Assessing Hydrologic Impacts on Water Resources in BC

Summary Report
Joint Workshop
BC Hydro
20 April 2010

20 August 2010

Markus Schnorbus

Dave Rodenhuis

PACIFIC CLIMATE IMPACTS CONSORTIUM

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Acknowledgements

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About PCIC

The mission of the Pacific Climate Impacts Consortium is to quantify the impacts of climate change and variability on the physical environment in Pacific North America. The Pacific Climate Impacts Consortium is financially supported by the BC Ministry of Environment, BC Hydro, the BC Ministry of Forests and Range as well as several regional and community stakeholders. For more information see *http://www.PacificClimate.org*.

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Assessing Hydrologic Impacts on Water Resources in BC

Executive Summary

The workshop on “Assessing Hydrologic Impacts on Water Resources in BC: Current Accomplishments and Future Vision” took place on 20 April 2010 at BC Hydro offices in Burnaby, BC. The key objectives of the workshop were threefold:

- to present PCIC accomplishments resulting from collaborative work with BC Hydro over the past three years
- to engage with and attract potential new consortium members
- to explore the implications of PCIC’s hydrologic impacts research for BC Hydro’s future adaptation and resource planning activities

Presentations were made by BC Hydro, Hydro-Québec, the Pacific Climate Impacts Consortium (PCIC), Ouranos, the University of Washington’s Climate Impacts Group (CIG) and the Western Canadian Cryospheric Network (WC2N).

The introductory session provided the context and background for PCIC’s current accomplishments and future direction. BC Hydro’s collaboration with PCIC stems from an acknowledgement of the need to take a long-term view towards its operations and to remain aware of the potential for changes in the natural environment that could affect the delivery of its services. PCIC’s collaborative nature and its unique expertise and potential for a province-wide capacity for responding to changing climate conditions have made a positive impression on BC Hydro. More generally, the BC government has included adaptation as part of the province’s Climate Action Plan, thereby strengthening its commitment to key activities such as the development of knowledge and tools for assisting public and private sector decision-makers prepare for adaptation to climate change.

Historical trends in mean temperature over the past century in BC (1901-2004) indicate that mean, minimum and maximum temperatures are increasing, with the greatest increases observed in minimum temperatures. This indicates that temperatures in BC are becoming less cool, rather than warmer. These trends in average temperature have been accelerating, especially in winter, over the last 50 years. Precipitation in the past century (1901-2004) has also been increasing, especially in some of the driest regions of the province and particularly in the winter.

In general, streamflow is shifting within hydro-climatic regimes, with coastal systems transitioning to rainfall regimes, and interior systems experiencing loss of snowpack which can lead to lower summer flows. Snowpack is declining across the province and in many regions outside BC to the south. Climate change projections for BC indicate that observed streamflow changes are expected to continue into the future. Increased temperatures will result in more rainfall and less snowfall, driving a shift to earlier freshet runoff in watersheds in north-eastern and south-eastern BC and potentially more dramatic regime shifts in coastal watersheds. An analysis of reservoir operations in the US portion of the Columbia River suggests that the existing management balance between hydroelectric power, flood control and in-stream flow augmentation will be disrupted by climate change, requiring adjustments in reservoir operating policies. As well, trans-boundary relationships between Canada and the United States will also be impacted by climate change.

Uncertainty of climate impact projections, which stems from several sources, was identified as a critical issue requiring further investigation. In particular, there is a need to understand the magnitude of uncertainty attributable to the *natural variability* of the climate system, which cannot be reduced.

Presentations from Hydro-Québec provided background, context and guidance on their approach to understanding and adapting to the effects of climate change on power generation operations. Hydroelectric power generation in Québec is highly climate dependent, as it is in BC. Consequently, Hydro-Québec recognized the strategic importance of evaluating the impacts of climate change and actively participated in the creation of the Ouranos consortium. Their research indicates that northern Québec may expect a surplus of runoff in the future in an area where Hydro-Québec generates a significant amount of power. Nevertheless, a lack of adaptation (structural and non-structural) could result in a 14% decrease in power generation, despite the increase in water availability.

Based on information presented throughout the morning workshop, participants had an opportunity to discuss and reflect on climate change implications and challenges with respect to five broad topics: power generation, aquatic ecosystems, extreme events, energy planning and trans-boundary water management.

For *power generation* it was recognized that different systems (e.g., coastal versus interior) could be affected differently by climate change and that the ability for BC Hydro to adapt will be strongly affected by current reservoir storage capacity. Power generated by independent power producers (IPPs) may be particularly sensitive to climate change effects.

The implications of climate change on *aquatic ecosystems* are changes to the amount and timing of streamflow and changes in water quality (e.g., water temperature). It was acknowledged that aquatic ecosystem response to local and regional change or disturbance is a large and complex problem requiring more research. Nevertheless, BC Hydro operations may need to be modified in order to mitigate the effects of climate change on aquatic ecosystem health, with possible tradeoffs concerning power generation.

Changes in the frequency and magnitude of *extreme events* due to climate change were recognized as an important focus of future research as implications extend from energy demand to infrastructure maintenance and operations, public safety and ecosystem health.

Future *energy planning* must focus on the direct effects of climate change on both power generation and energy demand. However, it was also recognized that projections of electricity demand will be affected by other factors unrelated to climate change (e.g., population growth, economic growth, energy pricing) or paradoxically related to climate change mitigation efforts (e.g., fuel switching and carbon taxation).

Trans-boundary water management will possibly add an additional element of complexity when adapting to climate change. Trans-boundary water management (whether provincial or international) can constrain our ability to adapt to meet (potentially) competing domestic demands, particularly if it is conducted under the auspices of a formal treaty (e.g., the Columbia River Treaty).

1. Introduction – Setting the Context

The workshop on "Assessing Hydrologic Impacts on Water Resources in BC: Current Accomplishments and Future Vision" took place on 20 April 2010 at BC Hydro offices in Burnaby, BC. Technical presentations were made by BC Hydro, Hydro-Québec, the Pacific Climate Impacts Consortium (PCIC), Ouranos, and the University of Washington Climate Impacts Group (see Attachment 1 – Workshop Agenda). A broad group of representatives from various government, industry and academic organizations attended (see Attachment 2 – Workshop Participation List).

Moderator Wendy Avis, BC Hydro Project Manager for Environment and Sustainability, opened the workshop by outlining its key objectives:

- to present PCIC accomplishments and highlight technical results stemming from the first three years of the consortium's four-year collaborative project with BC Hydro
- to engage with and attract potential new consortium members and partners interested in aiding and directing the scope of future PCIC research
- to explore the implications of PCIC's hydrologic impacts research for BC Hydro's future adaptation and resource planning activities

Four presenters (Chris O'Riley, James Mack, Dave Rodenhuis and Stephanie Smith) further elaborated these goals and set the introductory context for the ensuing technical discussions.

Chris O'Riley, BC Hydro's Senior Vice-President of Engineering, Aboriginal Relations and Generation, welcomed participants and speakers while recognizing the diverse audience in attendance. In particular, he noted the participation of former BC Hydro executive Bruce Sampson and current BC Hydro board member Peter Busby at the workshop, two leaders who have been instrumental in encouraging the utility company to consider the implications of climate change.

As electric power generation is a long-term and capital-intensive industry, BC Hydro needs to take a long-term view towards its operations and remain aware of the potential for changes in the natural environment that could affect the delivery of its services. Mr. O'Riley said that the relationship between PCIC and BC Hydro continues to be a source of pride for BC Hydro as the current multi-year research programme approaches its completion in December 2010. He concluded his welcome by stating his satisfaction with the quality of PCIC work and with its collaborative approach.

James Mack, Assistant Head of the Climate Action Secretariat at the BC Ministry of Environment, followed with his own welcome on behalf of the BC government. Mr. Mack commended BC Hydro for its early support of PCIC, stating that this contributed considerably to the establishment of the BC government endowment which helps maintain PCIC and its sister organization, the Pacific Institute for Climate Solutions (PICS).

Recently, the BC government included *climate adaptation* as part of the province's Climate Action Plan, strengthening its commitment to climate change adaptation through three key activities:

- building a strong foundation of knowledge and tools to help public and private decision-makers across BC prepare for climate change
- making adaptation a part of BC government business, ensuring climate change impacts are considered in planning and decision-making

- assessing risks and implementing priority adaptation measures in key climate-sensitive areas.

Mr. Mack also emphasized the provincial government's focus on clean energy and a low-carbon economy as well as its enthusiastic support for BC Hydro's leadership in this area.

David Rodenhuis, Director and President/CEO of PCIC, presented the consortium's perspective on the collaborative project with BC Hydro.

In January 2006 BC Hydro was the first to step forward in support of PCIC. An initial contract with BC Hydro tasked PCIC with the delivery of future streamflow projections on a number of key BC watersheds for the 2050s period, a goal that seemed virtually unattainable given the resources available at the time. Three years later PCIC is presenting those very results—a testament to the consortium's success.

While BC Hydro and the Ministry of Environment were the first members of the consortium, other stakeholders soon realized the value of the consortium model for the study of climate change impacts. Today, PCIC members and associates include:

- BC Hydro
- BC Ministry of Environment
- BC Ministry of Forests and Range
- Ouranos
- Water-Climate Impacts Research Center (W-CIRC)
- Pacific and Yukon Region, Environment Canada
- University of Victoria
- Pacific Institute for Climate Solutions (PICS)

Since the PCIC/BC Hydro Grant Contribution Agreement was signed in 2006, highlights of PCIC accomplishments include the following:

- publication of the climate overview
- establishment of a Technical Advisory Committee
- completion of the modelling and analysis for the Peace, Campbell and upper Columbia Rivers
- presentation of preliminary results at the current workshop

He added that the next step will be to interpret the results and compile a Synthesis Report to complete the project by December 2010.

Stephanie Smith, BC Hydro Manager of Hydrology and Technical Services, presented BC Hydro's perspective on the project and explained the company's choice to seek collaborative work with PCIC.

In 2004, BC Hydro was in the midst of public consultations regarding water use and licensing processes in the province when the question arose concerning future climate change impacts on BC hydrology. At the time there were no in-house tools for answering this question. PCIC's collaborative nature and its unique expertise and potential for developing a province-wide capacity for responding to changing climate conditions made a positive impression on BC Hydro.

While the workshop presentations contain largely preliminary results, the time is right for collecting feedback on these results and responding to the need for better information on climate change impacts on water resources while generating research questions for the next project phase.

2. Climate Change – Assessment of Hydrologic Impacts

2.1. Climate Overview: Katrina Bennett, PCIC Hydrologist

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Katrina Bennett presented an overview on the climatology of British Columbia, based in part on the Climate Overview Report (2007) on the current state of knowledge on hydro-climatology and future climate impacts in BC.

The climatology of British Columbia is variable, with a large range in temperature and precipitation across the province. PCIC used gridded maps and data products to show results for the whole province. However, it is important to realize that the availability of climate-related data is very limited due to the uneven placement of observation stations and/or the relatively short periods of time over which measurements have been collected. Consequently, there is little long-term or historical climate data available for some regions. The basis for the analysis was the CANGRID data interpolated to 50 km resolution.

Historical trends in mean temperature over the past century in BC (1901-2004) indicate that mean, minimum and maximum temperatures are increasing, with the greatest increases observed in minimum temperatures (0.17° C per decade). This indicates that temperatures in BC are becoming less cool, rather than warmer, or that nighttime low temperatures are increasing more than daytime highs. Seasonal trends indicate that mean temperatures are increasing for winter (0.22° C per decade) and spring (0.15° C per decade), while summer temperature changes are negligible (Figure 1). Autumn mean temperatures appear to be getting cooler in northern regions of BC. Looking at the 50-year (1951-2004) and 30-year (1971-2004) trends for BC we see that the average temperature increase has been accelerating, especially in winter.

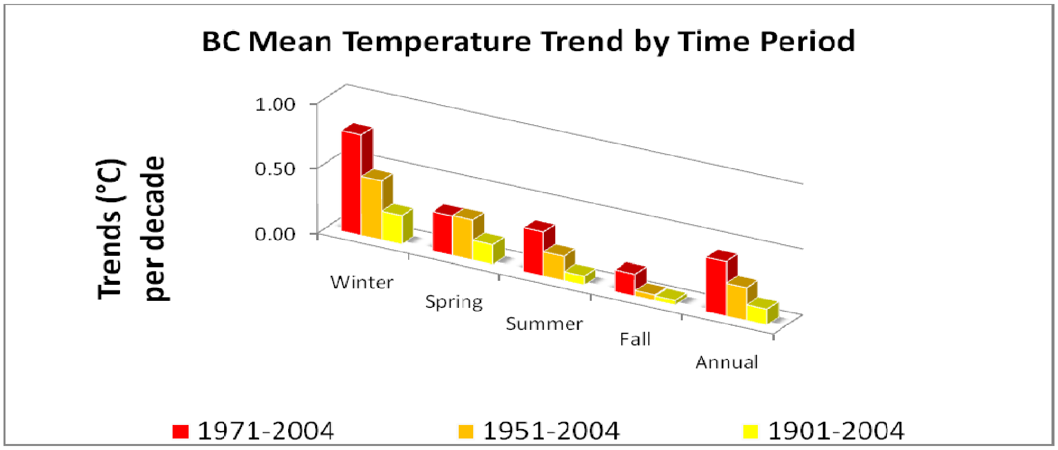

Figure 1: Trends in seasonal mean temperature in British Columbia. Results depend on the period of analysis, as indicated.

Precipitation in the past century (1901-2004) has also been increasing, especially in some of the driest regions of the province and particularly in the winter (2.4 % per decade). Winter precipitation has decreased in the 50-year trends (1951-2004) and 30-year trends (1971-2004) (Figure 2).

Climate variability in the province is illustrated by El Niño winter mean temperature and La Niña winter mean temperature and precipitation observations. Across BC, El Niño winter temperatures are 1.3° C degrees warmer on average, while La Niña temperatures are 1.0° C cooler compared to the long-term signal. For precipitation, El Niño winters tend to be about 5% drier than the average condition while La Niña winters tend to be approximately 4% wetter.

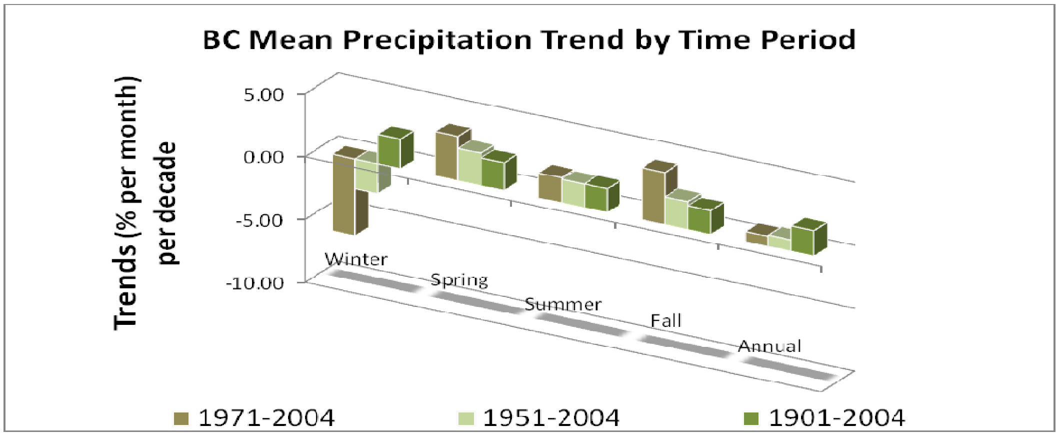

Figure 2: Trends in seasonal mean precipitation in British Columbia. Results depend on the period of analysis, as indicated.

In general, streamflow is shifting within hydro-climatic regimes, with coastal systems transitioning to rainfall regimes and interior systems experiencing loss of snowpack which can result in lower summer flows. Snowpack is declining across the province and in many regions outside BC to the south as well. Variability also impacts streamflow within hydro-climatic regimes as coastal systems experience increased autumn flows in addition to increased freshet during La Niña years. Snowpack responds to El Niño-Southern Oscillation (ENSO) events with declines during El Niño years and increases during La Niña years.

Future projections were provided in the Climate Overview using three different tools:

- course resolution (300 km) global climate models (GCMs)
- meso-scale resolution (45 km) regional climate models (RCMs)
- high resolution (1-4 km) elevation-corrected GCM/RCM projections

Only one of the GCMs (Canadian Centre for Modelling and Analysis's Canadian Global Climate Model, version 3, run 4) used for the Climate Overview 2007 report was analyzed. This model projects a 3.0 ° C increase in temperature and a 13% increase in precipitation for BC in the 2050s. The Canadian Regional Climate Model (version 3.7 run 4) projects a 2.7° C increase in temperature and a 14% increase in precipitation on average across BC. High-resolution projections can provide temperature, precipitation and other data for a community at a very fine scale but must be treated with caution due to uncertainties introduced through downscaling. Still, high-resolution results can be compared with historical results to illustrate a projected shift in temperature regimes, particularly for northern BC.

2.2. BC Watersheds: Peace, Campbell and Upper Columbia Rivers: Markus Schnorbus, PCIC Hydrologist and Acting Lead of the Hydrology Theme

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Markus Schnorbus presented preliminary results on hydrologic projections for three watersheds of interest to BC Hydro: the Peace River (at the W.A.C. Bennett Dam), the Campbell River (at Strathcona Dam) and the Columbia River (at Mica Dam).

The aim of the hydrologic impacts program at PCIC is to quantify the hydrologic effects of climate change and climate variability in Pacific North America. Currently the geographic scope of these efforts includes four watersheds: the Peace, the upper Columbia, and the Campbell Rivers plus the Fraser River basin (Figure 3). Projections of future climate are derived from several different GCMs driven by three emissions scenarios representing alternative trajectories of greenhouse gas emissions. Consequently, projections of future climate have uncertainties associated predominantly with inter-GCM output variability, as the effect of alternative emission scenarios is negligible for the 2050s (2041- 2070). Due to processing and storage overhead and information redundancy, PCIC used only a subset of 17 GCM-scenario combinations for hydrologic impact analysis. Climate projections indicate increased warming for all three study watersheds by the 2050s, both annually and for each of the four seasons. Precipitation projections show that the response (i.e., increase or decrease) is variable both geographically and seasonally.

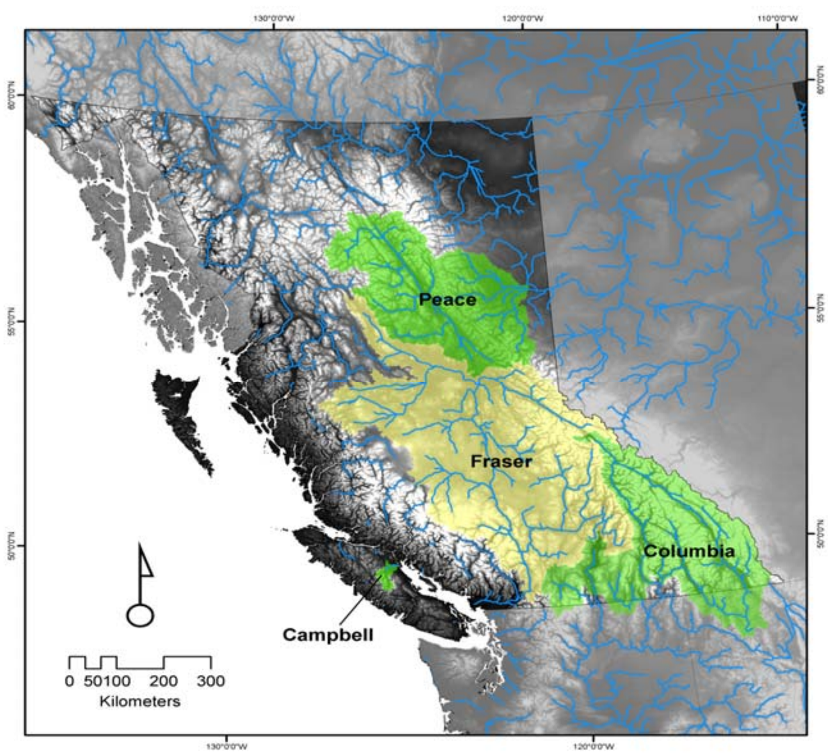

Figure 3: Map showing BC watersheds included in this study.

Streamflow projections were obtained by statistically downscaling the GCM projections to provide daily time series data which was subsequently used to force the Variable Infiltration Capacity (VIC) hydrology model. On an annual basis, discharge in the Peace and Mica basins is projected to increase in the future (10% and 12% between historic and future medians, respectively) but projected to remain the same in the Campbell. Seasonally, higher temperatures cause more precipitation to fall as rain and less as snow, generally resulting in increased runoff in the fall and winter, a shift to earlier freshet runoff in the spring and reduced runoff in the late summer and early fall. Nevertheless, the Peace and Mica basins will remain predominantly snowfall-dominated regimes in the 2050s (i.e., dominated by freshet runoff, albeit with a seasonal shift in the freshet and a potentially longer summer low-flow period). As of the 2050s the Peace exhibits greater sensitivity to climate change than the Mica. This is attributed to the fact that the hypsometry of the Mica is such that despite elevated temperatures, substantial areas in the Mica will still remain above the snow line and the shift from snow to rain will be less widespread than in the Peace. The Campbell River basin will experience the most dramatic response due to climate change, essentially transitioning from a hybrid-regime (rain and snow) to a predominantly rainfall-dominated regime with freshet runoff substantially reduced by the 2050s.

2.3. Results on the Columbia River Basin and Implications for Power Generation: Prof. Alan Hamlet, University of Washington; Associate, Climate Impacts Group

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Alan Hamlet presented on the impacts of projected climate change on energy supply and demand in the Pacific Northwest and Washington State.

The Climate Impacts Group recently completed several large surveys of climate change impacts across Washington State and the Columbia River basin for resource managers operating in the Pacific Northwest.

Prof. Hamlet reported that projected shifts in temperature and precipitation may lead to changes in streamflow and many watersheds will transition from snowmelt-dominated to more rainfall-dominated hydrologic regimes. Consequences include higher winter flows, a decline in the freshet peak, and lower spring and summer flows for the Columbia River in The Dalles. In the 2040s hydroelectric power production is projected to increase by 4.0% to 4.2% in winter, decrease by about 13% to 16% in summer, with annual reductions of approximately 2.5% to 4.0%. These changes in streamflow will affect energy production at times when energy demand must continue to be met (Figure 4). The largest changes in power production are projected to occur from June to September, during the peak air conditioning season.

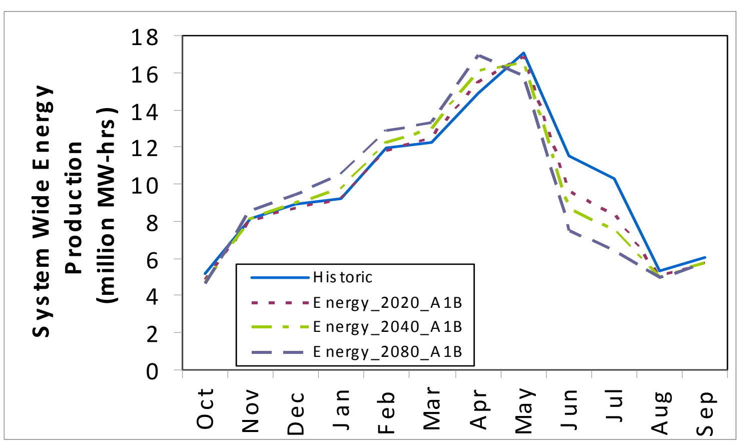

Figure 4: Seasonality of system-wide energy production (capacity at The Dalles) and estimates of future changes.

Projected streamflow changes can be input into a reservoir model, enabling future projections of impacts to regulated flow. A reservoir model has been run for the Priest Rapids Dam on the Columbia River mainstem (Figure 5). Regulated flow at this checkpoint strongly affects the ecologically important Hanford Reach. Minimum flow in the model simulations was 1,415 m^3/s (50,000 ft^3/s). As warming progresses, streamflows are at their minimum values and can only be supported through storage.

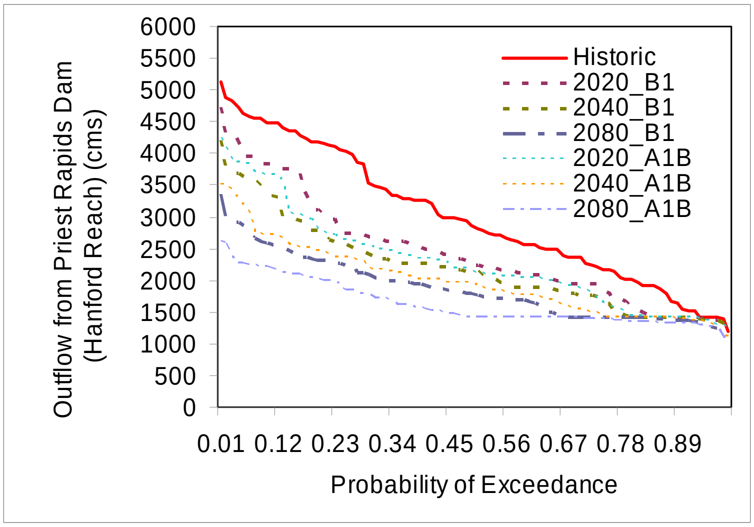

Figure 5: Example of reduced probability of outflow during the 21st century.

Three observations can be made:

- climate change will increasingly disrupt the existing balance between hydroelectric power, flood control, and in-stream flow augmentation in the basin, requiring adjustments in reservoir operating policies
- trans-boundary relationships within the Pacific Northwest and between Canada and the U.S. will be impacted, requiring potential adjustments to trans-boundary agreements such as the Columbia River Treaty
- loss of summer energy production may have important inter-regional impacts because of reduced local capacity and ability to provide energy transfers to the southwestern US in summer

Changes in primary energy demand for space heating and cooling needs were also examined by the Climate Impacts Group. These changes are a fundamental driver of residential and light commercial energy demand and are strongly influenced by temperature change. Therefore, projected temperature increases due to climate change may have important implications for individuals, utilities, and high-level state and regional planning. Despite a warming trend, the overall annual heating energy demand is still projected to increase due to population growth. Although currently a small fraction (<1%) of the total residential load in Washington State, the energy demand for cooling is projected to increase rapidly due to warmer temperatures and increased population growth, leading to greater use of air conditioning. Similarly, peak electrical demands in summer are likely to increase for the same reasons in the Pacific Northwest (Figure 6 and 7).

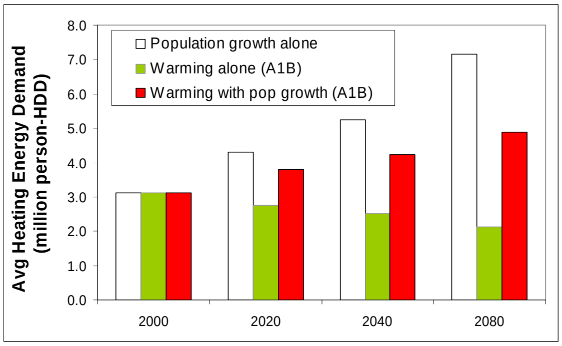

Figure 6: Change in heating demand projected for the 21st century in Washington State, USA.

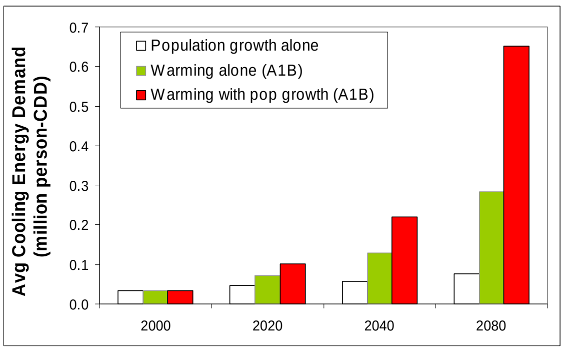

Figure 7: Change in cooling demand projected for the 21st century in Washington State, USA.

2.4. Mica Glacier and Hydrologic Modelling: Prof. Dan Moore, University of British Columbia, representing the Western Canadian Cryospheric Network (WC2N)

Presentation slides available at http://www.pacificclimate.org/resources/presentations

R.D. (Dan) Moore provided workshop participants with a presentation on the Western Canadian Cryospheric Network (WC2N), a climate research network linking seven universities funded by the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) as well as BC Hydro. The focus of the WC2N group is multi-faceted:

- to map glacial changes through time
- to provide statistical analyses of historic streamflow trends
- to model glacier and streamflow response to climate change, including the development of a new hydrologic modelling platform
- to extract and analyze snow cover patterns utilizing remote sensed imagery
- to inter-compare various glacier melt models

WC2N received additional funding from BC Hydro to model the effects of future climate and glacier change on streamflow in the Mica basin, located in the headwaters of the Columbia River basin. This study involves collaborators from the University of British Columbia (UBC) Department of Earth and Ocean Sciences (EOS), UBC Department of Geography, the University of Northern British Columbia as well as PCIC. The objectives of this work are twofold:

- generate projections of future glacier response and simulate changes in streamflow associated with a range of climate change scenarios for the glaciated Mica basin of the Columbia River
- provide uncertainty bounds on streamflow projections taking into account uncertainty in calibrated model parameters and uncertainty related to variations among GCMs and emissions scenarios

A glacial dynamics model developed by UBC EOS and a semi-distributed hydrologic model (HBV-EC) developed at Environment Canada are being applied to provide the projections of future changes to streamflow. The results from six GCMs using three emissions scenarios will be downscaled to drive the glacier and streamflow models. Initial results are expected in June 2010.

2.5. Climate Diagnostics: Dr. Daniel Caya, Director of Climate Science, Ouranos

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Daniel Caya presented results from his work on “regional climate diagnostics” to estimate changes in runoff for several watersheds in British Columbia. This alternative to the traditional method uses a regional climate model like the Canadian Regional Climate Model (CRCM4) instead of statistically downscaled GCM results, thus avoiding some of the weaknesses associated with the traditional approach.

Atmospheric fields and sea-surface conditions from five members of the Canadian Global Climate Models (CGCM3) were used to drive the Canadian Regional Climate Model (CRCM4) at 45 km resolution for several watersheds of the Peace and Mackenzie River watersheds. Estimates of streamflow were obtained directly from the CRCM4 fields as computed by the surface hydrologic balance from the Canadian Land Surface Scheme (CLASS2.7). It was shown that the overall runoff is projected to increase over much of BC.

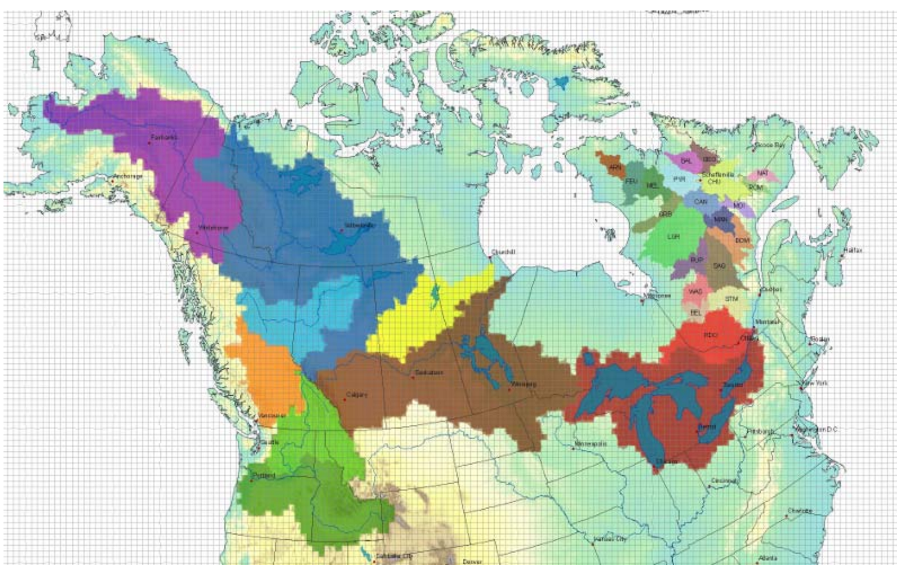

Figure 8: Map showing areas of hydrologic studies using the Canadian Regional Climate Model (CRCM).

While this approach holds considerable promise, Dr. Caya cautioned that there is still uncertainty in the estimates resulting from various sources in the regional climate projections, including an important contribution from the *natural variability* in the climate system as estimated by the differences in component members of the CGCM3.

Dr. Caya also noted that the uncertainty from this natural variability cannot be reduced and should be taken into account in every impact and adaptation study. It was shown that this uncertainty, which derives from internal variability, can have amplitude similar to other sources. The range in estimates of precipitation from different global and regional models can reach a magnitude comparable to the projected change expected by the 2050s. Although the project has produced concrete estimates for future conditions in the 2050s, further work is needed to refine the estimates of the uncertainty from the various sources. Specifically, the magnitude of the uncertainty originating from the natural variability needs to be better estimated using multiple members from another GCM to drive the CRCM.

3. Future Collaboration: The Ouranos and Hydro-Québec Example

3.1. Hydro-Québec Example: Claude Demers, Science Communicator, Hydro-Québec

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Claude Demers, Science Communicator at Hydro-Québec, presented the context for the power industry in that province, including generation, transmission, distribution, energy trading and the economic environment in Québec. Information on fuel sources for both Canada and the US were presented, showing that both Québec and BC currently have adequate resources for hydroelectric power generation, though the distance from source to area of demand requires lengthy transmission lines. Exports, representing an important proportion of company revenues, are expected to increase in the next few years.

Mr. Demers noted that Hydro-Québec, like its counterpart in BC, is highly climate dependant and therefore just as affected by climate change. Because of this, future climate conditions are an important factor in determining both the demand and supply of hydroelectric power for the coming decades (Figure 9). Anticipating the consequences of climate change on electric load, water inflows and extreme events encouraged Hydro-Québec to initiate a corporate research programme in 2001 to evaluate the impacts of climate change as a necessary precursor to the development of strategies for adaptation.

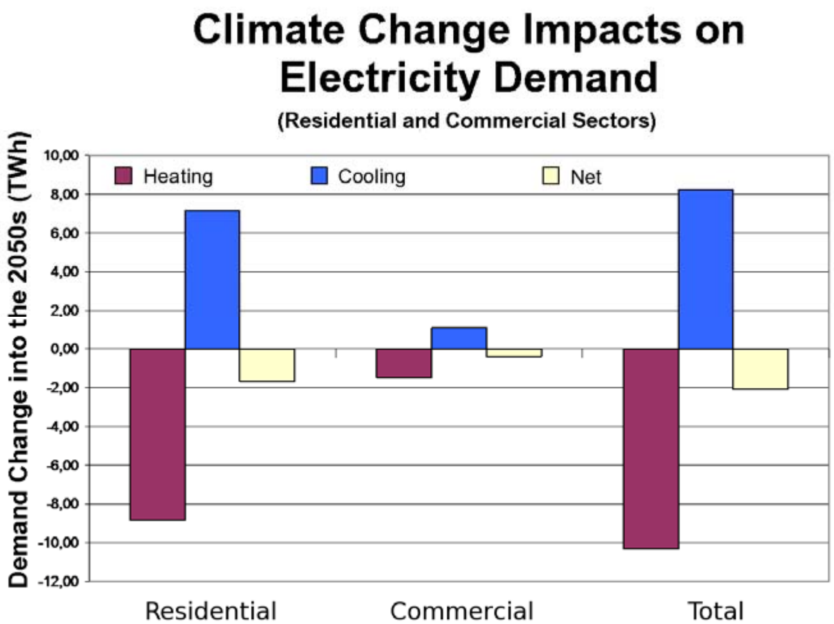

Figure 9: Projected impact on electricity demand in Québec as a result of projected temperature increase in the 2050s.

Lacking the necessary in-house expertise, Hydro-Québec participated in the creation of the Ouranos consortium in 2002. Ouranos works closely with Hydro-Québec to simulate climate projections tailored to the needs of the Québec energy industry. Since 2002, Hydro-Québec has invested $1 million per year and dedicated five full-time-equivalent personnel (researchers, practitioners, planners, etc.) specifically to climate change research, underlining its value to the utility company.

3.2. Hydro-Québec Business Perspective: Dr. René Roy, Climate Change Project Director, Hydro-Québec

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Dr. René Roy, Climate Change Project Manager at Hydro-Quebéc, made a presentation on the use of estimates of future climate conditions and water resources from a business perspective. He noted the importance of extreme weather/climate events for raising awareness of climate impacts on the reliability of power generation. The benefits of hydroelectric sources of power generation are measured in the billions of dollars and the risks reside primarily in water resources that are heavily affected by climate variability and change.

Dr. Roy offered workshop participants a presentation of results from an impact analysis performed using the well known “delta method”. This method consists of adding differences in temperature and precipitation (ratio) obtained from climate models (i.e., future climate) to climate observations (i.e., reference climate). Hydro-Québec considered 90 different climate projections, generated from combinations of climate models and greenhouse gas emissions scenarios provided by the Intergovernmental Panel on Climate Change (IPCC AR4). Both climate databases (observations as the reference and modified observations for time horizon 2050) were used as inputs to a global conceptual daily hydrological model to simulate the actual and future hydrological regime (90 different simulations) of 94 watersheds covering an area of 1.5 million km^2 in Québec. Hydro-Québec also decided to apply the so-called “direct” and “unbiased direct” methods, on the premise that a wider ensemble of methods would lead to a more accurate interpretation of results (Roy et al., 2008).

Figure 10 shows that no significant change in mean annual inflow are foreseen in southern Québec while a surplus of water may be observed along the northern shore of the St. Lawrence River. On the other hand, northern Québec can expect significant surplus runoff in the area where the utility generates a significant portion of the hydroelectricity. Dr. Roy noted that these results are not method-sensitive insofar as all three methods used show the same regional patterns. Interestingly, in the area where the runoff increase signal is stronger, the dispersion between the 90 hydrological simulations is relatively small.

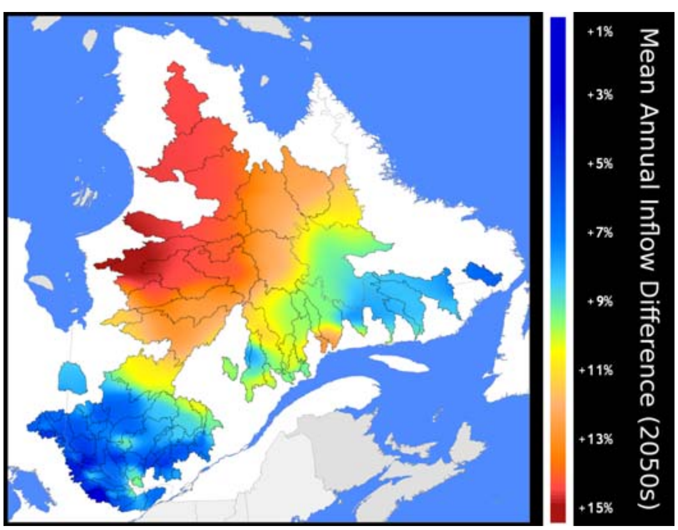

Figure 10: Projected change in mean annual inflow in Québec and eastern Ontario for the 2050s.

Adaptation measures could lead to a hydroelectric power generation increase of up to 15%, whereas without such measures (and despite the increase in water availability), output could decrease by as much as 14%. Dr. Roy offered a list of examples for structural and non-structural adaptation instruments for optimizing hydroelectric generation under these projected future conditions:

- divert water course of upstream tributaries
- create new upstream storage reservoirs
- increase the capacity of spillways
- modify the dimensions of canals or tunnels
- change the number and type of turbines used
- develop or improve hydrological forecasting tools
- make appropriate changes to operating rules and/or engineering design practices
- incorporate better coordination between hydroelectric operations and other water use projects sharing the watershed

Adaptation can be facilitated if the following requirements are met. The absence of any one of these requirements constitutes a barrier to adaptive management:

- climate change is generally slow and difficult to discern due to natural variability so long-term vision, monitoring and documentation are required
- climate and hydrology modelling is required *a priori* in order to establish different management strategies according to the various hypotheses and to decide on those strategies which will be implemented, including evaluation of the results of management actions to retain, reject, or refine the hypotheses
- managers will change over time so the hypotheses that are tested and retained, as well as those that are discarded, must be documented along with the reasoning behind these decisions
- since stakeholder interests may compete with one another, trust among the parties is rather important when resources are shared between different partners, and motivation for decisions must be clearly communicated, and the monitoring and evaluation must be acceptable to all interested parties
- organizational structure must value learning so judging managerial decisions predominantly by their success in achieving objectives is inimical to the adaptive management approach, since the value of the knowledge gained for future decisions is not accounted for
- one should accept the risk of adapting to a given foreseen future that may not actually occur

Possible barriers for adaptation were also presented:

- normal inertia of large organizations may prevent movement away from the status quo
- legal and political considerations, including internal rules, may limit the range for adaptation options
- jurisdictional conflicts may hinder change as different agencies with differing mandates and mission statements try to act consensually
- adaptation generally involves up-front costs that may not be easily recovered in future benefits, many of which may never materialize
- given the fixed discount rate typical for medium-term cost-benefit analysis for hydroelectric power installations, benefits (or expenses) beyond a timescale of a few decades are irrelevant

Dr. Roy concluded his presentation with a few points from a technical and organizational point of view. In terms of climate modelling, an important breakthrough in the field of regional climate modelling led Hydro-Québec to recommend that high-resolution climate models should be preferred for regional hydrological studies. Impacts studies show that Québec hydrological regimes will change in the future. To benefit from those changes, hydroelectric infrastructure must operate and eventually be planned and designed with those changes in mind. Otherwise, the expected inflow changes may not translate into an income surplus. From an organizational perspective, Dr. Roy recommended that research and development efforts in climatology and hydrology be maintained and the gap between research activities and planning/design operations be reduced. Finally, he suggested that continued collaboration within hydropower utilities should continue to be promoted.

4. Future Opportunities

4.1. PCIC Vision: Prof. Andrew Weaver, University of Victoria Professor and Canada Research Chair; PCIC Senior Scientist

Presentation slides available at http://www.pacificclimate.org/resources/presentations

Andrew Weaver, as PCIC Senior Scientist, presented his perspective on the consortium's capabilities and desirable direction for future projects. He highlighted the potential for future partnerships between BC Hydro, Hydro-Québec, PCIC, Ouranos, the University of Victoria, and UQAM in the development of a greater capacity to undertake regional climate modelling and climate impacts assessments in Canada. In particular, he outlined a proposal to create a comprehensive database of high-resolution future climate projections for Canada in the 21st century.

Prof. Weaver suggested that a regional climate model (RCM) could be integrated on two very high-resolution (15 km by 15 km) domains from 1950-2100: one for western Canada and another for eastern Canada (Figure 11). Initial focus would be on quantifying probabilistic projected 21st century changes in water availability, climate variability and climate extremes for use in energy planning in BC and Québec. Graduate students at UVic would be involved in the development of downscaling tools as well as specific applications for addressing user-specified problems defined through collaboration with PCIC and Ouranos. Such projects would also involve the analysis of downscaled surface winds that are particularly important for wind power generation and for assessing the potential for severe transmission line damage caused by extreme winds.

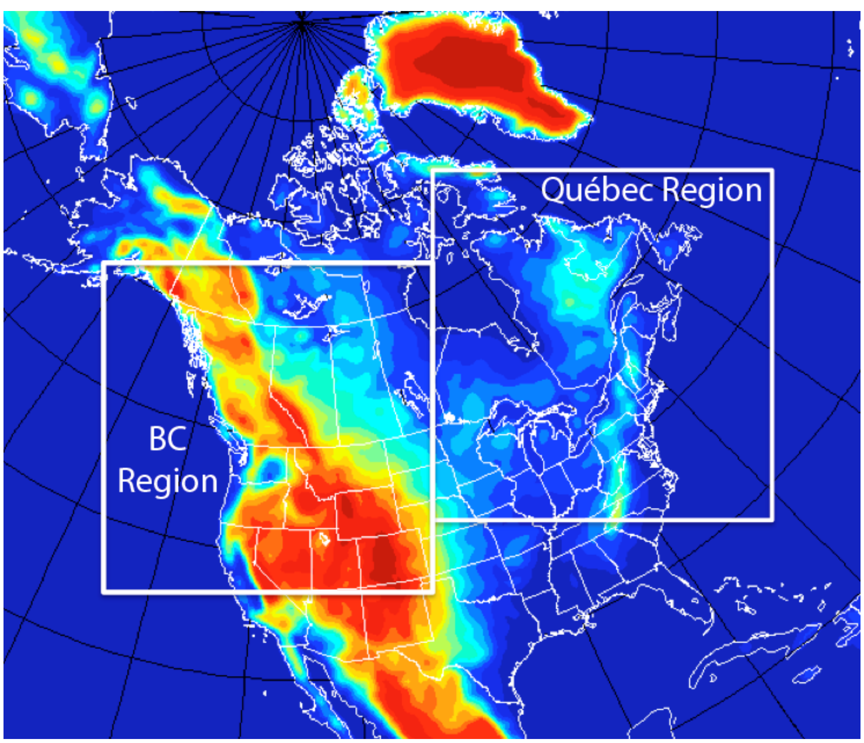

Figure 11: Topographic map of North America showing the proposed BC and Québec regional climate model domains at resolution 15km x 15km.

5. Roundtable Discussions

A series of roundtable discussions were held on the following selection of broad topics: Power Generation, Aquatic Ecosystems, Extreme Events, Energy Planning, and Trans-boundary Water Management. The purpose was to identify the needs of BC Hydro and other stakeholders concerning the impacts of climate change. These discussions included a wide range of opinions and expectations. The following summaries attempt to capture some of the major themes of the discussion, identified in consultation with the Table Lead for each topic. However, details of the discussions and some of the arguments were not recorded. The result is a summary of opinions that do not necessarily represent the position of BC Hydro or PCIC. However, these summaries will be considered as BC Hydro prepares plans for adaptation to future climate variability and change.

5.1 Power Generation

Table Lead: Kelvin Ketchum, BC Hydro

The Table Lead opened the session by presenting his review of the day's scientific presentations. Essentially, climate models project a warmer world with wetter winters and drier summers for much of BC and with the potential for more extreme events overall. BC's electrical demand is highest in the winter so powerplant generation in the Peace and Columbia River systems (80-85% of BC Hydro's heritage resources) is most needed during the winter. Therefore, these projected climate shifts may not result in reduced average generation (or reduced value) for BC Hydro's resources. In general, BC Hydro Resource Management employees consider that climate/weather variability is a more important factor than the climate change trend with respect to mid-term reservoir operations. Their philosophy is to expect and embrace uncertainty (i.e., model uncertainty). One of the key factors for BC Hydro will be forecasting in the face of uncertainty with respect to climate change. Therefore, improved forecasting resources may be required to deal with this uncertainty.

The issue of reservoir storage was mentioned as being a very important factor in dealing with the potential impacts of climate change. If the snowpack reservoirs are changing and melting out more quickly, then water reservoirs will have to be managed differently in response. However, this would depend on the system and its storage capacity. Some participants felt that BC Hydro might already have the resources to deal with projected streamflow changes or planned energy infrastructure may introduce the necessary flexibility.

Participants recognized that different hydro-power systems could be affected differently by climate change. For example, the systems on the South Coast might be more sensitive to climate change. In systems where glacial inflows contribute to runoff, the loss of glaciers along with snowpack changes could lead to a reduction in late summer flows for some systems. The question was raised with regards to the capacity of reservoirs to store large volumes of flow through winter without spilling. In coastal watersheds, a new balance between in-stream flow needs for fisheries and power generation may be required. Releases of cold water might also be required as the air temperature increases and leads to potentially higher stream temperatures for BC systems. This might be another consideration that will require BC Hydro systems to be flexible and responsive to climate change impacts.

The issue of independent power producers (IPPs)[i] was also raised with respect to system flexibility. There was concern that many of the 'new power resources' supplied by IPPs might only be available on a seasonal or intermittent basis. This may have a larger impact on the operation of the heritage BC Hydro system than the direct impacts of climate change. Furthermore, how does the change in runoff seasonality, combined with the integration of generation from new IPPs affect the operation of BC Hydro's heritage resources? The need to integrate climate change analysis with the investigation of generation patterns from these new power resources was highlighted several times by attendees, including the recommendation to expand the investigation of climate change impacts to IPP projects dependent upon wind and other sources of energy.

5.2 Aquatic Ecosystems

Table Lead: John Kelly, BC Hydro

With respect to aquatic ecosystems the implications of climate change are alterations to the amount and timing (e.g., seasonality) of runoff and streamflow as well as changes to water quality (e.g., turbidity, chemistry and temperature). Discussion generally acknowledged that: 1) more research is required to address the issue of how fish habitat health can potentially be affected by changes in streamflow patterns and water quality, and 2) BC Hydro operations may need to be modified in order to adapt to the pressures of climate change.

Discussion on the need for future research identified the complexity and scope of the problem. Freshwater systems in BC contain many different species with different and complex life histories distributed throughout a myriad of complex habitat types and flow regimes. It was suggested that future research should take a more heuristic approach and focus on understanding ecosystem function and services as opposed to focusing on individual species (usually species at risk). This led to the suggestion that freshwater systems should be managed at the ecosystem scale, with a full geographic assessment of the consequences of current impacts (i.e. regulation) and a quantification of vulnerability and risk associated with climate change. There was some concern expressed that we still lack a basic understanding of how aquatic ecosystems even respond to local and regional disturbance, let alone the knowledge to predict ecosystem response to the projected effects of climate change. Therefore, there is still a need for more "primary research", such as addressing how various species adapt to change or how sensitive ecosystems and species are to change. There is also the need to acknowledge the dynamic nature of ecosystems and to recognize their natural variability. Finding clarity on these issues is currently hindered by high uncertainty and an absence of advanced tools. The issue of data scarcity was also raised. More specifically, that research is hindered by a lack of local observations and there is a need to expand monitoring networks in BC.

The question was raised about the potential for BC Hydro to adjust operations to maintain (or improve) aquatic ecosystem health in light of potential climate change impacts. Specifically, could existing reservoir storage be used to maintain historical streamflow patterns/attributes (notwithstanding such issues as erosion and channel stability) and suitable stream temperatures (i.e. cold-water release)? It was acknowledged that adjustments to BC Hydro operations for the management of aquatic ecosystems may require some tradeoffs, particularly loss of power revenue.

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[i] An independent power producer (IPP) is a producer of electrical power that does not have a regulated load serving obligation. BC Hydro is a utility, with load-serving obligations, and thus is not an IPP. Electricity generation from most new IPPs is expected to be from clean and renewable sources, e.g. water, wind, biomass, tidal and ocean, geothermal, solar, and natural gas (with offsets) (MoE, 2010; ILMB, 2010).

5.3 Extreme Events

Table Lead: Janos Toth, BCTC

Potential changes in extreme events have implications not only for BC Hydro power operations and energy infrastructure (generation, distribution and transmission), but also for energy demand, maintenance and management of general infrastructure (transportation, communication, waste and water management, etc.), public safety, and ecosystem health and evolution (from changes in disturbance regimes). Extreme events are often quantified by both their magnitude (intensity) and frequency of occurrence. Some extreme phenomena, such as drought, precipitation or heat waves, are also quantified by the duration or persistence of the event. Many extreme events, such as floods and storm surges, are also of relatively short duration (hours to days) and some typically only affect a relatively small area. Therefore, quantifying extreme event behavior under future climates requires a more explicit understanding of changes in weather at high spatial and temporal resolution.

The discussion highlighted the need for further research in predicting the effects of climate change on a broad range of extreme events. Such events were generally classified as climatic extremes, hydrologic extremes and other extremes. Climatic extremes include temperature events (cold snaps and heat waves), precipitation events (intense rainfall, snow storms, and drought or long dry spells, and ice storms), and wind events (wind storms, storm surge and lake seiche). As well, it was noted that interaction among several variables can also influence extreme behavior. For example, warmer temperatures combined with increased precipitation may generate more extreme rainfall events. Hydrologic extremes include floods and high water events, low flow or hydrologic drought, and ice jams and ice jam flooding. Other ‘extreme’ events that are of concern are wildfire and debris slides or failures. The point was raised that there can also be effects on extreme events that may be indirectly related to climate change, so-called second- or third-order effects. For example, land use change (like the recent mountain pine beetle epidemic) may have a larger effect on hydrologic extremes than climate change in certain regions. The effect of increased drought severity or frequency may result in higher wildfire frequency which may indirectly lead to higher frequency of flooding, debris slides and sedimentation.

Quantifying changes in extreme event behavior requires knowledge of underlying changes in the statistical distribution of the variable or phenomena of interest. For instance, changes in extremes are sensitive not only to changes in the mean, but also to the variance and higher-order moments, and extremes can be very sensitive to relatively small distribution changes. As such, extreme event behavior is particularly susceptible to climatic non-stationarity and the discussion revolved around the particular challenges faced by planners, engineers, etc. who can no longer rely on the past as an accurate indicator of future risk. Moreover, common measures of risk (e.g., return period) essentially lose their meaning when the extreme event being quantified comes from a non-stationary climate.

There was some discussion on the limitations of using current climate and impact modelling to predict the response of extreme events to climate change. Specifically, questions were raised regarding the ability of global and regional climate models to accurately capture extreme behavior. By implication, this questions the ability of impact models, which obtain the climate signal from regional or global climate models, to accurately project changes in extreme events. In light of this, it was deemed important that future work focus on diagnosing the synoptic controls behind extreme events. Existing modelling results (e.g., downscaled high-resolution climate data) should nevertheless also be mined to obtain an initial quantification of extreme event changes. The issue of adequate observational data was brought up several times. The general view is that the very nature of infrequent extreme events means that high-quality historical data (e.g., climate, hydrometric, etc.) of sufficient duration are required to accurately quantify changes in extreme events. Many felt that this requirement was not being adequately met.

5.4 Energy Planning

Table Lead: David Ince, BC Hydro

The discussion of energy planning focused on the requirement to adapt to potential changes in both energy supply and demand. In other words, the significance of projected supply changes must be considered within the context of potential demand changes. Supply changes involve direct impacts of climate change to hydro-power supply as a consequence of changing streamflow, both for BC Hydro heritage operations and potential new run-of-river systems, as well as impacts to possible alternative energy sources (i.e., wind, solar or wave energy). Demand changes can be a function of both direct impacts from climate change (e.g., heating and cooling demand) as well as unpredictable social and economic factors. Nevertheless, it was generally agreed that energy planning is crucial because infrastructure decisions can have implications for BC Hydro operations for the next 100 years.

The issue of energy supply must not only consider the effects of climate change on heritage hydro projects, but also how much of future energy supply will rely upon new IPP projects which will exhibit their own specific sensitivities to climate change. Most of BC Hydro's generating capacity is derived from reservoir storage which will be affected by changes in the timing and magnitude of inflow. Although potentially sensitive to inflow changes (particularly smaller and/or coastal reservoirs), BC Hydro's reservoirs may arguably be less sensitive to climate change than many potential IPP projects which will have no storage (i.e., wind and ocean) or which rely entirely on natural storage (i.e., run-of-river). Essentially, the effects of climate change on the reliability of power supply is dependent upon the change in both the variability of the power source (streamflow, solar, wind, wave, or tidal) and amount of storage (natural or man-made). Clearly more work is required to project the effects of climate change on alternative sources of power, such as quantifying projected change in the magnitude and frequency of wind velocity, solar radiation, and ocean wave height.

Changes or trends in energy demand (base and peak) will be affected by many factors, one of which is climate change, but many which are unrelated (at least directly) to climate change. It can be expected that a change in climate will have a direct influence on energy demand, mainly through changes in heating and cooling requirements. This will be dependent upon changes in the magnitude, frequency and duration of heating- and cooling-degree-days in BC, but also in other potential markets in North America. A second issue is the degree to which climate-driven demand change will synchronize (or de-synchronize) with climate-driven supply changes. For instance, will a potential increase in summer cooling demand be exacerbated by a reduction in summer streamflow (or an extended low flow period) or reduced reservoir levels? Nevertheless, much of the future power demand in BC (and in potential external markets) will be controlled by factors independent of climate. These include population growth and distribution, technological changes (e.g., improved energy conservation), economic growth, and energy pricing. For example, the question arose as to whether adaptation measures might have implications for electrical usage. If cars shift from using gasoline to electrical power, what will be the increasing demands on the hydro power system and management of that system? The carbon tax, for instance, is focusing on incentives for BC residents to shift away from carbon usage. This shift could mean additional usage or pressure on the hydroelectrical system in BC. Needless to say, uncertainty regarding future trends in any of these non-climate factors is potentially quite high. It is also not clear which factors, climate-related or socio-economic, present a greater source of uncertainty.

5.5 Trans-boundary Water Management

Table Lead: Heather Matthews, BC Hydro

Adapting to climate change will require an approach that rationalizes the demands of competing interests. Trans-boundary water management adds the extra complication that adaptation must also consider both jurisdictionally internal *and* external (possibly competing) interests. Considered another way, trans-boundary water management is simply water management, but with the added dimension that it must consider the adaptation needs of two politically independent jurisdictions (countries or provinces). In this sense, trans-boundary water management will operate under the same climate change pressures as water management in general.

The discussion over the two sessions focused on trans-boundary water management on the Columbia and Peace River systems. Trans-boundary water management on the Columbia River system is under the auspices of the Columbia River Treaty (the "Treaty"), an international treaty between Canada and the United States governing the development and operation of dams on the upper Columbia River. The Peace River system is an example of provincial trans-boundary water management. The Peace River system originates in the northern Rocky Mountains of BC, where it is regulated by the W.A.C. Bennett Dam before draining eastward into Alberta.

In the case of the Columbia River Treaty, adaptation to climate change may be currently constrained by the provisions of the Treaty. The possibility of terminating or re-negotiating the treaty[ii] highlighted the need for a clear understanding of climate change impacts in the Canadian portion of the Columbia River and the impact upon domestic (and often competing) interests before addressing possibly competing international interests (i.e., the need "to get our house in order" first). This led to competing views on the use of tools and data, with some insisting that Canadian research should be based on tools and data independent from those of US researchers (i.e., independent validation of US studies), and others stating the need to use common and agreed-upon datasets, models and information. Suggestions for future research included: 1) furthering our understanding of the implication of changes in natural storage (snowpack and glaciers), particularly with respect to low flows and hydrologic drought, and 2) an integrated basin-wide assessment of the impacts of climate change (e.g., degree of difference in hydrologic response north and south of the border, impacts on different sectors/interests, and determination of storage).

As the provisions of the Treaty deal only with hydro-power generation and flood mitigation, a commonly held impression is that management for competing interests such as fisheries and wildlife, salmon restoration, recreation, domestic water supply, irrigation, navigation, and cultural resources are constrained. This issue may be further exacerbated under climate change.[iii] For example, some discussion focused explicitly on the desire for salmon restoration within the upper Columbia and the challenges posed by the fact that the current management of the system already

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[ii] There is no specified termination date for the Treaty, but it has a minimum length of 60 years. The treaty provides that either Canada or the USA can unilaterally terminate the Treaty any time on or after September 16, 2024, provided a minimum ten years written notice is given. However, if both the Canadian and United States' federal governments agree, the Treaty can be re-negotiated at any time. With termination, some Treaty provisions continue for the life of the projects, especially Called Upon flood control, Libby coordination obligations, and Kootenay River diversion rights (EMPR, 2010).

[iii] Based on discussion external to the roundtable sessions, it is the authors' understanding that this *may* be a common misperception in that the US and Canadian Entities have been given broad discretion to implement the treaty. In other words, there is scope within the operational practices of the Treaty Entities to manage water resources for interests other than hydro-power production and flood mitigation.

fails to sufficiently mimic a “natural” flow regime.[iv] The suggestion was raised that negotiation of a new treaty may allow for provisions that deal explicitly with additional interests other than flood control and hydro-power generation. Furthermore, given the asymmetrical changes occurring north and south of the border (e.g., projections of greater loss of snowpack in the US portion than the Canadian portion and proportionately more water coming from the upper Columbia River than the remainder of the basin), it seems plausible that the United States might seek to renegotiate the provisions of the Treaty.[v]

Discussions on the Peace River focused on how climate change may impact the Peace-Athabasca Delta. The Peace River joins the Slave and Athabasca Rivers in north-eastern Alberta where the three rivers form the large inland Peace-Athabasca Delta at the west end of Lake Athabasca, the largest boreal delta in the world. Discussion ensued on the role of regulation under projected climate change and what should be considered with respect to possible impacts on the Peace-Athabasca Delta (i.e., cumulative effects of projected streamflow and projected effects of climate change directly on the delta). Ice jamming issues downstream of the Peace River’s Bennett Dam (i.e., change in frequency and magnitude) was also identified as a key issue of concern. More study is required.

[iv] Fish passage in the upper Columbia River is currently blocked by the Chief Joseph Dam and the Grand Coulee Dam in the US.

[v] Canada and the United States have already begun a process to evaluate future options regarding the Treaty and have participated in joint technical studies (EMPR, 2010).

6. Concluding Statements

Representatives from BC Hydro and PCIC provided closing summations of the findings presented at the workshop. Both speakers expressed optimism that collaborations between PCIC and BC Hydro would continue.

Dave Rodenhuis, President and CEO of PCIC, offered the following summary of areas where the consortium can continue to grow and develop:

- hydrologic and climate modelling tools developed by PCIC have proven their value and provide a firm foundation upon which to expand the analysis
- WC2N network expertise in glacial inventory and modelling is commendable and could be incorporated in PCIC hydrologic projects
- PCIC should follow the example set by the University of Washington's CIG group in quantitatively applying hydro-climatic information for the purpose of planning adaptation to climate change
- the UVic-Ouranos proposal to apply a high-resolution climate model on a Pacific Grid would enhance PCIC capabilities for developing future climate projections, including uncertainty estimates, in the complex topography of British Columbia
- Hydro-Québec experience with embracing a long-term vision and strategy for energy planning and adaptation to climate change is a prototype for both PCIC and BC Hydro to emulate
- the ultimate success of hydro-climatic modelling in BC depends on creating and maintaining a comprehensive, province-wide database of climate-related data like temperature, precipitation, snowpack, streamflow, etc

Dr. Rodenhuis noted that adaptation to climate change and energy planning are closely related topics. Although PCIC does some contract work and consultation on its own, it acts primarily in collaboration with researchers and users. PCIC focuses on *targeted research*, bridging the gap between pure research and applications in order to support planning and adaptation to climate change impacts. Although the present results are preliminary, the partnership with BC Hydro has given PCIC the opportunity to demonstrate its value and capabilities with several analysis tools. The next step is to build on that success.

Renata Kurshner, BC Hydro Director of Generation Resource Management, noted that as the four-year collaborative project is nearing completion, there is an opportunity for BC Hydro to consider other research that may be required to support planning and decision-making into the future. She suggested a dual-role for BC Hydro:

- as a climate change leader, demonstrating environmental and social responsibility by example while providing its customers with enough information to make sound decisions
- as a service provider, obliged to serve its customers under all future conditions

Key issues of note include not only power generation and transmission, but also safety, sustainability of water resources, the future of the Columbia River Treaty, and providing customers with useful information for preparing to adapt to climate change. It is imperative that all BC Hydro departments think about how climate impacts will affect their sectors. Yet no single organization can provide enough expertise in all these areas to solve the issues involved. Consequently, BC Hydro continues to support the development of PCIC and the collaborative model.

References

Presentations

Climate Overview: Katrina Bennett, PCIC, Hydrologist.

BC Watersheds: Peace, Campbell and Upper Columbia & Kootenay: Markus Schnorbus, PCIC, Hydrologist.

Results on the Columbia River Basin and Implications for power generation: Prof. Alan Hamlet, University of Washington, Assistant Professor, Climate Impacts Group.

Mica Glacier and Hydrologic Modeling: Dr. Dan Moore, Professor, University of British Columbia, Western Canadian Cryospheric Network (WC2N).

Climate Diagnostics: Dr. Daniel Caya, Ouranos, Director, Climate Science.

Hydro-Quebec Example: Claude Demers, Hydro-Québec, Science Communicator.

Hydro Quebec Business Perspective: Dr. René Roy, Hydro-Québec, Climate Change Project Director.

(Presentations are available at http://pacificclimate.org/resources/presentations)

Publications

Integrated Land Management Bureau (ILMB), 2010. Independent power production in B.C.: An inter-agency guidebook for proponents. Province of British Columbia. 152 p. Available from http://www.al.gov.bc.ca/clad/IPP_guidebook.pdf.

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Roy, R., Pacher, Adamson, P., G., Roy, L., Silver, R. (2008). "Adaptive Resources Management for Water Resources Planning and Operations". Scientific and Technical Report requested by the World Bank.

List of Figures

List of Attachments

Attachment 1 – Workshop Agenda

April 20, 2010 ● 9:00am to 5:00pm ● BC Hydro, Edmonds Auditorium ● 6911 Southpoint Drive, Burnaby

Objectives:

- to report on PCIC accomplishments and highlight the technical results of the past 3+ years;
- to engage with and attract additional consortium members who will be interested in the results and may aid in directing the scope of PCIC's future research;
- to explore the implications of PCIC's hydrologic impacts research for BC Hydro's future adaptation and resource planning.

8:30	**Registration**	
	Check in at the BC Hydro security desk	
	Workshop registration in the Edmonds Auditorium	
	Continental breakfast provided	
9:00	**Introductions**	
	Moderator's Introduction	*Wendy Avis*, BC Hydro, Project Manager, Environment and Sustainability
	Welcome	*Chris O'Riley*, BC Hydro, Senior Vice-President, Engineering, Aboriginal Relations and Generation
	Preparing for Adaptation	*James Mack*, Climate Action Secretariat, Head
9:20	**Program – Context for this Project**	
	PCIC Development	*Dr. David Rodenhuis*, PCIC, Director and President/CEO
	Strategy and Context	*Stephanie Smith*, BC Hydro, Manager, Hydrology and Technical Services
9:35	**Climate Change – Assessment of Hydrologic Impacts**	
9:35	Climate Overview	*Katrina Bennett*, PCIC, Hydrologist
10:05	BC Watersheds: Peace, Campbell and Upper Columbia & Kootenay	*Markus Schnorbus*, PCIC, Hydrologist
10:50	**10 minute break**	

11:00 **Climate Change – Assessment of Hydrologic Impacts—continued**

11:00	Results on the Columbia River Basin and Implications for power generation	*Prof. Alan Hamlet*, University of Washington, Assistant Professor, Climate Impacts Group
11:30	Mica Glacier and Hydrologic Modeling	*Dr. Dan Moore*, Professor, University of British Columbia, Western Canadian Cryospheric Network (WC2N)
11:50	Climate Diagnostics	*Dr. Daniel Caya,* Ouranos, Director, Climate Science

12:20 Lunch

Buffet style lunch provided, served in the Edmonds Auditorium

1:00 Future collaboration: The Ouranos and Hydro-Québec example

1:00	Hydro- Québec example: Technical Results	*Dr. Rene Roy*, Hydro-Québec, Climate Change Project Director
1:30	Business Perspective	*Claude Demers*, Hydro Québec, Science Communicator

2:00 15 minute break

2:15 Future collaboration – Opportunities and direction

2:15	PCIC Vision	*Prof. Andrew Weaver*, University of Victoria Professor and Canada Research Chair,; Senior Scientist, PCIC
2:30	Roundtable Discussion "Cracker Barrel Sessions"—focus on BC Hydro needs 5 topics & 2 sessions: 1. Power generation–potential impacts 2. Extreme Events 3. Energy Planning–future demand 4. Trans-boundary water management 5. Aquatic Ecosystems	*Table experts,* see attachment
3:30	Table Summaries	*Table experts,* see attachment

4:00	**Conclusions**	
	PCIC	*Dr. Dave Rodenhuis*, PCIC, Director and President/CEO
	BC Hydro	*Renata Kurschner*, BC Hydro, Director, Generation Resource Management

4:30	**Informal Debriefing**	
	Drinks and snacks provided in the Edmonds Auditorium	

Attachment 2 – Workshop Participation List

BC Hydro
Chris O'Riley, Senior Vice-President, Engineering, Aboriginal Relations and Generation
Peter Busby, BC Hydro Board Member
Renata Kurschner, Director, Generation Resource Management
Greg Arnold, Senior Sustainability Coordinator
Wendy Avis, Project Manager, Environment & Sustainability
Sean Fleming, Hydrologic Modeller,
Adam Gobena, Statistical Hydrologist
Brenda Goehring, Manager, Environment & Sustainability
Nadja Holowaty, Resource Planning
David Ince, Manager, Load and Market Forecasting
Siobhan Jackson, Environmental and Social Issues Manager
Tara Laycock, Emergency Preparedness Manager
John Kelly, Manager, Water License Requirements Program
Kelvin Ketchum, Portfolio Manager, System Optimization
Heather Mathews, Manager of Operations Planning
Doug McCollor, Manager, Meteorology and Climate Services
Randy Reimann, Manager, Resource Planning
Patrice Rother, Manager, Environmental Strategies
Magdalena Rucker, Energy Planning
Darren Sherbot, Specialist Engineer, Generation Resource Management
Stephanie Smith, Manager, Hydrology and Technical Services
Frank Weber, Hydrologist
Scott Weston, Hydrology and Technical Services
Brian Fast, retired

PCIC
David Rodenhuis, Director
Katrina Bennett, Hydrologist
Anne Berland, Research Assistant, Hydrology
Trevor Murdock, Climate Scientist
Markus Schnorbus, Hydrologist
Andrew Weaver, Professor
Arelia Werner, Hydrologist

BC Ministry of Environment
Lynn Bailey, Assistant Deputy Minister
James Mack, A/Head, Climate Action Secretariat
Pieter Bekker, Manager, Water Use Planning and Utilities Sections
Allan Chapman, Head, River Forecast Centre
Glen Davidson, Director and Comptroller of Water Rights
Ben Kangasniemi, A/Manager Science and Adaptation
Jennifer Pouliotte, Climate Change Adaptation Advisor, Climate Action Secretariat
Fern Schultz, Director, Science Information Branch
Lee Thiessen, Director, Climate Change

BC Ministry of Transportation and Infrastructure
Kevin Baskin, Chief Bridge Engineer

Ouranos
Daniel Caya, Director, Climate Science

University of Victoria
Asit Mazumder,Professor, Department of Biology
Tom Pedersen, Director, Pacific Institute for Climate Solutions
Lawrence Pitt, Associate Director, Pacific Institute for Climate Solutions

University of British Columbia
Michael Church, Professor, Department of Geography
Garry Clarke, Professor Emeritus Glaciology, Earth and Ocean Sciences
Dan Moore, Professor, Department of Geography and Department of Forest Resources Management Forest Renewal BC Chair of Forest Hydrology
Hans Schreier, Professor (Emeritus), Institute for Resources, Environment and Sustainability

Simon Fraser University
Deborah Harford, Executive Director, Adaptation to Climate Change Team (ACT)

Environment Canada
Alex Cannon, Climate Scientist-Statistical and Regional Climatology
Dan Millar, Secretary, Canadian Section International Osoyoos Lake Board of Control
Catherine Ponsford, Science Policy Analyst
Paul Whitfield, Head, Environmental Sciences Section

University of Washington
Alan Hamlet, Research Assistant Professor, CIG

International Centre for Sustainable Cities
Bruce Sampson, Chair

Hydro-Quebec
Claude Demers, Science Communicator
Rene Roy, Climate Change Project Director

Fraser Basin Council
Steve Litke, Senior Program Manager
Bob Purdy, Director, External Relations and Corporate Development
Jim Vanderwal, Program Manager, Climate Change & Air Quality

Columbia Basin Trust
Kindy Gosal, Director, Water and Environment

BC Transmission Corporation
Janos Toth, Program Manager, Science and Technical Advisor, Strategic Research and Development

MITACS
Duncan Phillips, Vice-President, Business Development, Western Canada

WC2N
Shawn Marshall, Canada Research Chair in Climate Change

Okanagan Nation Alliance
Heidi McGregor, Aquatic Habitat Biologist

Canadian Columbia River Inter-tribal Fisheries Commission
Bill Green, Director

Manitoba Hydro
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