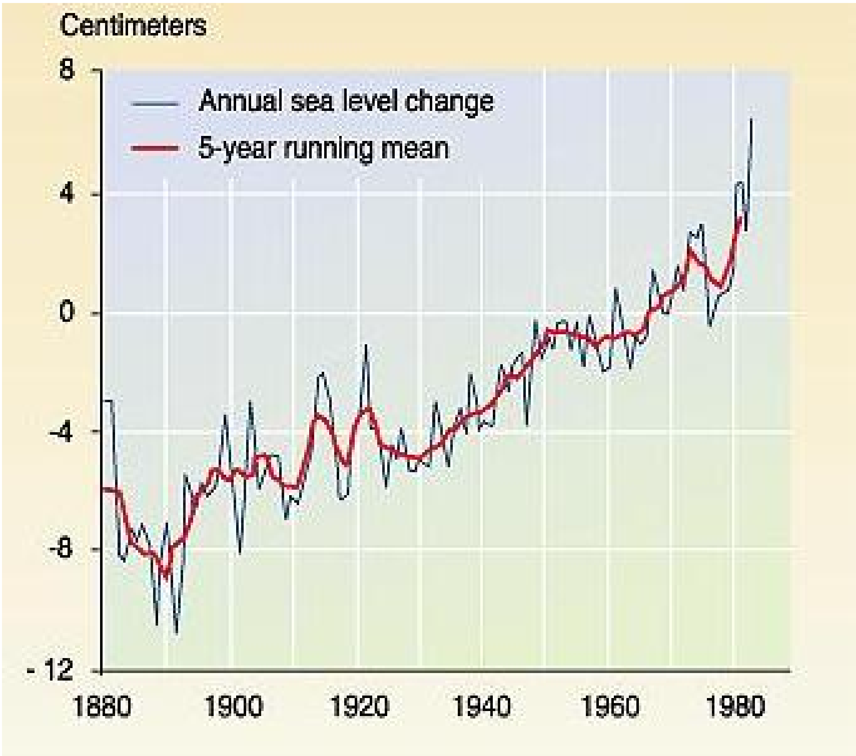

Figure N-2: Historical Rise in Sea Level

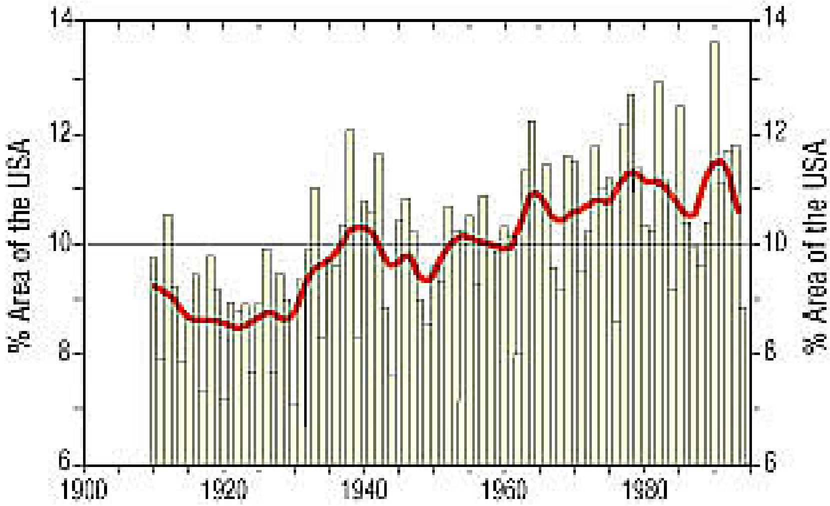

Figure N-3: Percentage of US Area Experiencing more Extreme Rainfall[2]

Causes of Global Warming

It has been scientifically proven that greenhouse gases (water vapor, carbon dioxide, methane, nitrous oxide and the man-made CFC refrigerants) trap heat in the Earth's atmosphere and tend to warm the planet. A schematic illustrating this effect is shown in Figure N-4. The Inter-governmental Panel on Climate Change (IPCC) concluded that the apparent global warming in the last 50 years is likely the result of increases in greenhouse gases, which accurately reflects the current thinking of the scientific community. Scientists know for certain that human activities are changing the composition of Earth's atmosphere. Increasing levels of greenhouse gases, like carbon dioxide, in the atmosphere since pre-industrial times have been well documented. Figure N-5 illustrates both temperature and carbon dioxide concentration increases over the past thousand years. While the uncertainty in data prior to the development of sophisticated temperature measuring devices in the 19th century may be rather large, it is apparent from this graph that both temperature and carbon dioxide concentration have increased more rapidly over the past 100 years.

Though ninety-eight percent of total greenhouse gas emissions are *naturally* produced (mostly water vapor) and only 2 percent are from man-made sources, over the last few hundred years, the concentration of man-made greenhouse gases in the atmosphere has increased dramatically. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30 percent, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15 percent. These increases have enhanced the heat-trapping capability of the earth's atmosphere and tend to remain in the atmosphere for periods ranging from decades to centuries. Figure N-6 shows the approximate makeup of greenhouse gases in our atmosphere today (excluding water vapor).

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[2] Source: Center for Climate Change and Environmental Forecasting (www.climate.volpe.dot.gov/precip.html)

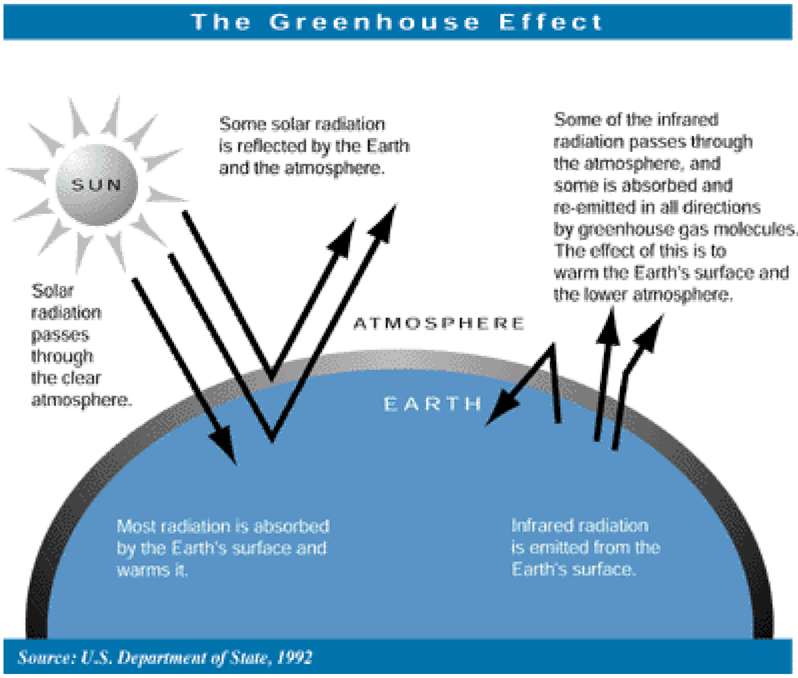

Figure N-4: The Greenhouse Effect[3]

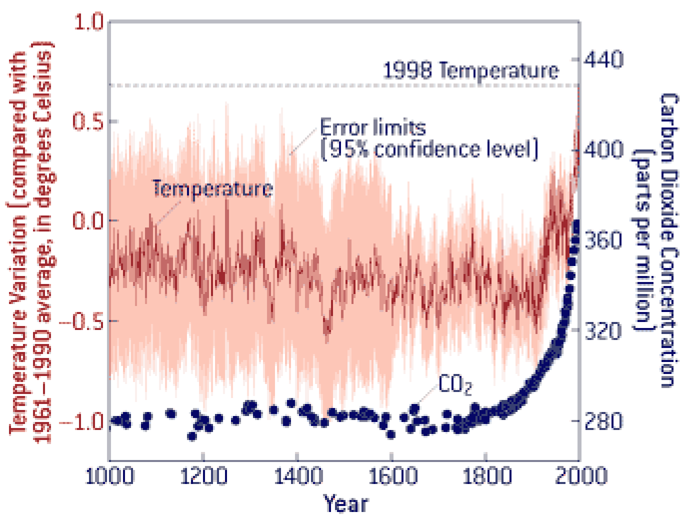

Figure N-5: Temperature and Carbon Dioxide Concentration over the last Century[4]

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[3] Source: U.S. Department of State, 1992
[4] Source: Intergovernmental Panel on Climate Change

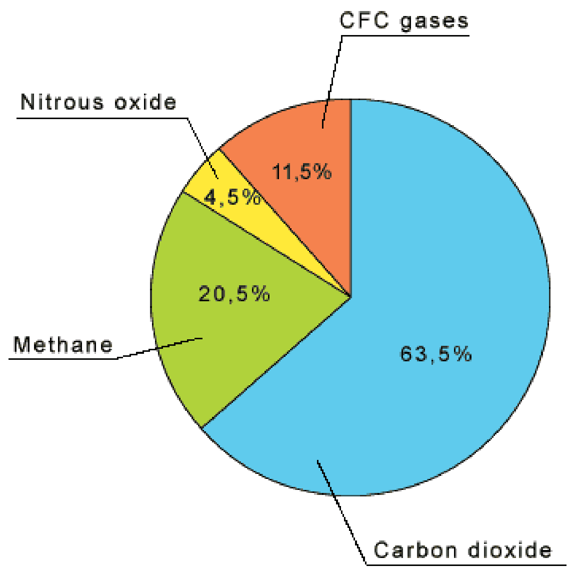

Figure N-6: Greenhouse Gases Worldwide[5]

Fossil fuels burned to run cars and trucks, heat homes and businesses, and power factories are responsible for about 98 percent of U.S. carbon dioxide emissions, 24 percent of methane emissions, and 18 percent of nitrous oxide emissions. Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share of emissions. In 1997, the United States emitted about one-fifth of total global greenhouse gases. Figure N-7 below provides a breakdown of the known sources of greenhouse gases. The largest contributors are electricity production and transportation, which both produce carbon dioxide. Together, they represent approximately one-third of the total man-made production of carbon dioxide. Industrial and commercial uses and residential heating make up about a quarter of the total. Figure N-8 illustrates the production of carbon dioxide by sector since 1970.

[5]Source: Institut Français du Pétrole (IFP) (http://www.ifp.fr/IFP/en/images/fb/gaz-effet-serre-fb04.gif)

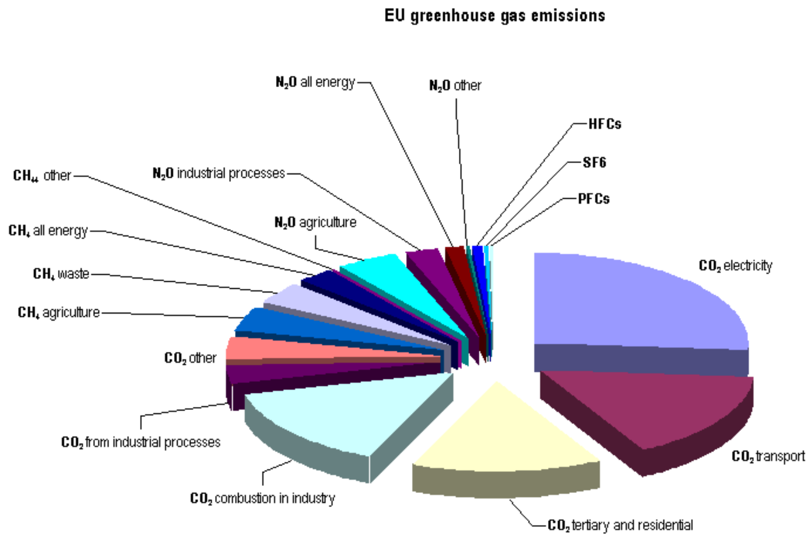

Figure N-7: Sources of Greenhouse Gases[6]

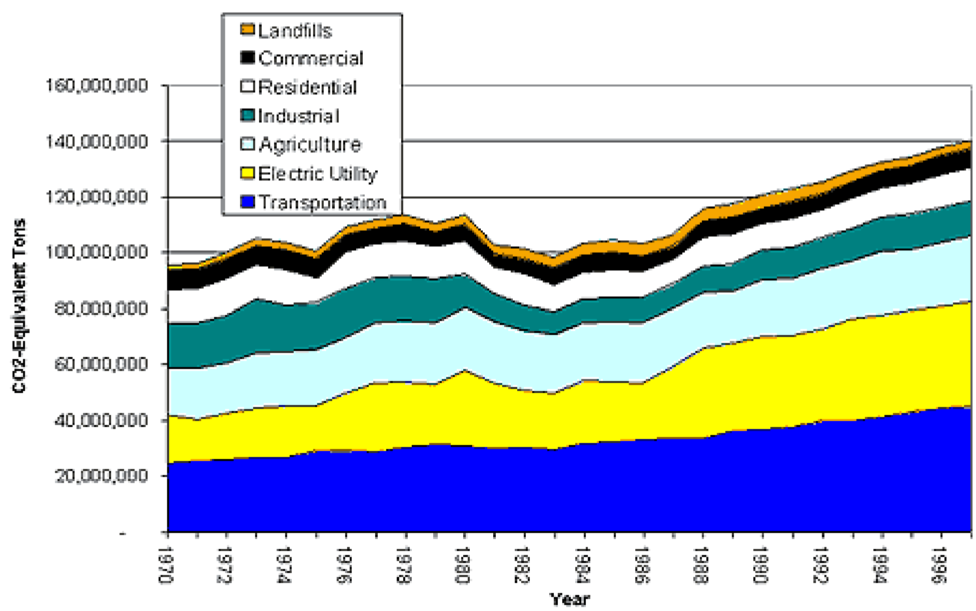

Figure N-8: Sources of Carbon Dioxide Production[7]

[6] Source: Climate Action Network Europe (www.climnet.org)
[7]Source: Minnesota Pollution Control Agency (www.pca.state.mn.us)

Figuring out to what extent the human-induced accumulation of greenhouse gases since pre-industrial times is responsible for the global warming trend is still under debate. This is because other factors, both natural and human, affect our planet's temperature. Scientific understanding of these other factors – most notably natural climatic variations, changes in the sun's energy, and the cooling effects of pollutant aerosols – remains incomplete.

As atmospheric levels of greenhouse gases continue to rise, scientists estimate average global temperatures will continue to rise as a result. By how much and how fast remain uncertain. Based on assumptions that concentrations of greenhouse gases will continue to grow the IPCC projects further global warming of 2.2 to 10°F (1.4 to 5.8°C) by the year 2100. This range results from uncertainties in greenhouse gas emissions, the possible cooling effects of atmospheric particles such as sulfates, and the climate's response to changes in the atmosphere. The IPCC goes on to say that even the low end of this warming projection "would probably be greater than any seen in the last 10,000 years, but the actual annual-to-decadal changes would include considerable natural variability."

Uncertainty Surrounding Climate Change

Scientists are more confident about their projections of climate change for large-scale areas (e.g., global temperature and precipitation change, average sea level rise) and less confident about the ones for small-scale areas (e.g., local temperature and precipitation changes, altered weather patterns, soil moisture changes). This is largely because computer models used to forecast global climate change are still ill equipped to simulate how things may change at smaller scales.

There are at least 19 different global models that simulate changes in temperature over time. Every one of these models, to some degree (no pun intended), projects a warming trend for the Earth. Each is a sophisticated computer model using 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 all play a major role in determining our climate.

Scientists who work on climate change models are quick to point out that they are far from perfect representations of reality, and are probably not advanced enough for direct use in policy implementation. Interestingly, as the computer climate models have become more sophisticated in recent years, the predicted increase in temperature has gotten smaller. Nonetheless, most climatologists concur that the warming trend is real and could have serious impacts worldwide.

Potential Impacts of Global Warming

One of the consequences of global warming is a more rapid melting of ice caps, which would increase the likelihood of flooding at coastal cities. Given the forecasted range of global temperature increase, mean sea level is projected to rise by 0.09 to 0.88 meters by 2100, due to melting ice caps and thermal expansion of the oceans (due to higher water temperatures). Warmer oceans could also lead to shifts in upwelling and currents and could have detrimental impacts to ecosystems.

Evaporation should increase as the climate warms, which will increase average global precipitation. There is also the possibility that a warmer world could lead to more frequent and intense storms, including hurricanes. Preliminary evidence suggests that, once hurricanes do form, they will be stronger if the oceans are warmer due to global warming. However, it is unclear whether hurricanes and other storms will become more frequent. Figure N-9 shows the frequency of hurricanes since 1949. In spite of the decline in hurricanes in 1994 and 1995, it appears that a trend exists toward more frequent occurrences, but the data is not conclusive.

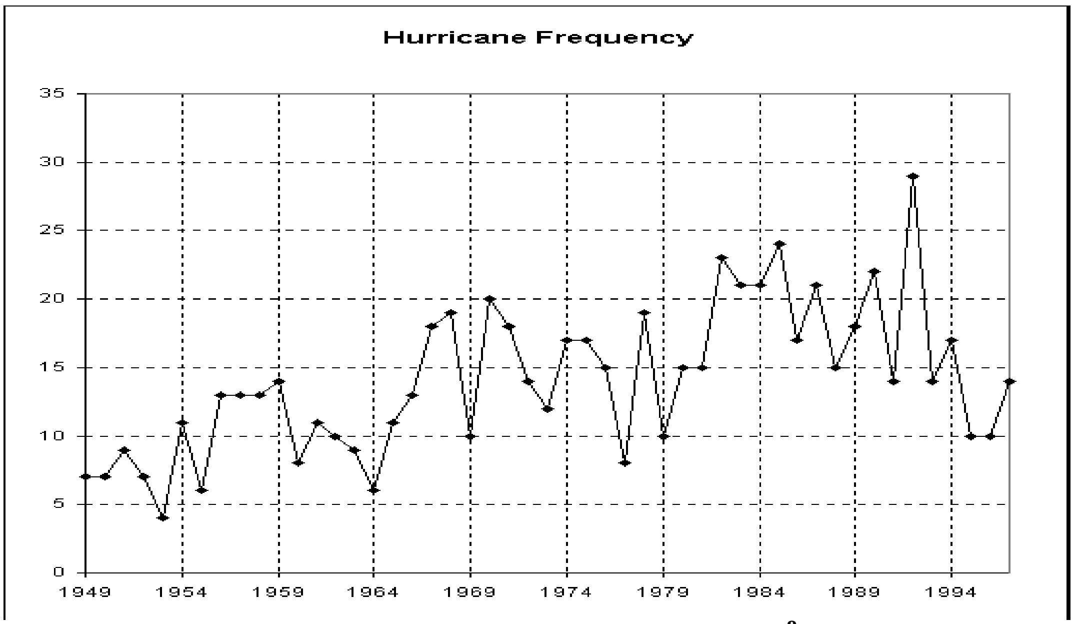

Figure N-9: Frequency of Hurricanes[8]

More and more attention is being aimed at the possible link between El Niño events – the periodic warming of the equatorial Pacific Ocean – and global warming. Scientists are concerned that the accumulation of greenhouse gases could inject enough heat into Pacific waters such that El Niño events would become more frequent and fierce. Here too, research has not advanced far enough to provide conclusive statements about how global warming will affect El Niño.

For the Northwest, models show that potential impacts of climate change include a shift in the timing and perhaps the quantity of precipitation. They also show less snow in the winter and more rain, thus increasing natural river flows. Also, with warmer temperatures, the snowpack should melt earlier, which would result in lower summer river flows. More discussion regarding these possible impacts and their implications is provided in the next section.

Actions to Address Climate Change

Global warming poses real risks. The exact nature of these risks remains uncertain. Ultimately, this is why we have to use our best judgment – guided by the current state of science – to determine what the most appropriate response to global warming should be.

[8]Source: TV Weather (www.tvweather.com)

In 1992 the United States and nations from around the world met at the United Nations' Earth Summit in Rio de Janeiro and agreed to voluntarily reduce greenhouse gas emissions to 1990 levels by the year 2000. The Rio Treaty was not legally binding and, because reducing emissions would likely cause unwanted economic impacts, many nations were expected not to meet that goal.

Representatives from around the world met again in December of 1997 in Kyoto to sign a revised agreement. Because of concerns regarding the possible economic effects, the treaty excluded developing nations. However, the US Senate voted 95-0 against supporting a treaty that doesn't include developing nations. At the time, the Clinton Administration negotiators agreed to legally binding, internationally enforceable limits on the emission of greenhouse gases as a key tenet of the treaty. The president's position presupposed that the potential damage caused by global warming would greatly outweigh the damage caused to the economy by severely restricting energy use.

The Clinton Administration also supported a system of tradable permits to be used by companies that emit carbon dioxide. These permits could be bought and sold internationally, giving companies an incentive to lower emissions and thus sell their permits. But this system would require massive international oversight on the order of a worldwide Environmental Protection Agency (EPA) to track carbon dioxide emissions, and the costs to consumers would be high.

The U.S. did agree to a 7 percent reduction of carbon dioxide emissions from what they were in 1990 -- a target to be met by 2008-12. This agreement would place further restrictions on energy generation from fossil-fuel burning resources. There appears to be as much controversy regarding the economic impacts of control policies for greenhouse gases as there is regarding the effects of climate change. In addition, suggestions were made to establish a vigorous program of basic research to reduce uncertainties in future climate projections and to develop a system that monitors long-term climate predictions.

ASSESSING IMPACTS TO THE NORTHWEST

Northwest Climate Models

Dozens of groups around the world are actively investigating global climate change and its potential impacts.[9] Most of these organizations have developed complex computer models used to forecast long-term changes in the Earth's climate. These models are used to estimate the effect of greenhouse gases on the Earth's climate. The most sophisticated of these models are known as "general circulation models" or GCMs. These models take into account the interaction of the atmosphere, oceans and land surfaces.[10] Each of these models has been "calibrated" to some degree and crosschecked against other such models to give us more confidence in their forecasting ability.

The one problem that global models share, however, is that their minimum geographical scale is generally too large to make predictions for small regions such as the Northwest. GCMs tend to do a very reasonable job of forecasting on a global basis, but unfortunately, that information is of no use to planners in the Northwest. Thus, a method of "downscaling" the output from these

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[9] http://stommel.tamu.edu/~baum/climate_modeling.html
[10] http://gcrio.org/CONSEQUENCES/fall95/mod.html

models has been developed.[11] This downscaled data matches better with hydrological data used to simulate the operation of the Columbia River Hydroelectric Power System. Thus, using temperature and precipitation changes forecast by global climate models, downscaled for the Northwest, an adjusted set of potential future water conditions and temperatures can be generated. The adjusted water conditions can be used as input for power system simulation models, which can determine impacts of climate change in the Northwest. Temperature changes lead to adjustments in electricity demand forecasts and river flow adjustments translate into both changes and temporal shifts in hydroelectric generation.

Projected Changes in Northwest Climate and Hydrology

Downscaled hydrologic and temperature data for the Northwest was obtained from the Joint Institute for the Study of Atmosphere and Ocean (JISAO)[12] Climate Impacts Group[13] at the University of Washington. This data was derived primarily from two GCMs, the Hadley Centre model (HC)[14] and the Max Planck Institute model (MPI)[15] although the Climate Impacts Group also uses other models.

The JISAO Climate Impacts Group at the University of Washington has compiled a set of projected future temperature and precipitation changes based on four global climate models.[16] Figure N-10 below illustrates those projections for the four models and also shows the mean (dark line). Two conclusions can be drawn from the figure below; 1) that each model shows a net temperature and precipitation increase, and 2) that there is great variation in both the temperature and precipitation forecasts.

For the Council's analysis, mean monthly temperature changes were used for both 2020 and 2040. Figure N-11 illustrates the temperature change forecast used for 2020 and 2040. Please note that in Figure N-11, the vertical temperature scale is in degrees Fahrenheit instead of Celsius and the horizontal time scale reflects an operating year (September through August) as opposed to a calendar year. Because the correlation between temperature change and water condition was not yet available, the analysis assumed that mean monthly temperature changes would apply to each water condition examined.

[11] 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."
[12] http://tao.atmos.washington.edu/main.html
[13] http://tao.atmos.washington.edu/PNWimpacts/index.html
[14] http://www.met-office.gov.uk/research/hadleycentre/models/modeltypes.html
[15] http://www.mpimet.mpg.de/en/web/
[16] The global climate models used for these scenarios were the HadCM2, HadCM3, ECHAM4, and PCM3. Mote, P., 2001: "Scientific Assessment of Climate Change: Global and Regional Scales," White Paper, JISAO Climate Impacts Group, University of Washington.

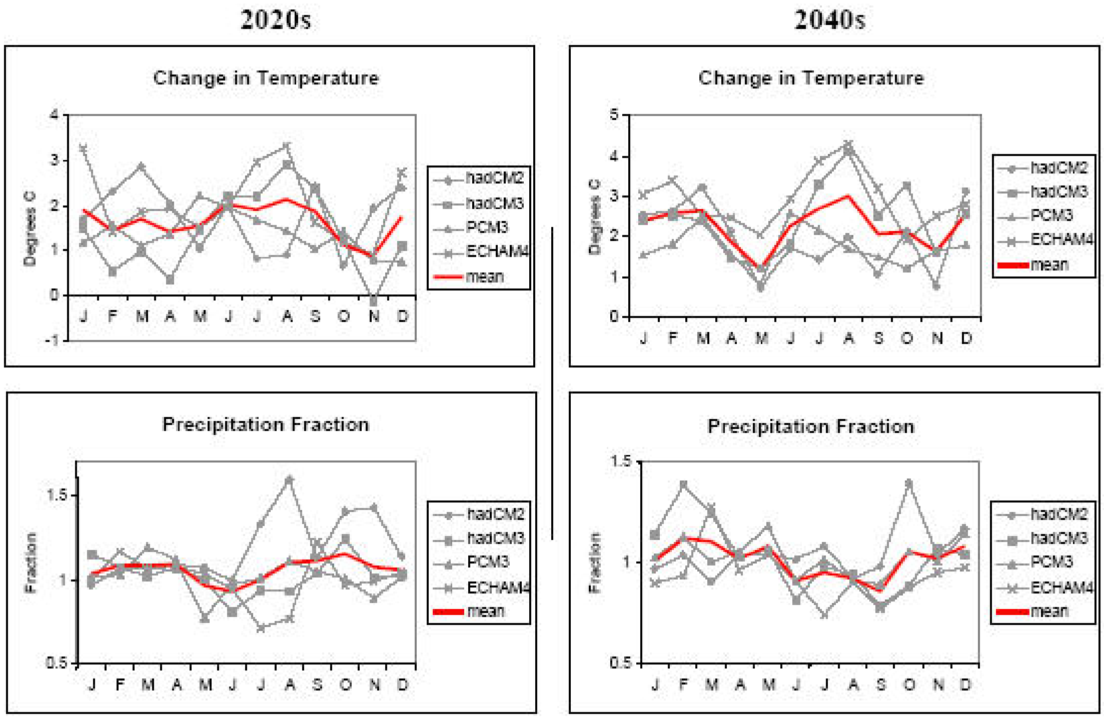

Figure N-10: Temperature and Precipitation Change Forecasts[17]

[17] Borrowed from CIG Publication No. 145, Hamlet, Alan, F., July 3, 2001: "Effects of Climate Change on Water Resources in the Pacific Northwest: Impacts and Policy Implications," JISAO Climate Impacts Group, University of Washington.

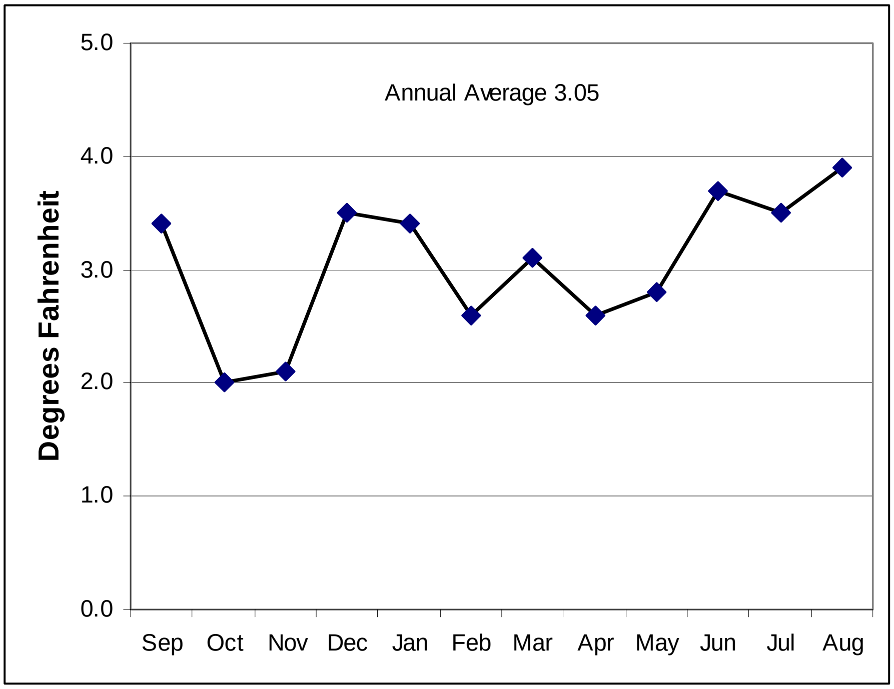

Figure N-11: Forecast Change in NW Monthly Temperatures by 2020

Table N-1: Forecast Temperature Increases for the Northwest (Degrees Fahrenheit)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
2020	3.4	2.0	2.1	3.5	3.4	2.6	3.1	2.6	2.8	3.7	3.5	3.9
2040	3.7	3.8	2.9	4.6	4.3	4.7	4.8	3.4	2.2	4.1	4.9	5.4

The Hadley Centre (HC) model generally shows an overall increase in precipitation across the year. The Max Planck Institute (MPI) model tends to forecast a drier future. Figures N-12a and N-12b compare the mean annual runoff volumes (in millions of acre-feet as measured at The Dalles Dam) for each scenario for 2020 and 2040. The historical mean is about 133 million acre-feet (maf). For this analysis, the historic water conditions from 1930-78 were used.

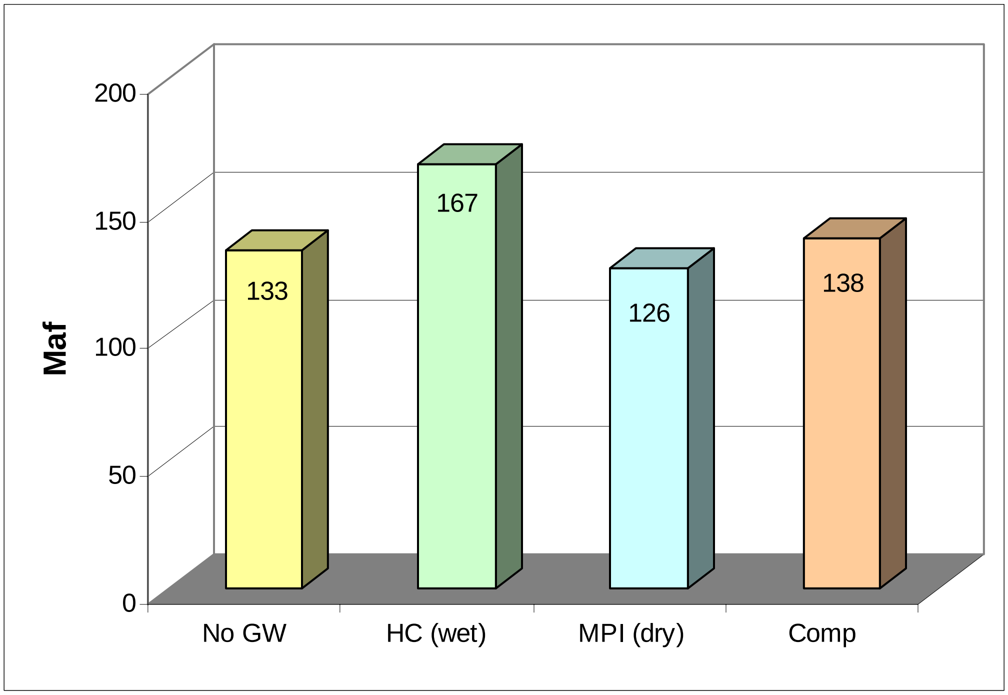

Figure N-12a: Annual Average Runoff Volume at The Dalles (2020)

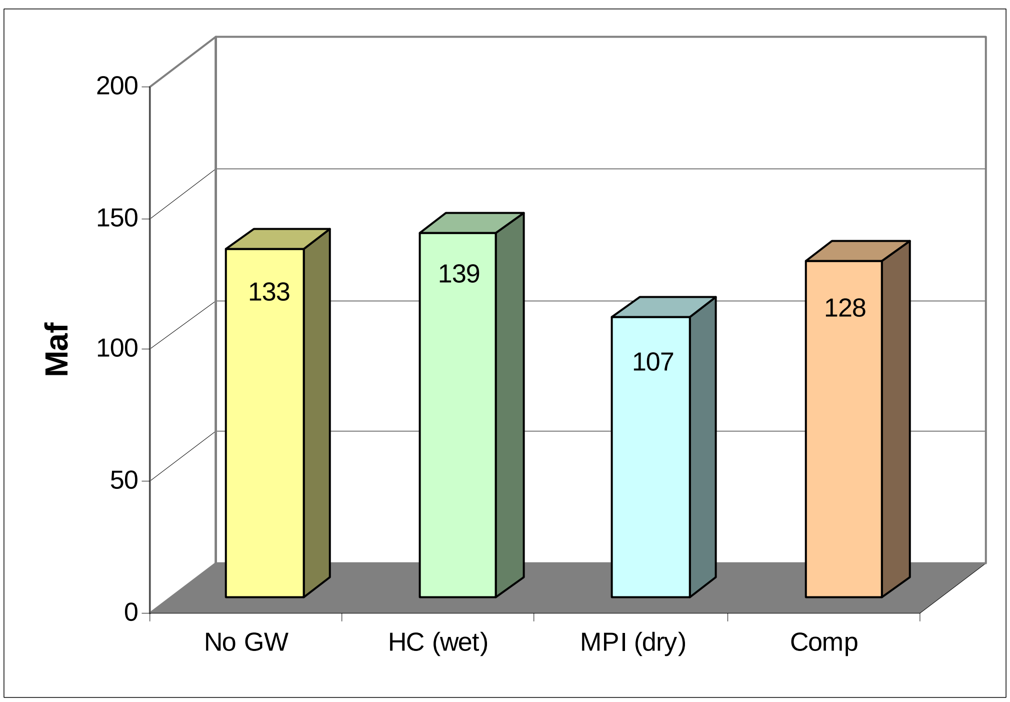

Figure N-12b: Annual Average Runoff Volume at The Dalles (2040)

For 2020, the HC model shows a greater annual runoff volume (167 Maf compared to the historical average of 133 Maf). Total useable storage in the Columbia River Basin is about 42 maf, with about half of that available in U.S. reservoirs. Under the HC scenario, the hydroelectric system should see about 34 Maf more water on an average annual basis. That is almost as much water as can be stored in all of the reservoirs on the Columbia River. This means that the region can displace more non-hydroelectric resources and sell more surplus hydroelectric energy in the wholesale market. Overall, it means that the region should see a decrease in the average cost of energy production.

The MPI model shows a slight annual decrease in river volume (126 Maf relative to the historical average of 133 Maf). While this reduction in average annual volume is not as large as the projected increase in volume under the HC model, it is still a significant amount of water. The 7 Maf reduction amounts to about a 5 percent drop in river volume, which translates into higher costs for the region because more expensive non-hydro resources must be run to make up the difference (or less revenue will be gained from the sale of surplus hydroelectric generation). More on the estimated cost under each of theses scenarios is discussed later.

For 2040, the HC model forecasts a much smaller increase in annual runoff volume (139 Maf as opposed to 167 Maf for 2020). Although smaller, the projected average annual river volume for 2040 is still 6 Maf larger than the historical average and should still result in lower overall average operating costs for the northwest power system. The MPI model for 2040 shows a much greater decrease in annual volume (107 Maf). This decrease of 26 Maf, relative to the historical annual average of 133 Maf, is more water than can be stored in U.S. reservoirs (21 Maf) and would increase the cost of operation.

Despite the inconsistencies between the HC and MPI models in terms of projected annual river volume, they both show greater winter period runoff (and consequently flows) and lower summer runoff. More information on this will be discussed in the next section.

Assessment of Impacts to the Power System

Three sets of hydrological data were produced for operating years[18] 2020 and 2040. Each is a downscaled and bias-adjusted set of water conditions generated using output from a particular global model. The first two sets of water conditions are derived from the HC and MPI models and the third set is derived from a combination of model runs (COMP). Other caveats regarding this study are specified below:

- Adjusted streamflows are only available for 1930-78 water conditions (out of the 1929-78 historical record generally used for Northwest power-system analysis)
- Only one monthly temperature adjustment is associated with each water condition (this implies no correlation between water conditions and temperature change)
- Operating guidelines (rule curves) for the hydro system have not been adjusted (i.e. flood control has not been adjusted for the change in spring runoff forecast nor have firm drafting limits been re-optimized)
- Summer demand sensitivity to temperature is likely too low (it must be increased to take into account the higher level of air-conditioning penetration)

[18] Power planners in the Northwest generally define an operating year to be from September through August.

- This analysis is a deterministic study, in the sense that each adjusted water condition was given an equal likelihood of occurring.
- The analysis modeled the current generating-resource/demand mix (no attempts were made to use projected resources or loads in 2020 or 2040)

Impacts to River Flows

Most global climate models indicate that the Northwest will become hotter across each month of the year. If this is true, then less precipitation will fall as snow in fall and winter months, thus reducing the amount of snowpack in the mountains. Also, more rain in winter months (as opposed to snow) means higher streamflows at a time when electricity demand is highest. This, plus the fact that demand for electricity is likely to decrease due to warmer winter months, should ease the pressure on the hydroelectric system to meet winter electricity needs. In fact, excess water (water than cannot be stored) may be used to generate electricity that will displace higher-cost thermal resources or be sold to out-of-region buyers.

While the winter outlook appears to be better from a power system perspective, a more serious look at flood control operations is warranted. Some global climate models indicate not only more fall and winter precipitation in the Northwest but also a higher possibility of extreme weather events, including heavy rain. This should prompt the Corps of Engineers to examine the potential to begin flood control evacuations prior to January, when they currently begin. Evacuation of water stored in reservoirs during winter months for flood control purposes will add to hydroelectric generation and further reduce the need for thermal generation.

However, any winter power benefits could be offset by summer problems. With a smaller snowpack, the spring runoff will correspondingly be less, translating into lower river flows. As mentioned earlier, lower river flows (and less hydroelectric generation) may not be a Northwest problem now because of the excess hydroelectric system capacity. Except for some small portions of the northwest, the region experiences its highest demand for electricity during winter months. However, as summer temperatures increase so will electricity demand due to anticipated increases in air-conditioning use. In addition, potentially growing constraints placed on the hydroelectric system for fish and wildlife benefits may further reduce summer peaking capability. It is also possible that summer air-quality constraints may be placed on northwest fossil-fuel burning resources (there are none currently), which would also decrease the peaking capability. The projected increase in Northwest summer demand along with potential reductions in both hydroelectric and thermal generation may force the Northwest to compete with the Southwest for resources. Currently, the Northwest has surplus capacity during summer months when the Southwest sees its peak demand and the Southwest is surplus in the winter months when the Northwest has its peak.

This unfortunately, is not the only summer problem inherent with a climate change. Because river flows are likely to decrease, 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 also mean that water temperature may increase, another factor contributing to smolt mortality. In a later section, some actions will be explored that may ease this situation, although in the worst case the region will have insufficient means to adjust to the forecasted changes.

Figures N-13a, N-13b and N-13c illustrate monthly average river flows at The Dalles for the historic water record and the climate-change adjusted water record (all based on historic natural flows from 1930 to 1978). Figure N-13a shows the HC model adjustments for both 2020 and 2040. The HC data reflects a warm-and-wet scenario, which translates into higher flows, especially in winter and early spring. Flows are lower in summer through early fall. As with all the climate model runs, flows in 2040 are projected to be lower than in 2020. In addition to the overall increase in river flow volume, the peak flow occurs a little earlier than the historic average. Peak flows in the HC adjusted data occur in mid-May as opposed to early June for the historic data. This same pattern exists for each of the three climate change scenarios examined.

Figure N-13b illustrates projected changes in average river flows for the MPI scenario (warm and dry). In this case, winter flows are higher but not nearly as much as in the HC case. Late spring and summer flows are greatly reduced. Again we see the slightly earlier peak in about mid-May. Figure N-13c shows average river flows for the COMP scenario, which is essentially an average of several climate change studies.

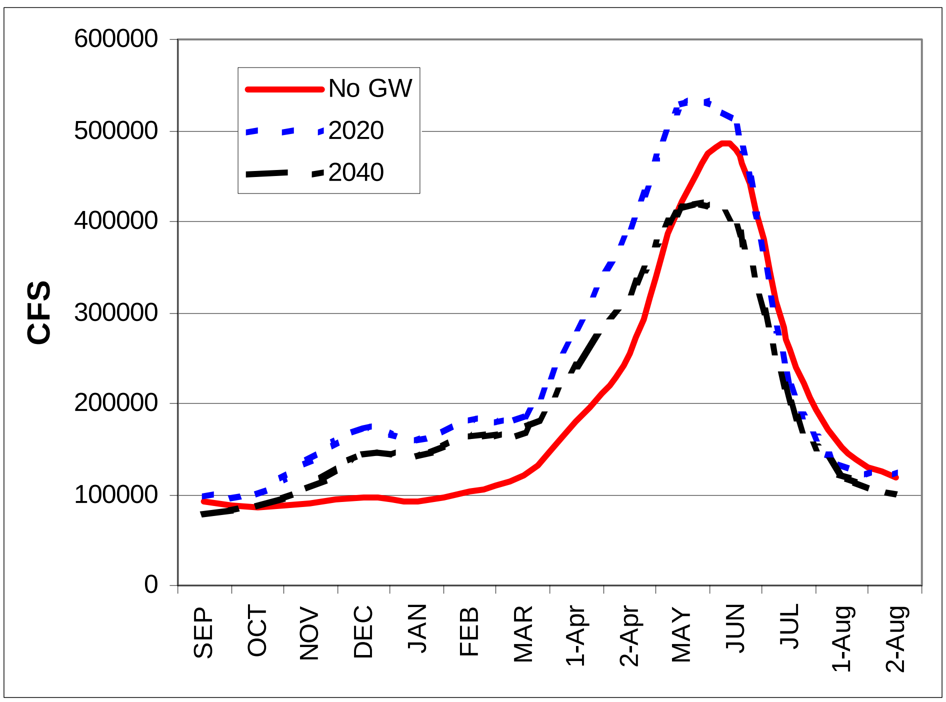

Figure N-13a: Average Unregulated Flow at The Dalles - HC (wet)

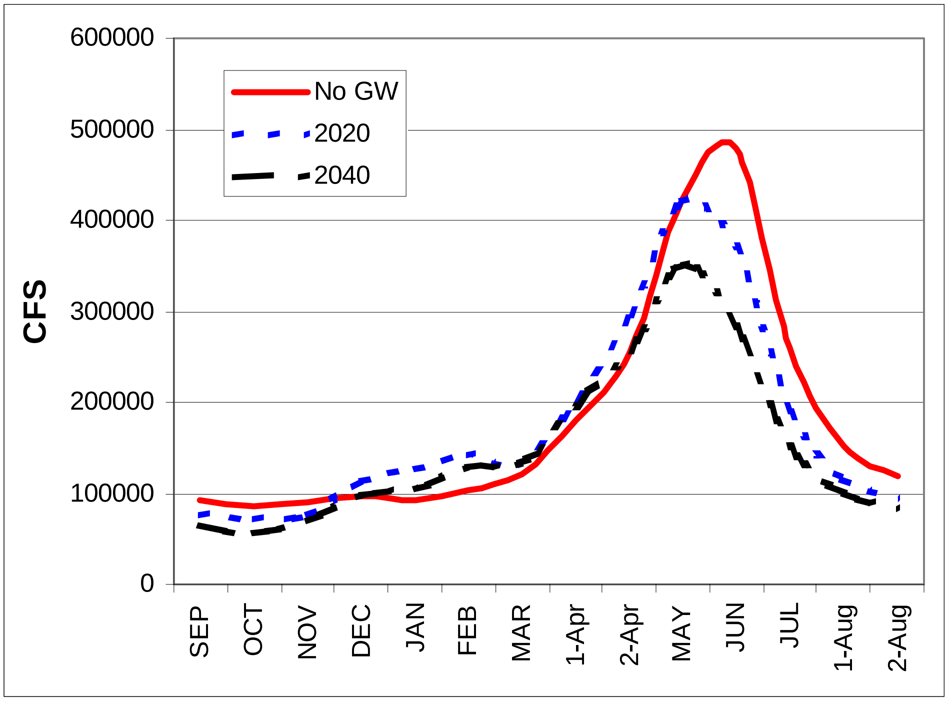

Figure N-13b: Average Unregulated Flow at The Dalles - MPI (dry)

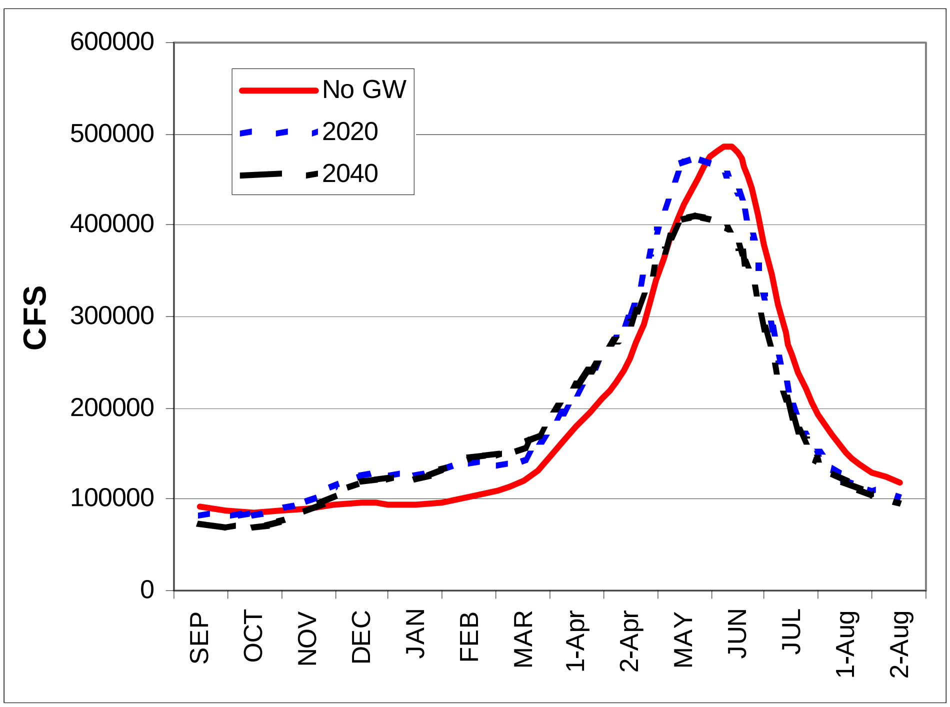

Figure N-13c: Average Unregulated Flow at The Dalles - COMP

Effects on Electricity Demand

There is a clear relationship between temperature and electricity demand. For electrically heated homes, as the temperature drops in winter months, electricity use goes up. Even for non-electrically heated homes, electricity use in winter tends to increase due to shorter daylight hours. Based on data from the Northwest Power Pool, for each degree Fahrenheit the temperature drops from normal, electricity demand increases by about 300 megawatts. This value has stayed fairly consistent over the past several years, in spite of the fact that a smaller percent of new homes are being built with electric heat. If this relationship holds true, then a five-degree increase in average temperature over winter months translates into about a 1500-megawatt decrease in electricity demand.

However, the Council does not rely on the Power Pool to estimate fluctuation in demand caused by temperature changes. Simulation models used by the Council use the HELM algorithm to assess demand variations as a function of temperature. Results of that relationship are presented in Figure N-14, which plots the average monthly temperature increase for 2040 and the corresponding change in electricity demand. For December, the average increase in temperature is about 5 degrees and the corresponding decrease in demand is nearly 2,000 megawatts. This is a little more than the Power Pool's anecdotal relationship would predict but the Power Pool's relationship is based more on hourly demand than monthly average demand.

In the summer, higher temperatures mean greater electricity demand because of greater air conditioning use. While the HELM model forecasts for winter demand decreases seem reasonable, at least on the surface, forecasts for summer demand increases are likely too low. Since the data for HELM was developed, air-conditioning penetration rates have increase significantly. In other words, a greater percentage of new homes are being built with air conditioning and more room-sized air conditioners are being used. Thus, forecasted increases in demand (per degree increase in temperature) for summer months (Figure N-14) are too low and must be revised.

However, power planners have rarely had to concern themselves with summer problems because the Northwest has historically not been a summer peaking region and because of the great capacity of the hydroelectric system. The existing power system is sufficient to "pick up" the additional demand that is projected for future summer months. However, with continued demand growth, increasing operating constraints on generating resources and perhaps little incentive to build, it is possible that at some future date the Northwest will be forced to plan for both a winter and summer peak. According to the Northwest Power Pool, the difference between winter peak load maximums and summer peak loads is getting smaller each year.

However, even if our analysis included higher summer demands, the operation of the hydroelectric system over those months would not likely change because of the rather rigid constraints for fish and wildlife protection. Without modifications to those constraints the decrease in forecasted natural summer flows (shown in Figure N-13) are not likely to be augmented by release of stored water in reservoirs. Under this assumption, higher summer demands would result in an increased cost to the region, either from reduced sales of surplus hydroelectric energy or from purchases from an expensive wholesale market.

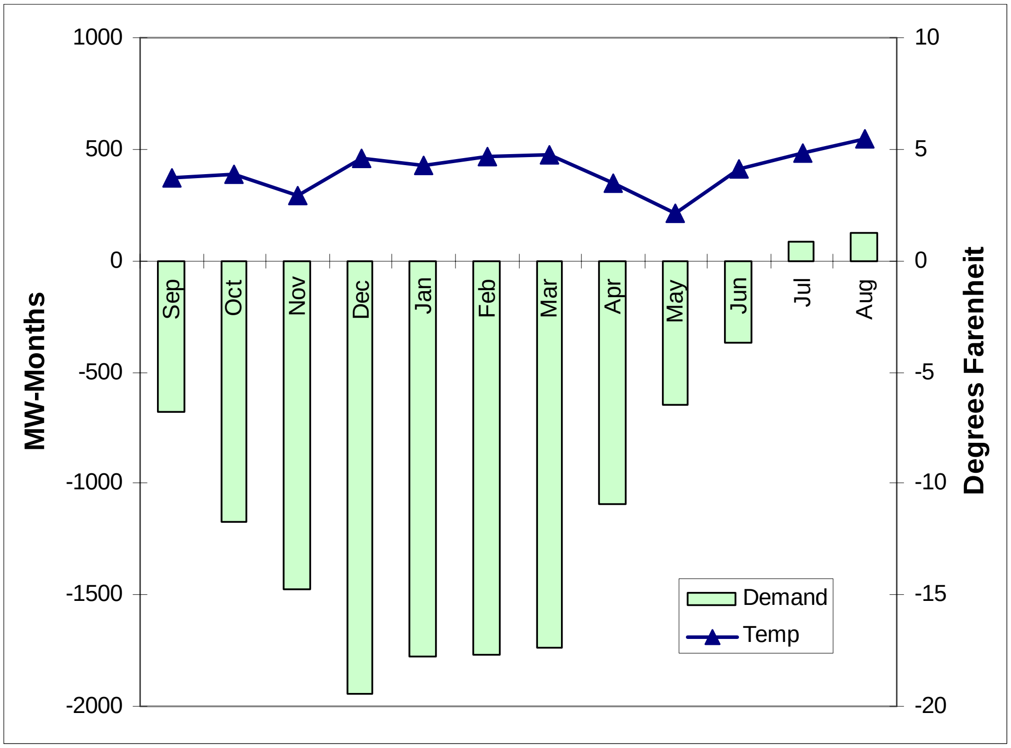

Figure N-14: Average GW Impacts to Temperature and Demand (2040)

Methodology Used to Assess Impacts to the Power System

To assess climate change impacts to the power system, the Council used two computer models. The first, GENESYS, simulates the physical operation of the hydroelectric and thermal resources in the Northwest. The second, AURORA©, forecasts electricity prices based on demand and resource supply in the West.

The GENESYS[19] computer model is a Monte Carlo program that simulates the operation of the northwest power system. It performs an economic dispatch of resources to serve regional demand. It assumes that surplus northwest energy may be sold out-of-region, if electricity prices are favorable. And, conversely, it will import out-of-region energy to maintain service to firm demands.

The model splits the northwest region into eastern and western portions to capture the possible effects of cross-Cascade transmission limits. Inter-regional transmission is also simulated, with adjustments to intertie capacities, whenever appropriate, as a function of line loading. Outages on the cross-Cascade and inter-regional transmission lines are not modeled.

The important stochastic variables are hydro conditions, temperatures (as they affect electricity loads) and forced outages on thermal generating units. The model typically runs hundreds of simulations for one or more calendar years. For each simulation it samples hydro conditions,

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[19] See www.nwcouncil.org/GENESYS

temperatures and the outage state of thermal generating units according to their probability of occurrence in the historic record.

The model also adjusts the availability of northern California imports based on temperatures in that region. Non-hydro resources and contractual commitments for import or export are part of the GENESYS input database, as are forecasted prices and costs and escalation rates.

Key outputs from the model include reservoir elevations, regulated river flows and hydroelectric generation. The model also keeps track of reserve violations and curtailments to service. Physical impacts of climate change are presented as changes in elevations and *regulated* flows due to the adjusted *natural* flows discussed earlier. Economic impacts are calculated by multiplying the change in hydroelectric generation with the forecasted monthly average electricity price.

Changes to Hydroelectric Generation

Table N-2 summarizes the economic results of the Council's study. The average annual change in hydroelectric generation is provided for each climate change scenario for both 2020 and 2040. What is clear from this table is that runoff volume (fuel for the hydroelectric system) makes a big difference in total annual generation. Under the MPI scenario (warm and dry), the hydroelectric system is estimated to lose about 700 average megawatts of energy in 2020 and 2,000 average megawatts by 2040. Current annual hydroelectric generation for the Columbia River system is about 16,000 average megawatts under average conditions and about 11,600 average megawatts for the driest year.[20] These energy losses are not cheap. The estimated regional annual cost of the MPI scenario is $231 million in 2020 and $730 million by 2040.

For a warm-and-wet scenario, the economic outlook is much better. With more fuel for the hydroelectric system, the region is forecast to see about 2,000 average megawatts more energy by 2020 and about 300 average megawatts more by 2040. The corresponding economic benefits are presented in Table 2 below. Under the combination scenario, the region will see a slight increase in generation by 2020 and a net loss of generation by 2040. This scenario shows a net increase in generation (and revenue) by 2020 but a net loss of generation and revenue by 2040.

[20] For another perspective, hydroelectric energy losses due to measures provided for fish and wildlife concerns amount to about 1,100 average megawatts.

Table N-2: Summary of Energy and Cost Impacts

	Change in Annual Energy (average megawatts)		Annual Benefits (Millions)	
	2020	2040	2020	2040
HC (wet)	1982	333	777	169
COMP	164	-477	74	-155
MPI (dry)	-664	-2033	-231	-730

Figure N-15 below illustrates the average monthly change in hydroelectric generation for each of the climate change scenarios. In each case, generation increases over the winter and early spring months and decreases in the late spring and summer months. The magnitude of the change depends on the specific scenario but for all climate-change scenarios examined, the direction of the change is the same.

Figures N-16 and N-17 illustrate the change in regulated outflows and cost. As expected, the same pattern of change observed in Figure N-15 for generation (higher values in winter and lower values in summer) exists for river flows and cost. Figure N-18 provides the average monthly electricity prices used to calculate economic costs/benefits.

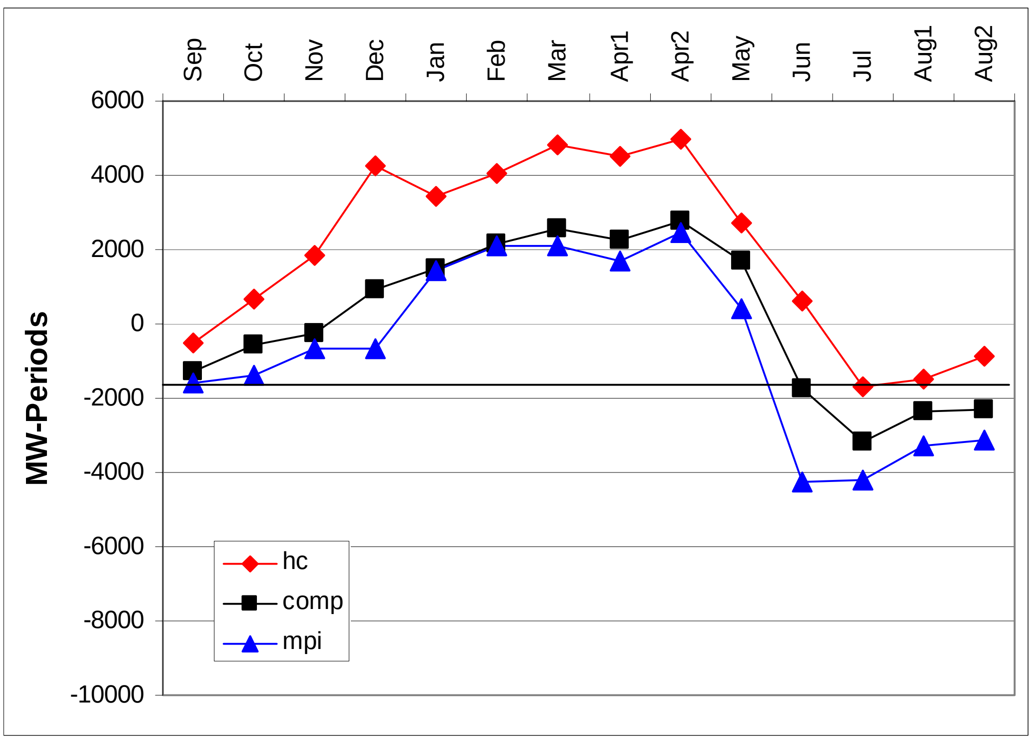

Figure N-15: Average Difference in Hydro Generation (2020)

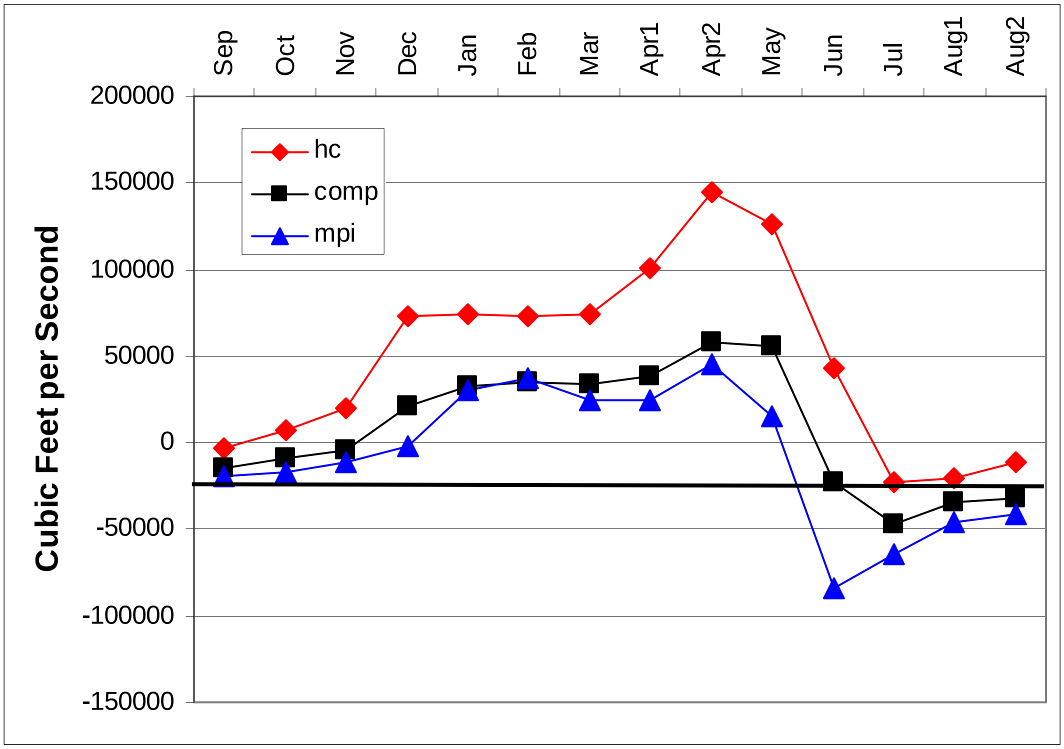

Figure N-16: Average Difference in Regulated Flows at The Dalles (2020)

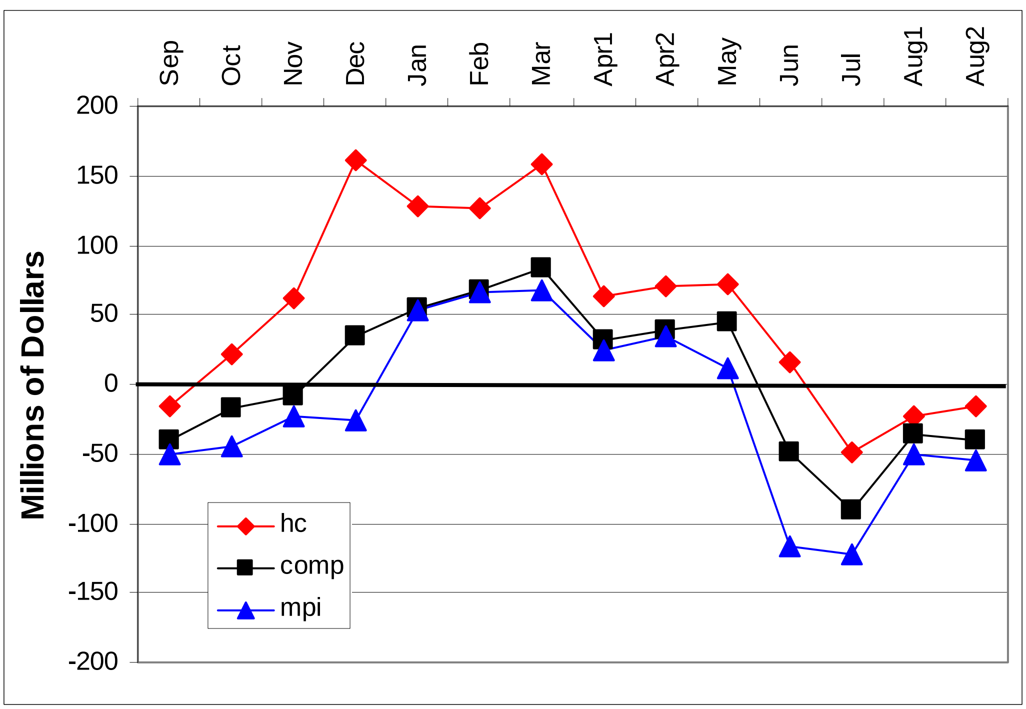

Figure N-17: Average Regional Benefits (2020)

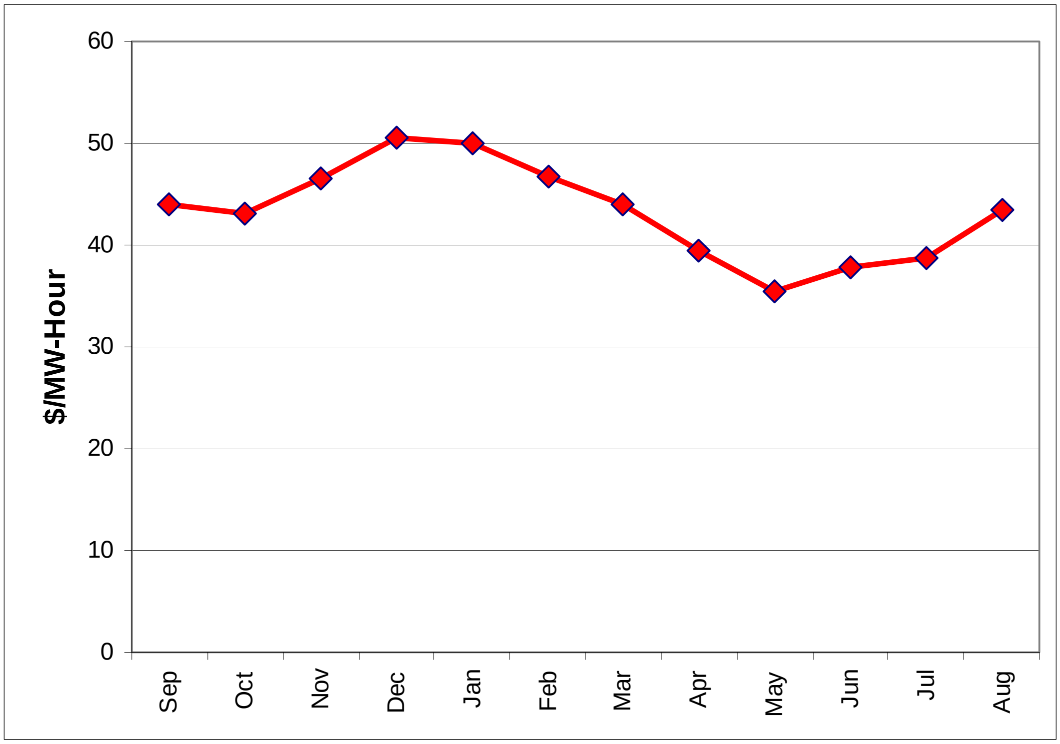

Figure N-18: Forecast Bulk Electricity Prices
(at Mid-Columbia, 2006 operating year, 2004 dollars)

Figures N-19 and N-20 illustrate the data in Table N-2 in graphic form. Conclusions drawn from this study are that; 1) the expected annual change in hydroelectric generation due to climate change depends heavily on forecasted changes to future precipitation (a very uncertain factor) and 2) power-system benefits or costs of climate change correspond directly with the change in runoff volume.

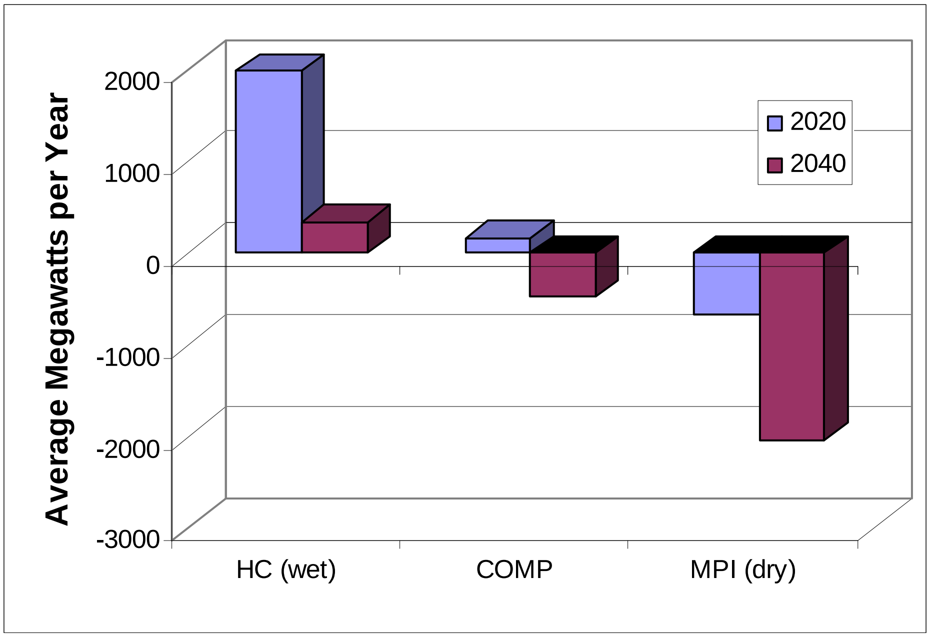

Figure N-19: Average Annual Change in Hydro Generation

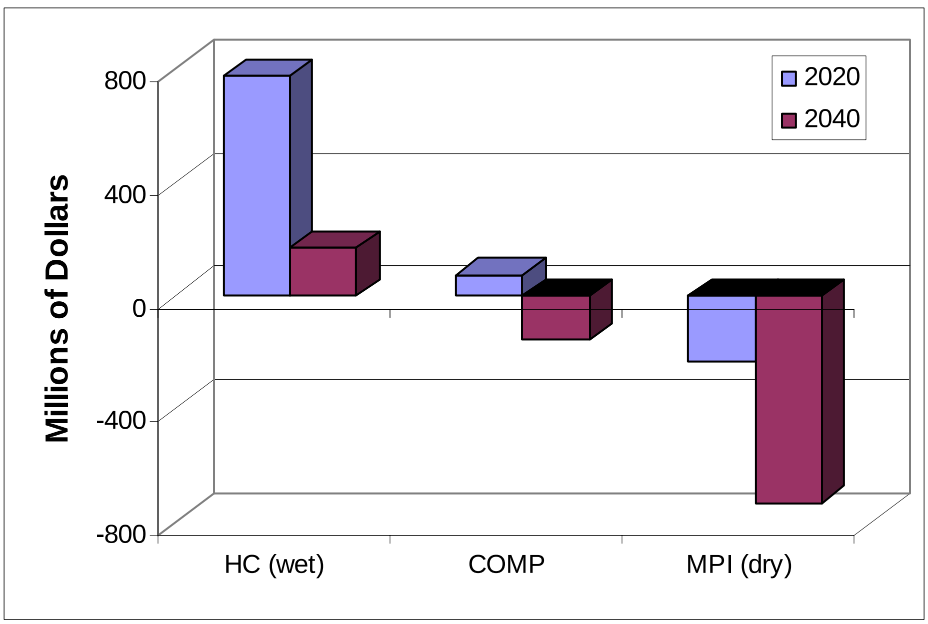

Figure N-20: Average Annual Regional Benefits

Other Impacts

Besides the impacts to river flows, hydroelectric generation and temperatures, climate change will affect the Northwest's interactions with other regions. Currently, both the Northwest and Southwest benefit from differences in climate. During the winter peak demand season in the Northwest, the Southwest generally has surplus capacity that can be imported to help with winter reliability. In the summer months, the opposite is 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 (such as the MPI case) the Northwest could see increased summer demand with greatly decreased summer hydroelectric production. It is possible that 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 resources may be needed to maintain summer service. This would likely raise the value of late summer energy, thereby increasing the economic impact of climate change to the northwest.

All of these impacts assume that no operational changes are made to the hydroelectric system. As described below in the section on mitigating actions, changes in the operation of the hydroelectric system may be significant. In which case, the impacts mentioned above may become better or worse. For example, if reservoirs were drafted deeper in summer months to make up for lost snowpack water, the increase in winter hydroelectric generation shown above would be reduced. A more realistic assessment of the physical and economic impacts must be done with an anticipated set of mitigating actions.

Improving the Analysis

There are several areas where we can improve this analysis. First of all, a larger set of water conditions (1929-1999) should be used. Secondly, a correlated set of monthly temperatures and electricity prices will be used for each water condition. Summer demand response to temperature changes will be revised to incorporate the latest data on air-conditioning penetration rates. In addition, the anti-bias river-flow adjustments are being refined, as are some other data from the Climate Impacts Group.

However, while the final results will change somewhat in magnitude when the revisions mentioned above are incorporated, the general conclusions should not. We can expect, for example, that summer flows will decrease regardless of the climate-change scenario. Only the magnitude of the decrease is still in question. Also, there is no doubt that hydroelectric generation will be shifted across the months of the year. Whether this benefits the region economically or not depends on the overall increase or decrease in river volume.

POTENTIAL MITIGATING ACTIONS FOR THE NORTHWEST

The development of this power plan for the Northwest incorporates actions intended to addresses future uncertainties and their risks to service and to the economy. Such uncertainties include large fluctuations in electricity demand, fuel prices, changes in technology and increasing environmental constraints. Though the effects of climate change remain imperfectly understood, it would be unwise for the Council to ignore its potential impacts to the region. Strategies should be developed to 1) help suppress warming trends and, 2) to mitigate any potential impacts.

In terms of suppressing warming trends, the region should place additional emphasis on reducing the net carbon dioxide production of the power system. Any incentive to reduce greenhouse gases should be examined and electricity customers should be encouraged to use their energy more efficiently. Other actions that would help include;

- Developing low carbon energy sources,
- Substituting more efficient lower-carbon producing energy technologies for older, less efficient technologies, and
- Offsetting unavoidable carbon dioxide production with sequestration technologies.

Reservoir Operations

While no immediate actions regarding reservoir operations are indicated by the analysis, the scoping process should begin to identify potentially mitigating operations to offset climate change impacts. Some of those actions may include:

- Adjust reservoir operating rule curves to assure that reservoirs are full by the end of June
- Allow reservoirs to draft below the biological opinion limits in summer months
- Negotiate to use more Canadian water in summer
- Use increased winter streamflows to refill reservoirs (US and Canadian)
- Explore the development of non-hydro resources to replace winter hydro generation and to satisfy higher summer needs.

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