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Report

International Joint Commission

Osoyoos Lake Plan of Study - Study 6: Climate Change and its Implications for Managing Water Levels in Osoyoos Lake

Project: 2011-8009.000

April 2011

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SUMMIT
ENVIRONMENTAL CONSULTANTS INC.
A Member of the Associated Engineering Group of Companies

Summit Environmental Consultants Inc.
200, 2800 - 29 Street
Vernon, British Columbia, Canada, V1T 9P9

TEL: 250.545.3672
FAX: 250.545.3654
www.summit-environmental.com

April 11, 2011

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Mr. Tom McAuley
Engineering Advisor
International Joint Commission, Canadian Section
234 Laurier Avenue West, 22nd Floor
Ottawa, Ontario K1P 6K6

Re: Study 6 – Implications of Climate Change for Managing Osoyoos Lake levels

Summit Environmental Consultants Inc. is pleased to provide a report to the International Joint Commission (IJC) on Study 6 of the Osoyoos Lake Plan of Study - *Climate Change and its Implications for Managing Water Levels in Osoyoos Lake*.

The report summarizes relevant historic climatic and hydrologic information, and summarizes future climate and hydrologic projections relevant to the management of Osoyoos Lake. The future projections are examined with reference to the lake level management regime specified in the Orders of Approval, and recommendations are provided for amending the Orders in 2013.

I trust this completes our assignment to your satisfaction. Please call if you have any further questions.

Yours truly,

Summit Environmental Consultants Inc.

B. T. GUY

Brian T. Guy, Ph.D., P.Geo., P.H.
Vice President and General Manager

Executive Summary

Water levels on Osoyoos Lake are managed according to Orders of Approval issued by the International Joint Commission (IJC). This study (Study 6) is one of several being conducted prior to the expiry of the current Orders in 2013. Its objective is to determine how robust the current Orders are in the face of past and future climate and hydrologic changes that affect Osoyoos Lake, and whether the Orders need to be amended to reflect these potential changes.

The study included assembling literature on past and future climate and hydrologic changes in the Okanagan and Similkameen River Basins, contacting researchers to obtain up-to-date research findings, and using this knowledge in an examination of the current Orders of Approval.

The level of Osoyoos Lake is continually managed to meet specified operating ranges in winter (November 1 to March 31) and summer (April 1 to October 31). The summer operating range depends on whether forecasts of spring inflows made by Canadian and U.S. forecasters exceed three thresholds. If any one of the three thresholds is not expected to be achieved, the lake operates in “drought” mode in the summer, which means that it can be filled and maintained at a level of up to 913.0 feet (and down to 910.5 feet) between April 1 and October 31. Otherwise, the summer lake level is maintained between 911.0 and 911.5 feet.

Although historical trends in climate and streamflow can be confounded by other signals, such as those of the Pacific Decadal Oscillation (PDO) and the El Nino Southern Oscillation (ENSO) cycle, recent large-scale trends relevant to the management of Osoyoos Lake are generally similar to present-day predictions of future changes.

The future management of Osoyoos Lake will likely have to contend with a suite of gradually changing conditions, including:

- Earlier spring runoff, which may necessitate changes to decision dates (i.e. when drought conditions are declared) and the dates of summer and winter operating ranges.
- Reduced snowpack and lower spring runoff, which may have a direct bearing on the total water supply in summer.
- Increased winter precipitation and warmer temperatures may cause more rain and less snow resulting in increased winter runoff. This additional water may help mitigate the lower spring runoff, but only if storage is available and utilized. If winter runoff were stored, summer lake levels could possibly be reached earlier.
- Projected higher water demand and higher evaporation from Osoyoos Lake will further increase the pressure on the reduced water supply.
- Potentially less accurate streamflow forecasts.

Although historical data suggests the hydrology associated with the three criteria used to declare a drought has not significantly changed since the Orders were drafted in 1982, projections of reduced April 1 – July 31 Similkameen River runoff and Okanagan Lake inflow suggest that the current criteria may trigger droughts with increasing frequency in the future. Future management of Osoyoos Lake will need to adapt to the projected advance in the annual hydrograph, both for Similkameen River and Okanagan River. Given the limited storage represented by Osoyoos Lake, and the projected reduction in supply and increase in demand, the risk of water deficits will increase in future.

Recommendations for amending the Orders are based on a desire to preserve the scientific linkage between the Orders and the hydrologic regimes of the two Basins, and improve management flexibility while at the same time having no negative impact. Based on projected climate and associated hydrologic changes, we recommend that the International Osoyoos Lake Board of Control consider the following:

1. Advancing the date on which drought declarations are made in the spring. Given that there may be considerable flow earlier in the season, the first declaration could be made on March 1.
2. Allow more flexibility in filling the lake. Increased flows are projected through winter and freshet is projected to occur earlier. Earlier storage may be required to take advantage of the available water.
3. Allow ramping over a defined period as opposed to setting strict date-specific water level requirements. This will provide flexibility into the future, which is particularly important given the wide range of projections for future water supply.
4. Evaluating whether the distinction between drought and non-drought conditions is required. In its place, a flexible lake management strategy that applies to all years could be developed.
5. Along with an evaluation of the requirement of the drought declaration, the use of fixed-dates for the summer and winter operating ranges should be evaluated in light of the projected future advance of the spring lake inflows.
6. Incorporate an adaptive management strategy that includes re-evaluation of the performance of the Orders every 10 years or after any year, with a view towards periodic refinement of the Orders. This concept recognizes the wide range in projected future conditions.

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1 Introduction

1.1 PROJECT UNDERSTANDING

Osoyoos Lake is an international water body, lying partly in Canada and partly in the United States of America (USA). Water levels on Osoyoos Lake are managed according to Orders of Approval issued by the International Joint Commission (IJC). The current Orders are due to expire in February 2013, and will be renewed at that time. Before renewal occurs, the IJC needs to decide whether the Orders should be modified. In 2006 Glenfir Resources was commissioned to explore issues associated with the Orders and to recommend studies accordingly. Study 6 was recommended to prepare the IJC for possible alterations to the hydrology of the Okanagan and Similkameen Basins that may take place because of changes to the climate. Climate change is likely to have progressive, significant, and lasting effects on the climate of the Okanagan and Similkameen Basins, and the potential extent of those effects has been the topic of research by a number of authors. Study 6 is intended to support decisions about thresholds for drought criteria, suitable lake levels, and the timing of lake level adjustments, and lead to possible changes in the Orders.

1.2 BACKGROUND

Approximately two-thirds of Osoyoos Lake lies in British Columbia, while one-third is located in Washington State. The Okanagan River flows into Osoyoos Lake at the north end of the lake and is the largest source of input to the lake. The outlet of Osoyoos Lake is located at the southern end of the lake; and the river flowing out of the lake is referred to as the Okanogan River. Zosel Dam, which regulates the lake levels, is located approximately 2.5 km downstream from the Osoyoos Lake outlet.

Zosel Dam is owned by the Washington State Department of Ecology and is operated to satisfy the interests of both Canada and the USA. The current Orders were written in 1982, with a Supplementary Order written in 1985. The Orders specify the operating range of Osoyoos Lake, which is implemented through the operation of Zosel Dam; and varies according to summer (April 1 to October 31) and winter (November 1 to March 31) operating ranges. The Osoyoos Lake operating ranges are presented graphically in Figure 1-1.

A full description of the lake operating regime is provided in Section 3.0, and summarized here. For the summer operating range, it is necessary to identify whether “drought” or “non-drought” conditions are expected before the operational range of Osoyoos Lake water levels is specified. Instead of the term “normal”, as used on Figure 1-1, in this report we use the term “non-drought”, to reflect the fact that both average and wet years are included in the non-drought years. The identification of drought or non-drought conditions is based on three separate criteria outlined by the Orders. These criteria are based on:

- forecast or actual flows in the Similkameen River,
- forecast or actual inflows to Okanagan Lake, and
- forecast or actual Okanagan Lake levels.

For the Similkameen River, water supply forecasts are produced by the National Weather Service, Northwest River Forecast Center; while for Okanagan Lake, water supply and lake level forecasts are produced by the River Forecast Center of the B.C. Ministry of Environment. Beginning April 1st, the International Osoyoos Lake Board of Control (IOLBC) reviews each forecast. If any of the three forecasts falls below the criteria as outlined in the Orders, a drought is declared, and the lake is maintained within the drought operating range.

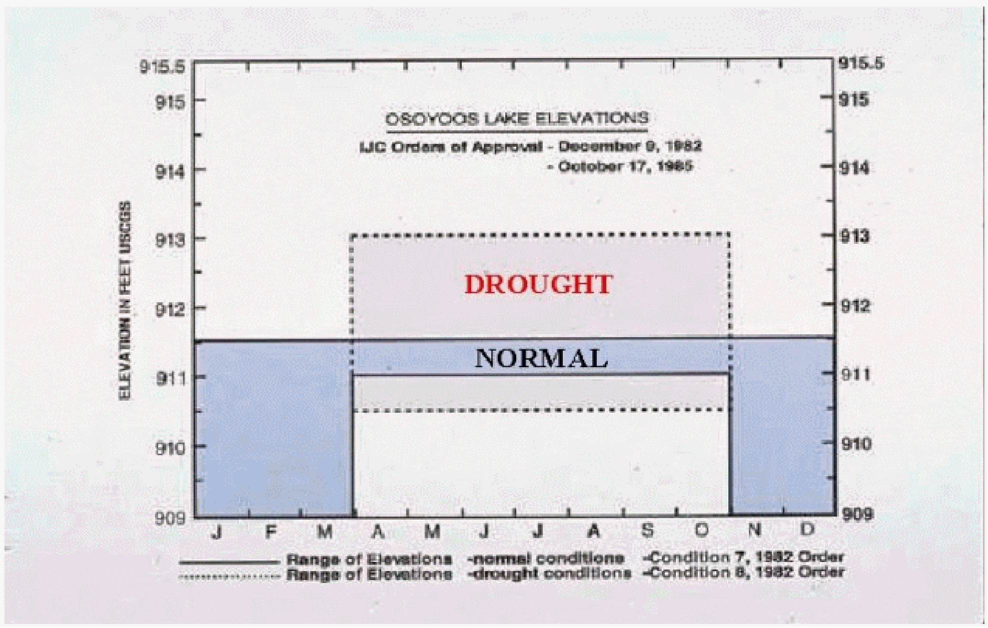

Figure 1-1
Osoyoos Lake operating ranges as outlined within the IJC's Orders of Approval (IJC 2000)

With the summer operating range of Osoyoos Lake governed by predictions of flow in the Similkameen and Okanagan Basins, climate change impacts occurring in either Basin could directly influence Osoyoos Lake levels. Recent scientific research and modeling suggests that the impacts of climate change within the Okanagan Basin could be significant.

1.3 PROJECT OBJECTIVES

Study 6 is designed to provide an understanding of the current state of knowledge of climate change science and modeling, as well as hydrologic modeling in both the Okanagan and Similkameen Basins. In addition, the study is intended to determine how robust the current Orders are with respect to a changing climate and provide recommendations to incorporate climate information into future Orders.

The specific objectives of Study 6 are to:

1. Determine the sensitivity of Okanagan and Similkameen basin hydrology to trends and variations in climate – in particular determine how drought frequency and lake levels have responded to the climate over the last century;
2. Identify what existing model simulations of future hydrologic conditions say about the potential effects of climate change on the hydrology of the Okanagan and Similkameen basins, and on water demand; including the magnitude of these changes relative to past experience and the shortcomings of the existing model simulations;
3. Assess the level of certainty surrounding the existing information and model projections;
4. Provide advice on the incorporation of climate change projections and, in particular, drought severity predictions, into forthcoming Orders of Approval for Osoyoos Lake; and
5. Provide advice on ensuring that future Orders of Approval are sufficiently adaptive to incorporate future climatic and hydrologic conditions.

1.4 STUDY OVERVIEW AND METHODS

The study was divided into several specific tasks:

1. Start-up meeting with the Contract Authority and Scientific Advisor (Tom McAuley and Dan Millar);
2. Literature review;
3. Summarize the predicted impacts of climate change;
4. Gap analysis;
5. Identify potential relevance to Orders; and
6. Reporting and presentation.

A start-up meeting occurred by telephone on January 14, 2011 between Brian Guy and Lars Uunila of the study team, and Tom McAuley and Dan Millar. At this meeting the project scope, objectives, deliverables, budget, and schedule were reviewed and clarified.

A review of literature relevant to historic climate and hydrology in the Okanagan and Similkameen basins was conducted. In addition, we identified relevant completed or ongoing work being undertaken on future changes to climate and hydrology in the two Basins. We contacted several researchers and summarized their research initiatives and contact information. This information is presented in Section 2.0 of this report.

Based on the literature review completed under Task 2, we then assessed and summarized specific predictions of the relevant climate and hydrologic models relevant to Osoyoos Lake management (Task 3). This information is presented in the Appendices to the report and is summarized in Section 2.0. Considering the state of knowledge of climate and hydrology, we identified areas where additional research would be beneficial to fill knowledge gaps (Task 4).

In Task 5, we considered the implications of the findings of the literature review on the Orders of Approval, in particular to the drought triggers, the timing of lake level adjustments, and the specific lake levels and operating ranges identified in the Orders. Task 5 is reported in Section 3.0 of this report.

Finally we prepared this report of our findings, as well as a summary report, and a Powerpoint presentation intended for a general audience.

2 Literature Review

The literature review began with a meeting of the study team, including specialist advisors Paul Whitfield and Denise Neilsen. A list of relevant research and researchers was compiled (Table 2-1, and Appendix A). Each of these individuals was contacted and asked to provide information on existing literature and ongoing studies relevant to past climates and hydrology, as well as on future climate change and its implications for the Similkameen and Okanagan Rivers and Osoyoos Lake. Relevant studies identified through this process are summarized in Appendix B. These researchers were asked to describe any current research initiatives that their own organizations have underway relevant to this study (Table 2.2), and list and provide information on any recent or unpublished papers or model results that could be used.

Specific model predictions most relevant to the present study were highlighted (Appendices C, D, and E, and Table 2-3). These findings are summarized in the text of Section 2.

2.1 RESEARCHERS AND RESEARCH INITIATIVES

Table 2-1 lists the researchers contacted during the present study. Table 2-2 lists the researchers with current research activities in the Okanagan or Similkameen River basins.

2.2 SUMMARY OF RELEVANT WORK

This section summarizes relevant hydro-climatological studies over the past century, and studies that have dealt with future climate change predictions for southern British Columbia and northern Washington State, with a focus on the Okanagan/Okanogan basin and the Similkameen River basin.

Many relevant studies were identified. Some have examined specific variables (e.g. temperature, precipitation, or streamflow) with relevance to specific applications (e.g. hydro-electricity, forestry, or agriculture). Many of the scenarios used to predict future climates came from a variety of International Panel on Climate Change (IPCC) assessment reports (e.g. First (FAR-1990); Second (SAR-1995); Third (TAR-2001) and Fourth (AR4-2007)). Appendix B summarizes the key documents (including comments on their relevance to the present study, the temporal and spatial scopes of the studies/models, and descriptions of model features and outputs). Table 2-3 provides a summary of Appendix B.

Table 2-1
Okanagan Climate Researchers and Affiliations

Climate Researcher	Title and Affiliation
Alila, Younes	Associate Professor, University of British Columbia
Allen, Diana	Professor, Simon Fraser University
Cannon, Alex	Senior Hydroclimatologist, Environment Canada; Adjunct Professor UBC
Cohen, Stewart	Research Scientist, Adaptation & Impacts Research Division Section (AIRS), Environment Canada, and Adjunct Professor, Department of Forest Resources Management, University of British Columbia
Coulson, Hal	Hydrologist (retired), B.C. Ministry of Environment
Fabro, Andrew	Librarian, Environment Canada
Gobena, Adam	Statistical Hydrologist, BC Hydro
Hamlet, Alan	Research Assistant and Professor, University of Washington
Hyatt, Kim	Research Scientist, Fisheries and Oceans Canada
Lall, Upmanu	Senior Research Scientist and Professor, Columbia University
Long, Karilyn	Fisheries Biologist, Okanagan Nation Alliance
Millar, Daniel	Senior Advisor, Water Issues, Environment Canada
Murdoch, Trevor	Climate Scientist, Pacific Climate Impacts Consortium, University of Victoria
Nielsen, Denise	Research Scientist, Agriculture and Agri-Foods Canada
Pike, Robin	Watershed Research Hydrologist, B.C. Ministry of Environment
Redding, Todd	College Professor, Department of Geography & Earth and Environmental Science, Okanagan College, Penticton
Schnorbus, Markus	Lead Hydrologist, Pacific Climate Impacts Consortium, University of Victoria
Scott, David	Associate Professor, University of British Columbia Okanagan
Tansey, James	Associate Professor, University of British Columbia
Weber, Frank	Hydrologist, Team Lead, Runoff Forecasting, BC Hydro
Whitfield, Paul H.	Emeritus Scientist, Environment Canada
Winkler, Rita	Research Hydrologist, B.C. Ministry of Forests

Table 2-2
Current Climate Research Initiatives in the Okanagan and Similkameen River Basins

Name	Current Research Initiatives
Cannon, Alex	Okanagan Water Supply and Demand Project Phase 3 climate scenarios: collaborating with Denise Neilsen from Agriculture and Agri-Foods Canada to develop improved climate datasets for the Okanagan Basin, and running additional climate-driven scenarios for the Okanagan. Also developing new climate datasets for the Similkameen River watershed
Hamlet, Alan	The Climate Impacts Group at the University of Washington has recently completed a comprehensive modelling study of the hydrologic impacts of climate change in the Columbia watershed.
Neilsen, Denise	Working with Ted van der Gulik of the B.C. Ministry of Agriculture to provide information on current and future irrigation demands in the Similkameen River watershed.
Pacific Climate Impacts Consortium (PCIC)	PCIC is continuing development of the Plan2Adapt Tool – an excellent tool for deriving climate projections and related hydrological implications. The tool generates maps, plots and data describing projected future climate conditions for British Columbia.
Schnorbus, Markus	PCIC currently has a hydrology model set up for the Okanagan and Similkameen watersheds (including historical and future climate data), and plan to complete additional hydrologic projection work sometime this year.

In general, air temperatures are expected to increase in future, and while precipitation trends are less clear, winter precipitation is expected to increase and summer precipitation is expected to decrease. As progressively more winter precipitation occurs as rain, snow depths and snow water equivalents are expected to decrease. Furthermore, the annual spring snowmelt period is expected to begin earlier in the spring; and snowmelt-generated peakflows will tend to be smaller. Rainfall will exert a progressively greater influence on the annual hydrological regime. Water demands are expected to increase while the growing season is expected to lengthen, further stressing the available water supply, which is likely to be more and more scarce at critical times, for example in the late summer and early fall. In addition, droughts are expected to occur with increasing frequency.

Recent work at the University of Victoria’s Pacific Climate Impacts Consortium (PCIC) and the University of Washington’s Climate Impacts Group is directly applicable to this study. PCIC has developed the ‘Plan2Adapt’ tool which provides estimates of future primary climate variables such as temperature and precipitation, as well as more complex parameters derived from these primary variables, for specified geographic areas. The University of Washington has recently completed a major study of climate change in the Columbia River Basin. These studies use the most up to date IPCC assessment scenarios (i.e. AR4), using an ensemble of climate models. In addition, the recently completed Phase 2 of the Okanagan Water

Supply and Demand Project (OWSDP) also provides information relevant to this study. The following three sub-sections of the report provide more detailed predictions and analyses from these sources.

Table 2-3
Summary of Past Trends and Future Predictions from Literature Cited in Appendix B

Climate	Envelope of Past Trends	Comments	Future Envelope	Comments	Source
Temperature	+0.9 to +1.8ºC/century (mean annual temperature)	Average, winter and summer all increasing, with greater increase in winter	+1 to +4 ºC/century 0ºC to 7.0ºC (winter) 0ºC to 7.5ºC (summer) +0.5ºC/decade	Winter increases more than summer	Cohen et al., 2006 Cohen et al., 2004 Cohen et al., 2000 Hamlet, et al., 2010 Merritt et al., 2006 Murdoch and Werner, 2010 MWLAP, 2002 Moore et al., 2010 Neilsen et al., 2010 PCIC, 2011 Pike et al., 2010 Pike et al, 2008b Rayne and Forest, 2010 Rodenhuis et al., 2007 Sherer and Pike, 2003 Schnorbus and Rodenhuis, 2010 Spittlehouse, 2008 Tohver and Hamlet, 2010 VOX Communication, 2003
Precipitation	Precipitation increase (25% in 50 years); +15 to 60cm/ century 3% to 6%/decade Southern B.C.: Winter precipitation Decrease (‘71-‘04; ’51-‘04 and 1950-2002) Increase (1901-2004) Summer & Annual precipitation Increase (1901-2004; ’51-’04 & ’71-04 and 1950-2002)	1901-2004; 1929-1998 summer precipitation: Increase 1970s to mid 1990s Winter precipitation: decrease in last 50 years 1929-1998 (%/decade): MAM +5% JJA +6% SON no trend DJF no trend	-50% to +25% (annual total) Winter precipitation (-5% to +25%) Summer precipitation (-50% to +5%)	Potential decrease in summer precipitation and increase in fall and winter precipitation	

Climate	Envelope of Past Trends	Comments	Future Envelope	Comments	Source
Snow depth	Decreasing snowpack Depth decreasing: -3%/decade (1935-2000) Earlier freshet: -8 days/decade Ice Free date: -6 days/decade		-88% to -3%		Adam et al., 2009 Cohen et al., 2000 Cohen et al., 2004 Cohen and Kulkarni, 2001 Hamlet et al., 2010 Hamlet and Lettenmaier, 1999 a/b Lee et al., 2009 Merritt et al., 2006 Mote et al., 2003 Mote et al., 2005 MWLAP, 2002 PCIC, 2011 Pike et al., 2008a/b Rodenhuis et al., 2007 Scherer and Pike, 2003 Schnorbus and Rodenhuis, 2010 U.S. Army Corps of Engineers, 2009 VOX Communication, 2003 Whitfield and Cannon, 2003 Winkler et al., 2005
Snow Water Equivalent (SWE)	Declines in much of western North America Declines in spring SWE	1935-2000 (no trend)	-28% to -70%		

Climate	Envelope of Past Trends	Comments	Future Envelope	Comments	Source
Streamflow	Increase (Nov to Feb) 10 to 25% less in dry season Up to 90% less in summer		-39% to +31% 10 to 25% less during dry season; and up to 90% less during summer Earlier spring peaks (4 to 8 weeks) Lower flows in high spring months More rain influenced hydrograph	Dependent on cool/warm season	Clair et al., 1998 Cohen and Kulkarni, 2001 Cohen et al., 2000 Hamlet and Lettenmaier, 1999 Leith and Whitfield, 1998 Loukas et al., 2002
Water Demands			Increase 12% to 61%	Okanagan	Cohen and Neale, 2006 Merritt et al., 2006 Neale et al., 2007 Neilsen et al., 2006 Neilsen et al., 2004 Reese, 2009 Toews and Allen, 2009a,b U.S. Army Corps of Engineers, 2009
Soil Moisture			Reduction (summer/fall)		Hamlet et al., 2010 Rodenhuis et al., 2007

2.2.1 University of Victoria, Pacific Climate Impact Consortium – Plan2Adapt Tool

The University of Victoria's Pacific Climate Impacts Consortium 'Plan2Adapt' tool provides outputs for the Okanagan-Similkameen, Central Okanagan and North Okanagan regions (website address: (http://plan2adapt.ca/plan2adapt.php). Graphical outputs from this tool for the Okanagan-Similkameen region are provided in Appendix C. Tables 2-4, 2-5 and 2-6 list the median and ranges of values expected for the 2020s, 2050s and 2080s as compared to the baseline period of 1961-90 for the three above-noted regions. These values are derived from a 15 Global Climate Model (GCM) ensemble, under the A2 and B1 CO_2 emission scenarios.

Table 2-4
Climate Change for the South Okanagan-Similkameen Region

Climate Variable	Time of Year	Projected Change (from 1961-90 baseline)					
		2020s		2050s		2080s	
		Median	Range	Median	Range	Median	Range
Mean Temp. (ºC)	Annual	+1.1ºC	+0.6ºC to +1.4ºC	+1.9ºC	+1.2ºC to +2.7ºC	+3.0ºC	+1.7ºC to +4.4ºC
Precip.	Annual Summer Winter	+4% -9% +2%	-1% to +7% -15% to +10% -3% to +10%	+6% -14% +6%	-2% to +10% -31% to 0% -2% to +15%	+8% -16% +10%	+1% to +17% -38% to -4% +3% to +24%
Snow Depth*	Winter Spring	-6% -33%	-16% to 0% -58% to -4%	-14% -57%	-25% to -3% -73% to -20%	-22% -78%	-41% to -9% -88% to -24%
GDD*	Annual	+175	+89 to +275	+379	+217 to +547	+571	+380 to +972
HDD*	Annual	-379	-521 to -234	-680	-961 to -422	-1056	-1560 to -609
FFD*	Annual	+15	+8 to +20	+26	+14 to +37	+39	+23 to +62

Source: UVic's PCIC Plan2Adapt Tool.

Notes:
GDD: Growing Degree Days (given in degree days)
HDD: Heating Degree Days (given in degree days)
FFD: Frost-Free Days
*These values are derived from temperature and precipitation.

Table 2-5
Climate Change for the Central Okanagan Region

Climate Variable	Time of Year	Projected Change (from 1961-90 baseline)					
		2020s		2050s		2080s	
		Median	Range	Median	Range	Median	Range
Mean Temp. (ºC)	Annual	+1.0ºC	+0.6ºC to +1.5ºC	+1.9ºC	+1.2ºC to +2.7ºC	+2.9ºC	+1.7ºC to +4.4ºC
Precip.	Annual Summer Winter	+4% -6% +3%	-1% to +7% -14% to +9% -2% to +9%	+7% -11% +7%	-2% to +10% -26% to -1% -1% to +16%	+8% -13% +12%	+2% to +15% -35% to 0% +3% to +23%
Snow Depth*	Winter Spring	-7% -33%	-16% to -1% -57% to -2%	-14% -57%	-25% to -4% -75% to -19%	-22% -77%	-44% to -9% -88% to -18%
GDD*	Annual	+187	+95 to +300	+382	+229 to +569	+601	+366 to +1031
HDD*	Annual	-366	-517 to -228	-669	-956 to -427	-1007	-1503 to -604
FFD*	Annual	+14	+8 to +20	+24	+13 to +35	+37	+21 to +60

Source: UVic's PCIC Plan2Adapt Tool.

Notes:
GDD: Growing Degree Days (given in degree days)
HDD: Heating Degree Days (given in degree days)
FFD: Frost-Free Days
*These values are derived from temperature and precipitation.

Table 2-6
Climate Change for the North Okanagan Region

Climate Variable	Time of Year	Projected Change (from 1961-90 baseline)					
		2020s		2050s		2080s	
		Median	Range	Median	Range	Median	Range
Mean Temp. (ºC)	Annual	+1.0ºC	+0.6ºC to +1.4ºC	+1.9ºC	+1.2ºC to +2.7ºC	+2.8ºC	+1.7ºC to +4.3ºC
Precip.	Annual Summer Winter	+4% -5% +4%	-1% to +7% -12% to +8% -2% to +10%	+6% -10% +7%	-2% to +10% -22% to -1% -1% to +16%	+6% -13% +12%	+3% to +14% -31% to +1% +2% to +24%
Snow Depth*	Winter Spring	-7% -32%	-16% to +1% -56% to -2%	-15% -57%	-27% to -2% -76% to -17%	-23% -76%	-46% to -10% -89% to -17%
GDD*	Annual	+188	+95 to +302	+382	+230 to +558	+584	+355 to +1034
HDD*	Annual	-357	-516 to -228	-666	-947 to -429	-983	-1466 to -600
FFD*	Annual	+14	+8 to +20	+24	+14 to +36	+37	+21 to +61

Source: UVic's PCIC Plan2Adapt Tool.

Notes:
GDD: Growing Degree Days (given in degree days)
HDD: Heating Degree Days (given in degree days)
FFD: Frost-Free Days
*These values are derived from temperature and precipitation.

The potential hydrological impacts for these regions, as stated by PCIC (2011), are highlighted below:

- Warmer annual temperature:
    - Changes in seasonality of streamflow
    - Increased evaporation
- Winter warming:
    - Mid-winter thaw events may cause ice jams and flooding
- Wetter conditions projected in winter:
    - Higher winter streamflows and extreme precipitation events may cause flooding, or increase the risks of more severe or more frequent floods and landslides
    - Increase in storm events
- Warmer, drier summers:
    - Possibility of more prolonged and intense droughts with lower water supply during periods of peak demand

  - Reduced soil moisture and increased evaporation, increasing irrigation needs at the same time of year that streamflows are expected to decline
  - Possible declines in recharge rates for groundwater sources

Overall, the region is predicted to warm, and annual precipitation is predicted to increase. Summer precipitation is likely to decrease and winter precipitation is likely to increase. The number of Growing Degree Days (i.e. days >5ºC) and the number of Frost-Free Days (i.e. days >0ºC) are both expected to increase, while the number of Heating Degree Days (i.e. days <18ºC) is expected to decrease.

2.2.2 University of Washington – Climate Impacts Group

The University of Washington's Climate Impacts Group (website address: http://www.hydro.washington.edu/2860/products/sites/) provides information for four sites on the Similkameen (i.e. at Oroville; at Princeton; near Hedley; and near Nighthawk) and six sites on the Okanagan (i.e. in B.C. at Okanagan Falls, Penticton, and near Oliver; and in Washington State at Malott; near Oroville; and near Tonasket). The work is reported in Hamlet et al. (2010). In this section we describe outputs generated for the two sites most relevant to this study: Okanagan River near Oliver and Similkameen River near Nighthawk.

Appendix D (D1 through D6) and Appendix E (E1 through E4) show graphical and tabular output for both sites for the following four parameters: total streamflow (dam^3), peak flows (m^3/s), low flows (m^3/s), and snow water equivalent (mm). In addition, for Okanagan River near Oliver, output is presented for precipitation (mm) and potential evapotranspiration (mm). These outputs are derived from a 10 GCM model ensemble, under the A1B and B1 emission scenarios for the periods centering on the 2020s, 2040s and 2080s. They are compared to the baseline period of 1970-1999.

The following points summarize the general trends for each variable for both sites:

Streamflow:

- Late fall, winter and early spring flows are forecast to be greater; while late spring, summer and early fall flows will be smaller
- Shift in hydrograph to earlier in the year
- Total flows for the year increase

Daily Peak Flows:

- Okanagan River near Oliver - average daily peak flows increase under both scenarios
- Similkameen River near Nighthawk - average peak flows decrease under both scenarios, except under A1B where they are predicted to increase by the 2080s
- Range of daily peak flow projections is considerable (i.e. ranges from less to greater than simulated baseline flows (1970-1999) at both sites, and by the 2080s the range begins to exceed simulated baseline flows for Okanagan River near Oliver)

Low Flows:

- Late summer/early fall low flows <u>decrease</u>, winter low flow flows <u>increase</u>

Snow Water Equivalent (SWE):

- Average SWE predicted to decrease in all periods under both scenarios

Precipitation (for Okanagan River near Oliver)

- Precipitation is expected to increase during late fall, winter and spring; and decrease over the summer and early fall.

Potential Evapotranspiration (for Okanagan River near Oliver)

- PET is expected to decrease in early to mid-fall, late spring and early summer; and increase in the winter, early spring and late summer.
- Annual PET will increase

Both the PCIC Plan2Adapt tool and the University of Washington's information use an ensemble of recent (i.e. AR4) climate models. The ensembles of models used are not the same, and the modelled areas selected for the simulations are not identical. In addition, the baseline periods are different (PCIC uses 1961-1990 while University of Washington uses 1970-1999). Also, although they both use the B1 emission scenario, i.e. the one with the lowest amount of global surface warming, PCIC uses the A2 emission scenario while University of Washington uses the A1B emission scenario (the A2 scenario is slightly warmer on average and has a larger range of temperatures than the A1B scenario - see Figure 2-1). Also, the middle period of future predictions centres on the 2050s for the PCIC data, while University of Washington centres on the 2040s. Because of these differences, it is expected that there could be some inconsistencies in the model outputs. Nevertheless, the general trends for both temperature and precipitation are consistent, and most of the hydrological implications of the predicted changes in climate are similar.

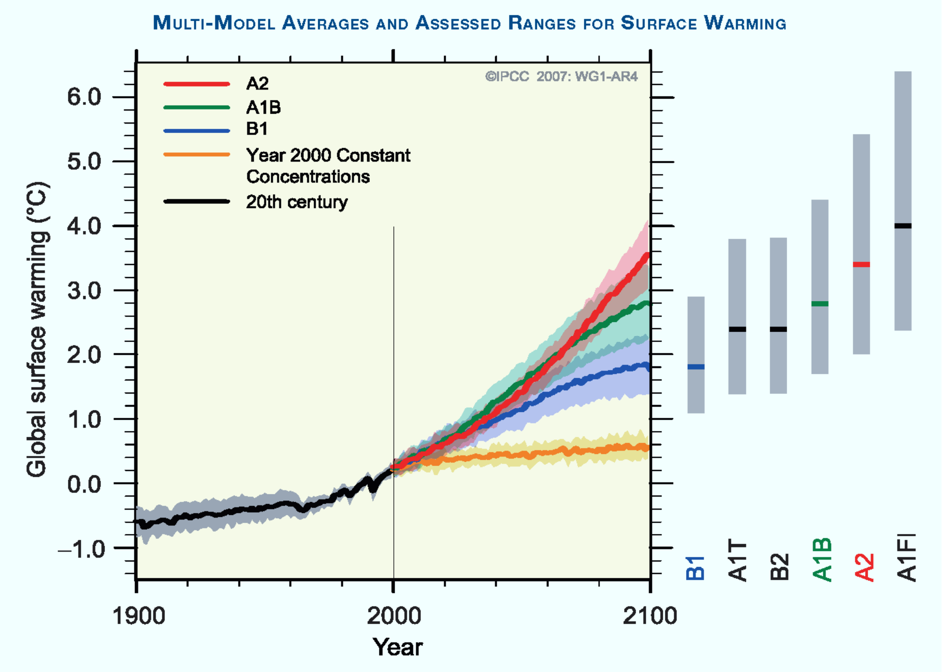

Figure 2-1
Multi-Modal Averages and Assessed Ranges for Surface Warming (from IPCC 2007)

Notes for Figure 2-1:
Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the **likely** range assessed for the six SRES (Special Report on Emissions Scenarios) marker scenarios. The assessment of the best estimate and **likely** ranges in the grey bars includes the AOGCMs (Atmospheric and Oceanic Global Climate Models) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. (Source: IPCC, 2007)

2.2.3 Phase 2 of the OWSDP

The recently completed Phase 2 of the Okanagan Water Supply and Demand Project (OWSDP) included calibrating a hydrologic model (using the Mike SHE model platform) to observed 1996-2006 climate and hydrologic conditions, then running 15 future scenarios, all driven by downscaled output of the CGCM2 climate model, using the A2 emission scenario. The calibrated hydrologic model is referred to as the Okanagan Basin Hydrology Model (OBHM). In Phase 2, that model was combined with the Okanagan Water Demand Model (OWDM) to create a water balance model for the basin (known as the Okanagan Basin Water Accounting Model (OBWAM). These models have produced specific predictions of weekly inflow to Osoyoos Lake via the Okanagan River for the calibration period 1996-2006 and for each of the 15 scenarios. These scenarios covered the impacts of climate change alone for the periods 2011-2040 (Scenario 25) and 2041-2070 (Scenario 26); as well as several combinations of climate change with other variables (e.g. size of the agricultural land base, population growth, improved water use efficiency, and other factors).

Figure 2-2 shows the projected average weekly water extraction from Osoyoos Lake for the mid-2020s (Scenario 25) and mid-2050s (Scenario 26). For the year as a whole, the extractions by the mid-2020s and mid-2050s are expected to increase by 11.3% and 21.6% respectively. The difference in weekly extraction from Osoyoos Lake relative to the baseline period (Figure 2-3) is greater earlier in the season during the 2050s, and relatively similar during both periods from about week 31. These figures demonstrate the effects of a longer irrigation season, as extractions are increased at both ends of the season.

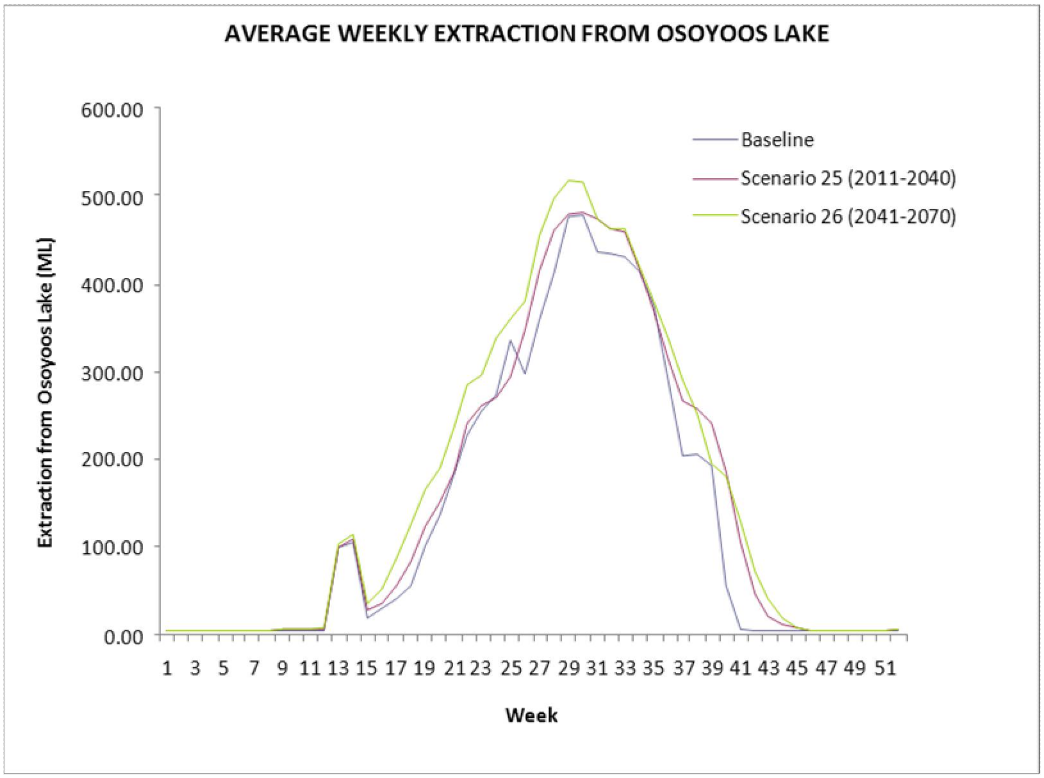

Figure 2-2
Average weekly water extraction from Osoyoos Lake for the 1996-2006 baseline period as well as for two future scenarios involving the effects of climate change alone.

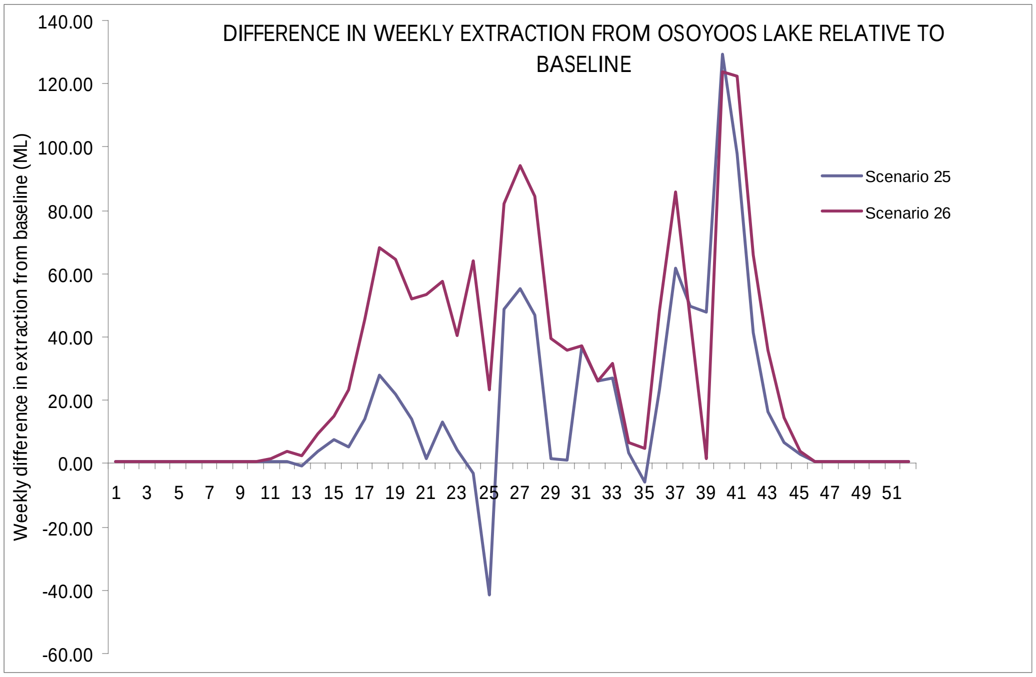

Figure 2-3
Difference in weekly water extraction from Osoyoos Lake relative to 1996-2006 baseline period for Scenarios 25 and 26.

2.3 GAP ANALYSIS

A significant research effort has been directed towards understanding climate change and its implications for the Okanagan and Similkameen River Basins. While for some parameters the models tend to converge towards consistent projections, for others there is less consistency, and for most projections, the range of the outputs is large. The following gaps are highlighted by the work performed in this study:

GCM improvement. Additional research effort should be expended to continuously improve GCMs. The IPCC is currently working on the 5th Assessment Report (AR5), which should be available by the middle of 2013.

Downscaling methods. Work on improving the climate downscaling methods that have been used in research in the Okanagan and Similkameen watersheds should continue. These methods have potential to improve the model representation of local scale climate.

Okanagan Basin Water Accounting Model. In Phase 3 of the Okanagan Water Supply and Demand project, the OBWB is currently examining a broader range of future climate scenarios than was examined in Phase 2. In addition, improvements to the OBWAM and its component models are planned over the next few years. These improvements will help to narrow our understanding of the potential future hydrologic response of the Okanagan River to climate change.

Water demands. Inflow forecasts used in the Okanagan provide estimates of net inflow, i.e. they implicitly (not explicitly) include water demands. As demands during the period covered by the forecasts change, the forecasts may lose accuracy. Also, water demands affect late summer/fall streamflow, which is predicted to decline in both rivers. Higher demands could further reduce streamflow in late summer and early fall. Work should continue in the Okanagan, and begin in the Similkameen, to provide improved estimates of water demands at all times of year. It is understood that the B.C. Ministry of Agriculture and Agriculture and Agri-Foods Canada (AAFC) are working this summer on a project to identify current and future irrigation water demands throughout the Similkameen basin.

Lake evaporation. Evaporation from the surface of Osoyoos Lake is likely to increase in future. However, current knowledge of lake evaporation is based on models that have not been ”ground-truthed”. Direct measurements of lake evaporation (such as are currently proposed by Environment Canada on Okanagan Lake), would help to reduce the current uncertainty over this important component of the water balance of the lake.

3 Implications of Climate Change for Management of Osoyoos Lake

3.1 INTRODUCTION

As described in Section 2.0, climate change will likely affect the water resources in the Okanagan and Similkameen River watersheds over the next several decades. Projected changes, which include earlier and lower spring runoff, an extended period of low summer flow, and higher winter flows, will affect the hydrology of Osoyoos Lake and the manner in which it is managed in future. In this section we briefly describe the main steps in the management of Osoyoos Lake, and how the existing International Joint Commission Orders of Approval for the operation of Zosel Dam are integral to the management of the lake. This section also reviews the key hydrologic parameters relevant to Osoyoos Lake that are projected to change in future, and how these changes might affect how the lake is currently managed, specifically with regards to the Orders of Approval. Finally, in light of the projected hydrologic changes, we have provided recommendations for consideration by the International Osoyoos Lake Board of Control when drafting the revised Orders for 2013. These recommendations are intended to increase management flexibility without causing negative impact on stakeholders.

3.2 OSOYOOS LAKE LEVEL MANAGEMENT

3.2.1 Description of Zosel Dam

Osoyoos Lake water levels are regulated by Zosel Dam. Zosel Dam was initially constructed in 1927 as a millpond dam to provide logs to Zosel Mill. As a result of complaints of high lake levels, the IJC held hearings to investigate the hydraulics of the outlet of Osoyoos Lake. Subsequently, the IJC released an Order in 1946 for an increase in the capacity of the dam to pass 2,500 ft^3/s (70.8 m^3/s) at a millpond elevation of 911.0 ft (277.7 m) USCGS (IJC 2000). In 1982, due to the deterioration of Zosel Dam, the IJC issued an Order of Approval for the reconstruction of the dam. As outlined in the Orders (IJC 1982) and Supplementary Orders (IJC 1985), Zosel Dam was to be relocated to its current location, downstream of Tonasket Creek. The reconstructed Zosel Dam was completed in 1987 and included a control structure, manual controls, and overflow weir.

The overflow weir is 198 ft (60.4 m) long and has a concrete top elevation of 913.0 ft (278.3 m) USCGS (WSDOE 1990). The control structure is 171 ft (52.1 m) long and consists of four spillways (each with a gate), two fishways, and other associated infrastructure (e.g. a control room, a stoplog storage vault, a dewatering pump vault, a gear actuator gallery, and an emergency generator room) (WSDOE 1990). The spillways are 25 ft (7.6 m) wide and have an upstream floor elevation of 906.0 ft (276.1 m) USCGS and a downstream floor elevation of 901.0 ft (274.6 m) USCGS; the spillways are designed to pass 2,500 ft^3/s (70.8 m^3/s) at an Osoyoos Lake elevation of 913.0 ft (278.3 m) USCGS (WSDOE 1990). The gates are each 25 ft (7.6 m) wide, 7.5 ft (2.3 m) tall, and can travel 13.5 ft (4.1 m) from fully open to closed; the fishways are located on either side of the spillway section and are 8 ft (2.4 m) wide, 73 ft (22.3 m) long, and each are designed to pass 45 ft^3/s (1.27 m^3/s) (WSDOE 1990). The Supplementary Orders (IJC 1985) require all necessary measures to ensure that the flow capacity of the Okanogan River, upstream and downstream from Zosel Dam is maintained. The WSDOE currently monitors the channel capacity of the Okanogan River, which is outlined within Study 8 (Summit 2010). Zosel Dam is owned by the WSDOE and operated under contract by the Oroville Tonasket Irrigation District (OTID).

3.2.2 Operation of Zosel Dam

The regulation of Osoyoos Lake for the collective benefit of Canada and United States is a complex process involving several agencies and several steps (Figure 3-1). These steps include the issuing of water supply forecasts (and updates) by the B.C. Ministry of Environment and the Northwest River Forecast Center, declaration of drought or non-drought conditions by the International Osoyoos Lake Board of Control (IOLBC), and regulation of Osoyoos Lake via Zosel Dam by the Oroville Tonasket Irrigation District (OTID), under contract with the Washington State Department of Ecology (WSDOE).

Osoyoos Lake water levels are managed by the closing and opening of the gates of Zosel Dam. The dam is operated following the procedures outlined within the Orders of Approval (IJC 1982) and WSDOE (1990) included in Table 3-1. The operation of Zosel Dam varies annually based on summer (April 1 to October 31) and winter (November 1 to March 31) operating ranges (Condition 7, Table 3-1). For the winter range, Zosel Dam is operated to maintain Osoyoos Lake water levels between 909.0 ft (276.1 m) and 911.5 ft (277.8 m) USCGS. However, for the summer range, the identification of *drought* and *non-drought* conditions, as defined through the Orders of Approval, is required before the operational range of Osoyoos Lake water levels is specified.

The identification of *drought* or *non-drought* conditions is based on three (3) separate criteria outlined in Condition 8 of the Orders (Table 3-1). These criteria are based on:

- Forecast or actual Similkameen River flow for April 1 to July 31,
- Forecast or actual inflow to Okanagan Lake for April 1 to July 31, and
- Forecast or actual maximum Okanagan Lake level in June and July.

Seasonal water supply forecasts are made between January and June by the B.C. Ministry of Environment, River Forecast Centre and the National Weather Service, Northwest River Forecast Center. While the precise methods used by each agency differ, they are both based on hydrologic models that explicitly consider the current year's snowpack, weather conditions, and streamflow. The expected water supply for Osoyoos Lake is based on the forecast inflow to Okanagan Lake (upstream of Penticton). This forecast is made (and revised) following the scheduled snow surveys by the B.C. Ministry of Environment on or near January 1, February 1, March 1, April 1, May 1, May 15, June 1, and June 15. Okanagan Lake is regulated by the B.C. Ministry of Environment to meet domestic and irrigation requirements, fisheries needs, and acceptable water levels for recreation, navigation, and tourism. As a result, the timing and volume of inflow to Osoyoos Lake, which is effectively equivalent to the net outflow of Okanagan Lake minus extractions and losses along Okanagan River, depends not only on natural inflows to Okanagan Lake but on how

Okanagan Lake is managed. Water levels on Okanagan Lake are regularly monitored and forecasts of summer water levels on the lake are made (and updated) by the B.C. Ministry of Environment.

Runoff forecasts for the Similkameen River are made and revised by the Northwest River Forecast Center at a similar frequency throughout late winter and spring as in B.C. As in B.C., forecasts are disseminated via water supply bulletins to government agencies and the public.

Beginning April 1st the IOLBC reviews each water supply forecast. If any forecast is below the criteria as outlined in Condition 8 (Table 3-1), a drought is declared. Drought declaration is generally based on the April 1st forecast; however, forecasts are updated every two (2) weeks and the declaration is re-assessed until July 31st. A drought declaration can be rescinded on the basis of subsequent forecasts. Accordingly, during the summer operating range, Zosel Dam is operated to maintain Osoyoos Lake water levels between:

- 911.0 ft (277.7 m) and 911.5 ft (277.8 m) USCGS under *non-drought* conditions, and
- 910.5 ft (277.5 m) and 913.0 ft (278.3 m) USCGS under *drought* conditions.

Annual Osoyoos Lake operating ranges are presented graphically in Figure 1-1.

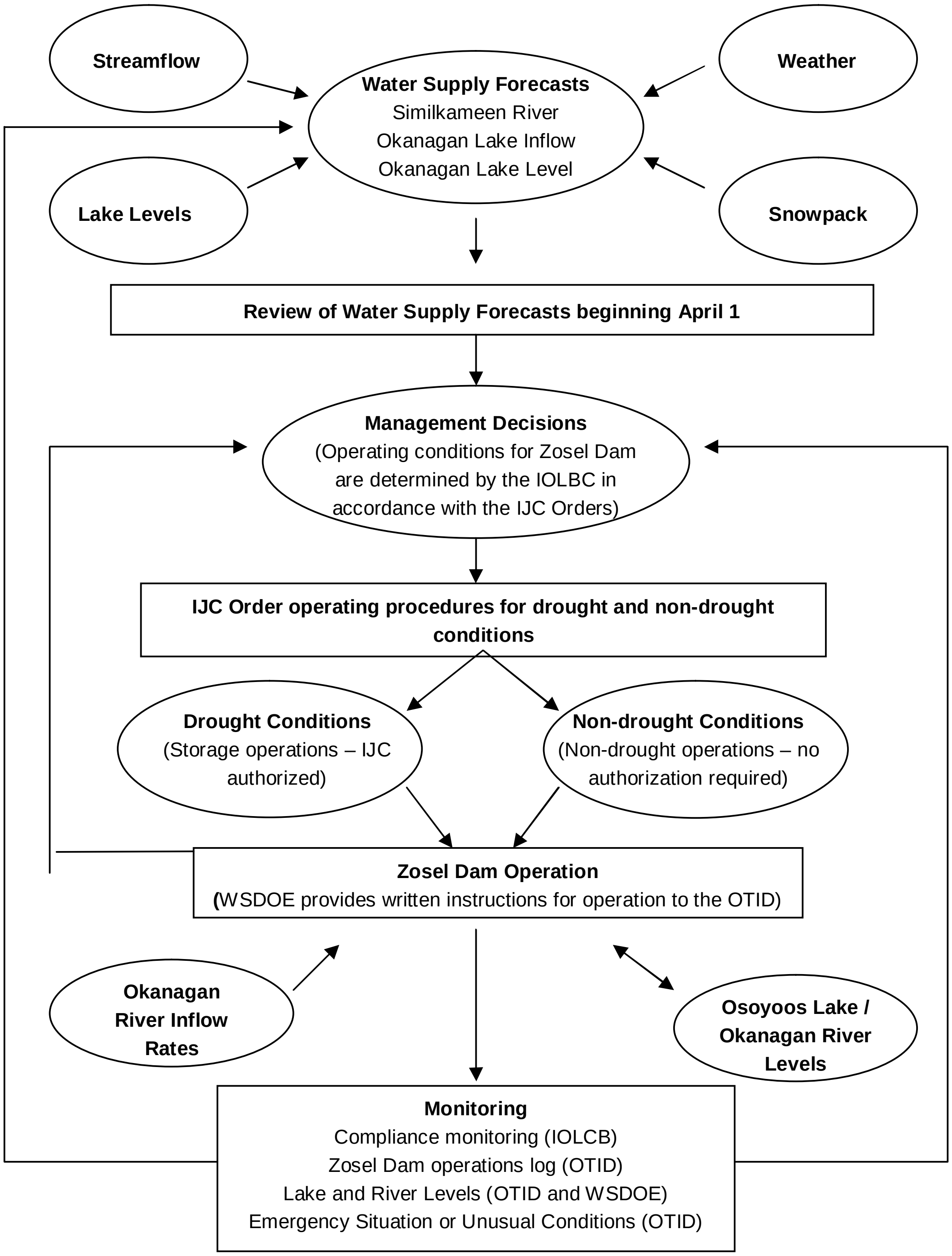

Figure 3-1

Key steps in the management of Osoyoos Lake

Table 3-1
Zosel Dam operational procedures

Criteria	Zosel Dam Operation	Reference
Condition 7	*"Upon completion of construction the Applicant, in consultation with the Board of Control appointed under Condition 14, shall operate the works so as to maintain the levels of Osoyoos Lake between elevation 911.0 and 911.5 feet (277.7 and 277.8 m) USCGS to the extent possible from 1 April to 31 October each year except under drought conditions in the Okanogan Valley (in Canada Okanagan Valley), as defined in Condition 8 and also during the appreciable backwater conditions and excessive inflows described in Condition 9. Furthermore, the Applicant shall operate the works so as to maintain the levels of Osoyoos Lake between elevation 909.0 and 911.5 feet (277.1 and 277.8 m) USCGS from 1 November to 31 March each year."*	Order of Approval (IJC 1982; 1985)
Condition 8	*"During a year of drought as determined by the Board of Control in accordance with the criteria set forth below, the levels of Osoyoos Lake may be raised to 913.0 feet (278.3 m) USCGS and may be drawn down to 910.5 feet (277.5 m) USCGS during the period 1 April to 31 October. The criteria are:* *(a) the volume of flow in the Similkameen River at Nighthawk, Washington for the period April through July as calculated or forecasted by United States authorities is less than 1.0 million acre-feet or* *(b) the net inflow to Okanagan Lake for the period April through July as calculated or forecasted by Canadian authorities is less than 195,000 acre-feet or* *(c) the level of Okanagan Lake fails to or is forecasted by Canadian authorities to fail to reach during June or July elevation 1122.8 feet (342.2 m) Canadian Geodetic Survey Datum.* *Drought year operations shall be terminated when in the opinion of the Board of Control none of the three criteria defining a drought year exist. The level of Osoyoos Lake shall then be maintained in accordance with Condition 7."*	Order of Approval (IJC 1982; 1985)
Condition 9	*"During appreciable backwater conditions caused by flows in the Similkameen River, particularly during the freshet period, and during abnormal excessive flows in the Okanagan River, the works shall be operated so as to maintain the level of Osoyoos Lake as near as possible to the elevations prescribed in Conditions 7 and 8 herein. In such an event every effort shall be made to lower the level of Osoyoos Lake in the shortest practicable time"*	
Condition 9 – WSDOE	*"The structure shall be operated to maintain the level of Osoyoos Lake within the prescribed elevations. When appreciable backwater conditions cause the Osoyoos Lake level to exceed 911.5 feet USCGS, all four gates shall be lifted clear of the water and remain open until the lake level returns to 911.5 feet (277.8 m) USCGS. Historical runoff patterns of the upper Okanogan River basin and the Similkameen River basin are similar and backwater occurs only during the spring freshet (May – June) when high flows are present in both rivers."*	Zosel Dam Operating Procedures Plan (WSDOE 1990)
Fisheries	*"The operation of Zosel Dam includes the passage of migrating fish. To the extent possible, the following fish consideration should be met when discharging water from Zosel Dam:* *1. Discharge 80% of the October average flow during the period between 1 October and 15 April in order to maintain egg/fry survival of Chinook salmon. Chinook spawning, incubation, and emergence occurs between mid-October and mid-April.* *2. Discharge 80% of the March average flow during the period between March and 15 June in order to maintain egg/fry survival of steelhead salmon. Steelhead spawning, incubation, and emergence occurs between mid-March and mid-June.* *3. Stream flows should remain at or above 300* ft^3/s *(8.50* m^3/s*) for full utilization of winter rearing habitats during the months of October to March.* *4. Juvenile sockeye salmon outmigration from the Osoyoos Lake nursery area extends from 20 April through 10 June. During this period, sufficient flow at the surface is needed to successfully pass fish through Zosel Dam and subsequently allow them to move downstream out of the Okanagan River. In the absence of any means to provide downstream fish migration at Zosel Dam, the stoplogs are used to form a waterfall to help the sockeye and steelhead pass through the dam. A few stoplogs are placed in the spillway and the gate is opened, allowing water to spill over the stoplogs.* *5. A stream flow of 200* ft^3/s *(5.66* m^3/s*) from 15 June to 1 August should be maintained if possible, for the protection of resident fisheries.*	Zosel Dam Operating Procedures Plan (WSDOE 1990)

3.3 RATIONALE BEHIND THE CURRENT DROUGHT CRITERIA

The declaration of a drought is currently based on meeting any one (1) of the three (3) criteria identified in Condition 8 of the Orders. To understand how robust these criteria may be in light of future climate change, it is necessary to understand the rationale used originally to define the criteria.

3.3.1 Condition 8 (a) – Similkameen River Runoff

Under Condition 8 (a), a drought may be declared if "the volume of flow in the Similkameen River at Nighthawk, Washington for the period April through July as calculated or forecasted by United States authorities is less than 1.0 million acre-feet"[1]. Historical runoff for the April 1-July 31 period on Similkameen River at Nighthawk is shown in Figure 3-2. Flow duration curves for the historical April 1 – July 31 runoff are presented in Figure 3-3; one curve represents the data prior to 1982 (prior to when the Orders were drafted), the other curve represents all data to 2009. According to Kris Kauffman of the IOLBC, the Similkameen River drought criteria of 1.0 million ac-ft between April 1 and July 31 represents a runoff that is not exceeded on average once every four years (i.e. 25% of the time) – and is similar to a statistic used by the US Geological Survey (USGS) for defining below normal flow conditions. On Figure 3-3, the hydrometric record suggests that before the orders were drafted in 1982, 1.0 million ac-ft was not exceeded in about 23% of the years, slightly below the 1 in 4 year criterion. It is however possible that a different period was used in the original analysis or that some rounding was done, to arrive at a criterion of 1.0 million ac-ft. If all historical data to 2009 is considered, 1.0 million ac-ft is not exceeded in 25% of the years, suggesting there may have been a slight trend towards lower flows in the Similkameen River in the past three decades.

It is important to note that the Similkameen River does not regularly supply water to Osoyoos Lake, but rather flows into Okanogan River downstream of the outlet of Osoyoos Lake (Summit 2010). Nevertheless, at times the Similkameen River has a significant hydrologic effect on the lake, particularly during periods of high flow. When flows in the Similkameen River exceed about 10,000 ft^3/s (283 m^3/s), a backwater effect in the Okanogan River occurs, which restricts outflows from Osoyoos Lake. Under extreme conditions, this backwater effect can even trigger reverse flows into Osoyoos Lake; however, this is rare and was last observed in 1976 (Summit 2010).

Although the Similkameen River does not normally flow into Osoyoos Lake, it is one of the three main criteria used to trigger a drought declaration for Osoyoos Lake. The Similkameen River criterion is used because this river represents a major source of water used to meet withdrawal demands from the Okanogan River in the U.S. In the event that the supply from the Similkameen River is predicted to be low, the Orders allow additional storage on Osoyoos Lake to help meet these demands.

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[1] 1.0 million acre-feet is equivalent to 1,233,500 dam^3.

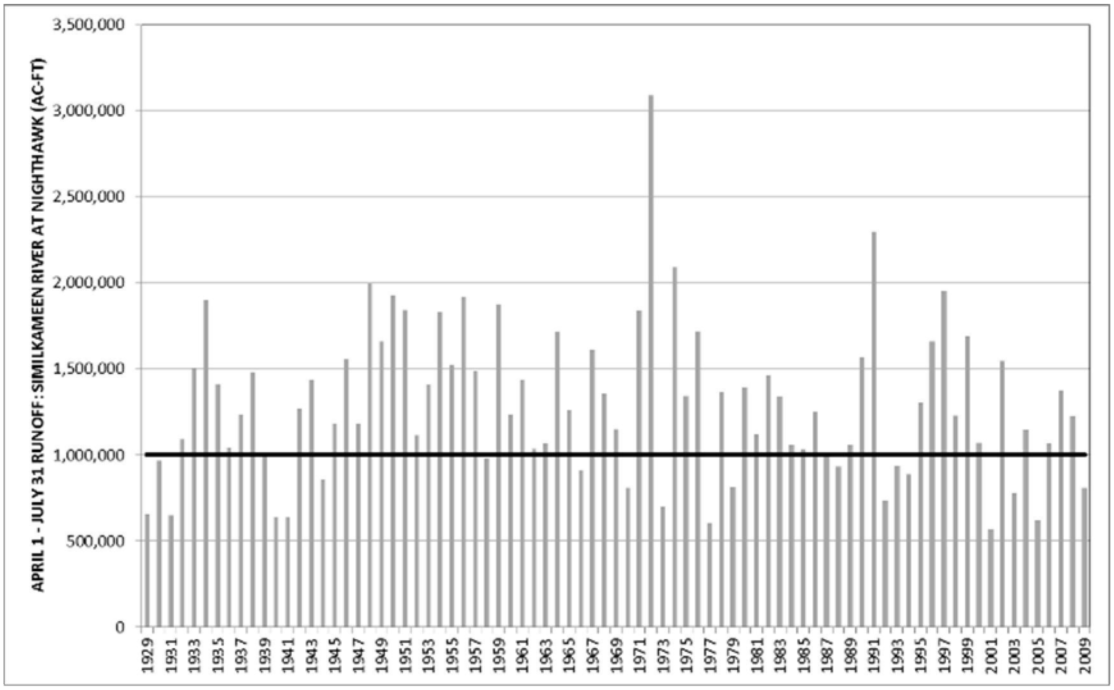

Figure 3-2
April 1-July 31 runoff of Similkameen River at Nighthawk (1929-2009.). The black line indicates the drought declaration criteria under Condition 8 (a).

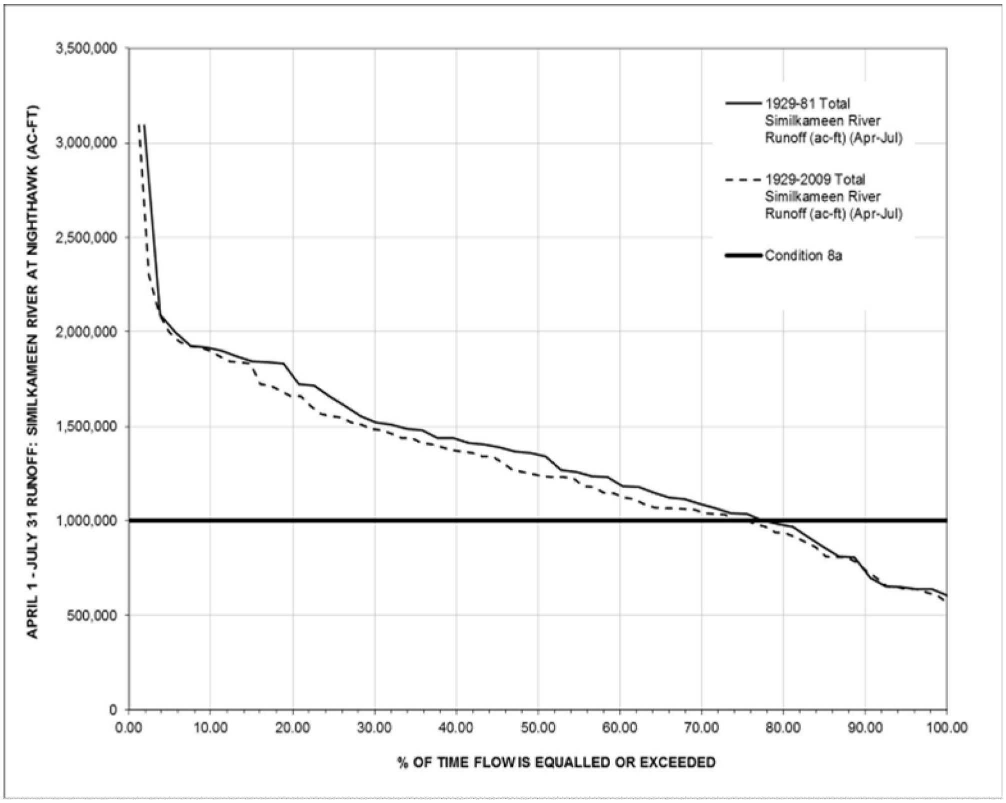

Figure 3-3
Flow duration curve: April 1 – July 31 Similkameen River at Nighthawk runoff (ac-ft). The bold black line indicates the drought declaration criteria under Condition 8 (a).

3.3.2 Condition 8 (b) – Okanagan Lake Inflow

Under Condition 8 (b), a drought may be declared if "the net inflow to Okanagan Lake for the period April through July as calculated or forecasted by Canadian authorities is less than 195,000 acre-feet"[2]. Historical April 1 – July 31 inflows to Okanagan Lake are presented in Figure 3-4, while duration curves for both the period of record to 1981 and to 2009 are plotted in Figure 3-5. The plots show that the drought criterion is not exceeded in about 20% of the years of record. This is consistent with the comments by Brian Symonds of the B.C. Ministry of Environment who indicated this threshold was based on an inflow that is not exceeded in about 1 in 4 years (i.e. 25%). No significant difference was noted between the period prior to 1982 and prior to 2009, suggesting overall inflows to Okanagan Lake have not significantly changed over the past several decades.

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[2] 195,000 acre-feet is equivalent to 240,000 dam^3.

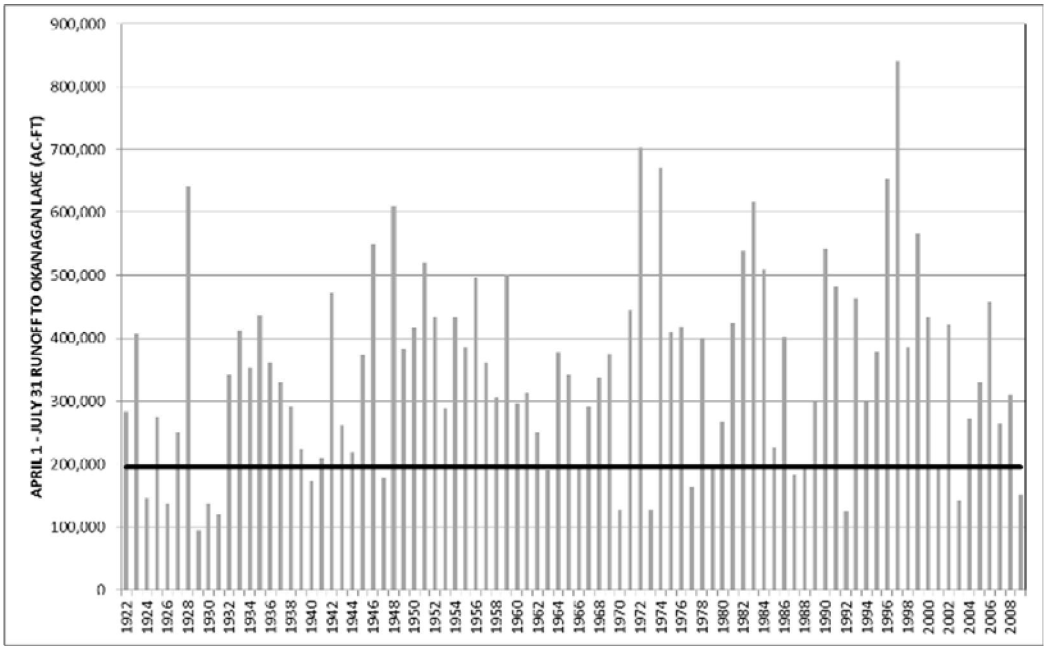

Figure 3-4
April 1-July 31 runoff to Okanagan Lake (1922-2009). The black line indicates the drought declaration criteria under Condition 8 (b).

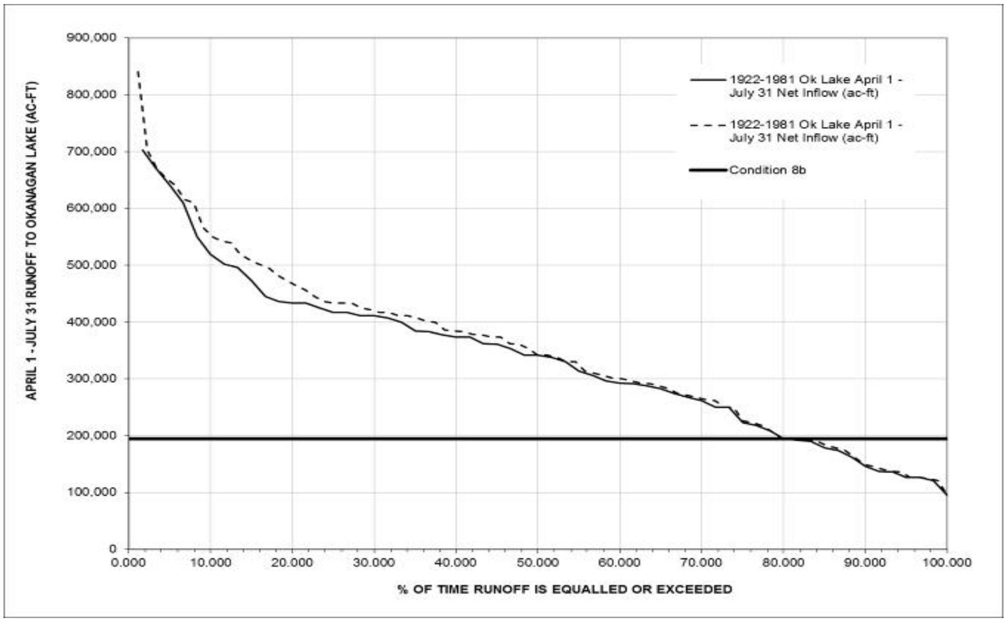

Figure 3-5
Flow duration curve: April 1 – July 31 runoff to Okanagan Lake (ac-ft). The bold black line indicates the drought declaration criteria under Condition 8 (b).

3.3.3 Condition 8 (c) – Okanagan Lake Water Level

Under Condition 8 (c), a drought may be declared if “the level of Okanagan Lake fails to or is forecasted by Canadian authorities to fail to reach during June or July elevation 1122.8 feet (342.2 m) Canadian Geodetic Survey Datum.” To provide historical context, the difference between the annual maximum June 1 – July 31 daily Okanagan Lake water level and the drought criteria is plotted in Figure 3-6. A duration curve of maximum June 1 – July 31 Okanagan Lake water levels is presented in Figure 3-7. Similar to the other two drought criteria, the frequency at which the criterion is not met in any given year is about 23%. No significant difference was noted between the periods prior to 1982 and prior to 2009. This suggests that similar to the inflows to Okanagan Lake, there is no apparent trend over time in the last several decades. It also suggests that management of the lake levels has remained reasonably consistent over that period

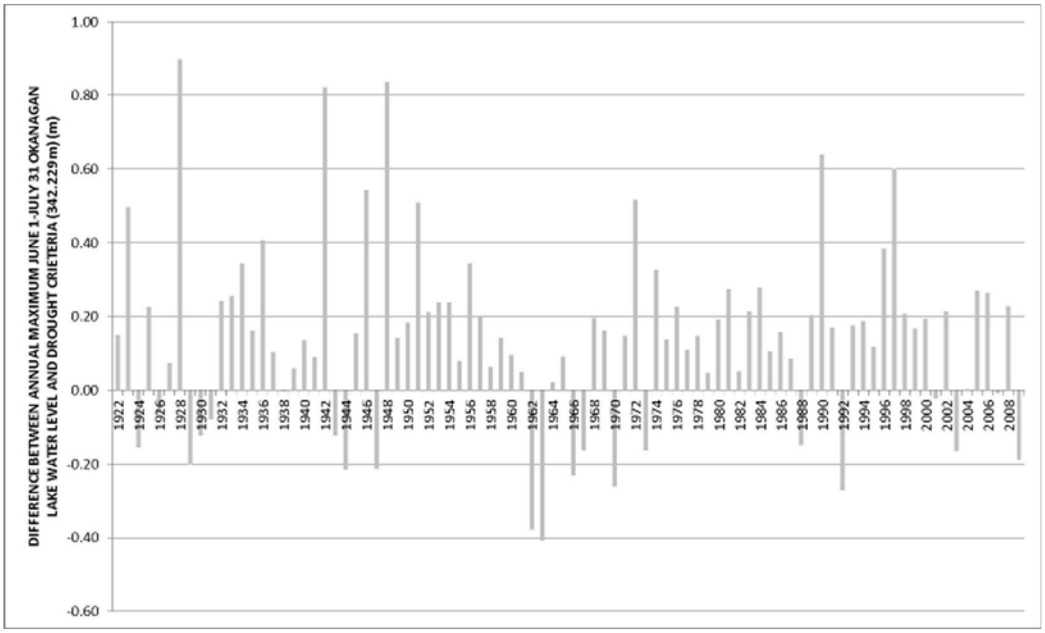

Figure 3-6
Difference between the annual maximum June 1 – July 31 Okanagan Lake water level and the drought criteria of 342.229m (1922-2009). Negative values indicate the lake level criterion was not met in that year.

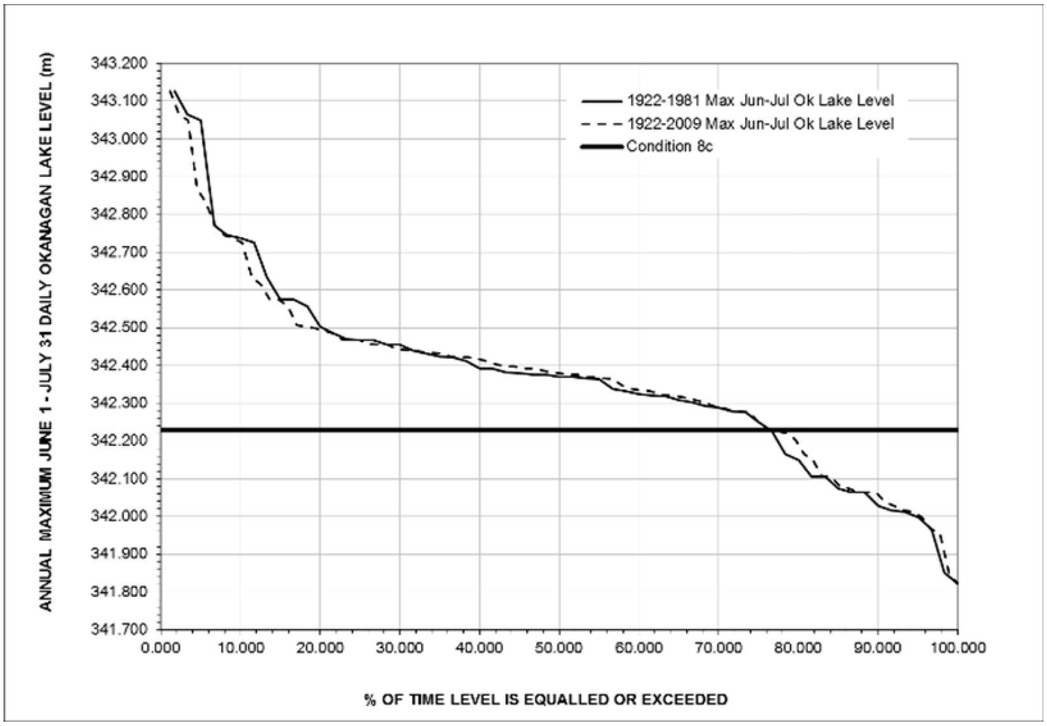

Figure 3-7
Lake level duration curve: annual maximum June 1 – July 31 daily Okanagan Lake levels (m) (1922-2009). The bold black line indicates the drought declaration criteria under Condition 8 (c).

In summary, there are three (3) criteria used to determine whether or not a drought is declared, each having a 20-25% probability of triggering a drought in any given year. Since only one of the three criteria is required to trigger a drought declaration, the probability of a drought declaration is actually greater than 20 - 25%. However, since the three criteria are not independent (e.g. Okanagan Lake levels depend on Okanagan Lake inflows, and inflows to Okanagan Lake tend to correlate with Similkameen River runoff), it is difficult to identify a precise probability. Based on the historical data presented above, there is little evidence to suggest that the hydrology associated with the three criteria has changed significantly over the past three decades. Nevertheless, based on climate change projections (Section 2.0), this may change in future.

3.4 SUMMARY OF POTENTIAL CHANGES IN KEY HYDROLOGIC PARAMETERS

3.4.1 Overview

As described in Section 2.0, future climate change will likely affect the climate and water supply. Based on several GCMs there is large uncertainty in future conditions; however, they generally indicate that the following will likely occur:

- Earlier spring runoff;
- Lower runoff in spring and late summer/fall;
- Higher runoff in winter (from increased precipitation, and higher proportion as rain);
- Slight increase in annual runoff; and
- Small changes in daily peak flows.

In response to increased temperatures, it is likely that water demand from all sectors (especially the agricultural sector - the largest user of water in the Okanagan Basin) will correspondingly increase in future. The following sections describe the projected changes for the key hydrologic parameters that affect the Orders of Approval for the management of Osoyoos Lake.

3.4.2 Key Hydrologic Parameters

<u>Similkameen River Runoff</u>
According to the projections compiled by Hamlet et al. (2010), annual runoff from the Similkameen River is expected to change only modestly in future. A +2% change is projected by 2020, +3 to +6% by 2040, and +8 to +9% by 2080. The distribution of flows, however, is expected to change over time. The current annual hydrograph is expected to advance by 4-8 weeks by 2080; this includes a shift towards an earlier spring freshet, and earlier flow recession, and thus a longer duration of summer low flow. At the same time, the total freshet volume is expected to decrease, however this will be somewhat offset by increased winter runoff.

Currently the Orders identify the April 1 to July 31 runoff as a drought criteria. Based on the projections by Hamlet et al. (2010), total runoff during this period is expected to change by -1% by 2020, -3% by 2040, and -7% to -16% by 2080.

<u>Similkameen River Peak Flow</u>
Similkameen River peak flows are important from a management perspective since flows in excess of 10,000 ft^3/s (283 m^3/s) create a backwater effect which affects outflows from Osoyoos Lake and the ability to manage Osoyoos Lake levels. Based on Hamlet et al. (2010), the duration of a backwater effect in any given year will likely decrease slightly and occur earlier in the spring by up to 4-8 weeks. Extreme peak flows on the Similkameen River are not expected to significantly change in future.

Okanagan Lake Inflow

Inflows to Okanagan Lake are expected to follow similar patterns as the Similkameen River, specifically with regards to the wholesale advance of annual hydrograph by several weeks. However, Hamlet et al. (2010) project a more dramatic decrease in freshet runoff as well as increase in winter runoff in the Okanagan. April 1 to July 31 inflow to Okanagan Lake is expected to change by -3% to -4% by 2020, -5% to -6% by 2040, and -10% to -15% by 2080.

3.5 IMPLICATIONS OF POTENTIAL CHANGES IN KEY PARAMETERS FOR LAKE LEVEL MANAGEMENT

3.5.1 Future Water Supply Forecasts

The forecasts provided by the B.C. Ministry of Environment, River Forecast Centre and the National Weather Service, Northwest River Forecast Center are fundamental to the management of Osoyoos Lake. Although the methods employed by each agency differ, they are both based on water supply models developed and calibrated using historical hydro-climatic data - data that already significantly varies from year to year (e.g. Figure 3-4). With the prospects of climate change, it is possible that the accuracy or reliability of these models could change. According to Dave Campbell, Head of the B.C. River Forecast Centre, the models in use in B.C. are progressively updated year over year with new information, and periodically adopt new techniques (e.g. principal component analysis was adopted in 1998), so that it is impossible to judge whether or not there has been any temporal trend in forecast accuracy. A similar process of model improvement is made by the U.S. National Weather Service. Given that the effects of climate change are likely to occur relatively gradually over a period of decades, we do not expect that the models currently in use will be made significantly less accurate or invalid by the expected shift in climate. The contrary is likely to occur as more sophisticated models are developed in future, possibly driven by more timely and accurate information (including remote sensing data).

Notwithstanding the continual improvement of the hydrologic models in use, water supply forecasts will remain subject to error from two factors: (1) they do not incorporate a forecast of the precipitation that will occur during the forecast period (April – July); and (2) they implicitly (not explicitly) incorporate the effects of water demands that will occur during the forecast period. Spring precipitation is difficult to forecast accurately beyond about 1 week. Long-term (1-3 month) forecasts are generally accurate about 50% of the time, equivalent to flipping a coin. Although spring precipitation changes have yet to be noticeable, according to the CGMs (Section 2.0), there is potential of increased spring precipitation variability, which could directly affect the uncertainty in long-term water supply forecasts. In addition, any trends or increased variability in early summer water demands could reduce the accuracy of the water supply forecasts over time.

3.5.2 Future Drought Declaration

As described in Section 3.3, there are three (3) criteria used in determining whether Osoyoos Lake should be managed under drought or non-drought operating ranges. For each criterion, a 20th - 25th percentile was used as the drought threshold. By examining the historical data prior to the drafting of the current Orders, and historical data right up to the present, there appears to be no significant change to the values currently defined in the Orders, which reflect the drought thresholds for Similkameen River runoff, Okanagan Lake inflow, and Okanagan Lake water level. There is some evidence that Similkameen River runoff is reducing, but it is not considered significant. As a result, we conclude that there has been little to no change in the frequency of drought declarations between 1982 and the present based on the existing criteria.

This may not however be the case in the future. According to Hamlet et al. (2010), we can expect the following:

- Similkameen River runoff (April 1 – July 31):
  - 1% reduction by 2020,
  - 3% reduction by 2040, and
  - 7-16% reduction by 2080.
- Okanagan Lake Inflow (April 1 – July 31):
  - 3-4% reduction by 2020,
  - 5-6% reduction by 2040, and
  - 10-15% reduction by 2080.

As a result of these projections of reduced seasonal flows, under the current drought criteria, the frequency of drought declarations would tend to increase.

3.5.3 Future Management of Osoyoos Lake Water Levels

According to the climate projections and hydrologic modeling of the Okanagan and Similkameen Rivers, the future management of Osoyoos Lake levels will likely have to contend with a suite of gradually changing conditions, including:

- Earlier spring runoff, which may necessitate changes to decision dates (i.e. when drought/non-drought conditions are declared) and current dates of summer and winter operating ranges.
- Reduced snowpack and lower spring runoff, which may have a direct bearing on the total water supply in summer.
- Increased winter precipitation and warmer temperatures may cause more rain and less snow resulting in increased winter runoff. This additional water may help mitigate the lower spring runoff, but only if storage is available and utilized. If winter runoff were stored, summer lake levels could possibly be reached earlier.
- Projected higher water demand and higher evaporation from Osoyoos Lake will further increase the pressure on the reduced water supply.

- Potentially less accurate streamflow forecasts (mitigated by the practice of continuous improvement that is applied to the forecast methods)

3.5.4 Future Water Supply and Demand from Osoyoos Lake

Are the water levels (and associated storage volumes) under the current Orders or Approval sufficient to meet future human and environmental needs given the projections for reduced seasonal supply and increased demand? The answer to this question is complex and not only depends on the natural water supply and demands (including evaporative losses from the lake, which are significant[3]), but also the available storage capacity of Osoyoos Lake and the management of Okanagan Lake and River upstream. Osoyoos Lake has a relatively limited lake level range and associated storage volume (Summit 2010). Based on Okanagan Water Supply and Demand Project modeling, annual water extractions from Osoyoos Lake are expected to increase on average by 11% for 2011-2040, and by 21% for 2041-2070. Such increases alone would place increased pressure on the available water in Osoyoos Lake. However, pressures would further be exacerbated by increased lake evaporation.

Given the current constraints, the total storage volume of Osoyoos Lake is unlikely to change in the future. As a result, the lake levels will continue to be managed within a relatively limited range (i.e. between 909 ft and 913 ft) in future. In order to mitigate the future effects of climate change, water may need to be stored earlier and for longer durations in future. While the current Orders provide a reasonable degree of flexibility, the fixed dates defining the summer and winter operating periods and the specified lake levels under drought and non-drought conditions for those periods can prove to be challenging from a lake management perspective. According to Brian Symonds of the B.C. Ministry of Environment, meeting the April 1st water level requirement (e.g. 911.0 ft under non-drought conditions) is often difficult, especially if lake levels are drawn down significantly over winter. Likewise, the October 31st water level requirement can prove challenging particularly if levels have been maintained near the drought condition maximum (913.0 ft). One option to improve management flexibility, particularly in light of climate change would be to require ramping of water levels over an extended period, as opposed to the sudden step-change dictated under the current Orders (Figure 1-1).

3.5.5 Summary

In summary, water supply forecasts are continually updated and are expected to maintain a level of accuracy similar to the present. There is a possibility, given a projected change in the pattern of spring precipitation and increased water demand in early summer, that additional variability may be introduced, which would increase the uncertainty of the water supply forecasts. Although historical data suggests the hydrology associated with the three criteria presently used to declare a drought has not significantly changed since the Orders were drafted in 1982, projections of reduced April 1 – July 31 Similkameen River

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[3] According to DHI (2010), mean annual evaporation from Osoyoos Lake is estimated at 1,063 mm (or 3 ½ ft);

runoff and Okanagan Lake inflow suggest that the current criteria may trigger droughts with increasing frequency in the future. A question this raises is whether the distinction between drought and non-drought conditions is indeed required in future. With a projected reduction in water supply and increase in demand, drought conditions may occur more frequently. Future management of Osoyoos Lake will need to adapt to the projected advance in the annual hydrograph, both for Similkameen River and Okanagan River. Measures such as scheduling the drought declaration earlier in the season and revising the Orders to reflect the timing and magnitude of the future water supply may be necessary. Given the limited storage represented by Osoyoos Lake, and the projected reduction in supply and increase in demand, the risk of water deficits will increase in future. Although there are non-binding agreements between B.C. and Washington State that are intended to maintain acceptable water levels in Osoyoos Lake, they do not necessarily apply under multi-year drought or under future climate.

3.6 RECOMMENDATIONS FOR AMENDING THE ORDERS

Our recommendations for amending the Orders are based on a desire to preserve the scientific linkage between the Orders and the hydrologic regimes of the two Basins, and improve management flexibility while at the same time having no negative impact. Based on the projected climate and associated hydrologic changes, we recommend that the International Osoyoos Lake Board of Control consider the following:

1. Advance the date on which drought declarations are made in the spring. Given that there may be considerable flow earlier in the season, the first declaration could be made on March 1.
2. Allow more flexibility in filling the lake. Increased flows are projected through winter and freshet is projected to occur earlier. Earlier storage may be required to take advantage of the available water.
3. Allow ramping over a defined period as opposed to setting strict date-specific water level requirements. This will provide flexibility into the future, which is particularly important given the wide range of projections for future water supply.
4. Evaluate whether the distinction between drought and non-drought conditions is required. In its place, a flexible lake management strategy that applies to all years could be developed.
5. Evaluate the use of fixed-dates for the summer and winter operating ranges in light of the projected future advance of the spring lake inflows.
6. Incorporate an adaptive management strategy that includes re-evaluation of performance under the Orders every 10 years, or after any year, with a view towards periodic refinement of the Orders. This concept recognizes the wide range in projected future conditions.

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A

Appendix A - Contact Information for Climate Change Researchers

Name	Title	Affiliation	Contact
Alila, Younes, Dr., P.Eng.mailto:Younes.Alila@ubc.ca	Associate Professor	Department of Forest Resources Management, Faculty of Forestry The University of British Columbia	2nd Floor, Forest Sciences Centre #2030 - 2424 Main Mall Vancouver, B.C. V6T 1Z4 Phone: (604) 822-6058 Fax: (604) 822-9106 Younes.Alila@ubc.ca
Allen, Diana, Dr.	Professor	Climate Change Impacts Research Consortium (CCIRC) Groundwater Resources Assessment under the Pressure of Humanity and Climate Change (GRAPHIC) Department of Earth Sciences Simon Fraser University	7239 TASC I Building 8888 University Drive Burnaby, B.C. V5A 1S6 Phone: (778) 782-3967 Fax: (778) 782-4198 dallen@sfu.ca
Cannon, Alex J., Dr.	Senior Hydroclimatologist Science Section Adjunct Professor	Meteorological Service of Canada Environment Canada UBC Department of Earth and Ocean Sciences, Climate Prediction Group	201-401 Burrard Street Vancouver, B.C. V6C 3S5 Phone: (604)-664-9245 Fax: (604)-664-9004 alex.cannon@ec.gc.ca www.ec.gc.ca

Name	Title	Affiliation	Contact
Cohen, Stewart J., Dr.	Research Scientist and Adjunct Professor	Adaptation & Impacts Research Section (AIRS), Environment Canada Dept. of Forest Resources Management, University of British Columbia	4617-2424 Main Mall Vancouver, B.C. V6T 1Z4 Phone: (604)-822-1635 Fax: (604)-822-9106 stewart.cohen@ec.gc.ca ; scohen@forestry.ubc.ca http://www.ec.gc.ca/scitech/default.asp
Coulson, H.	Engineer (retired)	B.C. Ministry of Environment, Lands and Parks.	c_barnard@shaw.ca
Fabro, Andrew	Library and Records Management Services Division Information Management Directorate Chief Information Officer Branch	Environment Canada	201- 401 Burrard Street Vancouver, B.C. V6C 3S5 Phone: (604)-666-5914 Fax: (604)-666-1788 andrew.fabro@ec.gc.ca www.ec.gc.ca
Gobena, Adam, Dr.	Statistical Hydrologist	BC Hydro	333 Dunsmuir Street Vancouver, B.C. V6B 5R3
Hamlet, Alan, F., Dr.	Research Assistant and Professor	Center for Science in the Earth System (CSES) Climate Impacts Group Department of Civil and Environmental Engineering University of Washington	Box 352700, Seattle, WA 98195 Phone: (206)-616-9361 hamleaf@u.washington.edu

Name	Title	Affiliation	Contact
Hyatt, Kim, Dr.	Research Scientist, Head, Salmon in Regional Ecosystems Program	Science Branch, Fisheries and Oceans Canada, Pacific Biological Station	3190 Hammond Bay Rd., Nanaimo, B.C. V9T 6N7 Phone: (250)-756-7217, Cell Phone: (250)-716-6172 Fax: (250)-756-7217 Kim.Hyatt@dfo-mpo.gc.ca
Lall, Upmanu, Dr.	Professor of Engineering Director, Columbia Water Center Senior Research Scientist, International Research Institute for Climate & Society	Department of Earth and Environmental Engineering Department of Civil Engineering & Engineering Mechanics Columbia University	918 Mudd, Dept. of Earth & Environmental Eng. 500 West 120th Street Columbia University, MC 4711 New York, NY, 10027 ula2@columbia.edu
Long, Karilyn	Fisheries Bilogist	Okanagan Nation Alliance	3255 C Shannon Lake Road Westbank, B.C.t V4T 1V4 Phone: 250.490-9779 ext 301 Toll Free: 1.866.662.9609 Fax: 250.490.9707 klong@syilx.org www.syilx.org or www.okanagannation.com
Millar, Daniel	Senior Advisor, Water Issues	Environment Canada Strategic Integration Office	201 - 401 Burrard St. Vancouver, B.C. V6C 3S5 Phone: (604)-664-9345 Fax: (604)-664-9126 Daniel.Millar@ec.gc.ca
Murdock, Trevor, M.Sc.	Climate Scientist	Pacific Climate Impacts Consortium	PO Box 1700 STN CSC University of Victoria Victoria, B.C. V8W 2Y2 Phone: (250) 721-6236 Fax: (250) 721-7217 tmurdock@uvic.ca

Name	Title	Affiliation	Contact
Neilsen, Denise, Dr.	Research Scientist	Agriculture and Agri-Food Canada Okanagan Basin Water Board Stewardship Committee	4200 Highway #97, South Summerland, B.C. V0H 1Z0 Phone: (250)-494-6417 Fax: (250)-494-0755 Denise.Neilsen@agr.gc.ca
Pike, Robin, P.Ag.	Watershed Research Hydrologist	Water Protection & Sustainability Branch B.C. Ministry of Environment	Phone: (250) 387-3256 Robin.G.Pike@gov.bc.ca
Redding , Todd, Dr.	College Professor	Geography and Earth and Environmental Science, Okanagan College FORREX	583 Duncan Avenue West Penticton, B.C. V2A 8E1 Phone: 250-492-4305 local 3272 tredding@okanagan.bc.ca
Schnorbus, Markus, Dr.	Lead Hydrologist	Pacific Climate Impacts Consortium (PCIC), University of Victoria	C197 Sedgewick Building PO Box 1700 Stn CSC University of Victoria Victoria, B.C. V8W 2Y2 Phone: (250)-853-3502 Fax: (250)-356-1202 mschnorb@uvic.ca http://www.pacificclimate.org
Scott, David, Dr.	Associate Professor	Department of Earth & Environmental Sciences University of British Columbia Okanagan	3333 University Way Kelowna, B.C. V1V 1V7 Office: SCI315 Phone: (250)-807-8755 Fax: (250)-807-8005 david.scott@ubc.ca

Name	Title	Affiliation	Contact
Tansey, James, Dr.	Prof., Executive Director, ISIS,	Sauder School of Business, University of British Columbia	2053 Main Mall, Vancouver, B.C. V6T 1Z2 Office Henry Angus 560 Phone: (604) 827-4443 james.tansey@sauder.ubc.ca
Weber, Frank	Hydrologist, Team Lead, Runoff Forecasting	BC Hydro	333 Dunsmuir Street Vancouver,B.C. V6B 5R3 Frank.Weber@bchydro.com
Whitfield, Paul H.	Emeritus Scientist	Meteorological Survey of Canada, Vancouver Environment Canada, Atmospheric Environment Program	401 Burrard Street Vancouver, B.C. V6C 3S5 Phone: (604)-664-9238 Cell: (604)-802-0643 Paul.Whitfield@ec.gc.ca
Winkler, Rita, Dr.	Research Hydrologist	Research Hydrologist, FORSCI - Forest Sciences B.C. Ministry of Forests, Mines and Lands.	1265 Dalhousie Drive, Kamloops, B.C. V2C-5Z5 Phone: (250)-828-4162 Fax: (250)-828-4154 Rita.Winkler@gov.bc.ca

B Appendix B - Tabular Summary of Relevant Literature

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
2011	PCIC (Pacific Climate Impacts Consortium)	Plan2Adapt Tool (accessed February 2011)	Excellent tool to use for climate projections and their hydrological implications. Generates maps, plots and data describing projected future climate conditions for British Columbia using: - data provided by the IPCC global climate model (GCM) and emissions scenarios for North America	Climate change Hydrology	1961-90 2020s 2050s 2080s	Similkameen Okanagan	ensemble of more than 15 GCMs; 30 different projections IPCC Fourth Assessment (AR4) A2 & B1 SRES	Several model outputs for the Similkameen and Okanagan.
2010	Hamlet et al.	Final Report for the Columbia Basin Climate Change Scenarios Project	Excellent summary for Pacific Northwest, including Similkameen and Okanagan Rivers. Projected changes for the 21st century relative to the 20th century Pacific Northwest climate. The total amount of warming in the 21st century will be greater than that observed in the 20th century. The rate of change in the 21st century will be greater than that observe in the 20th century. All seasons will be warmer. Increase in average annual temperature will likely exceed the range of 20th century variability. The projected change in average annual precipitation for all models combined is zero. Existing patterns of precipitation could be exacerbated in the future. Average annual precipitation will likely remain within the range of 20th century variability.	Hydrology Climate change	1916-2006 1970-1999 2020s 2040s 2080s	297 streamflow locations Pacific Northwest	Variable Infiltration Capacity (VIC) hydrologic model 10 GCMs A1B and B1 AR4	Annual Mean Temp: (Low; Avg; High) 2020: (+ 0.6; 1.1; 1.8ºC) 2040: (+ 0.8; 1.8; 2.9ºC) 2080: (+ 1.6; 3.0; 5.4ºC) Annual Mean Precipitation: (Low; Avg; High) 2020: (-9; 1.3; 12%) 2040: (-11; 2.3; 12%) 2080: (-10; 3.8; 20%) Output of Similkameen R …at Oroville …near Hedley …at Princeton …near Nighthawk (see section 2 of this report for some of the parameters for this site) Provides outputs for the following parameters for periods centering on 2020s, 2040s and 2080s: -monthly average total runoff -average total actual ET -Simulated daily flood statistics at the 20, 50 and 100-year return interval -Simulated 7Q10 low flow -Simulated monthly total PET for a tall reference crop -Simulated monthly total PET for a short reference crop -Monthly average total precipitation -First day of month total column soil moisture -Long term average of monthly routed streamflow -First day of month total snow water equivalent -Monthly average temperatures This site also provides outputs for the following Okanagan R sites: …near Tonasket …near Oroville …at Okanagan Falls …at Penticton …at Malott

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								…near Oliver (see section 2 of this report for some of the parameters for this site)
2010	Murdoch and Werner	Updated Past Trends and Future Projections for the Canadian Columbia Basin: 2010	Excellent recent summary on Columbia Basin, GCMs, RCMs and downscaling.	Climate Change	2050s	Columbia Basin	30 GCMs PDO ENSO	+1.2 ºC to +3.0ºC Winter precip: +1 to +13% Summer precip: -4 to -10%
2010	Neilsen et al.	Development and Verification of Daily Gridded Climate Surfaces in the Okanagan of British Columbia	Oakanagan encompasses approx. 8000km^2 in Southern B.C. between 46º56'N and 50º30'N and 118º37'W and 120º22'W Elevation of surrounding mountains range from 1600-2000masl 88% of the 550mm of annual precip is lost to evaporation and sublimation The southern basin is much warmer and drier then the northern basin In the bottom of the valley precip ranges from 300-400mm where the higher elevation receives up to 770mm	Climate General info about Okanagan River Basin	1960-2005	Okanagan Osoyoos Kelowna Vernon Joe Rich Creek Peachland	500m grid data PRISM ANUSPLIN Takes into account elevation, inversion, latitude UBC Model	Daily max temps more accurate than daily min temps. Mean absolute error (MAE) ranged 1.0ºC for max and 1.3-1.8ºC for min. Monthly MAE for precip averaged 10-18% Model slightly over estimates SWE Quality of results decline with elevation
2010	Pike et al.	Climate Change Effects on Watershed Processes in British Columbia (chapter 19)	Southern B.C. Winter: decreasing for the last 30- and 50-year periods (i.e. 1971-2004 and 1951-2004); but increasing for the last 100- year period (i.e. 1901-2004). Summer and Annual: increasing in all periods (i.e. 1901-2004; '51-'04 and '71-'04)	Chapter 19 Hydrology Climate Change	1973-2006	Similkameen River	CGCM3 HADCM3 ECHAM5 GFDL2.1 A2 and B1	Similkameen regime characterized as a nival/hybrid river; increased winter and spring flows and decreased summer flows Lower peaks than neutral during El Nino; and higher peaks than neutral during La Nina; lower peaks with warm PDO with advanced spring/summer freshet, and higher peaks with cool PDO
2010	Moore et al.	Weather and Climate (chapter 3)		Chapter 3 Climate Change	1961-1990 2020 2050 2080	Southern B.C.	7 models; 8 emission scenarios	Southern B.C.: 2020 (Temp and Precip) Winter 0-2ºC -5 to +15% Summer: 0.5 to 2ºC -30 to +5% 2050 (Temp and Precip) Winter 1.5-3.5ºC 0 to +20% Summer: 1.5 to 4ºC -35 to 0% 2080 (Temp and Precip) Winter 2-7ºC 0 to +25% Summer: 2.5 to 7.5C -50 to 0%

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2010	Schnorbus and Rodenhuis	Assessing Hydrologic Impacts on Water Resources in B.C.	Historical trends Temps are becoming less cool rather than warmer	Climate Change Hydrology	British Columbia	1901-2004 2050s	RCM 17 GCM scenarios CGCM3	Historical trends indicated mean, min and max temps are increasing with the greatest increase in min temps (0.17ºC per decade) Precip is also increasing in the past century (2.4% per decade) winter precip has decreased in the last 50yrs Streamflow is shifting within hydro-climate regimes, loss of snowpack can result in lower summer flows GCM projects a 3ºC increase in temp and 13% increase in precip for B.C. in the 2050 RCM projects a 2.7ºC increase and 14% increase in precip for B.C. Climate change will disrupt existing balance between hydroelectric power, flood control, and in-stream flow augmentation in the basin
2010	Tohver and Hamlet (Chap. 7 from Hamlet et al. 2010)	Impacts of 21st Century Climate Change on Hydrologic Extremes in the Pacific Northwest Region of North America	4 major mountain chains curve the landscape of the PNW-Coast Range, Olympics, Cascade Range and Rocky Mountains Future warming results in a progressive shift from snow dominant to transient basins and from transient to rain dominant basins The transient basins are predicted to be most sensitive to warming temp In a warmer climate the winter precipitation falling as rain instead of snow will intensify winter flood risk for transient basins Flood risks for rain dominant basins do not respond as quickly as transient basins Winter peak flows are thought to increase while summer peak flows are suggested to decrease	Climate change Hydrology	Pacific Northwest	1970-1999 2020s 2040s 2080s	GCMs IPCC AR4 VIC model 66 scenarios	The cascade region receives 250mm of precip in the low region where the high elevation sees 750mm of precip
2010	Rayne and Forest	Historical Trends in Annual Water Yields for the Okanagan Basin, British Columbia		Hydrology	1920-2010	Okanagan R at Okanagan Falls and near Oliver		Increasing trend in regional water yields Avg annual precip about 530mm with 80% lost due to evapotranspiration and evaporation The Okanagan lake may decline by 30% in 2080 due to warmer and drier summer

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2010	Moravec et al.	Oxygen-18 dynamics in precipitation and streamflow in a semi-arid agricultural watershed, Eastern Washington, USA	Understanding flow pathways and mechanisms that generate streamflow is important to understanding agrochemical contamination in surface waters in agricultural watersheds. Winter precipitation accounted for 67% of total annual precipitation and was found to dominate streamflow, tile drainage, and groundwater recharge. Deep soil pathways primarily generated summer streamflow while shallow soil pathways dominated streamflow generation during winter Summer in-stream evaporation fractions were estimated to be from 20% to 40%, with the greatest evaporation occurring from August to October. Evidence of altered precipitation conditions due to the Pacific Decadal Oscillation (PDO) in the Inland Northwest.		2000-2008	Eastern Washington Missouri Flat Cr.		
2010	Liggett and Allen	Comparing approaches for modeling spatially distributed direct recharge in a semi-arid region (Okanagan Basin, Canada)		Hydrology Groundwater recharge Water budget Okanagan Basin	1971-2000	South Okanagan Oliver area	HELP (Hydrologic Evaluation of Landfill Performance) Model useful for groundwater model calibrations	Mean Recharge 34-42 mm/year
2009	U.S. Army Corps of Engineers	Similkameen River Water Supply Study	Analysis of historical floods, minimum instream flow attainment and temperature data. Proposed alternative dams scenarios. Yakima basin will have difficulty in supplying water to all basin users, a decline in annual hydropower production (with substantial changes to summer hydropower production), possible reduction in flood risk due to loss of spring snow cover, and a transition from a snowmelt dominant basin to a basin in transition between rain and snow dominance by 2080. Similar results expected for Similkameen since no basins are predicted to remain snowmelt dominated by 2080. Rising stream temperatures predicted. Will reduce quality and quantity of freshwater habitat. Duration of temperatures causing thermal migration barriers are predicted to quadruple by 2080.	Climate Change SWE Water temperatures	2020s 2040s 2080s	Similkameen River	Quote model results from IPCC and UW CIG.	Changes highlighted: 2020s 1-April SWE -28 to -29% Avg. cool season streamflow +12% Avg warm season streamflow -18% 2040s 1-April SWE -38 to -46% Avg. cool season streamflow +19% Avg warm season streamflow -24% 2080s 1-April SWE -56 to -70% Avg. cool season streamflow +31% Avg warm season streamflow -39% Climate change comments from the IPCC and the UW CIG: Changes in precipitation, temperature and hydrologic regimes. Basin may undergo a transition from snow-dominated basin to transient rain/snow dominant basin, lessening of flood risk, increased summer temperatures that can exacerbate river temperatures, lower summer base flows.

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
			By 2026 several towns will have deficiencies in annual permitted water right volumes totaling 1600 acre-feet/year. Will require procurement of new permitted water rights. Could have an increase in summer municipal water demand. Irrigation demand rates may also change. Decrease in hydropower production and an increase in summer cooling demand by up to 400% predicted by the UW CIG. Reductions in flood risk due to loss of spring snow cover; thus lessening the need for storage. Lower summer flows, making it likely to have shortfall in meeting the minimum instream flows, thus more desirable to have additional storage available for this purpose.					
2009	Reese, A. (U.S. Army Corps of Engineers)	Modeling Analysis for the Similkameen River Water Supply Study	Similkameen contributes approximately 75% of average annual flow to Okanogan R. Report for proposed dams on Similkameen R. evaluating three different dam scenarios.	Hydrology Water Supply Irrigation Demands Power Generation Flood Control	1931-2007	Similkameen River	Stella	No climate change simulations discussed. Variations in proposed dams (i.e. small, med, large) would control water temperatures and also able to augment summer flows under low flow conditions.
2009a	Toews and Allen	Evaluating different GCMs for predicting spatial recharge in an irrigated arid region	Groundwater systems in arid regions particularly sensitive to climate change. Strong dependence of rates of ET on temperature and shifts in precipitation regimes.	Climate change Hydrology	1961-90 2020s 2050s 2080s	Oliver region	CGCM1 & 3.1 HadCM3 A2 SDSM HELP 3.80D Hydrologic Model	Modest increase of recharge Peak recharge shifting from March to February Lower recharge rates and higher PET predicted for summer months Potential growing season will expand between 3-4 weeks due to increases in temperature Prediction of future recharge is dependant on model selected Irrigation rates dominate total recharge during the summer months in this arid area Recharge in irrigated areas is significantly higher than natural recharge, with irrigation return flow between 25% and 58%. All of the future climates predict increased warming during summer months. All GCMs indicate potential reductions of precipitation during the summer at future time periods. Mean annual recharge rates have a median of 45 mm/yr, with first and third quartiles of 15 and 60 mm/yr, respectively. These values are approximately 20% of the annual precipitation.

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								Recharge simulations using irrigation yield significant increases in net recharge in the irrigation districts, from 250 mm/yr to 1000 mm/yr. Changes to recharge in future time periods for each GCM result in modest increases of recharge, but the magnitude of the changes vary considerably between model, suggesting that recharge modeling studies for future predicted climate change should consider a range of models. In the “most efficient” irrigation district, an increase of irrigation return and recharge may be at most a 0.4 mm/day increase, while in the “least efficient” district, it may be up to a 4 mm/day increase.
2009b	Toews and Allen	Simulated response of groundwater to predicted recharge in a semi-arid region using a scenario of modelled climate change	Future predicted climate change on groundwater. Related primarily to increases to irrigation return flow resulting from higher irrigation needs under warmer temperatures and a longer growing season. Higher water tables with future climate conditions; particularly in irrigation districts.	Hydrology Groundwater recharge Climate change	2050s 2080s Observed: 1961-2000	South Okanagan Oliver area	CGCM3.1	Increased contribution of recharge to the annual water budget: 2050: 1.2% 2080: 1.4% *related primarily to an increase in irrigation return flow (25-50%) Median value increases in groundwater level of up to 0.7 metres by 2080 Increased warming during summer months; especially late summer Potential decrease in precipitation in summer Increase in precipitation late summer to winter Crop water demands increase Increase growing season (3-4 weeks by 2080s) Temperature increases
2009	Smerdon et al.	An Approach for predicting groundwater recharge in mountainous watersheds	A study of the BX Creek Watershed Okanagan Basin is one of Canada’s fastest growing and most water limited regions Detailed info on the MIKE SHE model and steps Basin is characterized by snowmelt dominant upland and dry valley bottoms, seasonal runoff occurs in late summer	Hydrology Climate	1961-1991	BX Creek North Okanagan River Basin	MIKE SHE model MODHMS GSFLOW	Groundwater recharge is found to vary from 0 to 20mm/yr at low elevation and from 20-50mm/yr at high elevations 58% of the groundwater flux from upland areas occurs through a relatively narrow alluvial fan aquifer that extends to the valley bottom, and the remaining recharge is nearly equally divided between groundwater flow through the mountain block (20%) and direct recharge (22%).

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2009	Adam et al.	Implications of global climate change for snowmelt hydrology in the twenty-first century	Snow plays an important role in the water cycle Projected (annual) runoff volume changes are primarily associated with precipitation changes, and to a lesser extent, with changes in evapotranspiration (ET) Annual (and in some cases seasonal) changes in precipitation are a key driver of projected changes in annual runoff Projected warming produces strong decreases in winter snow accumulation and spring snowmelt over much of the affected area regardless of precipitation change Decreased snowpack produces decreases in warm season runoff in many mid- to high-latitude areas where precipitation changes are either moderately positive or negative in the future projections.	Climate change Hydrology	21st century 1949-2000 2025-2054 2040s	Western USA	VIC hydrological model NCEP NCAR 15 GCMs A2	
2009	Lee et al.	Optimized flood control in the Columbia River Basin for a global warming scenario	Anticipated future temperature changes in the mountainous U.S. Pacific Northwest will cause reduced spring snow pack, earlier melt, earlier spring peak flow and lower summer flow in transient rain-snow and snowmelt dominant river basins.	Climate change Hydrology Flood control; reservoir	20th century	Columbia Basin	HEC-PRM ColSim TAR	Warming temperatures and resultant streamflow timing shifts in the Columbia River Basin will disrupt the balance between current reservoir operations for flood control and the reliability of reservoir refill. For a simple climate change streamflow scenario based on a projected basin-wide annual average 2°C warming in the Columbia River Basin, the results show that storage deficits are exacerbated when using the current flood control rule curves because of altered streamflow timing. By comparison, optimized flood rule curves with systematically earlier (and in some cases reduced) flood evacuation in spring, coupled with adjusted refill timing up to 1 month earlier in the spring at some projects, decrease both monthly storage deficits (especially in moderate and high flow years) and flood risks.
2008a	Pike et al.	A Summary of Climate Change Effects on Watershed Hydrology	Overall rise in air temp for all seasons with greatest warming in the winter In the last 50 yrs there has been an increase of extreme wet and extreme dry conditions in the summer and a decrease of winter snowpack B.C. will experience greater warming periods and changes in precip then the global avg Scenarios say the atmosphere will increase its ability to evaporate	Climate Change Hydrology	1960-2010 Future Predictions	North, South and Central B.C.		The mean annual stream flow has decreased in the past 30-50 yrs Spring high flows have been starting earlier Changes in temp and precip will have a strong influence on hydrology, the following may be expected: • Increased atmospheric evaporative demand • Altered vegetation composition affecting evaporation/ interception • Increased lake temp

<table>
<tr><th>Date</th><th>Authors</th><th>Title</th><th>Summary</th><th>Relevance</th><th>Temporal Coverage</th><th>Spatial Coverage</th><th>Model Features</th><th>Outputs (past trend or modelled)</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>• Increased frequency and magnitude of storms
• Accelerated melting of permafrost
• Decreased snow accumulation and accelerated snow melt
• Glacier mass adjustments
• Altered timing and magnitude of stream flow</td></tr>
<tr><td>2008</td><td>Spittlehouse</td><td>Climate change, impacts, and adaptation scenarios: climate change and forest and range management in British Columbia</td><td></td><td></td><td>1961-90
2020
2050
2080</td><td></td><td>AR4
TAR
A2
B1
ClimateBC</td><td>Southern B.C.:

Winter
2020 0-2C; -5 to +15% precip
2050 1.5-3.5C; 0 to +20% precip
2080 2-7C; 0 to +25% precip
Summer
2020 0.5-2C; -30 to +5% precip
2050 1.5-4C; -35 to 0% precip
2080 2.5-7.5C; -50 to 0% precip</td></tr>
<tr><td>2008b</td><td>Pike et al.</td><td>Climate Change and Watershed Hydrology: Part 1- Recent and Projected Changes in British Columbia</td><td>Climate has become less cold rather than substantially warmer
Night time temps have increased rather than daytime

The change in temp has been linked to increased atmospheric water vapor and associated dew point and specific humidity trends during spring and winter

The rate of glacier loss in the Coast Mountains is almost double that of the previous two decades

Results show in the past 30-50 yrs:
• Increase mean monthly streamflow across Canada in march and April, with decrease in summer and fall
• Increase in annual min daily mean stream flow in B.C.
• Decrease in annual max daily mean stream flow
• Early start date of spring high flow season
• Earlier start date of annual max daily mean stream flow
• Earlier centroid of annual stream flow
• Earlier date of spring ice break up</td><td>Climate</td><td>Last
30-50 yrs
2050</td><td>B.C.
Columbia
Okanagan</td><td>GCM- IPCC 2007
15 GCM Projections</td><td>For B.C.:
Increased annual mean temp 0.5-2.0ºC
Annual min temp 1.0-2.5ºC
Annual max temp 0.5-1.5ºC

Avg annual precip. trends increased 22%

1950-2002 reduction in winter precip and increase in summer precip

20th century increase in annual snowfall from 1900-1970 followed by a significant decrease in 1980
Changes in air temp and precip by 2050:
<table>
<tr><th></th><th>Winter</th><th>Spring</th><th>Sum</th><th>Fall</th><th>Annual</th></tr>
<tr><td>Columbia Basin</td><td>1.8</td><td>1.5</td><td>2.4</td><td>1.8</td><td>1.9</td></tr>
<tr><td>Okanagan</td><td>2.0</td><td>1.8</td><td>2.6</td><td>2.0</td><td>2.0</td></tr>
<tr><td>B.C.</td><td>1.9</td><td>1.6</td><td>1.8</td><td>1.7</td><td>1.7</td></tr>
</table>
<table>
<tr><th></th><th>Winter</th><th>Spring</th><th>Sum</th><th>Fall</th><th>Annual</th></tr>
<tr><td>Columbia Basin</td><td>7%</td><td>8%</td><td>-8%</td><td>8%</td><td>4%</td></tr>
<tr><td>Okanagan</td><td>5%</td><td>12%</td><td>-8%</td><td>8%</td><td>5%</td></tr>
<tr><td>B.C.</td><td>7%</td><td>8%</td><td>-3%</td><td>9%</td><td>6%</td></tr>
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2007	Neale et al.	Urban water features: a multivariate analysis of population growth and climate change impacts on urban water demand in the Okanagan Basin, B.C.	Bridging the gap between global climate change and local water management adaptations	Hydrology Climate Change	May to Oct (irrigation season) 2020s 2050s	South Okanagan Oliver area	6 downscaled scenarios A2 & B2 emissions CGCM2; CSIROMk, HadCM3) TAR	Demands are projected to increase, exceeding licensed supplies in high growth scenarios. Can be offset to a large degree by demand management measures. Town of Oliver: Annual water demand estimated to be greater than 5000 ML Water use, best case around 2000 ML; and worst case greater than 7000 ML
2007	Rodenhuis et al.	Climate Overview 2007: Hydro-climatology and Future Climate Impacts in British Columbia	Excellent overview of past and future climate and hydrology for British Columbia.	Hydrology Climate change	1961-1990 1900-2004 2020 2050 2080	B.C. Okanagan Similkamen	IPCC AR4 Ensemble of 30 GCMs ENSO/PDO CRCM	Past: Max. temp. Okanagan: +1.3C/century Columbia: +1.0C/century SWE Okanagan:40% of stations increasing trend; 15% of stations decreasing trend Streamflow increased from May to August during La Nina years when compared to El Nino; also observed from Nov-Feb in the Similkameen R. Columbia Basin (2050): 10-25% reduction in flow during dry season and up to 90% during the summer months 2040: reduction in soil moisture in summer/fall B.C. (2050): warmer by 1.7ºC (1.2ºC to 2.5ºC) in both winter/summer seasons precip. to increase by +6% (+3 to +11%); mostly winter; summer decreases -3% (-9% to +2%) CRCM: Winter temps.: +2.0-4.2ºC Precip: varies up to 13% Snowpack -55%
2007	Scibek et al.	Groundwater-surface water interaction under scenarios of climate change using a high resolution transient groundwater model	Estimating future impacts of climate change on groundwater–surface water interactions Shift in river peak flow to an earlier date in a year; the shift for the 2040–2069 climate is larger than for the 2010–2039, although the overall hydrograph shape remains the same Maximum groundwater levels associated with the peak hydrograph are very similar to present climate because the peak discharge is not predicted to change, only the timing of the peak.	Climate change Hydrology	1960-1999 2020 2050	Grand Forks Aquifer within the Kettle River in B.C. Granby R	CGCM1 Downscaling	The river-aquifer interaction has a maximum flow rate between 11% and 20% of river flow during spring freshet – on average, the river contributes about 15% of its spring freshet flow into aquifer storage, and within 30 to 60 days most of that water is released back to the river as baseflow. Storage rates are less than 50% of inter-zonal groundwater flux, and 15–20% of river-aquifer flux.

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2006	Cohen and Neale	Participatory Integrated Assessment of Water Management and Climate Change in the Okanagan Basin, British Columbia – Final Report	Timeline created by workshop participants: 1904-1914: 40,000 acres of land irrigated between Vernon and Osoyoos 1920s: South OK Lands Project – Irrigation channel in South OK (Oliver and Osoyoos) 1986-87: Zosel Dam (Osoyoos L) reconstructed 2013: IJC orders regarding Osoyoos L expire	Hydrology Climate change Water Management	1961-90 2020 2050	Okanagan, to the mouth of Osoyoos Lake Oliver	HadCM3 A2 (most severe case of the six moderate scenarios examined) UBC Watershed Model	Climate change significant influence on water management planning. Water demands predicted may occur in excess of a decade earlier (e.g. by 2040s). Under Hadley A2 predictions, 2020 and 2050, lower and earlier peaks. 1961-90: OK Lake levels remained within prescribed limit Agricultural demand fluctuated between 20-80 million m3; and residential demands indicated an increasing trend due to population growth. Medium rate of population growth: agricultural and residential demands increase; inflows marginally lower; but OK Lake levels still maintained within prescribed limits. Upland region's agricultural and residential demands not met due to longer warmer growing season. Negative balance indicating supply is insufficient to meet demand. With a high rate of population growth, agricultural and residential demands increase, and OK Lake levels maintained between prescribed limits. But, continued deterioration of system in meeting agricultural and residential demands in uplands. 2050s, OK Lake levels would drop (since providing to uplands), and some valley outflows drop to zero. Some years, shortfall is more than 40 million m3.
2006	Cohen et al.	Learning with local help: expanding the dialogue on climate change and water management in the Okanagan region, British Columbia, Canada	Comprehensive regional assessment of the impacts of climate change on water resources Develop integrated climate change and water resource scenarios Field research, computer-based models, and dialogue	Climate change Hydrology	1961-1990 2020 2050 2080	Okanagan	CGCM2 HadCM3 CSIROMk2 A2 PDOs UBC watershed model (Quick 1995)	Last 30 years…warming trend 1970s to mid 90s, increasing summer precipitation (contrary to projections) Future projections increase in winter precipitation (also contrary to trends since 70s) 2020 increase 1.0-2.5 C 2050 increase 1.5-4C winter increase 2-4C summer 2080 increase 3-5 C Precip 2050 + 5 to 25% winter -35% summer

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								Hydrologic scenarios for Whiteman Creek 1961-1990 Earlier/lower peaks (Cdn and Auz models); earlier/higher peaks (German model) UBC watershed model is a suitable model for a region such as the Okanagan Basin
2006	Merritt et al.	Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia	Increase in winter temperature of 1.5–4.0 ºC and a precipitation increase of the order of 5-20% Summer precipitation is more variable with predicted change ranging from zero to a 35%decrease Summer temperatures were simulated to increase by approximately 2–4 ºC Early onset of the spring snowmelt, a tendency towards amore rainfall dominated hydrograph and considerable reductions in the annual and spring flow volumes in the 2050s and 2080s.	Hydrology Climate change	2020 2050 2080	Okanagan Basin	UBC Watershed Model CGCM2 CSIROMk2 HadCM3 A2 & B2 TAR UBC Watershed Model Downscaling (SDSM)	Earlier onset of spring snowmelt, more rainfall dominated hydrographs and reductions in the annual and spring flow volumes in the 2050s and 2080s. Longer low flow period. Low flows generally reduced in magnitude. Increase in winter temps: 1.5-4ºC Increase in summer temps: 2-4ºC Winter precipitation 5-20% Summer precipitation more variable (0 to -35%) Scenarios raise questions over the availability of future water resources in the Okanagan Basin, particularly as extended periods of low flows into upland reservoirs are likely to coincide with increased demand from agricultural and domestic water users. Earlier onset of spring peak flows (up 4 to 8 weeks) with reduced magnitude of peak flows. Reduced snowpack (e.g. Vaseaux Cr)
2006	Neilsen et al.	Potential impacts of climate change on water availability for crops in the Okanagan Basin, British Columbia		Climate change Hydrology	1961-1990 2020 2050 2080	Okanagan River Basin Oliver Penticton Summerland Trout Creek	CGCM2 CSIROMk2 HadCM3 18 Scenarios A2 & B2 Downscaling (SDSM) PRISM	Models and emission scenarios resulted in increase for water demand from 12% to 20% for the 2020's, 24 to 38% in the 2050's and from 40-61% for the 2080's Increase in peak demand and increase demand would occur at the end of each growing season The growing season could be lengthened by 30-35% at the end of the century; changes to PET; pasture/forage crops to have highest demand for water Unable to meet demands in years of future extreme climate. Increased frequency of drought (defined as 36% of total annual flow)

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								Highest risk to Trout Ck system coincides with high demand years and with low supply years Under A2, 2050s, supply and demand threshold exceeded (1 yr in 6); and by 2080s (1 yr in 4 to 1 yr in 2) Projected increases in demand may be lower than modeled (limitation).
2005	Winkler et al.	Measured differences in snow accumulation and melt among clear cut, juvenile, and mature forests in southern British Columbia	Difference between snow accumulation and snowmelt in clear cut area vs mature spruce area Studies have shown that snow accumulation and melt rates decrease as the canopy density increases Melt water outflow Snow accumulation Average snowmelt Melt water outflow	Climate Snow accumulation and melt Forest Hydrology	1995, ’96. ‘97	Mayson Lake B.C. (north of Kamloops)		1 April SWE was 32% and 14% less under the mature and juvenile forests respectively than in the clearcut
2005	Mote et al.	Declining mountain snowpack in western North America			1925-2000	Western North America		Declines in springtime SWE have occurred in much of NA west
2004	Huby	Okanagan Water: The introduction of an eight-point action plan.				Okanagan valley		P ~ 554mm (100%) ET ~ 419mm (-76%) E ~ 54mm (-10%) Human consumptive use ~ 19mm (-3%) Net through flow ~62mm (11%)
2004	Cohen et al.	Expanding the Dialogue on Climate Change & Water Management in the Okanagan Basin, British Columbia – Final Report		Hydrology Climate change	1961-90 2020 2050 2080	Okanagan	CGCM2; HadCM3; CSIROMk2 A2 and B2 UBC Watershed Model	2050s Winter temps +1.5-4.0ºC Precip. +5 to 25% Summer temps +2-4ºC Precip 0 to -35% Earlier recession of snowpack Shift in peak flows to earlier More rainfall dominated hydrograph Considerable reductions in annual and freshet volumes, particularly 2050s and 2080s
2004	Neilsen et al.	Impact of climate change on crop water demand in the Okanagan Valley, B.C.		Climate change Agriculture	1961-90 2080s	Okanagan Valley	CGCM1 PRISM	Predicted values of crop demand were slightly lower than expected, i.e. 745 mm/yr vs 820-1000 mm/yr Total annual water consumption for 1996-99 predicted was reasonably similar, i.e. 46.9 m^3 x 10^6 vs 51.8 m^3 x 10^6 For the region as a whole, estimated crop water demand increased by 37%, from 745 to 1021

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
								mm/year between present day and the 2080s.
2003	VOX Communications	Climate change in the Columbia Basin	Workshop with key speakers, i.e.: Phillip Mote Stewart Cohen Alan Hamlet	Climate change Hydrology	Since 1920s 1948-2000 2020 2040	Pacific Northwest Columbia Basin Okanagan	CGCM1 and 8 other models	Past trends: Temp: nearly all stations showing positive trends (0.5-2.0ºC) Precip: nearly all stations showing positive trends (15-60cm/century) Earlier freshet (1948-2000) Snow depth decreasing Future: 0.5ºC increase per decade Future: Less snow, both in depth and breadth; thus less SWE Increase precip.(i.e. rain) on the order of 10% for PNW Rivers peak earlier in the year (high confidence); but changes in total annual and peak flows (low confidence) Snowmelt dominated basins earlier peaks and lower minimum flows More water in late winter and early spring; less water in summer 1.7ºC warmer by 2025 2.5ºC warmer by 2045 Significant summer droughts 2-3 times more frequent
2003	Scherer and Pike	Effects of Forest Management Activities on Stream flow in the Okanagan Basin	Peak runoff for streams occur in spring (April-July) mostly from melting snow primarily from melting snowpacks above 1200m Mean annual temp of basin 6ºC w/ a winter mean of -3.5ºC and a summer mean of 15ºC Annual precip 250-300mm in valleys 400-600mm in plateau area >1000mm in alpine area The water available in an avg runoff year is low, the basin gets 554mm of precip, 419mm used for evapotranspiration and infiltration and 122mm flows in the lake leaving 13mm for irrigation	Climate Forest Hydrology		Okanagan Basin		Climate Change (based on MWLAP 2002) Temp: 1898-1995 + 0.9-1.8 ºC/century Projected change: + 1-4 ºC/century Lows increase more than highs Precip: 1929-1998 + 3-6 %/decade Projected change: 10% until 2050s 10-20% by 2090 SWE: 1935-2000 No trend (%/decade) Snow depth: 1935-2000 -3 %/decade

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
2003	Whitfield and Canon	Changes in climate and hydrology of South Central B.C. 1976-1995	Statistically significant changes occurred during spring and fall than during summer or winter Earlier onset to the melting of the winter snowpack, followed by lower peak and recession streamflows during the spring, summer, and early fall months. In the western portion of the study area early winter streamflows increased Increase in early winter rains in the western portion of the study area. In streams with existing withdrawals, significant decreases in flows were observed from fall until spring, with an overall decrease in streamflow between the two decades.	Climate Hydrology	1976-1995	South central B.C. Similkameen Kettle Okanagan		
2003	Mote et al.	Variability and trends in mountain snowpack in western North America		SWE	1950-2000	Western North America		Widespread decline in springtime SWE Increase (positive significant trends) in Nov-March temperatures Increase in precipitation (although many not significant, many are in excess of 25% in 50 years)
2002	MWLAP	Indicators of climate change for British Columbia 2002	Trends	Climate change	20th century 21st century 1895-1995	Southern interior	n/a	+1.1ºC avg temp MAM +1.2ºC/century JJA +0.9ºC/century SON +0.8ºC/century DJF +1.8ºC/century Max temp: +0.9ºC/century Min temp: +1.4ºC/century Max temps: MAM +1.2ºC/century JJA no trend SON no trend DJF no trend Min temps: MAM +1.2ºC/century JJA +1.3ºC/century SON +0.8ºC/century DJF +2.4ºC/century Avg Precip: +3%/decade MAM +5%/decade JJA +6%/decade SON no trend/decade DJF no trend/decade Snow:

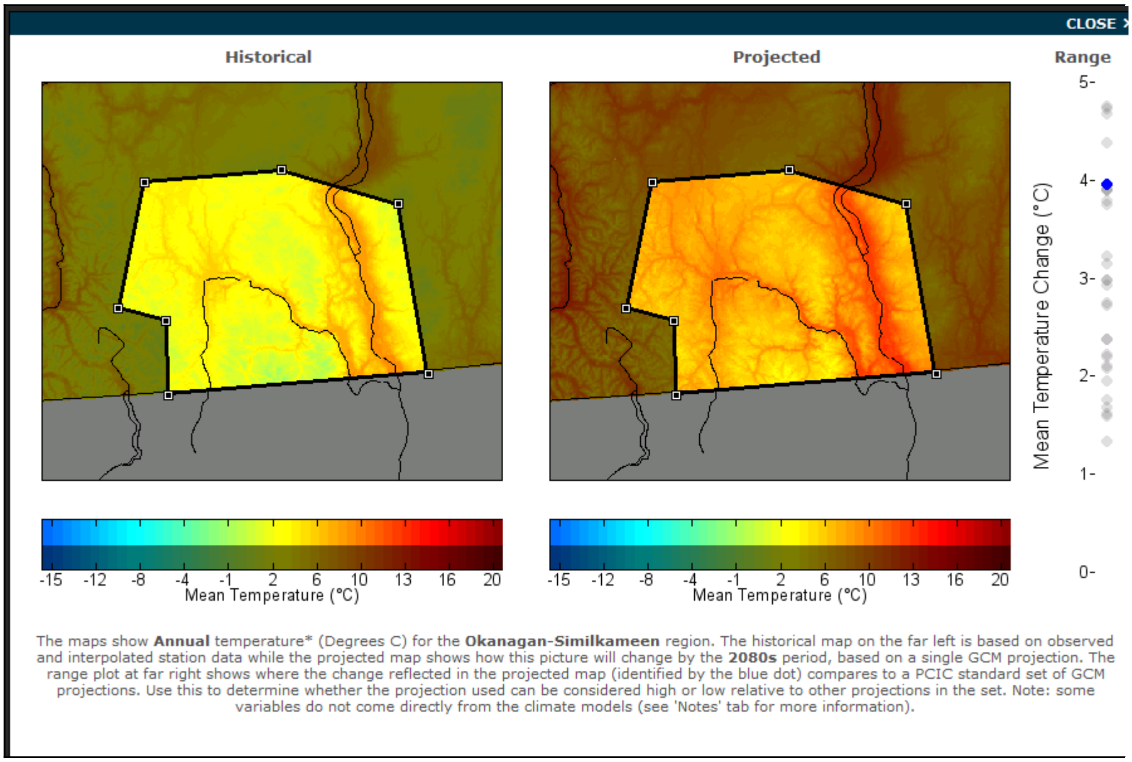
Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
								No trend Snow depth: -3%/decade Date of first melt: -8days/decade Ice free date: -6days/decade Upper Similkameen R.: -earlier snowmelt -extended low flow period -greater autumn rain -lower summer flow Growing degree days: +5%/century
2002	Loukas et al.	Potential climate change impacts on flood producing mechanisms in southern British Columbia, Canada using the CGCMA1 simulation results		Hydrology Climate change	2080-2100	Illecillewaet Basin (tributary of Columbia Basin)	UBC Watershed Model CGCM (A1)	Basin wetter and warmer climate with a decrease in the number and magnitude of peak flows and flood events
2001	Cohen and Kulkarni	Water Management & Climate Change in the Okanagan Basin		Hydrology Climate change	1961-90 2020 2050 2080	Six sub-watershed of Okanagan Basin	HBV Hydrological Model CGCM1 ECHAM HadCM2 IS92 PRISM	Earlier onset of spring peak flows (up to 6 weeks) with reduced magnitude of peak flows. Similkameen: earlier onset to spring, lower fall flows and higher early winter flows Okanagan/Kettle: same as above, but lower winter flows Climate variability due to El Nino episodes and Pacific Decadal Oscillation (PDO) Changing climate: Higher temps and decreased snowpack Changing hydrology: Earlier peaks in spring freshet; more precipitation projected, but seasonal breakdown inconsistent; no consensus on total water flow changes in the system
2000	Cohen et al.	Climate change and resource management in the Columbia River Basin	Comparison between MPI, UKMO, and GFDL for 2020 and 2050 The Columbia system produces more hydroelectricity than any other river system in North America with an avg of 18,500 megawatts	Climate change, climate impacts, water resources, hydrology	2020 2050	Columbia River Basin	IPCC, 1996 IS92 GFDL MPI UKMO	The Canadian portion of the basin has the greatest areas of precipitation , the Canadian portion also accounts for major hydropower due to runoff, as well flood flows have been affected due to snowmelt from Canada 15% of Basin is in Canada but accounts for 30% of rivers total discharge

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
								Storage projects can store 30% of annual runoff changing the shape of the hydrograph *Predictions for changes in annual avg temp for 2050:* GFDL: 3.39ºC MPI: 2.57ºC UKMO: 5.5ºC Projected retreat of mountain glaciers will strongly affect hydrology, once glacier diminishes natural flow could fail by 20-90% Earlier seasonal peaks with possible reductions in total annual flow and lower minimum flows. Tendency towards reduced reliability to meet objectives for power production, fisheries, and agriculture. Reliability to meet flood control objectives would be relatively unchanged in some scenarios but reduced in others. Precipitation heavily concentrated in a few high elevation areas; intermountain rain shadow; flow dominated from snowmelt from those high elevation areas; melt from glaciers contributing to late summer flows. Winter precipitation, mostly at lower elevations, will fall more as rain than snow, and annual snowpack will tend to melt earlier resulting in earlier peak in the annual hydrograph.
1999a	Hamlet and Lettenmaier	Columbia River streamflow forecasting based on ENSO and PDO climate signals	A simple method has been devised to incorporate the El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) climate signals into the well-known extended streamflow prediction forecasting approach. The results demonstrate the increase in lead time and forecast specificity over climatology that can be achieved by using PDO and ENSO climate information to condition the forecast ensembles.	Climate Change ENSO PDO	1989-98	Columbia Basin		

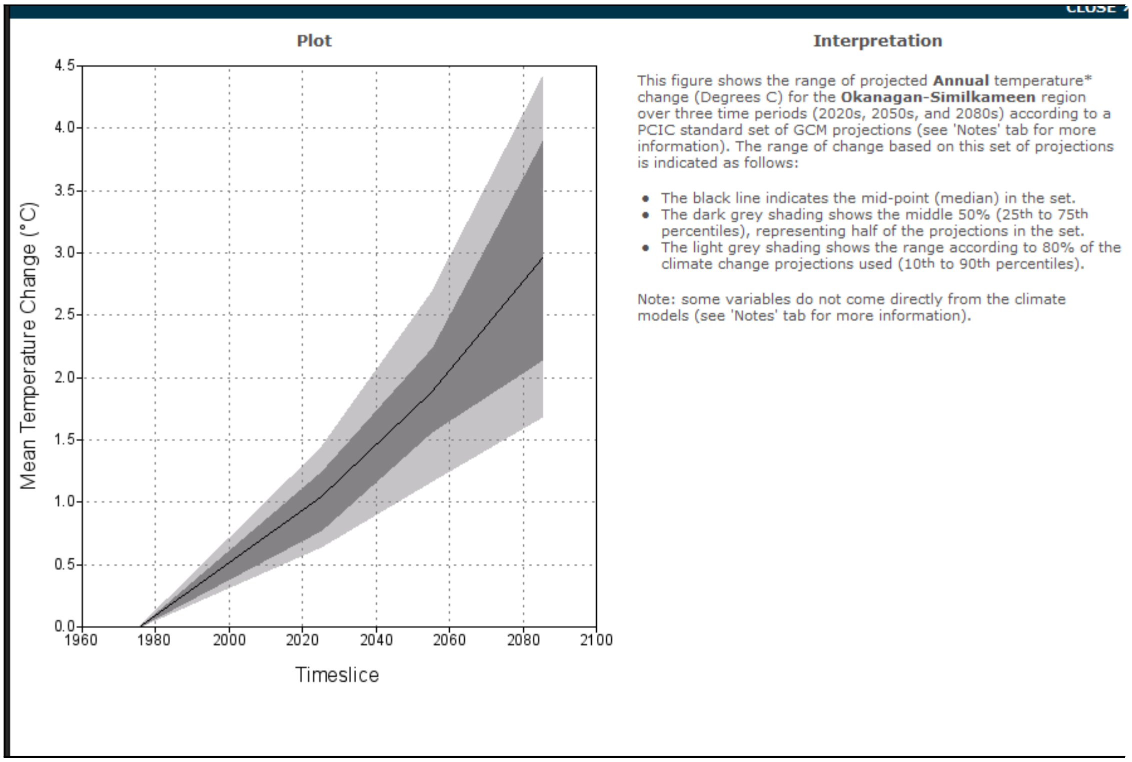
Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
1999b	Hamlet and Lettenmaier	Effects of climate change on hydrology and water resources in the Columbia River Basin.		Hydrology Climate change	2025 2045 2095	Columbia Basin	VIC Hydrological Model CGCM1 HadCM2 ECHAM4	Significant increase in winter runoff volumes due to increased winter precipitation and warmer winter temperatures, with resulting reductions in snowpack.
1998	Leith and Whitfield	Evidence of climate change effects on the hydrology of streams in south-central B.C.			1971-95	Similkameen		Earlier freshet Lower late summer – early fall flows Higher early winter flows
1998	Clair et al.	Changes to the runoff of Canadian ecozones under a doubled CO2 atmosphere		Hydrology Climate change	1980-94	Montane Cordillera	Hydrologic Model: an artificial network (ANN) model Climate Model: CGCM2 (times two CO_2)	Predicted increases in total runoff for the Pacific and Montane Cordillera ecozones. An earlier onset of the spring melt was predicted along with increased winter and early spring flows in these two ecozones.
1974	B.C. Water Resource Service	Summary report of the Consultative Board including the comprehensive framework plan		Lake Levels	1980 2000 2020	Osoyoos Lake	n/a	Osoyoos Lake: 200-yr flood elevation is 919.25 feet Flood plain zone up to 921 feet Maintain levels during drought periods Flooding more frequent on this lake (once every 10 years on average) With recommended improvements in place, Okanagan R discharge at Penticton can be increased by 15% to 12,000 acre-feet per month in flood years with little effect to Osoyoos L levels (where flooding is caused largely by backwater from the Similkameen). Baseflow of 100 cfs required to support ecological and aesthetic resources (under drought conditions) Osoyoos L level range: 909-919 ft
1974	McNeil	Factors affecting the level of Osoyoos Lake	- the most effective method of reducing the Osoyoos lake peak elevation in these two years would be by reducing the peak flow on the Similkameen - had the flow from Okanagan lake not been reduced at the height of the Similkameen R freshet, the peak elevagtion reached by Osoyoos Lake would have been almost on and a half feet higher thn actually occurred - abnormally heavy snowpack on both the Similkameen and Okanagan Valley watersheds		1928- 1948 and 1972 freshets			When combined flows of the Okanagan/Similkameen exceed 17,000 cfs, these flows affect flow in the Okanoga R between the outlet from Osoyoos L and its junction with the Similkameen This has occurred in 1948, 1972 and 1974
1973	Coulson	Osoyoos Lake Flooding		Lake levels	1972 1948	Osoyoos Lake	n/a	1972 highest on record since 1929. Although, evidence that the 1894 peak was 1.5 feet higher than that of 1972.

Date	Authors	Title	Summary	Relevance	Temporal Coverage	Spatial Coverage	Model Features	Outputs (past trend or modelled)
								Caused by backwater from Similkameen R. Lake levels can increase by as much as 1 ft/day. It has been shown that a drastic reduction on outflow at Penticton during freshet has very little effect on peak levels of Osoyoos Lake. The most satisfactory flood control for Osoyoos Lake would be a storage dam on the Similkameen R with an improved channel on Okanogan R below Oroville. Similkameen R reacts quickly to changes in weather conditions. Usually a 1-day lag from upstream flows to the station at Nighthawk. Difficult to have reliable forecasts during extreme flows and due to complex hydraulics of Osoyoos L levels.
1971	Coulson	Reverse flows into Osoyoos Lake	The magnitude of the reverse flow is dependent on the flow in the Similkameen R and the level of Osoyoos Lake. Between 1943-70, reverse flows occurred: 1948; 1949; 1950; 1955; 1960 and 1968. Regulation of flows on Okanagan R upstream from Oliver would have little effect o the level of Osoyoos Lake during periods of high flow on the Similkameen R. A sharp reduction of flows at Oliver would only increase reverse flows at Oroville by approximately the same amount.					
1968	Lawson	Groundwater flow systems in the crystalline rocks of the Okanagan Highland, British Columbia	Groundwater flow systems Hydraulic conductivity varies exponentially with depth The lower impermeable boundary is estimated at 1000 ft below the ground surface The water table occurs at an average depth of 10 ft below surface			Okanagan highland		Local flow systems within the upper 125 to 150 ft conduct an estimated 10 to 17 Imperial gallons per day per foot thickness in a two-dimensional flow, constituting the quantitatively significant flow systems in the Okanagan Highland

C Appendix C - PCIC climate change projections for Okanagan - Similkameen region



The maps show **Annual** temperature* (Degrees C) for the **Okanagan-Similkameen** region. The historical map on the far left is based on observed and interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. The range plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standard set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).

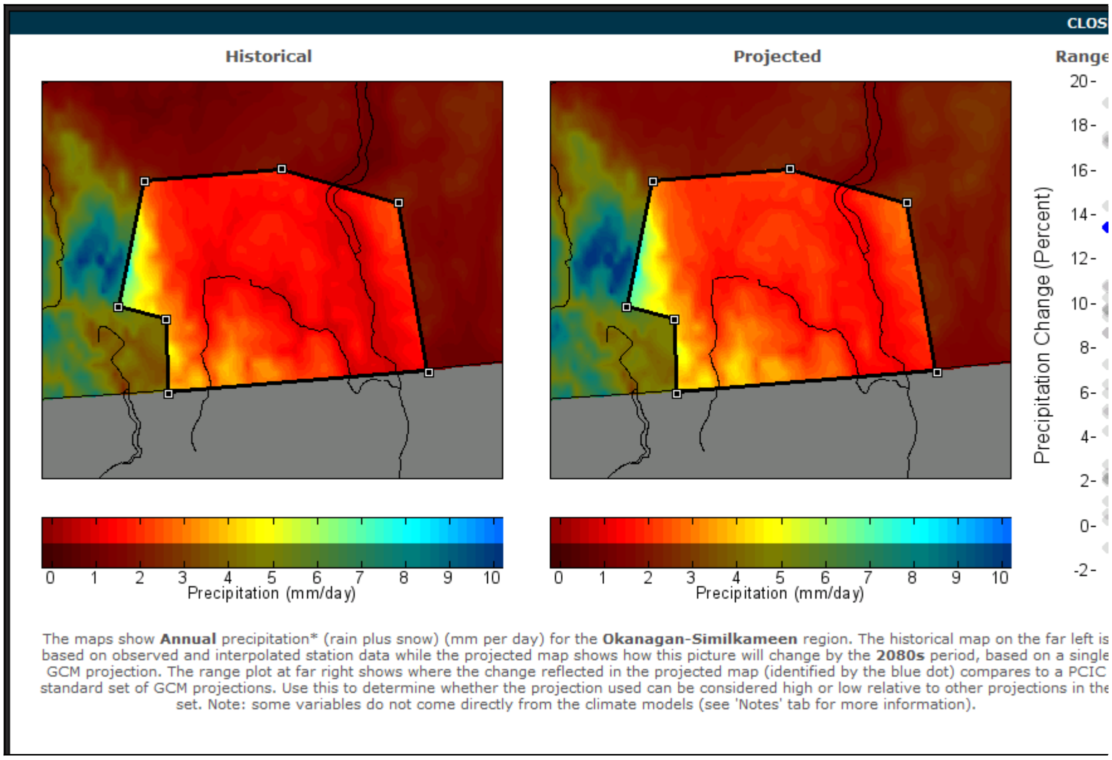


Interpretation

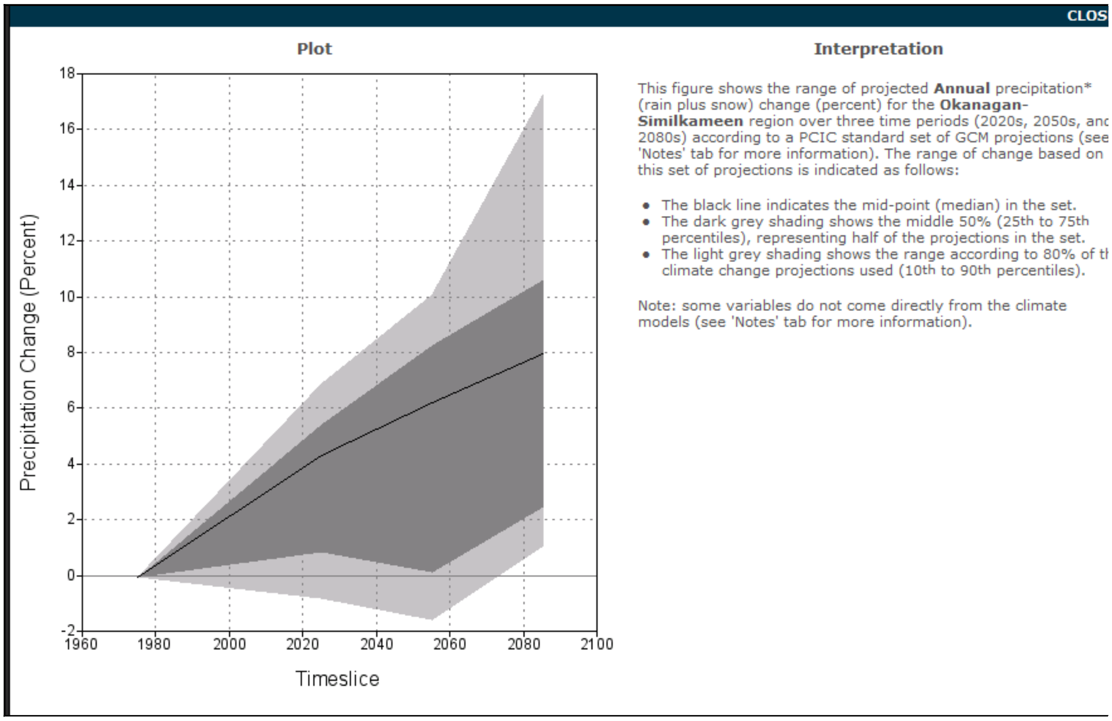
This figure shows the range of projected **Annual** temperature* change (Degrees C) for the **Okanagan-Similkameen** region over three time periods (2020s, 2050s, and 2080s) according to a PCIC standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projections is indicated as follows:

- The black line indicates the mid-point (median) in the set.
- The dark grey shading shows the middle 50% (25th to 75th percentiles), representing half of the projections in the set.
- The light grey shading shows the range according to 80% of the climate change projections used (10th to 90th percentiles).

Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).



The maps show **Annual** precipitation* (rain plus snow) (mm per day) for the **Okanagan-Similkameen** region. The historical map on the far left is based on observed and interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. The range plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standard set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).



This figure shows the range of projected **Annual** precipitation* (rain plus snow) change (percent) for the **Okanagan-Similkameen** region over three time periods (2020s, 2050s, anc 2080s) according to a PCIC standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projections is indicated as follows:

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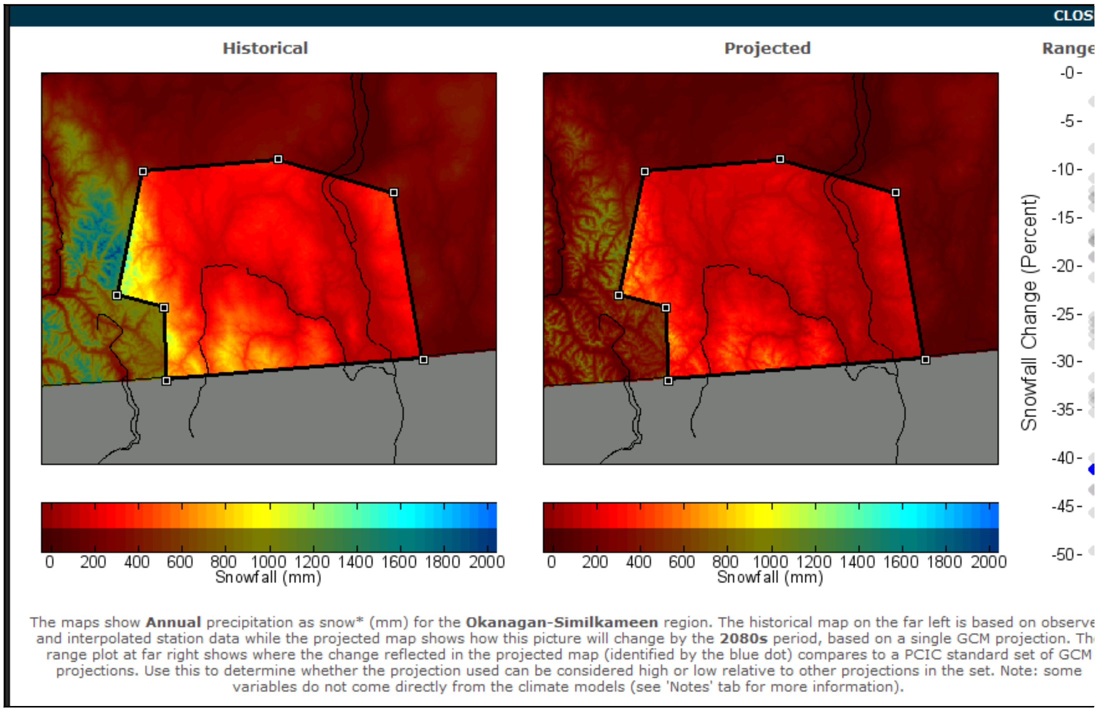
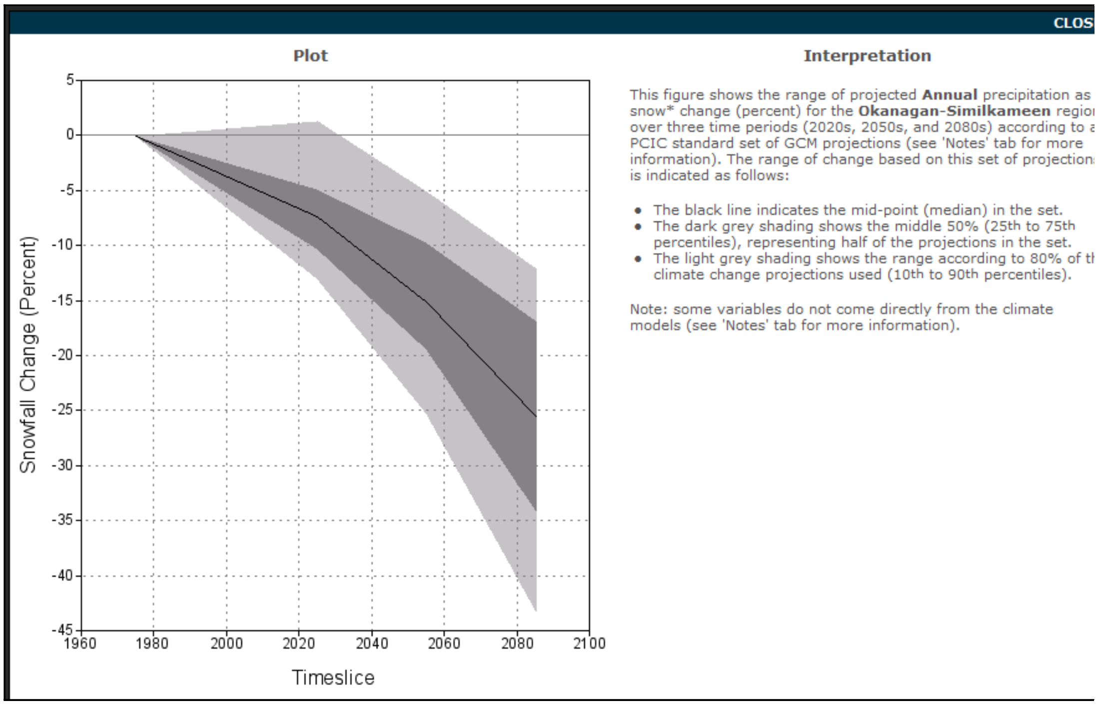


The maps show **Annual** precipitation as snow* (mm) for the **Okanagan-Similkameen** region. The historical map on the far left is based on observe and interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. Th range plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standard set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).



This figure shows the range of projected **Annual** precipitation as snow* change (percent) for the **Okanagan-Similkameen** regio over three time periods (2020s, 2050s, and 2080s) according to a PCIC standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projection is indicated as follows:

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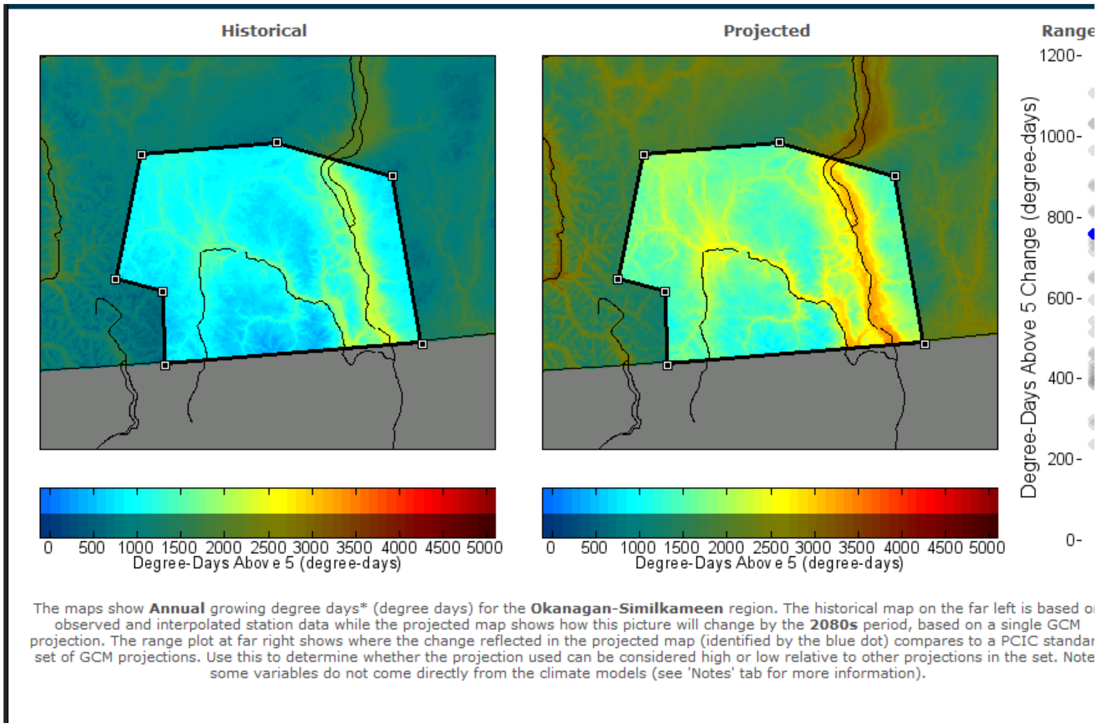
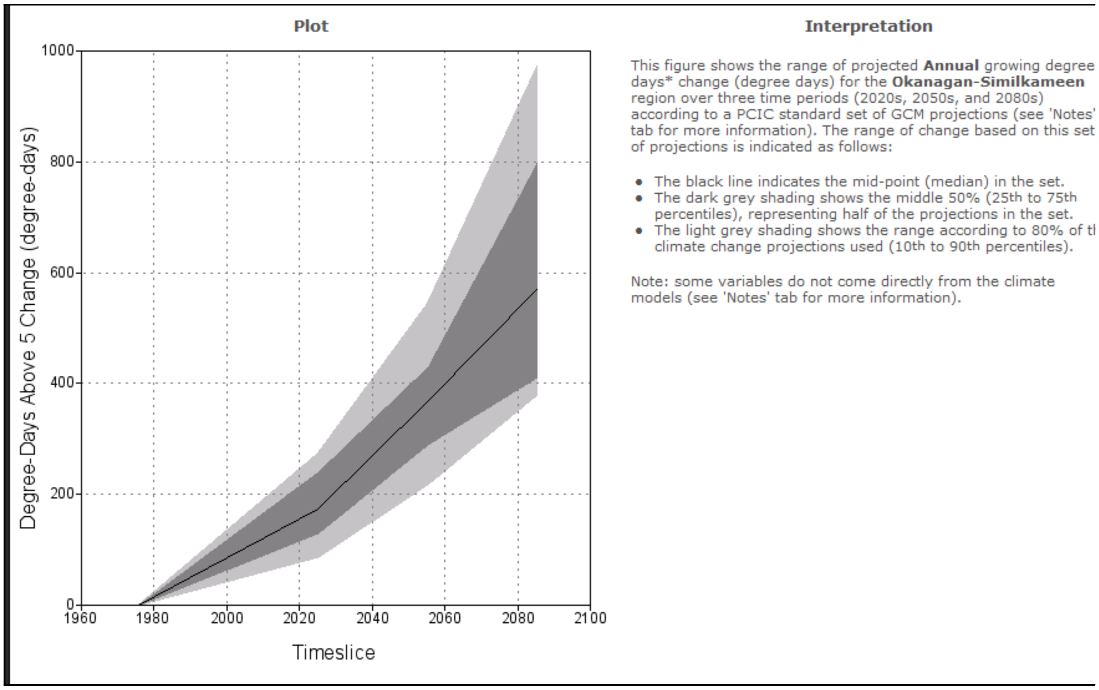


The maps show **Annual** growing degree days* (degree days) for the **Okanagan-Similkameen** region. The historical map on the far left is based o observed and interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. The range plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standar set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Note some variables do not come directly from the climate models (see 'Notes' tab for more information).



This figure shows the range of projected **Annual** growing degree days* change (degree days) for the **Okanagan-Similkameen** region over three time periods (2020s, 2050s, and 2080s) according to a PCIC standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projections is indicated as follows:

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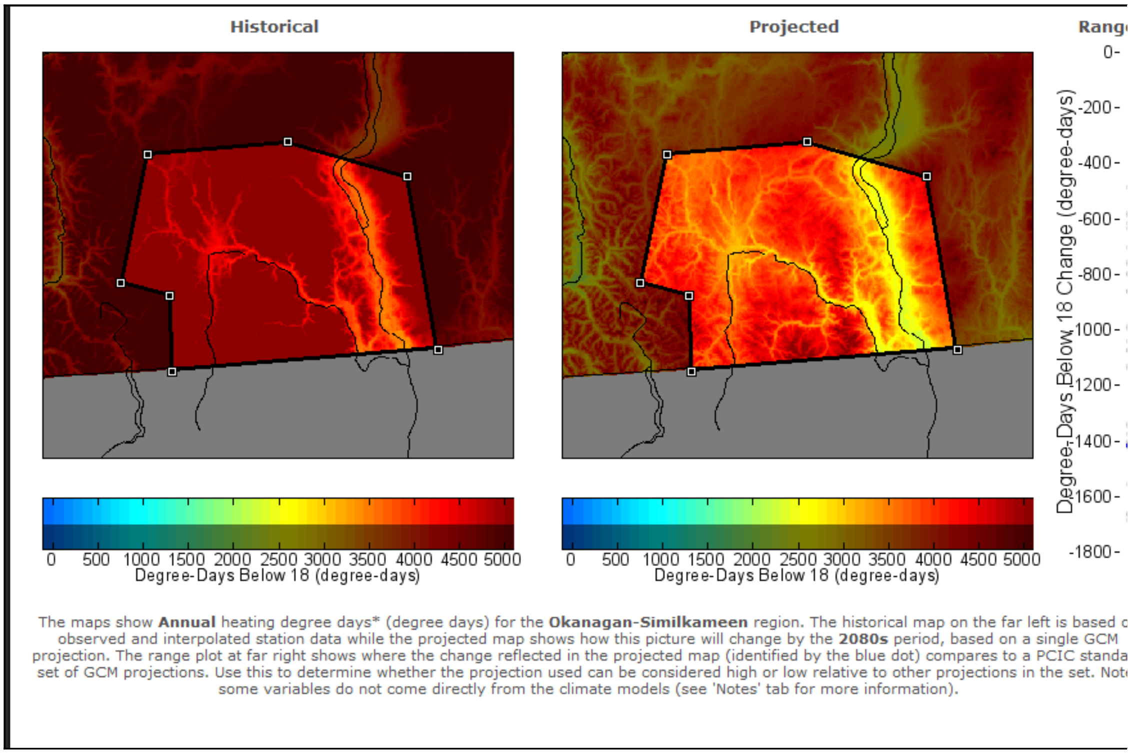
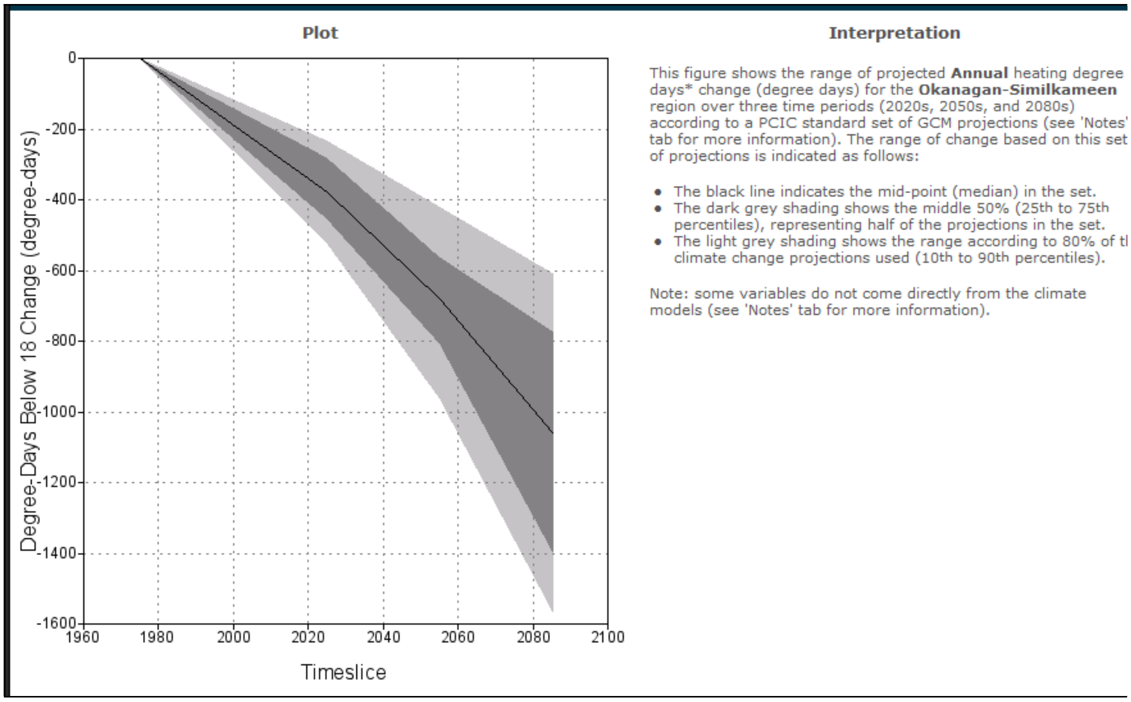


The maps show **Annual** heating degree days* (degree days) for the **Okanagan-Similkameen** region. The historical map on the far left is based c observed and interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. The range plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standa set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Not some variables do not come directly from the climate models (see 'Notes' tab for more information).



This figure shows the range of projected **Annual** heating degree days* change (degree days) for the **Okanagan-Similkameen** region over three time periods (2020s, 2050s, and 2080s) according to a PCIC standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projections is indicated as follows:

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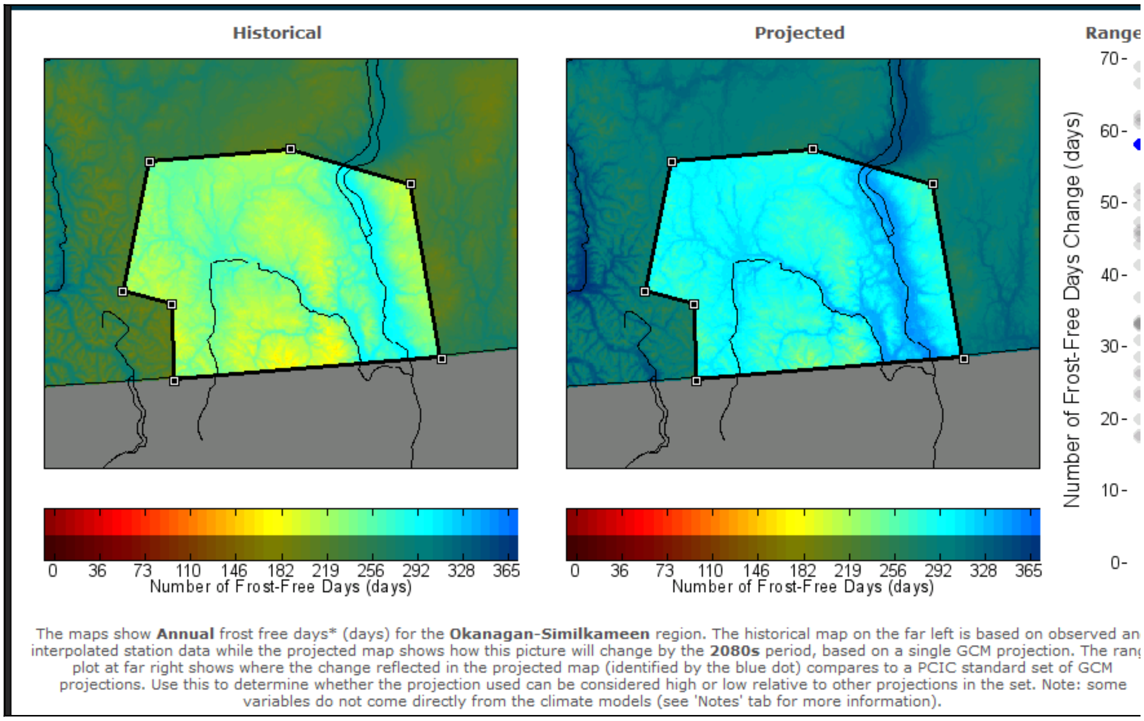
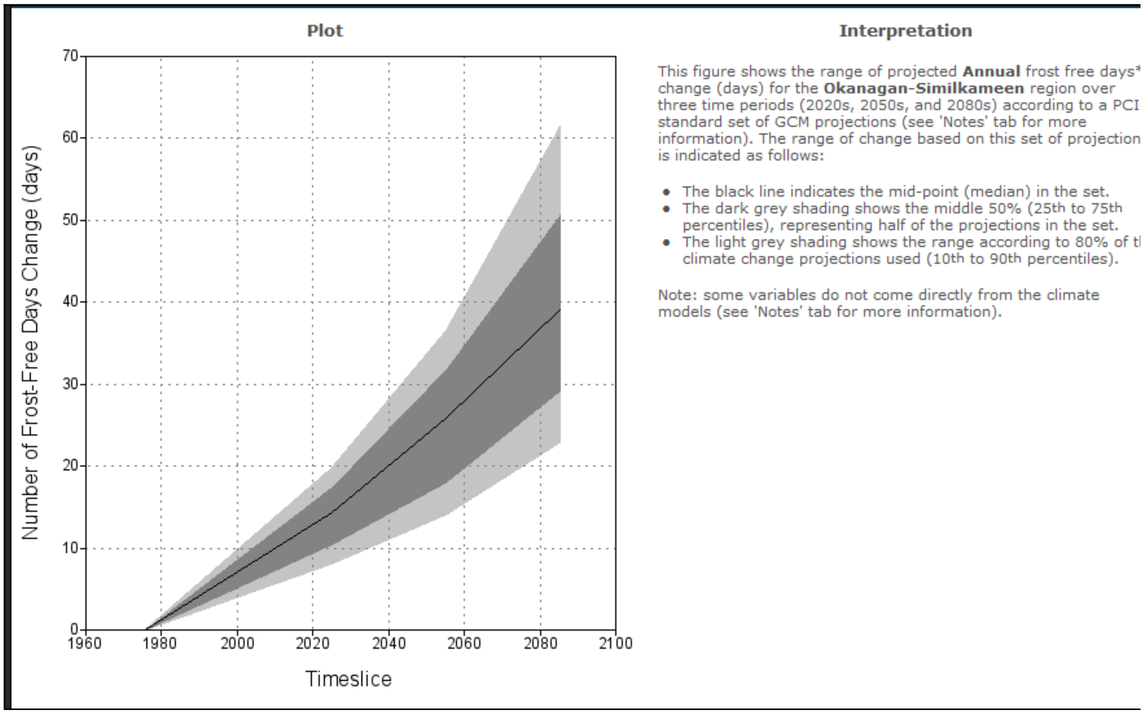
Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).



The maps show **Annual** frost free days* (days) for the **Okanagan-Similkameen** region. The historical map on the far left is based on observed an interpolated station data while the projected map shows how this picture will change by the **2080s** period, based on a single GCM projection. The rang plot at far right shows where the change reflected in the projected map (identified by the blue dot) compares to a PCIC standard set of GCM projections. Use this to determine whether the projection used can be considered high or low relative to other projections in the set. Note: some variables do not come directly from the climate models (see 'Notes' tab for more information).



This figure shows the range of projected **Annual** frost free days* change (days) for the **Okanagan-Similkameen** region over three time periods (2020s, 2050s, and 2080s) according to a PCI standard set of GCM projections (see 'Notes' tab for more information). The range of change based on this set of projection is indicated as follows:

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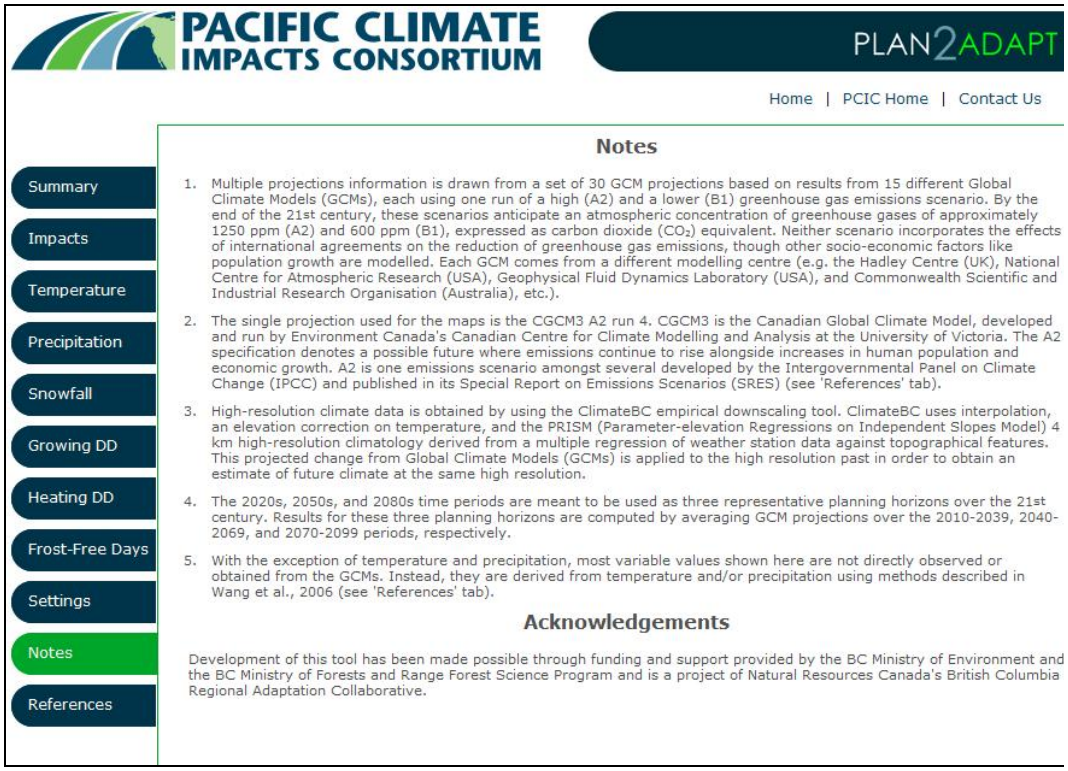

Notes

1. Multiple projections information is drawn from a set of 30 GCM projections based on results from 15 different Global Climate Models (GCMs), each using one run of a high (A2) and a lower (B1) greenhouse gas emissions scenario. By the end of the 21st century, these scenarios anticipate an atmospheric concentration of greenhouse gases of approximately 1250 ppm (A2) and 600 ppm (B1), expressed as carbon dioxide (CO_2) equivalent. Neither scenario incorporates the effects of international agreements on the reduction of greenhouse gas emissions, though other socio-economic factors like population growth are modelled. Each GCM comes from a different modelling centre (e.g. the Hadley Centre (UK), National Centre for Atmospheric Research (USA), Geophysical Fluid Dynamics Laboratory (USA), and Commonwealth Scientific and Industrial Research Organisation (Australia), etc.).
2. The single projection used for the maps is the CGCM3 A2 run 4. CGCM3 is the Canadian Global Climate Model, developed and run by Environment Canada's Canadian Centre for Climate Modelling and Analysis at the University of Victoria. The A2 specification denotes a possible future where emissions continue to rise alongside increases in human population and economic growth. A2 is one emissions scenario amongst several developed by the Intergovernmental Panel on Climate Change (IPCC) and published in its Special Report on Emissions Scenarios (SRES) (see 'References' tab).
3. High-resolution climate data is obtained by using the ClimateBC empirical downscaling tool. ClimateBC uses interpolation, an elevation correction on temperature, and the PRISM (Parameter-elevation Regressions on Independent Slopes Model) 4 km high-resolution climatology derived from a multiple regression of weather station data against topographical features. This projected change from Global Climate Models (GCMs) is applied to the high resolution past in order to obtain an estimate of future climate at the same high resolution.
4. The 2020s, 2050s, and 2080s time periods are meant to be used as three representative planning horizons over the 21st century. Results for these three planning horizons are computed by averaging GCM projections over the 2010-2039, 2040-2069, and 2070-2099 periods, respectively.
5. With the exception of temperature and precipitation, most variable values shown here are not directly observed or obtained from the GCMs. Instead, they are derived from temperature and/or precipitation using methods described in Wang et al., 2006 (see 'References' tab).

Acknowledgements

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D

Appendix D - Okanagan River at Oliver – climatic and streamflow projections (from Hamlet et al., 2010)

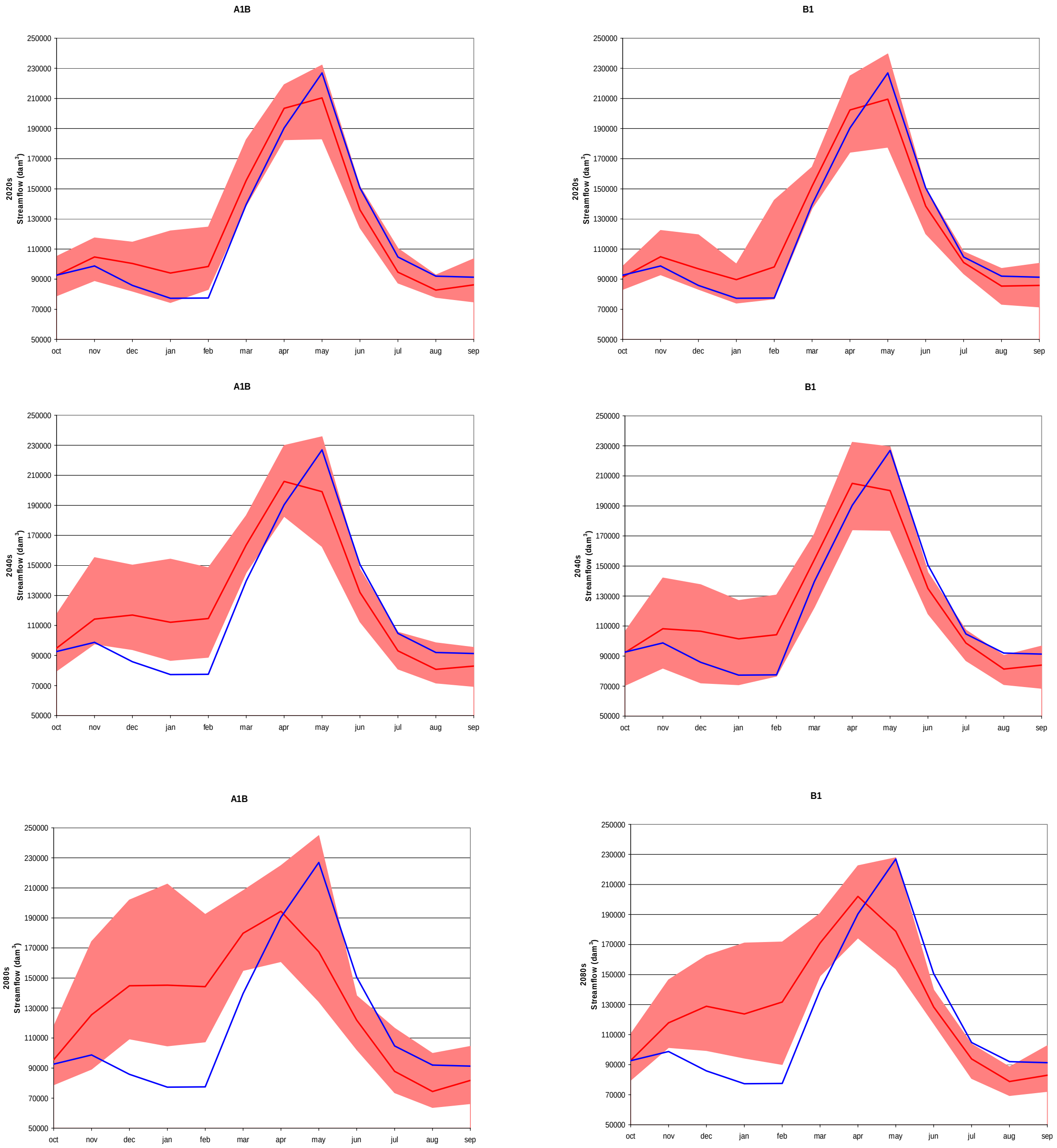

Figure D1. Okanagan River at Oliver: long term average of monthly routed streamflow volumes (units: dam^3) for the 2020s, 2040s and 2080s, under the A1B and B1 emission scenarios. Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections (Source: Hamlet et al., 2010).

Table D1. Okanagan River at Oliver: long term monthly streamflow projections

Month	Historical Simulated Volumes (1970-99)	A1B									B1								
		2020s			2040s			2080s			2020s			2040s			2080s		
	Dam^3	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	92664	0.999	0.852	1.134	1.024	0.860	1.267	1.031	0.851	1.271	0.986	0.897	1.064	0.996	0.760	1.148	1.001	0.859	1.191
Nov	98738	1.061	0.901	1.190	1.157	0.989	1.572	1.271	0.904	1.765	1.062	0.941	1.240	1.096	0.830	1.439	1.194	1.027	1.483
Dec	85853	1.170	0.956	1.335	1.362	1.093	1.750	1.687	1.275	2.352	1.128	0.970	1.392	1.241	0.840	1.602	1.501	1.158	1.894
Jan	77308	1.217	0.964	1.579	1.450	1.121	1.995	1.878	1.355	2.749	1.160	0.958	1.295	1.312	0.917	1.643	1.601	1.220	2.213
Feb	77518	1.270	1.072	1.608	1.479	1.146	1.915	1.861	1.386	2.481	1.266	0.992	1.838	1.344	0.988	1.686	1.699	1.162	2.216
Mar	139626	1.114	0.994	1.308	1.172	1.040	1.312	1.287	1.110	1.491	1.087	0.981	1.177	1.104	0.878	1.227	1.225	1.068	1.366
Apr	190395	1.068	0.959	1.151	1.082	0.959	1.207	1.021	0.845	1.181	1.063	0.915	1.181	1.077	0.914	1.220	1.061	0.916	1.169
May	226922	0.927	0.807	1.023	0.877	0.716	1.039	0.738	0.592	1.079	0.923	0.783	1.056	0.882	0.765	1.011	0.788	0.678	1.004
Jun	150590	0.903	0.824	1.007	0.877	0.747	0.980	0.810	0.680	0.918	0.920	0.798	0.999	0.896	0.784	0.968	0.853	0.780	0.929
Jul	104757	0.904	0.834	1.054	0.889	0.773	1.008	0.838	0.702	1.113	0.965	0.894	1.034	0.942	0.830	1.025	0.895	0.771	0.990
Aug	91985	0.900	0.847	1.009	0.878	0.779	1.071	0.809	0.693	1.085	0.929	0.797	1.056	0.885	0.772	0.983	0.857	0.754	0.962
Sep	91281	0.945	0.820	1.135	0.909	0.760	1.045	0.896	0.727	1.145	0.941	0.784	1.102	0.920	0.750	1.059	0.909	0.790	1.125
	Total (Year)	1.022	0.894	1.174	1.058	0.891	1.276	1.095	0.873	1.426	1.020	0.881	1.169	1.030	0.831	1.203	1.072	0.898	1.287
	Total (Apr-Jul)	0.958	0.858	1.061	0.937	0.801	1.068	0.850	0.700	1.077	0.968	0.841	1.075	0.950	0.822	1.063	0.897	0.783	1.032

Source: Hamlet, et al., 2010.

Notes:

- Apr-Jul cells are shaded grey
- ‘blue’ values = more water forecasted; ‘red’ values = less water forecasted
- considerations during this time frame:
  - the range of flows/volumes predicted varies considerably
- Total volumes for the year are increasing under both scenarios for all periods; and decreasing during Apr-Jul

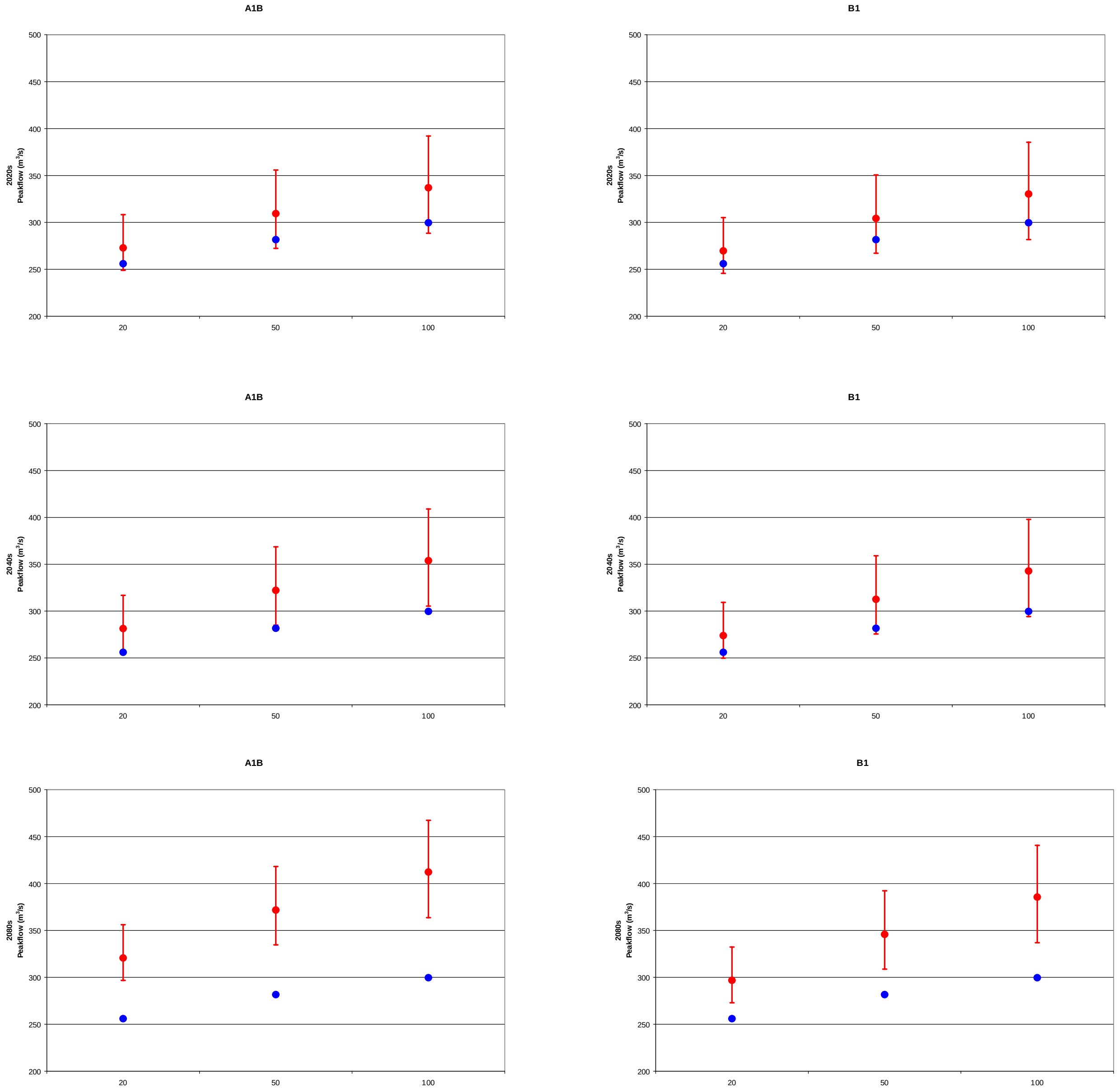

Figure D2. Okanagan River at Oliver: simulated daily flood statistics at the 20, 50 and 100-year recurrence interval estimated using fitted Generalized Extreme Value (GEV) probability distributions for the 2020s, 2040s and 2080s, under the A1B and B1 emission scenarios. Blue circles show simulated historical value, red circles show the range of values for hybrid delta scenarios (horizontal line shows the ensemble average) (Units: m^3/s) (Source: Hamlet et al., 2010).

Table D2. Okanagan River at Oliver: simulated daily flood statistics at the 20, 50 and 100-year recurrence interval

		A1B									**B1**								
Recurrence Interval (years)	**Historical Simulated Peak Flow (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	m^3/s	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
20	256	1.066	0.972	1.205	1.099	0.914	1.273	1.253	1.091	1.558	1.054	0.926	1.201	1.070	0.953	1.215	1.160	0.992	1.363
50	282	1.099	0.967	1.263	1.144	0.917	1.314	1.320	1.128	1.613	1.080	0.909	1.311	1.110	0.975	1.269	1.228	1.026	1.433
100	300	1.125	0.963	1.309	1.181	0.920	1.366	1.376	1.148	1.655	1.102	0.896	1.409	1.144	0.990	1.364	1.286	1.038	1.490

Notes:

- the average peak daily flows increase in all periods under both scenarios
- the range of peak flows predicted also varies considerably; and by the 2080s the range begins to exceed baseline flows simulated for the 1970-99 period (except for the 20 year recurrence interval during the 2080s under the B1 scenario)

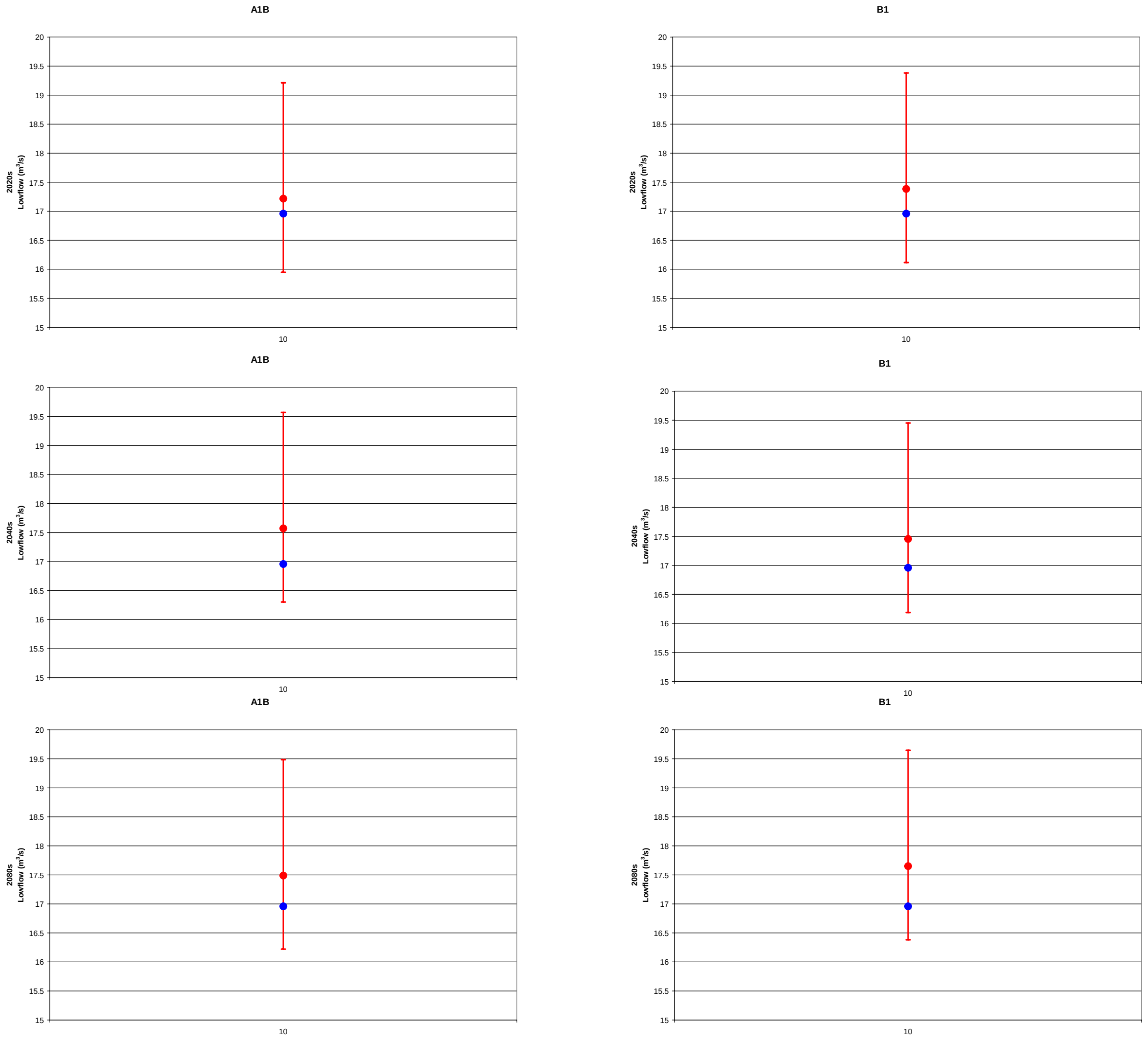

Figure D3. Okanagan River at Oliver: simulated 7Q10 low flow statistics estimated using fitted Generalized Extreme Value (GEV) probability distributions. Blue circles show simulated historical value, red circles show the range of values for hybrid delta scenarios (horizontal line shows the ensemble average) (units: cms) (Source: Hamlet et al., 2010).

Table D3. Okanagan River at Oliver: simulated 7Q10 low flow statistics

		A1B									B1								
Recurrence Interval (years)	**Historical Simulated Low Flow (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	m^3/s	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
10	17	1.015	0.940	1.133	1.036	0.953	1.135	1.031	0.911	1.150	1.025	0.930	1.120	1.029	0.830	1.134	1.041	0.932	1.161

Notes:

- the winter low flows increase in all periods under both scenarios?
- the range of low flows predicted also varies considerably

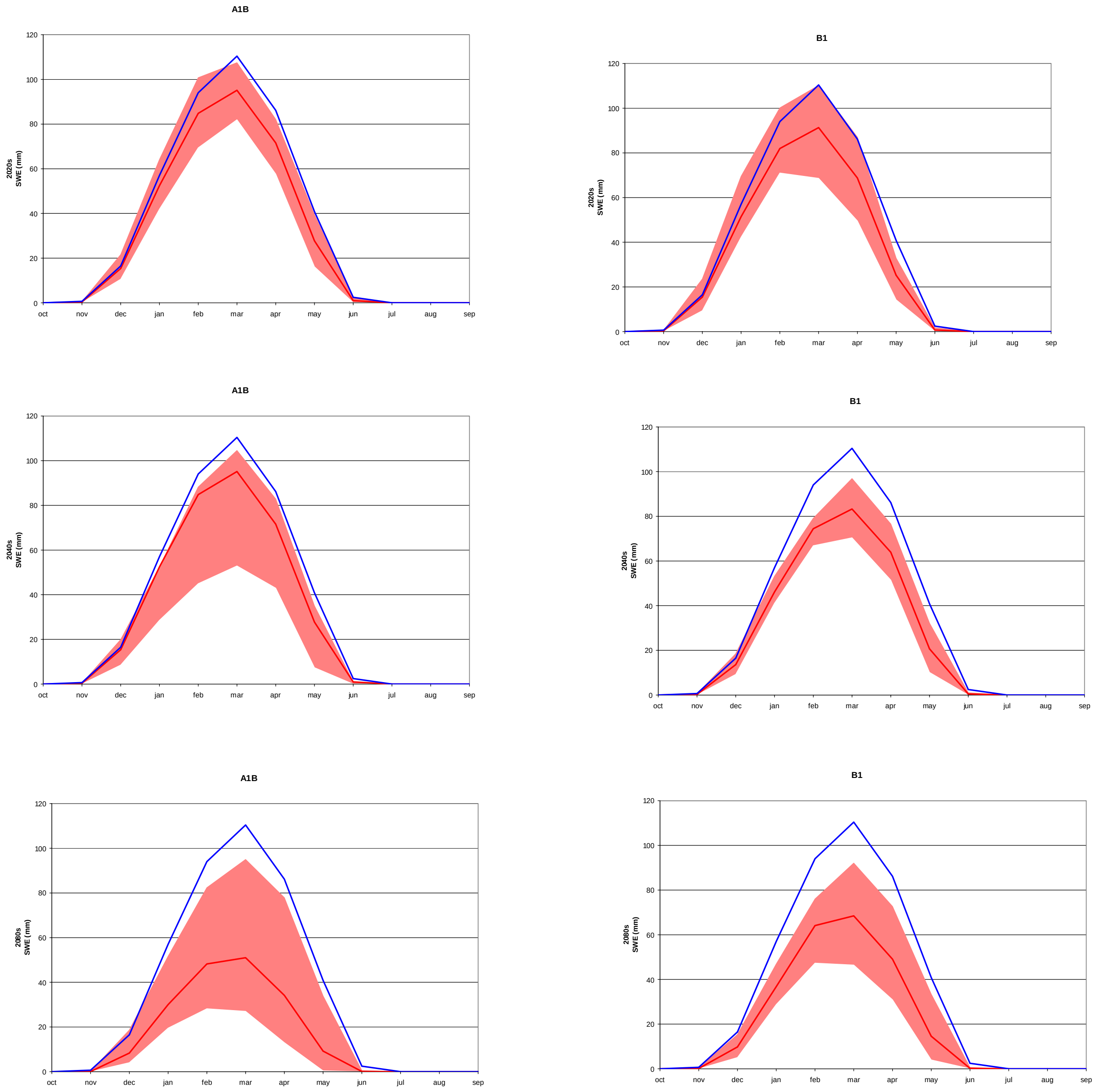

Figure D4. Okanagan River at Oliver: first day of month total snow water equivalent averaged over the entire basin expressed as an average depth (units: mm). Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections. (Source: Hamlet et al., 2010).

Table D4: Okanagan River at Oliver: first day of month total snow water equivalent

		A1B									B1								
Month	**Historical SWE (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	mm	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	0.6	0.589	0.246	0.846	0.274	0.077	0.523	0.094	0.000	0.308	0.538	0.246	0.892	0.404	0.046	0.861	0.231	0.000	0.661
Dec	16.5	0.933	0.642	1.306	0.761	0.517	1.207	0.505	0.246	1.129	0.937	0.568	1.429	0.825	0.562	1.119	0.594	0.307	0.928
Jan	57.0	0.920	0.735	1.124	0.753	0.501	0.919	0.527	0.342	0.905	0.903	0.742	1.219	0.809	0.720	0.932	0.645	0.505	0.822
Feb	94.0	0.902	0.738	1.072	0.755	0.478	0.938	0.513	0.300	0.876	0.872	0.755	1.065	0.792	0.711	0.841	0.682	0.503	0.808
Mar	110.4	0.862	0.742	0.973	0.709	0.479	0.947	0.462	0.245	0.860	0.827	0.622	0.998	0.754	0.638	0.877	0.620	0.421	0.834
Apr	86.1	0.831	0.669	0.953	0.683	0.498	0.962	0.397	0.151	0.904	0.798	0.575	1.010	0.742	0.597	0.889	0.570	0.359	0.844
May	40.9	0.679	0.395	0.964	0.488	0.180	0.856	0.225	0.010	0.828	0.618	0.349	0.805	0.506	0.248	0.787	0.356	0.097	0.816
Jun	2.4	0.398	0.053	0.841	0.171	0.004	0.400	0.036	0.000	0.192	0.286	0.065	0.694	0.188	0.004	0.408	0.075	0.008	0.237
Jul	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Aug	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sep	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes:

- Apr-Jul cells are shaded grey
- during this time frame, the average SWE is predicted to decrease in all periods under both scenarios; and the range is expected to be less than the simulated historical SWE values for all periods under both scenarios (except during the 2020s under the B1 scenario)

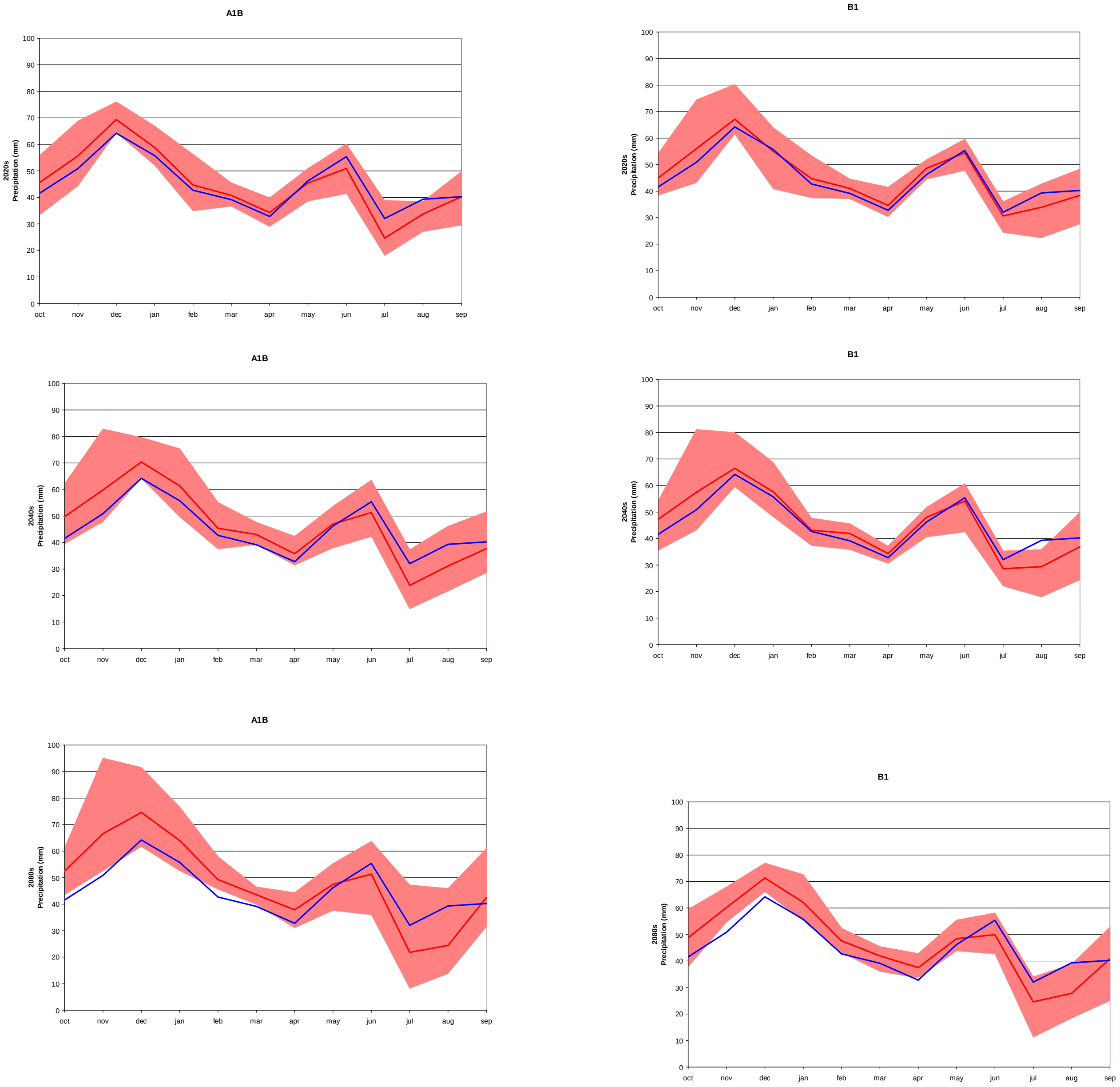

Figure D5. Okanagan Rive at Oliver: monthly average total precipitation over the entire basin expressed as an average depth (units: mm). Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections (Source: Hamlet et al., 2010).

Table D5. Okanagan Rive at Oliver: monthly average total precipitation over the entire basin

		A1B									B1								
Month	**Historical Precipitation (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	mm	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	41.6	1.097	0.800	1.343	1.197	0.949	1.495	1.262	1.046	1.472	1.081	0.922	1.301	1.136	0.853	1.301	1.174	0.907	1.432
Nov	50.9	1.094	0.870	1.352	1.177	0.940	1.628	1.309	1.032	1.869	1.101	0.847	1.463	1.130	0.847	1.595	1.184	1.073	1.335
Dec	64.2	1.080	1.002	1.184	1.096	0.999	1.240	1.162	0.960	1.426	1.046	0.957	1.249	1.036	0.925	1.245	1.110	1.028	1.198
Jan	55.8	1.055	0.933	1.200	1.100	0.889	1.351	1.148	0.941	1.374	0.988	0.731	1.147	1.034	0.863	1.233	1.114	0.989	1.302
Feb	42.7	1.047	0.816	1.318	1.064	0.878	1.291	1.154	1.067	1.356	1.049	0.877	1.250	1.010	0.874	1.117	1.116	1.010	1.227
Mar	39.2	1.041	0.934	1.162	1.099	1.000	1.217	1.112	1.016	1.188	1.048	0.946	1.138	1.071	0.914	1.164	1.071	0.919	1.161
Apr	32.8	1.046	0.882	1.215	1.091	0.959	1.291	1.155	0.945	1.352	1.055	0.922	1.265	1.047	0.932	1.133	1.145	1.025	1.306
May	46.2	0.983	0.832	1.101	1.017	0.819	1.161	1.027	0.811	1.197	1.051	0.961	1.122	1.038	0.875	1.119	1.047	0.946	1.199
Jun	55.4	0.919	0.746	1.085	0.926	0.762	1.146	0.927	0.649	1.150	0.983	0.861	1.076	0.978	0.767	1.096	0.901	0.769	1.049
Jul	32.0	0.770	0.561	1.211	0.746	0.466	1.165	0.681	0.255	1.474	0.957	0.760	1.126	0.894	0.687	1.103	0.769	0.349	1.063
Aug	39.3	0.858	0.687	0.978	0.793	0.549	1.173	0.622	0.349	1.168	0.863	0.568	1.086	0.748	0.454	0.912	0.708	0.466	0.986
Sep	40.2	1.000	0.732	1.236	0.937	0.708	1.281	1.055	0.779	1.514	0.953	0.684	1.199	0.916	0.604	1.238	1.015	0.620	1.312

Notes:

- Apr-Jul cells are shaded grey
- during this time frame, the average precipitation is predicted to increase during April of 2020 (A1B), and during April/May for 2020 (B1) and under both scenarios for the 2040s and 2080s
- the average precipitation is predicted to decrease in May of 2020 (A1B), and from June to July for all time periods under both scenarios
- the range varies from less to greater than the simulated historical

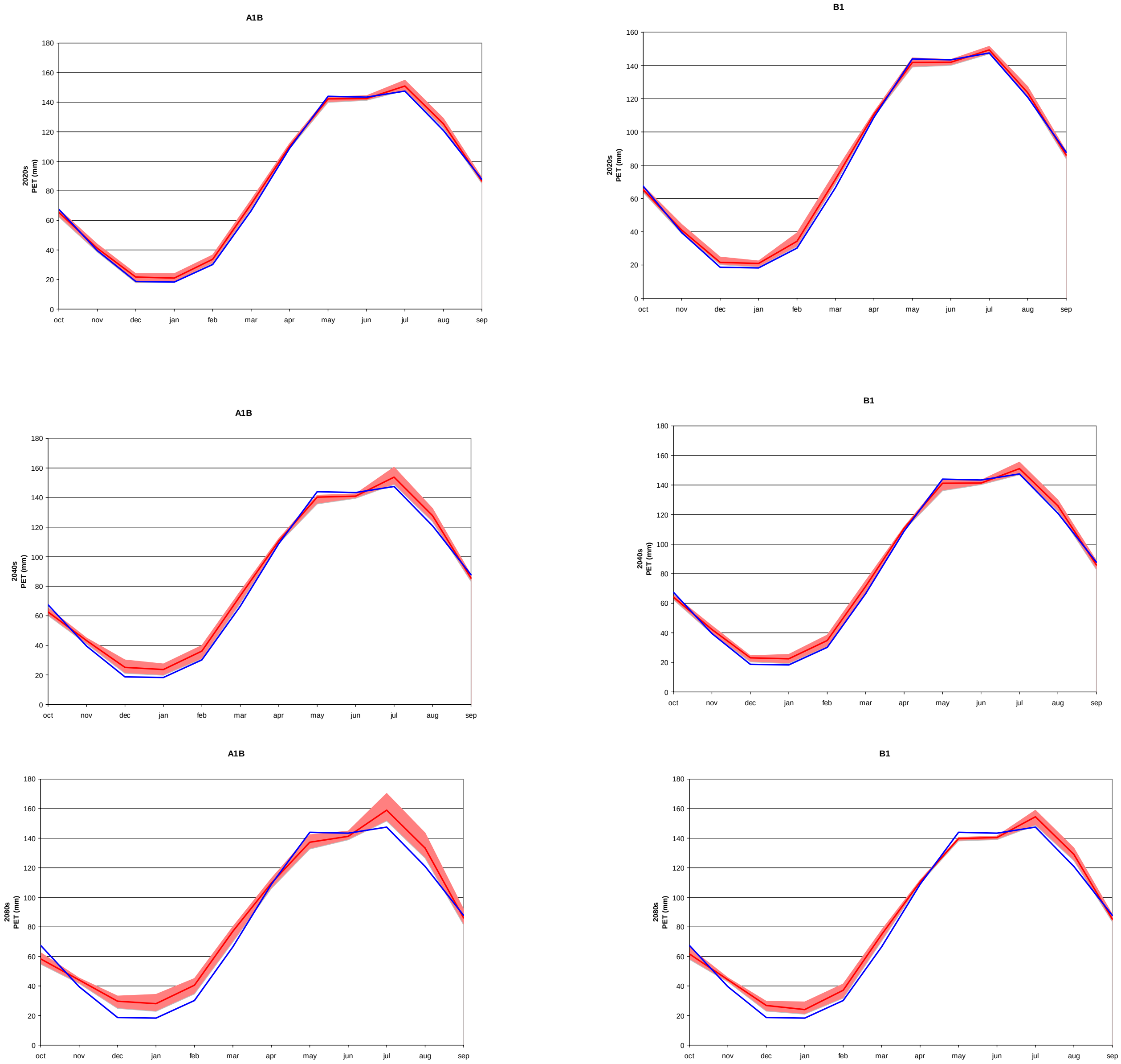

Figure D6. Okanagan Rive at Oliver: simulated monthly total Potential Evapotranspiration (PET) for a short reference crop modeled as well-watered grass (units: mm). Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections. Some caution should be exercised in interpreting winter values since the effects of snow on surface energy are not included in the calculations (Source: Hamlet et al., 2010).

Table D6. Okanagan River at Oliver: simulated monthly total Potential Evapotranspiration (PET)

		A1B									**B1**								
Month	**Historical PET (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	mm	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	67.4	0.970	0.924	1.002	0.929	0.893	0.970	0.865	0.811	0.927	0.967	0.943	1.002	0.952	0.925	0.975	0.915	0.859	0.980
Nov	39.5	1.039	0.976	1.111	1.094	1.035	1.139	1.115	1.054	1.149	1.037	0.985	1.124	1.068	0.996	1.133	1.119	1.080	1.154
Dec	18.7	1.163	0.955	1.285	1.345	1.129	1.615	1.592	1.329	1.781	1.157	1.081	1.329	1.236	1.086	1.314	1.438	1.231	1.589
Jan	18.2	1.151	1.007	1.316	1.296	1.083	1.506	1.535	1.252	1.883	1.145	1.028	1.231	1.230	1.052	1.395	1.318	1.147	1.604
Feb	30.2	1.117	1.027	1.216	1.199	1.025	1.325	1.344	1.146	1.495	1.136	1.032	1.305	1.155	1.016	1.276	1.231	1.052	1.373
Mar	66.5	1.068	1.019	1.112	1.107	1.029	1.153	1.158	1.049	1.205	1.077	1.036	1.146	1.075	0.996	1.132	1.125	1.059	1.171
Apr	108.7	1.013	0.996	1.031	1.017	1.001	1.032	1.008	0.974	1.037	1.017	1.003	1.030	1.018	1.006	1.028	1.015	1.005	1.027
May	144.0	0.988	0.971	0.998	0.974	0.942	0.984	0.954	0.921	0.989	0.985	0.966	1.004	0.981	0.946	0.995	0.971	0.960	0.977
Jun	143.4	0.993	0.985	1.007	0.983	0.973	0.994	0.985	0.969	1.010	0.990	0.977	1.002	0.985	0.978	0.999	0.980	0.969	0.987
Jul	147.5	1.023	1.002	1.050	1.042	1.009	1.088	1.077	1.028	1.154	1.013	0.996	1.027	1.024	0.996	1.054	1.047	1.008	1.077
Aug	120.9	1.037	1.013	1.068	1.057	1.023	1.097	1.102	1.046	1.187	1.022	1.004	1.053	1.041	1.011	1.074	1.067	1.032	1.103
Sep	87.8	0.987	0.967	1.014	0.974	0.948	1.000	0.981	0.926	1.047	0.981	0.955	1.008	0.979	0.943	1.012	0.972	0.950	1.008

Notes:

- Apr-Jul cells are shaded grey
- the range varies very closely to the simulated historical values, and for the month of July the range exceeds historical simulated values for all periods under both scenarios

E

Appendix E - Similkameen River near Nighthawk- climatic and streamflow projections (from Hamlet et al., 2010)

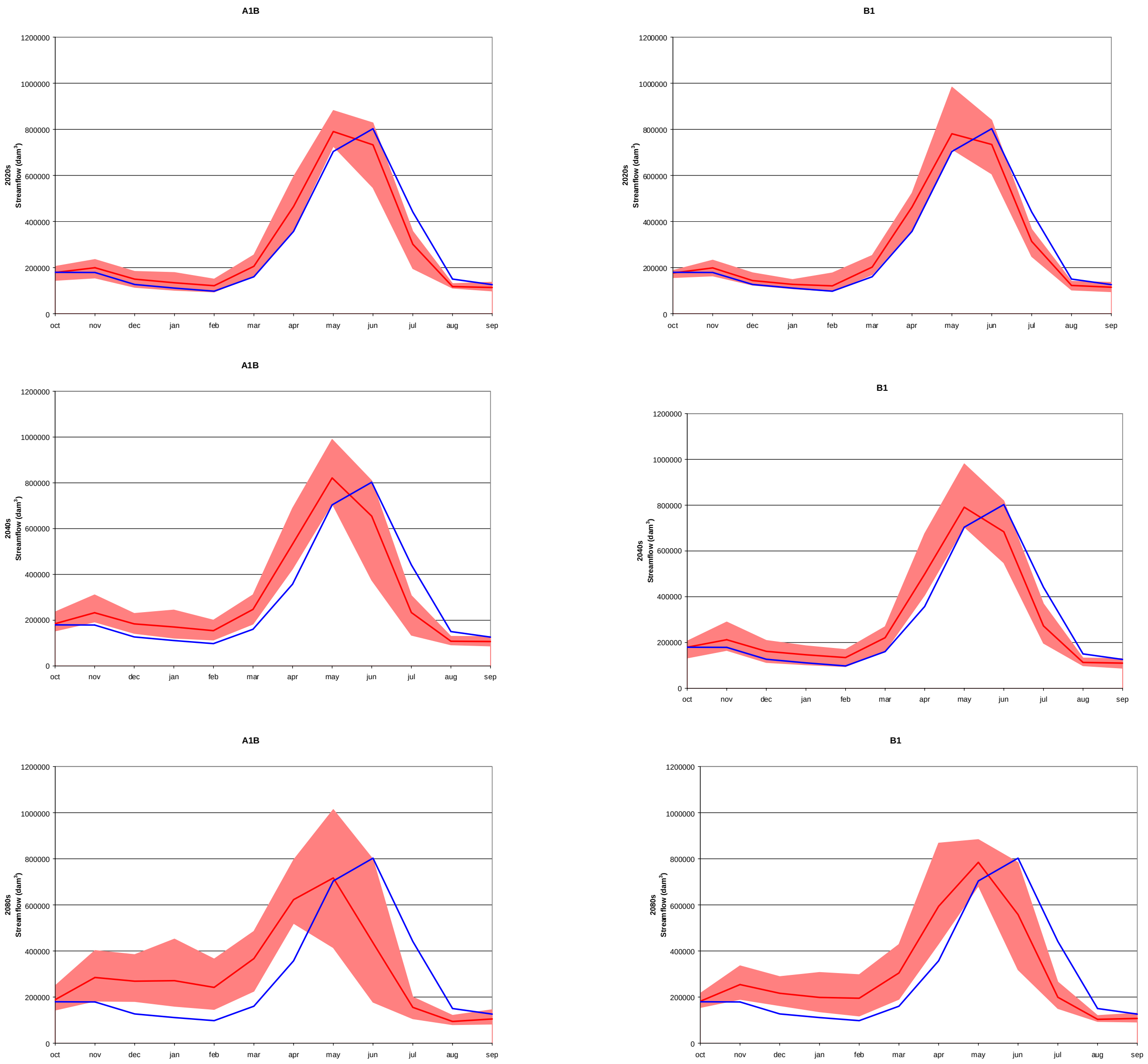

Figure E1. Similkameen River near Nighthawk: average of monthly routed streamflow volume (units: dam^3) for the 2020s, 2040s and 2080s, under the A1B and B1 emission scenarios. Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections (Source: Hamlet et al., 2010).

Table E1. Similkameen River near Nighthawk: average of monthly routed streamflow volume

		A1B									**B1**								
Month	**Historical Simulated Volumes (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	Dam^3	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	179593	0.996	0.805	1.143	1.029	0.850	1.315	1.051	0.799	1.392	0.983	0.872	1.045	0.999	0.738	1.151	1.013	0.861	1.205
Nov	178995	1.115	0.866	1.316	1.299	1.075	1.737	1.593	1.017	2.247	1.111	0.915	1.300	1.185	0.924	1.619	1.420	1.062	1.876
Dec	126961	1.180	0.899	1.448	1.448	1.120	1.809	2.118	1.423	3.026	1.133	0.975	1.399	1.274	0.888	1.649	1.705	1.281	2.275
Jan	111230	1.207	0.911	1.609	1.531	1.094	2.200	2.436	1.437	4.062	1.144	0.976	1.336	1.317	0.924	1.669	1.785	1.224	2.758
Feb	97774	1.243	0.964	1.538	1.576	1.157	2.050	2.472	1.493	3.739	1.236	0.993	1.814	1.371	0.967	1.733	1.994	1.205	3.040
Mar	160484	1.281	1.021	1.591	1.542	1.139	1.939	2.287	1.403	3.025	1.261	1.055	1.577	1.379	1.015	1.680	1.898	1.186	2.669
Apr	357207	1.303	1.019	1.665	1.490	1.187	1.929	1.743	1.455	2.225	1.296	1.018	1.466	1.396	1.139	1.892	1.662	1.207	2.431
May	703940	1.123	1.032	1.253	1.167	1.007	1.406	1.018	0.589	1.440	1.109	1.014	1.397	1.124	1.002	1.393	1.115	0.969	1.255
Jun	802865	0.913	0.681	1.031	0.815	0.467	1.008	0.543	0.221	0.994	0.914	0.755	1.046	0.852	0.683	1.020	0.695	0.397	0.976
Jul	441685	0.682	0.444	0.810	0.529	0.304	0.696	0.352	0.240	0.453	0.711	0.562	0.830	0.618	0.445	0.837	0.451	0.340	0.602
Aug	150261	0.782	0.738	0.871	0.719	0.613	0.863	0.627	0.533	0.805	0.818	0.684	0.937	0.753	0.655	0.882	0.689	0.626	0.799
Sep	126295	0.902	0.780	1.085	0.847	0.692	1.020	0.831	0.654	1.150	0.910	0.754	1.078	0.871	0.694	1.030	0.850	0.726	1.033
	Total (Year)	1.022	0.819	1.204	1.056	0.793	1.335	1.092	0.703	1.575	1.018	0.858	1.212	1.026	0.819	1.291	1.076	0.791	1.433
	Total (Apr-Jul)	0.993	0.795	1.155	0.972	0.712	1.213	0.837	0.528	1.218	0.994	0.838	1.177	0.974	0.805	1.234	0.926	0.686	1.215

Source: Hamlet et al., 2010.

Notes:

- Apr-July cells are shaded grey
- ‘blue’ values = more water forecasted; ‘red’ values = less water forecasted
- considerations during this time frame:
  - the range of flows/volumes predicted is considerable
- Total average volumes for the year are increasing under both scenarios for all periods; and decreasing during Apr-July

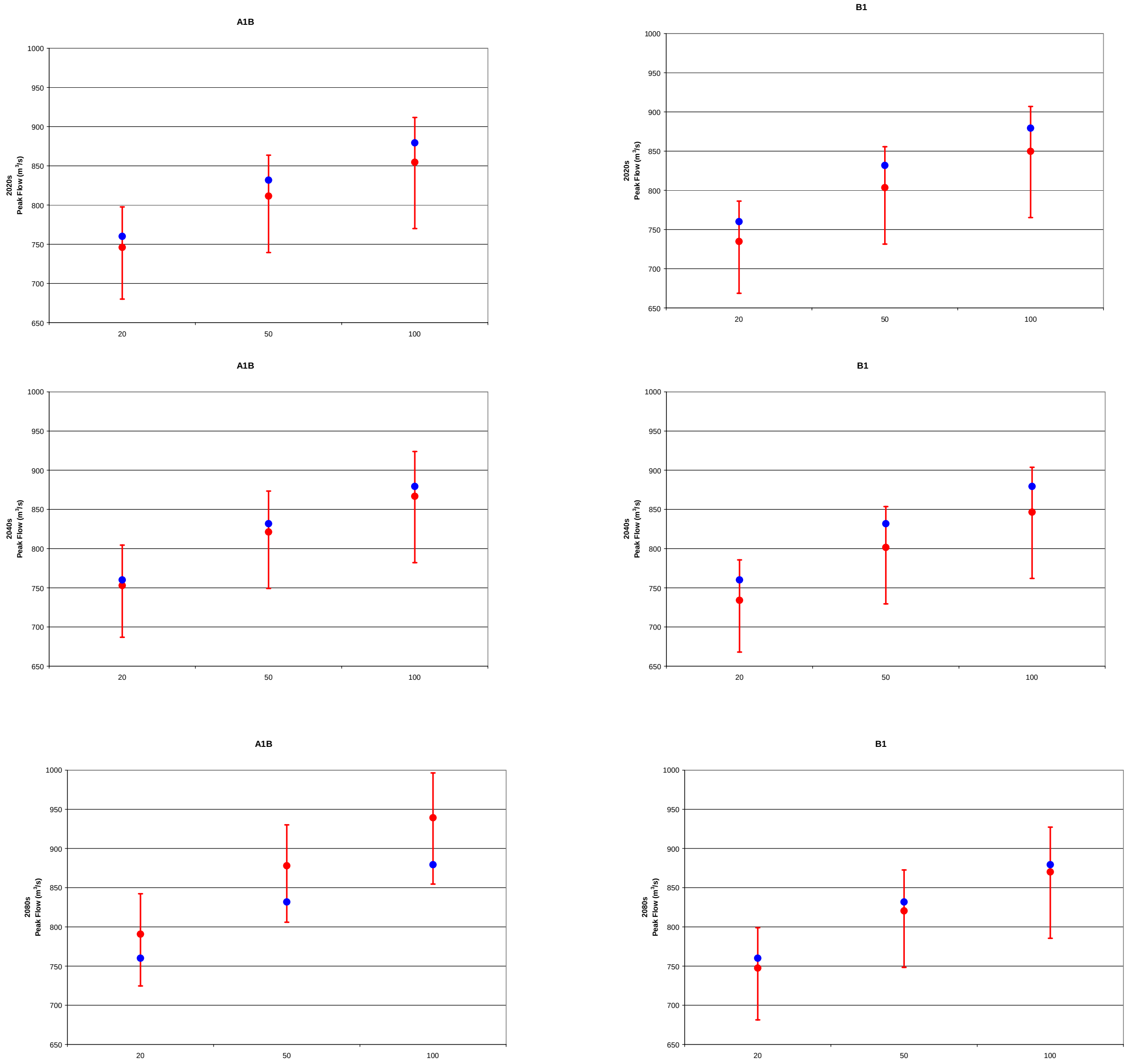

Figure E2. Similkameen River near Nighthawk: simulated daily flood statistics at the 20, 50 and 100-year recurrence interval estimated using fitted Generalized Extreme Value (GEV) probability distributions for the 2020s, 2040s and 2080s, under the A1B and B1 emission scenarios. Blue circles show simulated historical value, red circles show the range of values for hybrid delta scenarios (horizontal line shows the ensemble average) (units: m^3/s) (Source: Hamlet et al., 2010).

Table E2. Similkameen River near Nighthawk: simulated daily flood statistics

		A1B									B1								
Recurrence Interval (years)	**Historical Simulated Peak Flow (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	m^3/s	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
20	760	0.981	0.895	1.049	0.991	0.890	1.163	1.040	0.878	1.328	0.967	0.868	1.081	0.966	0.834	1.089	0.983	0.884	1.105
50	832	0.976	0.889	1.038	0.987	0.898	1.159	1.055	0.878	1.352	0.966	0.860	1.079	0.964	0.829	1.079	0.986	0.878	1.101
100	879	0.972	0.876	1.037	0.986	0.904	1.157	1.068	0.877	1.370	0.966	0.853	1.101	0.963	0.827	1.073	0.989	0.873	1.099

Notes:

- the average peak flows are not expected to change significantly
- the range of peak flow changes is considerable

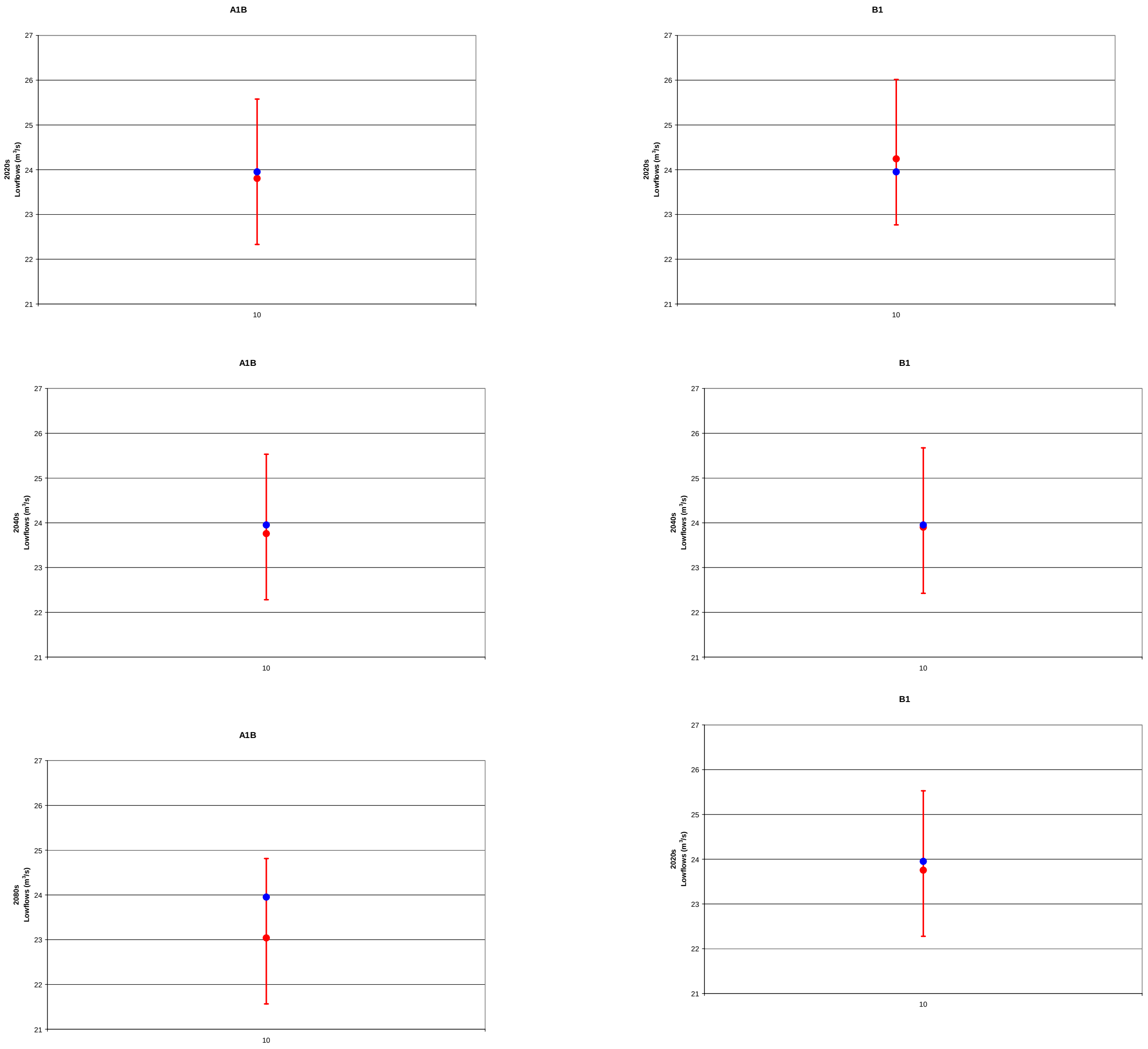

Figure E3. Similkameen River near Nighthawk: simulated 7Q10 low flow statistics estimated using fitted Generalized Extreme Value (GEV) probability distributions. Blue circles show simulated historical value, red circles show the range of values for hybrid delta scenarios (horizontal line shows the ensemble average) (units: m^3/s) (Source: Hamlet et al., 2010).

Table E3. Similkameen River near Nighthawk: simulated 7Q10 low flow statistics

		A1B									B1								
Recurrence Interval (years)	**Historical Simulated Low Flow (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	M^3/s	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
10	24	0.994	0.932	1.068	0.992	0.916	1.053	0.962	0.878	1.033	1.012	0.949	1.096	0.998	0.887	1.090	0.992	0.919	1.094

Notes:

- although average monthly flows in winter are expected to increase, the 7Q10 flows are not expected to change much
- the range of low flows is considerable

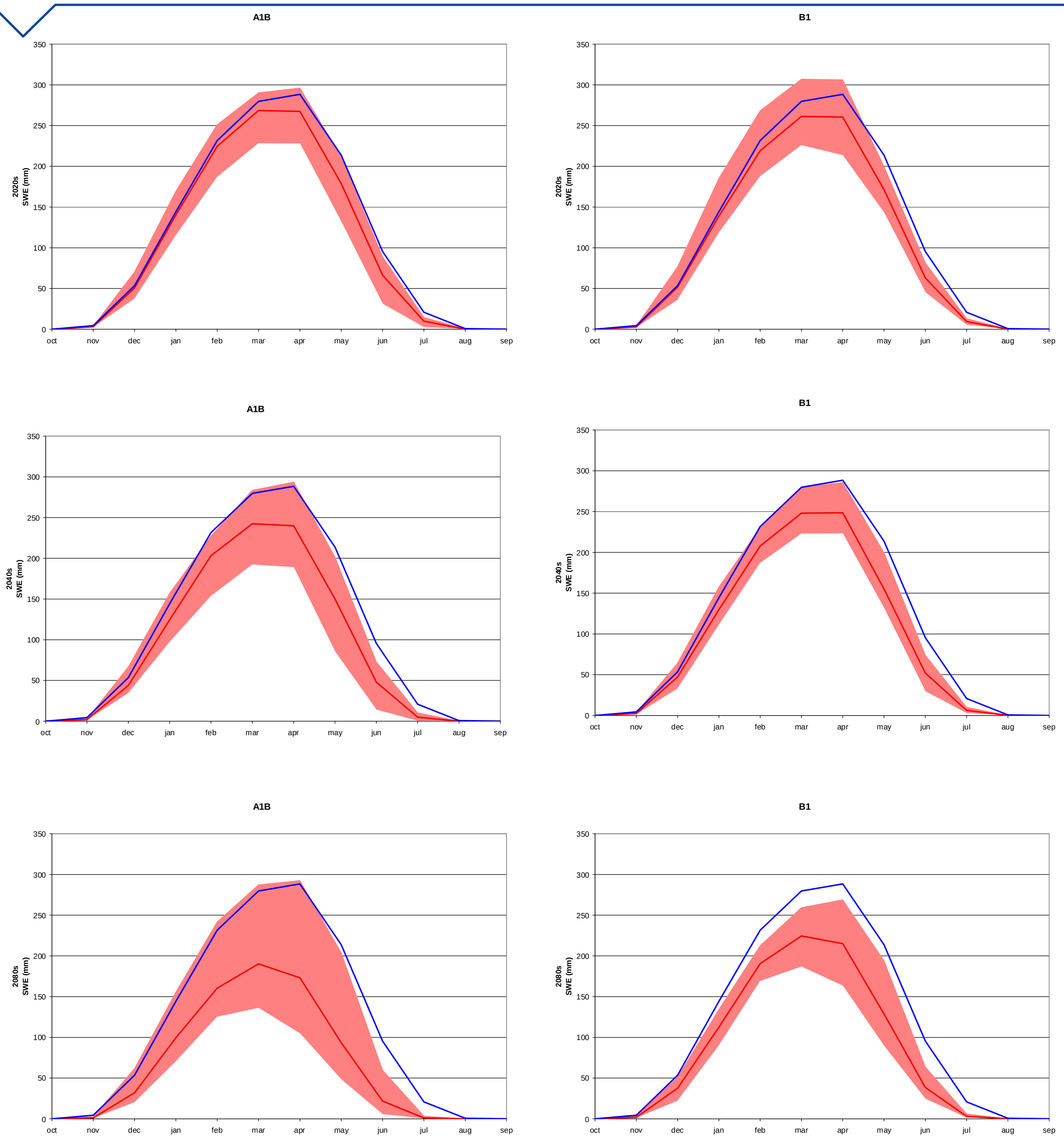

Figure E4. Similkameen River near Nighthawk: first day of month total snow water equivalent averaged over the entire basin expressed as an average depth (units: mm). Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections. (Source: Hamlet et al., 2010).

Table E-4. Similkameen River near Nighthawk: first day of month total snow water equivalent averaged over the entire basin

		A1B									B1								
Month	**Historical SWE (1970-99)**	**2020s**			**2040s**			**2080s**			**2020s**			**2040s**			**2080s**		
	mm	Ratio			Ratio			Ratio			Ratio			Ratio			Ratio		
		Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Oct	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nov	4.4	0.685	0.499	0.860	0.439	0.289	0.621	0.249	0.111	0.530	0.642	0.440	0.869	0.535	0.233	0.822	0.395	0.174	0.801
Dec	53.5	0.946	0.693	1.312	0.821	0.636	1.245	0.597	0.372	1.155	0.966	0.667	1.433	0.881	0.610	1.201	0.700	0.407	0.954
Jan	144.3	0.972	0.796	1.175	0.863	0.671	1.089	0.690	0.486	1.078	0.962	0.819	1.283	0.900	0.767	1.091	0.780	0.622	0.930
Feb	231.6	0.970	0.805	1.084	0.877	0.662	0.982	0.693	0.539	1.044	0.946	0.809	1.158	0.897	0.806	0.995	0.823	0.729	0.918
Mar	279.8	0.960	0.815	1.038	0.866	0.686	1.014	0.680	0.486	1.027	0.934	0.806	1.097	0.887	0.796	0.999	0.803	0.667	0.927
Apr	288.4	0.928	0.790	1.027	0.832	0.654	1.018	0.600	0.362	1.014	0.903	0.740	1.062	0.862	0.773	0.991	0.746	0.566	0.933
May	213.7	0.836	0.616	0.990	0.702	0.398	0.943	0.437	0.225	0.954	0.802	0.668	0.935	0.725	0.614	0.933	0.603	0.418	0.908
Jun	95.5	0.695	0.324	0.931	0.501	0.143	0.762	0.229	0.056	0.625	0.661	0.471	0.853	0.545	0.307	0.774	0.404	0.254	0.666
Jul	20.8	0.477	0.107	0.704	0.238	0.013	0.492	0.048	0.004	0.161	0.449	0.242	0.622	0.301	0.126	0.484	0.145	0.053	0.287
Aug	0.7	0.219	0.014	0.507	0.048	0.000	0.246	0.000	0.000	0.000	0.205	0.055	0.370	0.079	0.000	0.219	0.023	0.000	0.109
Sep	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes:

- Apr-Jul cells are shaded grey
- during this time frame, the average SWE are predicted to decrease in all periods under both scenarios; and the range is expected to be less than the simulated historical SWE values by the 2080s under the B1 scenario, and for all periods and both scenarios from the months of May to July