Water Management & Climate Change in the Okanagan Basin

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Sponsoring Agency

This project was supported by a grant from the Climate Change Action Fund (Project A 206), Adaptation Liaison Office, Natural Resources Canada, 601 Booth Street, Room 388, Ottawa ON, K1A 0E6.

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EXECUTIVE SUMMARY

Water resources, their management and use, are known to be sensitive to variations in climate, and will be influenced by projected climatic change. This study concerns potential implications of climatic change for the Okanagan region of British Columbia. The study has two main goals:

- To identify climate change impacts and possible adaptation strategies for the Okanagan region, and
- To test an approach for engaging resource managers and regional stakeholders as collaborators in research and dialogue on climate change impacts and adaptation.

The use of climate scenarios, hydrologic modeling, and dialogue enables the inclusion of issues that may be difficult to model. Dialogue is used for those indicators and processes that include a human component, such as fisheries management or regional institutional arrangements.

Recent trends indicate that the regional climate is becoming warmer and wetter. Minimum temperatures have increased at a greater rate than maximum temperatures. Frost-free days have increased by 3.1 days/decade during the 20th century.

Climatic change scenarios, obtained from simulations from three climate models, indicate a temperature increase of 1.0-2.5°C from the 1961-1990 base period to the 2020s, and 3-5°C by the 2080s. Higher precipitation is projected for winter, but the climate model simulations do not agree on the direction of change for summer.

The recent warming has led to changes in streamflow. Observed changes in unregulated streams include earlier onset of the annual spring peak, lower fall flows and higher early winter flows. Regulated streams are showing decreases in discharge.

The hydrologic scenarios were calculated using a locally developed variant of a Swedish model known as HBV. HBV is sensitive to changes in both climate and landscape. In this study, however, only scenarios of climatic change were assessed. Results for the climate scenarios for six unregulated creeks within the Okanagan Basin indicate earlier onset of spring peak flows, by as much as 4-6 weeks. The peak is generally lower than current peak flows. All areas show loss of snowpack, with the highest elevation creeks showing the smallest loss. Winter flow increases, while summer flow decreases. There is no consensus on scenario changes to total annual flow.

The dialogue process consisted of focus group exercises designed to elicit views on impacts, adaptation, and implications of adaptation choices. Participants were shown the results of the climatic and hydrologic simulations during workshops held in January and March 2001. They identified impacts for forestry, agriculture, fisheries, infrastructure, health and ecosystems. These included changes in operating seasons, risks (e.g. fire, pests) and wildlife habitats.

Subsequent consideration of adaptation options resulted in a preference for structural measures, particularly intervention to prevent impacts (e.g. snow making, dams at high elevations, controls on land use and irrigation). Other popular alternatives were developing alternative uses for resources (e.g. alternative energy, grey water) and changing land use plans (e.g. densification of urban land).

Participants were then asked to consider implications of adaptation choices. Considerable attention was given to water licensing (e.g. sensitivity to increased license rates, need for more bureaucracy, loss of control to downstream users), flow regulation through dams (e.g. change from natural hydrograph, impacts on erosion and downstream fisheries), and potential restrictions on development (e.g. creates conflict over future visions). Many comments indicated a need for additional research and outreach activities (e.g. develop regional archive of water supplies and use, explore options for xeriscaping) or changes in consultative processes associated with a particular option.

This was a short-term exercise in the use of scientific models to form the foundation for a regional dialogue on climate change impacts and adaptation. For this effort to be effective over the long term, there needs to be a sustained investment in this process.

1.0 PURPOSE OF THE STUDY

Water resources, their management and use, are known to be sensitive to variations in climate, and will be influenced by projected climatic change. Hydrologic studies of various watersheds throughout the world (Schriner and Street, 1988; Arnell *et al*., 2001) suggest changes in total annual flows, seasonal aspects of water supply and demand, implications for ecosystems, and challenges for managers in meeting multiple objectives (energy, irrigation, navigation, flood control, etc.).

The Columbia Basin has been the subject of some detailed case studies (Mote *et al*., 1999; Hamlet and Lettenmaier, 1999; Miles *et al*., 2000), and there has been an initial attempt to bring in transboundary perspectives (Cohen *et al*., 2000). This work suggests that a warmer climate would lead to changes in hydrology, including reduced snow pack and earlier snowmelt peaks, with subsequent implications for regional water supplies and fisheries. The earlier peak would lead to increased flow during winter months and an earlier flood season. Less water would be flowing during the summer months when irrigation demand is highest. Low summer flows would also affect hydroelectricity production and salmon habitat.

These findings have contributed to a growing dialogue on water management and climate change on the American side of the Columbia Basin. This needs to be matched by a similar dialogue in Canada, and ultimately, a bi-national one. Although basin-wide hydrologic assessments have been done, detailed hydrologic studies on the Canadian side were not part of this. The Okanagan region is one such area needing attention. The Okanagan is already experiencing rapid population growth and land use changes, with associated stresses on its water resource systems.

Another important aspect is the need to broaden the dialogue on adaptation (Smith *et al*., 2001). Changes in climate parameters may change opportunities and risks, but climate represents only one of many issues to be considered in resource management and use. In principle, there are many technical and institutional options available, but the implications of selecting any particular options have not been explored in a long-term planning and climate change scenario context. Certain options, such as new water pricing regimes or water banks (Bruce *et al*., 2000; Miller, 2000) are being considered and tested in areas facing water shortages now (e.g. California). However, it is not clear how these or other options would perform under a particular scenario of regional development (e.g. conversion of pasture to high intensity horticulture, urban growth, tourism growth, demands from the Columbia system) or a different climatic and hydrologic regime (e.g. longer warmer growing season, higher summer demand for electricity, changing winter/spring flood regime, changing fire and disease risks).

Besides the impacts and adaptation challenges being faced by the Okanagan and Columbia watersheds, there is also an important methodological concern – bringing regional aspects of climate change into a global-scale research and policy environment. Analyses within natural and social sciences have long been faced with the tradeoff of choosing between the difficulties of accounting for complex regional detail, and the ease of simpler aggregation accompanied by unrealistic assumptions about natural processes and human behaviour. National and global model-based impacts studies are, by necessity, highly aggregated. These incorporate assumptions about adaptation choices, and their acceptance into practice. Damage costs and adaptation costs and benefits have been estimated for the U.S. using these kinds of assumptions (Mendelsohn and Neumann, 1999). Results can be quite sensitive to what is assumed about

Figure 2-1. The Okanagan Valley (www.panorama-map.com/z-pointsite/zoka.html)

levels of shoreline protection, choice of tree species for planting, etc., and how widespread these practices would become during the scenario time period.

If we're going to estimate the costs of climate change impacts, and the value of any adaptation investments, there needs to be more attention given to the development of adaptation scenarios that could reflect regional opportunities and constraints associated with any options that might be considered. Just because a growing season may become longer doesn't mean that all decision makers will be able to adjust to this in the same way or at the same pace. What would stakeholders really do in the face of such changes? How would governments, communities and the private sector incorporate uncertain scenarios of climatic change into their planning? This suggests that dialogue with stakeholders needs to be an explicit part of the process of framing research questions and carrying out impact and adaptation assessments.

This study of Okanagan water resources and climate change implications has two main goals:

a) to identify climate change impacts and possible adaptation strategies for the Okanagan region, and
b) to test an approach for engaging resource managers and regional stakeholders as collaborators in research and dialogue on climate change impacts and adaptation.

2.0 BACKGROUND

The following section describes the Okanagan regions current water resource situation, including a case study of one watershed under stress. The scenarios of climate and hydrology describe the area outside of the context of development pressures and expanding demand on natural resources.

2.1 Regional Context

The Okanagan Valley is located in the southern interior of British Columbia, situated around Okanagan Lake (Figure 2-1). The valley is approximately 160 km in length and encompasses approximately 8200 km^2 of land surrounding Okanagan Lake and Okanagan River (Okanagan Basin Water Board 1974, in OBWB 2000).

The Okanagan has a dry continental climate as the Valley sits in the rain-shadow of the Coast and Cascade Mountain Ranges. The semi-arid climate receives approximately 30 cm of precipitation per year; of this 85% is lost through evapotranspiration and evaporation from local lakes. The resultant gradient of climatic conditions in the Valley is shown in Table 2-1.

The main water sources for the Okanagan are the tributary streams, which generally supply good quality water, are gravity fed and fairly inexpensive. However; there have been outbreaks of both *giardiasis* and *cryptosporidiosis* in the water of Valley communities.

The Okanagan basin encompasses 13 municipalities, 3 regional districts, 4 First Nation communities and 59 “improvement districts” all of which share responsibility in water delivery. Various water managers oversee more than 45 community watersheds, 6900 water licenses (Okanagan + Shuswap) and over 385,000 acre-feet in water allocations. This has left very little leeway for further water allocations as most streams are listed as either “fully recorded” or “water shortage”.

Table 2-1. Transect of Climatic Conditions in the Okanagan Valley, B.C. (North to South)

Station	Armstrong	Vernon	Kelowna	Penticton	Oliver
Precipitation (mm)	448	387	315	290	305
Snowfall (m)	1.35	1.09	0.89	0.56	0.60
July Temp. (ºC)	19.2	20.2	20.3	20.1	23
Jan. Temp. (ºC)	-6.4	-6.0	-3.5	-2.9	-2.0
Frost Free Days	196	226	228	235	257

Precipitation and Snowfall are mean annual values. Temperatures are mean values (Cannings *et al*., 1987)

Currently dams on Kalamalka, Okanagan, Skaha and Vaseaux Lakes control water flows, in order to provide for both consumptive needs and flood control. There is also secondary management in place to provide for fish, as imposed controls on waterways and lake levels can impede the spawning ability of fish and alter various aquatic habitat niches. Kokanee, rainbow trout and sockeye salmon are the primary species local management initiatives focus on (OBWB, 2000).

The extensive natural resources of the Okanagan Valley contribute to the region’s thriving tourism industry. Over 1 million tourists visit the region each year, bringing approximately $830 million dollars into local communities (HRDC, 2001). As well as the natural resources, recreation opportunities abound throughout the region including snow skiing at local Big White, Apex and Silver Star ski resorts and golf at more than 50 golf courses in the valley. The high season for Okanagan tourism is during the summer when 53% of the years visitors embark on local lakes, parks and other hot spots, while 20% visit during the wine season of autumn, 10% during the winter ski season and 18% arrive in the spring (HRDC, 2001).

Agriculture and farming have been part of the Okanagan since the 1850s. Although many crops including Tobacco and Hops have come and gone in the valley, by the mid 1980’s the Okanagan and Similkameen Valleys had become the most prominent location for 90% of orchards and 95% vineyards in the province (Pidwirny and Gow, 2001). Today, Okanagan agricultural land use consists of 23% cropland, 8% fruit orchards, 1% grapes, 54% improved pasture, and 8% unimproved pasture. As of 1996, there were 2278 farms, with 78,283 ha of farmed land, and 16,151 ha under crops. Between 1976 and 1996, the total area farmed has decreased from 80,428 ha to 78,283 ha, likely due to urbanization (Statistics Canada 1996).

The Okanagan has various climatic and topographic features that contribute to its agricultural success. Some of these features include mild winters with high snowfall, which together are able to protect dormant trees and vines. Springtime in the Okanagan is mild; supporting delayed budding, while the long hot summers promote local fruit development (Pidwirny & Gow, 2001). The arid Okanagan summers, however beneficial for fruit development, provide insufficient moisture and irrigation is steadily used to support the growing crops. The valley contains diverse set of microclimates, as shown in Table 2-1, each location supporting a different array of crops. In Penticton and Oliver, warmer climates allow for the growth of soft fruits like cherries, apricots, and peaches, while North of Penticton to Vernon, apples are more common and further north of Vernon, very hardy crops and dairy farming are the norm (Pidwirny and Gow, 2001).

Due to the need for irrigation and irregular terrain, many industrial methods are utilized in the Okanagan in order to achieve high agricultural yields. The local agriculture industry depends on the use of pesticides and fertilizers, which in combination have caused questions about the health risks for residents, local wildlife and various aquatic habitats. These chemicals are potential hazards for lake eutrophication, imposed anoxic conditions (Osoyoos Lake), and algae blooms - all of which could contribute to significant aquatic perturbations.

The rapid population growth in the Okanagan (Figure 2-2) has led to significant land use changes, specifically loss of farmland. As local farmland decreases, a larger problem becomes apparent as the Okanagan Valley is relied upon as one of only two significant areas in Canada that can sustain tender fruit and grape production, the other being the Niagara Peninsula. Any changes to the ability of these areas to support the national demand for fruit and other local crops could have serious economic implications.

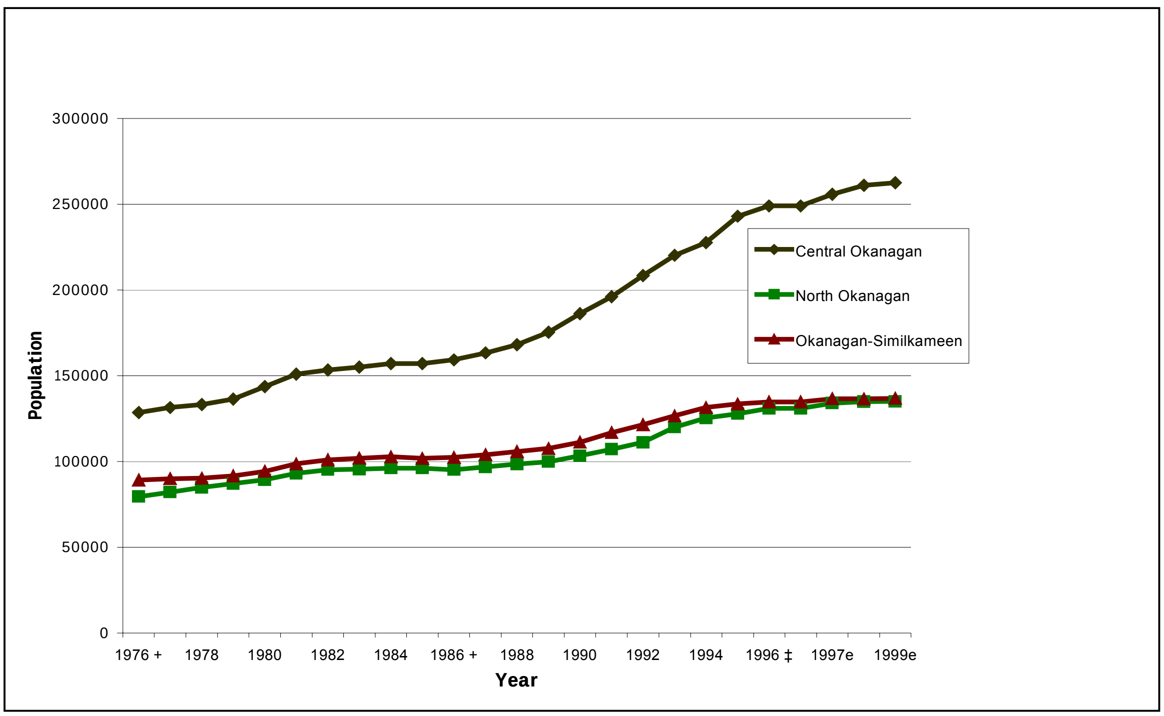

Figure 1-2. Okanagan Population 1976-1999

Forestry and Mining Industries have both played large roles in the formation of Okanagan communities, from the early gold rush days to the present. Mining in the Thompson-Okanagan (Okanagan + Kamloops area) still maintains 19% of the provinces total although many sites have been closed in the valley within the last 10 years and its role appears to be diminishing.

Forestry in the Okanagan is allocated based on a fiber supply called the Annual Allowable Cut (AAC). The AAC is the amount of timber allowed by the Ministry of Forests to be cut from a Timber Supply Area (TSA) in one year. This fiber source is best understood as a long term loan, as forestry companies must replant logged areas to a sufficient stocking standard, in a predetermined length of time, prior the responsibility of the area reverting back to the government. Fiber sources in the Okanagan extend beyond TSA's, as Tree Farm Licenses (TFL's), Non-Okanagan Crown forest land and private land supply the industry with 37% of the fiber used every year. In the Okanagan approximately 27% of the land base is considered unsuitable for harvesting (British Columbia Forest Service, 2000), and approximately 4,106,000 cubic meters of wood is milled per year (Ministry of Forests, 2001). It is difficult to sum up the total area of the Okanagan watershed impacted by forestry activities over the many years of timber extraction, as most government and data collection boundaries do not correlate with watershed boundaries. A general understanding of the area of the region impacted by forestry activities can be gained through the use of satellite photography. It is also important to be aware of the many factors that are considered and managed for in Okanagan forests. Other than timber harvesting, considerations of practicing foresters have been analyzed in a recent review of the Okanagan TSA which included requirements for biodiversity, visual quality, ungulate winter range, and community watersheds (British Columbia Forest Service, 2001).

2.2. Case Study: Trout Creek

Trout Creek flows into Okanagan Lake just south of Summerland and is the second largest watershed in the Okanagan. The Trout Creek watershed provides a variety of resources for the surrounding built and natural environments. The watershed is a source of recreation, irrigation and domestic water supply for local communities. The area provides habitat for various land and water-based flora and fauna that are niche specific to the unique climate and topography found in the south Okanagan.

The catchment area of Trout Creek is approximately 759 km^2. The mainstream itself is 72 km long and falls from an elevation of 2017 m to 340 m at Okanagan Lake. Approximately 255 km of the Trout Creek system is described as providing 'fish bearing reaches' for species including rainbow trout, mountain whitefish, brook trout and potentially spawning kokanee (MOELP 2000). Over time, Trout Creek has created a large delta of alluvial material and these impacts continue several hundred meters into Okanagan Lake (MOELP 2000).

The Trout Creek watershed averages 550 mm precipitation with 60% falling as snow. The average annual discharge is 2.1 m^3/s. There are 80 to 85 water licenses issued for irrigation, domestic supply and storage. The licenses allow 18.6 M m^3/y for diversion and approximately 13 M m^3/y of water to be stored. The Summerland Water District has 15 of the licenses, which represents 97% of the flow volume for diversion (Dobson Engineering, 1998).

The lower reaches of Trout Creek exemplify a trend in the Okanagan of increasing development and intensification of agriculture. The developed land base in this area is steadily increasing and putting pressure on both the natural areas and the sites historically used for agriculture. Due to this pressure and a changing industry, many farms, orchards and vineyards have intensified their production through the use of variations like dwarf species. This change, combined with increasing demands remaining from other developments, has resulted in higher water per acre usage of the local resources.

Forestry and recreation have been greater forces in the upper reaches of the watershed with visual estimates of impacted areas reaching 30% in some areas. In 1998, the Equivalent Cut

Area (ECA) was 17% of the watershed with some sub-watersheds up to 32% (e.g. Camp Creek). An environmental assessment of the logging activities in the watershed indicates that there is a moderate peak flow hazard due to logging activities in Isinok, Lost Chain, North Trout, and Upper Trout Creek. There are also high surface erosion hazards for 5 of the 11 major sub-basins in the watershed (Dobson Engineering, 1998). Logging from 1998 to 2003 is expected to result in from a 0% to 5% increase in the areas logged in the sub-watersheds. In light of this data, in combination with the potential incremental effects of climate change, there will likely be effects on water supply and quality for the main water users like the Summerland water district (see Section 6).

Trout Creek is a bellwether watershed that is able to tell many of the land use stories of the region, such as the impacts from development pressures, agriculture and irrigation demands, forestry impacts and growing recreation activity. When these trends are combined with the global stress of climate change, what would the implications be? The many scenarios obtained from climate models, combined with other analysis tools and local knowledge, produce information that can help visualize and personalize what this global trend could mean locally in the Okanagan Basin (see Section 3). In Trout Creek, local industries and resident lifestyles are currently putting substantial pressure on the natural environment. This environmental strain greatly complicates the regions ability to respond to a changing environment and climate.

3.0 STUDY FRAMEWORK

Scenarios and dialogue are the products of this study, so the framework has to enable both of these to develop. Several steps are needed:

a) understand the region’s use of and concerns for water resources,
b) generate regional scenarios of climate change from global-scale climate models,
c) develop regional scenarios of hydrologic changes based on the climate change scenarios, and
d) create dialogue through existing and new processes to obtain stakeholder views on climate change impacts, potential adaptation options, and implications of choosing any of these options.

Figure 3-1 illustrates how these four study components are linked. The relatively short duration of available time for this study (one year) precluded consideration of a major effort at modeling all natural and human processes relevant to climate and water. Rather than developing an all-inclusive model of water resources, in which the connections to climate and management decisions are mathematically expressed, the approach here is to use dialogue to complement mathematical models. This enables the inclusion of issues that may be difficult to model in such terms. Mathematical models are used strategically to generate information on known environmental indicators and processes (temperature, precipitation, snow pack, runoff, streamflow). Dialogue is used for those indicators and processes that include a human component (irrigation, land use, forestry, fisheries, institutional arrangements).

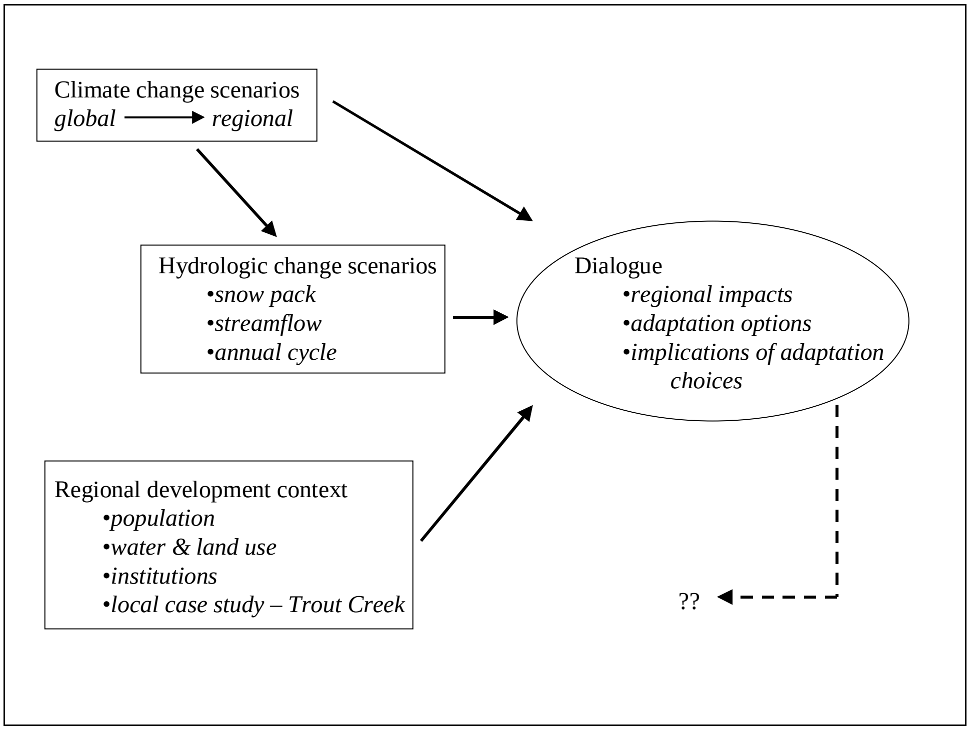

Figure 3-1. Okanagan Climate and Water Resource Impacts Study Framework.

This is not to suggest that the development of climatic and hydrologic scenarios have led to predictions with any known levels of probability or accuracy. There are a number of important uncertainties associated with these modeling efforts (see Sections 4 & 5). The models are based on established physical principles, but additional steps have been necessary to apply these tools to this location and scale. Throughout this report, we refer to model-based results as scenarios, rather than as forecasts with a known probability or accuracy. The full range of possible outcomes is not known.

An important technical challenge is downscaling of global scale climatic simulations to regional scale scenarios. Although sophisticated statistical and dynamical downscaling techniques are being explored, they have not yet been sufficiently developed for this area. In this study, we employ a simple approach using General Circulation Model (GCM) data at its original resolution (see Section 4). The use of single GCM grid cells and the interpolation of surrounding grid cells are simple techniques to apply, but carry with them considerable uncertainty. We justify their application here by noting that the magnitude and direction of projected changes in climate are consistent with other scenarios developed for the Columbia basin of which the Okanagan is a part (Hamlet and Lettenmaier, 1999).

The question marks in the framework represent uncertainty in the post-study impacts of the dialogue initiated by this work. It has been the intention of this component to build on existing regional consultation processes, such as the watershed round tables, stewardship councils, and the Okanagan Basin Water Board to bring regional stakeholders into the study. Two sets of focus group exercises have been organized to initiate dialogue on impacts and adaptation, and to learn about possible connections between climate change and regional development (see Section 6). Once the final report of this study is completed and distributed within the region, it is up to regional actors to decide how to proceed. However, this also presents an opportunity for follow-up research (see Section 7).

4.0 CLIMATE CHANGE IN THE OKANAGAN BASIN

4.1 The Climate of the Okanagan Basin

The Okanagan Basin is located in south central British Columbia and is part of the Southern Interior Ecoprovince, lying east of the crest of the Coast and Cascade mountain ranges and west of the Columbia Mountains. Due to the rain shadow effect of these mountain ranges, the region contains some of the warmest and driest areas of the province in the summer. The Okanagan Basin is nested within the Thompson Okanagan Ecoregion, characterized by rolling plateaus and large north south valley systems with rich glacial deposits carved by river paths. The mean annual temperatures of the major valleys is approximately 6°C with a summer mean of 15°C and a winter mean of -3.5°C. The mean annual precipitation ranges between 250-300 mm in the major valleys to 400-600 mm in plateau regions, to over 1,000 mm in sub alpine and alpine areas. Sub alpine areas support lodgepole pine, engelmann spruce and sub alpine fir. At lower elevations, mixed forests of lodgeople pine, trembling aspen, white spruce and douglas fir cover the rolling landscape. Drier valley bottoms support drought-adapted species such as douglas fir and pine grass, or scattered ponderosa pine among bluebunch wheat grass and sagebrush. Varied grasslands, sagebrush, and antelope bush characterize the most arid areas south of Penticton. Many animal species inhabit this unique habitat including bighorn sheep, mule and white-tailed deer, elk, black bear, coyote, bobcat and cougar. Bird species include blue grouse, waterfowl and long-billed curlew. Reptiles, such as rattlesnakes, are found the more arid areas of the region (ESWG, 1996).

4.2 Global Climate Change

Over the past century, the earth's mean global temperature has increased by 0.6 ±0.2°C (IPCC, 2001). Since the mid 1970s warming has accelerated, suggesting that this increase is not just a cyclic trend but also a response to an increase in atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) nitrous oxide (N_2O) and tropospheric ozone (O_3). Since pre-industrial times, CO_2, the most important greenhouse gas, has increased by 31%, CH_4 by 151%, N_2O by 17% and O_3 by 36% (IPCC, 2001). Collectively, this increase in greenhouse gases has altered the radiative balance of the earth to the point that it is now having a discernible influence on the global climate (IPCC, 1996). As concentrations of greenhouse gases continue to rise, the greatest warming is predicted for higher latitudes and in the interior of continents. Higher latitudes are expected to experience more warming due to the melting of snow and ice which will result in greater absorption of solar energy and enhanced heat transfer from oceans to land. Similarly, the interiors of continents are especially sensitive due to their vulnerability to temperature extremes. In addition, warming is expected to be higher for the northern hemisphere than the southern hemisphere due to more land mass in the former and enhanced deep water ocean circulation in the latter. Consequently, Canada may experience a greater temperature change over the next several decades than most regions of the world. Already a change in climate has been observed in many parts of British Columbia, including the Okanagan Basin.

4.3 Climate Variability

Climate variability occurs due to both internal and external factors influencing the earth's climate system. Year to year variability is common, and temperature anomalies in British Columbia are especially pronounced during El Niño episodes, which have a 2-7 year return period. On a larger scale, an important phenomenon influencing decadal climate variability in British Columbia is the Pacific Decadal Oscillation (PDO). The cool phase of the PDO is associated with higher than normal atmospheric sea level pressures in the North Pacific between the months of November and March, resulting in warmer than normal sea surface temperatures in the central North Pacific and cooler than normal sea surface temperatures off the west coast of North America. The warm phase of the PDO is the opposite and is characterized by warmer than normal sea surface temperatures off the west coast of North America (Nicholls *et al*., 1996). The PDO has a 20-30 year cycle whose cool and warm phases have had a discernible influence on the climate of western North America over the past century (Mantua *et al*., 1997). The 20th century began with cooler annual temperatures from about 1900 to 1925 (cool PDO phase), which were followed by warmer temperatures between 1925-1945 (warm PDO phase). Cooler temperatures again predominated between 1945-1975 (cool PDO phase), followed by a resumption of warmer temperatures in the last quarter of the 20th century. In spite of the decadal scale temperature variability associated with the PDO, temperatures have continued to rise and the rate of increase has accelerated, especially during the last quarter of the 20th century. There is now almost unanimous consensus among scientists that the continued rise in atmospheric concentrations of greenhouse gases are influencing global warming on a scale unprecedented in human history.

4.4 Climate Change in the Okanagan Basin: The Past 100 Years

Climate trends can be determined by analyzing data collected at climate stations over the past century. Minimum daily temperatures are a good indicator of nighttime lows. Figure 4-1 shows the annual minimum temperatures measured at the Vernon Coldstream Ranch climate station from 1901 to 1999. Although decadal oscillations have occurred over the period of record, minimum annual temperatures at Vernon Coldstream Ranch have increased by approximately two degrees over the past century. Daily maximum temperatures have also increased at this station (Figure 4-2), although not as much as minimum temperatures. The greater increase in minimum temperatures is likely due to increased nighttime cloud cover, which minimizes heat loss to the atmosphere. Observed increases in both minimum and maximum temperatures at the Vernon Coldstream Ranch are paralleled by warming trends observed at nearby Kamloops, Summerland and Cranbrook (Brewer and Taylor, draft, 2001), indicating that this is not an isolated occurrence but a general warming trend in south central and eastern British Columbia.

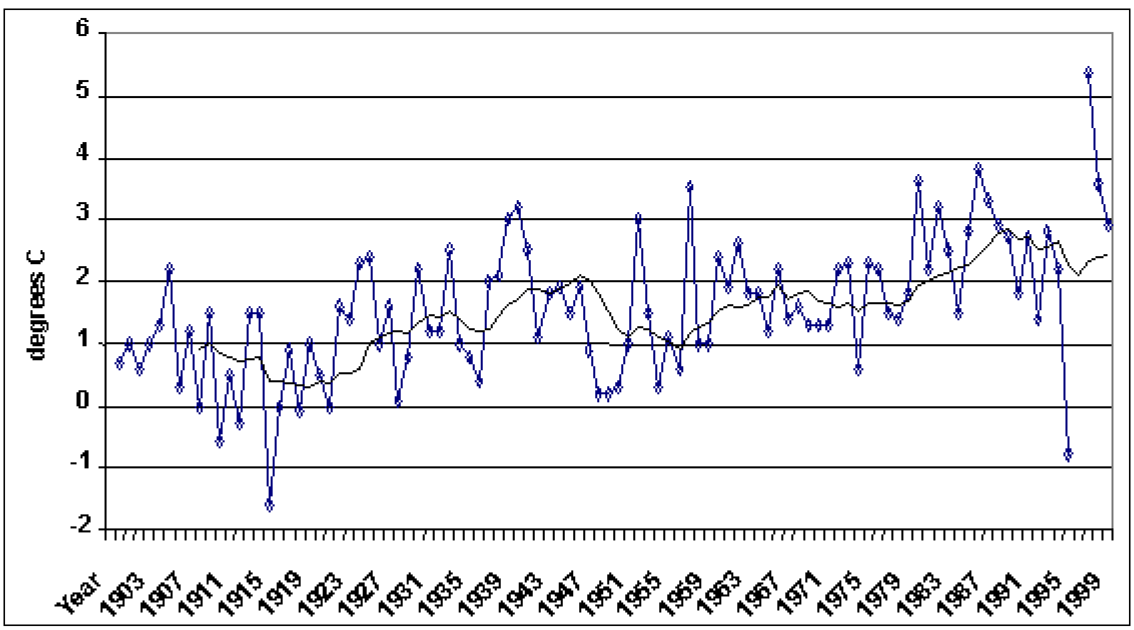

Figure 4-1. Trend in Minimum Temperature at Vernon Coldstream Ranch

Decadal oscillations in temperature are an important modifier of climate, as indicated by the lower minimum temperatures between approximately 1945 to 1975 (Figure 4-1) which are linked to low PDO indices associated with the most recent cool phase of the Pacific Decadal Oscillation (Mantua *et al*., 1997). Conversely, warm cycles, which were most pronounced during the 1940s and in the last two decades of the 20th century, correspond to positive PDO indices associated with the warm phase of the Pacific Decadal Oscillation.

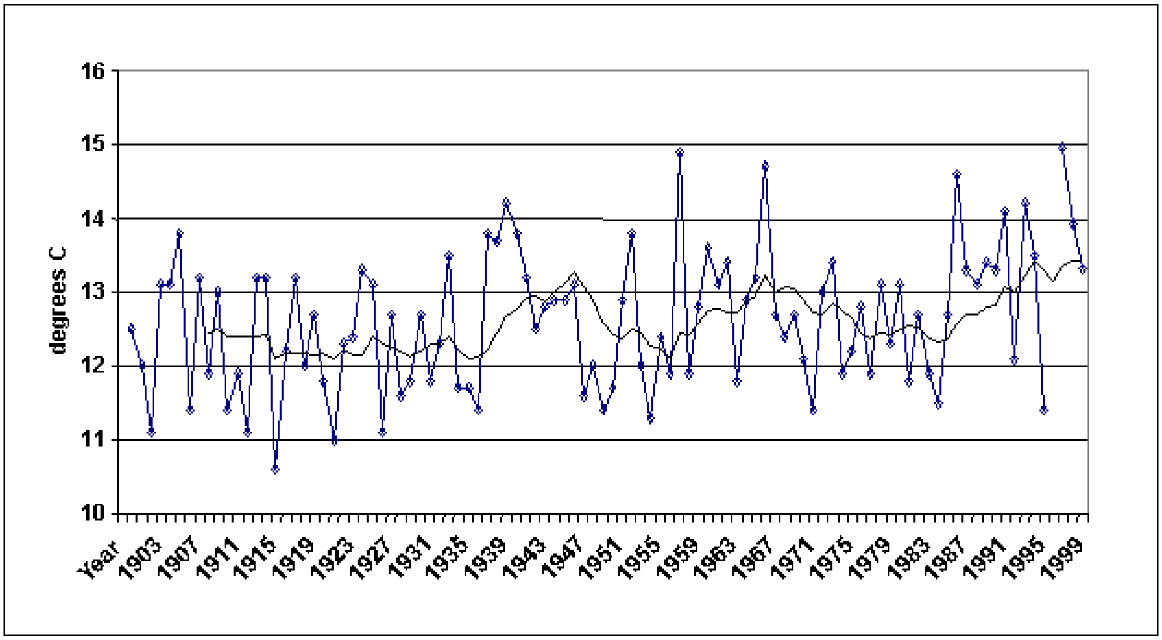

Figure 4-2. Trend in Maximum Temperature at Vernon Coldstream Ranch

The number of frost-free days per year is a good indicator of the growing season in a given region. Figure 4-3 presents the number of frost-free days per year at Summerland between 1907-1993. An increasing trend is evident in the time series with the number of frost-free days increasing by 3.1 days per decade over the period of record, equivalent to 27 fewer days with frost by 1993. This trend is highly statistically significant, reflecting the parallel increase in minimum temperatures at this site. Similar increasing trends of comparable magnitude have been observed at other stations throughout B.C (Brewer and Taylor, draft, 2001).

An increasing trend in precipitation has also been observed in the Okanagan Basin. Figure 4-4 shows annual precipitation values at Kelowna Airport over the 20th century. Decadal scale variability is a prominent feature of the precipitation pattern at Kelowna Airport. The century began with a brief wetter period for the first decade followed by a drier period through the 1920s and 1930s. A wetter period followed in the 1940s followed by a drier period between 1950 and the late 1970s. Wetter conditions returned in the 1980s, coinciding with the resumption of warmer temperatures throughout British Columbia. In spite of the observed decadal variability, precipitation has increased by approximately 125 milliliters over the past one hundred years. A significant correlation was found between spring maximum temperatures and precipitation. This suggests that increased rates of evaporation, resulting from warmer temperatures, have likely increased the amount of rainfall in the area during the spring months. A significant increase in the amount of precipitation of a similar magnitude has also been found at other southern BC locations such as Summerland and Cranbrook (Brewer and Taylor, draft, 2001), reflecting a larger global trend towards an increase in precipitation (IPCC, 2001), believed to be a natural consequence of an intensification of the hydrological cycle in response to rising temperatures.

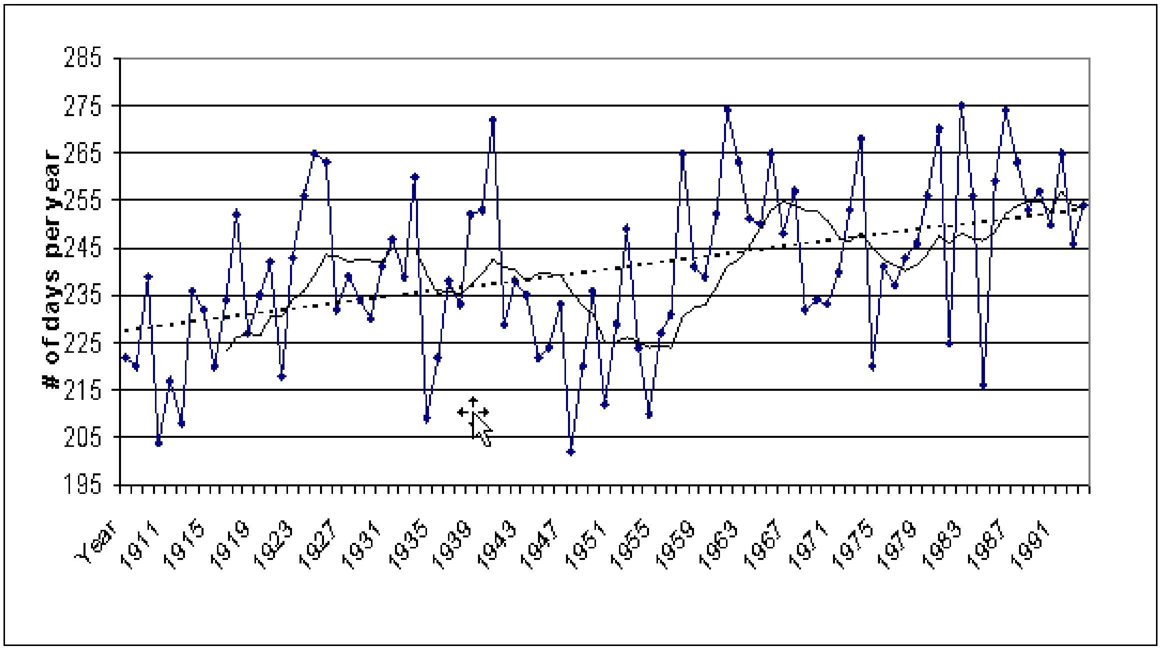

Figure 4-3. Trend in Frost Free Days at Summerland

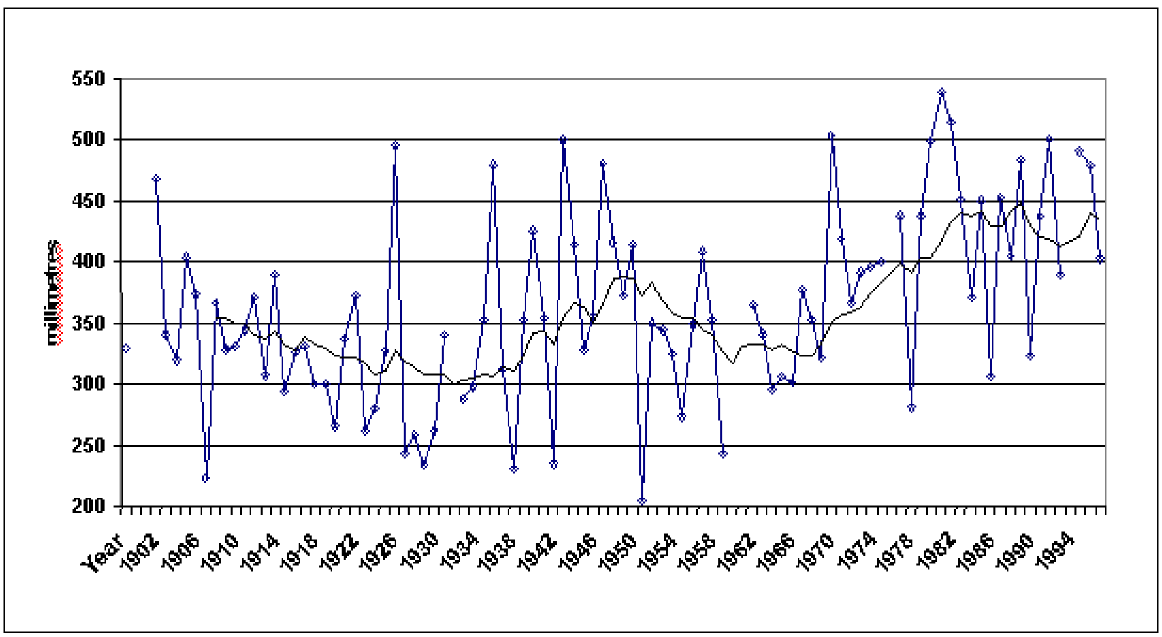

Figure 4-4. Trend in Total Precipitation at Kelowna Airport

4.5 Establishing a Baseline: Climate Normals

Before we look at climate change in the Okanagan Basin, it is important to establish a baseline against which to measure this change. Climate normals represent the climate at a given station based on average measurements over the most recent 30 year period on record. The most recent climate normals were computed for the period spanning from 1961-1990. Figure 4-5 shows the most recent temperature and precipitation normals measured at Kelowna Airport. As expected, peak minimum and maximum temperatures occurred during July and August while the lowest temperatures occurred in January. Note that average maximum summer temperatures were around 27°C, while minimum winter temperatures averaged around –8°C. Precipitation was most abundant during the summer, from May to October, and during the winter in December and January. In this area, summer precipitation occurs largely due to local convective activity, while winter precipitation is usually linked to weakened synoptic systems (winter storms) originating in the Pacific Ocean. Kelowna Airport received about 366 millimeters of precipitation per year, reflective of the relatively dry climate of this region. This is a relatively low amount compared to central coastal areas of BC receiving over 3,000 mm of precipitation per year.

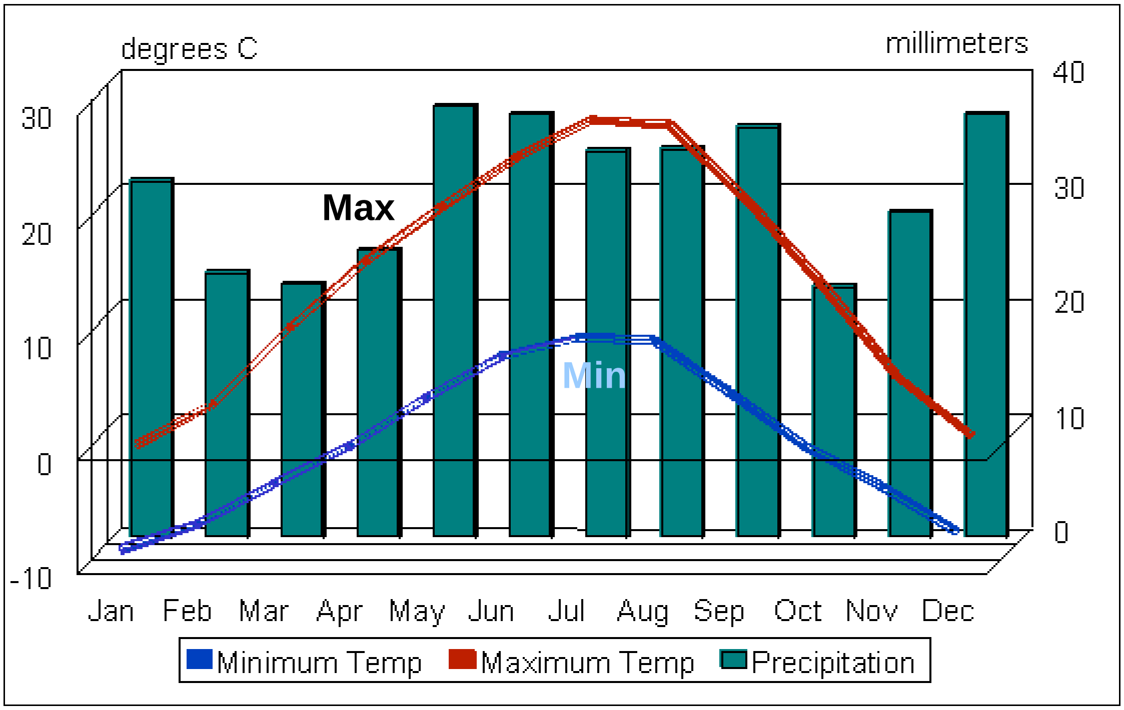

Figure 4-5. Temperature and Precipitation Normals (1961-1990) at Kelowna Airport

4.6 <u>Predicting Climate Change</u>

4.6.1 *Global Climate Models*

Global climate models are used to make predictions about the future state of the world's climate. Coupled general circulation models (GCMs) simulate the climate system using mathematical equations that describe the earth's radiation budget, its translation into heat and motion and the operation of the water cycle. An example of such a model is the Canadian Global Coupled Model (CGCM1), developed by the Canadian Centre for Climate Modeling and Analysis in Victoria, British Columbia. CGCM1 is composed of four key components: an atmospheric general circulation model, an ocean general circulation model, a simple land surface model and a thermodynamic sea ice model. Within each of these four models, physical processes are simulated according to the best scientific knowledge to date. The atmospheric general circulation model is composed of 10 vertical levels and has a horizontal resolution of approximately 3.7° latitude and longitude (about 400 km). The model contains interactive simulations of atmospheric pressure and circulation, wind stress, cloud processes and precipitation. The ocean general circulation model, with 29 vertical layers and a horizontal resolution of 1.8° x 1.8° (about 200 km), is able to reproduce large-scale features of the ocean circulation as well as variations in temperature and salinity. Physical attributes of continents such as topography and soil properties are included in the simple land surface model, which calculates runoff and soil moisture based on the balance between precipitation, surface evaporation and water holding capacity of the soil. Lastly, the thermodynamic sea ice model allows ice to grow and melt in response to seasonal change. These individual models are coupled together to most accurately represent the interaction between the atmosphere, hydrosphere, geosphere and biosphere.

Using a combination of historical climate data, physical data and expected increases in aerosols and greenhouse gases, CGCM1 is able to generate climate scenarios for three time slices: 2010-2039 (2020s), 2040-2069 (2050s) and 2070-2099 (2080s). These scenarios are generated at spatial resolution of 400 km and a temporal resolution of one month.

Coupled general circulation models similar to the Canadian counterpart have also been developed by the UK, Germany, USA, Australia and Japan. On a large scale, simulations generated with these different coupled models are in relatively good agreement. For example, all models predict a global temperature rise in response to a doubling of CO_2 over the 21st century. They do differ, however, in their sensitivity to this change, as reflected in their prediction of the exact temperature rise. Similarly, the models all predict warming to be greater at high latitudes and in the interior of continents. Where they differ, however, is in their regional projections of the magnitude of warming at the regional scale and in the magnitude and direction of precipitation changes. Discrepancies between models occur largely as a result of the different assumptions built into the various models. Such assumptions include modeled processes of heat and energy transfer between the atmosphere, oceans and land, modeling of cloud parameters and land-atmosphere interactions (e.g. evaporation and evapotranspiration rates).

Another source of variability between models arises from differences in the starting point from which the model is run. Because of the natural variability of climate, the initial starting point will have an effect on the modeled results. To minimize errors relating to internal climate variability, an ensemble of runs is often run from several starting points. The range of results from the different ensemble runs is an indicator of the uncertainty due to climate variability. The results are often averaged together to provide a more robust estimate of a climate scenario (Kattenberg *et al*., 1996).

Because of the relatively coarse resolution of global climate models, GCMs are limited in their ability to predict changes at a regional scale. This is due primarily to limited computational ability, as fully coupled GCM computer runs at a regional scale are still time prohibitive. Given these uncertainties, potential users of GCM simulations should consider these climate projections as likely scenarios, not absolute predictions.

4.6.2 *Model Inter-comparisons*

The amount of agreement between different GCMs is considered to be a good indicator of the degree of confidence in a particular climate projection. Comparison among models is achieved by using the same baseline data (1961-1990 normals) and expected CO_2 and aerosol increase over a given period of time. The standard IS92a scenario, which employs the observed CO_2 levels to 1990 followed by a 1% increase of CO_2 and aerosols for each year thereafter (IPCC, 1996), is commonly used for this purpose. Figure A1-1 (Appendix 1) compares the results of Canadian, German and British model simulations of minimum temperature in the Okanagan Basin for the 2020s. The three Canadian simulations indicate different climate scenarios based on three ensemble members, which represent different initial starting conditions. All three models agree that minimum temperatures will increase across the four seasons, although they differ in the exact magnitude of the change. The Canadian model predicts that minimum temperatures will increase relatively evenly across the four seasons. In contrast, the German model predicts minimum temperatures to increase more during the winter and summer, while the British model predicts the largest increases to occur during the winter and spring. In spite of these seasonal differences, the models agree that the minimum temperature will rise and that this rise will be somewhere between 1.0-2.5°C. These projections are in agreement with observed increasing trends in minimum temperatures in south central British Columbia over the 20th century.

Figure A1-2 compares model projections for maximum temperatures in the Okanagan Basin for the 2020s. The Canadian, German and British models are in relatively good agreement, predicting an increase in maximum temperatures of approximately 1.0- 2.5°C. Seasonally, however, there are some differences, with the Canadian model predicting the increase to be most pronounced during the spring months as opposed to the summer months, as the German model predicts.

Climate predictions can also vary substantially from one model to another. This is especially true for precipitation scenarios, where there is a greater degree of uncertainty in the underlying processes. Figure A1-3 compares model projections of seasonal change in total precipitation for the Okanagan Basin for the 2020s. Results are expressed as percent change from the most recent climate normals (1961-1990). The Canadian, German and British models are in relatively good agreement in their projections of winter and spring precipitation, however they differ substantially in projections for the summer and fall seasons. This difference is especially evident for the summer where the German model predicts precipitation to decrease by as much as 18%, which is substantially different than the 1% decrease predicted by the Canadian model or the 3% percent increase predicted by the British model. In terms of projections over the entire year, both the Canadian and British models are predicting a general increase in annual precipitation.

4.6.3 *Climate Change Scenarios for the Okanagan Basin – PRISM Maps*

Climate maps are a convenient way of illustrating how climatic conditions vary across the landscape. The topography of British Columbia is very rugged, so the variation in the climate can be large over a relatively small area. Generally, conditions become colder and wetter with increases in elevation. Thus, valleys in the Okanagan are generally much warmer and drier than conditions at higher elevations. These features are reflected in the climate maps, which were prepared using the 1961 to 1990 climate normals and based on the PRISM model. The PRISM model is a statistical approach to climate mapping that is premised on the strong variation in climate with elevation. PRISM uses linear regression of temperature and precipitation on elevation in conjunction with a digital elevation model to extrapolate vertically into areas where station data are not available. PRISM fills a significant gap in the climate monitoring network by providing interpolated surfaces of temperature and precipitation that incorporate the influence of topography and coastal proximity on climate. In the absence of a dense climate network, it is not possible to verify the accuracy of these maps, but they are widely accepted as a good estimation of the current climate.

The Spatial Climate Analysis Unit at Oregon State University prepared the PRISM maps. They were constructed at a resolution of 4 kilometers, resulting in highly detailed climate maps. To simulate the climate of the future, baseline climate data were perturbed by simulations derived from the much coarser (400 kilometer resolution) Canadian global climate model (CGCM1) to produce detailed climate scenarios for three time slices: the 2020s, 2050s and 2080s. Naturally, we cannot know the future climate to the degree of precision implied by these PRISM maps. It is important to keep in mind that these maps represent physically plausible scenarios of future climates, rather than forecasts or predictions.

Figure A1-4 shows PRISM maps of model projections for January mean minimum temperatures for the Okanagan Basin. According to model simulations, January minimum temperatures will be between 3-4°C warmer in the 2080s compared to the period between 1961-1990. This change is expected to occur gradually with an approximate one-degree change for each time slice. Higher mean minimum temperatures combined with wetter winters would result in a smaller snow pack and earlier spring runoff (see Section 5). Potential impacts of wetter winters are discussed in Section 6.

Figure A1-5 presents July mean maximum temperatures for the Okanagan Basin for the 2020s, 2050s and 2080s. The simulated increase is approximately 1.5°C per time slice, as shown in the PRISM maps. This warming will result in a temperature difference of between 3-5°C higher for the 2080s compared to the most recent temperature normals (1961-1990). Potential impacts of higher temperatures (e.g. fisheries, agriculture) are discussed in Section 6.

CGCM1 projections predict an increase in precipitation of approximately 10-20% by the 2080s for the 400 km square grid area encompassing the Okanagan Basin (CCCma, 2001). PRISM map projections reflect a corresponding increase in precipitation (Figure A1-6); however, as these increases are gradual and relatively small, they are difficult to see at the resolution provided by the PRISM maps. Nevertheless they indicate that the region is expected to experience a wetting trend over the 21st century. This is in agreement with historical records, which show a 30% increase in annual precipitation over the past century in this area. In general, precipitation is expected to increase during the fall and winter and decrease slightly during the summer. A drier summer, coupled with warmer temperatures would result in an extended low flow period in the late summer and early fall and a larger requirement for irrigation and water storage. Conversely, a wetter and warmer winter, spring and fall would result in higher annual stream flows, an earlier spring freshet, greater chance of flooding and higher risk of landslides.

4.7 Effects of Climate Change on Degree Days

Degree days are commonly used as an indicator of climate in a particular region. Growing degree-days are used in agriculture as an index of crop growth. They are defined as the number of degrees that the mean daily temperature is above 5°C (the temperature at which plant growth begins to occur) summed up over the course of a month or a year. According to Canadian model simulations (Figure A1-7), the number of growing degree days in Kelowna will increase from a peak of just over 400 degree days in July (for the 1961-1990 period) to approximately 550 degree days by the 2080s. Over the entire year, this represents a 51% increase over the baseline period. In addition, the growing season will begin earlier and end later. By the 2080s crops may begin sprouting as early as February and last well into the end of October. Such changes could benefit local agriculture by increasing the yearly crop output as well as the type and variety of crops that could be grown in the region. On the negative side, a milder winter could increase pest survival resulting in a larger incidence of crop damage (see Section 6).

Heating degree-days are used to estimate the heating requirements of buildings. They are defined as the cumulative number of degrees that the mean temperature is below 18°C in a given month or year. According to CGCM1 projections, heating degree days for the month of January in Kelowna are expected to decrease from just under 700 degree days to just under 600 degree days by the 2080s (Figure A1-8). Over the entire year this represents a 28% decrease in heating degree days, which could translate into significant savings for space heating. Such savings however would likely be offset by extra costs associated with air conditioning and swimming pool use during the summer months.

Cooling degree days are used to estimate the cooling requirements of buildings. They are defined as the cumulative number of degrees that the mean temperature is greater than 18°C in a given month or year. CGCM1 projections indicate that cooling degree days in Kelowna for the month of July are expected to double by the 2050s (Figure A1-9), compared to the 1961-1990 period, and then nearly triple by the 2080s. Over the entire year, cooling degree days are expected to increase by 200% by the 2080s. This compares with an estimated 28% reduction in heating degree days by the 2080s, indicating that any savings derived from the reduction in heating degree days may be exceeded by the additional cost of air conditioning, depending on local responses to this change (see Section 6).

4.8 Conclusion

Analysis of climate data collected over the past 100 years clearly indicates that the climate of the Okanagan Basin has changed over the 20th century. Increasing trends have been observed for both maximum and minimum temperatures, with minimum temperatures showing the most pronounced changes. Similarly, precipitation has increased in the Okanagan Basin, reflecting an intensification of the hydrological cycle in response to increased temperatures. These climatic changes have been observed throughout most of British Columbia and are reflective of larger scale global trends associated with a disturbance in the radiation budget, largely attributed to an increase in greenhouse gases. Global climate model projections for the Okanagan Basin the 21st century indicate a continuing increasing trend in both temperature and precipitation. There is relatively good agreement among different GCMs with respect to future season specific temperature changes, however, there is less certainty regarding future seasonal distribution of precipitation. Climate projections for the Okanagan Basin indicate an increase in growing degree days with possible benefits to regional agriculture. Similarly, projections call for a decrease in heating degree days with associated savings in space heating. However this is likely to be more than offset by a much higher increase in cooling degree days, reflecting air conditioning requirements.

Overall, in spite of the existing uncertainties related to applying coarse GCM projections on a regional scale, the relatively good agreement between observed temperature and precipitation trends with projected trends indicates that a fair amount of confidence can be placed in these projections in spite of uncertainty in the future seasonal distribution of precipitation. Further advances in regional climate modeling and improved downscaling techniques should further refine predictions of future climate states at a regional level.

5. 0 HYDROLOGY

5.1 Introduction

Meteorological variability provides the driving force for hydrological variability in the landscape. However, the landscape has a modifying influence on the distribution of water in time and space in such a way that water quantity, as measured at any single point in the surface water network on the landscape, is not necessarily a direct result of recent meteorological events. The routing of water through the landscape transforms linear meteorological inputs into non-linear hydrological outputs.

The complex interaction between climate and hydrology can be examined using several analytical approaches; including statistical analysis of existing data, temporal and spatial climate analogue techniques, empirical modeling and hydrological process modeling. The use of any one technique in isolation can lead to misinterpretation by over-simplification of complex phenomena. Klemes (1990) argues that modeling of climate change often fails to do more than to reveal the obvious (e.g. increased precipitation will yield increased runoff and increased temperatures will result in increased evapo-transpiration). In this paper three techniques are used to assess the hydrological consequences of climate change on the Okanagan Basin: statistical, temporal analogue, and process modeling.

5.2 Methods

(This section contains a technical discussion on hydrology methods and tools. Some equations appear in the text.)

Statistical techniques are dependant on existing data. Whereas statistical analysis is of limited value for extrapolation as far beyond the observed data set as is necessary for this study, it is useful to identify whether trends identified in observed data are consistent with changes predicted by the process modeling approach. The statistical modeling approach is not constrained by the assumptions associated with downscaling from the GCM to the hydrological process model. Hence, statistical analysis can be used to identify trends at the time scale of hydrological extremes and thus provide inference about the future prospects for hydrological extremes that cannot be provided from analysis of the process model results.

In this paper, climate change analogues from the period of record are used to establish context for the process model results. The analogues can help in determining whether assumptions implicit in process modeling can be supported with existing data. Furthermore, the climate analogues assist in translating results to a practical level for stakeholder consultation. It is easier for a stakeholder to relate to the hydrology within his/her experience, complete with the knowledge of the real consequences of that year, than it is to relate to an absolute quantification of change in a hydrological variable. The spatial analogue technique (e.g. examining the hydrology of a region with a similar landscape but a climate that matches the predicted climate) is beyond the scope of this study.

5.2.1 *Statistical modeling: Statistical Analysis of Changes in Climate and Hydrology of South Central BC 1976-1995*

Data presented here were extracted from daily temperature, precipitation, and streamflow series from Environment Canada’s national databases. These daily data sets were smoothed to 5 day (precipitation and streamflow) and 11 day periods (temperature) for the two decades. This results in calculated average conditions during each 5 day or 11 day period for 1976-1985 and 1986-1995 decades. Statistical significance is determined using the method of Leith and Whitfield (1998) who assessed significance of changes using robust non-parametric statistical test.

The differences between the decades are presented using polar plots to enhance the visualization of changes in magnitude/timing between the two decades. In these figures increases between decades are shown in green, and decreases in yellow. Statistically significant differences are indicated with red arrowheads (increase) or blue arrowheads (decrease). Results from statistical tests were then grouped using the automated clustering procedure described in Whitfield and Cannon (2000a). Further description for each variable is given in section 5.3.

Patterns in natural streams were characterized by an earlier onset to melting of the winter snowpack, followed by lower peak and recession streamflows during the spring, summer, and early fall months. In the western portions the study area early winter streamflows increased, while in the eastern portion winter flows decreased. The difference between these two areas is due to the 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.

5.2.2 Temporal Analogue determination

As an aid to interpretation of process-model simulated results, in the context of inter-annual streamflow variability, an index is used to rank the climatic similarity of observed data with respect to the predicted climate for the 2080 scenario. This index calculated as:

$$I_{wy} = 1 - \frac{SI_{wy} + BI_{wy}}{2} \quad (1)$$

where I_{wy} is the index for any given water year wy (October 1 to September 30), SI_{wy} is a shape index for that water year and BI_{wy} is a bias index for that water year. The shape index is given as:

$$SI_{wy} = \sum_{m=1}^{12} \frac{(T_{m,wy} - T_{m,1970})^2}{(T_{m,2080} - T_{m,1970})^2} \quad (2)$$

where m is an integer representing each of the 12 months of the water year, $T_{m,wy}$ is mean temperature for month m in the given water year, $T_{m,1970}$ is the mean monthly temperature for month m, for the climate normal period (1961 to 1990), and $T_{m,2080}$ is the mean monthly temperature for month m for the 2080 scenario (2071 to 2100). The bias index is given as:

$$BI_{wy} = \frac{T_{2080} - T_{wy}}{T_{2080} - T_{1970}} \quad (3)$$

where T_{2080} is the mean temperature for the 2080 scenario, T_{wy} is the mean temperature for the given water year, and T_{1970} is the mean temperature for the climate normal period.

This index is calculated for each water year for which we have streamflow record. In this way each year of record is compared to the 2080 scenario. Hence, the 2080 scenario has an index score of 1, the climate normal period has a score near zero and any given year will have an index score that is either more similar to the predicted climate (i.e. a positive sign) or less similar (negative sign) to the predicted climate with respect to the climate normal mean.

Interpretation of this analogue must be done with some caution because of the simplicity of the index algorithm, which ignores precipitation. To aid in interpretation the indexed years are also categorized into four groups according to whether they are: warm-wet, warm-dry, cool-wet or cool-dry with respect to the period of record mean precipitation and temperature.

5.2.3 Process modeling

The HBV-EC model, used in this study, is a locally developed variant of the HBV model developed in Sweden by Sten Bergstrom (1995). This model provides several advantages including: minimal data requirements, ease of calibration, and computational efficiency. These advantages are achieved without compromise of the ability of model to represent the hypsometric complexity of the chosen watersheds.

The HBV-EC model is composed of a set of algorithms that represent dominant hydrological processes and the storage and routing of water in the landscape. As the actual physics of these processes cannot be explicitly resolved with available data, calibrated parameters are used to simplify the model algorithms. Optimum parameter values are determined by comparison of model output with observed data. A number of assumptions are implicit with this modeling approach and these assumptions confine the interpretation of results as being reasonable if, and only if, model assumptions are valid for the scenario being simulated.

Beven (2001) discusses several assumptions that are problematic for hydrologists attempting to reproduce hydrological variability within a numerical-modeling environment. Addressing the full context of hydrological assumptions is beyond the scope of this paper, however, within the context of this study, there are two specific modeling assumptions that must be addressed:

1. The assumption that the landscape used for calibration of model parameters is hydrologically similar to the landscape simulated in an altered climate, and

2. The assumption that the predicted shifts in the mean monthly temperature and the mean monthly precipitation are uncomplicated by any change in the skewness, or kurtosis of the daily data around the mean monthly values in an altered climate.

In the first instance, one might reasonably assume that land-use change will occur over the time frame between the climate change scenarios. This change may be a result of anthropogenic forcing (e.g. agriculture, forestry, or urbanization) or due to ecosystem forcing (e.g. change in elevation of tree-line as a result of climate warming). In either case, model parameters calibrated to the native landscape will not be valid in the altered landscape. As the future condition of the landscape is not known, the model is not capable of reproducing what will happen in that altered landscape, but only what might happen if the landscape does not change. However, accepting this assumption of hydrologic similarity simplifies the interpretation of results. For example, if both land-use and climate were altered in the model domain, it would be relatively difficult to interpret some of the more subtle effects of climate change that may be masked by land-use change. As such, results based on this assumption are useful for discussion purposes about the climate change issue, but should not be used for specific planning purposes.

The second assumption, that the statistical properties of the future climate will be similar to the existing climate, with the exception of shifts in the monthly mean, cannot be explicitly validated within the context of our current climate modeling capabilities. This simplifying assumption is necessary to downscale from the resolution of the global climate models to a scale of hydrological relevance. At issue is the effect that any unknown changes in the intensity-duration-frequency distribution of precipitation may have on hydrological response characteristics for a given basin. The current generation of global climate models do not have sufficient spatial resolution to solve for convective storms that would be capable of delivering intense rain, and even if that resolution was available, convective parameterization is required that could not be justified for an unknown future landscape. That the assumption of stationarity of monthly climate frequency distributions with respect to the mean cannot be justified essentially invalidates model results at any time scale finer than the monthly means. This precludes analysis of hydrological extremes based on model scenarios, as annual extremes are typically expressed in units less than a month (e.g. maximum daily, maximum instantaneous, 7-day low-flow etc.). However, the violation of this assumption does not affect interpretation of seasonal flow distribution (i.e. time resolutions greater than or equal to monthly time scale).

The model was calibrated using a split sample method whereby the hydrometric record is split into two periods. The first period is used to optimize the model parameters and the second period is used to validate the optimized parameters. The performance measure chosen for model optimization and validation is the Nash-Sutcliffe model efficiency (NSME) calculated as:

$$\mathrm{NSME} = 1 - \left[\sum_{i=1}^{n} (Q_{p(i)} - Q_{o(i)})^2 \Big/ \sum_{i=1}^{n} (Q_{o(i)} - \overline{Q}_p)^2 \right] \qquad (4)$$

where $Q_{p(i)}$ is predicted discharge at time i, $Q_{o(i)}$ is observed discharge at time i and $\overline{Q}_p$ is mean predicted discharge.

The calibration and validation time periods complete with the NSME scores are provided in Table A2-1. The performance scores show that the model does a good job of estimating the hydrographs for these stations and that there is very little loss in model efficiency when the model is run with verification data. This increases our confidence in the model's ability to produce reasonable results when run with a perturbed climate.
Locations were selected for hydrological modeling based on:

1. The geographic diversity of the Okanagan basin,
2. Un-regulated flow regime,

3. At least ten years of hydrometric data, and
4. Proximity to a climate monitoring station with concurrent temperature and precipitation data.

This selection process resulted in six Water Survey of Canada hydrometric stations being chosen (Table A2-1), which were associated with five different climate stations.

The global climate model scenarios provide predictions over a coarse spatial domain where each grid point represents approximately 160,000 km^2 of land area. However, the hydrological model is sensitive to local climate variability within the area of the watersheds, which range from 34 to 117 km^2 in size. Furthermore, in order to apply the calibrated hydrological model parameters to scenario data, the scenario data must be specific to the location of the climate station used for calibration. As there is no physical basis for downscaling GCM grid data to a singular point in the landscape (see Section 4), the monthly climate normal means of temperature and precipitation were perturbed by the magnitude of the change predicted for each scenario for each of the climate models used. The resultant monthly means were then linearly re-distributed to create a daily time-series of temperature and precipitation for each scenario.

5.3 Results

5.3.1 *Statistical modeling*

5.3.1.1 TEMPERATURE

In South-central BC we examined 20 stations with complete records and one station with some missing data. All of these stations demonstrated the same pattern shift. This pattern is found in cluster #2 of the nine described in Whitfield *et al* (in prep). This pattern shift is described as showing significant increases in temperature during spring and fall. Four examples of this pattern are shown in Figure A2-1 (Appendix 2).

5.3.1.2 PRECIPITATION

All 19 stations with complete records and 2 stations with a partial record represent cluster #3 from Whitfield *et al* (in prep) who found 12 clusters across Canada.
All stations within the study area show the same pattern: This pattern is described as having significant increases in summer and winter precipitation, and significant decreases in spring and early fall precipitation. Four examples of this pattern are shown in Figure A2-2.

5.3.1.3 NATURAL STREAMS

There are 21 natural streamflow stations in South-central BC with data available for the two decades of interest. Whitfield and Cannon (2000a, 2000b) found that 8 stations fell into cluster #4c and 13 stations into cluster #6. In this classification system the ‘c’ indicates a type of snowmelt hydrology which is consistent across the area. These two groups of stations each occur in spatially coherent regions: The 4c stations in the western portion and the 6c in the central and eastern portion. The 4c stations demonstrate earlier onset to spring, lower fall flows, and higher early winter flows (Similkameen i.e. 08NM134- Figure A2-3). The 6c stations demonstrate an earlier onset to spring, lower fall flows and lower winter flows (Okanagan/Kettle - i.e. 08NM142, 08NM171, 08NM174 - Figure A2-3).

5.3.1.4 REGULATED STREAMS

Whitfield (2001) examined 5 Okanagan streams with modifications of the natural flow regime: (withdrawals, diversions etc.). All the streams in this group showed decreases in discharge that was consistent across all stations. These stations in particular show statistically significant decreases in fall, winter and spring. Figure A2-4 shows four examples of this type of pattern, which only occur in the Okanagan Valley.

5.3.1.5 SUMMARY

Between the decades 1976-1985 and 1986-1995 changes in temperature and precipitation patterns were observed in south-central BC. More statistically significant changes occurred during spring and fall than during summer or winter, with significant increases in temperature and decreases in precipitation noted during these time periods.

Patterns in natural streams were characterized by an earlier onset to melting of the winter snowpack, followed by lower peak and recession streamflows during the spring, summer, and early fall months. In the western portions the study area early winter streamflows increased, while in the eastern portion winter flows decreased. The difference between these two areas is due to the 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.

5.3.2 *Analogue and process modeling*

The results are presented as a series of posters (Figures A2-5 to A2-20) to stimulate dialogue in stakeholder workshops. The first six posters are catchment specific and summarize information relevant to each of the six study watersheds. This includes: catchment description, location, land-cover, hypsometry, annual hydrographs, annual mean flow and annual snowpack. The sixth poster summarizes the snowpack simulations for all six of the study areas. Interpretation of the hydrographs is aided by knowledge of these predicted changes in the nature of snow accumulation and melts. The next four posters summarize the seasonal effects of climate change on streamflow. There are two posters summarizing the effects on the low flow season and finally there are two posters summarizing the effects on the high flow season. High and low flow magnitudes are not presented because those statistics are very sensitive to meteorological sequencing at a scale less than the resolution of the GCM's.

In general, for each of the catchment-specific posters, a shift in timing and magnitude of the annual hydrograph can be seen generally to an earlier, lower peak. The nature of the change is controlled by various catchment characteristics of which basin hypsometry is felt to be most significant. For example, Dave's creek, which has the smallest catchment area and the lowest maximum elevation, has the greatest net loss of snowpack in the modeled scenarios. As a result, winter streamflow response is, in part, enhanced as a large percentage of the winter precipitation falls below the snowline in a climate change scenario and is therefore immediately available for runoff. The large magnitude of the change in winter flow is due to an earlier snowmelt peak that occurs in late winter rather than early spring.

In graphs showing the scenario predictions in the context of climate analogues, a regression line is shown if the regression is significant at the 95% confidence interval. The presence of a line (e.g. the graph showing Dave's creek on the poster of timing of peak flow, Figure A2-7) shows that the predicted consequence is consistent with observed effects during years that have similarities with the predicted climate. The actual presence of such a trend could be confirmed by statistical analysis of the existing time-series. However, the value of a process modeling approach is for identifying those instances where the predicted consequence is out-of-range, or near the extremes in the range of observed data, but for which there is no trend with respect to the analogues (e.g. the graph for Dave's Creek on the poster of duration of peak flow). This pattern indicates that a regime-shift may be imminent which cannot be anticipated by trend analysis. In this instance, one may infer that the basin has a tolerance for inter-annual climate fluctuations which impact seasonal snowpack storage. However, the future climate may push the snow line high enough in the catchment that the basin then becomes sensitive to these inter-annual fluctuations hence causing a dramatic shift in the mean volume of the freshet runoff.

The total basin snowpack poster shows bar graphs of the model generated April 1st snowpack for each of the GCM scenarios with respect to the mean snowpack from the period of record. In every instance, the snowpack is predicted to decrease. The geo-spatial context of the decrease is quite complex, and is related to basin hypsometry, latitude and basin aspect. The largest decline in snowpack is predicted to be Dave's Creek, which is also the lowest elevation station and has a south-facing aspect. Whiteman Creek has a similar maximum elevation but is further north with an east-facing aspect and isn't predicted to experience the same magnitude of snowpack loss. The stations with the least predicted loss of snowpack are the highest elevation stations (Vaseux and Bellevue Creeks).

The seasonal posters provide interpretation of the hydrograph changes observed on the watershed posters. For example, winter season flow increases in every case, and the trend is significant with respect to the climate analogues. This response is consistent with the notion of warmer winter temperatures resulting in increased occurrence of liquid precipitation events and increased quantities of winter precipitation. The magnitude of the percentage change in winter flow is much greater than the magnitude of change for any other season. The magnitude of this increase is due, at least in part, to the advance of the spring freshet, which is illustrated on the poster showing the timing of peak flow. Enhanced winter flow has important water quality implications because the winter is typically groundwater-discharge dominated, and in an altered climate, the groundwater chemical signature will be diluted by increased surface water runoff.

The signal is less clear for mean flow during the spring season. Only two cases (Vaseux and Pearson) show a significant trend with respect to the climate analogues. In most cases the climate change scenarios predict an increase in flow during the spring, probably due to a re-apportioning of flow due to an earlier freshet. An interesting exception is Dave's Creek, which shows a decreasing trend in the climate scenarios. The spring freshet is already early for Dave's Creek and advancing the timing of the freshet moves the event into the winter season, which in turn helps to account for the extreme magnitude of the change in winter streamflow.

Summer season flow is generally predicted to decrease, and in many cases this prediction is consistent with climate analogues (e.g. Whiteman, Camp and Bellevue Creeks). One may infer that this decrease is due to less snow available in the system to augment summer flow and at least in two cases, (Whiteman and Bellevue Creeks, which have a substantial portion of catchment area at low elevation) there is already evidence of that effect. An alternate hypothesis for low summer flow is that enhanced evapo-transpiration caused by warmer temperatures may be responsible. This hypothesis is not supported by the climate analogues, which show that cool years from the period of record are among the lowest of summer flows (e.g. 1973).

The fall season predictions show no significant trends with respect to the climate analogues.

The date of peak flow is generally predicted to advance earlier in the season. However, it should be noted that the use of a 30-year climate scenario average masks important diagnostic information. For example, peak flow occurred during the fall season in 1986 and 1987 for Whiteman Creek and in the year 1979 at Vaseux Creek. Using an average Julian date for peak flow is clearly inappropriate for stations where the peak can be either in the spring freshet or in the fall. These results are presented to illustrate that while an earlier freshet peak can be expected in general, in some cases, (e.g. Whiteman and Vaseux) there will also be an increase in the number of years where the annual peak occurs in the fall.

The duration of high flow is an indirect measure of the volume of the annual peak. This statistic is used because it should be less sensitive to the problem of downscaling from the GCM data to the catchment scale than other peak flow statistics. In all cases, the climate change scenarios for this statistic are at the lower end of the scatter shown for the climate analogues, however only three stations (Whiteman, Camp and Pearson) show a statistically significant trend in the plots. Paradoxically, five of the stations (all except Pearson) show an increasing tendency within the climate change scenarios. The analogue years, which plot closest in magnitude to the scenario peak flow durations, can be cool and dry (e.g. 1979 and 1973), warm and dry (e.g. 1977 or 1987) or warm and wet (e.g. 1988). This lack of predictive capability of the analogue years reduces the diagnostic value of this statistic.

5.4 Discussion

The hydrologic sensitivity of the Okanagan landscape to climate change varies amongst catchment areas. For some streams, changes in seasonal timing and magnitude of flow will follow trends already apparent in the observed record, and the thirty year mean for each of the predicted scenarios may be within the range of inter-annual variability. In these cases, aquatic ecosystems and local economies may have the capacity to adapt to the projected change. In other instances, the results of this investigation indicate that a regime shift, outside of the realm of recent experience for local communities, may be imminent.

6.0 DIALOGUE

6.1 Ongoing Regional Consultation Process

The Okanagan Basin Water Board (OBWB) remains the primary basin wide body addressing issues that transcend district and city boundaries. The OBWB consists of three elected officials from the each of the valley's Regional Districts and is legally constituted to tax for water management initiatives agreed upon by the three Regional Districts. The mandate of the OBWB stretches beyond water quality and quantity and currently focuses on issues of sewage and aquatic weed control. The OBWB has recently been directed by the Regional Districts to improve inter-jurisdictional consultation on such issues as non-point source pollution from on-site treatment systems, storm water discharges, water conservation and to work toward more uniform valley standards and goals.

In addition to the OBWB, Fisheries and Oceans Canada has funded a 'Habitat Conservation and Stewardship Program Coordinator" to set up local stewardship roundtables and to work with local volunteers and stakeholders on specific streams and watersheds of local interest. The current stewardship coordinator is in the preliminary stages of initiating a 'Central Okanagan Stewardship Centre' in order to develop a central support, resource and coordination centre for volunteer groups and the public at large to access government resource management information for land, water and air, stewardship initiatives (CORS, 2001).

There are also other Provincial and Municipal Initiatives in the valley including; the Land and Resource Management Plan containing the "Protected Areas Strategy", the Okanagan Valley Transportation Plan and Highway 97 Inland Corridor Initiative, Regional Growth Management Strategies as well as the South Okanagan Ecosystem Recovery plan (OBWB 2000). Each of these initiatives although not focused on water specifically, have implications for water use and aquatic habitat in the Okanagan Valley.

There remains little direct collaboration between the various districts and city water managers in the basin due to limited communication lines and heavy workloads. Currently some streamlining of water suppliers and water purveyors is taking place in order to improve the general efficiency of water management and delivery in some areas but, a broader, more inclusive, basin wide management approach to water resources is not expected in the near future.

6.2 Focus Groups

The focus group is the most commonly known type of group interview. Conceived by sociologists (Merton *et al*., 1956) during the 1940s, it is most commonly used for marketing and to a lesser extent, political purposes. The focus group is primarily an exploratory tool, a self-contained means of data collection, or a method that can profitably be used in combination with other techniques. It was all three in these workshops.

The focus groups we employed were usually comprised of about 7-10 people, with a minimum of 4 and maximum of 12. The purpose was to allow for shared insight and diverse understandings of the issues. Most of the focus groups were comprised of participants who knew, or knew of one another, although there were enough strangers to avoid the development of hierarchical relationships and reluctance to discuss contrary ideas (group-think),

Focus groups are distinct from other group interactions because they produce data of specific interest to the researcher. Not intended to develop consensus, they are the best way to express the desire to learn from participants' greater experience. These focus groups provided every individual with the chance to make a contribution. They kept one person or a coalition of individuals from dominating the group and encouraged shy or inhibited group members to participate. We were able to obtain responses from the entire group so as to ensure the fullest possible coverage of the topic.

6.2.1 *Focus Group: Agenda Script*

The January & March workshop agendas followed a "script" of planned exercises. After a period of time to allow the participants to view posters illustrating the climatic and hydrologic trends and scenarios (Sections 4-5) and to ask questions, the workshops began.

The January gatherings had three objectives, the overarching goal of which was to begin a regional dialogue on climate change implications for water operations.

1. To determine the impacts of climate change on water resources
2. To determine if the impacts scenario makes a difference to stakeholders' operation and use of water, and
3. To identify potential adaptations to climate change.

Each of the meetings began with the presentation of the models and their first order impacts. Following this step, we asked participants why this information mattered, the corollary of which asks participants why they were in attendance. Pairs of participants created a list of reasons of why they are concerned about what the hydrological model represents for their operation or institution.

The purposes of this exercise were:

1. To explain what the climate and hydrology models suggest before discussing regional impacts.
2. To give participants an opportunity to explain "where they are coming from" to others in attendance.

The next step focused on identifying past, present, and future (scenario) impacts. In pairs, participants brainstormed the possible impacts (present and future) of climate change for their operation in this region of the Okanagan. Again, people worked in pairs for 15 minutes, and this was followed by a round table of 30 minutes. The purposes were:

1. To link model-based scenarios to local observations and perspectives.
2. To list potential impacts of scenario changes in climate and hydrology (Box 6-1).
3. To consider impacts that are already happening in another location and whether these could be replicated here.

In the first of the three January workshops, we had participants cluster the impacts into scenarios, a kind of "where-we-are-heading" detailing of four future scenarios. The clustering of these impacts was designed to act as a precursor to a discussion of future adaptation scenarios. We placed the impacts on a continuum (e.g., cost- benefit and immediate – delayed). We then asked the participants to pick two by vote, with the 2 most diverse being the criteria. After we chose quadrants we then fit impacts into the 4 quadrants. The impacts were “plotted out” into the relevant quadrant. This means that impacts might be closer or farther from the middle where axes intersect.

BOX 6-1. Examples of Climate Change Impacts Suggested by January focus groups
Climate Change Impacts (on water management) • Extended growing season • Increased demand for irrigation • Management of seasonal shortages/scarcity • Reduced water quality • Degradation of fish habitat • Increased water-use conflicts.

This work proved difficult and the decision was made to advance the March workshop objective of getting concrete expressions of impacts (e.g., specific amounts of monetary costs associated with low water levels etc). The result was that the third breakout session featured the illumination of the impacts using three questions:

1. Are these impacts public, private, or both?
2. Are many people going to be affected or just a few?
3. Who are the players who could respond to this impact?

The March 2001 workshop had three objectives that were directly related to the January ones. These were:

1. To generate adaptation priorities based on the impacts and implications list that was generated in January.
2. To determine the implications of prioritized climate change adaptation options.
3. To gather input on future research and dialogue.

Participants were organized into topical breakout groups (Agriculture, Forestry and Ecosystems, Health and Recreation, Infrastructure/Land Use/Tourism). In the first breakout session, each group was to brainstorm adaptations to each of the climate change impacts in the water regime. We then prioritized the adaptations by having each group brainstorm adaptation options and then shared these with the whole group. The breakout groups then ranked items on the list by choosing the four they thought were most important. Box 6-2 provides some examples (see Section 6.3 for more discussion).

BOX 6-2. Examples of adaptation strategies (for water management)
• Increase the supply of water • Increase storage facilities • Seek new sources • Use reclaimed water for non-potable use • Reduce the demand for water • Water conservation programs • Reduce irrigated acreage • Adopt agricultural practices that reduce soil moisture loss

A second breakout session examined the implications of adaptations for water operations. Participants were re-assigned into 4 new mixed non-sectoral groups where each member brainstormed with a partner on the possible impacts (present and future) of adaptation choices for their operation or area of interest. These are the intended and unintended consequences of pursuing alternatives such as increasing supply and decreasing demand (e.g., discussion of costs/benefits/risks associated with these strategies such as increasing storage facilities). An example is shown in Box 6-3.

BOX 6-3. Example of Implications of Adaptations for Agriculture

Adaptation	Costs	Benefits	Risks
Increase water storage capacity on farms	• monetary investment • land required for sitting of reservoirs • land use concerns associated with location of reservoir • environmental concerns associated with building reservoir	• ensures adequate water supply for crop irrigation • insures against drought (peace of mind) • side benefits: can use water for non-agricultural use, if needed	• money invested in building new reservoirs, but extra water not immediately required (over-preparation)

We then brainstormed on the dialogue that needs to take place and how future research can facilitate this dialogue. Essentially a 'next steps' conversation, we saw the need for three kinds of feedback. The first asked participants how they thought we should continue the climate change dialogue? We also sought insight on the process for dialogue on impacts/adaptation; that is, which groups need to talk further or who should take charge to implement an adaptation. The third question involved the identification of research needs or knowledge gaps. This step replaced an evaluation of the workshop as it constituted an assessment of the whole process.

6.3 Stakeholder Reaction to Scenarios

6.3.1 *Data analysis*

Dialogue with workshop participants was recorded on flipcharts and in the notes of the participants at the meetings. Following the meetings, the notes taken by each pair of facilitators from each of the workshop groups were merged, resulting in the production of three aggregate documents: impacts, adaptations, implications. Figure A3-1 summarizes the discussion from the workshops: the first box shows the modeled impacts, the second box shows the impact areas that were ranked in the first set of workshops, and the third box shows the ranked adaptation options that were the product of the full-day workshop in March. These three documents were used as the basis of the data analysis. The feedback from each group in these documents was clustered by the sector they described and a coding process was used to do this more systematically. It should be noted that a number of comments from the meetings are not reflected in this analysis since they were not consistent with the approach of the project. The first was a resistance to the notion that we should intervene on any level in response to climate change impacts. The second assertion that reappeared a number of times during the workshops was that the effects of climate change would be swamped by the impacts of future population increases in the region, and associated demands that would be created for water resources and land.

The notes were analysed using *Atlas/ti,* a qualitative data analysis tool (as was previously done in Cohen *et al*., 2000). The data analysis process involved the coding of the text in the documents in order to reduce the amount of data and to enable the researchers to make some generalizations from the workshops. The process of coding involves labeling sections of the text with discrete codes with comments attached to each one. The comments elaborate on the meaning of the code and a single code may be allocated to many sections of the text if this represents a recurrent theme. The meaning of the code is developed in the comment as it is assigned to a greater number of segments of the text. Once an internally consistent list of codes has been developed, the codes themselves can also be clustered in order to identify further levels of generalization. The remainder of this section focuses on the interpretation of the data through this process.

Figures A3-2 to A3-7 are flow charts that illustrate the results of the discussions on impacts and implications in the first set of workshops. Six sectors are profiled. The first set of boxes at the left of each figure show the modeled impacts. The second set of boxes show the impacts specific to each sector (health and recreation, agriculture, forestry, infrastructure, ecosystems, fisheries). The third set of boxes are further implications of these impacts that came out during the workshop discussions. For instance in Figure A3-7, Fisheries Impacts and Implications, the figure illustrates how higher temperature will lead to eutrophication and lower oxygen, the implication of which is higher fish kills.

6.3.2 *Impacts*

The groups at the March workshop were presented with the climate change impacts identified in the January workshops. The notes from these meetings have been edited so that they only include only the primary impacts of the climate change scenarios. Primary impacts refers to the direct impacts of climate change on biogeophysical systems as distinct from impacts that result from adaptation, i.e. increased demand on groundwater. The impacts are summarised in Table 6-1.

Table 6-1. Okanagan Climate Change Impacts

Sector	Impacts
Health and Recreation	• Increased risk of water-borne diseases • Decreased water quality • Short winter recreation season • Decline in summer water quality • Change in sport fishery • Summer instream quantity decline • Drought stressed forests • Longer growing season
Forestry	• Species viability change • Longer growing season • Soil stability problems (erosion) • Change in harvesting seasons • Changes in disease and pest regimes • Change in forest fire frequency and intensity
Agriculture	• Higher crop yields and variety (higher CO2) • Negative impact on dry land agriculture • Longer growing season • Warmer winter (less winter kill of pests) • Changes in pests, loss of beneficial pests and new invasive species • Changes in disease affecting crops and livestock • Changes in weeds and invasive species • Where crops grow best will change (species shift) • Less water available (more evapotranspiration, lower flows in fall) • Climate extremes limiting agriculture potential
Fisheries	• Temperature change • Aquatic weed growth (eg millfoil) • Fish species shift: Good for carp, bass, Bad for salmonids • Fish abundance [and distribution] changes • Change in aquatic food chain • Longer growing season • Eutrophication and lower dissolved oxygen • Flow change • Longer low flow periods • Impacts on fish lifecycle: Delayed spawning, early migration downstream • Changes in waterfowl lifecycle • Increased sediment [and turbidity] • Lower oxygen due to lower turbulence
Infrastructure and Urban Land Use	• Increased fire potential • Increased risk to homes • Increased water demand • Domestic • Extended irrigation season • New uses (i.e. dust control) • Increase in water-borne diseases • Water supply decreased • Change in hydrology- higher, earlier peaks • Water quality, erosion increases
Recreation and Tourism	• Species shift/ ecosystem change • Winter recreation impacts • Shorter season

	• Ski hill investment • Decreased lake levels • Impacts on sport fish • Shift in fish habitat • Decreased soil stability • Increased nutrients/algae • Summer in-stream quantity and quality decline
Ecosystems	• Shift in biogeoclimatic zones • Differential impacts by elevation • Increased pressure on endangered species-birds • Vegetation and forestry changes included riparian • Changes in insects species/abundance • Change in habitats (increase grasslands) • Infiltration by new insect species from south • Lower insect mortality during winter • Amphibian habitat loss • White pelican migration north • Bird food supply • Migration of non-native plant species into the area (millfoil) • Desertification • Species migration through corridors

6.3.3 *Climate change adaptation*

In the March session, the breakout groups focused on adaptations to the range of climate change impacts that had been identified. These findings were the most significant of the day and the analysis of adaptation is in two parts. The first section below maps out the codes, which describe the different general forms of adaptation. These are clustered into structural adaptation, social adaptation and 'other'. The numbers beside each code describe the number of times the code appears in the notes.

Structural Adaptation
Of the total list of responses to impacts, structural measures were most common. The approaches suggested responding to reduce the impacts of climate change, without changing social practices. The most frequent comment was the need to intervene in natural systems to prevent changes in the availability of natural resources. In addition, there was a strong emphasis on the need for defensive expenditures to ameliorate the effects of changed conditions. The mechanisms for mitigating the effects are described in the next three codes, which recommend regulation through pricing, access and land use.

Social Adaptation
In contrast to structural measures, this cluster of comments suggests that a response to climate change impacts in to change social practices. These suggestions ranged from changing energy and water supply technologies, through to the need for public education and lifestyle change

Other
The final three codes are fairly self explanatory. The group suggested that alternative governance structures needed to be considered, that more research was required to support decision making and that it might be most appropriate to take a 'hands off' approach that allows biogeophysical to evolve in response to changing conditions.

Table 6-2. Adaptation to Climate Change Impacts

Cluster	Code – (occurrences)	Comment
Structural Adaptation	Intervene-24	Human intervention to prevent impacts, i.e. more snow making. Implies no change in use but interventions to maintain status quo e.g. fish species. Help migratory fish move upstream. Build upland dams and regulate flow. Control erosion. Increase fish hatcheries and decrease fish take. Improve riparian areas to offset climatic impacts. Increased retention of stormwater. Plant new genetic varieties and introduce new technologies for pests.
	Defensive expenditure-10	Investment in defensive infrastructure i.e. fire protection. Improve warnings and signage. Spend on medical treatment for water borne disease and increase water quality treatment. Buy out water licences. Aerate lakes to compensate for temperature changes. Increase species diversity to increase resilience.
	Priced regulation-5	Regulate resource use, i.e. water, through pricing and metering.
	Regulate access-4	Regulate access to ecosystems, increase conservation of species.
	Regulate land/water use-17	Control forms of agricultural land use, land use ecosystem oriented. Change land use to for change lake and creek levels. Control irrigation. Protect watersheds and ecological corridors. Prevent clearcutting. Reduce fertilzer use.
Social Adaptation	Alternative resource use-16	Develop alternative infrastructure in response to changes in demand i.e. alternative energy sources. Small scale water storage. Find alternate water sources, use grey water systems. Plant different crops. Change timing of irrigation and harvesting practices. Manage in terms of ecological costs. Keep options open to CC.
	Educate to change-4	Educate people to reduce risks i.e. building materials. Increase demand management. Educate people about ecosystems.
	Lifestyle change-8	Change leisure lifestyle, i.e. different winter sports, different fishing. Reduce watering of lawns and water consumption. Change the 'need for green'
	Land use planning-12	Densification of urban land use, control of development processes, better and appropriate land use planning. No encroachment on fire zones.
Other	Hands off-5	Reduce the number of dams and allow for natural regulation. Allow species to adapt to Climate change. Reduce chlorination
	More research-5	Need to know more about flow regimes, snowpack etc. Better understanding of habitats before intervening
	Improve governance-3	Better integration among agencies. Watershed level management.

Having identified this wide range of adaptation options, the workshop groups were asked to prioritise the options. The adaptation options are listed here:

- Use water more efficiently
- Pay for water
- Restrict development and or population
- Irrigation methods (practices, systems)
- Metering
- Inventory supply and prioritize water users
- Water licensing
- Increased enforcement
- Change in timing
- Buyouts
- Develop more water storage/other sources
- Regulate flow and erosion through dams
- Adapt silviculture practices
- Develop new seedling varieties (forestry)
- Better integration of government agencies
- Include climate change possibilities when making land use decisions
- Consider ecological costs in resource management
- Consider social costs, making adaptation decisions

6.4 <u>Implications of Adaptation Choices</u>

In many ways, thinking through the implications of the adaptation options that were proposed was the hardest part of the workshop. These implications are third order effects of climates, the unintended impacts of adaptation interventions in response to the bio-geophysical impacts of climate change. The notes from the meeting were edited to exclude comments that were not consistent with the definition of implications we provided to the groups. The most common error was to confuse adaptations with implications. The options and their implications were then clustered and edited to reduce duplications. The final list is included in Table 6-3.

This list includes a mixture of predicted implications and expressed needs for additional research or changes in consultative processes associated with a particular option. These needs may become barriers to implementation.

Table 6-3. Implications of Adaptation Options

Adaptation	Implication
Water Licensing	Through metering • It is difficult for people to give up their own use for downstream users • economic costs of retrofitting • political costs of implementation, especially if retroactive. • Sensitivity to increased licence rates • External demand for Canadian water Through restrictions on development • politically unpalatable to concentrate population • different attitudes by generation • population control here may attract more migrants Through changes in irrigation methods • fiscal costs when compensation required • positive implications for natural forests Through greater enforcement • keeps everyone equal

	• need for more officers and bureaucracy, leading to greater costs • resistance due to ignorance • government accountability at the local level By changing timing of releases • need education for people responsible for water management • affects agriculture and tourism – need for balance across sectors • implication for hydro
Regulate Flow through Dams	Less vulnerable to natural fluctuations With dams- not able to return to natural hydrograph Water storage- good sites already gone (cheap sites) If site is too low- water quality is impacted Need to make sure there will be enough water to fill up the dam! Affects fisheries coming downstream Loss of peak flow → a change in stream cross section Dams effect erosion positively (regular, creates habitat) and negatively (change in physical structure such as wetland and habitat loss) Infrastructure costs $ (capital, maintenance) Save $ in flooding costs BC Hydro makes $ Displacement of people, animals etc. Habitat implications of reservoirs: mercury release? Metals? Uranium? Decreased nutrients downstream
Better integration of government agencies	Harmonization of common goals- different levels Stewardship groups should give input into policy
Climate change and land use	Need to consider land AND water use Need better science More accurate models are needed to increase confidence Opportunity to let people know (with information age) what is happening Resistance by vested interests to change land use access
Population control and restricting Development	Politicians need to play a role- they tend to support growth Creates conflict in communities over change, growth, use
Adapt silviculture Practices	Species may not survive for 100 years (ones being planted now)
Cost implications of Adaptations	Societal costs of increasing water efficiency/management. Who pays? Is cost recoverable? Equity implications of water management (low income burden) Development restrictions will inhibit ability to respond (tax base) Socio-economic vulnerability increases Globalization intensifies this challenge Valuation is inherently divisive when cooperation is needed Resistance because of changes in wealth distribution Concerns around demands for compensation

7.0 FUTURE WORK

This study has brought together different forms of knowledge to initiate a dialogue on water resource management and climate change in the Okanagan region. Some insights have been obtained from this exercise, but challenges remain. Can a basin-wide scenario of hydrologic impacts be constructed? Can different scenarios of adaptation be explored to see their impacts on water and land use? Can an integrated assessment for the region be produced, incorporating results of simultaneous assessments of land and water use, using common scenarios?

During the March workshop in Kelowna, participants were asked to recommend next steps for this process. These are summarized in Table 7-1.

Table 7-1. Next Steps for Okanagan Water Resources and Climate Change Studies.

	Climate	Water Supply	Water Use	Other
Institutional		• Centralized water authority with technical/research capabilities	• Groundwater legislation	
Modelling	• Regional scenarios	• Effects of dams and land use on water temperature	• Land & water use scenarios	
Monitoring	• Snowpack and related indicators	• Shifts in Okanagan hydrologic regime • Trends in other regions	• Trends in other regions	• Flora and fauna
Outreach			• Options for dryland landscaping	• Regional water-related success stories
Research Support		• Inventory/archive of surface water & groundwater • Data collection standards	• Inventory/archive of surface water & groundwater use • Data collection standards	

Workshop participants also raised a number of questions regarding research process. How could a multi-stakeholder dialogue be sustained? How could values and individual priorities be accounted for in research (e.g. determining an 'appropriate balance' in water use among various users)? Are there analogues of future Okanagan climate/water scenarios already visible in other regions (e.g. eastern Washington state), and if so, how could these contribute to the dialogue in the Okanagan?

This study showed that regional scenarios of changing climate and hydrology could be constructed in a short time, and be communicated to regional decision makers and stakeholders as part of a dialogue on the future of water in the Okanagan. In order for this effort to be effective over the long term, research, monitoring and dialogue need to be sustained. That is the challenge that faces anyone concerned about the regional implications of climate change.

The multi-disciplinary character of climate change means that many are interested but few make direct investments. Climate change science has a natural home within the atmospheric sciences and related disciplines (e.g. oceanography, ecology), but climate change impacts/adaptation has difficulty finding room at the Inn, or in knowing which Inn to go to. Regional circumstances are unique, and local knowledge has an important role to play in impacts/adaptation research, monitoring, dialogue, and ultimately, some form of response. It is hoped that this case study experience will lead to the evolution of a regional home for climate change dialogue in the Okanagan.

8.0 ACKNOWLEDGEMENTS

The research team consisted of the following:

- **Team Leader**
  Stewart Cohen
- **Climate Scenarios**
  Bill Taylor, Roxanne Brewer, Eric Taylor
- **Hydrologic Scenarios**
  Stuart Hamilton, Dave Hutchinson, John Martin, Jacek Scibek, Paul Whitfield
- **Trout Creek Case Study**
  Erin Embley, Ken Hall, Les Lavkulich
- **Stakeholder Dialogue**
  Rob VanWynsberghe, Wendy Avis, Jeff Carmichael, Maggie Julian, Tanuja Kulkarni, Pamela Robinson, James Tansey

This study was funded by the Climate Change Action Fund, Govt. of Canada (Project No. A-206). Additional in-kind support was provided by Environment Canada (Adaptation & Impacts Research Group, and Pacific & Yukon Region) and the University of British Columbia (Sustainable Development Research Institute, and Institute for Resources and Environment).

We would like to express our appreciation to Greg Armour (Okanagan Basin Water Board), Michelle Broshard (Okanagan Similkameen Boundary Regional Stewardship Coordinator), Ted van der Gulik (B.C Ministry of Agriculture), Dawn Machin (Okanagan First Nations Alliance), Peter Schwarzhoff (Environment Canada) and Kim Hyatt (Department of Fisheries and Oceans) for their assistance in identifying regional contacts and publicizing this study.

We would like to thank those who participated in the January and March workshops; Kevin Ade, Jack Allingham, Greg Armour, Jane Bender, Heidi Bennett, Scott Benzer, Janette Bigney, Mary Bowcock, Steve Bryson, Ron Cannan, Barrie Clark, Renee Clark, Stan Combs, Jeff, Curtis, Lorne Davies, Les Deuling, Peter Dill, Mike Dorion, Paul Doyle, Joe Falkoski, Ted Fuller, Steve Gormley, Tracy Gow, Sylviane Guernier, Leah Hartley, Web Hallaver, Juergen Hansen, Robert A. Hawes, Markus Heiunrichs, Greg Henderson, Laura Hooke, Brian Jantz, Ted Jeffery, Ray Jubb, Walter Koch, Darwyn Kutney, Shayla Lawrence, Terry MacDonald, Don McKee, Bruce Mohen, James Moller, Jules Morris, Lisa Mose, Denise Neilson, Smiley Nelson, Harrold Norris, Brian Nuttall, Janine Nyvell, John Parsons, Allan Patton, John Peshbridge, Toby Pike, Denis Potter, Peter Schwarzhoff, Elaine Sharp, Jim Shaver, Dave Smith, Scott Smith, Carmen Stanek, Judie Steeves, Bruce Sumner, Andrew Swetlishoff, Jake Theissen, Ian Walker, Lena Warrington, Mike Watkins, Mark Watt, Dean Watts, Allen Weins, Roger Wysocki

We would also like to thank Troy Gauthier of the Sustainable Development Research Institute for his computer support.

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APPENDIX 1: Climate Observations

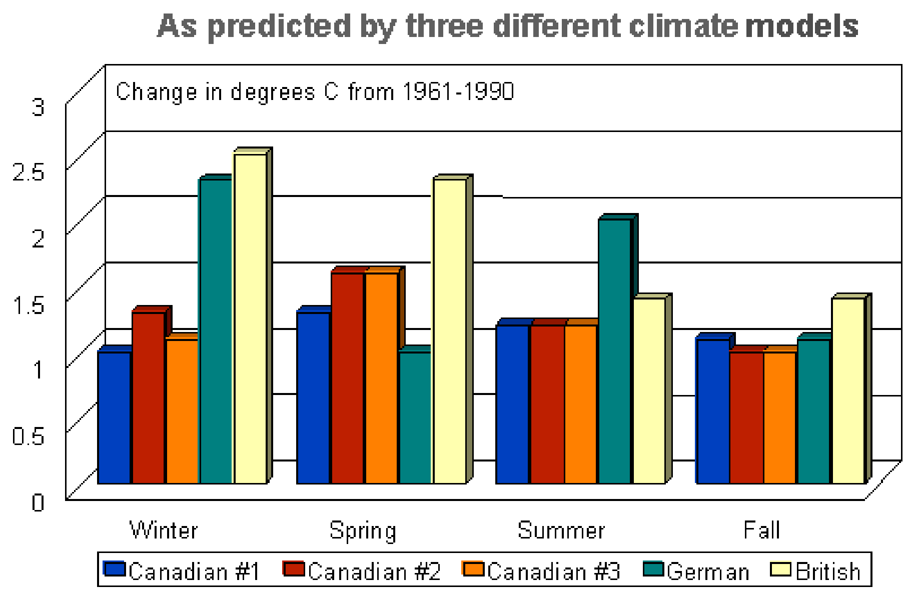


Figure A1-1. Seasonal Change in Minimum Temperature (°C) in the Okanagan Basin – 2020s

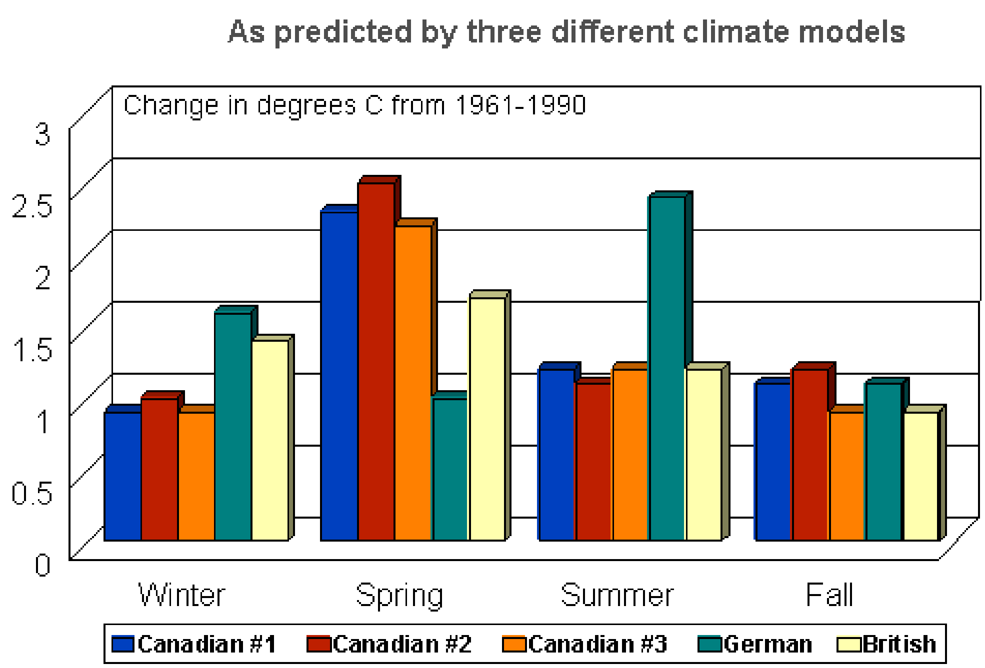


Figure A1-2. Seasonal Change in Maximum Temperature (°C) in the Okanagan Basin – 2020s

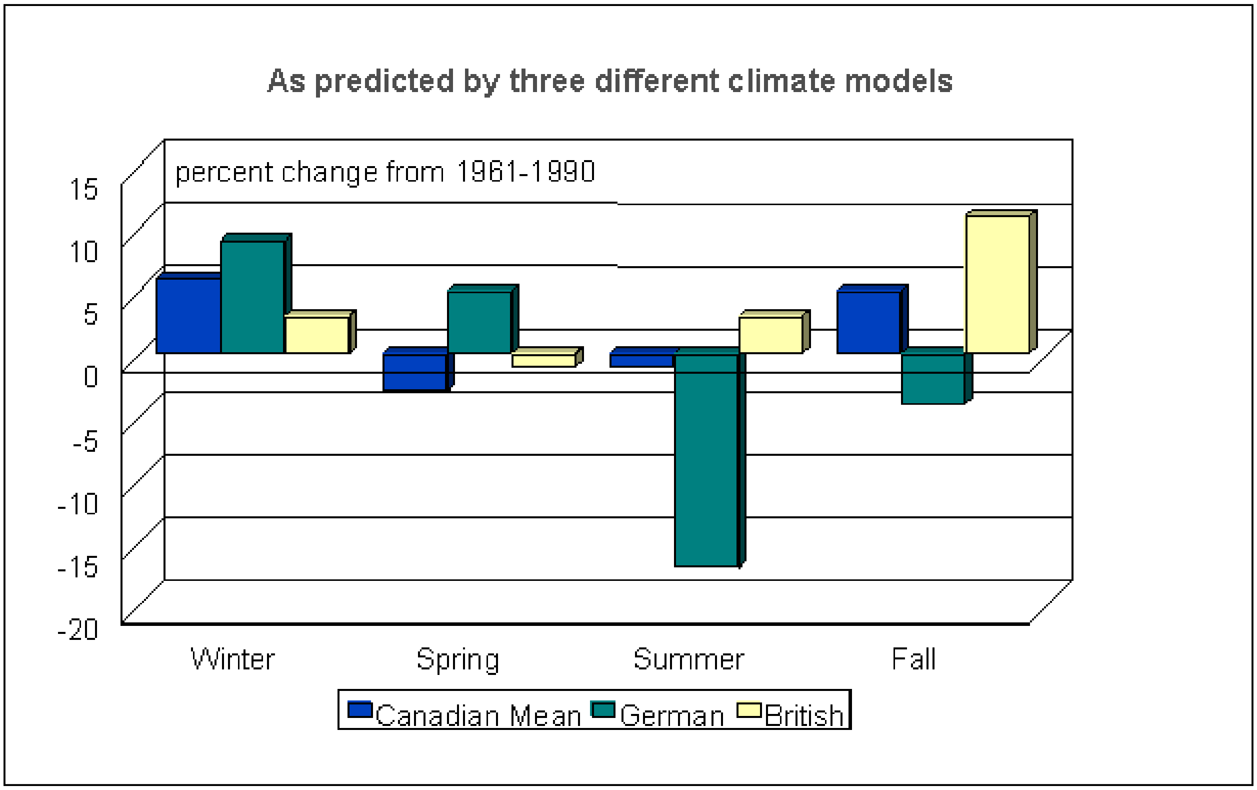


Figure A1-3. Seasonal Change in Precipitation (%) in the Okanagan Basin – 2020s

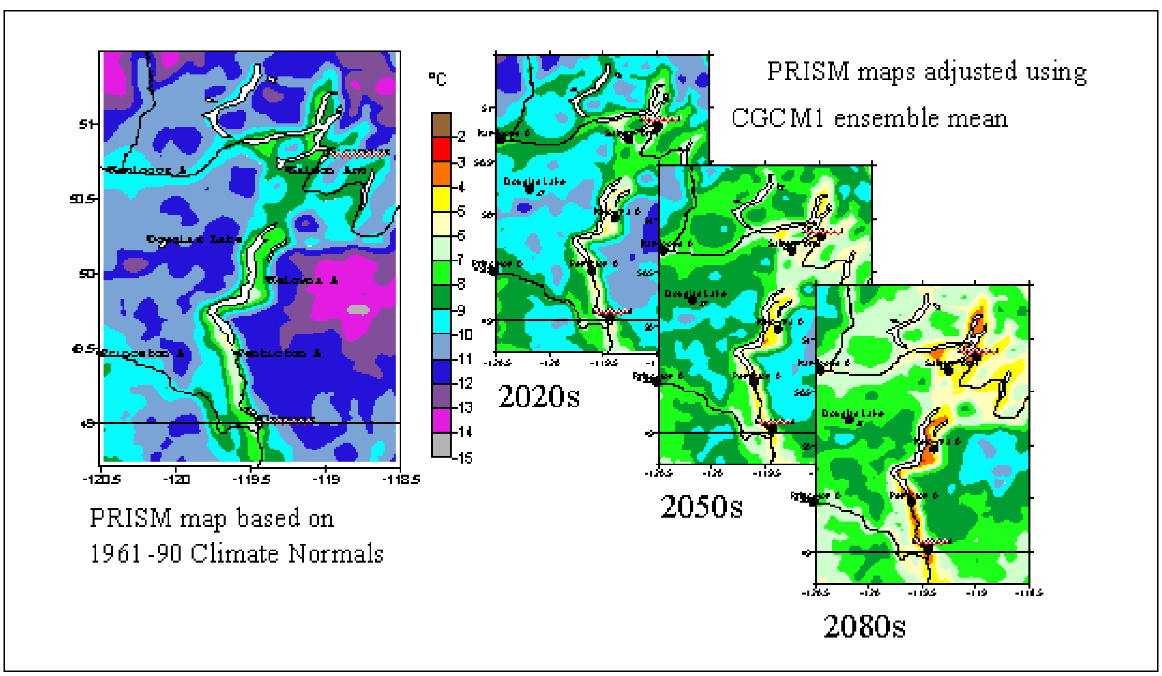


Figure A1-4. Projections of January Mean Minimum Temperature in the Okanagan Basin

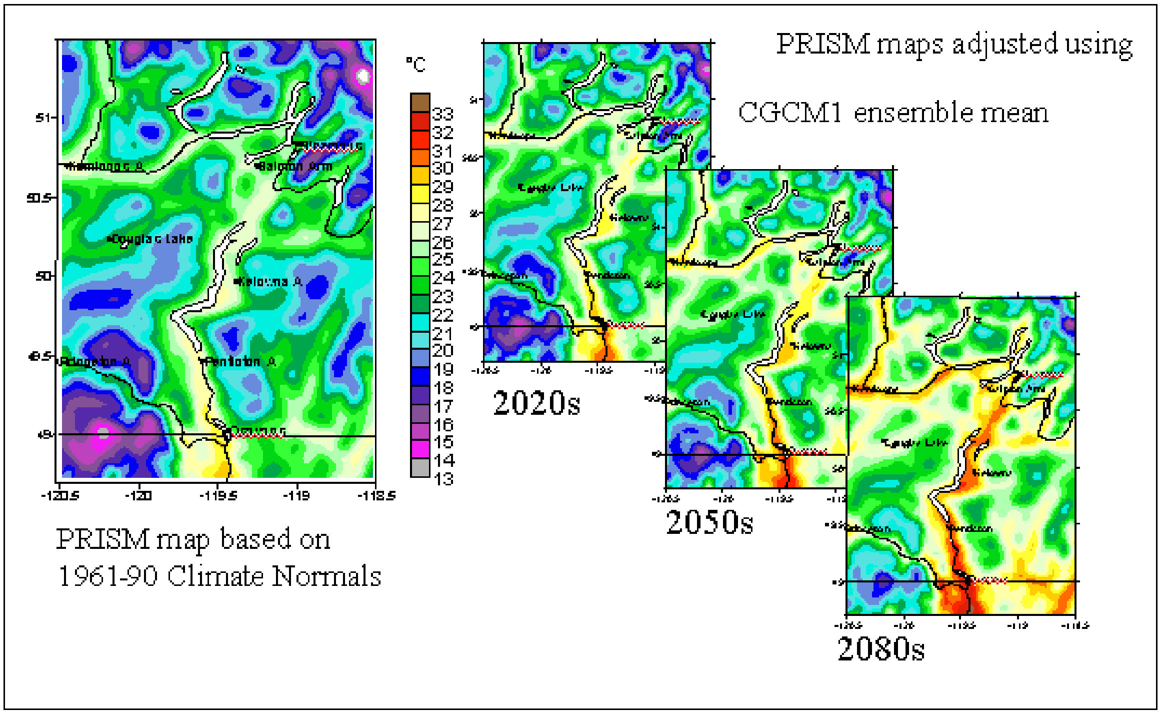


Figure A1-5. Projections of July Mean Maximum Temperature in the Okanagan Basin

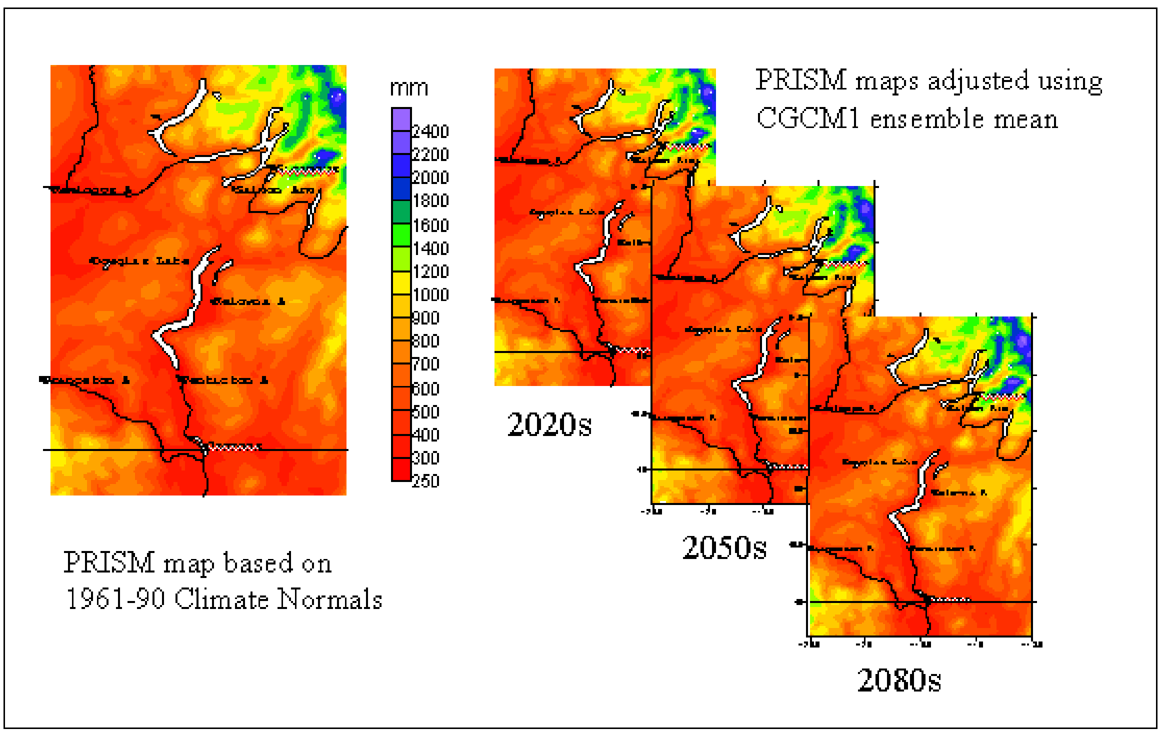


Figure A1-6. Projections of Annual Total Precipitation in the Okanagan Basin

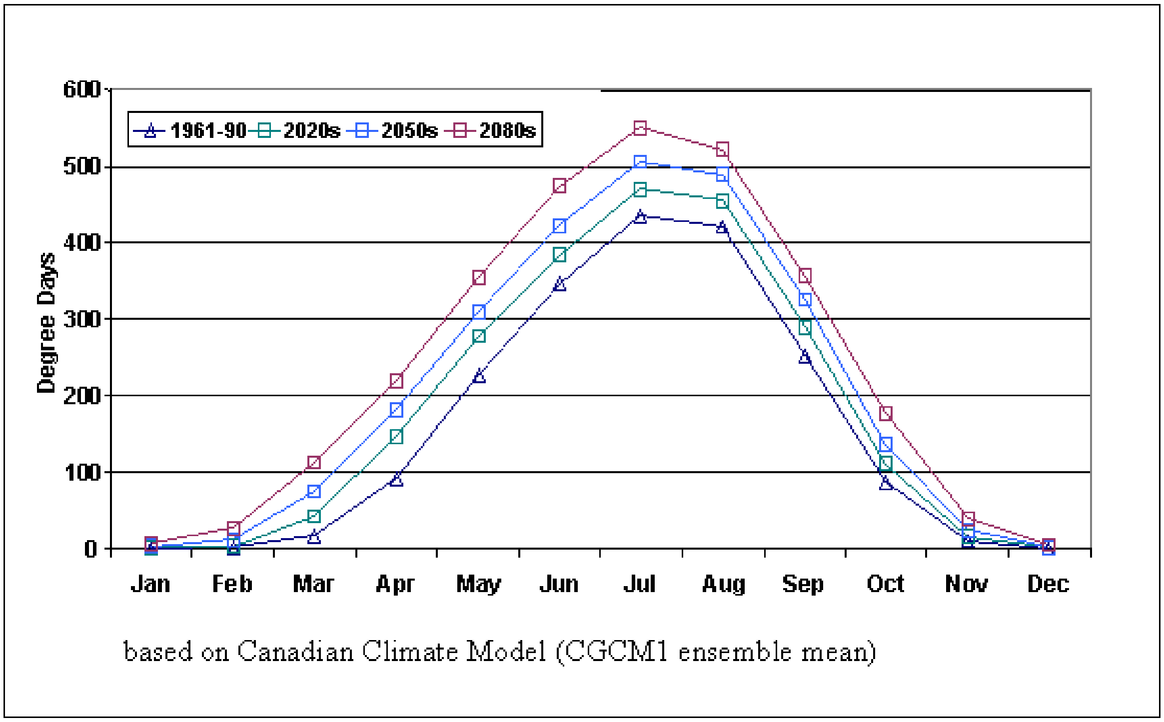


Figure A1-7. Projected Changes in Growing Degree Days (> 5°C) at Kelowna Airport

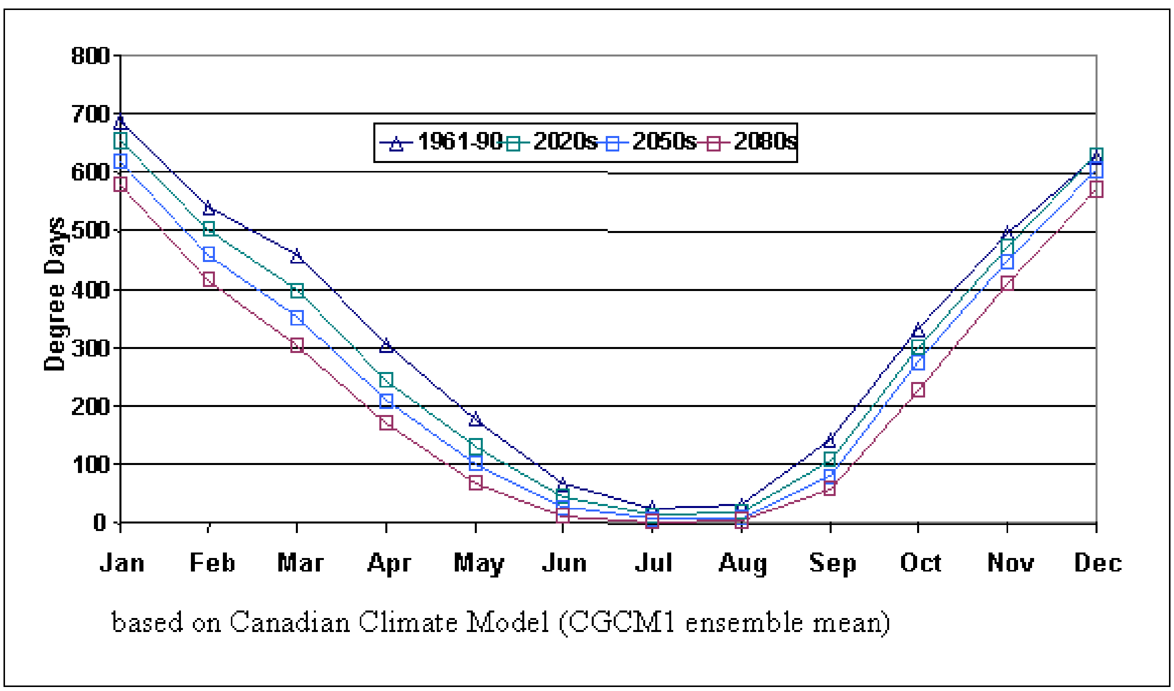


Figure A1-8. Projected Changes in Heating Degree Days (< 18°C) at Kelowna Airport

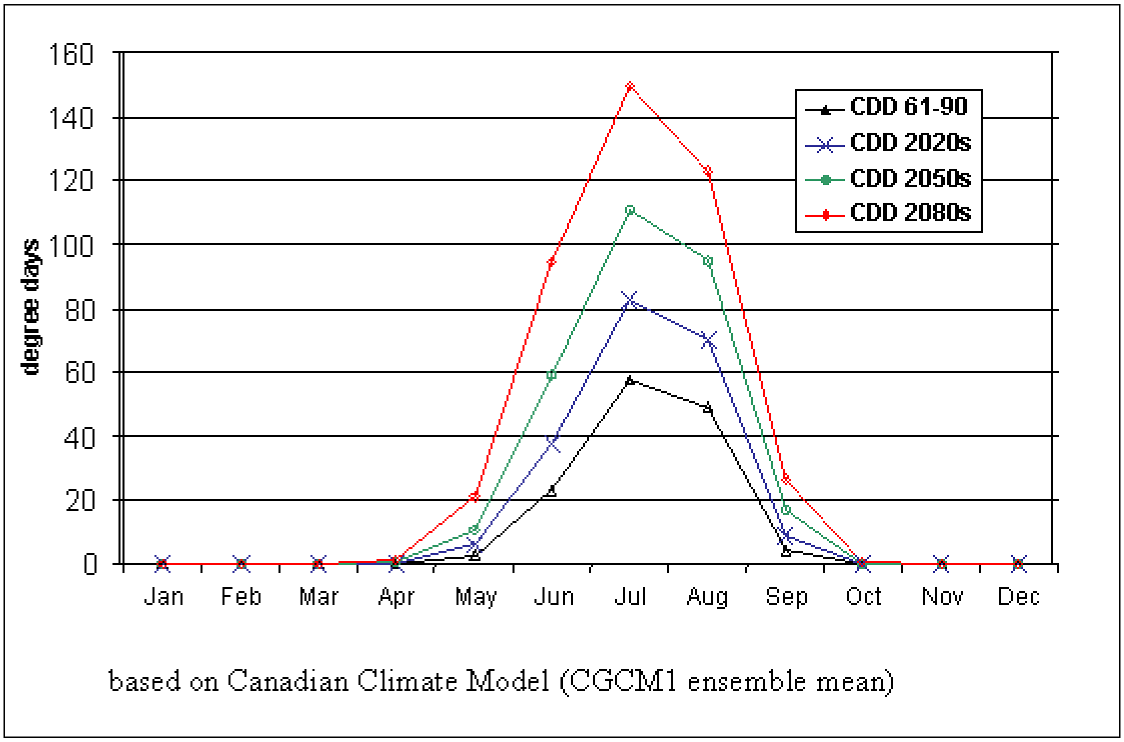


Figure A1-9. Projected Changes in Cooling Degree Days (> 18°C) at Kelowna Airport

APPENDIX 2: Hydrological Observations

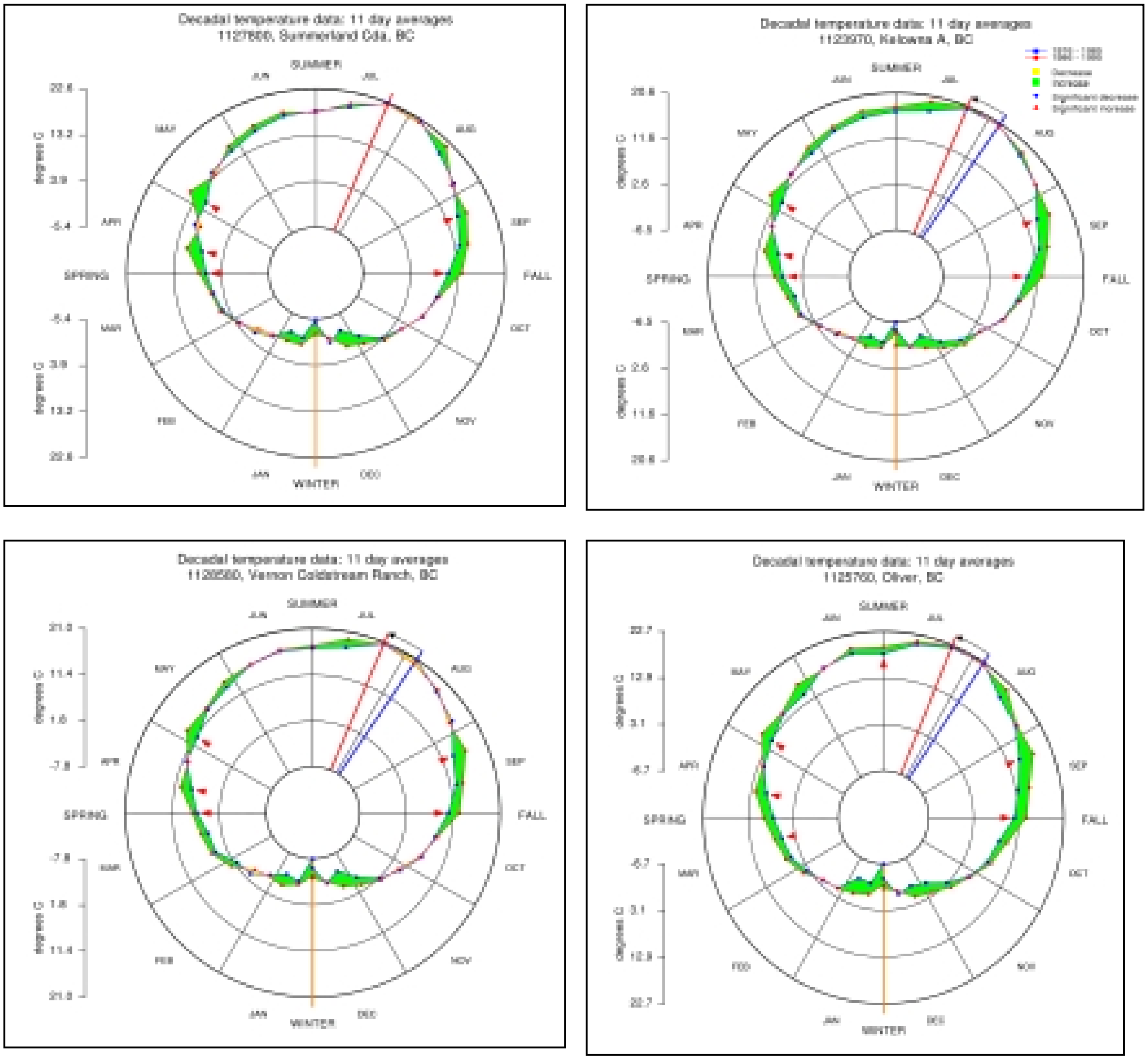


Figure A2-1. Examples of recent shifts in temperature for 11 day time periods in the Okanagan Valley. Green indicates an increase between the two decades and yellow a decrease. Arrowheads indicates statistical significance.

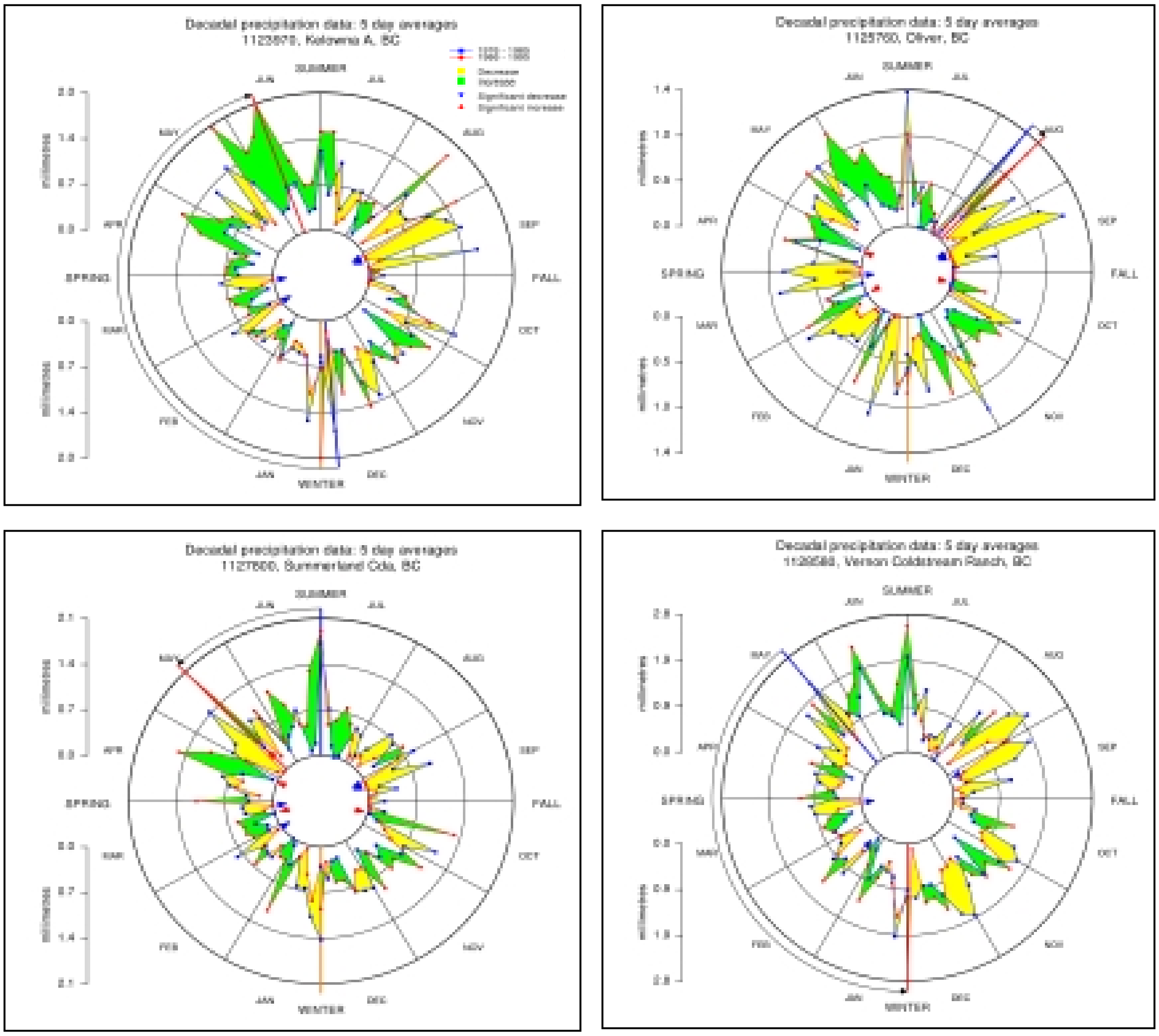


Figure A2-2. Examples of recent shifts in precipitation for 5 day time periods in the Okanagan Valley. Green indicates an increase between the two decades and yellow a decrease. Arrowheads indicates statistical significance.

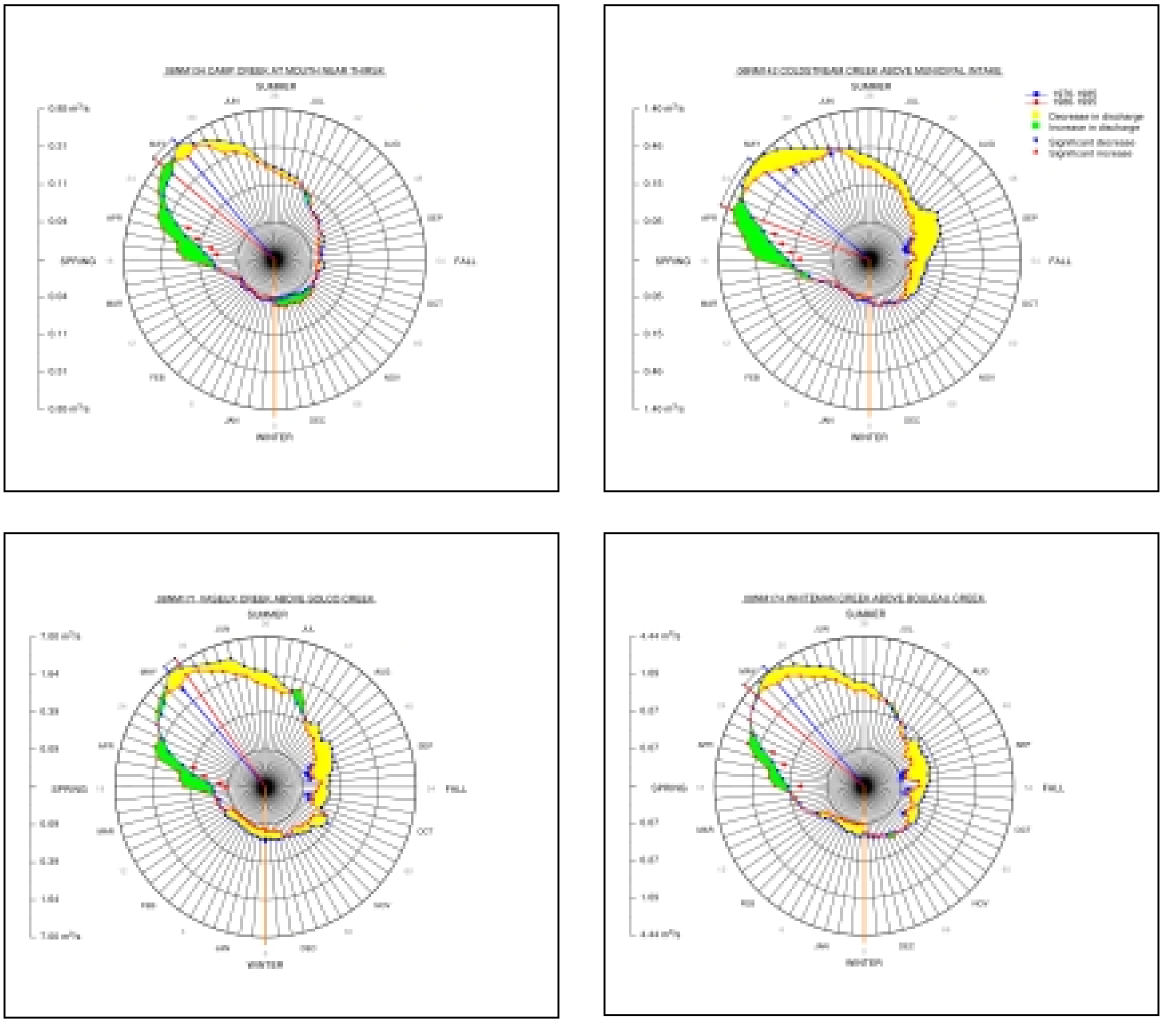


Figure A2-3. Examples of recent shifts in natural streamflows for 5 day time periods in South-central BC. Green indicates an increase between the two decades and yellow a decrease. Arrowheads indicates statistical significance.

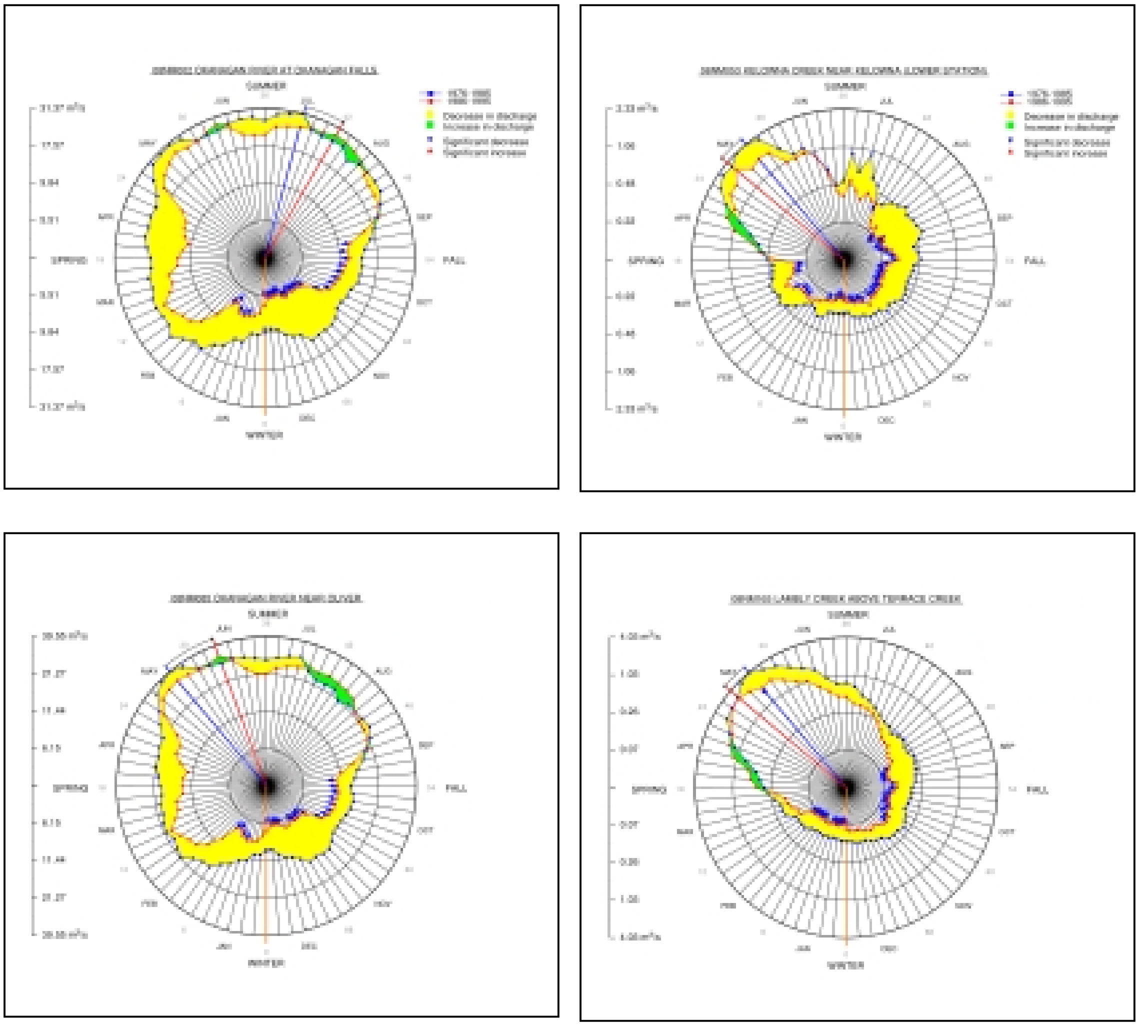


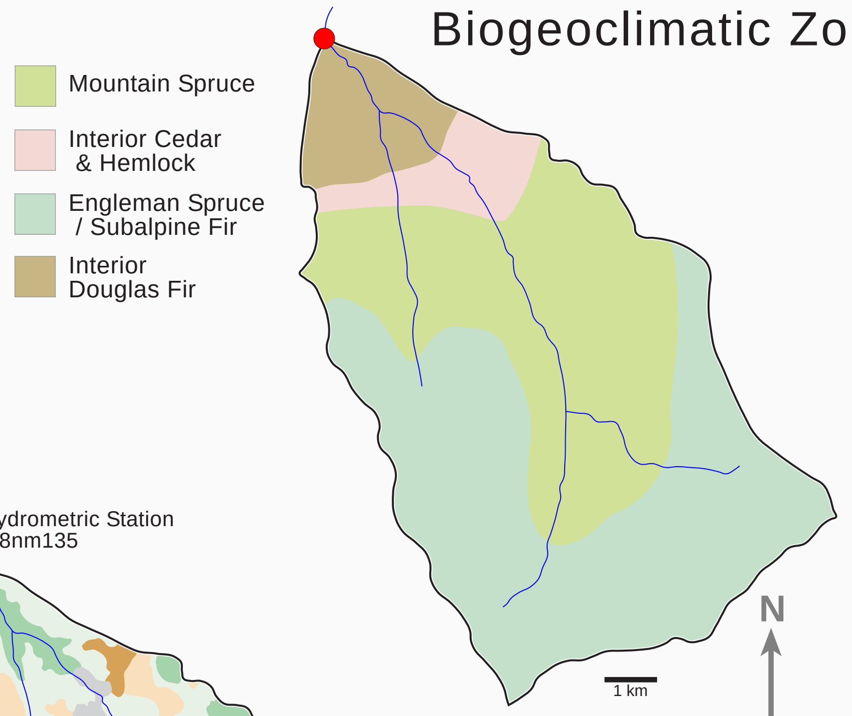
Figure A2- 4. Examples of recent shifts in altered streamflows in South-central BC. Green indicates an increase between the two decades and yellow a decrease. Arrowheads indicates statistical significance.

Table A2-1 Description of hydrometric and climate stations used for hydrological modeling

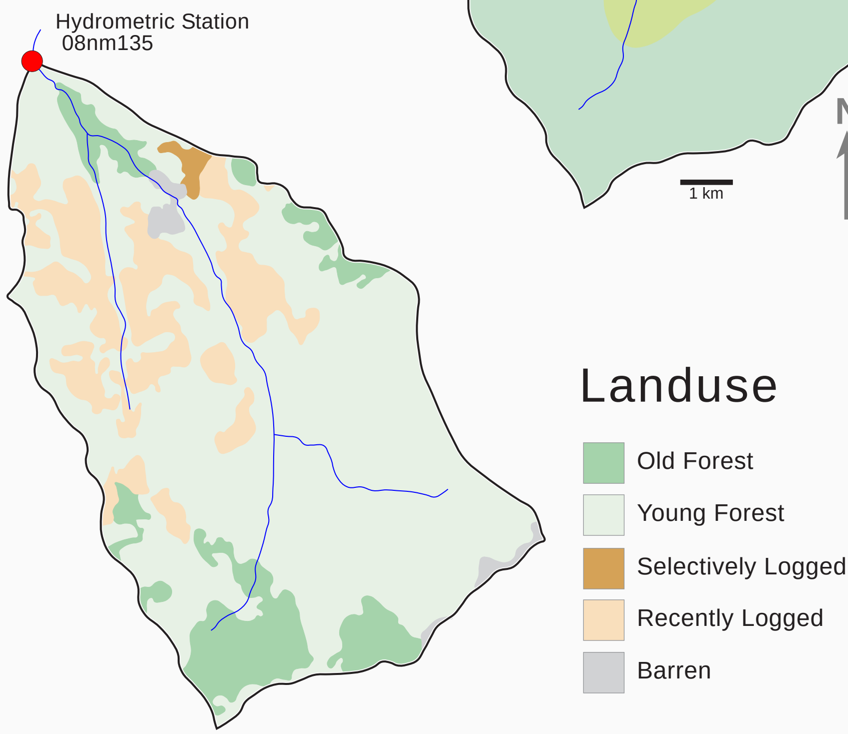
Station Name	Bellevue Creek near Okanagan Mission	Camp Creek near mouth near Thirsk	Daves Creek near Rutland	Pearson Creek near the mouth	Vaseux Creek above Solco Creek	Whiteman Creek above Bouleau Creek
ID	08NM035	08NM134	08NM137	08NM172	08NM171	08NM174
Area (km^2)	77.2	34	34.1	72.8	117	114
Elevation (m)	1550	1480	1350	1550	1700	1300
Start of record	1920	1965	1965	1970	1970	1971
End of record	1986	1999	1986	1987	1999	1999
Years of Record	29	35	22	18	30	29
Climate data						
climate station	**Kelowna Airport**	**Peachland Brenda Mines**	**Joe Rich Creek**	**Joe Rich Creek**	**Oliver STP**	**Vernon Coldstream Ranch**
CS ID	1123970	1126077	1123750	1123750	1125766	1128580
CS elev. (m)	430	1520	875	875	297	482
Calibration Period						
Start	10/01/69	10/01/77	7/01/70	10/01/70	10/15/70	10/01/71
End	9/30/79	9/30/87	9/30/76	9/30/77	9/01/81	9/30/81
NSME	0.81	0.8	0.57	0.77	0.78	0.76
Qo	0.38	0.148	0.135	1.15	0.901	0.617
Qp	0.378	0.142	0.165	1.053	0.892	0.546
Verification Period						
Start	10/01/79	10/01/69	10/01/76	10/01/77	10/01/86	10/01/81
End	7/03/86	9/30/75	1/31/83	1/31/83	5/31/99	9/30/96
NSME	0.8	0.79	0.55	0.74	0.73	0.77
Qo	0.502	0.182	0.133	1.115	0.915	0.623
Qp	0.443	0.169	0.116	0.974	0.951	0.587

Bellevue Creek

Biogeoclimatic Zones



Landuse

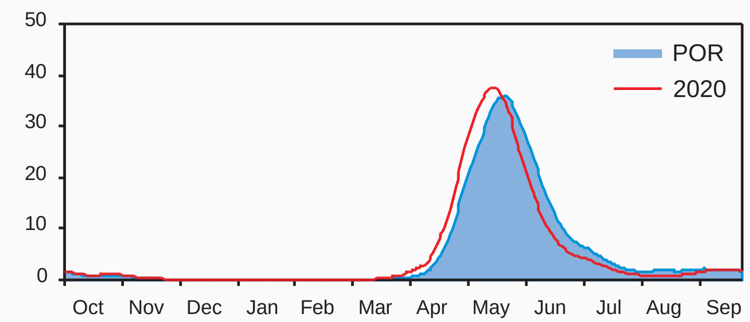


Catchment description

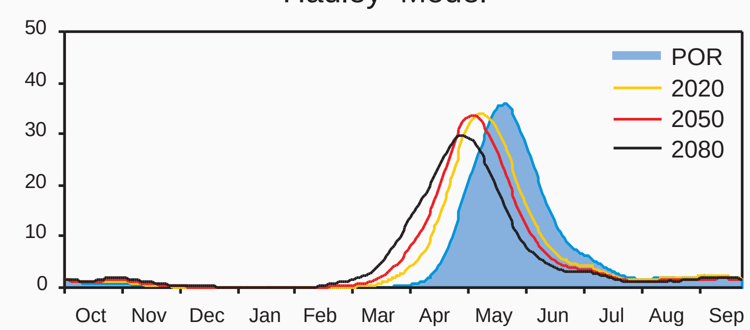
Bellevue Creek near Okanagan Mission (WSC station id 08NM035) is a tributary to Okanagan Lake South of Kelowna. The gauged catchment area is 77.2 km2. This is a very steep catchment with a range of elevation from 700 to 2200m.

Predicted Changes in Annual Hydrographs

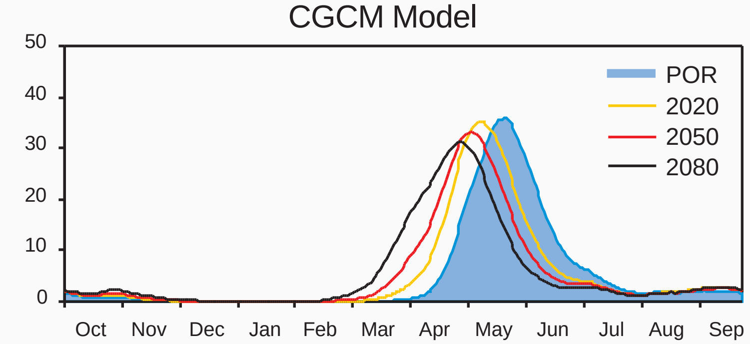
ECHAM4 Model



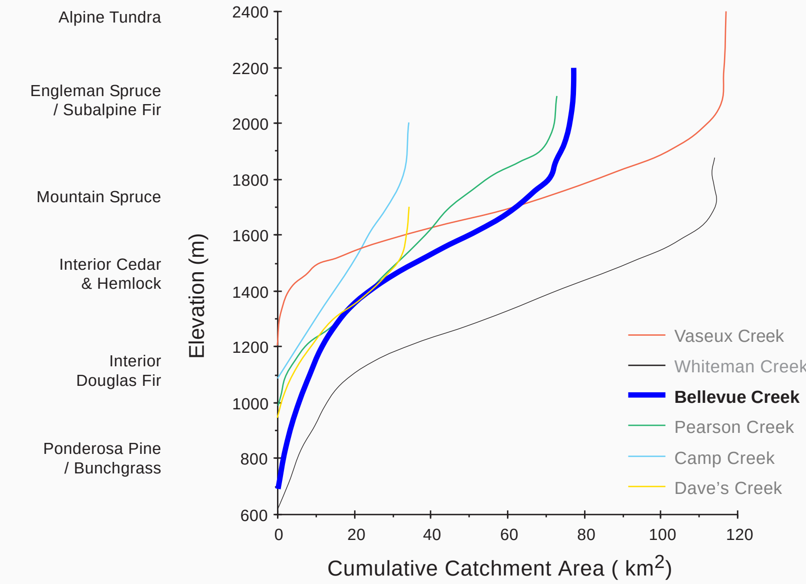
Hadley Model



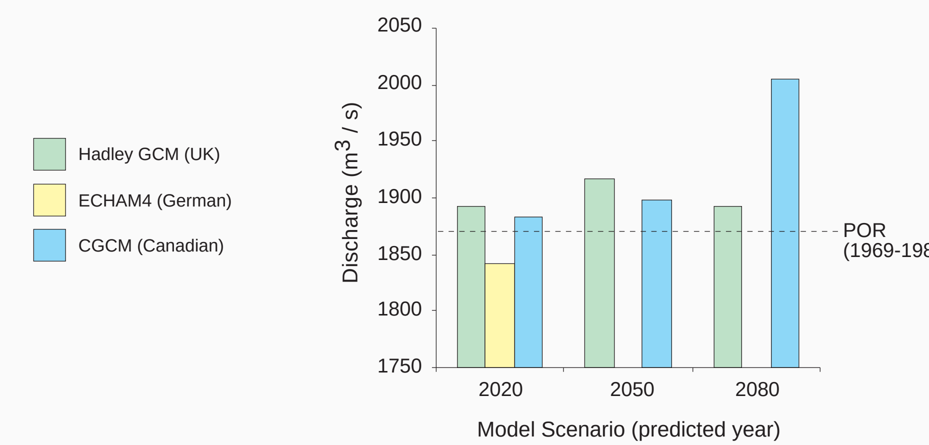
CGCM Model



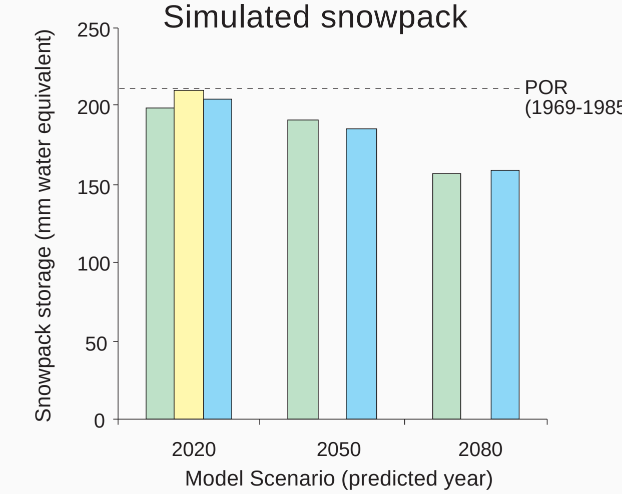
Hypsometric Curves



Total Annual Flow

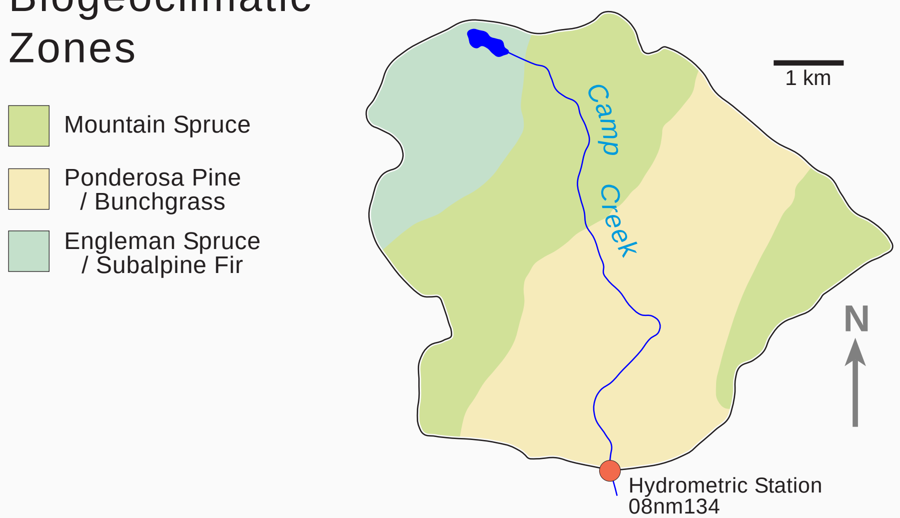


Simulated snowpack

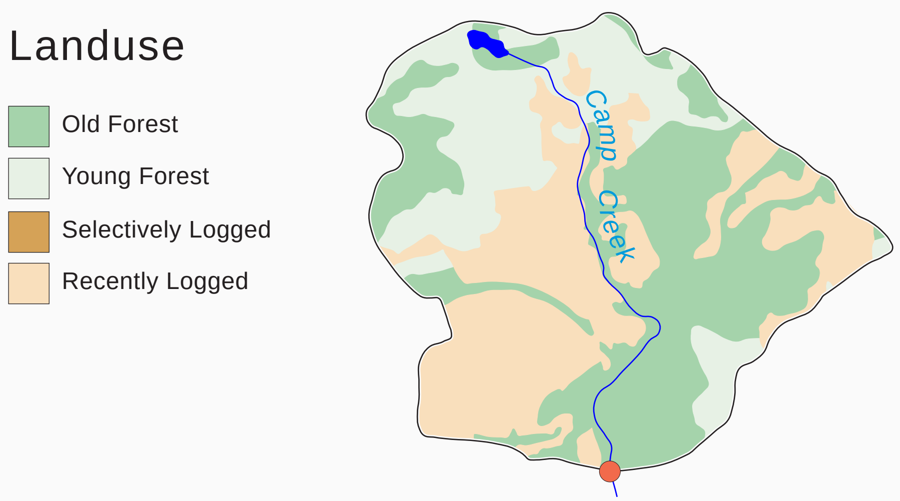


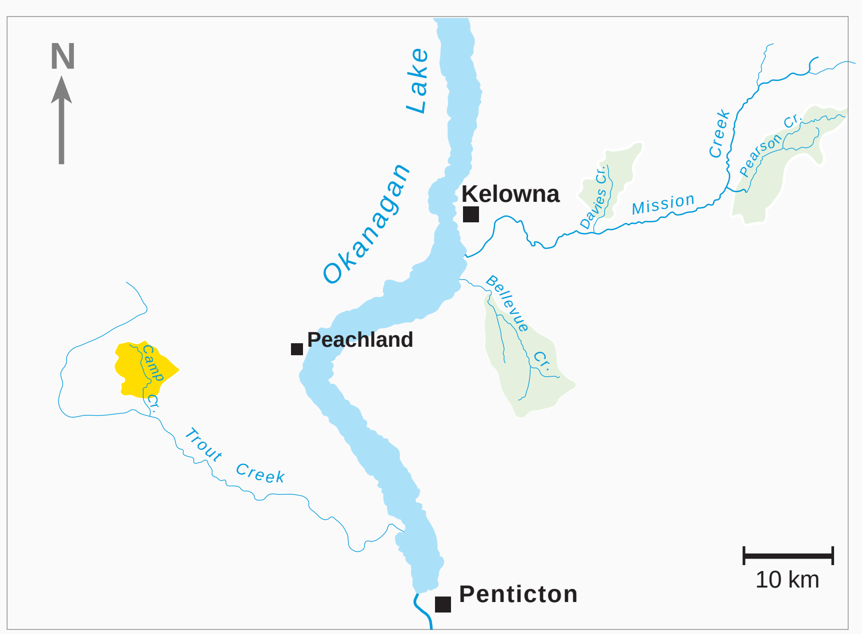
Camp Creek

Biogeoclimatic Zones



Landuse

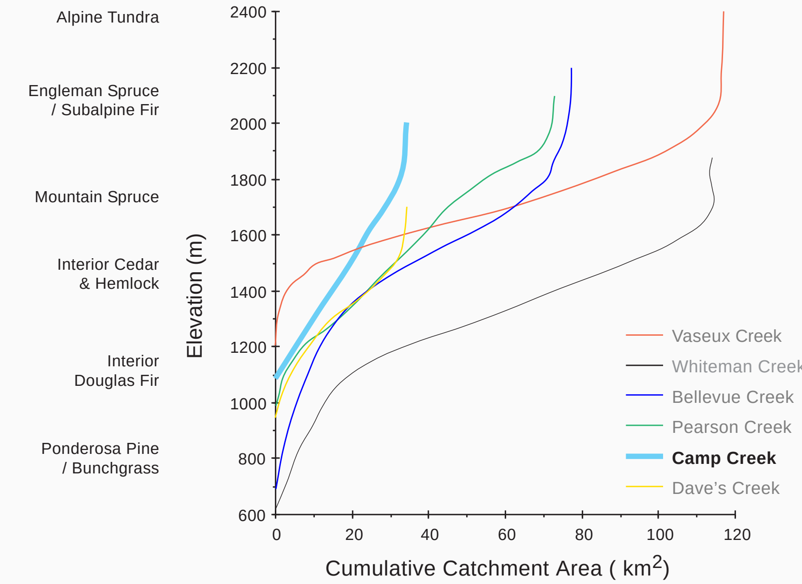




Catchment description

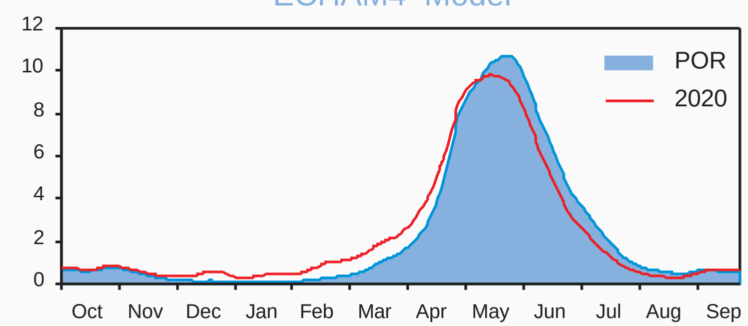
Camp Creek (WSC station id: 08NM134) is a small (34 km2) tributary to Trout Creek; one of the main tributaries feeding Okanagan Lake. The basin is very steep, with elevations ranging from 1100 to 2000 metres.

Hypsometric Curves

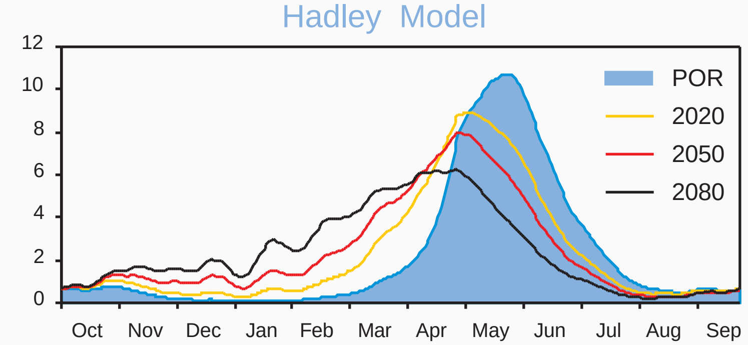


Predicted Changes in Annual Hydrographs

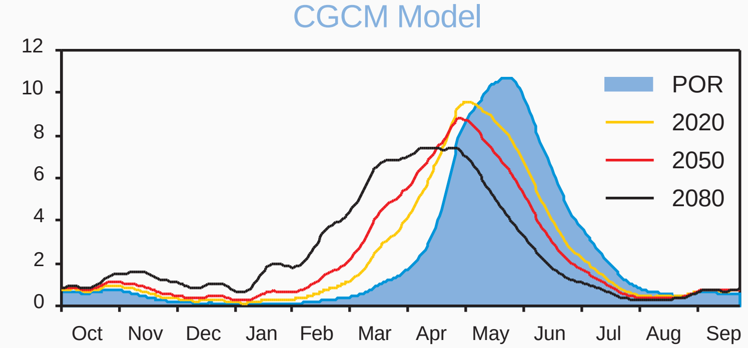
ECHAM4 Model



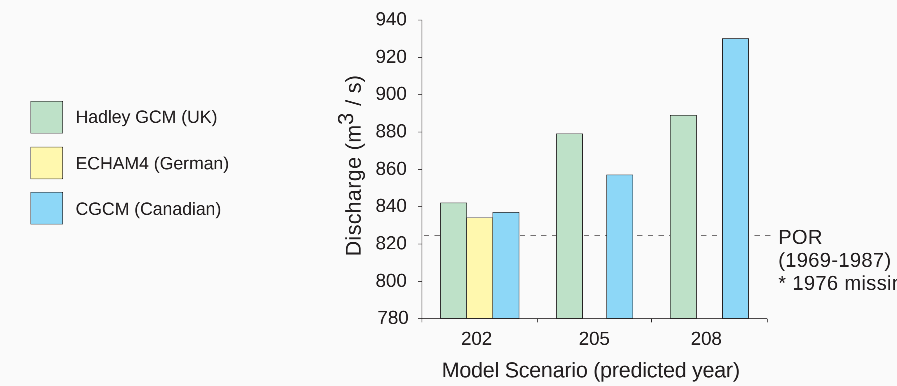
Hadley Model



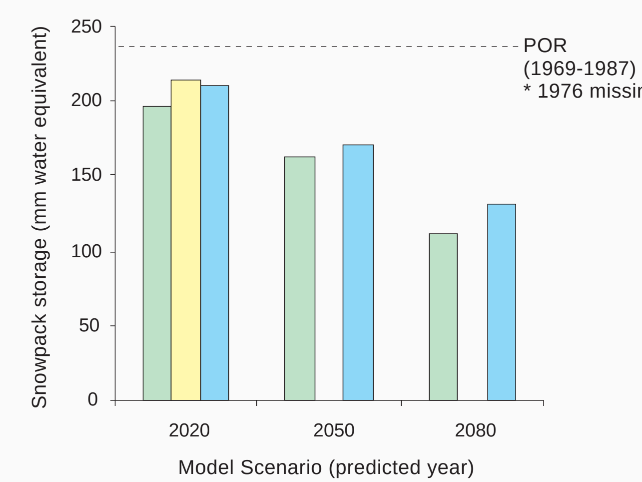
CGCM Model



Total Annual Flow

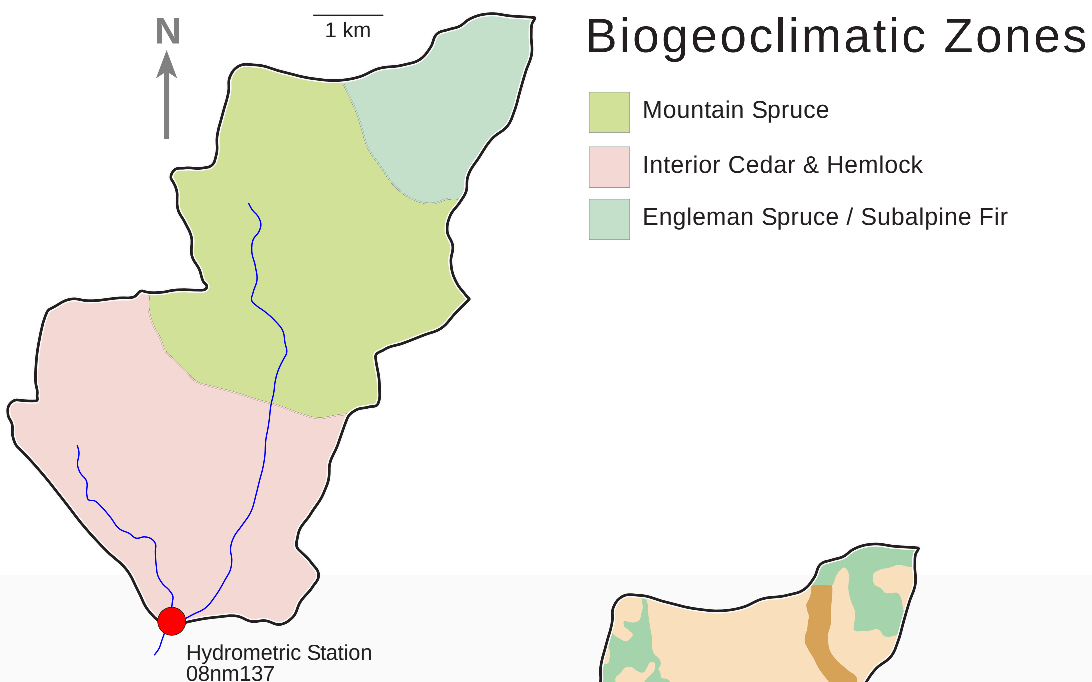


Simulated snowpack

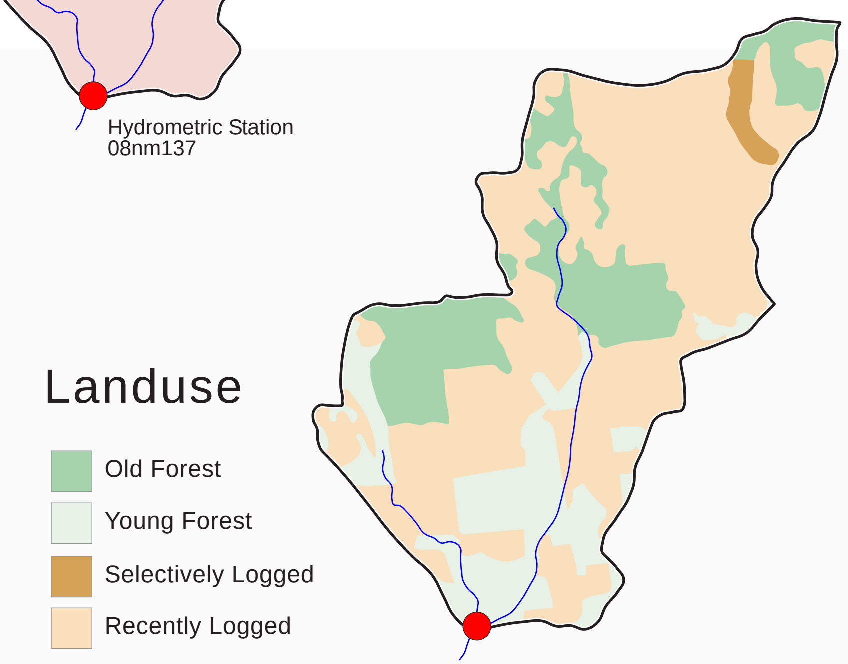


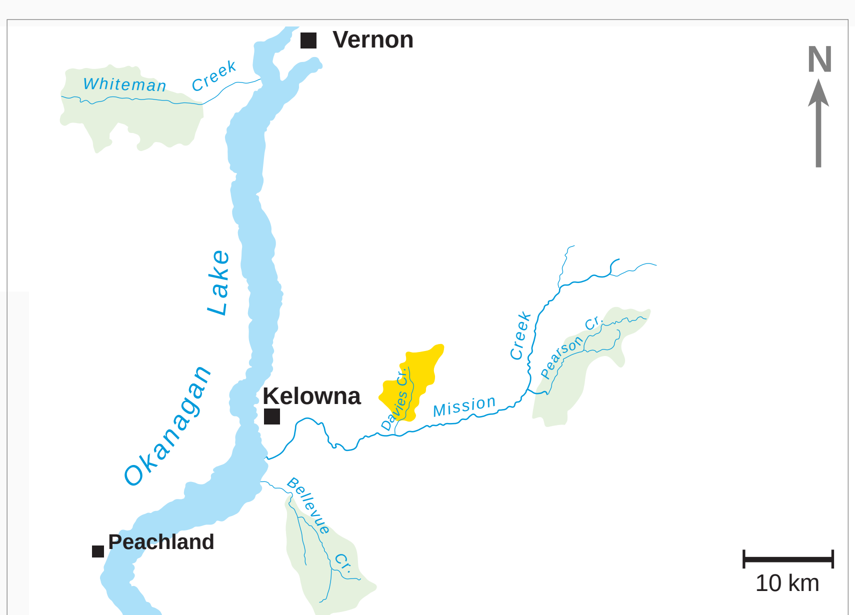
Dave’s Creek

Biogeoclimatic Zones



Landuse



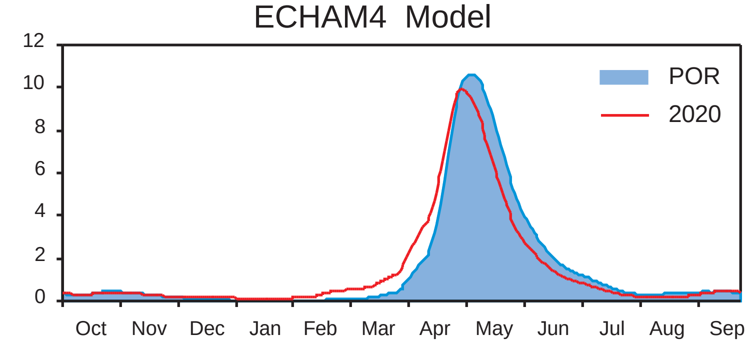


Catchment description

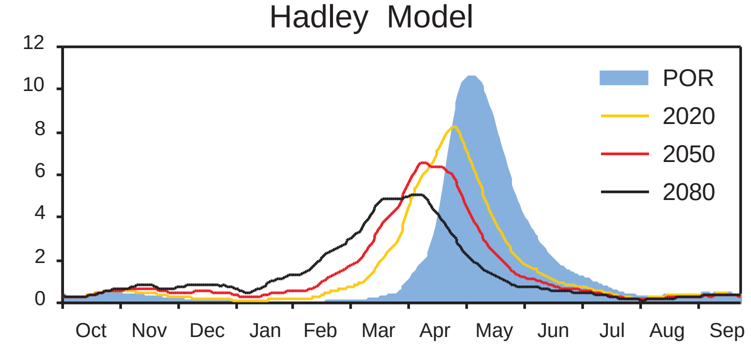
Dave's Creek (WSC station id: 08NM137) is a small (31 km2) tributary to Mission Creek; one of the main tributaries feeding Okanagan Lake. The basin is relatively steep compared to other basins selected in this study. Elevations range from 900 to 1700 metres with the median elevation being approximately 1300 metres. Dominant biogeoclimatic zones are Interior Cedar Hemlock, Englemann Spruce Subalpine Fir, and Montaine Spruce. The basin has been extensively logged, with only small stands of old growth remaining.

Predicted Changes in Annual Hydrographs

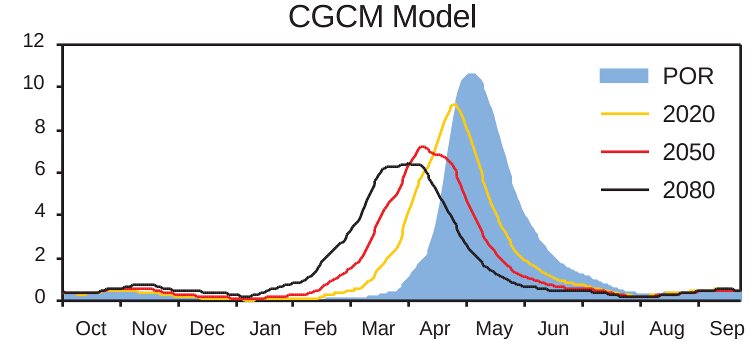
ECHAM4 Model



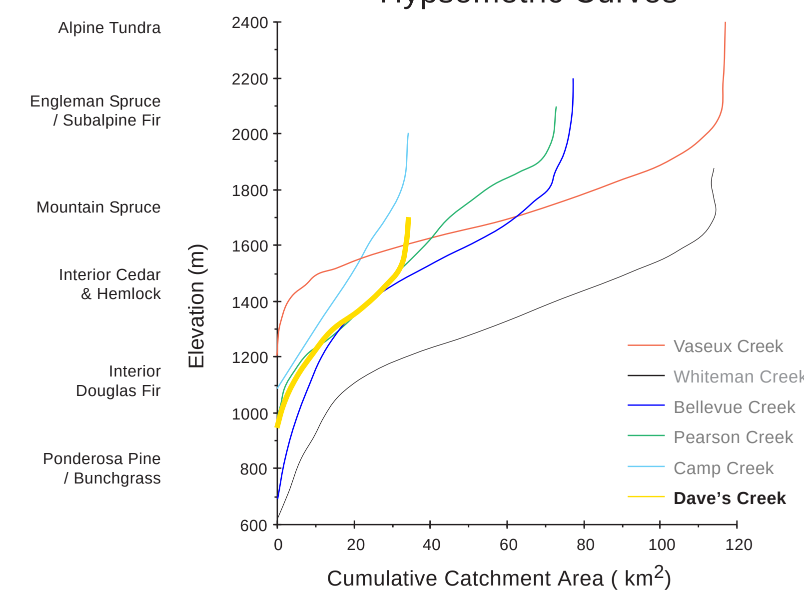
Hadley Model



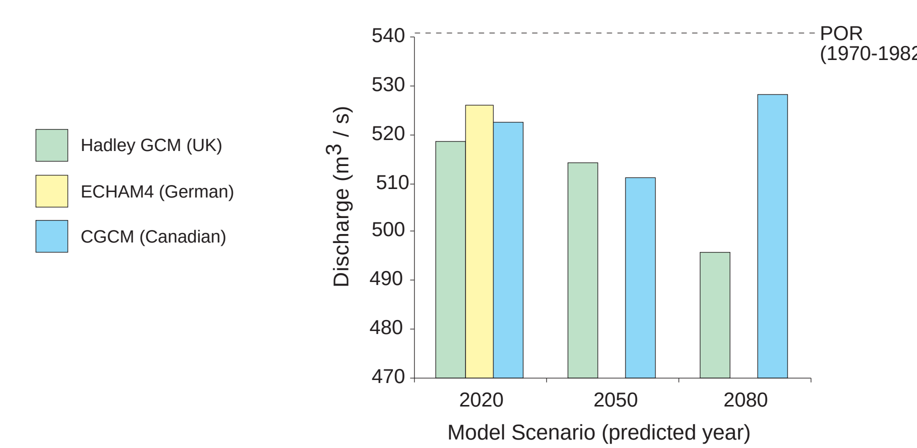
CGCM Model



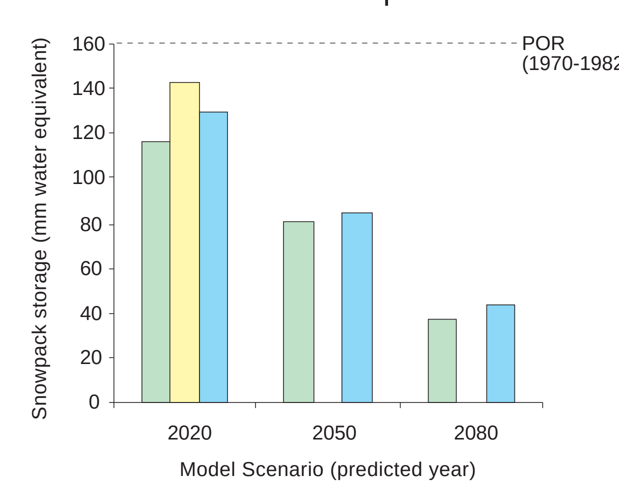
Hypsometric Curves



Total Annual Flow

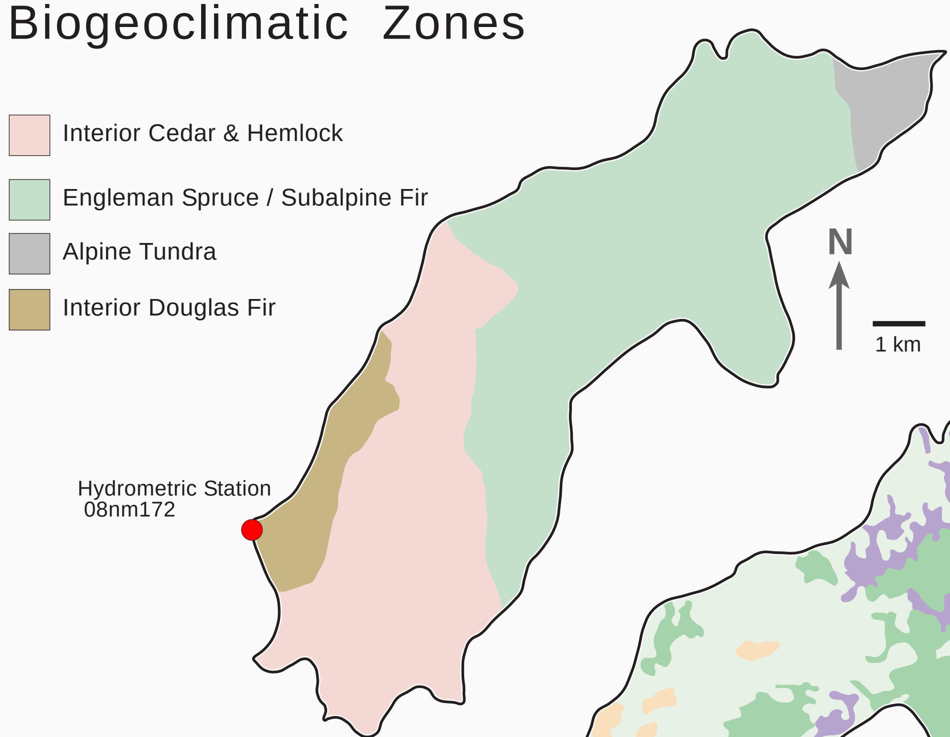


Simulated snowpack

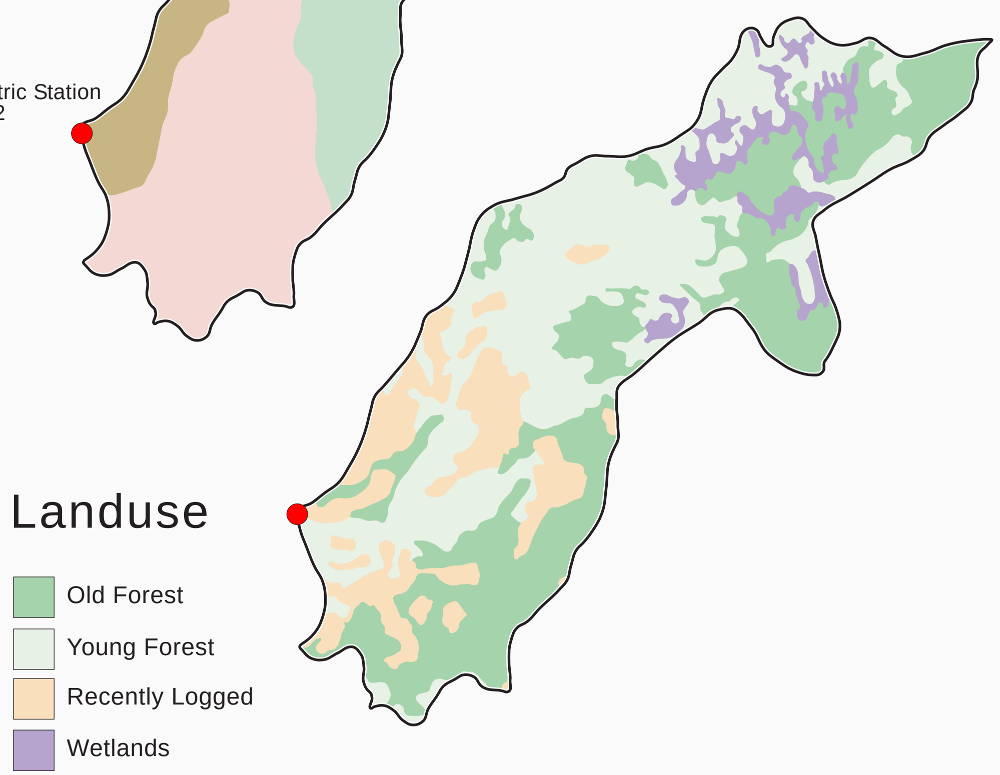


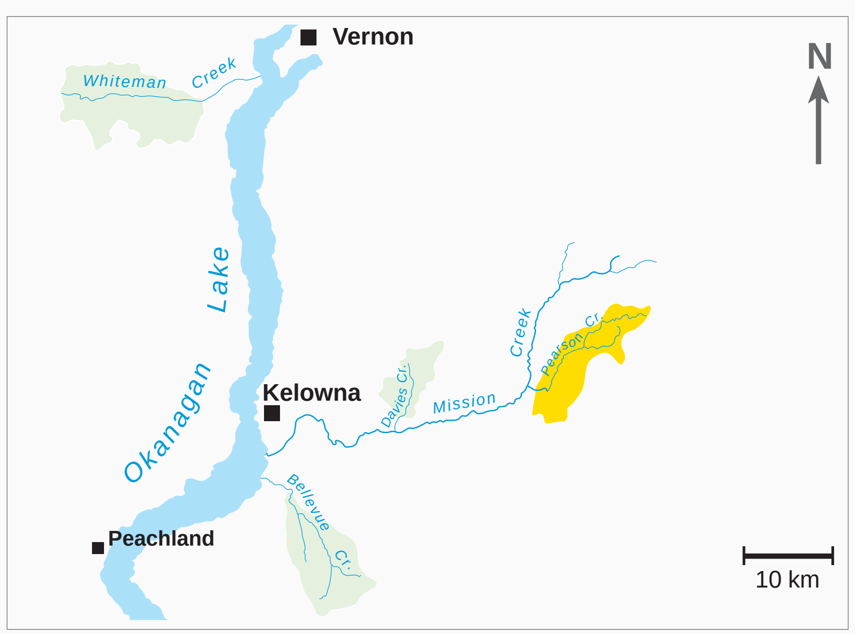
Pearson Creek

Biogeoclimatic Zones



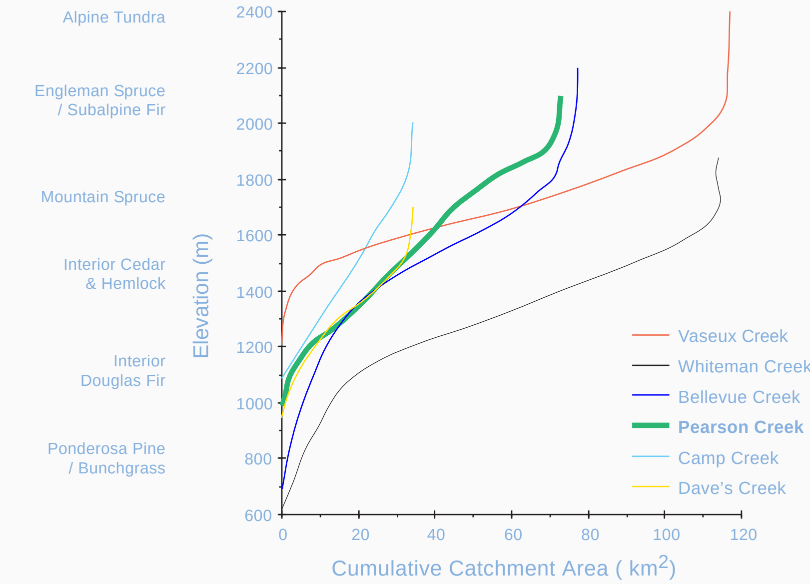
Landuse



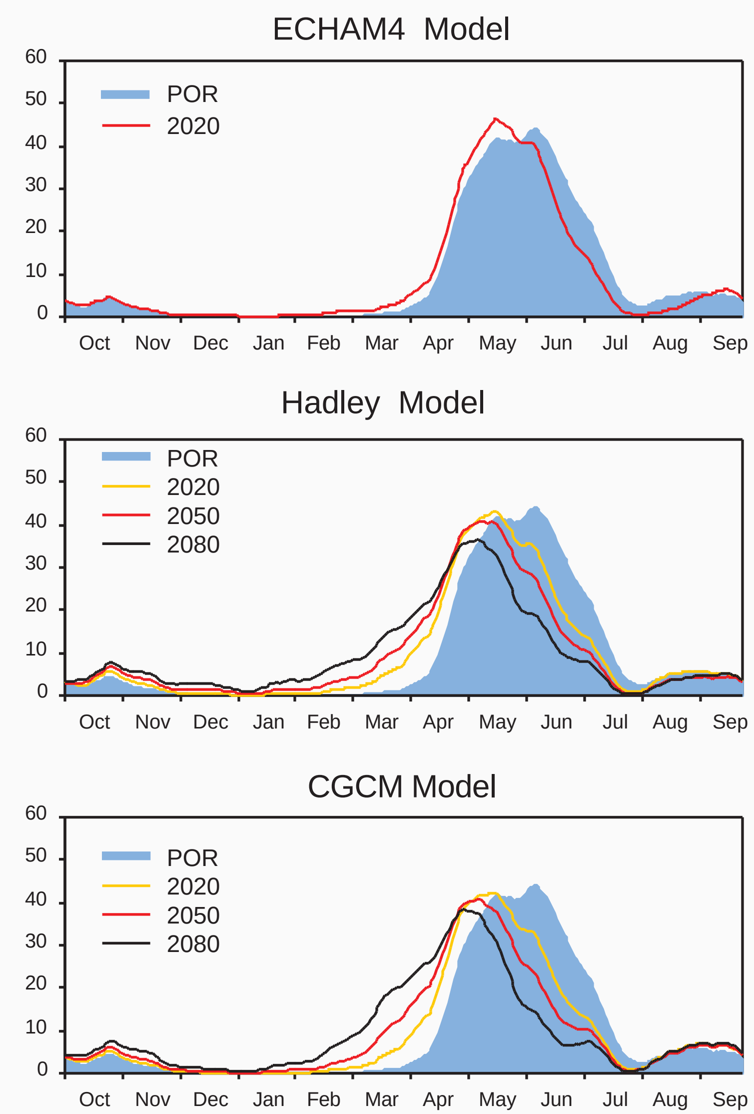


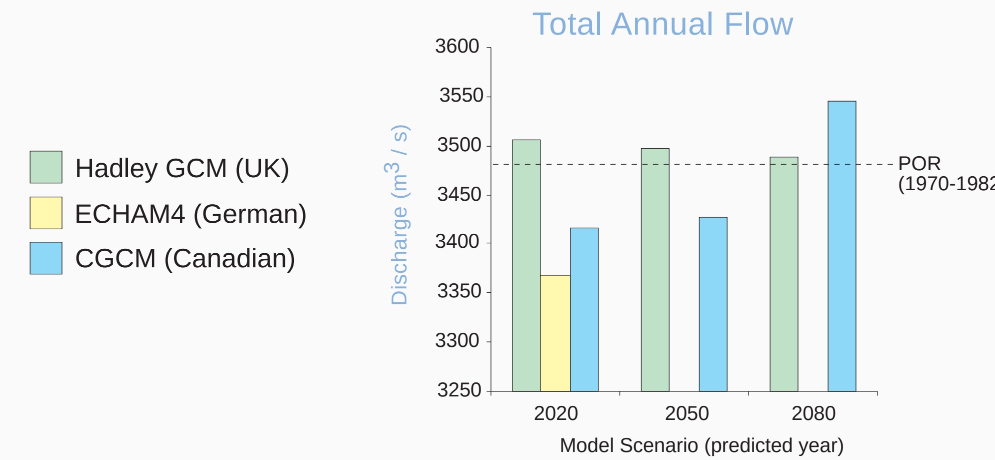
Catchment description

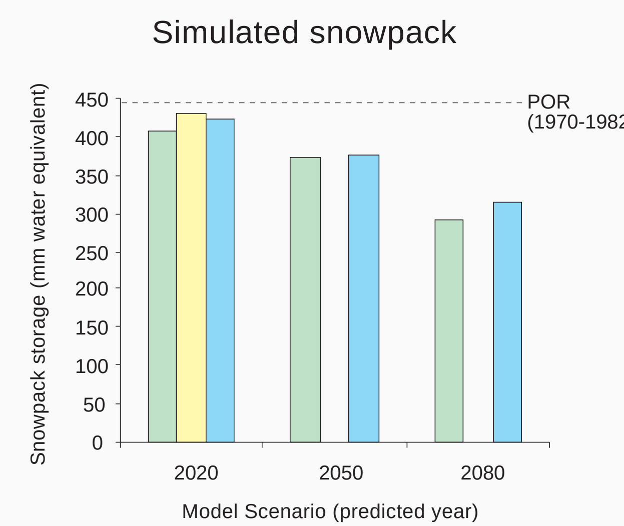
Pearson Creek (WSC station id: 08NM172) is a moderate-sized (73 km^2) tributary to Mission Creek; one of the main tributaries feeding Okanagan Lake. The mean annual discharge is 0.85 m^3/s, and the period of record extends from 1970 to 1982.



Predicted Changes in Annual Hydrographs

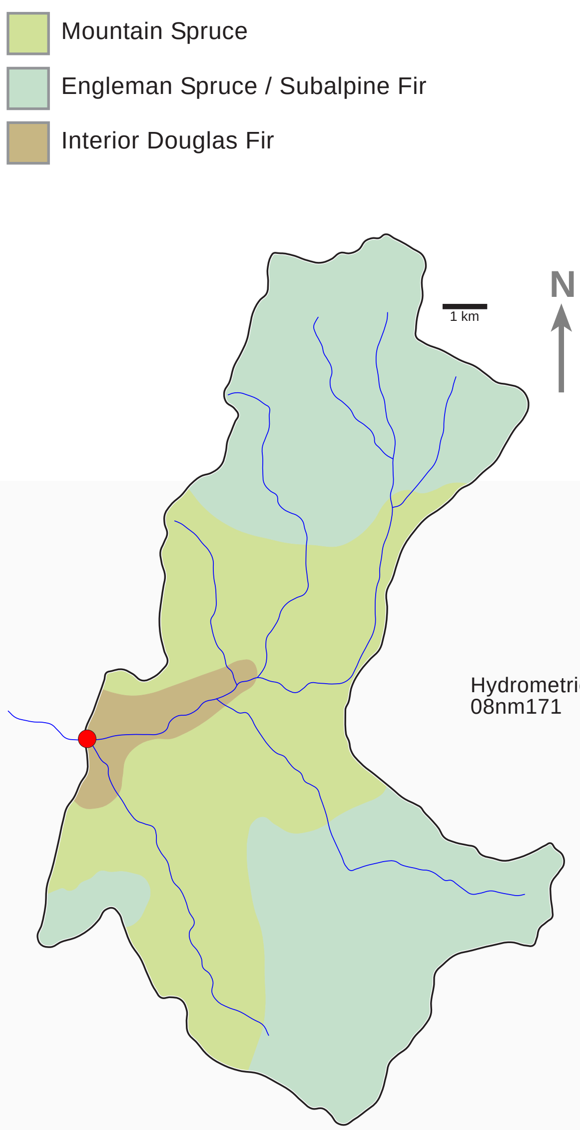




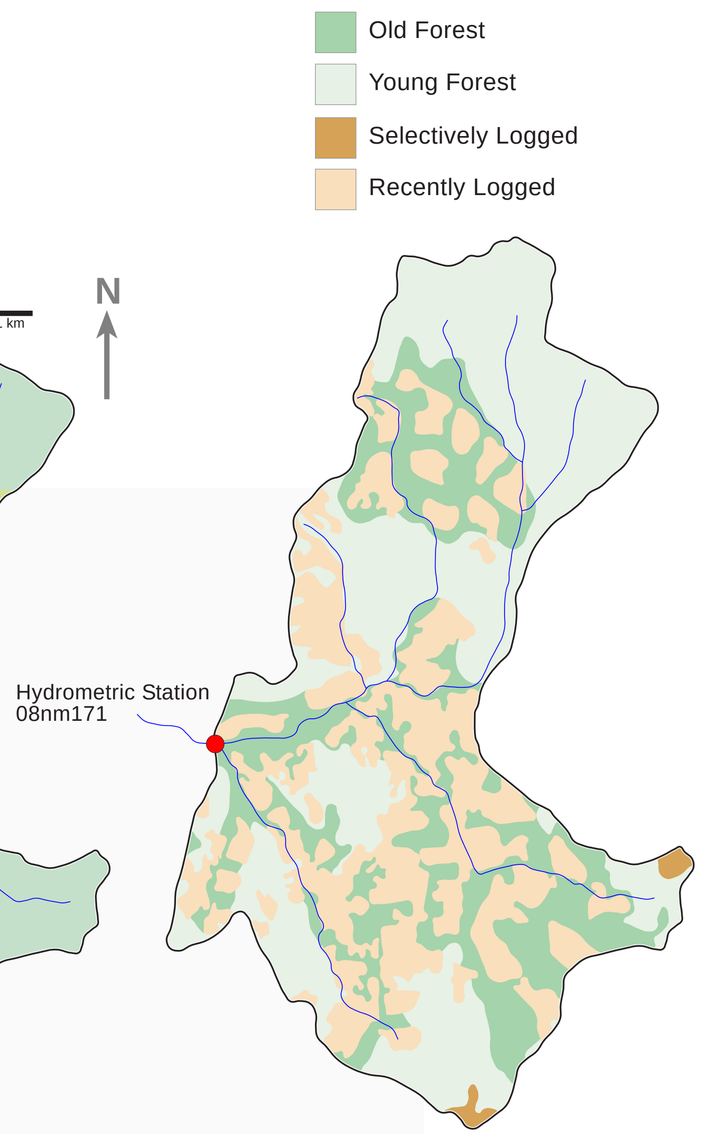


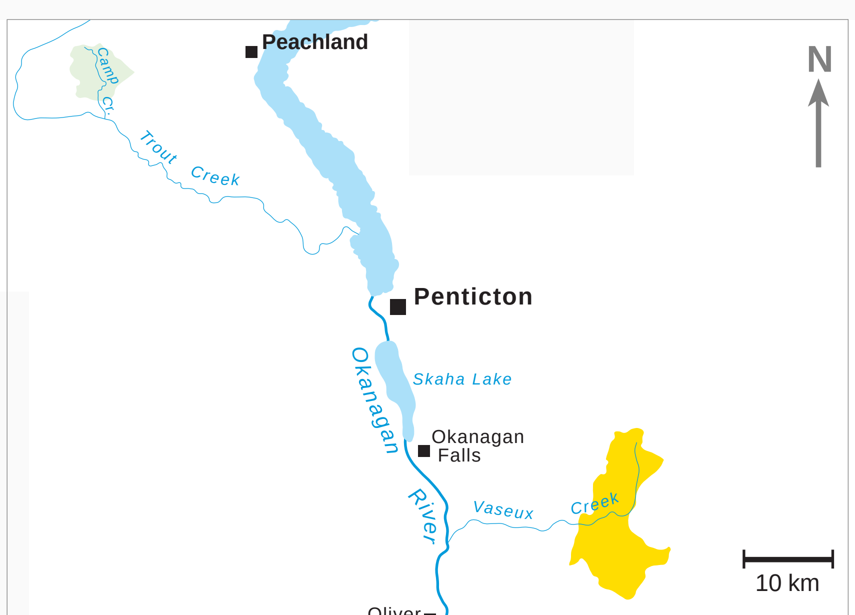
Vaseux Creek

Biogeoclimatic Zones



Landuse

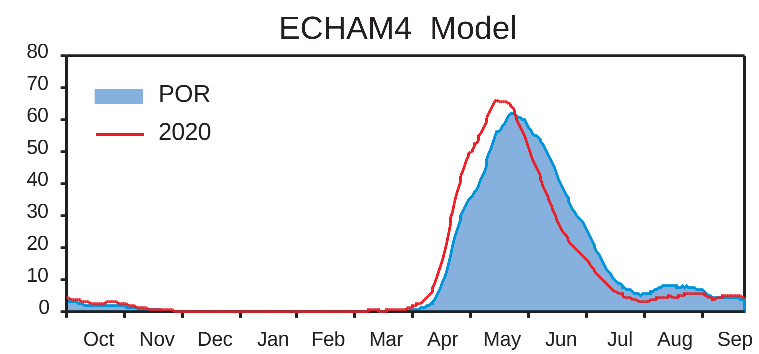


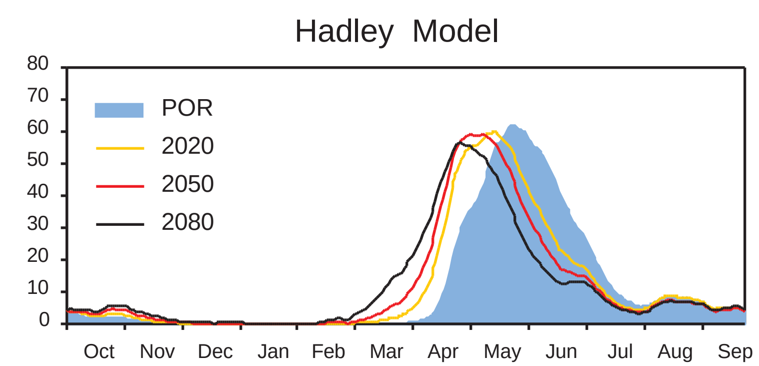


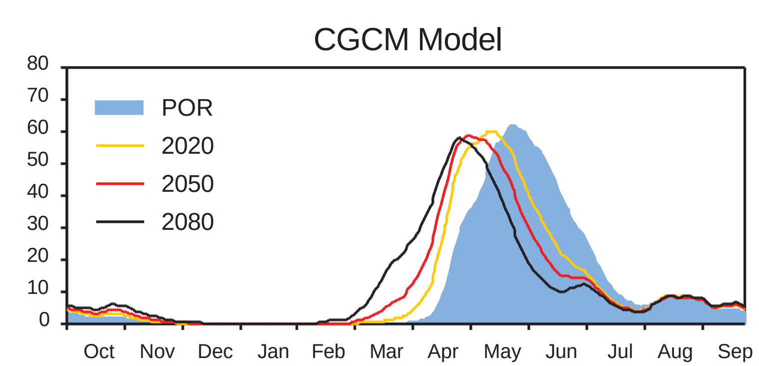
Catchment description

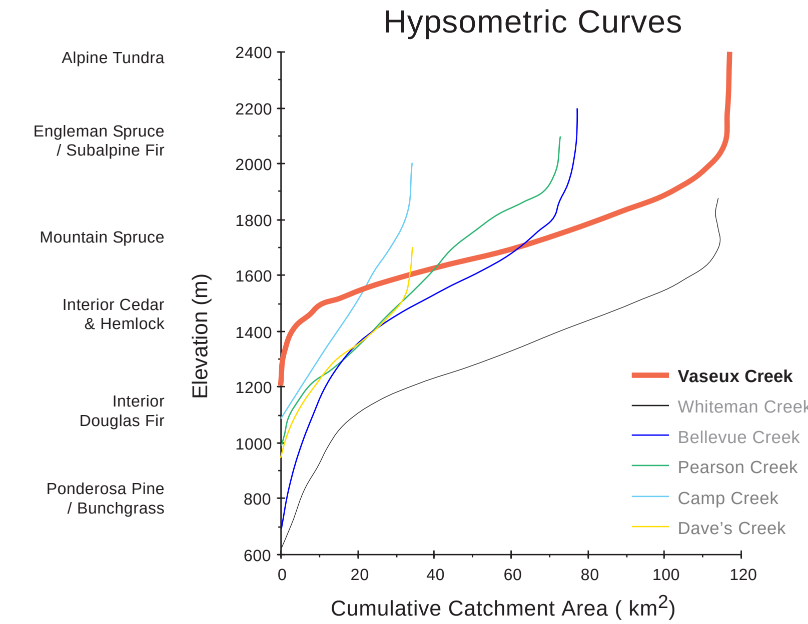
Vaseux Creek above Solco Creek (WSC station id 08NM171) is a tributary to the Okanagan River downstream of Okanagan Falls. The gauged catchment area is 117 km2. This is a high elevation station with a median elevation of 1700 m, with a range from 1200 to 2400 m. The station has been in operation for 30 years from 1970 to 1999.

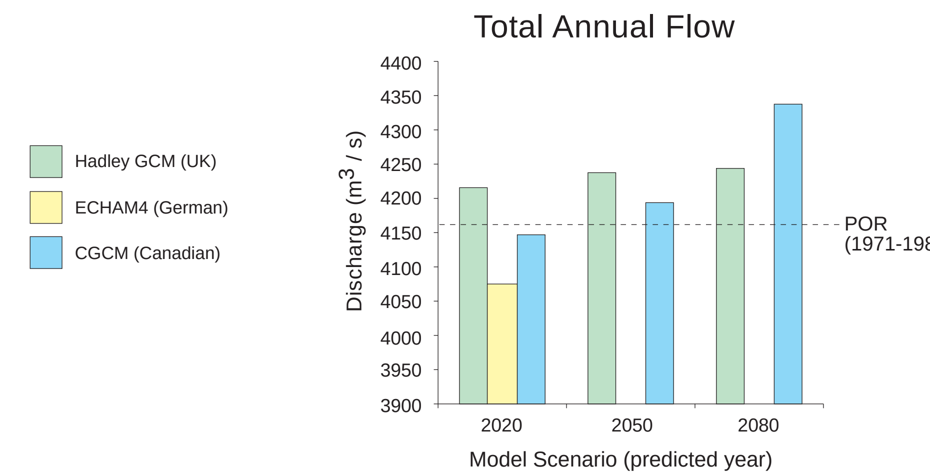
Predicted Changes in Annual Hydrographs

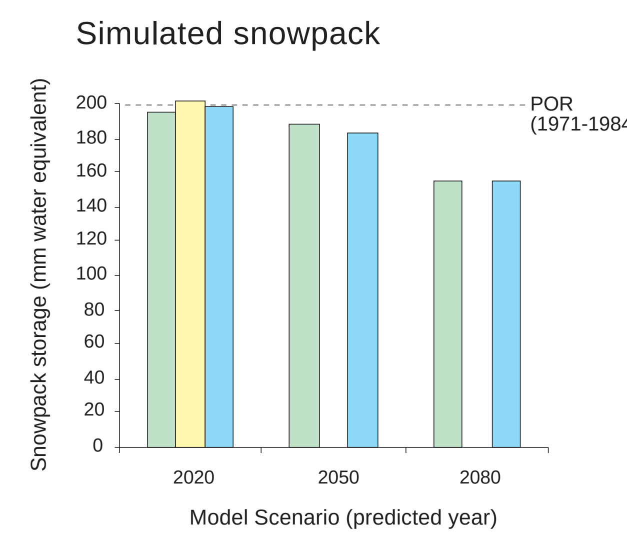






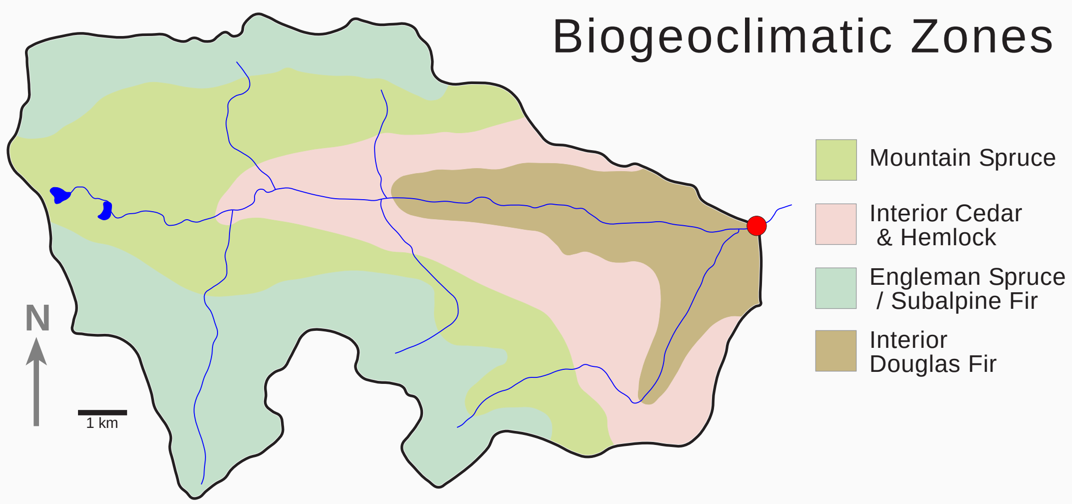




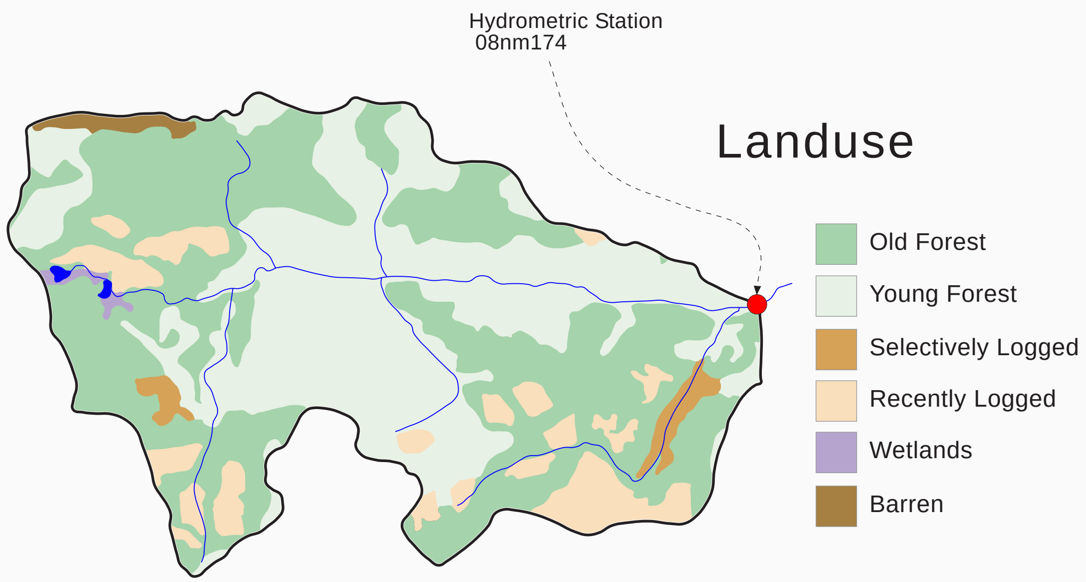


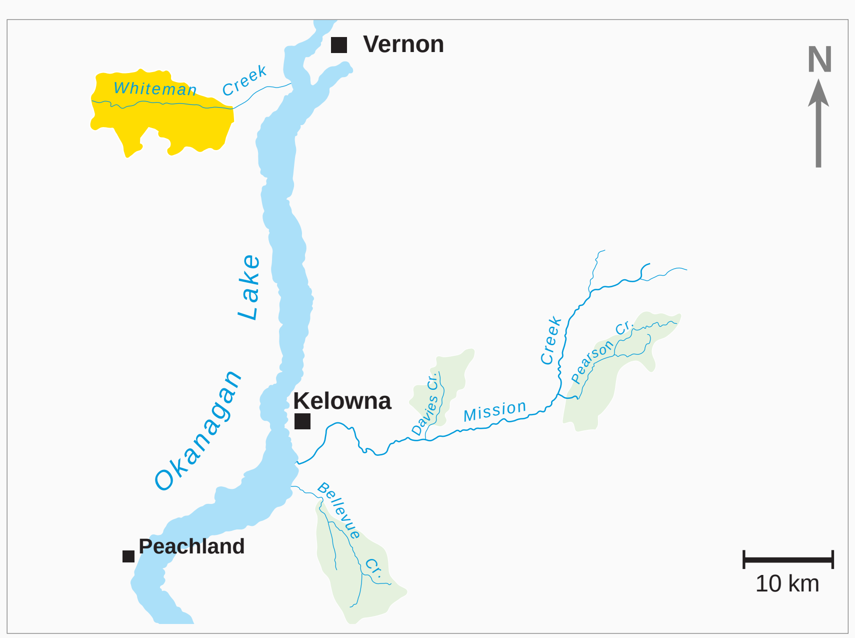
Whiteman Creek

Biogeoclimatic Zones



Landuse

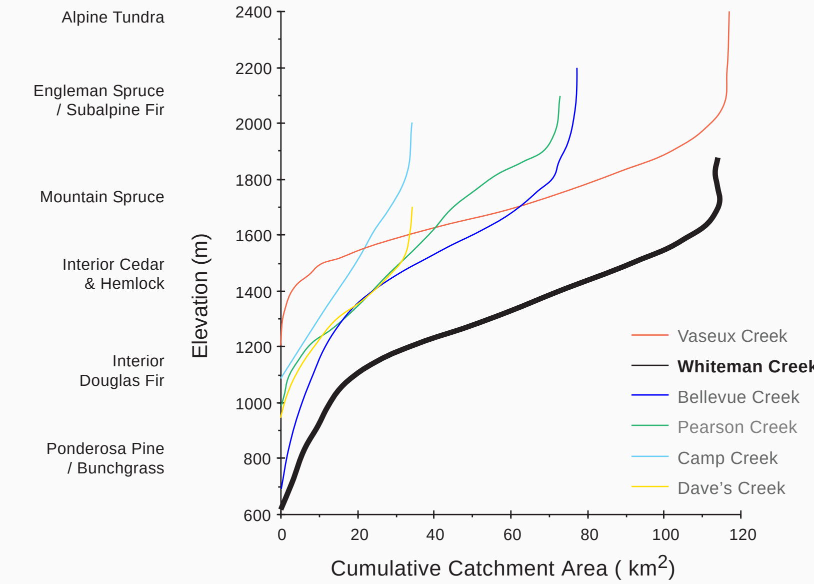




Catchment description

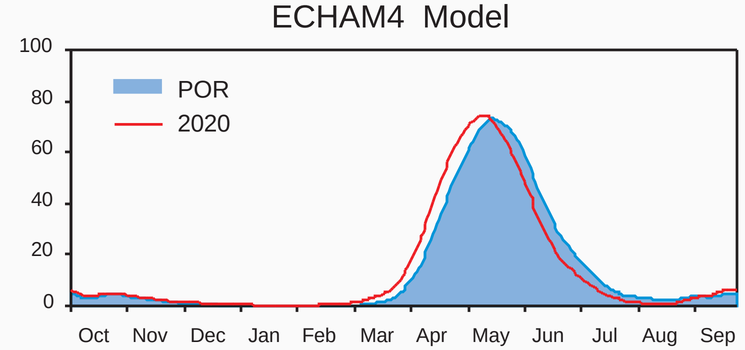
This is the second largest catchment of the six used in this presentation, and is similar in size to Vaseux Creek catchment. The period of record extends from 1971 to 1996...

Hypsometric Curves

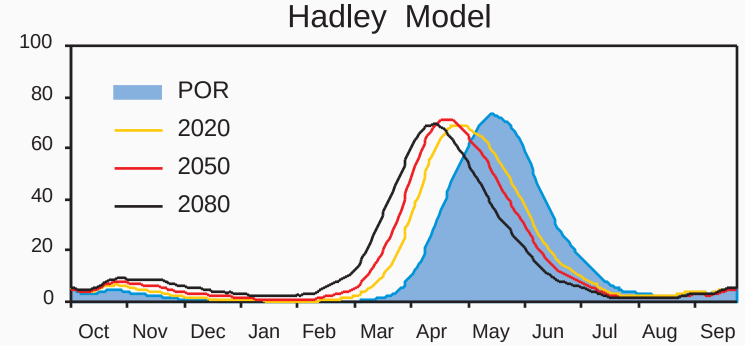


Predicted Changes in Annual Hydrographs

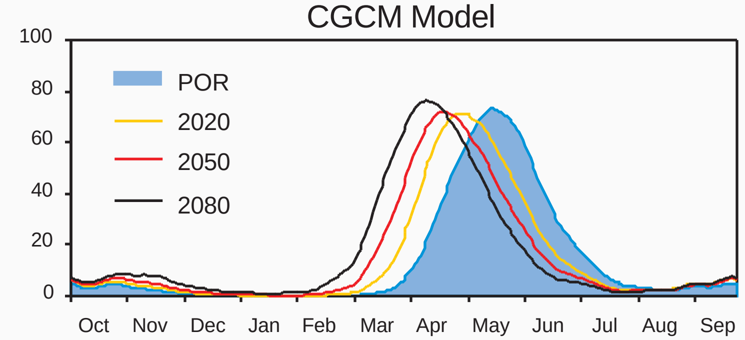
ECHAM4 Model



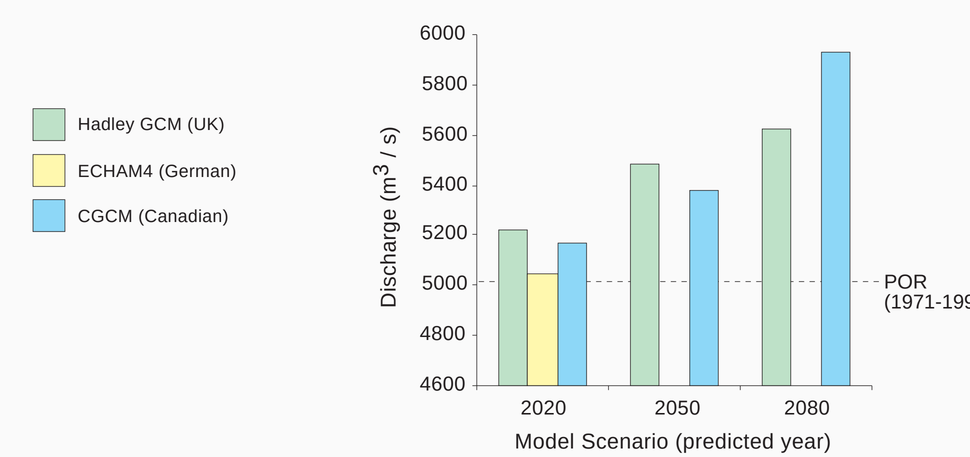
Hadley Model



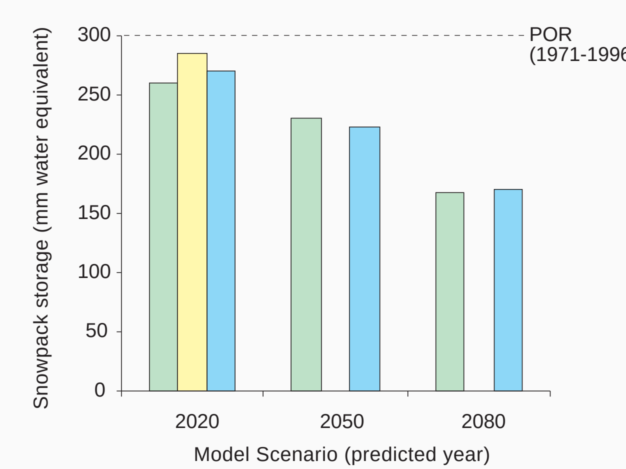
CGCM Model



Total Annual Flow



Simulated snowpack



Okanagan Region: Total Basin Snowpack (April 1)

Predictions by the three Global Climate Models for selected creeks

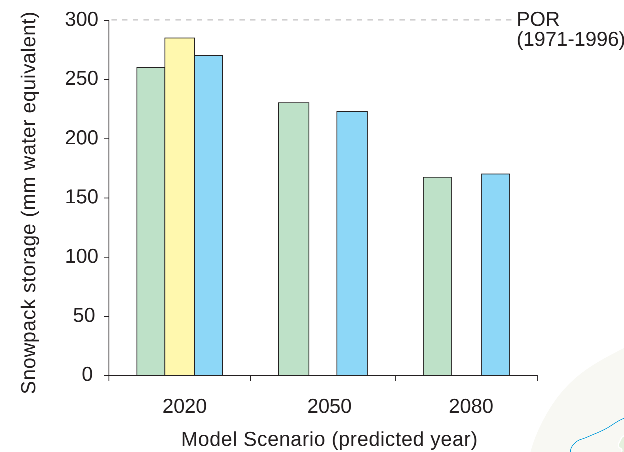
Overview:

High elevation snowpacks are the main source of runoff for most creeks within the Okanagan region. Snowpacks represent an integration of winter precipitation stored on the landscape that sustains runoff during spring and summer months. The "April 1" snow measurement is often used as a predictor of total available spring runoff. The following graphs illustrate how the modelled April 1 snowpack for selected creeks may vary under the climate predictions for three Global Climate Models: Hadley (UK), ECHAM4 (German), and CGCM (Canadian). The graphs illustrate changes in snowpack storage, which is the total volume of snow stored within the basin measured as a depth-equivalent. All creeks exhibit a decrease in April 1 snowpack storage between the period of record (POR) and the three climate scenarios: 2020, 2050, 2080 which represent predicted climates for the 2011 to 2040, 2041 to 2070, and 2071 to 2100 periods respectively. Little change in April 1 snowpack storage (compared to the period of record) is predicted for the 2020 scenario. However, the 2050 and 2080 scenarios suggest that April 1 snowpack storage may be reduced by 30-60% (compared to the period of record). The reduction in April 1 snowpack storage means less available runoff to augment runoff during the summer low-flow period.

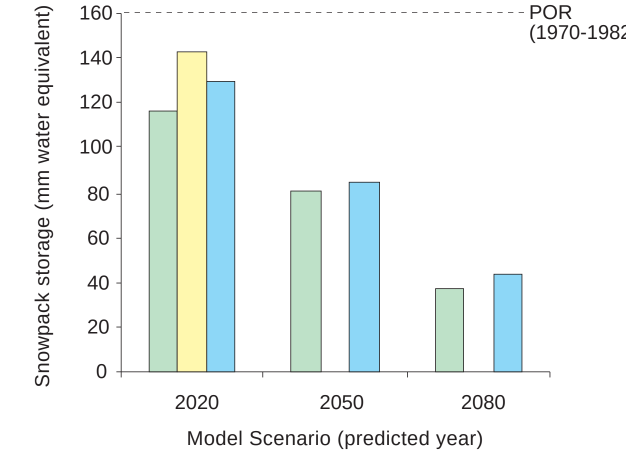
- Hadley GCM (UK)
- ECHAM4 (German)
- CGCM (Canadian)

Whiteman Creek

Whiteman Creek shows a decrease in April 1 snowpack storage under the three GCM scenarios. By 2080, April 1 snowpacks are predicted to decrease by up to 40% compared to the period of record.

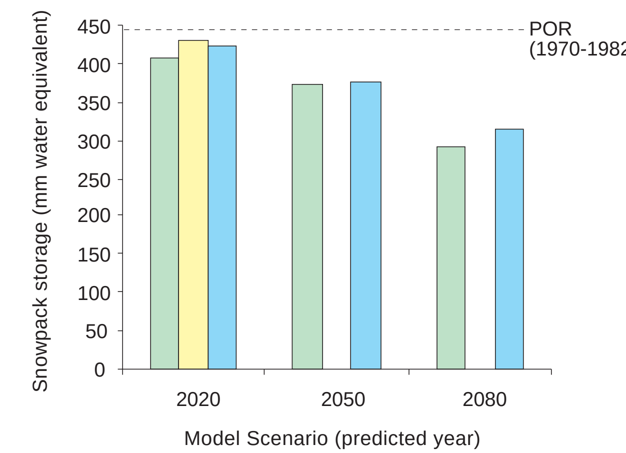


Dave's Creek



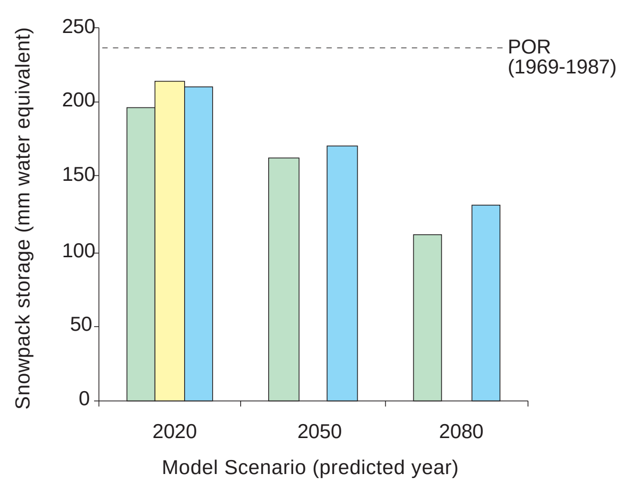
Pearson Creek

Pearson Creek shows little change in snowpack storage for the 2020 scenario. However, snowpack storage is predicted to decrease by up to 30%, compared to the period of record, by the 2080s. Predicted April 1snowpack storage for the 2080 scenario may be reduced by up to 75% compared to the period of record. The large reduction in snowpack storage may be related to the relatively low elevation of the catchment.



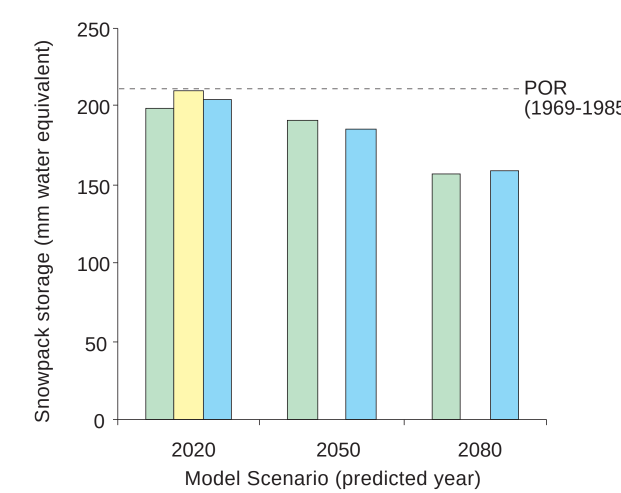
Camp Creek

Camp Creek shows a decrease in April 1 snowpack storage under the three GCM scenarios. By 2080, April 1 snowpacks are predicted to decrease by up to 40% compared to the period of record.



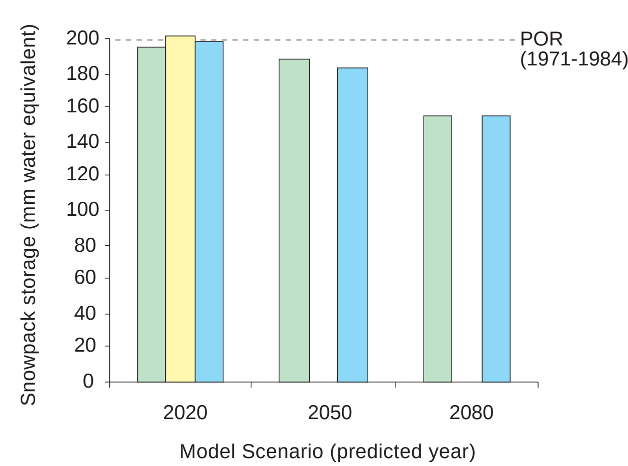
Bellevue Creek

Bellevue Creek shows a decrease of approximately 30% in April 1 snowpack storage for the 2080 scenario, as compared to the period of record.



Vaseux Creek

Vaseux Creek shows no change in snowpack storage for the 2020 scenario and a decrease of approximately 30% for the 2080 scenario, compared to the period of record.



Okanagan Region: Mean Flow During Spring Season (Mar - May)

Predictions by the Canadian Global Climate Model for selected creeks

Overview:

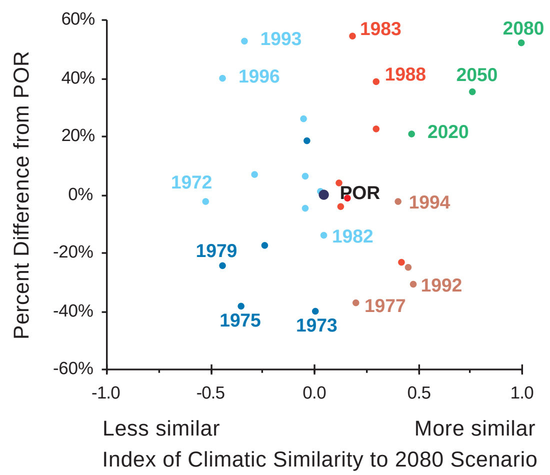
These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

Streamflow during the spring period is sensitive to antecedent snowpack. If there will be less snow accumulation over the winter months, spring flow volumes will be reduced. However, earlier melt means that more snow will melt in the spring and less in the summer, which may result in an increase in spring flow.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model

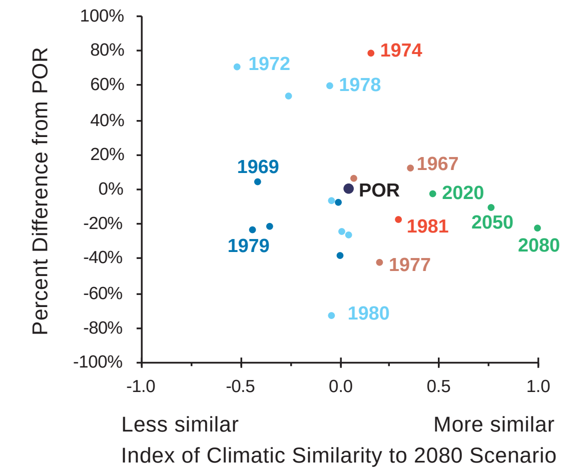
Whiteman Creek

The low apparent sensitivity of Whiteman Creek to climate effects on spring flow is, in part, a result of the fact increases in flow in March and April will be offset by decreases in flow in May with little net change averaged over the season.



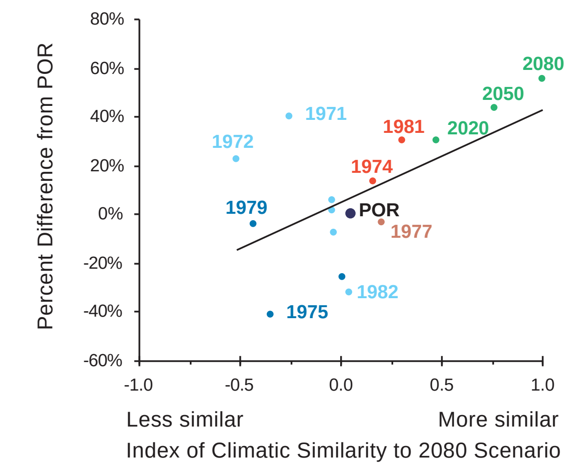
Dave's Creek

There is no statistically detectable trend in spring discharge for Daves Creek. This is because it is a relatively low elevation station. As a result, the snowmelt freshet is typically finished by the end of May. There will likely be fewer high flow years like 1971, 1972, 1974 and 1978.



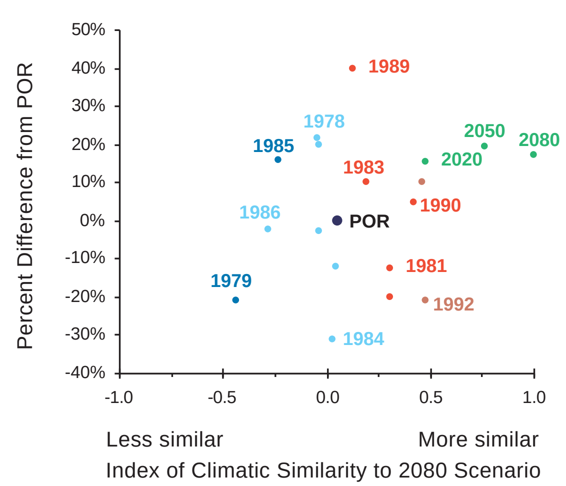
Pearson Creek

A significant upward trend in spring flow is evident for Pearson Creek. There are however several years (e.g. 1971, 1972, 1974, 1981) that also show very high spring flows either because of high snowpack (1971, 1972)or because of earlier melt(1974, 1981)



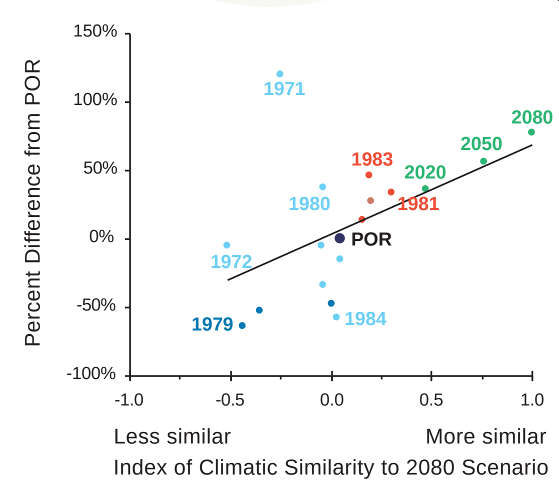
Camp Creek

Increases are predicted for Spring flow at Camp Creek, but the trend is not significant, and the mean predicted spring flow will be less than observed in 1989, which was a warm-dry year with very early snowmelt.



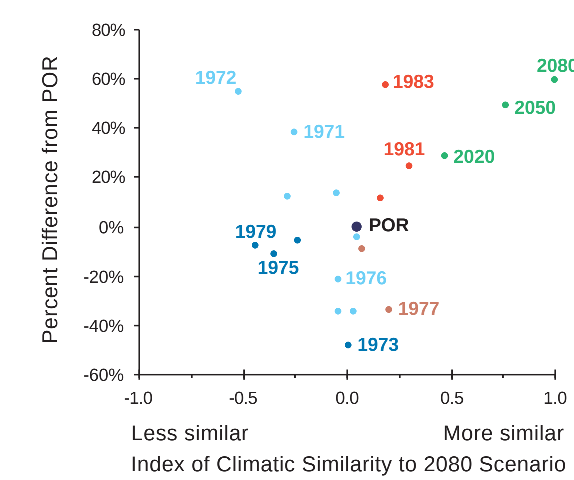
Vaseux Creek

There is a strong upward trend in spring flow in Vaseux creek. This trend is a result of earlier snowmelt runoff, similar to the year 1971 where the peak flow occurred in May.



Bellevue Creek

The low apparent sensitivity of Bellevue Creek to climate effects on spring flow is, in part, a result of the fact increases in flow in March and April will be offset by decreases in flow in May with little net change averaged over the season.



Okanagan Region: Mean Flow During Summer Season (Jun - Aug)

Predictions by the Canadian Global Climate Model for selected creeks

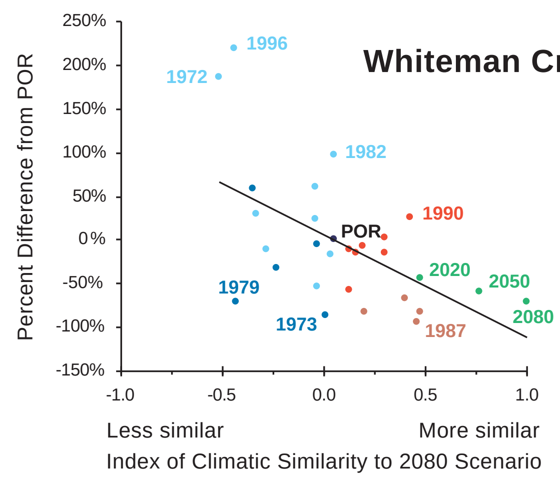
Overview:

These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

Summer streamflow is not expected to change too dramatically from the period of record reference period. The water balance during this period will be a function of the changes predicted for precipitation and to a lesser degree, changes in the amount of evaporation due to warmer temperatures.

Year label	Type
1979	cool wet years
1979	warm wet years
1979	warm dry years
1979	cool dry years
1979	predicted by model

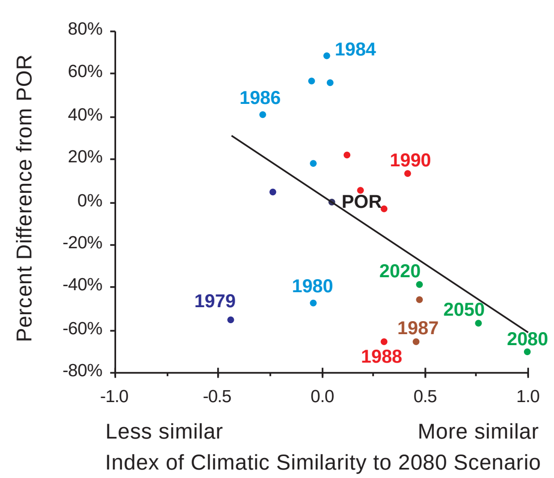
Whiteman Creek



Summer flows are predicted to be lower than normal, but the average predicted for each of the scenarios is within the range of summer flows observed during the period of record.

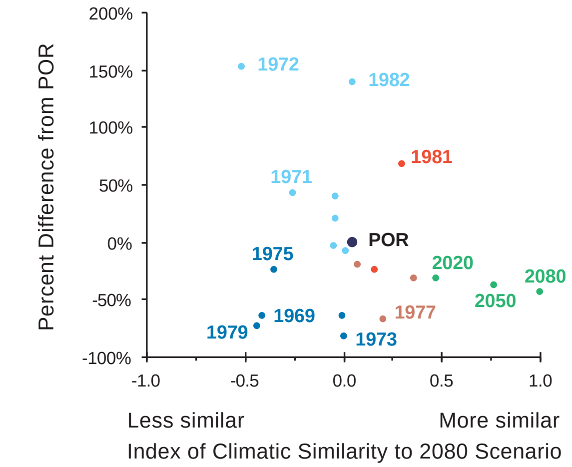
Camp Creek

A negative tendency is apparent for summer flow for Camp Creek



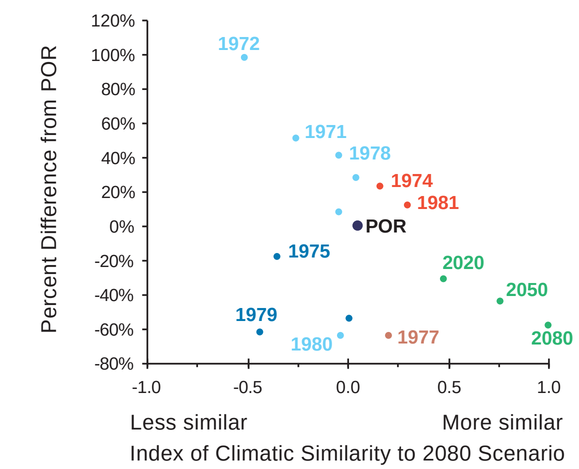
Dave's Creek

Summer flows are predicted to be lower than normal, but the average predicted for each of the scenarios is within the range of summer flows observed during the period of record.



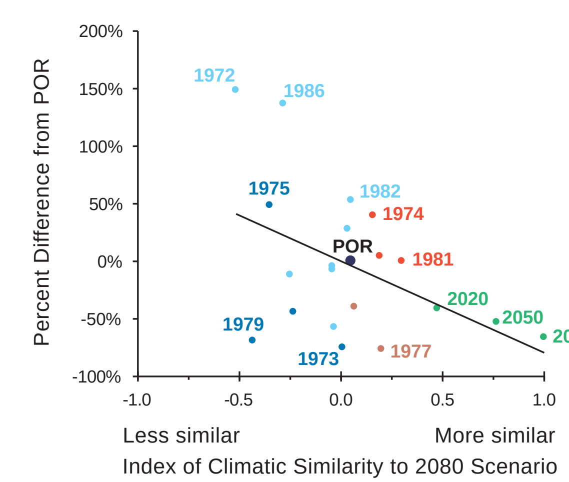
Pearson Creek

Summer flows are predicted to be lower than normal, but the average predicted for each of the scenarios is within the range of summer flows observed during the period of record.



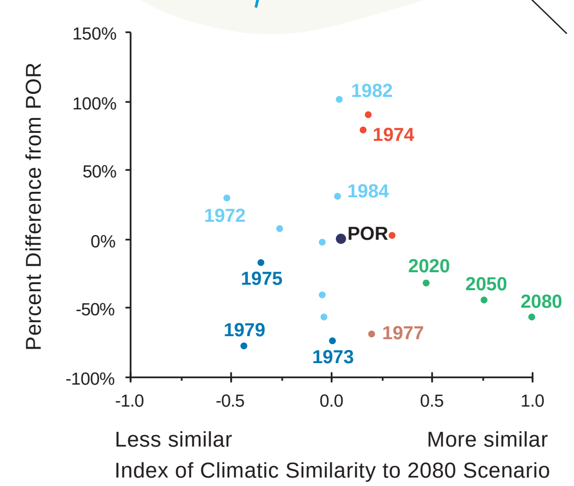
Bellevue Creek

Summer flows are predicted to be lower than normal, but the average predicted for each of the scenarios is within the range of summer flows observed during the period of record.



Vaseux Creek

Summer flows are predicted to be lower than normal, but the average predicted for each of the scenarios is within the range of summer flows observed during the period of record.



Okanagan Region: Mean Flow During Fall Season (Sep - Nov)

Predictions by the Canadian Global Climate Model for selected creeks

Overview:

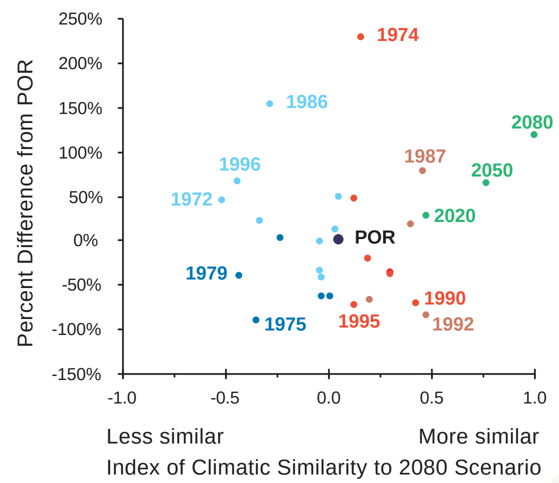
These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

Streamflow during the Fall can be sensitive to whether proecipitation falls as rain or as snow. In a warmer climate, more of the precipitation will fall as rain and run off immediately. The magnitude of the effect is largely a function of how much of the precipitation during this season falls as snow during the period of record. Higher elevation stations are more likely to experience a significant change in Fall Streamflow

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model

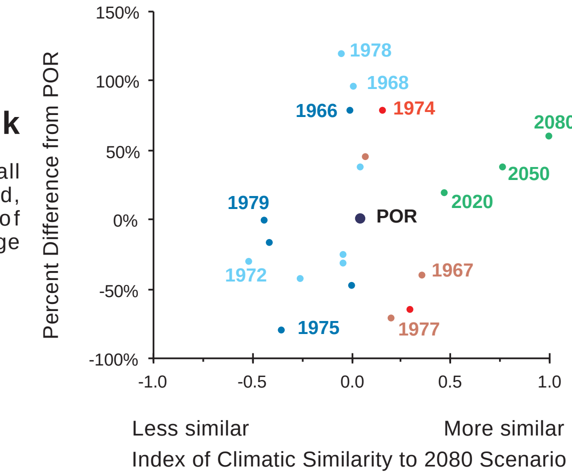
Whiteman Creek

A slight increase in Fall discharge is predicted, within the range of observed Fall Discharge



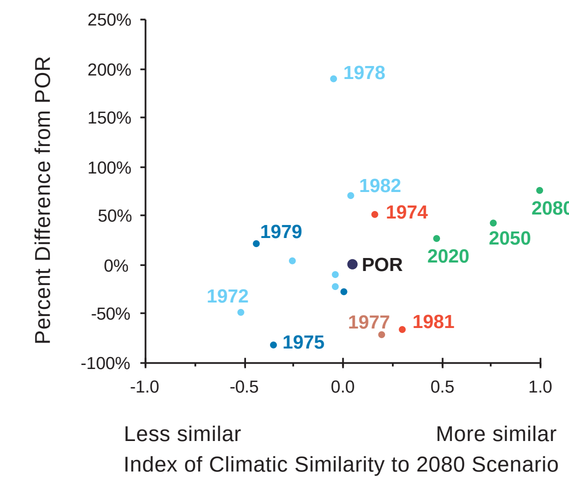
Dave's Creek

A slight increase in Fall discharge is predicted, within the range of observed Fall Discharge



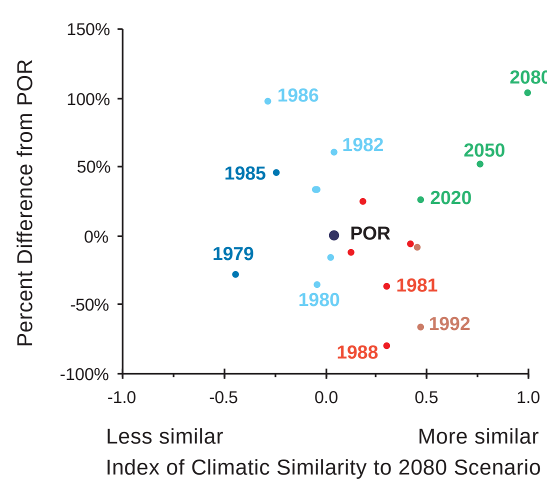
Pearson Creek

A slight increase in Fall discharge is predicted, within the range of observed Fall Discharge



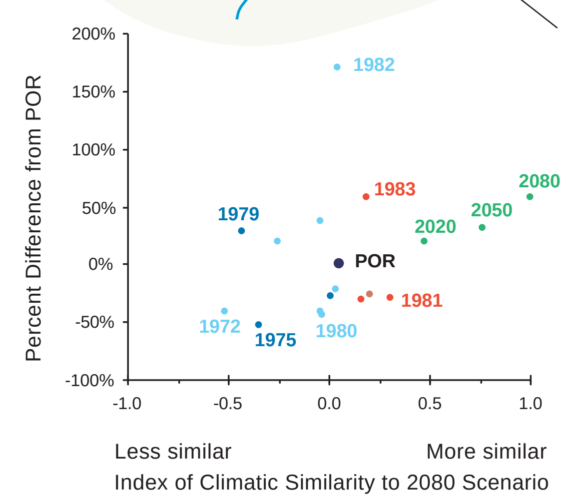
Camp Creek

A slight increase in Fall discharge is predicted, within the range of observed Fall Discharge



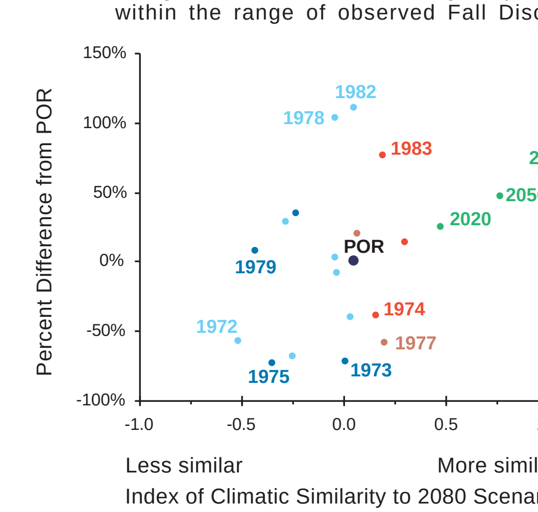
Vaseux Creek

An increasing trend is evident for Fall discharge. In 1982 (a cool-wet year) Fall rains produced discharge in excess of the averages predicted in the climate change scenarios.



Bellevue Creek

A slight increase in Fall discharge is predicted, within the range of observed Fall Discharge



Okanagan Region: Mean Flow During Winter Season (Dec - Feb)

Predictions by the Canadian Global Climate Model for selected creeks

Overview:

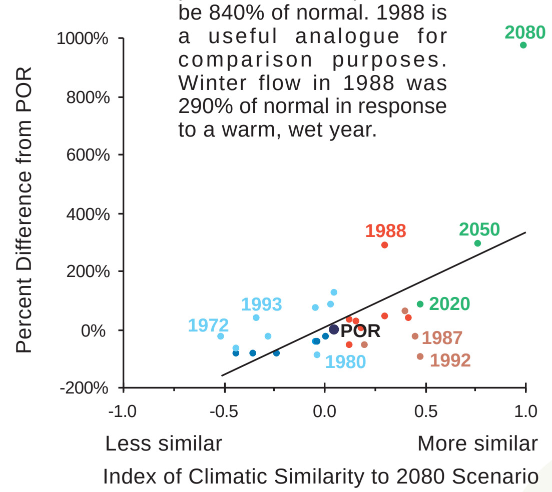
These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

These graphs show that streamflow is predicted to increase through the winter months in response to shorter, warmer, wetter winters. The magnitude of the increase depends on how much of a change there will be from a hydrolgical regime where most of the precipitation falls as snow and is therefore unavailable for runoff - to a regime where the precipitation falls as rain and is therefore available immediately for runoff. The predicted change in flow can be quite dramatic as a percentage of 'normal'.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model

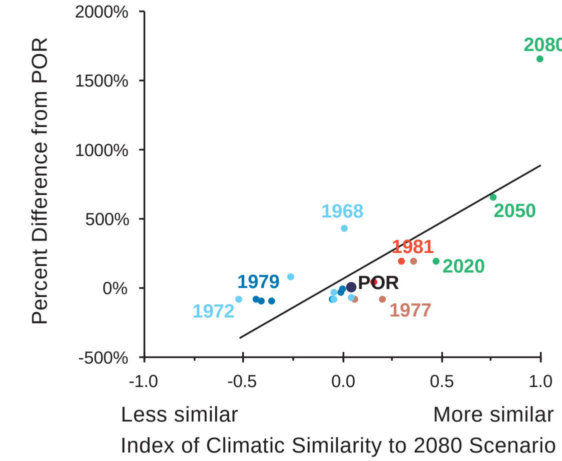
Whiteman Creek

Whiteman Creek winter streamflow shows a significant upward trend with predicted flow expected to be 840% of normal. 1988 is a useful analogue for comparison purposes. Winter flow in 1988 was 290% of normal in response to a warm, wet year.



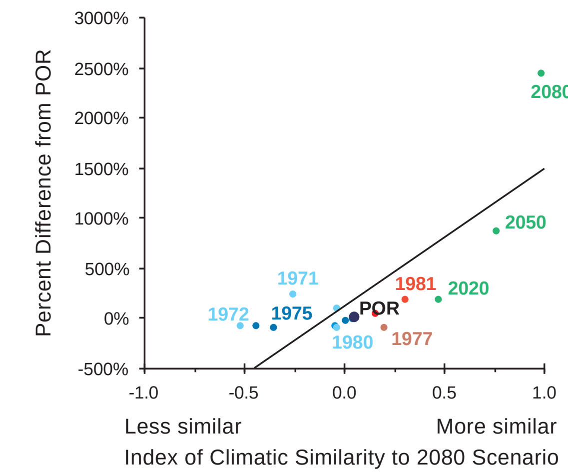
Dave's Creek

Dave's Creek shows a very significant predicted increase in winter flow. The highest winter flow on record is 1968 which was 400% above normal which is still much less than the 1650% increase predicted by the 2080 scenario.



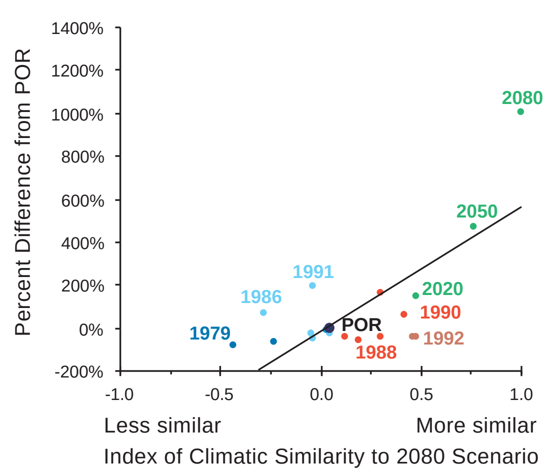
Pearson Creek

Pearson Creek shows a very significant increase in flow predicted during the winter months. Most of this increase is in the months of December and January. There are no analogues in the period of record for flow increases of this magnitude.



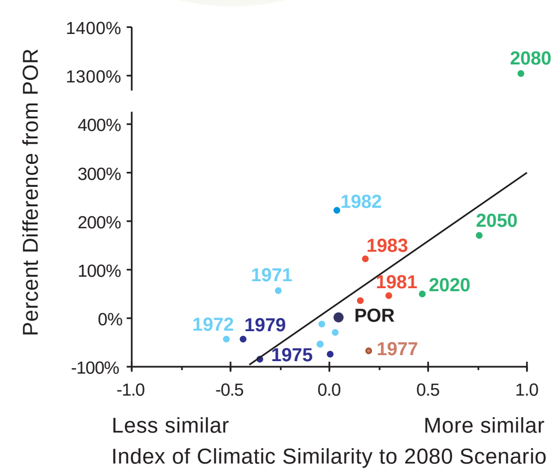
Camp Creek

A 1200% increase in winter flow is predicted for Camp Creek. The highest flow observed during the period of record was 1991 which was a cool-wet year with a winter flow which was 190% above normal.



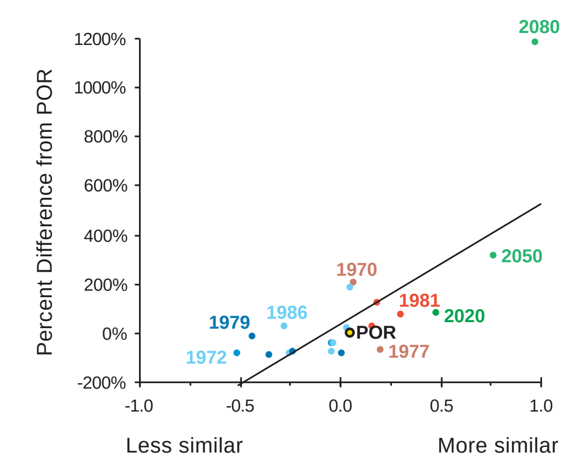
Vaseux Creek

Vaseux Creek shows a significant trend towards higher streamflow, with predicted streamflow for 2080 being arproximately 500% higher than recorded during the period of record. 1982 and 1983 were both high flow years, 1982 was cool-wet whereas 1983 was warm-wet.



Bellevue Creek

Bellevue Creek winter streamflow will increase to about 960% above normal by the 2080's. The highest winter streamflow on record was recorded in 1970 which was a warm-dry year during which the winter discharge was about 200% above normal.



Okanagan Region: Duration of Low Flow

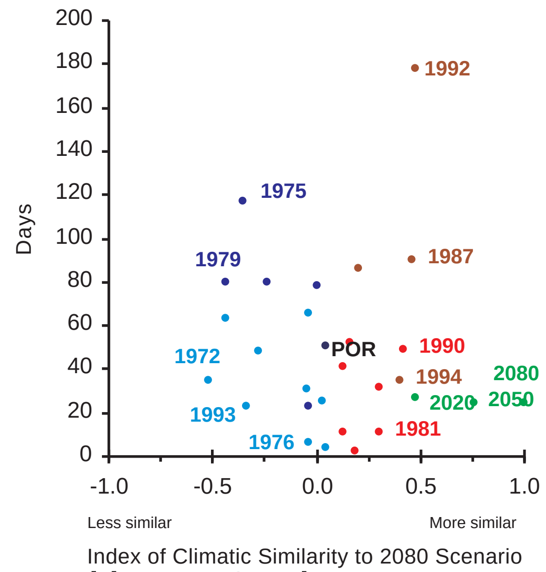
Predictions by the Canadian Global Climate Model for selected creeks

Overview:

These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are: warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

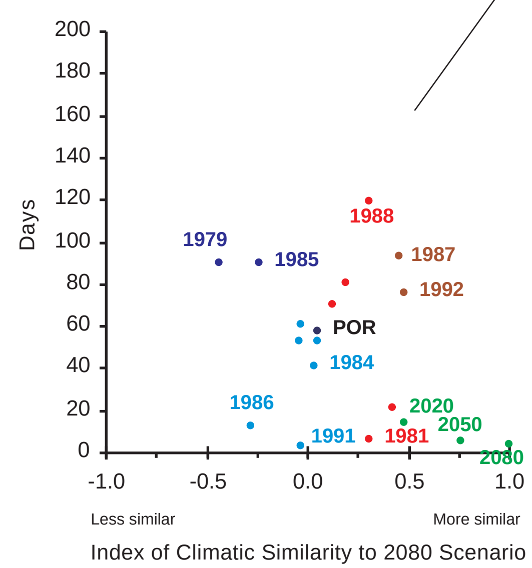
Low flow occurances are a result of extended absences of inputs from snowmelt or rainfall. Extended periods of sub-freezing weather intercept the supply of atmospheric water in the snowpack. A decrease in the duration of low flow is likely as the winters become shorter, warmer and wetter.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model



Whiteman Creek

There will not be any significant change in the duration of low flow for Whiteman creek. There is however a tendency to have fewer years like 1992 which had an extended low flow during a warm dry year.

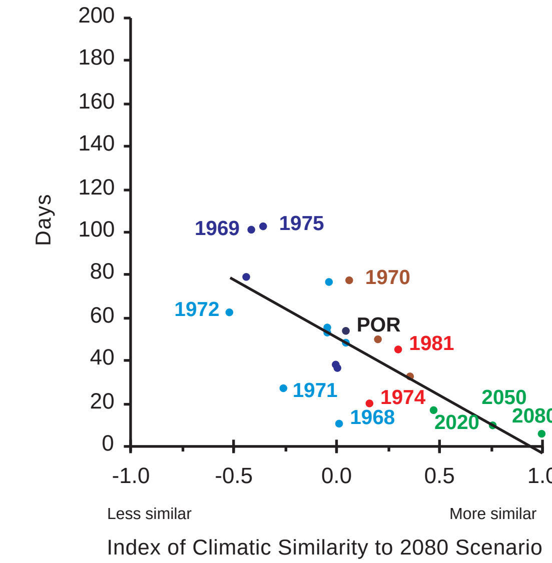


Camp Creek

The change at Camp creek will be quite profound the period of low flow will be quite short and can be contrasted to 1988, when the creek was in low flow conditions for almost 1/3 of the year.

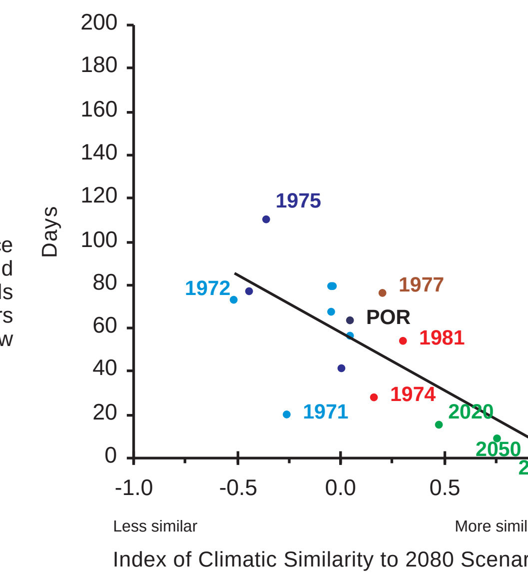
Dave's Creek

Dave's Creek will experience more winters like 1968, 1974 and 1971 with short duration low flow.



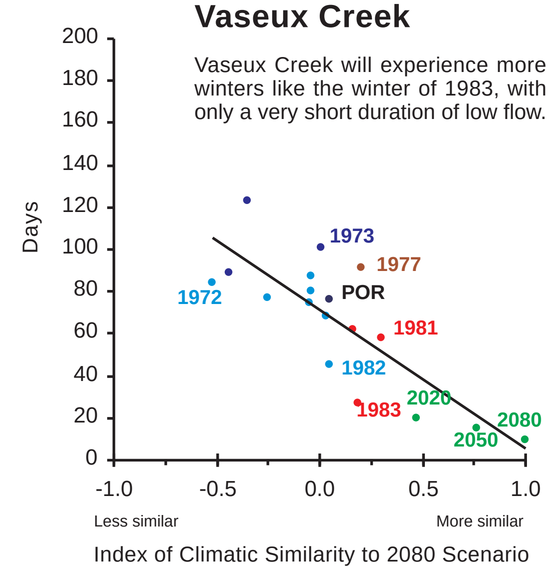
Pearson Creek

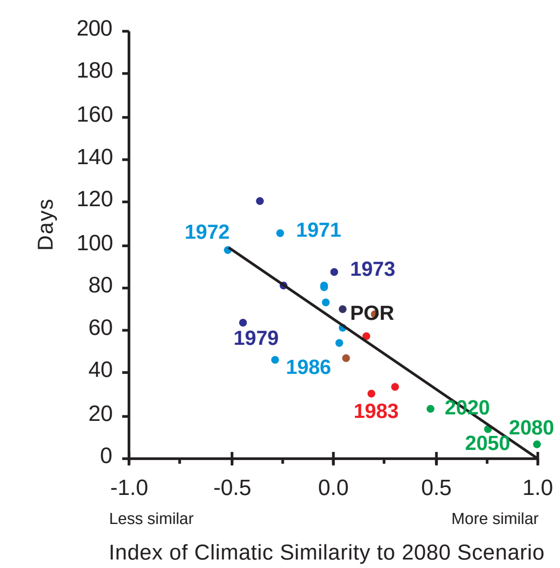
Pearson Creek will experience more winters like 1971 and 1974 with very short periods of low flow and fewer winters like 1975 with an extended low flow period.



Vaseux Creek

Vaseux Creek will experience more winters like the winter of 1983, with only a very short duration of low flow.





Bellevue Creek

Similar to Camp Creek the change in Bellevue Creek will be quite profound in response to shorter, warmer, wetter winters. 1981 and 1983 are both good analogues for the future regime.

Okanagan Region: Date of Low Flow

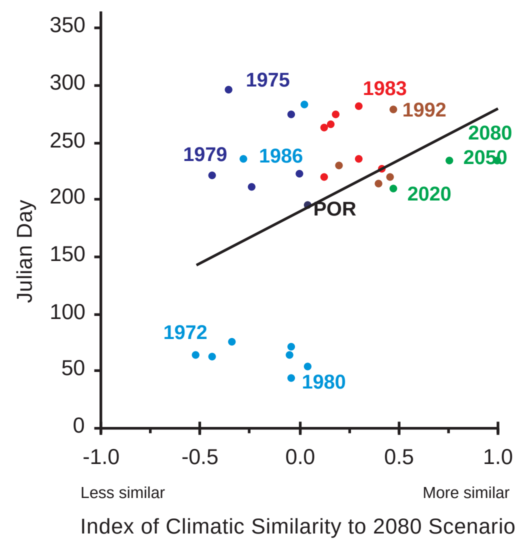
Predictions by the Canadian Global Climate Model for selected creeks

Overview:

These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are: warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

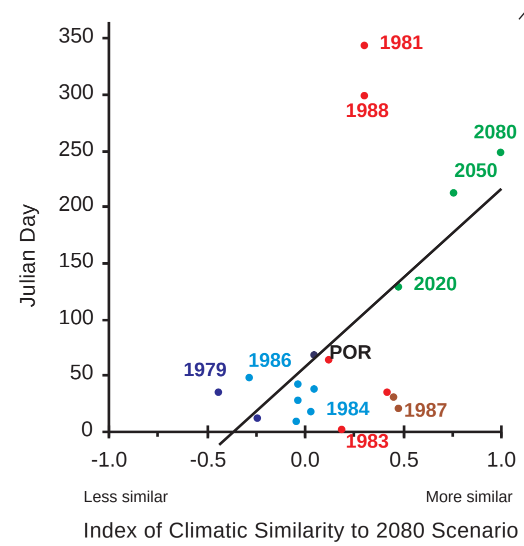
The date of low flow is typically in late winter or early spring for snow-dominated streams and in late summer for rain- dominated streams. In general, one would expect an earlier date of low flow for snow-dominated streams in a warmer climate. However, for several streams, we see a shift in seasonality of low flow from late winter to late summer. A shift from one regime to another could result in profound ecosystem effects that cannot be accurately predicted.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model



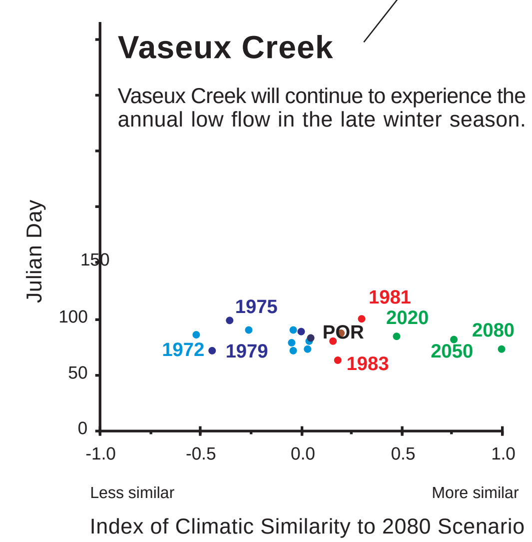
Whiteman Creek

Whiteman creek shows a distinctly bi-modal pattern in the timing of low flow. Cool-Wet years such as 1980 and 1982 almost always experience the annual low flow in the spring whereas in most other years the annual low flow occurs in the late summer. The models show that in the future, almost all of the low flow episodes will occur in the late summer.



Camp Creek

Camp creek has been rain-dominated in some years(1981,1988), but has most often been snow-dominated. The predictions show that in the future there will be more years in which the annual low flow occurs in late summer.

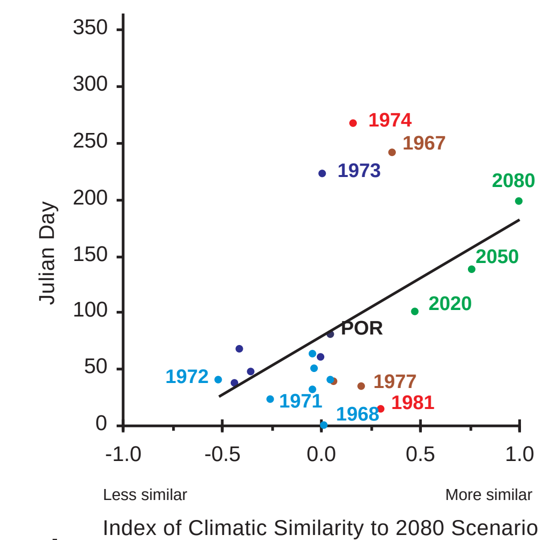


Vaseux Creek

Vaseux Creek will continue to experience the annual low flow in the late winter season.

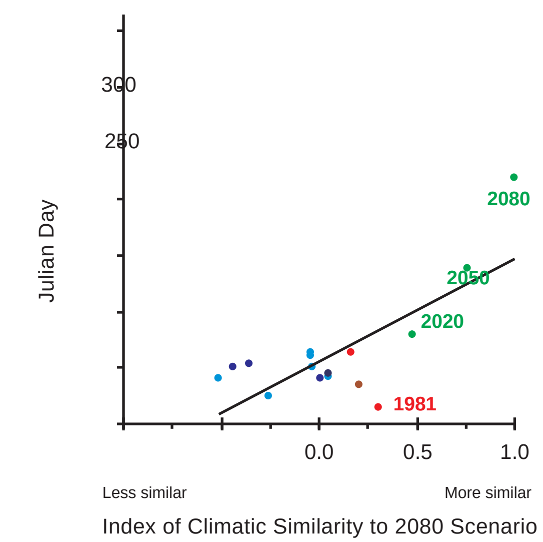
Dave's Creek

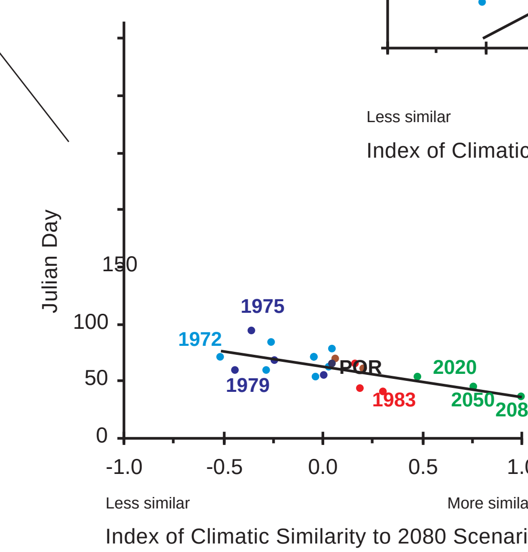
Dave's creek has been rain-dominated in some years(1967,1973,1974), but has most often been snow-dominated. The predictions show that in the future there will be many more late-summer occurences of the annual low flow That this stream has a history of shifting between regimes likely means that the aquatic ecosystem has the capacity to adapt to the regime shift



Pearson Creek

Pearson Creek is predicted to show a pronounced shift in seasonality from an snow dominated regime to a rain-dominated regime.





Bellevue Creek

Bellevue Creek will remain snow-dominated but the timing of low-flow will be earlier as shorter winters result in an earlier onset of snowmelt to end the winter recession.

Okanagan Region: Duration of High Flow

Predictions by the Canadian Global Climate Model for selected creeks

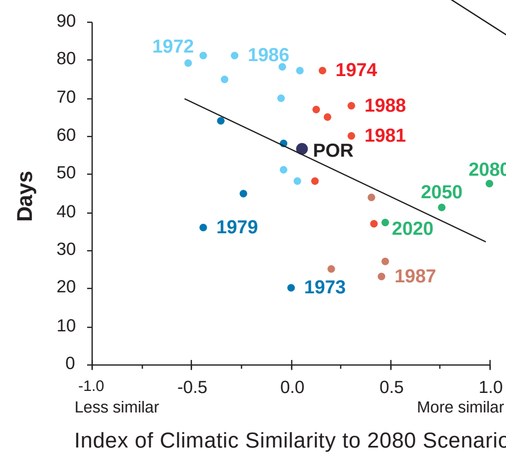
Overview:

These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are: warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

The duration of high flow for snowmelt-dominated streams is an indication of the total volume of snow that is available to melt. In general, the less snow there is, the shorter the duration of high flow. A similar pattern is evident in the graphs for all stations where the predicted duration of high flow is less than almost any of the years for which we have data. This change will occur by the 2020's and then there is little additional change in subsequent scenarios. This is significant in that it signals a shift from a snowmelt dominated regime to a bimodal regime, where there are an increasing number of days of high flow due to rain but a decreasing number of days of high flow due to snowmelt. The fact that the predicted scenarios are all at the low end of the scatter of data indicate that there are few or no analogues in the present record for the future hydrological regime. All stations shown are currently snowmelt dominated and all will become increasingly bi-modal as a result of climate change.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model

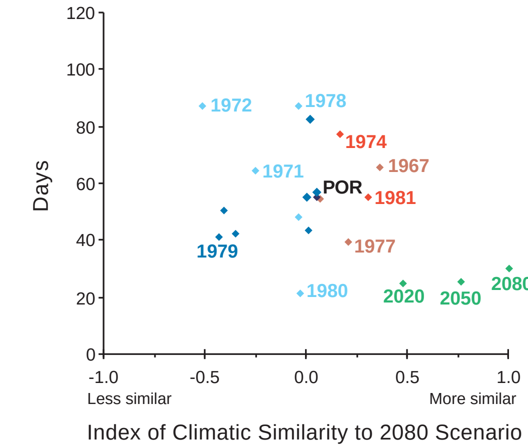
Whiteman Creek



There is a significant negative trend to the duration of peak flow which is supported by the climate change modeling. This is a result of lower snowpacks which are needed to sustain high water for a long period of time. High water will occur mor frequently in the fall months driven by rain event which tend to be much shorter in duration than snowmelt events.

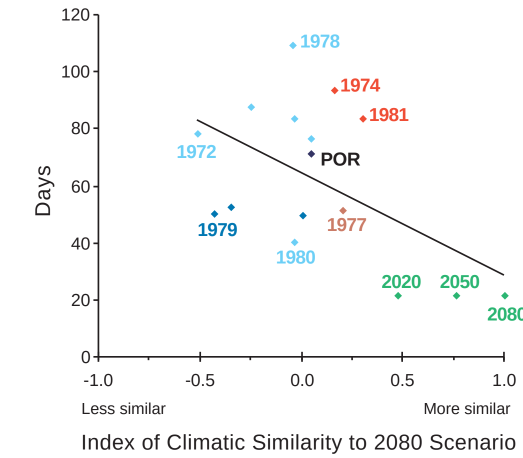
Dave's Creek

The year with the lowest duration of high flow (1980) was cool and wet and hence not a very useful analogue for the predicted effect. There is no trend in the scatter of data, indicating that there will be a relatively abrupt shift to the new regime. The effect will be apparent by the 2020's



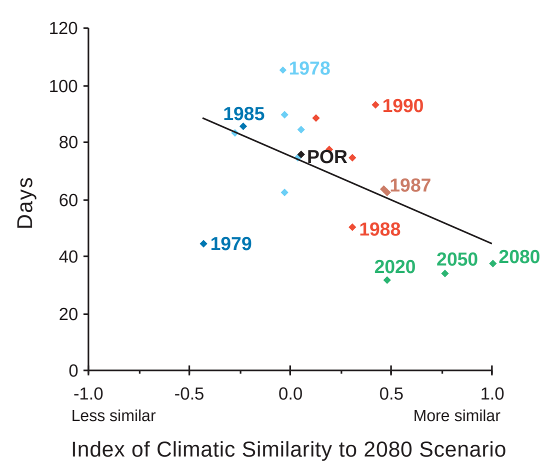
Pearson Creek

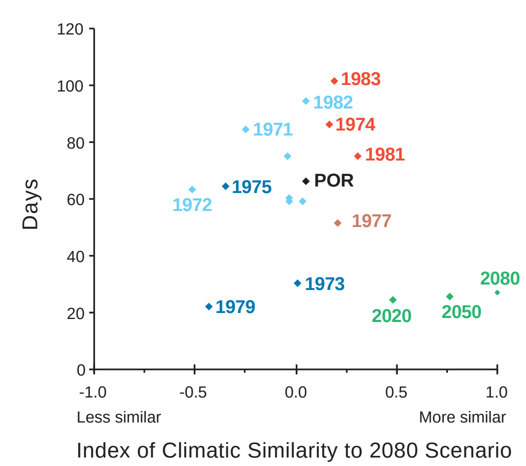
The year with the lowest duration of high flow (1980) is still much greater than the predicted high flow regime. That year was cool and wet and hence not a very useful analogue for the predicted effect. There is no trend in the scatter of data, indicating that there will be a relatively abrupt shift to the new regime. The effect will be apparent by the 2020's



Camp Creek

Only 1979 is roughly similar to the predicted scenarios. This year had low snow pack combined with cool temperatures, and as such is not a very good analogue for the warm conditions predicted. There is no trend in the scatter of data, indicating that there will be a relatively abrupt shift to the new regime. The effect will be apparent by the 2020's



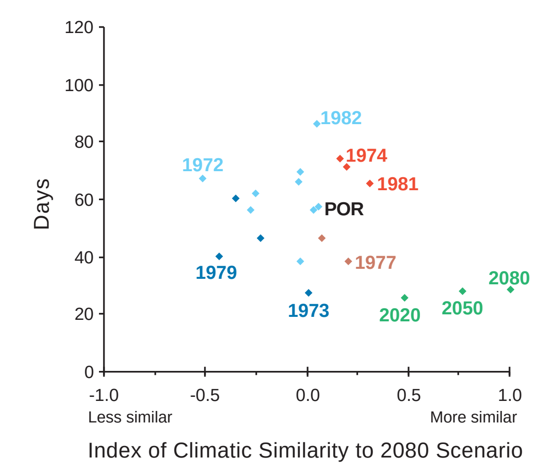


Vaseux Creek

Only two years (1973 & 1979) are roughly similar to the predicted scenarios. These years had low snow pack combined with cool temperatures, and as such are not very good analogues for the warm conditions predicted. There is no trend in the scatter of data, indicating that there will be a relatively abrupt shift to the new regime. The effect will be apparent by the 2020's

Bellevue Creek

Only 1973 is roughly similar to the predicted scenarios. This year had low snow pack combined with cool temperatures, and as such is not a very good analogue for the warm conditions predicted. There is no trend in the scatter of data, indicating that there will be a relatively abrupt shift to the new regime. The effect will be apparent by the 2020's



Okanagan Region: Date of Peak Flow

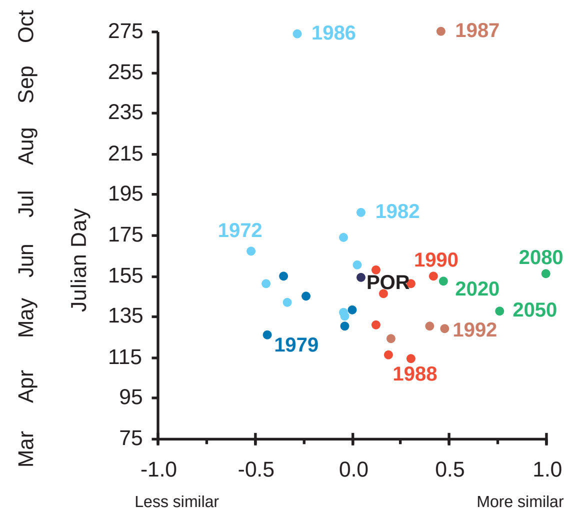
Predictions by the Canadian Global Climate Model for selected creeks

Overview:

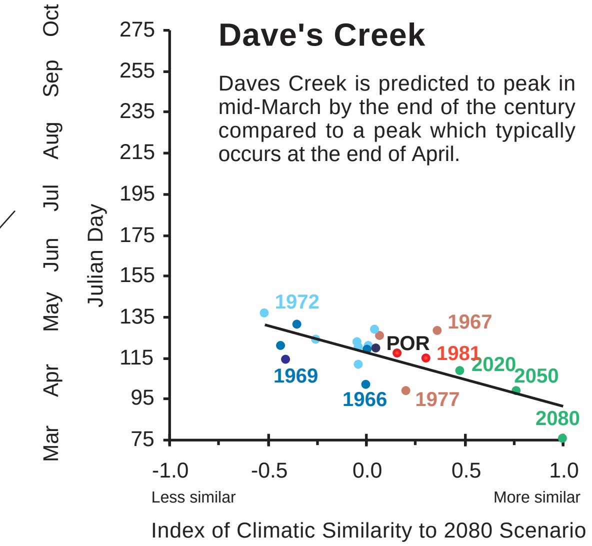
These graphs show how these streams may respond to the climate as predicted by the Canadian Global Climate Model (GCM) for the 2080 scenario (which covers the period from 2071 to 2100). Individual years from the period of record are plotted according to an index of similarity to the 2080 scenario. Years which plot to the right hand side of the graph indicate that the climate in those years is more similar to the predicted climate change than those years which plot to the left hand side. The years are also colour coded according to whether they are: warm-dry, warm-wet, cool-dry or cool-wet with respect to the reference period of 1961-1990. In general, warm wet years are more similar to the predicted climate and cool-dry years are least similar. However, hydrological response is extremely sensitive to seasonal patterns resulting in a wide scatter around the mean for the period of record (POR). The mean for the 2020 scenario (from 2011 to 2040) and the 2050 scenario (from 2041 to 2060) are also shown as reference points. If a regression line is shown, then the trend indicated by the line is significant at the 95% confidence level.

The timing of peak flow in snowmelt-dominated streams is a function of how much energy is available to melt snow after snow accumulation peaks. In general, warmer temperatures will mean that snowmelt will occur earlier because there is more heat in the early spring to melt the snowpack. However, the timing effect is most pronounced for low elevation streams because the period of snow-cover will be much shorter at those elevations.

Year label	Type
• 1979	cool wet years
• 1979	warm wet years
• 1979	warm dry years
• 1979	cool dry years
• 1979	predicted by model

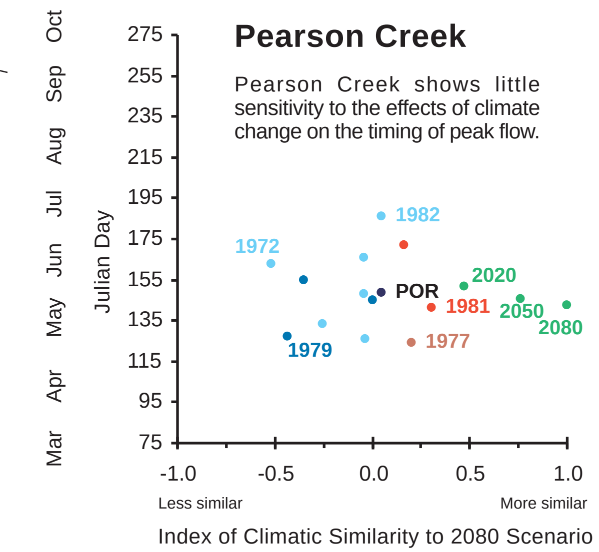


Whiteman Creek shows little apparent sensitivity to the effects of climate change on the timing of peak flow. The years, 1986 and 1987, were years in which the annual peak occurred in the fall.



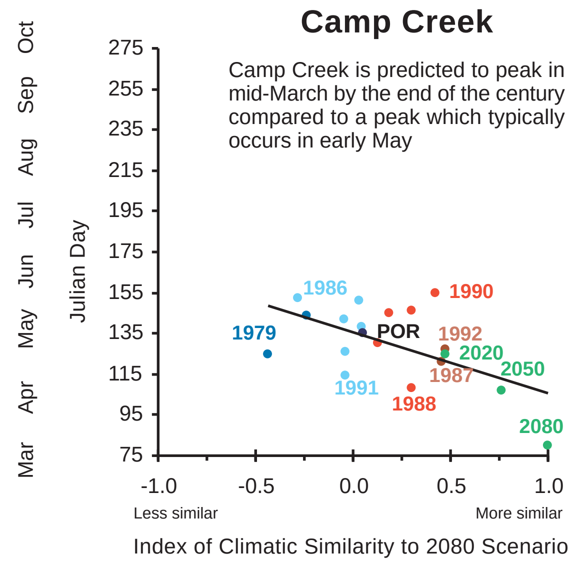
Dave's Creek

Daves Creek is predicted to peak in mid-March by the end of the century compared to a peak which typically occurs at the end of April.



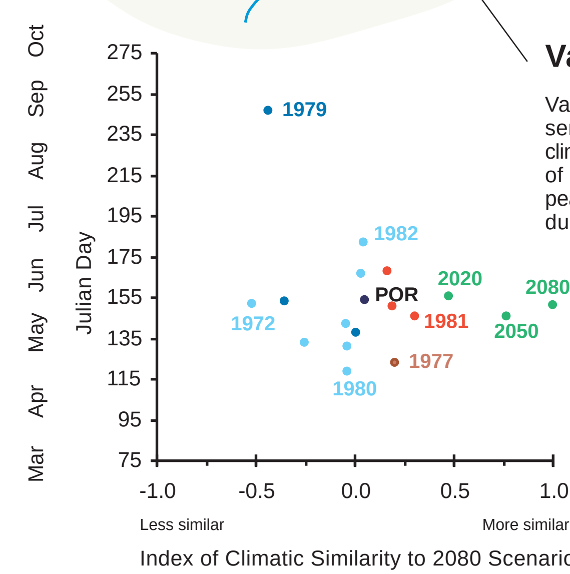
Pearson Creek

Pearson Creek shows little sensitivity to the effects of climate change on the timing of peak flow.



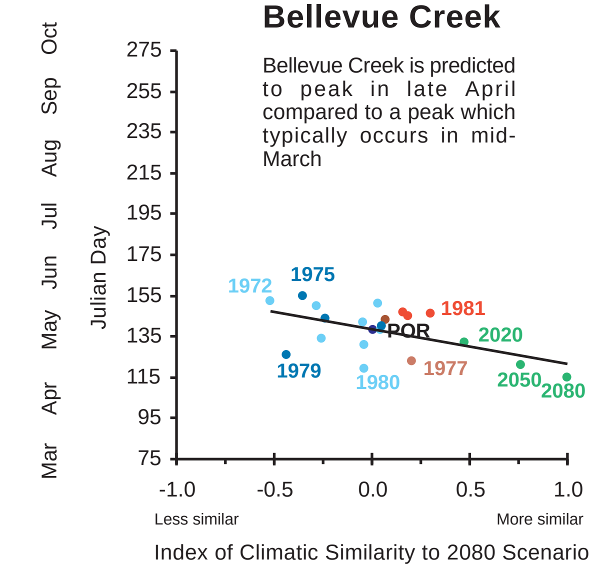
Camp Creek

Camp Creek is predicted to peak in mid-March by the end of the century compared to a peak which typically occurs in early May



Vaseux Creek

Vaseux Creek shows little sensitivity to the effects of climate change on the timing of peak flow. The date of peak flow for 1979 occurred during the fall.



Bellevue Creek

Bellevue Creek is predicted to peak in late April compared to a peak which typically occurs in mid-March

APPENDIX 3: Focus Group Results

MODELED IMPACTS

Changing Climate

- Higher temperature
- Decreased snowpack

Changing Hydrology

- Earlier peaks in spring freshet
- More precipitation projected, but seasonal breakdown is inconsistent
- No consensus on total water flow changes in the system

RANKED IMPACT AREAS

- Fisheries
- Tourism
- Decreased water quality
- Impacts of uncertainty
- Changes to water budget and water supply
- Disparity b/w high and low elevations
- Low flows in fall (timing and quantity)
- Species shift and ecosystem changes
- Air quality – health impacts
- Increased demand for agricultural land and irrigation
- Changes in pests
- Changes in fire regime
- Changes in land use
- Aquatic ecosystem
- Increased demand for water; groundwater; domestic; irrigation

RANKED ADAPTATION OPTIONS

- Use water more efficiently: Pay for water, Restrict development and or population, Irrigation methods (practices, systems), Metering
- Inventory supply and prioritize water users
- Water licensing: Increased enforcement, Change in timing, Buyouts
- Develop more water storage/other sources
- Regulate flow and erosion through dams
- Adapt silviculture practices; Develop new seedling varieties
- Better integration of government agencies
- Include climate change possibilities when making land use decisions
- Consider ecological costs in resource management
- Consider social costs, making adaptation decisions

Figure A3-1. Summary of Ranked Impacts and Adaptations

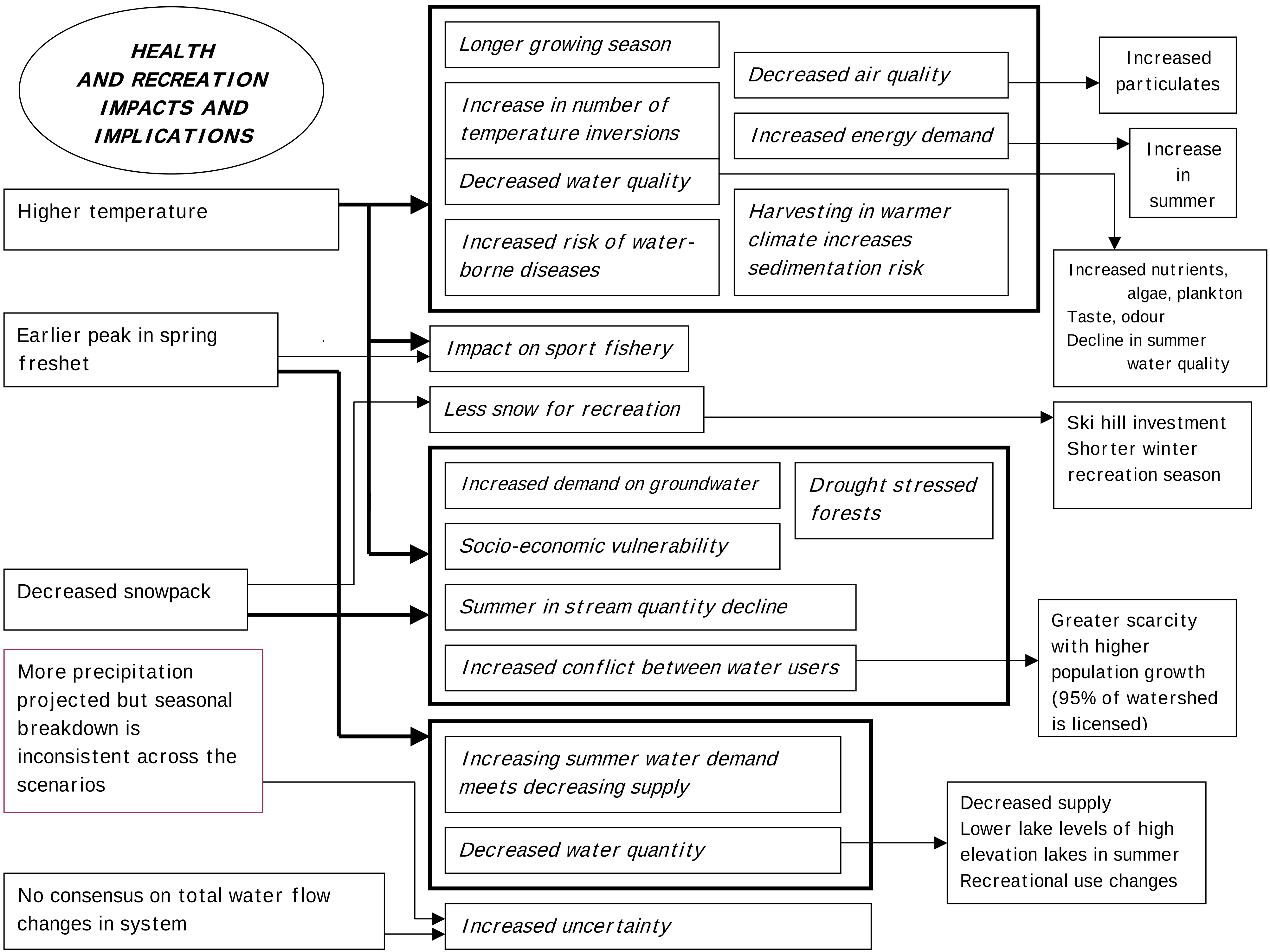


Figure A3-2. Summary of Impacts and Implications for Health and Recreation

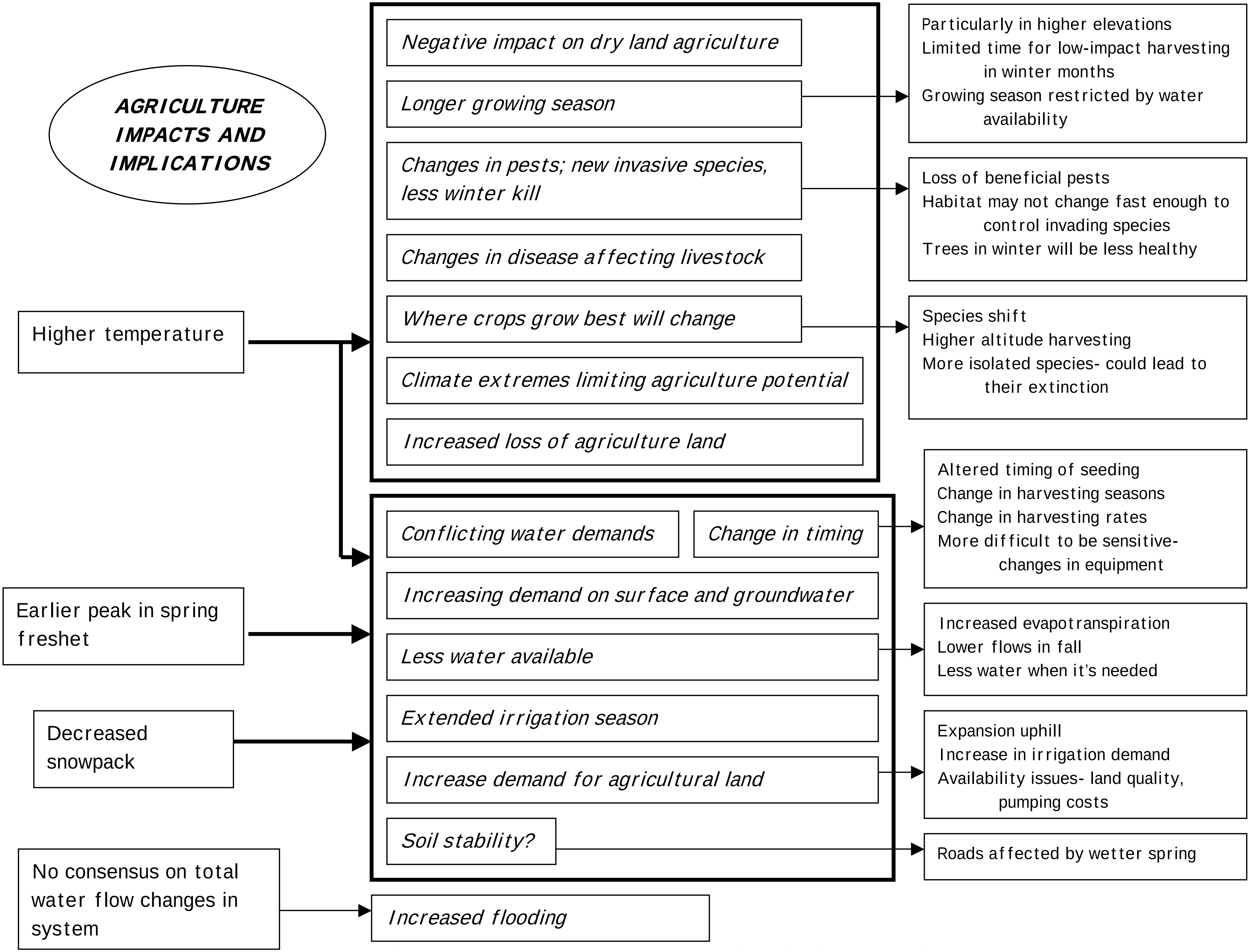


Figure A3-3. Summary of Impacts and Implications for Agriculture

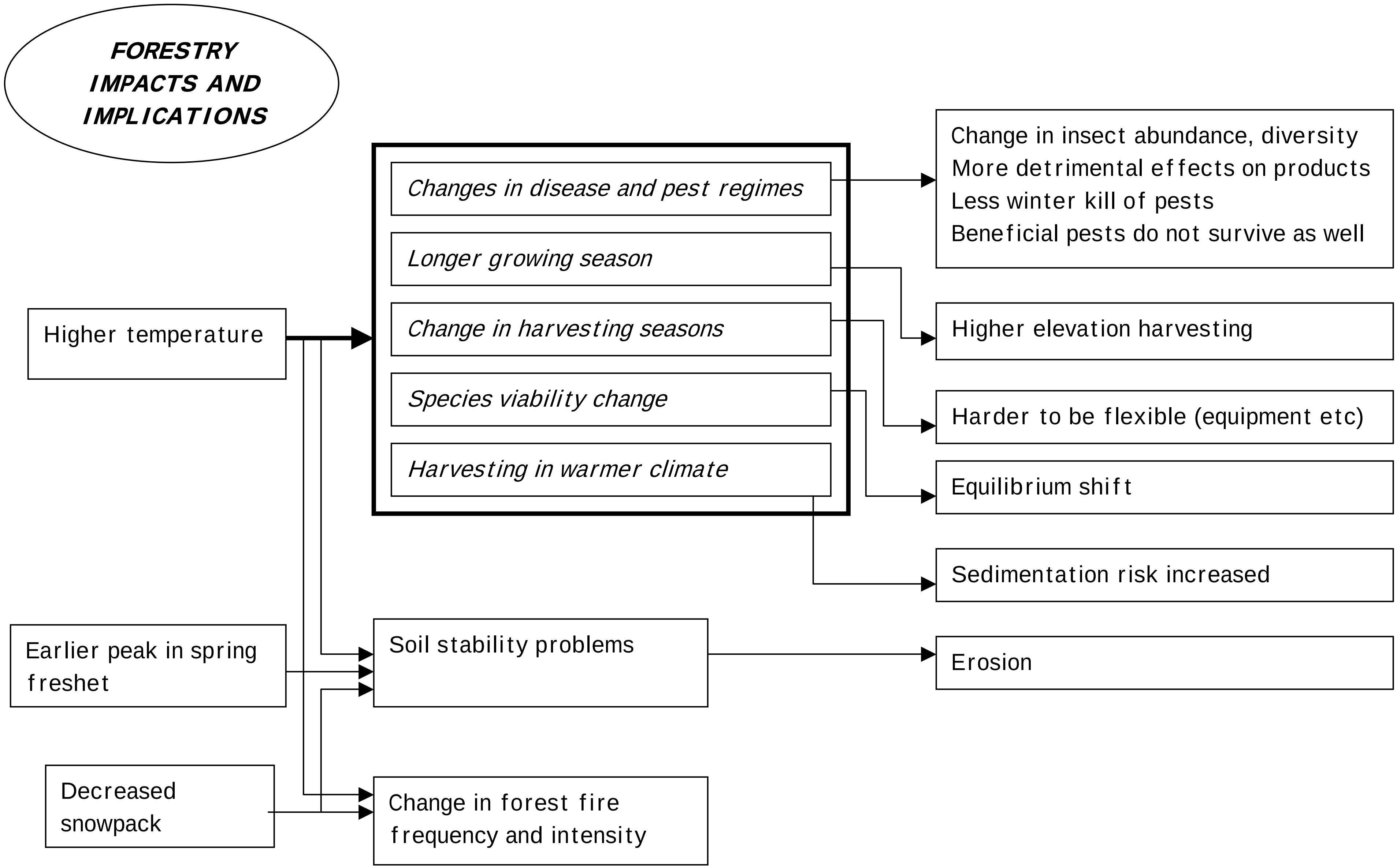


Figure A3-4. Summary of Impacts and Implications for Forestry

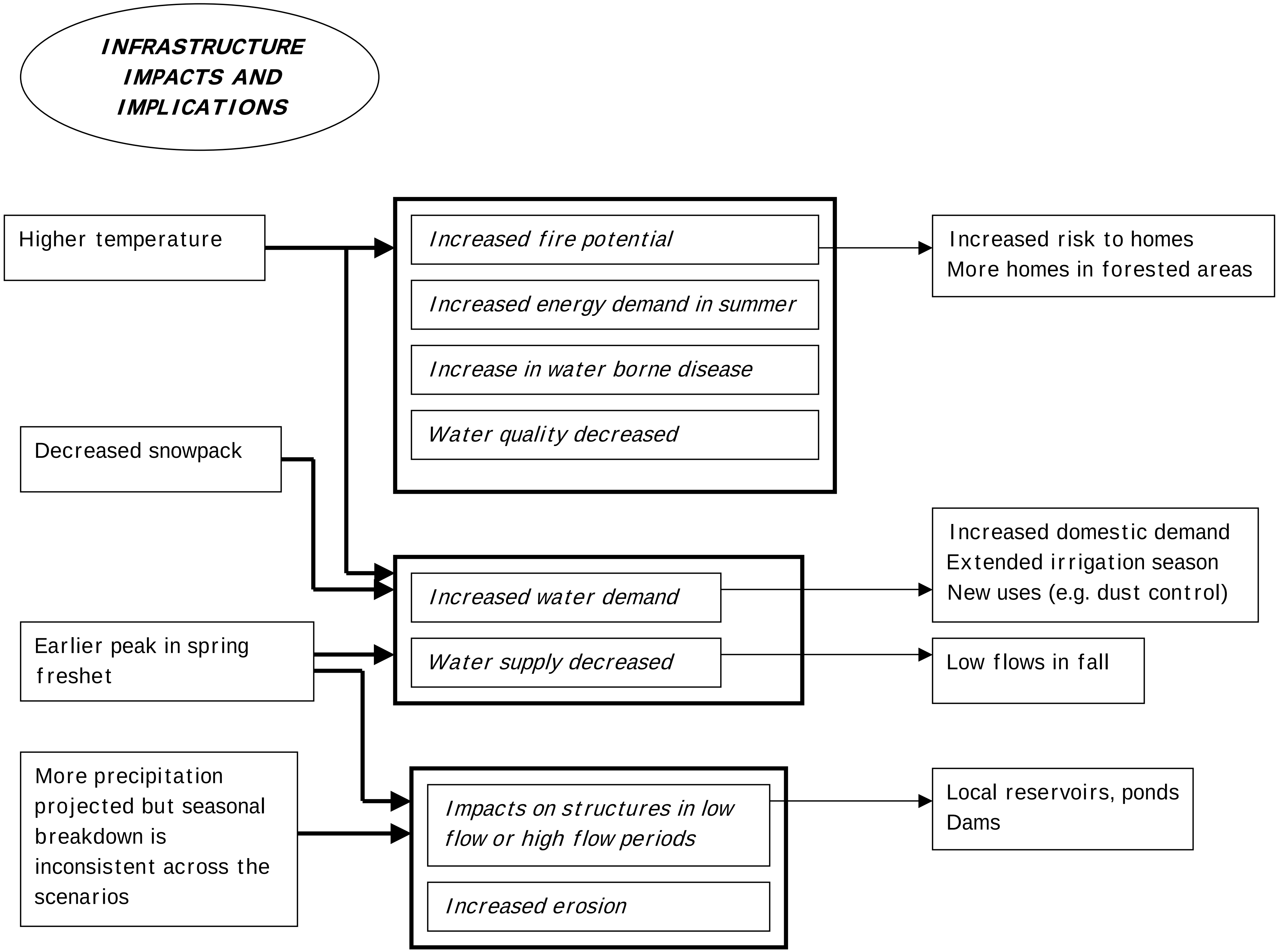


Figure A3-5. Summary of Impacts and Implications for Infrastructure

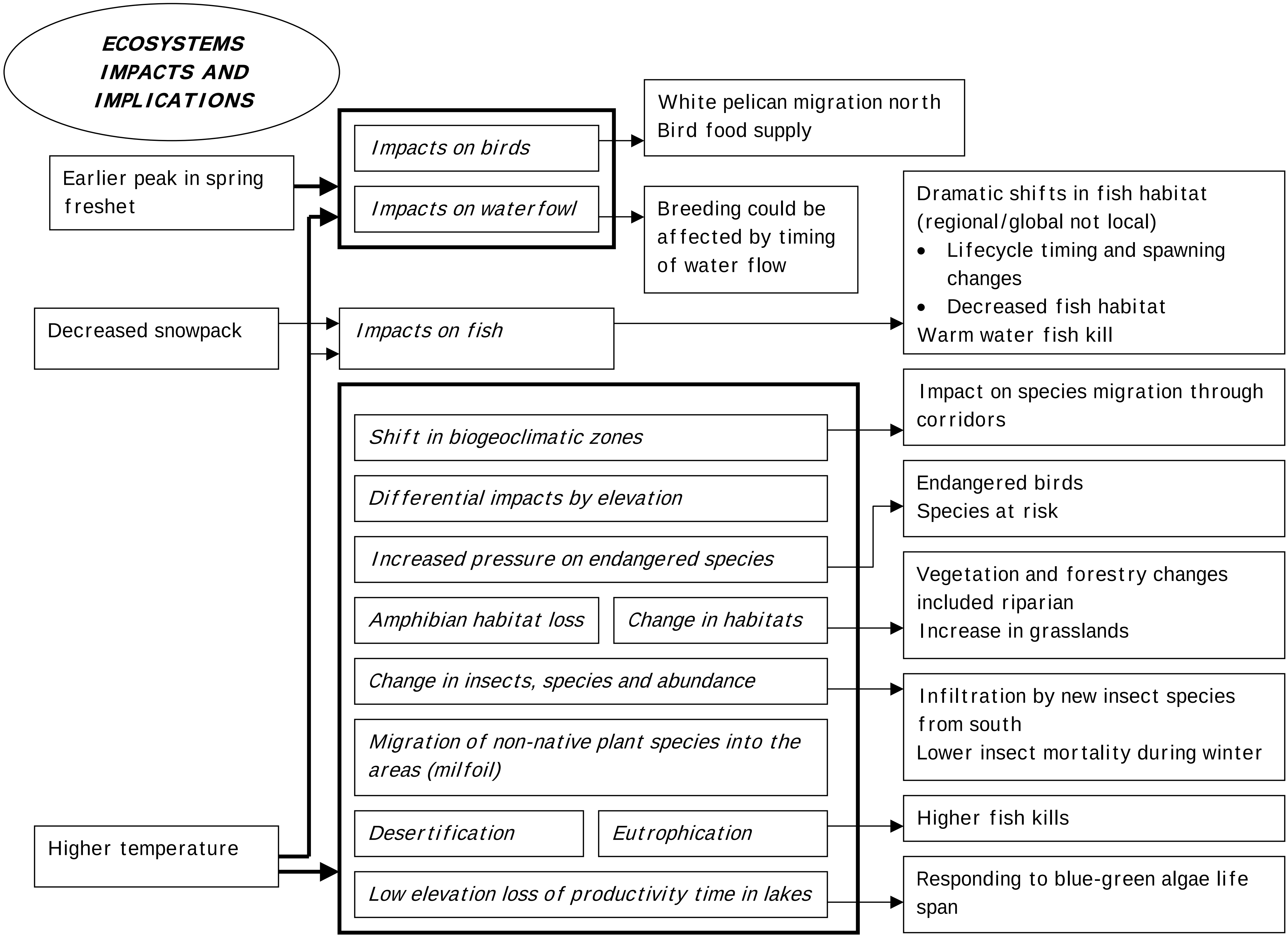


Figure A3-6. Summary of Impacts and Implications for Ecosystems

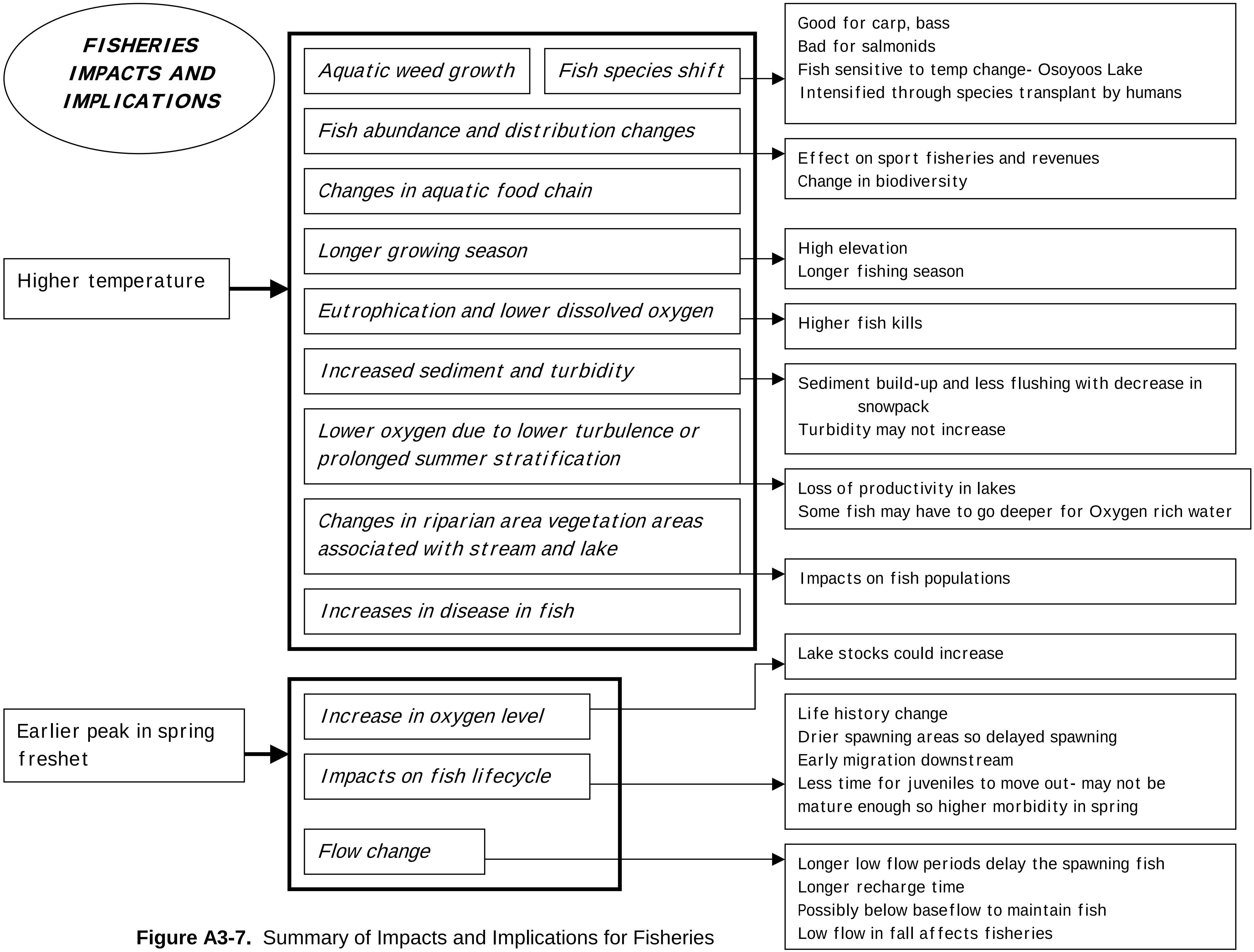


Figure A3-7. Summary of Impacts and Implications for Fisheries