



Water Monitoring and Climate Change in the Upper Columbia Basin

Summary of Current Status and Opportunities

JANUARY 2017

Acknowledgments

This report was written by Martin Carver based on a wide range of existing information and emerging science. It integrates elements of a water resource compilation by Janice Brahney and new supplemental analyses of historic and projected climates provided by Greg Utzig. Reviews and valuable feedback were provided by Greg Utzig and Faron Anslow.

Contributions of the following individuals are gratefully acknowledged:

Faron Anslow, Climatologist, Pacific Climate Impacts Consortium

Marley Bassett, Fish Restoration Biologist, Ministry of Forests, Lands and Natural Resource Operations

Ayla Bennett, Program Manager, Elk River Alliance

Dan Byron, Team Leader, Large Water Systems Program, Interior Health Authority

Mary Anne Coules, Stakeholder Engagement Advisor, BC Hydro

Sarah Crookshanks, Research Geomorphologist, BC Ministry of Forests, Lands and Natural Resource Operations

Claire de la Salle, Program Manager, Friends of Kootenay Lake Stewardship Society

Laura Duncan, Technical Coordinator, Columbia Basin Water Quality Monitoring Program

Ryan Durand, Biologist, Durand Ecological Ltd.

Richard Johnson, Principal, Slocan Lake Research Centre

Peter Jordan, Research Geomorphologist (retired), BC Ministry of Forests, Land and Natural Resource Operations

Georg Jost, Senior Hydrologic Modeller, BC Hydro

Heather Leschied, Living Lakes Canada

Ingrid Liepa, The Connecting Link

Brian Menounos, Professor and Canada Research Chair in Glacier Change, University of Northern British Columbia

Dan Moore, Professor, University of British Columbia

Trevor Murdock, Lead – Regional Climate Impacts, Pacific Climate Impacts Consortium

Darcie Quamme, Biologist, Integrated Ecological Research

Jolene Raggett, Aquatic Resource Biologist, BC Ministry of Environment

Justin Robinson, Research Assistant, Selkirk Geospatial Research Centre

Paul Saso, Technician, Consultant

Stephanie Strachan, Environmental Studies Scientist, Environment and Climate Change Canada

Carrie Thurston, Environmental Impact Assessment Biologist, BC Ministry of Environment

Greg Utzig, Conservation Ecologist, Kootenay Nature Investigations Ltd.

Water Protection and Sustainability Branch, BC Ministry of Environment, Victoria, BC

Jennifer Yeow, Microbiologist, Slocan River Streamkeepers

Cover: Slocan City, looking north over Slocan Lake.

Table of Contents

1.0	Understanding Water in the Columbia Basin	1
1.1	Introduction	1
1.2	Basin Water Resources	2
1.3	Basin Climate	4
1.4	Pressures on Basin Water Resources	9
1.4.1	Land Use	9
1.4.2	Climate Change	13
2.0	Status of Water Monitoring in the Basin	22
2.1	Scope of Water Monitoring	22
2.2	Water Quantity Monitoring Efforts and Data Providers	24
2.3	Water Quality Monitoring Efforts and Data Providers	28
2.4	Community-Based Monitoring of Water Quality and Water Quantity	32
3.0	Notable Trends and Impacts	37
3.1	Snow and Glaciers	37
3.2	Rivers and Streams	40
3.3	Wetlands, Lakes and Reservoirs	43
3.4	Groundwater	44
4.0	Basin Water Resources in a Warmer Climate	46
5.0	Future Needs and Opportunities	48
	References	52
	Appendix 1. Definitions and Acronyms	55
	Appendix 2. Seasonal Historic and Projected Climate for Selected Hydrologic Regions	58

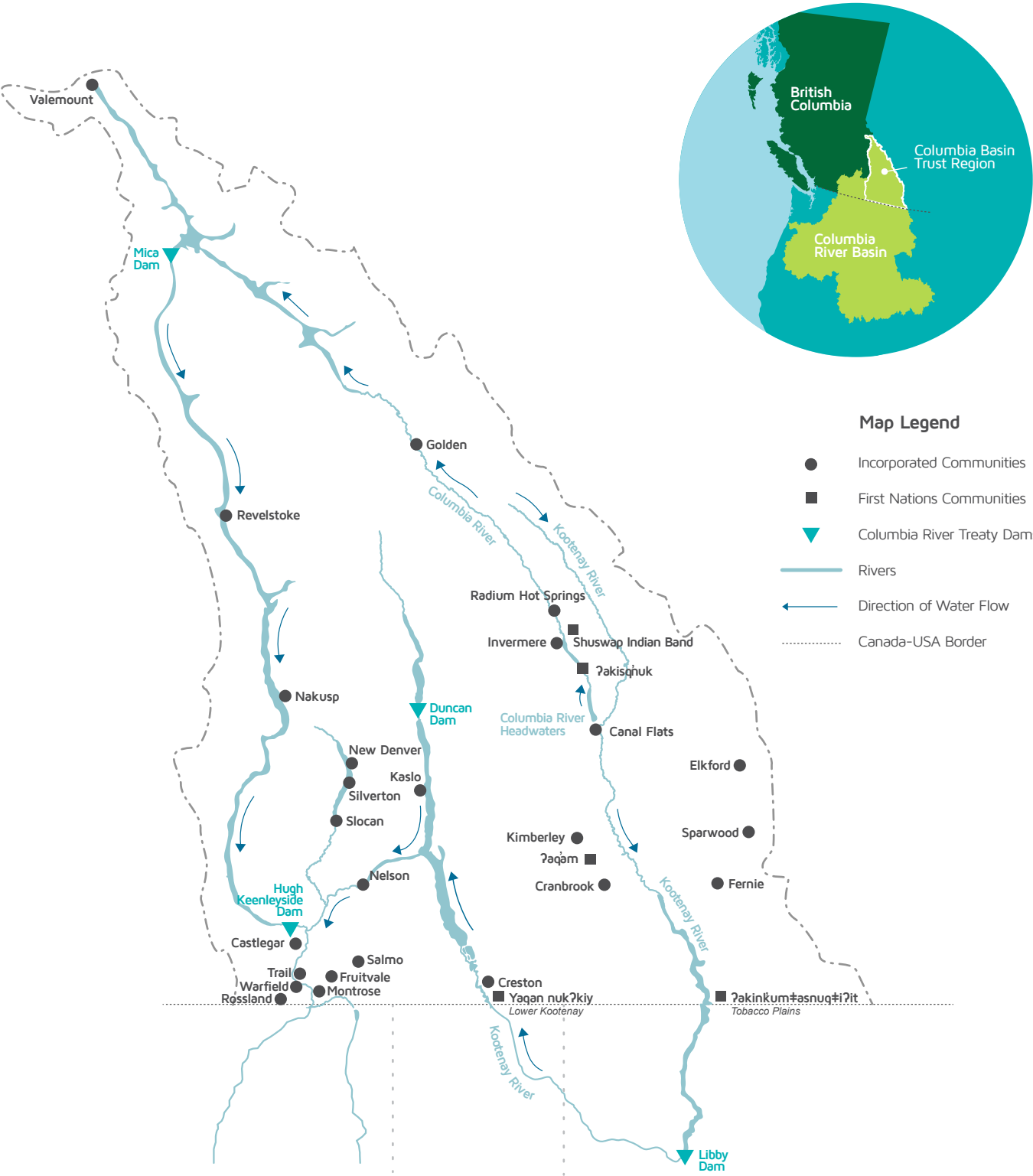
List of Figures

Figure 1. The Columbia, Kootenay and Pend d'Oreille rivers and their tributary watersheds, which range in size up to 3,000 km ² in addition to the larger Slocan and Elk river watersheds	3
Figure 2. Basin hydrologic regions as indicated by patterns of climate and surface runoff	5
Figure 3. Seasonal and annual a) temperature and b) precipitation distributions of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC, 1961-1990; under 1,500 m)	7
Figure 4. Conceptual illustration of Basin land uses and water resources	9
Figure 5. Major dams, protected areas and other significant land uses in the Basin	11
Figure 6. Extent of inundation of landscape component by reservoirs. (Utzig and Schmidt 2011).....	12
Figure 7. Historic and projected a) winter and b) summer temperature of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC for areas under 1,500 m).....	15
Figure 8. Historic and projected a) winter and b) summer precipitation of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC for areas under 1,500 m).....	16
Figure 9. Historic and projected summer climatic moisture deficit for five selected hydrologic regions distributed across the Basin (data from ClimateBC for areas under 1,500 m)	17
Figure 10. Baseline and projected proportion of winter precipitation that occurs as snow in the populated valley bottoms of five selected hydrologic regions distributed across the Basin (data from ClimateBC).....	19
Figure 11. Baseline and projected proportion of winter precipitation that occurs as snow at elevations in the upper 60 per cent (by area) of five selected hydrologic regions distributed across the Basin (data from ClimateBC)	19
Figure 12. Climate, snow and glacier monitoring sites within the Basin established by agencies and regulated industry	26
Figure 13. Hydrometric stations and lake/reservoir and groundwater monitoring sites within the Basin, established by agencies and regulated industry	27
Figure 14. Water quality monitoring sites within the Basin established by agencies and regulated industry	30
Figure 15. Monitoring sites undertaken through community-based and citizen science monitoring	34
Figure 16. Proportion of hydrologic regions covered by glaciers.....	38
Figure 17. History of active climate, snow, hydrometric and water quality monitoring stations maintained by major government agencies	48

List of Tables

Table 1. Relative climate across the Basin's ten hydrologic regions.....	6
Table 2. Elements of water quantity monitoring	23
Table 3. Scope of monitored water quality parameters and media	24
Table 4. Basin water quantity data provided by agencies and regulated industries.....	25
Table 5. Water quality monitoring led by government agencies.....	29
Table 6. Distribution of source types of Basin water supplies, according to size, as estimated by the Interior Health Authority.....	32
Table 7. Basin water-related data provided through community-based and citizen science monitoring	33

Columbia Basin Trust Region



This map is a graphical representation and may not be to scale.

1.0 Understanding Water in the Columbia Basin

1.1 Introduction

Clean and abundant fresh water is a defining feature through much of British Columbia, and particularly within the Canadian portion of the Columbia River Basin. At the same time, water resources and aquatic ecosystems in this region are changing as a consequence of land use and climate change. While many Basin ecosystems may still be functioning within their long-term natural ranges of variation, the future condition and characteristics of these ecosystems can no longer be projected based on the region's climate to date.

This report, commissioned by Columbia Basin Trust (the Trust), provides a snapshot of current scientific knowledge about water resources within the Trust region (the Basin), and outlines the scope and extent of water monitoring efforts in the Basin, the changes projected to occur due to climate change and the challenges and opportunities associated with strengthening water monitoring efforts to meet future information needs. It is intended for Basin residents, natural resource managers, professional and citizen scientists, and others to better understand and prepare for changes underway in Basin water resources, and highlights key challenges and opportunities associated with the current state of knowledge of Basin water resources.

Three key questions guide the report:

1. What is the current state of water monitoring within the Basin and the associated scientific understanding of the state of Basin water resources?
2. What are the expected effects of projected climate change on Basin water resources?
3. What opportunities exist to improve our understanding of Basin water resources in the future?

The document begins with an overview of Basin water resources, including various effects from land use and climate change. A detailed summary of Basin water monitoring follows along with a selective account of significant scientific understanding of snow and glaciers, rivers and streams, wetlands, lakes and reservoirs. In considering the pressures on these water resources from a warming climate, land use and human demand, future needs are identified for expanded water monitoring, scientific analysis and understanding.

Definitions and acronyms are provided in Appendix 1.

1.2 Basin Water Resources

The Basin's water resources are made up of a network of snow and glaciers, lakes and reservoirs, rivers and streams, wetlands and groundwater. The science of hydrology examines the movement, distribution and quality of water in these waterbodies.

Surface water in the Basin is distinguished by the Kootenay and Columbia river systems and their many tributaries, as shown in Figure 1. Both rivers rise south of Invermere, flowing north-south in opposite directions to eventually meet at Castlegar. In the Basin's southeastern corner, the Flathead River flows south into the Pend d'Oreille River in the USA, which returns to Canada before eventually draining into the Columbia River just north of the USA border. Similarly, the Kootenay River flows into the USA before returning to Canada south of Creston. Rivers and creeks draining into these major systems come in a variety of sizes as illustrated in Figure 1.

Watersheds under 500 km² in area generally have limited floodplain development. As a result, their hillslopes can directly affect the watercourses below. In addition, they generally function as hydrologically responsive, integrated units. In the mid and lower reaches of the much larger Slocan and Elk river systems, there are well developed floodplains with distinct ecological zones plus upslope and upstream processes that generally have much less direct connection with the rivers below. The other area groupings shown in Figure 1 have intermediate behaviour. In addition, the value and uses associated with stream systems may sometimes correspond to their size. For example, major hydroelectric installations are more often situated within larger watersheds whereas domestic consumption of surface water is generally preferred from smaller watersheds.

The Columbia River is the fourth largest river by annual discharge in North America (after the Mississippi River, the St. Lawrence River and the Mackenzie River). For the entire Columbia River watershed (to Astoria, Washington), the Basin provides about 40 per cent of the annual runoff¹ even though it is only 15 per cent of the watershed by area. In what is known as British Columbia's "Interior Wet Belt", the Basin includes areas that are intermediate between British Columbia's maritime and continental biomes. Approximately 65 per cent of the Basin's annual precipitation falls as snow, the melting of which contributes 32 per cent of annual stream flow during June, July and August (Schnorbus *et al.* 2014). Glaciers, permanent snowfields and groundwater store water over longer periods than the annual snowpack.

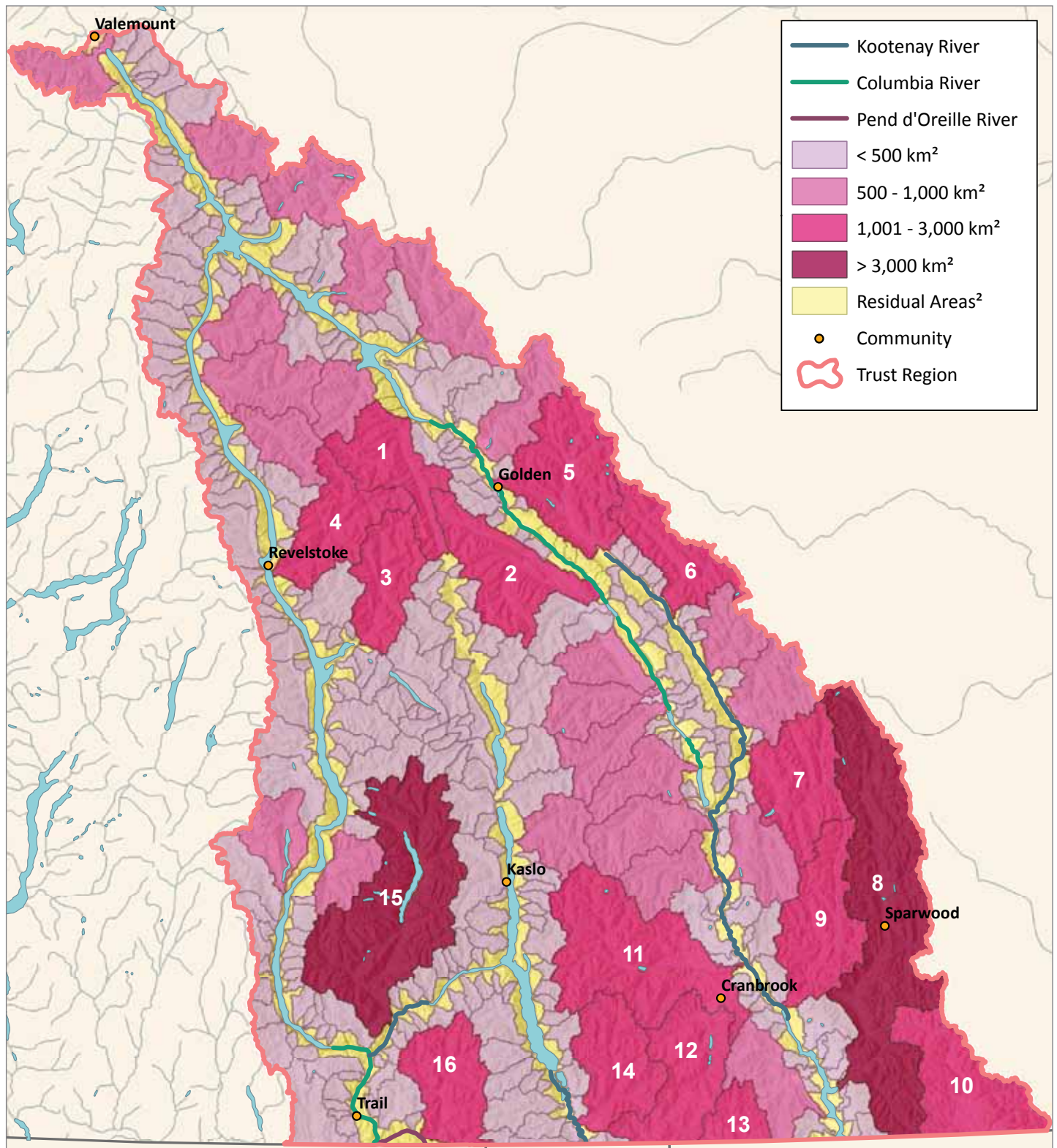
Basin watersheds over 1000 km² as shown in Figure 1

1 Beaver River	7 White River	13 Yahk River*
2 Spillimacheen River	8 Elk River	14 Goat River
3 Incomappleux River	9 Bull River	15 Slocan River
4 Illecillewaet River	10 Flathead River*	16 Salmo River
5 Kicking Horse River	11 St. Mary River	
6 Vermilion River	12 Moyie River*	

*Flows directly into the USA

1 *Climate Change in the Canadian Columbia Basin – Starting the Dialogue* (Columbia Basin Trust, 2006).

Figure 1. The Columbia, Kootenay and Pend d'Oreille rivers and their tributary watersheds, which range in size up to 3,000 km² in addition to the larger Slocan and Elk river watersheds.¹



1. The seven communities identified on this and subsequent maps are intended to provide additional geographical reference points for the reader.
2. Residual areas are small watersheds that drain directly into major rivers.

1.3 Basin Climate

Climate varies significantly over the Basin's approximately 80,000 km² area, shaped largely by Pacific coastal influences from the west, continental influences in the east and minor boreal influences in the north. Air masses that carry moisture to western North America, including the Columbia Basin, generally originate in the Pacific Ocean where they are influenced by sea surface temperatures, and their trajectories are controlled by atmospheric conditions such as the location of the jet stream.

Maximum temperatures occur in valley bottoms and maximum precipitation occurs at high elevation. The western portion of the Basin is known as the Interior Wet Belt due to relatively greater precipitation from Pacific air masses as they rise over the Selkirk and Purcell Mountains. The drier eastern portion reflects the rain-shadow effect of the Northern Monashee, Selkirk and Purcell Mountains, as well as continental air masses that may infiltrate through the Rocky Mountains from the east.

Basin hydrology is strongly influenced by prevailing patterns of temperature and precipitation. Changes in temperature drive changes in precipitation and can also significantly influence annual and seasonal stream flows. Changes in precipitation volume influence lakes, wetlands and hydrologic processes such as surface runoff and groundwater recharge. In addition, temperature:

- influences the extent that precipitation goes into overwinter storage as snow and longer-term storage as glacial ice.
- affects the timing and rate of snowmelt, which influences spring floods and summer/fall drought.
- controls evaporation rates that influence stream flows, lake and reservoir levels.
- may modify precipitation available for runoff.

Ten distinct hydrologic regions have been delineated in the Basin based on watershed boundaries and averages of climate and streamflow, as illustrated in Figure 2.² Their respective climates are described in general terms in Table 1.

Reconstructions of past and future climate can be assembled to contrast climate across the Basin. The qualitative descriptions provided in Table 1 are reflected quantitatively in the seasonal and annual temperature and precipitation distributions shown in Figure 3.

2 Map prepared by G. Utzig, with technical contributions from J. Brahney and M. Carver.

Figure 2. Basin hydrologic regions as indicated by patterns of climate and surface runoff.

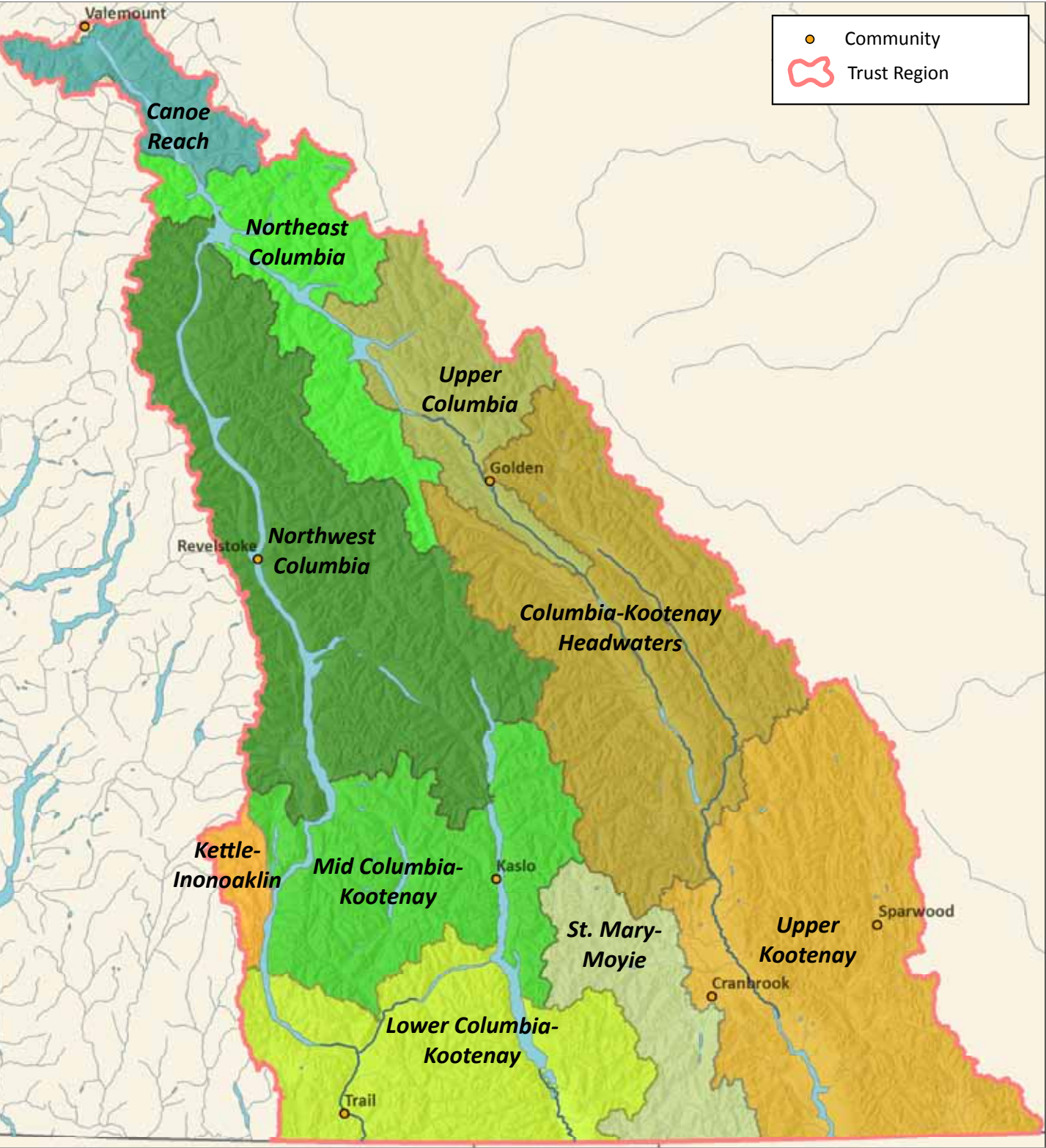


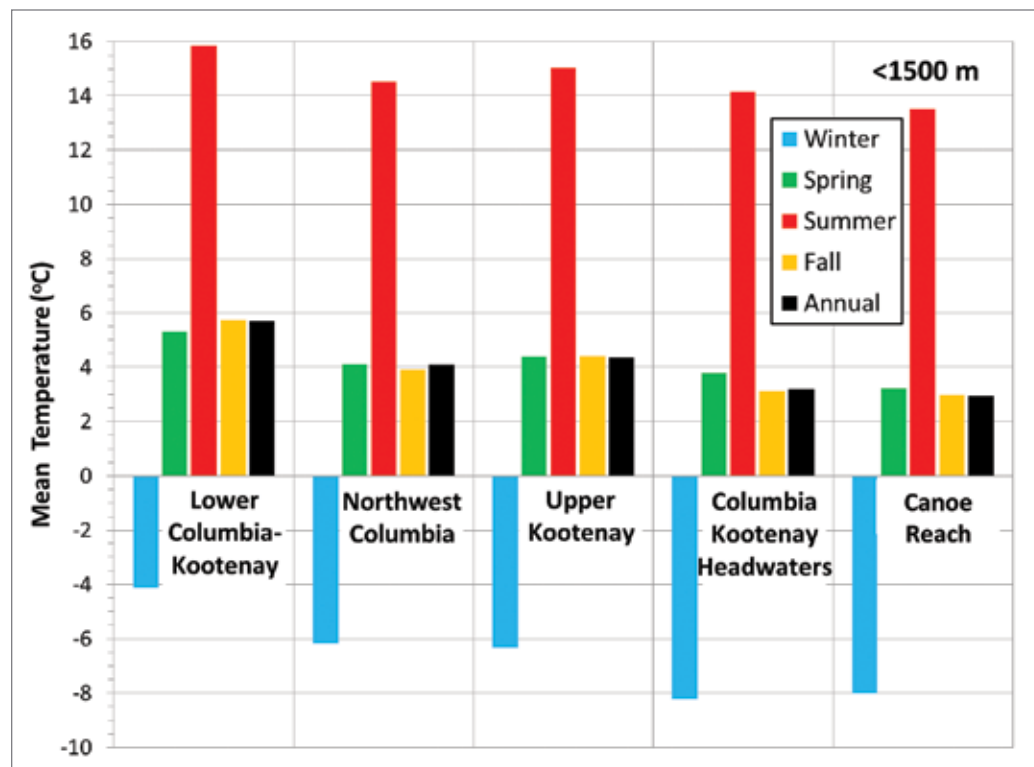
Figure 3 illustrates how climate varies across five hydrologic regions selected to portray the general range of climate experienced across the Basin. These quantitative representations of climate across the Basin (historic and projected) are limited by the non-representative locations of climate monitoring stations and the sparsity of high-elevation precipitation data (i.e., above 1,500 m).

Table 1. Relative climate across the Basin’s ten hydrologic regions.

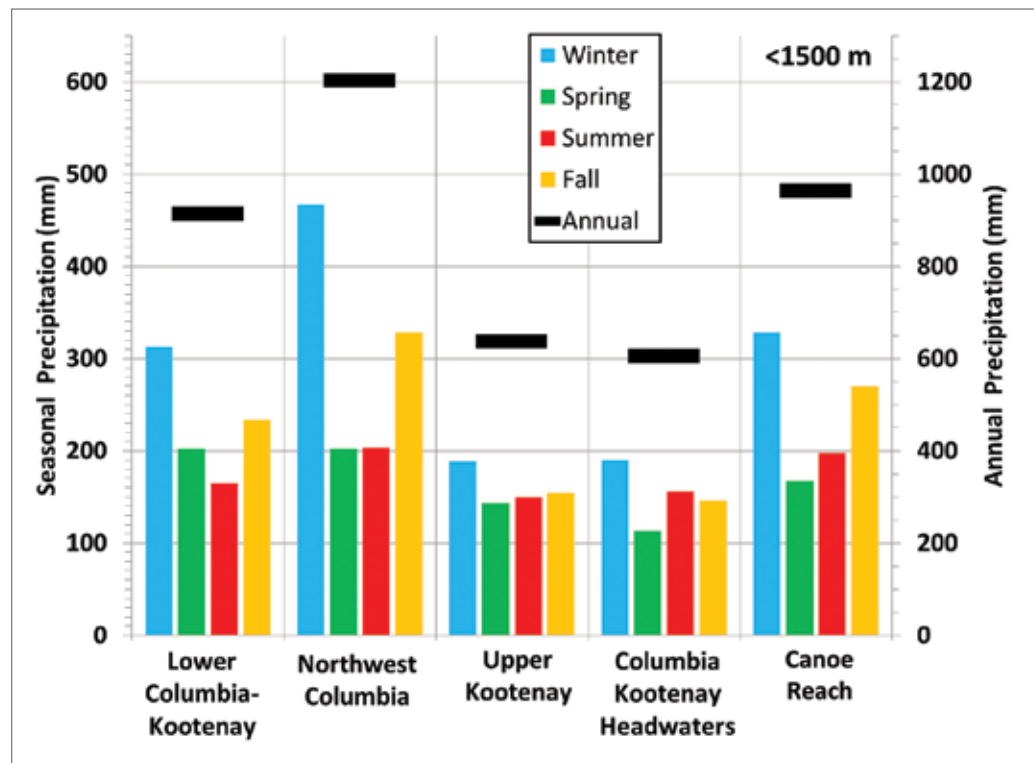
Hydrologic Region	Climate Overview
Canoe Reach	Moderate moist summers, cold moist winters with moderate snowpacks
Columbia-Kootenay Headwaters	Warm moist summers, cold dry winters with moderate snow packs at higher elevations
Kettle-Inonoaklin	Very hot dry summers, mild winters with moderate-to-low snowpacks. Transitional to regions west of the Basin.
Lower Columbia-Kootenay	Hot dry summers, moderately cool winters with moderate snowpacks at higher elevations
Mid Columbia-Kootenay	Transitional between Northwest Columbia and Lower Columbia-Kootenay
Northeast Columbia	Warm wet summers, cold wet winters with deep snowpacks
Northwest Columbia	Moderate wet summers, wet cool winters with deep snowpacks
St. Mary-Moyie	Transitional between Lower-Columbia Kootenay and Upper Kootenay
Upper Columbia	Warm moist summers, cold wet winters with moderate snowpacks at higher elevations
Upper Kootenay	Very dry to moist hot summers, cold dry winters with low-to-moderate snowpacks

Figure 3. Seasonal and annual a) temperature and b) precipitation distributions of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC, 1961-1990; under 1,500 m).

a) Temperature



b) Precipitation



Winter temperatures trend colder from south to north, with winter temperatures lowest in the Rocky Mountain Trench (Canoe Reach, Columbia-Kootenay Headwaters and Upper Kootenay regions) and highest west of the Purcell and Selkirk Ranges. Summer temperatures are the highest in the Lower Columbia-Kootenay and lowest in the Canoe Reach. The Columbia-Kootenay Headwaters has the most continental climate, showing the greatest difference between coldest and warmest seasons, whereas the Lower Columbia Kootenay and Northwest Columbia regions are wetter and exhibit smaller differences.

Precipitation is greater in winter than summer and varies spatially in a pattern distinct from temperature. The regions west of the Selkirk and Purcell Ranges and those north of the Purcell Range in the Rocky Mountain Trench have significant maritime influences. This is reflected in their seasonal distribution of precipitation, with most precipitation occurring in fall and winter. In the southern Rocky Mountain Trench, regions are dominated by continental influences and precipitation is distributed more evenly across seasons. The greatest annual precipitation occurs in the maritime-influenced regions and the least in the continental-influenced areas. The Northwest Columbia region is the wettest, the Upper Kootenay and Columbia-Kootenay Headwaters are the driest, and the Canoe Reach and Lower Columbia-Kootenay regions are intermediate. The Columbia-Kootenay and Upper Kootenay regions show persistently low precipitation in the spring, summer and fall whereas precipitation in the other regions rises in the fall. Generally, the distribution of total precipitation at higher elevations mirrors that of lower elevations, and the total amounts usually increase with elevation.

Selected quantitative comparisons of the ten hydrologic regions can be explored further using ClimateBC³ which applies well-established understanding of temperature change along elevation gradients to improve baseline climate estimates derived from data of monthly climate variables, providing high statistical accuracy (Wang *et al.* 2012, Hamann *et al.* 2013).

3 See <http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/#ClimateBC>

1.4 Pressures on Basin Water Resources

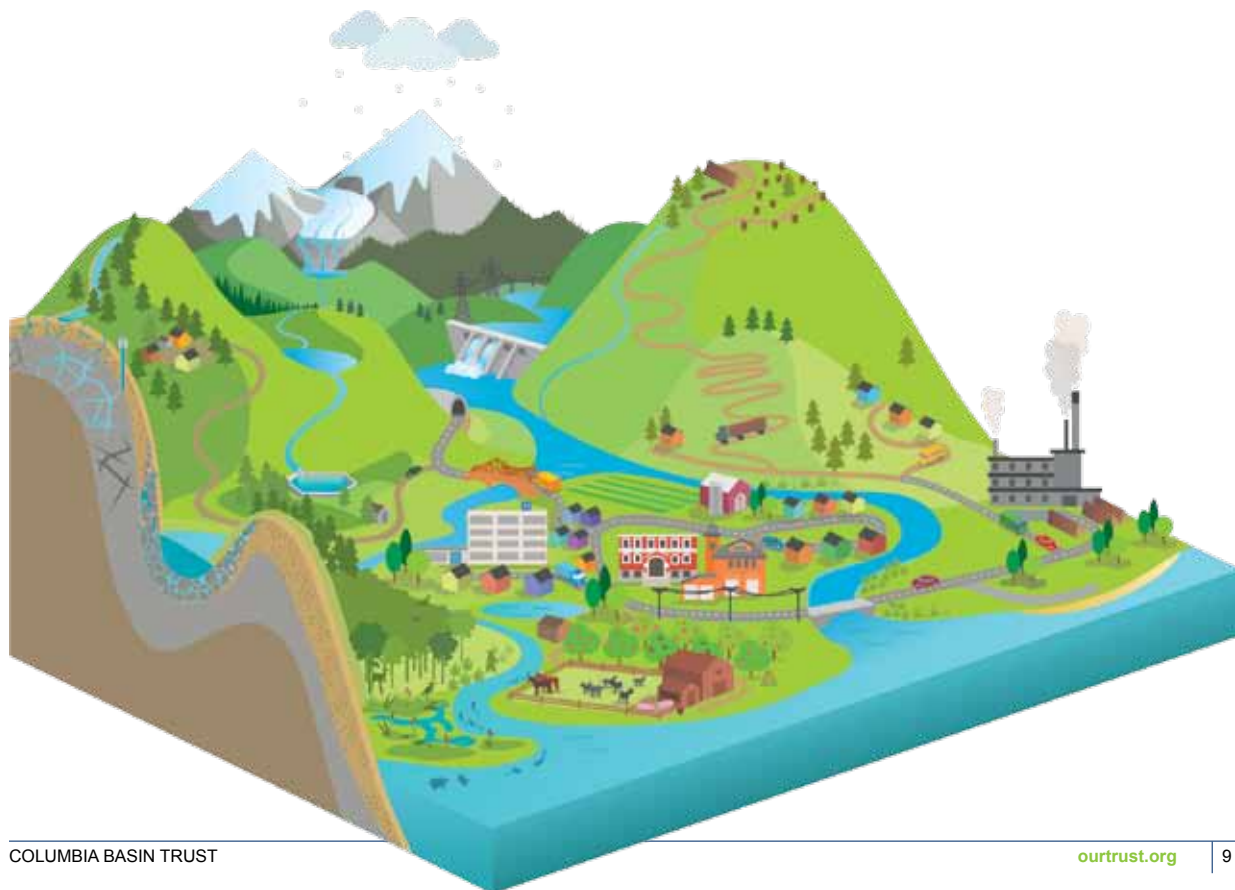
The condition of the Basin's water resources is influenced by current and historic human activities and the growing impacts of climate change. As land use and climate change intensify, assumptions based on past ecosystem behaviour and water availability can no longer be relied upon going forward. There is a growing need for consistent, timely and reliable information about water quantity and quality to support responsive and sustainable stewardship of water resources, land-use planning, water-use planning, and effective natural hazard detection and response. A recent evaluation of the Trust's Water Smart initiative underscored the importance of good data in addressing the interactions between climate change, water supply and demand, and land use at the community level (Schreier *et al.* 2016).

The hydrologic system is interconnected and thus, as described in Section 2, a more complete understanding of current status and trends in Basin hydrology requires monitoring of snow and glaciers, rivers and creeks, lakes and reservoirs, wetlands and groundwater. A synopsis of current scientific insights and significant gaps in understanding is provided in Section 3.

1.4.1 Land Use

The quality and quantity of water resources in the Basin are influenced by human activities and associated infrastructure. Figure 4 provides a conceptual illustration of land uses and human activity that can influence water quality and quantity, such as dams, reservoirs, agriculture, industry, forestry, housing, town sites, paved and unpaved roadways.

Figure 4. Conceptual illustration of Basin land uses and water resources.



Dams and Reservoirs

As illustrated in Figure 5, the Basin's two major river valleys are dominated by 19 dams built for flood control and hydropower generation between 1922 and 1982 (Utzig and Schmidt 2011), which resulted in the loss of over 1600 linear kilometres of stream habitat. The Grand Coulee Dam, built in Washington in 1941, has had far-reaching effects on the upstream Columbia River system by preventing passage of anadromous salmon and steelhead. The Arrow, Duncan and Kinbasket reservoirs, created in the 1960s through the Columbia River Treaty, flooded complex mixes of river and lake systems, and wetland and forested ecosystems. Additional dams and reservoirs have also affected the underlying river ecosystems and further modified ecological functions and processes in associated wetlands and riparian areas. These reservoirs include Revelstoke, Koocanusa, Whatshan, Pend d'Oreille, Brilliant, Kootenay Canal and other smaller reservoirs under 0.25 km² in footprint (e.g., Cranberry, Elko, Aberfeldie and Spillimacheen).

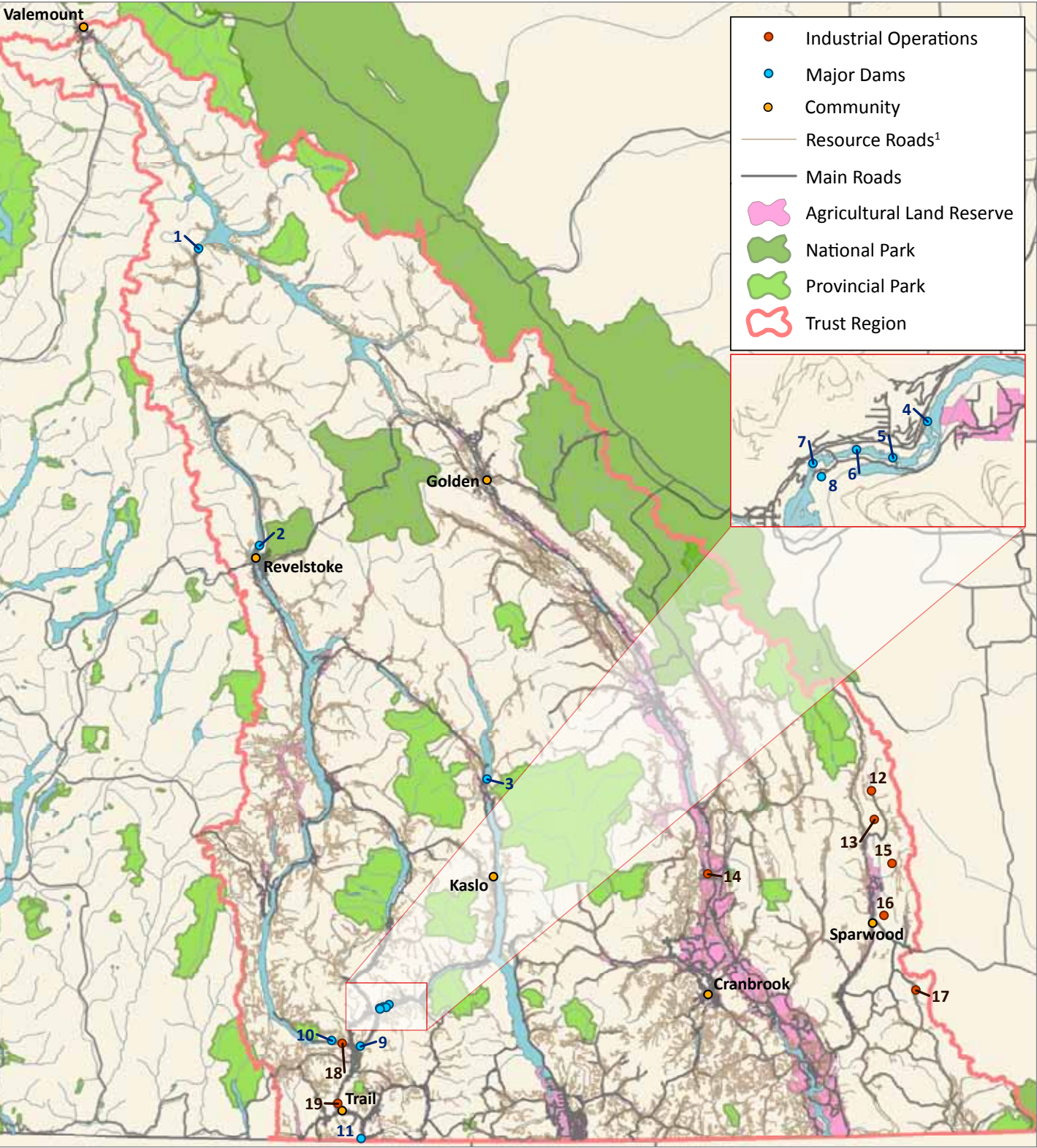
The Basin's eight largest reservoirs inundate 1,216 km², an area almost the size of Yoho National Park. Figure 5 presents their relative impact to pre-existing landscape elements. These dams have deeply altered natural flow patterns, flood dynamics and the ecological function of valley-bottom ecosystems (wetlands, lakes, rivers, streams, riparian areas and upland forests). Lake/reservoir habitat increased from 414 km² to 1,108 km² as numerous lakes were replaced by reservoirs with surface levels fluctuating in support of flood control and hydropower production, significantly altering the diversity and type of pre-dam habitats. Although most of the inundated area was aquatic, extensive upland areas were also affected. Reservoirs behind the dams are generally managed to modify the timing of water flow by reducing peak discharges and increasing low flows, resulting in shoreline and foreshore issues associated with fluctuating water levels.

While most tributaries to the Kootenay and Columbia rivers remain naturally flowing, their hydrology is affected by a variety of land uses including forestry, mining, hydropower, range, agriculture and recreation. Widespread resource road construction and conversion of old-growth and mature forests to younger forests and other cover types including clearings, have altered how precipitation and runoff behave at and near ground surface. This may cause increased sediment supply and snow accumulation, enhanced melt rates, drainage diversion and soil compaction. These changes can lead to modified flood frequencies, increased basin water yield and peak flows, altered low flows and, in some situations, destabilized channels. Decades of fire suppression have increased forest vulnerability to wildfire and insect outbreaks, such as the mountain pine beetle, which also affect snow accumulation and melt dynamics.

Human Settlements and Land Use

Human settlements have altered aquatic ecosystems along the main river valleys throughout the Basin. Most of the agriculture and grazing in the Basin has some effect on riparian areas and water quality locally in proportion to its intensity. Draining and dyking in the 1930s in the Creston flats at the southern end of Kootenay Lake down to Bonner's Ferry converted extensive riparian forests and seasonally-flooded wetlands to agricultural croplands. In response, the Creston Valley Wildlife

Figure 5. Major dams, protected areas and other significant land uses in the Basin.



1. At the scale of this map, the extent of resource roads can be illustrated only as an approximation and therefore will appear to cover more land than actual.

Key for major dams and industrial operations in Figure 5

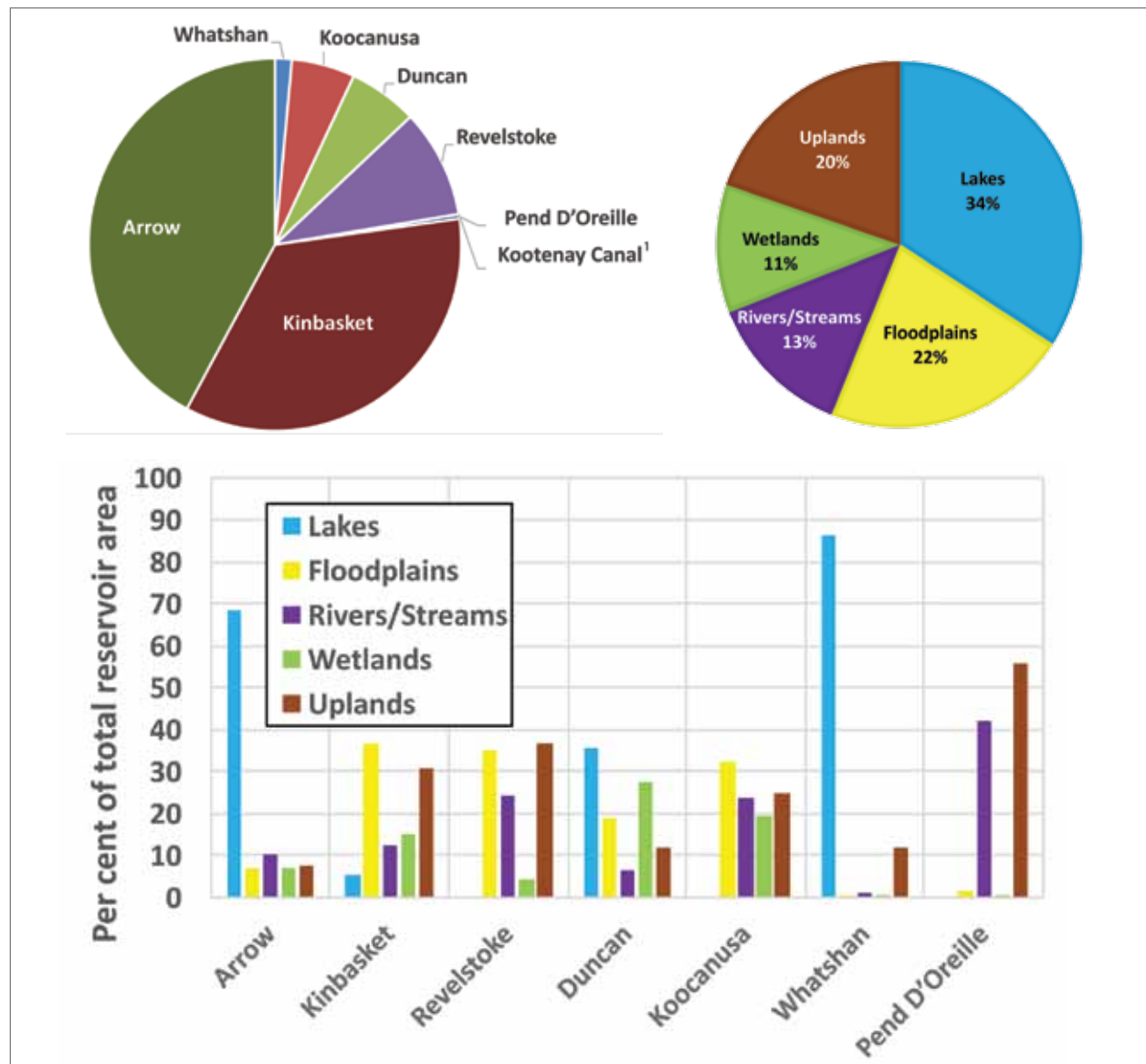
Major dams

1 Mica Dam	7 South Slocan Dam
2 Revelstoke Dam	8 Kootenay Canal
3 Duncan Dam	
4 Corra Linn Dam	9 Brilliant Dam
5 Upper Bonnington Dam	10 Hugh Keenleyside Dam
6 Lower Bonnington Dam	11 Waneta Dam

Industrial operations

12 Teck Fording River Mine	17 Teck Coal Mountain Mine
13 Teck Greenhills Mine	18 Zellstoff Celgar Pulp Mill
14 Skookumchuck Pulp Mill	19 Teck Smelter & Refinery
15 Teck Line Creek Mine	
16 Teck Elkview Mine	

Figure 6: Extent of inundation of landscape component by reservoirs. (Utzig and Schmidt 2011).



1. The Kootenay Canal inundated 48.7 hectares of, almost entirely, upland habitat. It is not shown on the bar graph plot.

Management Area was established to maintain a portion of the original area as managed wetlands that provide staging, nesting and rearing habitat for over 300 bird species in addition to habitat for another 60 mammal, fish, reptile and amphibian species. The network of provincial parks, provincial ecological reserves and national parks provide additional direct protection to aquatic systems located within these designated areas.

Linear developments such as railways, highways and utility corridors have contributed to changes in hydrology at and near the ground surface through drainage diversions, changes in snow accumulation, increased runoff efficiency and sedimentation. In some locations, industrial activities such as coal and metal mining, smelting and pulp mills have contributed to downstream contamination of river systems, although releases of contaminants have declined significantly over the decades as a result of improved emission-control technologies and stricter regulations.

Sewage treatment facilities, industrial runoff and widespread rural development introduce sources of contamination to waterways throughout the Basin via point releases and from distributed sources. The spread of invasive aquatic species, shoreline development and recreational activities have also affected Basin water resources in many locations. Kootenay Lake, BC's fifth largest lake, has had its aquatic environment altered by dams, the historic addition of nutrients from industrial activities, the intentional introduction of mysid shrimp and rural development along its shores.

1.4.2 Climate Change

The Basin's climate has been changing throughout the past century and is expected to continue changing through the present century and beyond. High-resolution climate data for climate change studies and applications in British Columbia are available from ClimateBC, a computer program that uses historical weather station data and regional outputs from Global Climate Models (GCMs) to reconstruct past climates and project future seasonal and annual climate variables.⁴ ClimateBC data inform the historic⁵ and future climate comparisons presented in Figures 3, 7 through 11, and Appendix 2.⁶

- 4 Historic and projected climate is extracted from ClimateBC using a one-km grid (Wang et al. 2012). All the data are interpolated between individual climate stations and GCM outputs using the Parameter Regression of Independent Slopes Model (PRISM) interpolation method. Projections are taken from the mean of an ensemble of 15 GCM scenarios from the Coupled Model Intercomparison Project phase 5 database (CMIP5), corresponding to the Intergovernmental Panel on Climate Change Assessment Report 5 (IPCC AR5). Two emissions scenarios were considered: Representative Concentration Pathway (RCP) 4.5 represents a moderately-low emissions scenario consistent with intermediate GHG mitigation; RCP 8.5 represents a high GHG emissions scenario similar to current rates. Some outputs present mean results for each emission scenario for five hydrologic regions distributed across the Basin (Appendix 2), and some present a mean of the two emission scenarios (Figures 7-11). More information on the projected data is available at: <http://adaptwest.databasin.org/pages/adaptwest-climate>.
- 5 ClimateBC is in the process of updating its historic climate records for the 1990s to the 2010s by adding data from additional climate stations in the Interior mountains. Once these changes are finalized, if warranted, an update to some of the climate graphs in this report may be released. The future projections shown on these graphs would be unaffected by such an update.
- 6 There is unquantified uncertainty of about plus/minus (+/-) one or two degrees around each of the means. Uncertainty is often presented in more detail (e.g. variability corresponding to 10th and 90th percentiles), but is not shown here to simplify the figures. Adaptation planning for specific locations will require more in-depth analysis of uncertainty.

Temperature Changes

Figure 7 provides historic and projected mean annual winter and summer temperatures from the 1900s through to 2100 for the five selected hydrologic regions.

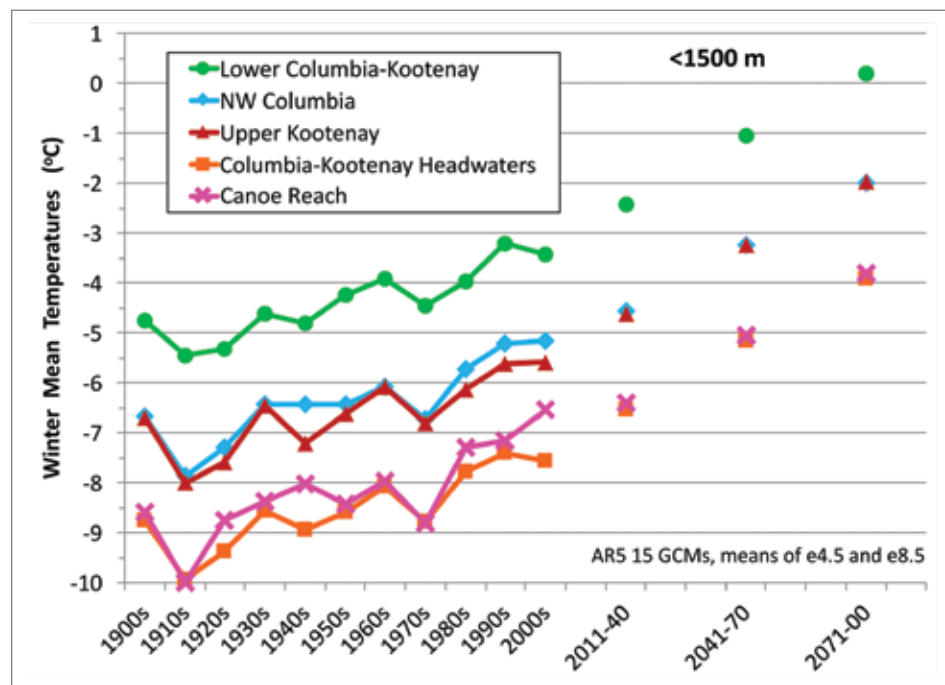
Winter temperatures are increasing throughout the period with lowest temperatures during the 1910s. Mean winter temperatures in all regions dropped in the 1970s. Only the Canoe Reach region increased in the 2000s. Mean winter temperatures in the Lower Columbia-Kootenay (under 1,500 m) may be above freezing by the end of this century while those in Northwest Columbia and Upper Kootenay hydrologic regions approach the freezing level. Overall, mean winter temperatures in all regions have increased to the early 2000s by about 1°C (from a 1961-1990 baseline) and are projected to go up another 3°C by the end of this century. Mean summer temperatures are also rising during this period, with the projected rate of temperature increase expected to outpace increases in the twentieth century during the remainder of this century. For illustration purposes, 6°C separates the mean annual temperatures of Golden and Vancouver.

During the same period, mean annual temperatures have increased about 1°C (net change from 1961-1990 baseline to the early 2000s) and are projected to go up another 4°C by 2100.⁷ The significance of these temperature increases can be better understood by comparing them to the range in average annual temperatures across the Basin. As shown in Figure 7, only 3°C separates the hottest and coldest regions yet this difference is associated with sharply different biogeoclimatic subzones as expressed by their distinctive patterns of vegetation.

7 Temperature projections presented here appear to be slightly higher than those derived from PCIC's Plan2Adapt (<https://pacificclimate.org/analysis-tools/plan2adapt>), which are derived from older CMIP3 GCM scenarios (AR 4). Temperature projections in this report are not directly comparable to the projections in Plan2Adapt for a number of reasons. These include different GCMs (CMIP 3/AR4 vs CMIP 5/AR5), different assumptions about projected emissions (B1-A2 vs RCP 4.5-8.5), contrasting methods for determining spatial distribution of temperatures (detailed vs. regional gridding), and applying the projections to different areas (hydrologic regions vs. Regional Districts vs. ecosections; low elevations vs. all elevations). However, recent temperature projections for the USA Pacific Northwest, including Canada's Columbia Basin (Dalton *et al.* 2013), are consistent with those in this report, indicating that the most recent GCMs are generally showing increased projected warming for this region.

Figure 7. Historic and projected a) winter and b) summer temperature of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC for areas under 1,500 m).

a) Winter temperature



b) Summer temperature

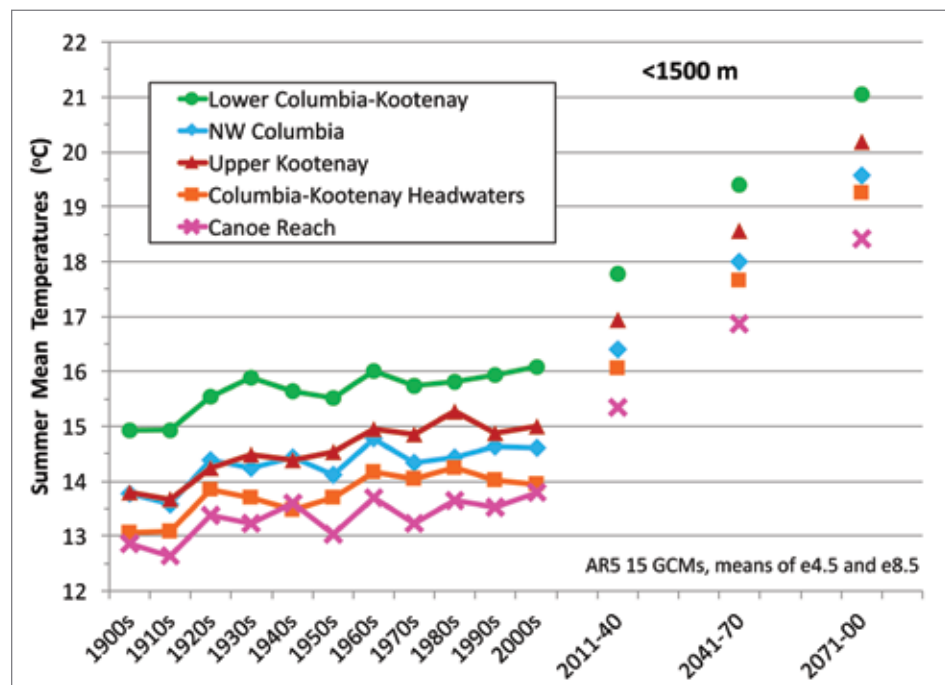
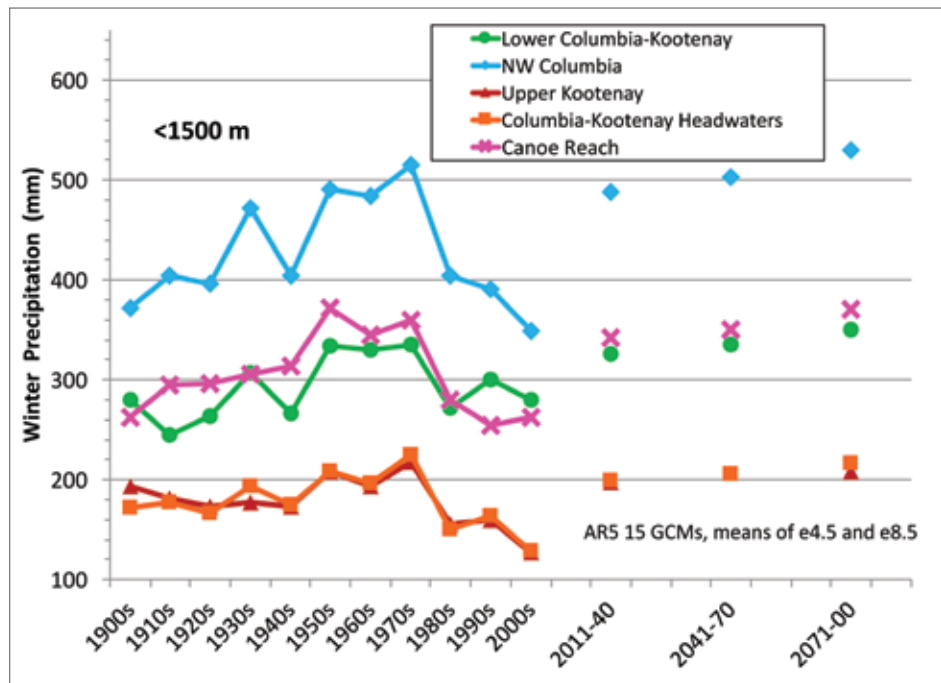
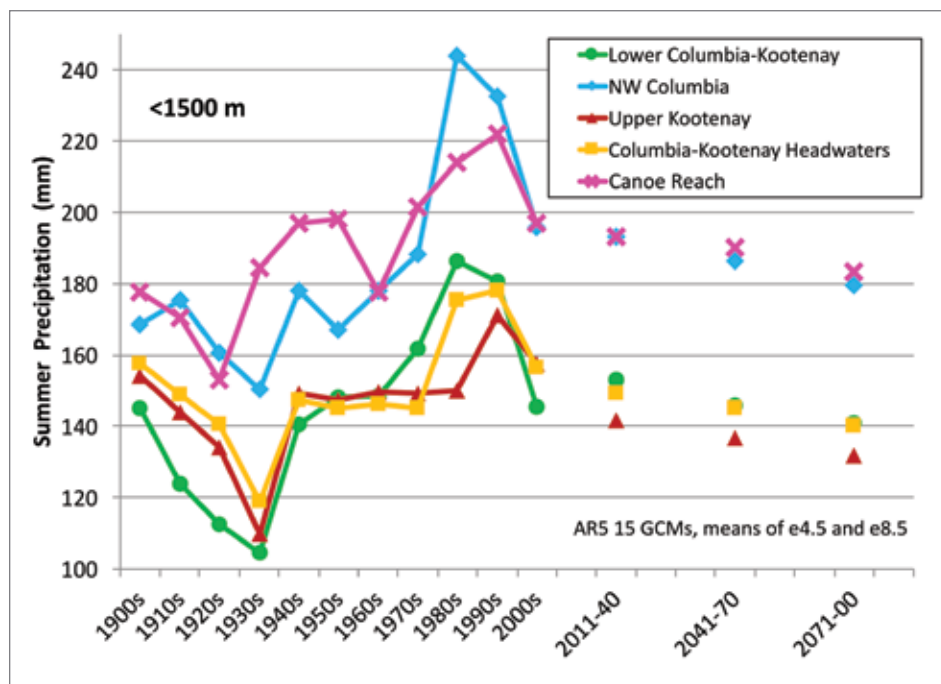


Figure 8. Historic and projected a) winter and b) summer precipitation of five contrasting hydrologic regions, distributed throughout the Basin (data from ClimateBC for areas under 1,500 m).

a) Winter precipitation



b) Summer precipitation



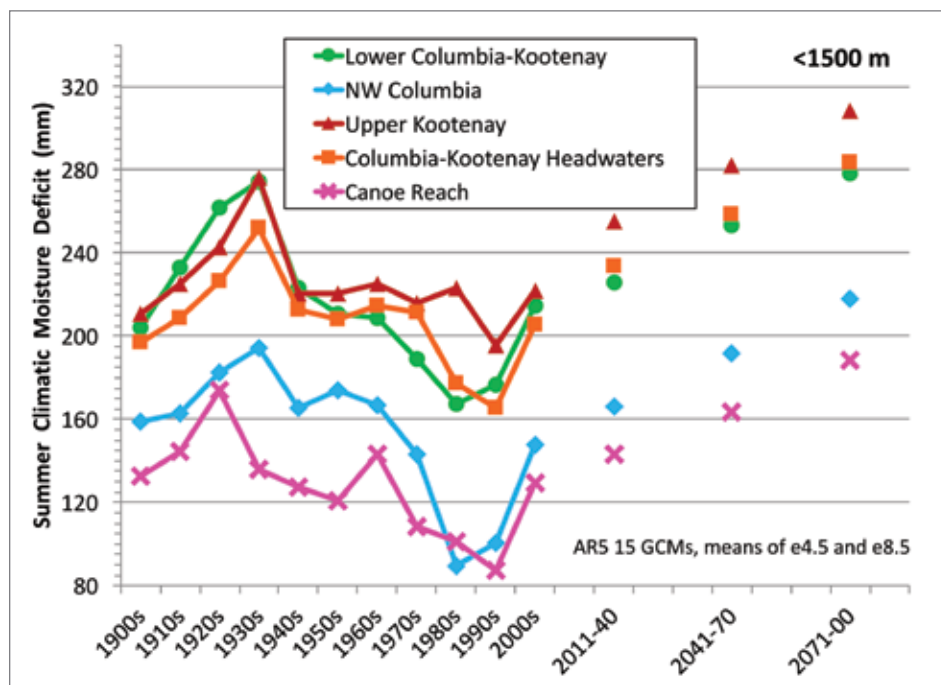
Precipitation Changes

Figure 8 provides historic and projected mean winter and summer precipitation for the same five hydrologic regions. Mean winter precipitation increased from the 1900s through the 1970s, followed by a downward trend from the 1980s, generally decreasing until the early 2000s. Projections indicate modest increases in winter precipitation through the rest of this century in all regions, rising slightly above the historic highs of the 1970s. Mean summer precipitation is highest in the Northwest Columbia and the Canoe Reach hydrologic regions and lower and similar in the other regions. Historic trends show a decrease in summer precipitation until the 1930s (1920s in the Canoe Reach) then increasing trends into the 1980s and 1990s before a second downward trend into the early 2000s. The ensemble of GCM projections shows the downward trend continuing to the end of this century. The projected downward trend appears to be steeper in the southern regions, especially on a percentage basis. Due to the lack of monitoring data at high elevations, it is difficult to provide reliable historic and projected precipitation changes. However, there is indication from data in the USA that high-elevation precipitation may actually have declined⁸ (Luce *et al.* 2013).

Changes in Climatic Moisture Deficit

These combined patterns in historic and projected summer temperature and precipitation are reflected in Figure 9 which compares historic and projected summer climatic moisture deficits for the five selected hydrologic regions. As a measure of evaporative loss compared to precipitation inputs,

Figure 9. Historic and projected summer climatic moisture deficit for five selected hydrologic regions distributed across the Basin (data from ClimateBC for areas under 1,500 m).



8 This decline is attributed to greenhouse-gas-induced weakness in lower tropospheric winter westerlies, which are strongly correlated with high-elevation precipitation and weakly correlated with low-elevation precipitation.

climatic moisture deficits integrate temperature and precipitation effects, providing a useful measure of the moisture needed for vegetation growth that must be met from sources other than rain (e.g., soil moisture, irrigation) to avoid the impact of drought.

Moisture deficit increased early in the last century, peaked in the 1930s (1920s in Canoe Reach), then followed a generally decreasing trend after the 1930s until the 1980s and 1990s, after which an upward trend re-established. There were widespread and large fires in many parts of the Basin during the 1920s and 1930s. The pattern in summer moisture deficit reflects the trends in summer precipitation and summer temperature. GCM modelling projects that it will continue a steep upward trend, driven by increasing summer temperatures and decreasing summer precipitation, potentially reaching levels exceeding the 1930s by the end of this century with the added context of much higher summer temperatures (including higher extreme temperatures). Such changes have obvious implications for summer drought, wetland decline, vegetation stress and wildfire. All of the hydrologic regions show the same pattern of change; however, it is the hotter and drier regions that are expected to experience the harshest consequences.

Decline in Snow Occurrence

Another aspect of climate change with implications for water resources is the decline in snow occurrence at low and high elevations. Seasonal temperatures across the Basin (Figure 7a) influence the proportion of total annual precipitation falling as snow in any given area. The warmer hydrologic regions exhibit lower percentages of precipitation falling as snow. Figure 10 illustrates the change in proportion of winter precipitation that falls as snow for the populated valley-bottom areas for the five selected hydrologic regions. In the Lower Columbia-Kootenay hydrologic region, these areas already experience under 50 per cent of the winter precipitation as snow. This is expected to fall below 15 per cent by the end of the century. In the colder regions, the winter proportion for populated areas is expected to decline to almost 50 per cent by the end of the century.

Snowfall at high elevation provides critical support for late-summer low flows throughout the Basin. The extent to which winter precipitation shifts from snow to rain provides a measure of the vulnerability of annual low flows to decline. To characterize this, Figure 11 presents the change in proportion of winter precipitation that falls as snow for those areas that lie within the upper 60 per cent area by elevation — above the H60 — in the five selected regions. Again, it is notable that the proportion in the Lower Columbia-Kootenay was above 85 per cent during the 1961-1990 baseline period and is expected to drop to almost 50 per cent by the end of the century. The cooler regions are expected to drop to about 80 per cent in the same time period.

It appears that certain trends were in place in the Basin until the 1980s to 1990s at which time new patterns emerged. This is consistent with the increasing momentum of climate change observed since the 1980s. Although such general trends are evident in the data, it is important to note that each hydrologic region is unique in its decadal patterns and some also seasonally. Detailed historic and projected seasonal and annual changes in the climate (including changes in rain vs. snow proportion in all four seasons) for these five selected hydrologic regions are provided in Appendix 2.

Figure 10. Baseline and projected proportion of winter precipitation that occurs as snow in the populated valley bottoms of five selected hydrologic regions distributed across the Basin (data from ClimateBC).

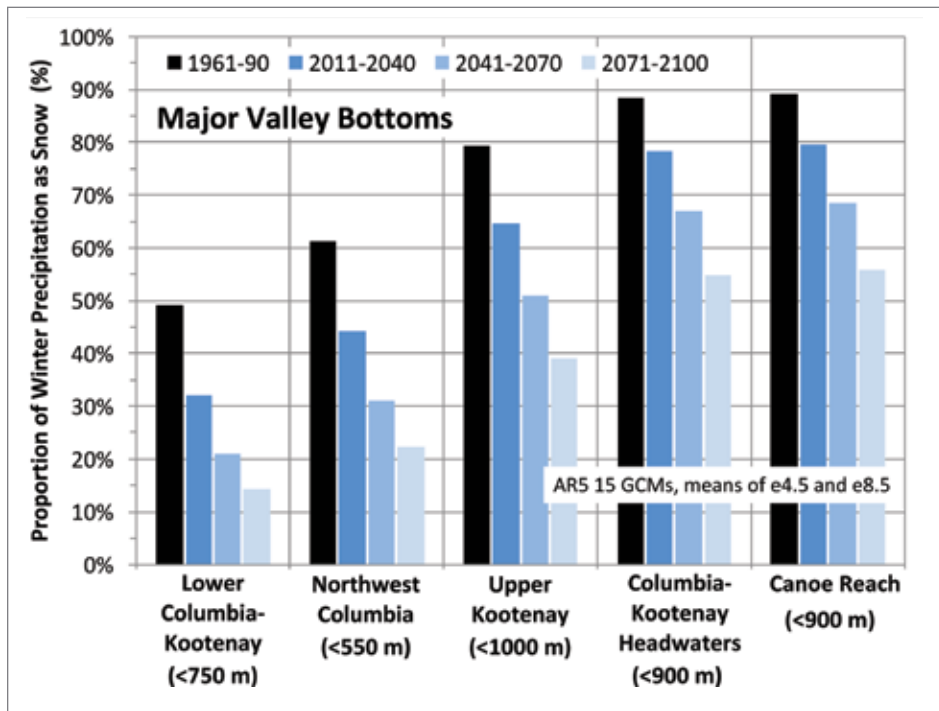
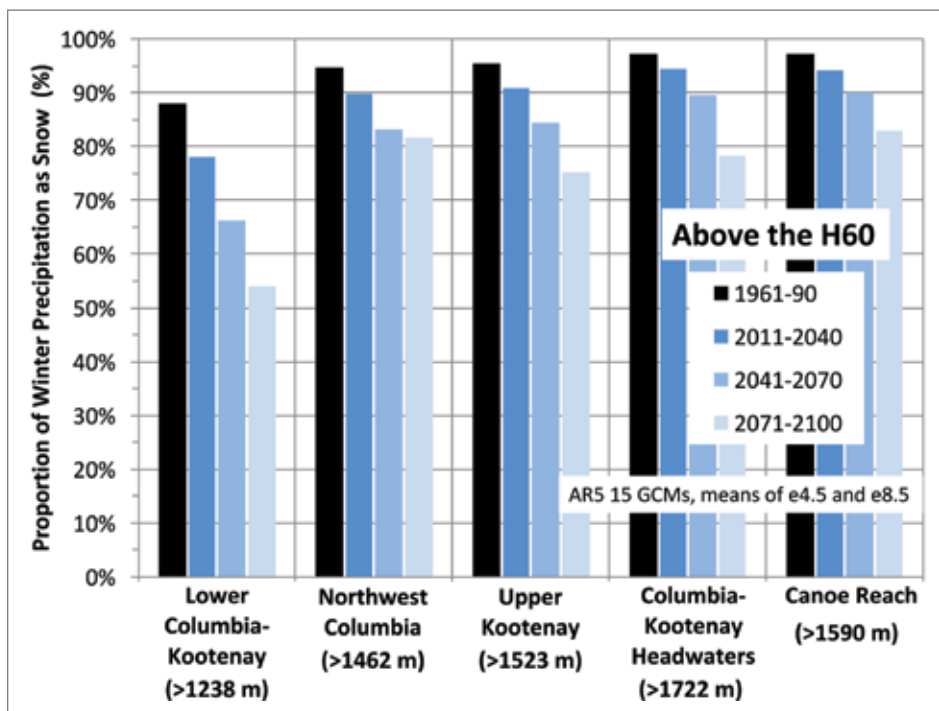


Figure 11. Baseline and projected proportion of winter precipitation that occurs as snow at elevations in the upper 60 per cent (by area) of five selected hydrologic regions distributed across the Basin (data from ClimateBC).



The Influence of Major Climate Modes in the Basin

Heat held dynamically in the Pacific Ocean creates modes of climate variability that can strongly influence the climate of western North America. The most significant climate modes are the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), also known as the Interdecadal Pacific Oscillation (IPO – Henley *et al.* 2015).⁹

ENSO and PDO are associated with patterns of organization of surface sea temperatures in, respectively, the tropical and northern Pacific Ocean. These two patterns have direct influence on the weather in BC through the atmosphere. Each mode has a warm phase and a cool phase. During ENSO's warm phase (El Niño), temperatures at the ocean surface in the eastern and central tropical Pacific become much warmer than average while the western tropical Pacific Ocean temperatures become cooler than average. During ENSO's cool phase (La Niña), the temperature patterns reverse. PDO is primarily defined by the pattern of ocean surface temperatures in the North Pacific northward of the tropics. During its warm phase, a westward-facing horseshoe of warmer-than-normal ocean temperatures is present with its southern arm covering Hawaii, its northern arm reaching along the Alaska panhandle toward the Aleutian archipelago and the arch situated at North America's west coast. The exact opposite pattern sets up during the PDO's cool phase.

There is a strong simultaneous correlation between ENSO and PDO. The ocean preserves a memory of recent conditions and, as a result, the current year's PDO is influenced by the previous year. The combination of the current and previous year's conditions helps cause the decades-long behaviour identified as the PDO (Newman *et al.* 2003). Since the late 1970s and early 1980s, the proportion of precipitation falling as rain rather than snow has increased in the Basin. This change toward rain coincided with a transition from a cool to warm phase of the PDO which was brought about by a period of more dominant ENSO warm events. From 1977 into 1998, there were eight El Niño winters, two of which were the strongest on record, and only three La Niña events. These conditions were conducive to warmer temperatures and greater proportions of precipitation falling as rain in the Basin.

Of the two, ENSO has the most well-understood link between temperature and precipitation conditions as observed in the Basin, via a well-studied phenomenon called the “atmospheric bridge” which links the tropics with the mid-latitudes (Alexander *et al.* 2002), creating statistically significant correlations between warmer-than-normal winter temperatures in BC during El Niño events, and colder-than-normal winters during La Niña events (Rodenhuis *et al.* 2009). The PDO's influence on temperature is much smaller and is not statistically significant over the Basin (Rodenhuis *et al.* 2009; Dong and Dai 2015; Zang and Delworth 2015). For both climate modes, the relation with precipitation is less statistically significant than with temperature. ENSO has the strongest relation between observed precipitation and both warm El Niño and cool La Niña events which are, respectively, drier and wetter over the Basin during winter. For both phenomena, the precipitation influence is strongest during the winter months when the mid-latitude storm track is most active.

9 The North Pacific Index and the Pacific North American Pattern are two additional climate modes known to be related to North American climate (including the climate of British Columbia) but can be viewed as secondary atmospheric reorganizations resulting from ENSO events. The Arctic Oscillation has a minimal influence on the climate of southern British Columbia. Discussion of these three climate modes is beyond the scope of this summary.

It is not clear how ENSO will evolve under a changing climate. Although there may be more frequent events (Merryfield, 2006), their projected sign (El Niño vs. La Niña) and intensity remain uncertain (Merryfield, 2006; Collins *et al.*, 2010). With climate change, connections between a given tropical event and the seasonal weather over the Columbia Basin are also expected to change due to changes in atmospheric circulation as a whole (Meehl *et al.*, 1993), but it is not yet possible to project the changes to ENSO and the PDO. Although climate modes do not detract from real long-term changes in temperature and precipitation, they contribute to climate variability and thus complicate analysis, particularly of short-term data.

2.0 Status of Water Monitoring in the Basin

Water monitoring can provide valuable data to inform scientific understanding and stewardship of water resources, including the availability, quality and appropriate use for community water supplies, fish habitat, hydropower, food production, fire protection and recreation among many other applications and considerations. Given the pressures on Basin water resources resulting from climate change and land-use activities, the availability of reliable and up-to-date water monitoring data is becoming increasingly important for effective planning and management, including long-term investments in land use and infrastructure, community water supply and ecosystem stewardship.

Monitoring is undertaken by a mix of federal, provincial, regional and local organizations, including community-based and citizen science monitoring initiatives. The data can be used to:

- Determine the current status and health of water resources.
- Identify long-term trends in watersheds and aquatic ecosystems.
- Detect emerging hazards and assess associated risks.
- Establish baseline and reference conditions.
- Set water quality objectives.
- Evaluate regulatory compliance and performance.
- Calibrate and validate predictive models.
- Guide water stewardship and land management efforts.
- Inform water supply planning.
- Identify opportunities for and limitations to economic development.

In addition to maintaining ongoing monitoring programs, access to historic data is invaluable to achieving these outcomes because all observations of good quality and reliability are useful for calibrating models. Improved model calibration is desirable when simulating future conditions.

2.1 Scope of Water Monitoring

Water Quantity Monitoring

Sufficient up-to-date information on water quantity enables an accurate assessment of water availability and effective responses to anticipated changes. This may be particularly relevant to higher-volume users such as communities, hydropower operators, agricultural producers, industrial operations and snowmaking at ski resorts, and may also benefit commercial and private recreational users. Table 2 shows how different aspects of water quantity are monitored.

Table 2. Elements of water quantity monitoring.

Monitored Element	Monitoring Details
Climate	Basic parameters: temperature, precipitation (rainfall, snowpack), humidity, wind speed/direction.
	Details: <ul style="list-style-type: none"> • Daily precipitation • Equivalent water volume of snowfall • Rainfall intensity over short periods (e.g. one hour) • Snow depth at snow courses¹; snow water equivalent at snow pillows² • Evaporation Monitoring temperature and other climate-related variables helps in the interpretation of the status of all water resources.
Glaciers	Remote sensing of glacier's spatial extent, surface elevation, repeat photographic records of extent and location of equilibrium line, annual (or longer-term) depth measurements of ice thickness and annual/seasonal snow accumulation and melt, and measurements of surface flow rates through outlet stream discharge.
Rivers and streams	Total flow rate passing a specified point, per second. Continuously monitored to determine annual peak and low flows, timing of peak and low flows and mean annual discharge.
Lakes and reservoirs	Vertical level of water surface at a specified location through time.
Wetlands	Layout and size of wetland, as determined by mapping and may include seasonal water depths.
Groundwater	Available flow rate from a well location, at specified depths below the surface, as determined by pumping tests.

1 Physical snow depth and weight are measured at snow courses. A snow course is a series of approximately 10 snow sample points spaced at approximately 30-metre intervals. All snow-water equivalents (SWE) from each sample point are measured manually and then averaged to arrive at one SWE value for the whole snow course.

2 The water present in the snow is measured at snow pillows. A snow pillow is an automated snow monitoring station.

Water Quality Monitoring

Monitoring water quality and the condition of waterbodies assists in understanding the overall health of associated ecosystems, both aquatic and terrestrial, and informs suitable uses for the water. Water quality is generally described in reference to physical, chemical and biological characteristics. Typical measurement parameters are summarized in Table 3. Due to the wide range of variables and the costs associated with sample analyses, water quality monitoring plans typically focus on a subset of specific parameters, based on monitoring objectives and the statistical approach.

Table 3. Scope of monitored water quality parameters and media.

Monitored Aspect	Typical Parameters and Media Monitored for Water Quality ¹
Physical characteristics	Temperature, turbidity, conductivity, pH, dissolved oxygen and total suspended solids (TSS)
Chemical characteristics	Nutrients, ions, metals, organics and other contaminants
Biological characteristics	Bacteria (e.g., fecal coliforms and E. coli), sediments, tissue residue, benthic invertebrates and indicators of net primary productivity (e.g., zooplankton, phytoplankton and algae)

¹ There are different approaches to characterizing the scope of sampling for water quality analysis. Table 3 provides a simplified mix of sampling parameters and sampling media. Further detail is available elsewhere, for example: http://www2.gov.bc.ca/assets/gov/environment/waste-management/industrial-waste/industrial-waste/water_air_baseline_monitoring.pdf

2.2 Water Quantity Monitoring Efforts and Data Providers

Water quantity data are gathered by governmental and non-governmental entities such as industries, universities, and community and environmental groups. In the Basin, Environment and Climate Change Canada (ECCC), the BC Ministry of Environment (MoE), the BC Ministry of Forests, Lands and Natural Resource Operations (MoFLNRO) and hydroelectric companies provide most of the standardized and publicly-available water quantity data, as summarized in Table 4, which also includes research collaborations. The Pacific Climate Impacts Consortium (PCIC) website provides an integrated data portal¹⁰ to assist users in identifying monitoring sites and acquiring associated data. Sites maintained by local citizen science and community-based monitoring groups are addressed in section 2.4.

Figures 12 and 13 show locations of long-term federal and provincial monitoring stations, including discontinued sites. Government data have historically provided the most long-term quality-assured data sets. Although coverage has declined over the past two decades, these stations remain the best option for tracking water quantity in the Basin. Low-elevation areas in the southern Basin are generally the best served in monitoring of water quantity by the existing government hydrologic monitoring network. High elevations (above 1,500 m) and small watersheds are not well represented by the present network, particularly in respect to precipitation.

Under BC's system of aquifer classification, 157 Basin aquifers have been mapped as shown in Figure 13, and provide important information related to groundwater quantity. The majority of Basin aquifers remain unmapped.¹¹

¹⁰ See <https://www.pacificclimate.org/data>

¹¹ Additional information on factors related to groundwater quantity is available from BC's WELLS database http://www.env.gov.bc.ca/wsd/data_searches/obswell/map/

Table 4. Basin water quantity data provided by agencies and regulated industries.

Element Monitored	Organization Undertaking the Monitoring ¹	Extent of Monitoring Sites ²
Climate ³	ECCC	35 sites
	MoFLNRO (Wildfire Management Branch and West Arm research sites)	43 sites
	BC Ministry of Transportation and Infrastructure (MoTI)	35 sites
	BC Hydro	21 sites
Snow ⁴	MoE	9 automated snow pillows 39 manual snow courses
Glaciers	Columbia Basin Snow and Glacier Research Network (CBSGRN) - Parks Canada, University of Northern British Columbia (UNBC), Geological Survey of Canada (GSC), BC Hydro, MoE, PCIC, ECCC, and Natural Resources Canada	Glacier mass balance monitoring: Wapta and Illecillewaet (Parks Canada) Bryce-Castleguard (GSC), Kokanee and Zilmer (UNBC)
	The National Snow and Ice Data Centre (World Glacier Monitoring Service) provides additional satellite data also available through NASA.	“Supersites” ⁵ established and observed through the 2014/15 hydrologic year: Yoho, Conrad and Nordic glaciers (CBSGRN)
Streams that are tributary to the Columbia and Kootenay rivers	ECCC	51 stations 31 discontinued (>30 yrs data) 10 discontinued (10-30 yrs data)
	MoFLNRO	At least 4 stations of variable duration (1993-2010) ⁶
Lakes and Reservoirs	ECCC	6 stations – Arrow (2), Kinbasket, Duncan, and Kootenay Lake (2) ⁷
Groundwater	MoE	5 well sites ⁸
	MoE	157 mapped aquifers

1 Available public domain data are largely provided by the listed entities. Other monitoring data exist yet are either unavailable or difficult to access.

2 The number of sites is subject to change over time. To obtain the most current information, contact the responsible organization.

3 MoE maintains air quality monitoring stations in the Basin. These focus on wind speed, air temperature and relative humidity and do not provide year-round precipitation data.

4 Automated snow stations include temperature, cumulative precipitation and snow-water equivalent (SWE). Data from manual stations are taken on or near the first of the month and include depth and SWE. There are 41 snow observation stations (of any kind) with more than 30 years of data and 20 stations with more than 50 years of data. The snow pillow in the Redfish watershed is managed by MoFLNRO.

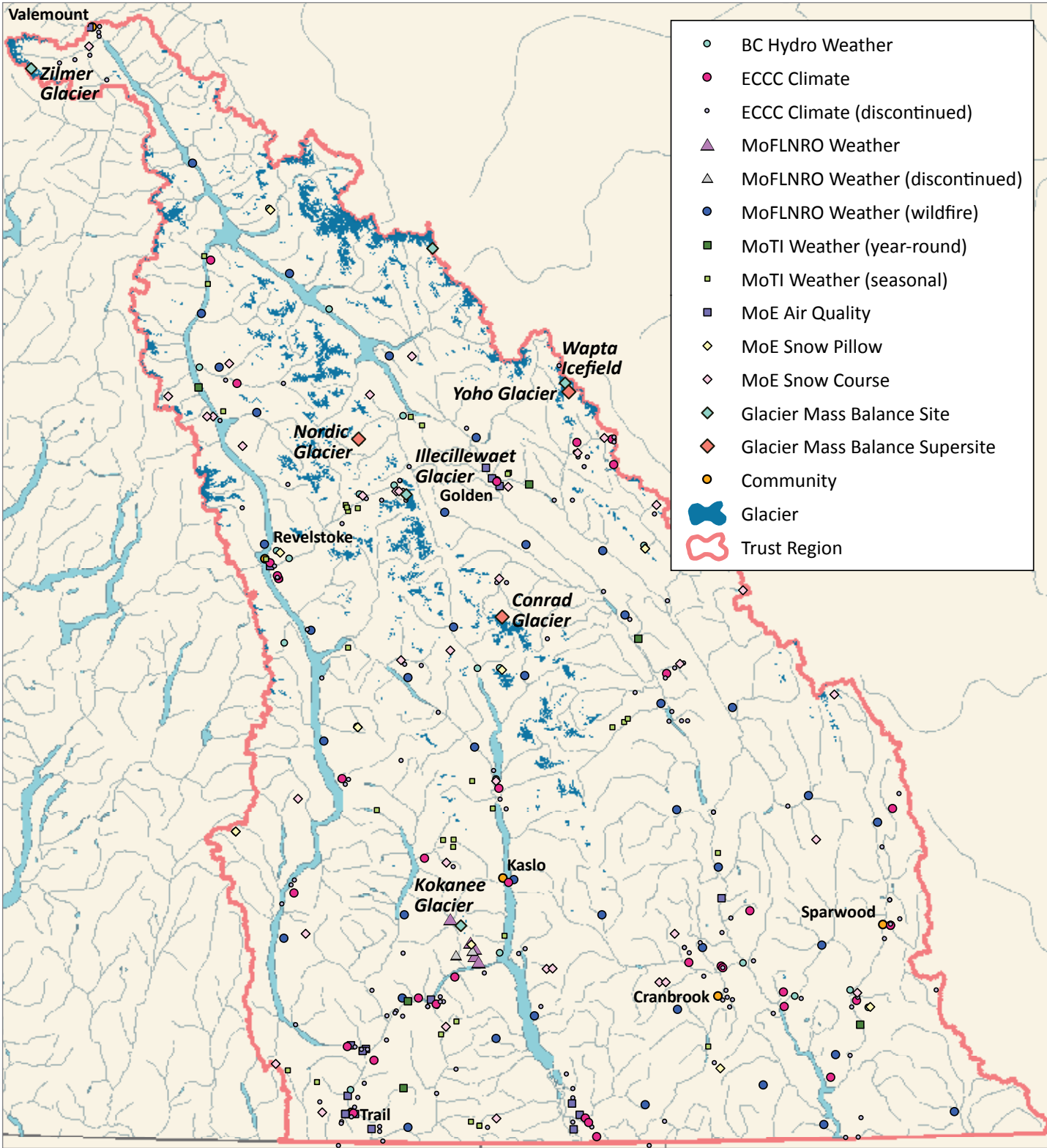
5 Supersites will aggregate glacier mass-balance, remote sensing, stream flow, snow pillow and climate monitoring around individual glaciated watersheds to support a deeper understanding of observed glacial change.

6 For example, Redfish Creek (1993-2010); Laird Creek (1993-2003); Gold Creek (1999-2003); Cotton Creek (2002-2010); and Sitkum Creek (2008-2012), all with multiple monitoring sites.

7 Data are available from 16 level stations on Kootenay Lake in place at various times from 1923-1949.

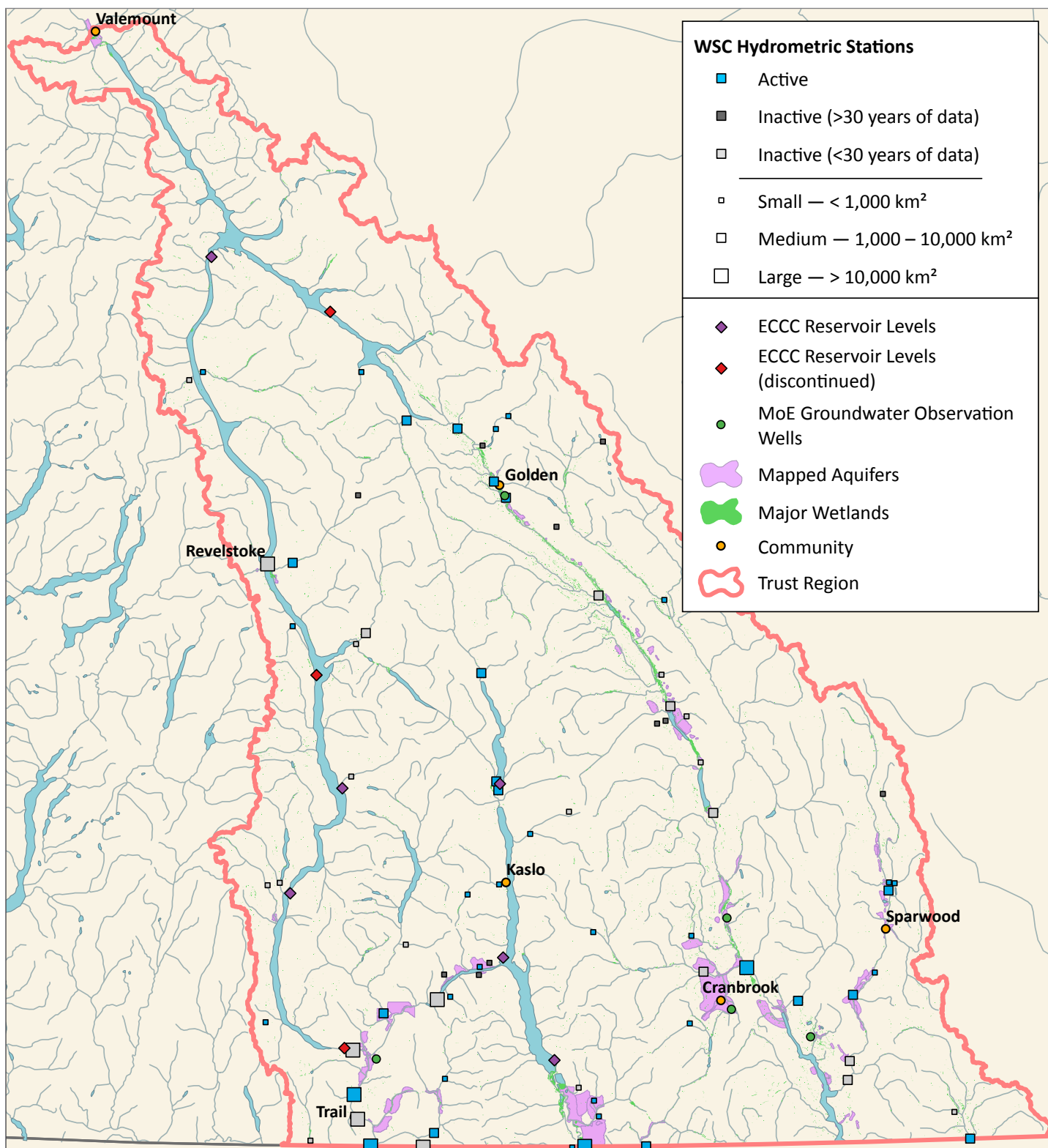
8 Castlegar (1966); Cranbrook (1985); Golden (1989); Jaffray and Wasa Lake (2005).

Figure 12. Climate, snow and glacier monitoring sites within the Basin established by agencies and regulated industry.¹



1 The status and location of stations are subject to change over time. To obtain the most current information, contact the responsible organization.

Figure 13. Hydrometric stations and lake/reservoir and groundwater monitoring sites within the Basin, established by agencies and regulated industry.



Glacier data are collected through routine monitoring of glaciers by the Geological Survey of Canada as well as research programs carried out by BC universities. The historical data are generally available up to one to two years before present to allow for publication of the data (or derived projects) in peer-reviewed literature.

Due to the Basin's hydrologic diversity, the current network of monitoring stations represents only a small fraction of the sites that could be monitored to provide a well-rounded understanding of water quantity. The significant cost of monitoring water quantity is a key limitation in creating an adequate network. Historically, precipitation and runoff at higher elevations have been poorly monitored. In addition, over the past few decades, the federal and provincial governments have reduced their hydrometric monitoring, especially on smaller streams. Because existing monitoring networks predated the need for regional climate impacts monitoring, the current network does not represent an optimal configuration for tracking and understanding the full range of implications of climate change on water supply for Basin ecosystems and people. With climate change, high-elevation precipitation and runoff is changing in ways that are not fully understood and are difficult to study without monitoring data from high-elevation stations and for smaller streams. Additional data and related scientific understanding would make it possible to improve the health of ecosystems, better plan land uses, help communities adapt to a changing climate, optimize use of municipal funds available for provision of water supply, and evaluate opportunities for and constraints to economic development.

2.3 Water Quality Monitoring Efforts and Data Providers

Basin water quality data are gathered by governments, industries and community-based monitoring groups. ECCC's Water Quality Monitoring and Surveillance Division (WQMSD), ECCC's Water Survey of Canada (WSC) and the MoE provide most of the long-term water quality data relating to long-term ecosystem and waterbody health, as summarized in Table 5.¹² Many sites are discontinued; however, the historic data are substantial.¹³

ECCC conducts a long-term water quality monitoring program focused on documenting the physical and chemical characteristics of larger streams within the Basin (including the Columbia and Kootenay rivers). The Canadian Aquatic Biomonitoring Network (CABIN) is also maintained through ECCC. Most of these sites are run jointly by ECCC and MoE.

CABIN monitoring is carried out in a coordinated fashion by ECCC and MoE, and the data are used in the development of the Columbia Basin CABIN model. The Trust provides financial support to community-based groups conducting CABIN monitoring in the Basin while MoE (and Parks Canada) undertake CABIN monitoring directly and by providing technical assistance to community-based monitoring groups. In the Basin, the CABIN program is focused primarily on medium-to-large tributaries to the Columbia and Kootenay rivers. Figure 14 shows the locations of these government-led water quality monitoring sites.

12 Other data have been gathered in shorter-term (≤ 5 years) research projects and in support of private-sector development projects; they are difficult to access yet may be of considerable local value.

13 See <https://www.ec.gc.ca/eaoudouce-freshwater/default.asp?lang=En&n=50947E1B-1#longterm>

Table 5. Water quality monitoring led by government agencies.

Element Monitored	Organization Undertaking the Monitoring ¹	Status/Details
Columbia and Kootenay rivers	ECCC – WQMSD	6 river sites (2 discontinued)
	ECCC – WSC (sediment only)	7 discontinued sites
Tributaries	ECCC and MoE – CABIN	139 stream sites retained for periodic reference sampling
	ECCC – WQMSD	2 stream sites (5 discontinued)
	ECCC – WSC (sediment only)	38 discontinued sites
	Global Environment Monitoring System ²	3 stream sites
	BC Ministry of Forests ³ and forest licensees	About 50 stations of variable duration from 1980s to present ⁴ Dozens of sites - unavailable ¹
Groundwater	MoE	3 sites ⁵
Reservoirs	Fish and Wildlife Compensation Program	Arrow Reservoir (9 sites)
Lakes	Fish and Wildlife Compensation Program	Kootenay Lake (8 sites)
	MoE	8 lakes (initiated in 2015)

¹ In addition to the sites listed in the table:

- Interior Health Authority and local government water utilities monitor withdrawals from streams, lakes and groundwater at 958 sites in the Basin in relation to meeting standards for the quality of drinking water and recreational water.
- Dozens of small-to-medium-sized streams have been monitored under the Forest Renewal British Columbia initiative (1990s) and in subsequent government-funded programs in support of forestry activities; while monitoring continues at some sites, past data are poorly archived and present data are largely unavailable to the public.

² GEMS provides data submitted by governmental and non-governmental groups. GEMS data from the Basin is provided by Environment and Climate Change Canada for parameters reported through the Fresh Water Quality Monitoring Program. Further details can be found at: <http://www.gemstat.org/default.aspx>.

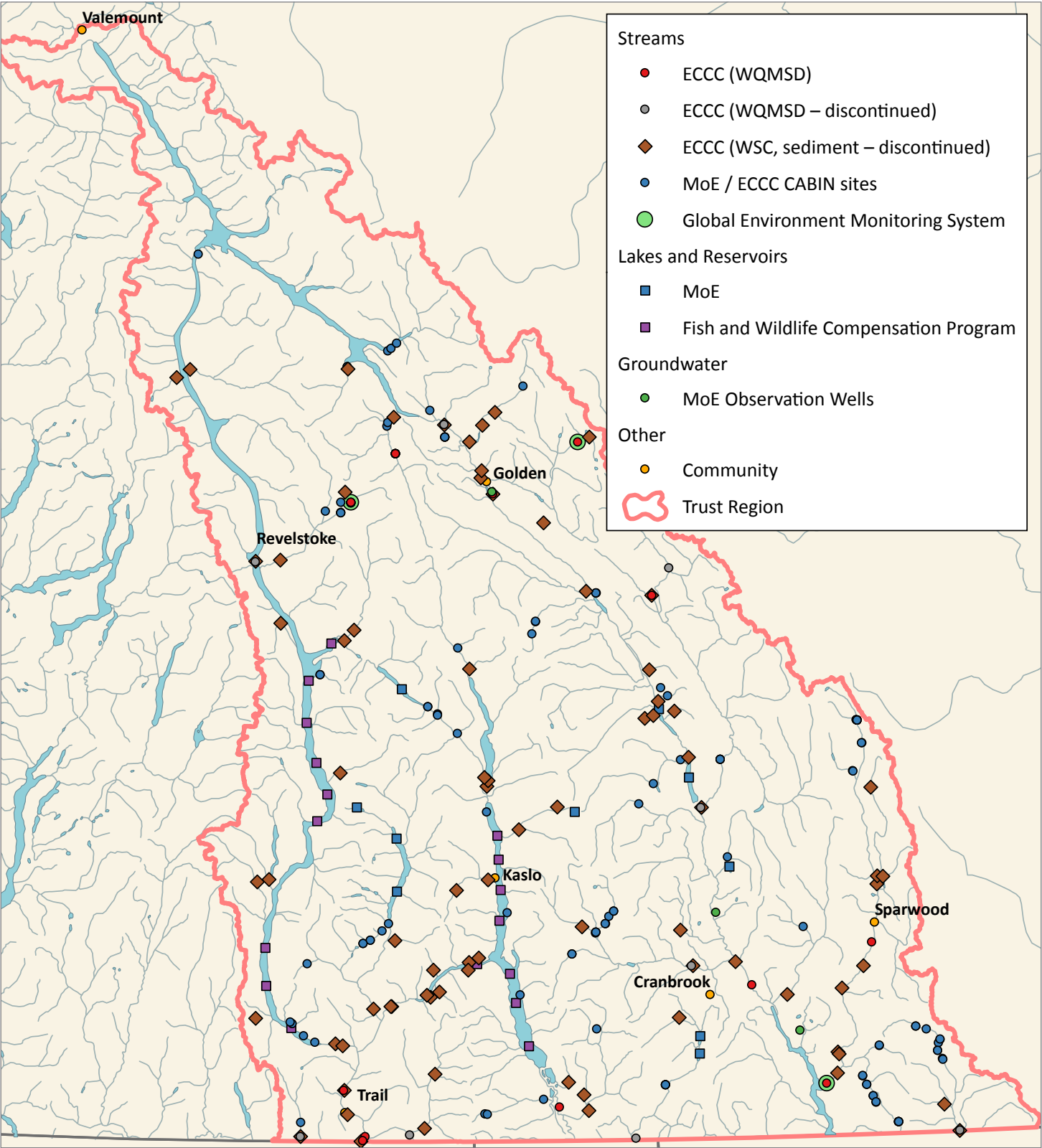
³ The former Ministry of Forests is currently an entity within the Ministry of Forests, Lands and Natural Resource Operations.

⁴ Notable sites include Redfish (1993-2010); Laird (1993-2003); Gold (1999-2003); Cotton (2002-2010).

⁵ MoE conducts irregular long-term semi-annual sampling and analysis at three of its Observation Wells: Wasa, Jaffray and Golden.

Since 2006, CABIN has been recognized as an integral part of the long-term freshwater quality monitoring network in Canada. It incorporates biological information with traditional physical and chemical water monitoring. Macroinvertebrate samples are collected to assess changes to aquatic ecosystems over time using the Reference Condition Approach (Reynoldson 1997). The network of CABIN sites are composed of longer-duration reference sites and a number of short-duration “test” or “impact” sites. Under the Reference Condition Approach, an array of reference sites is sampled to characterize the biological condition of a region, against which test sites are compared. Only the longer-duration sites are included in Table 5. The 139 reference sites are generally focused on systems with fewer land-use impacts (often in parks) and draining somewhat smaller watersheds (generally under 500 km² as shown in Figure 1). The test sites emphasize larger systems such as the Columbia, Kootenay, and Elk rivers and other systems that experience impact from land-use activities. Generally, only two reference sites, or “sentinel” sites are monitored each year, with the rest resampled at about 10 per cent per year. The sampling work is shared by MoE with ECCC, Parks Canada and community groups. As discussed below, citizen science and community-based monitoring groups are becoming increasingly interested and engaged in monitoring local water sources, using the same CABIN protocol used in the federal and provincial programs.

Figure 14. Water quality monitoring sites within the Basin established by agencies and regulated industry.¹



¹ Due to the concentration of sites in certain locations, not all points will be visible on this map. To obtain the most current information, please contact the responsible organization.

This long-term monitoring initiative using CABIN and the Reference Condition Approach includes MoE's recently-established lake-monitoring program. To improve understanding of water quality for lakes in British Columbia, MoE initiated a long-term water quality monitoring program in 2015 that includes four of the larger (natural) lakes in the Basin: Columbia, Moyie, Slocan and Windermere. MoE is expanding the program to include Summit, Trout, Premier and Whiteswan lakes. Expected parameters under this new program consist of Secchi depth, vertical temperature and dissolved-oxygen profiles, phytoplankton, zooplankton, chlorophyll-a, hardness, total metals, nutrients and ions.¹⁴

Stream water quality monitoring has been undertaken for the past two decades in support of forestry activities within the Basin's forest land base (with some dating back to the 1980s). This monitoring has been funded largely by the Province of BC through successive programs. Streams were monitored for stream flow and water quality with an emphasis on sedimentation, temperature and other parameters potentially influenced by forestry activities. If assembled and analyzed collectively, these data may hold the opportunity to provide regional and sub-regional insight into the relative condition of Basin watersheds.

The Fish and Wildlife Compensation Program (FWCP) undertakes long-term water quality monitoring at eight sites on Kootenay Lake and nine sites on Arrow Reservoir as part of its nutrient enhancement program to support aquatic ecosystem health, and fish populations in particular. Kootenay Lake and Arrow Reservoir are known to be affected by nutrient depletion due to dams.¹⁵

Many of BC Hydro's annual reports include water quality information (e.g., gas supersaturation, temperature) associated with the Kinbasket, Duncan and Arrow reservoirs and the rivers immediately downstream of their respective dams. Gas supersaturation is an excess of dissolved gas, which can be a water quality concern with many dams. At certain levels, over time, it can have negative impacts on fish, particularly young fish. As a result, gas supersaturation is actively managed by the hydroelectric industry.

The Interior Health Authority (IHA) requires water suppliers to monitor their raw water source. In consultation with the IHA, a monthly, bimonthly or quarterly frequency is commonly followed as a standard monitoring frequency, particularly for larger water systems, but the requirement varies in accordance with the nature of the source. The monitoring sites are generally located at low elevation near settled areas. Monitoring of raw drinking water quality focuses on bacteriological parameters (notably *E. coli* and fecal coliforms) with additional parameters for larger drinking water systems, such as turbidity of stream sources. Auditing and compliance with water quality guidelines focus on treated water.

Table 6 presents the distribution of systems according to size (number of connections) and the type of source. In general, the higher number of connections, the larger the water system. Water systems with over 300 connections are typically municipal water systems or large Improvement Districts and other utilities. Other systems with hundreds of connections are generally the smaller community

14 Nutrients include chlorophyll a, chloride, total nitrogen, total Kjeldahl nitrogen, nitrite, nitrate, total phosphorus, dissolved phosphorus, orthophosphate, silica, total organic carbon. Ions include sulphate, calcium and magnesium.

15 Kootenay Lake by Duncan Dam in the north and Libby Dam in the south; Arrow Reservoir by upstream impoundments due to Mica Dam and Revelstoke Dam.

Table 6. Size distribution of source types of Basin drinking water supplies, as estimated by the Interior Health Authority.

Source Type	Number of Connections on the System		
	< 15	15-300	> 300
Surface flows and springs	130	60	11
Lakes	20	14	3
Groundwater	330	103	6
Combined sources	9	5	6

systems distributed within the regional districts. Systems under 100 connections serve mobile home parks, ski hills, campgrounds, a variety of other small commercial users, and single-family homes. Water quality data are also collected for recreation sites for waterbodies that are generally situated near population centres.

This monitoring tends to be seasonal and conducted over variable timeframes, depending on the nature of the source and its intensity of use. For example, larger systems are generally sampled more often because of the increased population at risk; surface water sources and unconfined aquifers are sampled more often due to their overall higher vulnerability. Purveyors of water from large sources submit annual reports to IHA and the long-term data are typically made available by the purveyor upon request.

Long-term sampling and analysis of groundwater occurs at three of MoE's Observation Wells which are located on type "1a" aquifers, following MoE's system of aquifer classification. Type 1a is defined as "vulnerable and populated." Samples are analyzed for metals, various forms of nitrogen and phosphorus and anions. As mentioned earlier, IHA also oversees the collection and analysis of water for municipalities using well water.

2.4 Community-Based Monitoring of Water Quality and Water Quantity

The Columbia Basin is home to many local community and environmental groups carrying out community-based and citizen science monitoring programs. These programs often arise due to a shared interest in understanding waterbodies important to local communities and provide an opportunity to fill gaps in local and regional water monitoring data.

Community-based monitoring is community-initiated data collection, yielding data that remain accessible to the community after the collection is complete and no matter who collected the data. Community-based monitoring programs generally follow established provincial or federal protocols or appropriate variations.

Citizen science monitoring is defined as the collection of data, led by members of the public and, typically, in collaboration with professional scientists. The collaboration expands opportunities for scientific data collection and provides access to scientific information by community members.

Table 7. Basin water-related data provided through community-based monitoring.

Hydrologic Feature	Organization Undertaking the Monitoring	QT	QL	Status/Details
Climate and snow	North Kootenay Lake Water Monitoring Project	✓		1 snow site (+1 for 2016)
	Ski resorts ¹	✓		3 snow sites
Streams	Columbia Basin Water Quality Monitoring Program	✓	✓	24 sites in 14 streams
	North Kootenay Lake Water Monitoring Project	✓	✓	6 sites (+1 planned)
	Wildsight		✓	5 sites in 5 streams
	Slocan Valley Water Monitoring Program	✓	✓	9 sites (discontinued)
Lakes	Lake stewardship groups ² (large lakes)		✓	5 lakes ³
	Lake stewardship groups ² (small lakes)		✓	7 lakes ⁴
Wetlands	Slocan Wetland Assessment and Monitoring Program		✓	22 sites (begun in 2014)
Groundwater	Living Lakes Canada	✓		1 well site ⁵ (11 additional wells in 2016)
	Slocan Lake Research Centre			Aquifer mapped on Lemon Creek fan; further mapping is funding dependent.

1 Ski resorts are included with community-based monitoring sites because this monitoring is not regulated.

2 The BC Lake Stewardship Society guides local groups in conducting tiered water quality monitoring (three levels), with some occasional technical assistance from MoE.

3 Sites: Columbia, Kootenay (at 3 locations), Moyie, Slocan, Windermere lakes

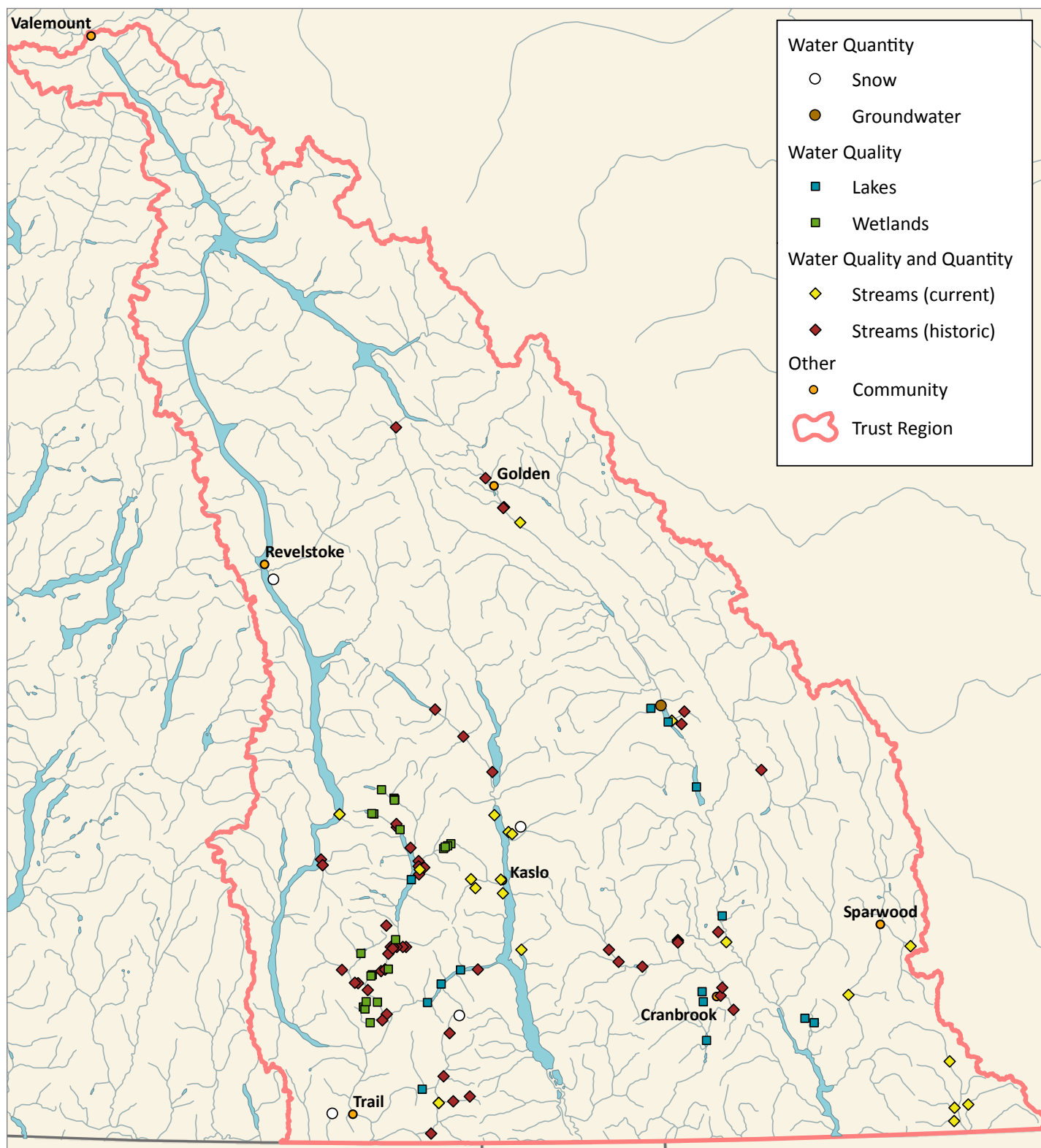
4 Sites: Erie, Tie, Jim Smith, Lillian, New, Rosen, Wasa lakes

5 One site is in place since October 2013. Eleven additional sites are confirmed for installation in 2016.

Table 7 provides an account of the sites illustrated in Figure 15. Water quality monitoring carried out by Water Improvement Districts are not included in this section because these organizations are mandated and overseen by IHA.

The Columbia Basin Watershed Network Society (CBWN) has a membership that consists of dozens of local community-based monitoring groups situated across the Basin. The CBWN assists these watershed groups in their scientific, educational and training activities.

Figure 15. Monitoring sites undertaken through community-based monitoring.



North Kootenay Lake Water Monitoring Project

The North Kootenay Lake Water Monitoring Project (NKLWMP), funded in part by the Trust, has taken over stream monitoring sites from the Kaslo and District Community Forest Society. The NKLWMP is expanding the earlier monitoring program to include new snow and hydrometric sites to inform local stewardship and natural-hazard risk reduction through improved knowledge of watershed behaviour in a changing climate. The data from this project, in conjunction with other agency and industry data, will help communities on the North Arm of Kootenay Lake better adapt to changing conditions related to climate change and watershed disturbance.

Columbia Basin Water Quality Monitoring Project

The Columbia Basin Water Quality Monitoring Project (CBWQMP) is a Trust-supported project that provides support to community-based watershed groups seeking to become better stewards of their local water resources by carrying out place-based¹⁶ water monitoring programs. Current membership is eight groups: Arrow Lakes Environmental Stewardship Society, East Shore Freshwater Habitat Society, Elk River Alliance, Mainstreams Environmental Society, Salmo Watershed Streamkeepers Society, Slocan Lake Stewardship Society, Wildsight Golden and Wildsight Regional.

Monitoring sites include major tributaries in the Basin along with smaller ones that provide important environmental services, such as the Lardeau River, Salmo River, Slocan River and Joseph Creek, among others (see Figure 15). All sites have CABIN monitoring done annually in the fall in addition to water chemistry and temperature parameters throughout the year. Discharge measurements are also collected. The following groups have previously collected data in conjunction with the CBWQMP: Friends of the Lardeau River, Slocan River Streamkeepers Society, St. Mary Rural Residents Association, Wildsight Kimberley-Cranbrook and Living Lakes Canada.

Other Community-Based and Citizen Science Monitoring Programs

Several major lakes have dedicated local groups carrying out monitoring and assessment programs: Slocan Lake Stewardship Society, Friends of Kootenay Lake Stewardship Society, Lake Windermere Ambassadors and the Columbia Lake Stewardship Society. One example of these efforts is water quality sampling carried out at a number of locations along the length of Columbia Lake to monitor ecological health of the lake.

Two major wetland complexes in the Basin that are designated Ramsar sites¹⁷ are the Columbia Wetlands and the Creston Valley Wetlands. Both wetlands are the focus of stewardship efforts. The Columbia Wetlands Stewardship Partners and the Creston Valley Wildlife Management Area are focused on the sustainability of these wetlands within their respective areas and both include citizen science contributions. Neither wetland complex has been subject to regular water monitoring; however, water quality data are gathered on an occasional basis in support of research objectives. For example, in 2009 and 2010, Columbia Wetlands Stewardship Partners supported detailed

¹⁶ Place-based initiatives emphasize interdisciplinary learning rooted in local natural and human-created environments and promotes active, responsible citizenship.

¹⁷ Ramsar sites are established pursuant to the International Convention on Wetlands of International Importance especially as Waterfowl Habitat.

research that involved monitoring water quality and depth in 40 wetlands within the Columbia wetland complex in addition to sediment core analyses to detect contamination.

In 2014, the Slocan Wetlands Assessment and Monitoring Program initiated an extensive mapping program of small wetlands within the Slocan Valley. This program includes application of CABIN wetland monitoring protocols along with sampling for water quality parameters.

Wildsight has been using the CABIN protocol to monitor four stream sites in the Flathead watershed since 2013, expanding to five sites in 2014. The objective of the monitoring program is to compare impacts from logging in drainages that are heavily logged historically, drainages that have recently been logged, and drainages that are designated High Conservation Value Forests (under the Forest Stewardship Council) with no logging activity. The data from this project are shared with industry and support conservation efforts in the watershed.

Living Lakes Canada is expanding its aquifer monitoring program in 2016 to add sites at Cranbrook-Kimberley (four sites), Castlegar (two sites), Wardner-Jaffray, Golden, Kootenay Lake, Creston and Slocan in addition to its present Invermere site. Funding arrangements for these new monitoring wells are in place for the near-term. Living Lakes Canada and MoE intend that some of these sites will become part of BC's Observation Well network in the future.

The Community Collaborative Rain Hail and Snow Network (CoCoRaHSN) is a grassroots initiative to measure precipitation in citizens' backyards. This network aims to provide accurate, timely, high-quality precipitation data for end users. By encouraging volunteer weather observing, CoCoRaHSN is increasing the geographical density of precipitation data available in North America. At this time, a few monitoring sites in the Basin are part of this network.¹⁸

18 See <http://www.cocorahs.org/Canada.aspx>

3.0 Notable Trends and Impacts

The Basin spans a large area with considerable variability in climate and land use. Despite the gaps in coverage and the uneven nature of available water monitoring data, scientific knowledge of Basin water resources has identified some notable trends and impacts that have implications for communities and ecosystems along with opportunities to address important gaps in knowledge.

3.1 Snow and Glaciers

Snow and ice play a pivotal role in Basin hydrology because water is stored during colder periods and released during warmer periods, supporting downstream ecosystems and human needs. The snowpack provides important recharge for groundwater and wetlands while also contributing to summer and fall low flows in Basin rivers and streams. As introduced earlier, approximately 65 per cent of the Basin's annual precipitation falls as snow, which later melts and drives the annual spring freshet (Schnorbus *et al.* 2014). The percentage varies locally depending on climate, elevation, aspect and wind exposure. Snow conditions at any given site vary annually as a result of the ordinary variability of weather, longer-term effects of ENSO and other climate modes and climate warming.

From 1956 to 2005, Basin snowpacks declined 20 per cent at northern sites and 24 per cent at southern sites. The part of this decline due to the climate modes discussed in s.1.4.2 has been partitioned statistically, revealing a decline in snow (in terms of snow-water equivalent) of five and six percent in the northern and southern Basin respectfully. These declines are inferred to have occurred in response to warming associated with climate change (Chapman 2007).

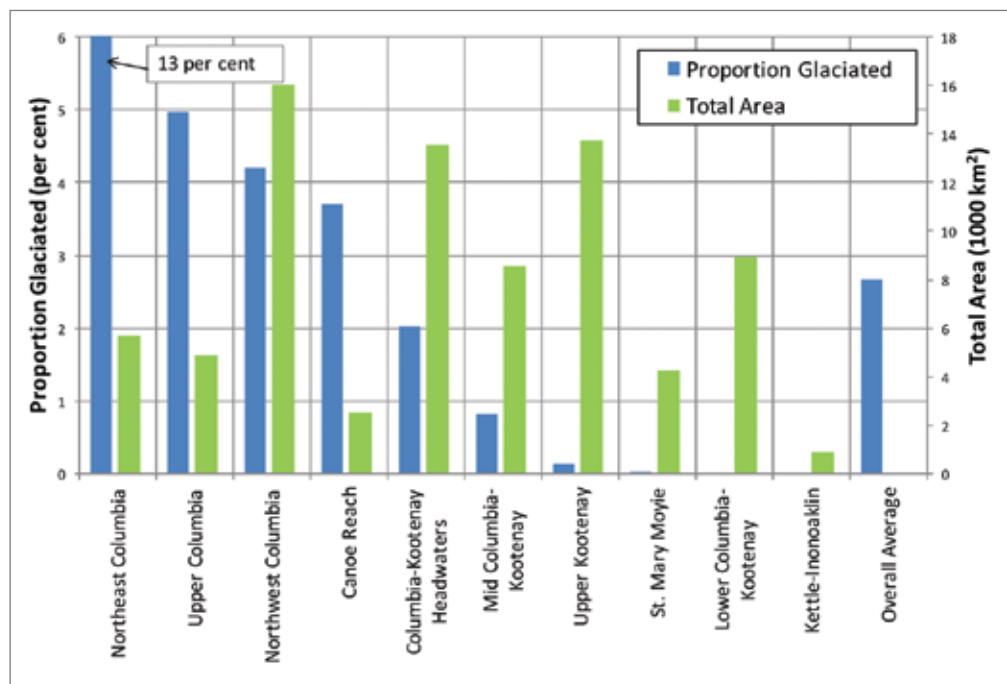
The annual date when the snowpack disappears is an important measure in understanding the state of water resources. Earlier dates contribute to lower soil moisture levels and a longer recession period within the annual hydrograph. These differences lead to reduced low-flow levels in summer and fall, lower total water availability from the snowpack during warmer months and, potentially, drought. Over time, changes in the climate are reflected in the forest, which changes, in part, in response to differences in the timing of snowpack disappearance. It has been found that differences in disappearance date of only 50-100 days correspond to differences in forest type, highlighting the potential for this effect as temperatures continue to rise (van der Kamp 2012).

Winter precipitation is projected to increase modestly over the coming decades; however, as warming reduces the proportion of precipitation falling as snow, a decline in snowpack is expected, leading to hydrologic changes. Given that mean winter temperatures at lower elevations in the Lower Columbia-Kootenay region are already at or close to the freezing level, the populated valley bottoms in this and other regions may have little or no snowpack in the coming years. Even at mid-to-upper elevations, warming and precipitation shifts to rain may outpace the overall increase in precipitation leading eventually to a net reduction in sustained snowpack into the summer. Such changes would contribute to reduced late-summer stream flow described in section 3.2 (Schnorbus *et al.* 2014).

According to a recent glacier inventory carried out at UNBC, there were 1,787 glaciers in the Basin in 2013, covering 1,593 km² (Menounos 2016). Although glaciers contribute far less to annual runoff than does the snowpack, where they occur, their late-summer melt provides critical support to annual stream low flows and influences water quality by reducing stream temperatures and increasing turbidity (Moore *et al.* 2009). In 1985, glaciers covered 2.67 per cent of the Basin area according to BC Terrain Resource Information Mapping. In the UNBC study, it was documented that between 1985 and 2013, 22.9 per cent of the glacial area was lost. During the first 20 years, glacial area declined at an average rate of 0.7 per cent per year increasing to 1.1 per cent per year in the final eight years, relative to 1985 (Menounos 2016).

Figure 16 shows the Basin's distribution of glaciers by hydrologic region, as of 1985. (Although glacial retreat has accelerated since 1985, the relative regional occurrence of glaciers will likely have remained similar.) The highest density of glaciers is in the Northwest Columbia and Northeast Columbia hydrologic regions. In the Basin's glacier-fed Mica watershed (an area of 20,742 km² draining across the Mica Dam), meltwater contributions to August and September stream flow can be as high as 25 and 35 per cent respectively (Jost *et al.* 2012). The ongoing difference between a glacier's accumulation and ablation (loss due to melting and evaporation) is its mass balance, which over time determines whether the glacier increases or decreases in volume. Glacial mass balance is sensitive to shifts in climate. Warmer temperatures and reduced snowfall will cause a reduction in glacial ice, which has downstream implications for Basin water resources.

Figure 16. Proportion of hydrologic regions covered by glaciers.



As a result of recent warming, glaciers are diminishing throughout the Basin with glacial area down 16 per cent from 1986 to 2000, outpacing British Columbia's overall rate of decline of 11 per cent during 1985-2005 (Jost and Weber 2013). Glaciers in the southern Basin are smaller and losing their extent faster than those in the north. In a warmer climate, glacier resources are expected to decrease further, with some glaciers disappearing in the next 50 years depending on their current size, latitude and elevation. Under some emissions scenarios, a near total loss of Basin glacial ice has been projected for 2100 (Clarke *et al.* 2015).

A lack of long-term glacial mass-balance data limits detailed understanding of glacial decline and corresponding implications for Basin hydrology. In response, the Columbia Basin Snow and Glacier Research Network was formed in 2014 to advance understanding of the Basin's glaciers, including their contributions to Basin water resources. Five glacier "supersites" were established in an effort to help explain the causes and implications of glacier decline. Monitoring at supersites is being conducted through direct measurement of change for five glaciers in addition to associated climate and stream flows.

Analysis of hydrometric records for glacial watersheds in conjunction with climate projections provides an indirect method to understand the status of decline in Basin glaciers. Although detecting glacial melt is complicated by the annual melt of the snowpack, this complication can be addressed by examining August and September flows when summer snowmelt is at a minimum and rainfall is also typically low. Using a range of approaches, available studies agree on a strong decline in glaciers in the Basin through this century (Stahl and Moore 2006; Jost *et al.* 2012; Clarke *et al.* 2015).

As warming increases, glacial meltwater contributions to streamflow increase as more ice melts each year. As the glacier continues to decrease in size, its meltwater contribution to streamflow peaks in what is known as "peak melt rate", then begins to decrease due to the reduced amount of ice available to melt, even though the rate of melting remains high. As the glacier continues to shrink, the contribution eventually wanes, especially in the late summer months, leading to reduced late-season flows. The peaking and subsequent decline of glacier contributions to stream flow is key to understanding and modeling future Basin stream-flow response to climate change in glacial watersheds.

When will Basin glaciers pass their peak melt rates? Some evidence points to a peak that has passed while other analysis suggests the peak will come later, perhaps during 2020-2040. Although the date of peak melt rate remains uncertain for locations across the Basin, the date is expected to advance from south to north, with some southern locations possibly having passed peak glacial melt rate already. The northern regions with higher glacier density and wetter or colder climates may experience peak glacial melt sometime over the next two decades (Clarke *et al.* 2015).

The withdrawal of glaciers is expected to lead to increased geomorphic hazards including slope failures and outburst floods from water stored in glaciers and in moraine-dammed lakes (Moore *et al.* 2009). Further, although there is no local information available, the melting of permafrost (potentially found at higher elevations in the northern Basin) can also affect slope stability (Geertsema *et al.* 2006) and water quality (Frey and McClelland 2009). It appears that there is little or no published data on water quality directly associated with snowpack and glaciers. Atmospheric deposition may be able to shed light on this aspect; however, there is no such monitoring of airborne contaminants in the Basin.

3.2 Rivers and Streams

Stream discharge varies greatly around the Basin, shaped by geology, the size and characteristics of drainage areas, climate and snowpack, glaciers, land use, and the regulation of flows at dams for hydropower and flood control. Water filters through the landscape, eventually being routed to groundwater, escaping through evapotranspiration, or being transported via runoff to a stream channel or to a lake, wetland or reservoir. Changes in climate influence water contributions to the region as well as water storage as snowpack and glacial ice. Changes in the timing and volume of stream flows will reflect changes in climate, surface conditions, vegetation cover and water storage within a catchment.

The major tributary systems to the Columbia and Kootenay rivers include the Upper Kootenay (1,841 km²), St. Mary (2,696 km²), Slocan (3,348 km²) and Elk (4,304 km²). These large systems are monitored and thus provide opportunities to evaluate changes in annual hydrographs. Despite complicating factors such as climate modes introduced earlier, trends can be determined for monitored catchments. In addition, trends identified in tributary systems within a hydrologic region may be applicable in inferring changes taking place in unmonitored catchments within the same hydrologic region.

Streams across western North America have been observed to be shifting toward an earlier freshet and centre volume of flow¹⁹ (Stewart *et al.* 2005; Regonda *et al.* 2005). In Basin streams, the dates of freshet onset and centre volume have not changed appreciably since measurements began. Despite a slight net increase in precipitation over the last 100 years (see Appendix 2), annual catchment runoff yields have decreased as the temperature has increased. While the cause of these apparent discrepancies remains unclear, they point to the complexities inherent in catchment runoff processes as the climate warms and historic runoff processes and precipitation regimes reorganize. For example, evaporative losses may be exacerbated by reservoirs and an upward trend in temperature over the past 30 years. Snowpacks may now be melting earlier, consistent with climate change projections. The net observed reduction in flows with warming appears to contradict modelling work carried out for the Basin that projects increases in catchment yields into the 2050s (Schnorbus *et al.* 2014). These discrepancies between observations and model projections warrant further investigation to determine the cause of recent declines in yield.

As historic streamflow patterns shift in response to climate change, the potential for lower late-season flows creates particular concern, with a multiplicity of factors at work. The low flows in smaller and lower-elevation watersheds and in watersheds without glaciers are especially vulnerable to warming because a greater proportion of precipitation is received as rain and does not go into storage as snow for subsequent melt during the late summer and early fall when stream flows are low. GCMs show that summer precipitation is projected to decline, which would intensify the decline in low flows. A shift from snow to rain has already been shown to decrease Basin water yield (Berghuijs 2014). Warmer springs will induce an earlier freshet and warmer summers will lead to increased evapotranspiration, further decreasing summer flows. In glacier-fed streams, the enhanced melt rate of glaciers may counteract these effects for some years until peak glacial melt,

¹⁹ The centre volume of flow is the date at which half the annual water yield of a stream has been discharged.

after which a further decline in low flows will occur. As mentioned above, although there remains uncertainty as to the current status of peak glacial melt, it is expected to occur first in the warmer and drier southern regions (where it is likely to have occurred already), and last in the cooler and wetter northern areas. The loss of these contributions will be particularly problematic for ecosystems and human uses during warm dry summers following winters with low snowfall accumulation. Despite projected increases in winter precipitation, this is not expected to compensate for these various declines (Hirose and Marshall 2013).

As discussed earlier, the Columbia River and Kootenay River are highly regulated by a system of 19 dams in Canada and a larger system of dams in the USA. Current dam operations reduce the size of the spring flood while increasing winter low flows. These two systems of dams, and others on some of the larger tributary watersheds, span multiple hydrologic regions and hydrologic influences and, as a result, integrate upstream effects such as annual water yield and date of peak flow.

Most future climate scenarios project increases in annual precipitation and rates of evaporation, reductions in snowpack and earlier spring snowmelt. On average, such changes would result in earlier and potentially larger peak flows, and reduced low flows, where the magnitude and timing of these changes will vary by watershed. There is also likely to be an increase in the frequency of extreme events such as high-intensity precipitation and extended droughts.

How these changes will influence actual flow regimes in the lower reaches of the Columbia and Kootenay river systems will depend on how the entities²⁰ responsible for dam operations adapt to these changes. It is possible that the shape of the hydrograph will be largely maintained despite the ongoing warming and reduced wintertime storage as snow. As climate change proceeds, operational regimes may be altered incrementally to adjust for outcomes due to climate change (floods, droughts and losses due to evaporation). In considering the balance between management of flows in the major rivers of the Basin and climate change-related influences, it remains unclear the extent to which the Columbia and Kootenay river hydrographs will change under future climates. This is an area of active research by BC Hydro, PCIC and others. According to Jost and Weber (2013), streamflow projections for the Mica basin in the 2050s point to an increase in mean annual flow, presumably due to an expected increase in precipitation.

Water quality concerns in the Columbia and Kootenay rivers result primarily from dams and major industrial activities. A large dam can lead to changes in downstream water quality, including increased river temperature, gas supersaturation and modification of sediment and nutrient flows. These issues already exist to varying degrees in these two rivers and are, to some extent, cumulative downstream. Discharges by large industrial point sources have been reduced significantly as a result of improved pollution control technologies and more stringent regulations.

The Columbia River Integrated Environmental Monitoring Program (CRIEMP) was formed by key stakeholders in government and industry to assess the status of ecological health of the Columbia River between Hugh Keenleyside Dam and the Canada-USA border. CRIEMP partners now include all levels of government, local industry, First Nations and non-governmental organizations. CRIEMP's mission is to "collaborate on aquatic ecosystem monitoring, evaluation and reporting

20 BC Hydro, Fortis and Columbia Power Corporation.

and to effectively communicate such information to stakeholders and the public.”²¹ CRIEMP is led by a scientific committee and supported by the long-term monitoring programs identified in Table 5 and supplemented by targeted short-term water quality studies, particularly in the lower Columbia River. These monitoring programs can assist in identifying strategies to address or mitigate concerns associated with industrial discharges.

Water quality in the tributaries of the Kootenay and Columbia rivers is highly variable, influenced by surrounding land uses and the size and complexity of their tributaries. Forestry, range, agriculture, rural development and transportation infrastructure are common distributed sources of impact. Effects from urban development occur locally. When sedimentation levels or riparian damages alter stream channels, either as a result of human activities or natural processes, water quality problems can arise and persist for many years. Where surface water is used for domestic consumption, IHA-mandated water monitoring can provide insights on water quality. IHA boil-water advisories are present throughout the Basin and some persist for extended periods of time, reflecting localized concerns on water quality for human consumption.

Effluent from municipal wastewater treatment plants may contain nutrients, bacteria, pathogens, heavy metals, hormones and pharmaceuticals. Downstream effects generally depend on the volume of effluent discharged, the quality of sewage treatment and the assimilative capacity of the receiving water. While discharges from municipal sewage treatment plants may affect downstream water quality locally in smaller tributaries, the effects frequently diminish sharply downstream of where the tributary joins the Kootenay River or Columbia River.

Outside of protected areas, forestry occurs throughout the Basin. Its impact on water quality can include sedimentation and damage to aquatic habitats, due largely to roads and trails and, in some limited locations, increased water temperatures caused by the removal of forest canopy and vegetation. The consequences of these effects are somewhat moderated by the maintenance of forested riparian areas along many larger streams. BC’s Forest and Range Evaluation Program²² provides a provincial-level interpretation of outcomes associated with forestry, based on connecting coarse-scale morphological information to inferred water quality and aquatic-ecosystem integrity.

Decades of fire suppression have created high fuel loads in Basin forests increasing their vulnerability to wildfire. Large hot wildfires can lead to hydrologic effects such as increased peak flows, increased sedimentation and a decline in channel stability that can have enduring effects on water quality. Given the prospect of warmer, drier summers associated with climate change, annual area burned by wildfire is expected to increase. For a study area within the Mid Columbia-Kootenay hydrologic region, Utzig *et al.* (2011) project an increase in annual area burned (across all GCMs) of almost 30 times by the 2050s. Reducing fuel loads in forest stands adjacent to human settlement is a first step to reducing some of the direct effects of these hazards.

Water quality concerns associated with mining can include the long-term effects of chronic exposure to low levels of metals, bioaccumulation of toxins, sediment contamination and acid mine drainage. Coal mining in the Elk Valley is associated with persistent impacts to the Elk River and to a lesser extent, the Kootenay River. Selenium contamination is of particular concern in addition to levels of

21 See <http://www.criemp.org>

22 See <https://www.for.gov.bc.ca/hfp/frep/>

nitrate, sulphate and cadmium.²³ There has been increased attention to addressing these effects and water quality monitoring within the Elk has supported mitigative steps. Other mining-related water quality concerns are more localized and associated with historical mining activities, including poorly-built roads. Mountain-top removal and valley fill often accompanied these historic mining operations with additional effects that are not well studied. From research elsewhere, it is likely that these additional effects include biological impairment, alteration of stream chemistry, increased downstream flows due to valley fill soils acting as unconsolidated aquifers, increased annual runoff due to decreased evapotranspiration associated with de-vegetation, and changes in peak flows due to changing drainage areas (Miller and Zegre 2014).

3.3 Wetlands, Lakes and Reservoirs

The Basin has experienced extensive loss of valley-bottom wetland and riparian ecosystems due to the construction of dams and reservoirs for flood control and hydroelectric development and, to a much lesser degree, due to agricultural development. The remaining natural lakes and wetlands constitute important hydrologic elements of the Basin. Kootenay Lake is the fifth largest body of standing water in British Columbia, spanning 104 km from south to north. Other significant lakes include Trout Lake, Slocan Lake, Lake Windermere, Columbia Lake and Moyie Lake. Some areas of Lake Windermere and Kootenay Lake have experienced foreshore loss and deterioration due to shoreline development. The Columbia River Wetlands, situated between Invermere and Golden, and the Creston Valley Wildlife Management Area at the base of Kootenay Lake are Ramsar wetlands of international importance. Many small and ephemeral wetlands located on private land have been drained and filled. Climate change also threatens wetland longevity through accelerated evaporation and potential reductions of inflows.

Current and legacy issues associated with dams and reservoirs in the Columbia River system have led to short-term and long-term changes to water quality in these systems. Changes include altered annual hydrologic regimes and disrupted biological processes such as natural disturbance regimes, ecosystem energy dynamics and nutrient cycling.

Grand Coulee Dam in Washington has caused nutrient changes to ecosystems throughout Canada's Columbia River system and within the Kootenay River system below Bonnington Falls – the pre-dam limit to salmon passage. The effect has been a loss of nutrients that were previously brought by salmon from the Pacific Ocean to Basin floodplains. In addition to the loss of salmon passage, there is the legacy loss, due to dams, of large river habitat and associated floodplains and the nutrient exchanges that used to occur during flooding of the floodplains.

The dams and reservoirs have affected functions for individual species and populations, including seasonal migrations, genetic exchange, predator/prey relationships, reproduction and dispersal. These impacts can extend into non-impacted watershed units, especially those downstream of dams and reservoirs, for example, Kootenay Lake and the lower Columbia River (Utzig and Schmidt 2011). Dams upstream of Grand Coulee Dam (Duncan, Libby, Mica and Revelstoke dams) have created nutrient deficits in Kootenay Lake and Arrow Reservoir due to sediment and nutrient capture behind them.

23 See <http://www.teck.com/news/stories/2016/working-together-on-environmental-monitoring-in-the-elk-valley>

Other major Basin reservoirs, notably Kinbasket and Duncan, do not have upstream dams thus their nutrient inflows remain relatively intact.²⁴

The FWCP's nutrient enhancement program, as supported by its water quality monitoring program, is the major ongoing response to these changes. Significant challenges exist in maintaining a suitable balance of nutrients and predator-prey relationships within these managed ecosystems.

Data on lake water quality is generally restricted to larger lakes due to the limited lake monitoring in place. Monitoring of Lake Windermere and support from the BC Lakes Stewardship Society and MoE have informed the development of specific Water Quality Objectives that identify target conditions for this lake in relation to its uses and characteristics. Over time, Water Quality Objectives may be developed for other large lakes such as Kootenay, Slocan and Columbia. For smaller lakes—and other large lakes for which water quality monitoring remains unavailable—status must be inferred by making assumptions about inputs and associated land uses.

Understanding of water quality in the Basin's wetlands remains limited by the absence of long-term monitoring efforts. Improved wetland data offer opportunities to increase overall resilience in the face of climate change. Wetlands are high-value landscape elements that provide multiple environmental services including habitats for a wide diversity of species, water sources during low-flow periods, and buffering of increased sedimentation and other ecosystem impacts. Improved data on their occurrence and status enable their many beneficial roles to be recognized, harnessed and potentially protected.

3.4 Groundwater

Basin groundwater resources are not well understood due to a lack of mapping, monitoring and analysis. In the Basin's mountains, groundwater distribution is shallow, irregular and generally relates to fracture systems that discharge largely to mountain streams and lakes (Parsons and Quinn 2013). Late-summer stream flows are highly dependent on groundwater contributions and glacial melt (where glaciers occur) because most of the seasonal snow-melt has already occurred and summer precipitation can be scarce. Current and projected reductions in snow accumulation and glacial ice have been shown to result in reduced water supply in the Basin, particularly during summer low-flow periods (Bürger *et al.* 2011). These changes increase the importance of groundwater resources in maintaining base flows for streams in the Basin.

The details of how and to what extent climate change will affect Basin groundwater resources remain unclear. Climate change can modify groundwater directly by altering precipitation type and amount, infiltration processes, surface waterbodies and evapotranspiration rates, and indirectly through expected increases in human withdrawals as surface streams become less reliable and human demand for water increases (Green *et al.* 2011). An analysis of Basin groundwater vulnerability has not yet been carried out and more work is required to evaluate potential effects of climate change on groundwater resources.

24 Revelstoke Reservoir has an upstream dam but this reservoir is operated as a run-of-river facility and was not a lake prior to being dammed, thus nutrient issues are likely of lower concern.

Generalized modeling, supported by field observations in the western United States, indicates that expected increases in winter precipitation may be accompanied by substantial declines in summer stream flows due, at least partly, to complex groundwater responses resulting from changes in surface water and surface conditions (Huntington and Niswonger 2012). There may be similarities in dynamics between surface water and groundwater in the Basin, potentially further complicated by the Basin's history of repeated glaciations and the complexity of resulting deposits. These results reinforce the need for increased groundwater monitoring in the Basin to help resolve uncertainties associated with efforts to model Basin hydrology under future climates.

Two notable exceptions to the general lack of groundwater data are associated with a large industrial smelter in Trail and coal mining in the Elk Valley. In both locations industrial contaminants have been found in nearby groundwater and are subject to on-going monitoring programs as actions are taken to improve groundwater quality.²⁵ Elsewhere local groundwater issues may be present in association with sewage-ground-infiltration and landfill sites, particularly over unconfined aquifers. The extent of concern remains unknown due to limited monitoring and analysis. Some water purveyors that rely on groundwater are obliged by IHA to routinely monitor their raw water quality.

25 See <http://www.teck.com/operations/canada/operations/trail-operations/trail-groundwater-remediation-plan> and <http://www.e-know.ca/news/sparwood-council-facts-41/>

4.0 Basin Water Resources in a Warmer Climate

Seasonal and annual temperatures in the Basin are rising faster than global rates (MoE 2015) and are projected to keep increasing through this century. The outcomes will primarily be contingent on the scope and scale of future greenhouse gas emissions (IPCC 2014). Human activities have transformed many parts of the Basin, particularly in the major river valleys where dams extensively modify the hydrographs and reservoirs have inundated significant ecosystems. Various point and distributed sources of impacts to water resources also exist in the major river valleys and many tributary watersheds.

In the coming decades, as annual and seasonal temperatures climb, further direct hydrologic impacts are projected to occur in addition to various indirect and secondary impacts associated with geomorphic and biological ecosystem responses. Impacts may also result from potential changes in human activities as the condition of water and other resources change.

Diminished snowpacks, melting glaciers and higher temperatures (especially in the summer) collectively point to a future with lower low flows, increased incidences of drought and seasonal changes to water tables. The significance of these effects is expected to be greater in warmer and drier hydrologic regions such as the Lower Columbia-Kootenay, the Upper Kootenay and the Columbia-Kootenay Headwaters. The cooler and wetter hydrologic regions such as Canoe Reach and the Northwest Columbia could expect to experience these changes to a lesser extent and/or in a delayed timeframe.

Under projected climates, water quality concerns are expected to accelerate in magnitude and introduce new challenges. Many of these water quality effects will be an indirect byproduct of changing hydrology.

Wildfire is likely to increase in frequency resulting in a range of subsequent changes, depending on fire severity: in addition to direct sedimentation of streams and rivers, soils may be affected leading to changes in runoff patterns and, in concert with the changing climate, potential changes in forest types (Utzig *et al.* 2011). As surface soils adjust to the new climates, particularly on sloping ground, landslides and glacial lake outbursts may lead to enhanced rates of sedimentation and declining water quality. Longer periods of lower flows projected with future climates will reduce the potential for dilution to mitigate water quality concerns.

Simultaneously, higher water temperatures are likely to create various biological effects. Bacteria can live longer and grow more rapidly. Aquatic habitat may reach critical lethal temperatures for resident organisms, particularly cold-water fish species. Algal blooms could become more frequent, especially where nutrients are in abundance. Nuisance and invasive species generally propagate faster in warmer temperatures. Species adapted to warmer temperatures could colonize the Basin as their ranges expand northward. Displacement of indigenous species through climate change and the spread of invasive species, such as zebra and quagga mussels, can cause direct and indirect changes in water quality.

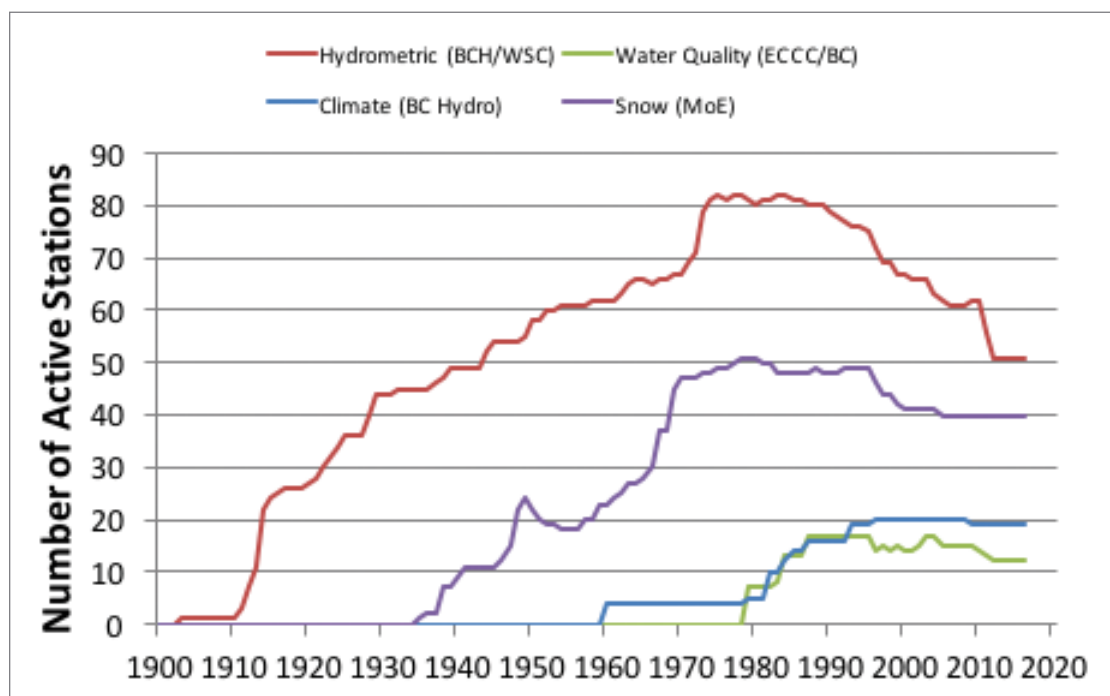
The relative magnitude of future changes in water quality will vary according to location and the interplay between human activities and climate change. At the local level, the main influences on water quality will be nearby human activities and land use. Deterioration of water quality due to climate change will occur over broader areas, and local impacts can be expected where landslides, flooding and fires take place. Hydrologic regions that are currently drier and hotter are expected to become more vulnerable, more quickly, than those that are now wetter and cooler.

5.0 Future Needs and Opportunities

Overall scientific understanding of Basin water resources highlights their sensitivity to climate change and some land uses. Various land-use activities within the Basin have impacted water resources and now, increasingly, climate change is projected to yield a distinctly different future for water resources. The quickening rate of change in climate conditions is revealing a growing gap between water status and scientific understanding of it, particularly in light of declines in monitoring effort as illustrated by Figure 17.

Addressing gaps in knowledge would help Basin communities and land managers better understand and adapt to current water-related challenges and those that are projected to arise in the future particularly due to climate change. Water monitoring data enable improved planning to benefit ecosystem health, better avoid land-use conflicts, prepare for increased natural hazards, address municipal information needs around water supplies, and strengthen economic development affected by water resources. Significant opportunities for addressing knowledge gaps are described below.

Figure 17. History of active climate, snow, hydrometric and water quality monitoring stations maintained by major government agencies.



Snow and Glacier Measurement Opportunities

A priority opportunity lies in improving the measurement of snow and glacier dynamics because these inputs to the hydrologic system drive change in many other facets of water quantity and water quality. Since approximately 65 per cent of the Basin's precipitation falls as snow, it is particularly important to improve monitoring and analysis of changes in snow accumulation and melt. Present snow courses and snow pillows (including ECCC climate stations) are either not distributed in a representative manner across all hydrologic regions or are not distributed appropriately by elevation to characterize high-elevation locations. These gaps highlight important opportunities to improve the makeup of the overall snow monitoring network.

An improved understanding of the status of glacial melt is of direct importance to understanding the future of low flows in watersheds where glaciers occur. The Columbia Basin Snow and Glacier Research Network will assist in addressing the gaps in monitoring and assessing glacier change. Adding additional glacier supersites in representative locations would be appropriate given climate variability across the Basin.

Analysis of Available Snow Data

Whereas additional snow data are needed, more analysis can be accomplished with the snow data already available. The analysis (to 2005) could be extended to the present to better understand how fast snowfall is changing in relation to climate change. This analysis could include core data provided by BC's Snow Survey and Automated Snow Pillow networks, as well as data from other sources such as the BC Hydro network. Bringing together all the snow data would facilitate assessment and selection of new high-elevation monitoring sites.

Other Monitoring Opportunities

The larger low-elevation rivers and reservoirs, including Kootenay Lake, are generally satisfactorily monitored for water quantity and quality. Contaminant point sources are largely addressed through regulatory means. It is the smaller watersheds, higher-elevation stream sites and distributed non-point-source effects that need increased attention. An improved understanding would assist communities and resource managers in planning more effectively in response to climate change. Small representative watersheds can be instrumented for streamflow, among other variables, and be selected to be representative within hydrologic regions.

Understanding the effects of municipal and industrial point-sources and distributed land uses like forestry operations has been an important focus for water quality monitoring, with provincial and federal water quality guidelines providing criteria for water quality in relation to its expected use. An integrated water quality "report card" could systematically bring together and analyze data on smaller surface streams (including IHA data) to highlight trends and vulnerabilities for a variety of uses. This could include consideration of results from BC's Forest and Range Evaluation Program.

Monitoring of Small Lakes and Wetlands

Wetlands and small lakes are particularly important to water supply and to sustaining environmental flows in river systems. Given the historic and extensive loss of major wetlands and expected increases in episodes of water scarcity, mapping and tracking small wetlands, including high-elevation sites, would increase understanding of water storage and supply reliability under future seasonal dry periods. This knowledge would be directly useful in safeguarding aquatic habitats and maintaining community water supplies during periods of water scarcity. Monitoring the extensive and relatively less-disturbed Columbia River Wetlands would also be beneficial, given their international status and ecological significance. Monitoring of natural lake levels may provide important information about rates of evaporation.

Groundwater Monitoring

There is little long-term quantitative understanding of groundwater resources due to a widespread lack of groundwater monitoring throughout the Basin. Given the new demands likely to be placed on groundwater under future climates, additional monitoring and analysis are recommended to better understand its potential particularly since more surface water sources may become seasonally restricted or of inadequate quality, or both. Groundwater may become essential as an alternate water source in the drier and hotter hydrologic regions, especially in late summer and early fall.

Tiered/Structured Monitoring

Gaps in monitoring can be addressed through a structured approach that includes classifying the gaps by hydrologic region and landscape characteristics and by their value in answering key questions related to land management, municipal and regional planning, natural-hazard response, ecosystem stewardship and economic development.

A carefully-selected long-term “backbone” network can be identified to provide consistent baseline information across all regions, land attributes and climates. This network would need to address high-elevation data gaps (especially for precipitation) and monitoring in northern locations, including streamflow. More in-depth monitoring can address other priorities such as valued ecosystem services, present and projected threat levels, and the establishment of baselines through monitoring undisturbed (or less disturbed) areas.

Ideally, long-term agreements could be reached with the major monitoring providers so that the future backbone network remains adequate and stable. This would provide improved direction and a stronger basis for the growth of community-based monitoring and clarity as to where these complementary efforts are best applied. It would also support the development of municipal, business and community adaptations to climate change. For example, monitoring the progress of climate change across all ten hydrologic regions can highlight emerging Basin vulnerabilities so that adaptations can be undertaken where they are needed most urgently. Representative monitoring within hydrologic regions may enable effective modelling to project overall change in water supply across regions, with local towns and watershed groups potentially better suited to address regional variation within a hydrologic region, particularly in relation to important local water sources.

Improved Data Availability

Data availability can be improved through streamlined archival and retrieval technologies, perhaps by working with PCIC to expand the range of data available on its station data portal.²⁶ Data from major long-term government monitoring programs are generally available, with some exceptions. Currently, data from short-term programs and efforts that are out-sourced in some capacity (including community-based and citizen science monitoring) can be challenging to obtain. These data could be valuable for continuing calibration and refinement of simulation models, including climate change projections and hydrologic modelling. These historic and ongoing data should be captured and archived so they can be utilized in future scientific analyses. A more thorough and systematic approach to collecting and warehousing water monitoring data could improve the ability of applied scientists to identify relevant management thresholds in aquatic ecosystems, deepen understanding of potential limitations on municipal water supplies due to climate change, clarify local agricultural opportunities and constraints, target preparedness for increased natural hazards, and inform a host of factors related to regional economic development.

26 See <https://www.pacificclimate.org/data>

References

- Abatzoglou JT 2011. Influence of the PNA on declining mountain snowpack in the Western United States. *International Journal of Climatology* 31 (8):1135-1142.
- Alexander MA, I Bladé, M Newman, JR Lazante, N Lau and JD Scott 2002. The Atmospheric Bridge: The Influence of ENSO Teleconnections on Air-Sea Interaction over the Global Oceans. *Journal of Climate* 15:2205-2231.
- BC Ministry of Environment 2015. *Indicators of Climate Change for British Columbia: 2015 Update*. March 2015.
- Bürger G, J Schulla and AT Werner 2011. Estimates of future flow, including extremes, of the Columbia River headwaters. *Water Resources Research* 47, W10520, 18 p.
- Chapman A 2007. *Trend in April 1st Snow Water Equivalent at Long-Term British Columbia Snow Courses, in Relation to ENSO, PDO and Climate Warming*. Unpublished report. BC Ministry of Environment, River Forecast Centre, Victoria BC, 7 p.
- Clarke GKC, AH Jarosch, F Anslow and more 2015. Projected deglaciation of western Canada in the twenty-first century. *Nature Geoscience* 8:372–377.
- Collins M, S An, W Cai, A Ganachaud, E Guilyardi, F Jin, M Jochum, M Legaigne, S Power, A Timmerman, G Vecchi and A Wittenberg 2010. The impact of global warming on the tropical Pacific Ocean and El Niño. *Nature Geoscience* 3:391-397.
- Dalton MM, PW Mote and AK Snover 2013. *Climate Change in the Northwest - Implications for Our Landscapes, Waters, and Communities*. Island Press, 230 p.
- Dong B and A Dai 2015. The influence of the Interdecadal Pacific Oscillation on temperature and precipitation over the globe. *Climate Dynamics* 45:2667-2681.
- Frey KE and McClelland JW 2009. Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrological Processes* 23 (1):169-182.
- Geertsema M, Clague JJ, Schwab JW and Evans SG 2006. An overview of recent large catastrophic landslides in northern British Columbia, Canada. *Engineering Geology* 83 (1–3):120-143.
- Gobena AK, Weber FA, Fleming SW 2013. The Role of Large-Scale Climate Modes in Regional Streamflow Variability and Implications for Water Supply Forecasting: A Case Study of the Canadian Columbia River Basin. *Atmosphere-Ocean* 51 (4):380-391.
- Green TR, Taniguchi M, Kooi H, Gurdak JJ, Allen DM, Hiscock KM, Treidel H, and Aureli A 2011. Beneath the surface of global change: Impacts of climate change on groundwater. *Journal of Hydrology* 405 (3–4):532-560.
- Hamann A, T Wang, DL Spittlehouse, and TQ Murdock 2013. A comprehensive, high-resolution database of historical and projected climate surfaces for western North America. *Bulletin of the American Meteorological Society* 94: 1307–1309.

- Hamlet AF, Lettenmaier DP 1999b. Effects of Climate Change on Hydrology and Water Resources in the Columbia River Basin. *Journal of the American Water Resources Association* 35 (6):1597-1623.
- Hirose JMR and Marshall SJ 2013. Glacier Meltwater Contributions and Glaciometeorological Regime of the Illecillewaet River Basin, British Columbia, Canada. *Atmosphere-Ocean* 51(4):416-435.
- Holdren JP 2015. *Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing*. Memorandum from the Office of Science and Technology Policy to the heads of Executive departments and agencies in the USA, 11 p.
- Huntington JL and Niswonger RG 2012. Role of surface-water and groundwater interactions on projected summertime streamflow in snow dominated regions: An integrated modeling approach. *Water Resources Research* 48 (11):W11524.
- Intergovernmental Panel on Climate Change (IPCC) 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, RK Pachauri and LA Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 p.
- Jost G and F Weber 2013. *Potential Impacts of Climate Change on BC Hydro-Managed Water Resources*. BC Hydro, Burnaby BC, 27 p.
- Jost G, Moore RD, Menounos B, Wheate R 2012. Quantifying the contribution of glacier runoff to streamflow in the upper Columbia River Basin, Canada. *Hydrol Earth Syst Sci* 16 (3):849-860.
- Luce CH, JT Abatzogou and ZA Holden 2013. The missing mountain water: slower westerlies decrease orographic enhancement in the Pacific Northwest USA. *Science* 342:1360-1363.
- Meehl GA, GW Branstator, WM Washington 1993. Tropical Pacific Interannual Variability and CO₂ Climate Change. *Journal of Climate* 6:42-63.
- Merryfield WJ 2006. Changes to ENSO under CO₂ Doubling in a Multimodel Ensemble. *Journal of Climate* 19:4009-4026.
- Miller AJ and NP Zegre 2014. Mountaintop removal mining and catchment hydrology. *Water* 6:472-499.
- Moore RD, Fleming SW, Menounos B, Wheate R, Fountain A, Stahl K, Holm K, Jakob M 2009. Glacier change in western North America: influences on hydrology, geomorphic hazards and water quality. *Hydrological Processes* 23 (1):42-61.
- Newman M, GP Compo and MA Alexander 2003. ENSO-Forced Variability of the Pacific Decadal Oscillation, *Journal of Climate* 16:3853-3857.
- Parsons ML, O Quinn 2013. Ground water resources of the mountain ground water regions. Chapter 11 in *Groundwater Resources of British Columbia*, BC Ministry of Environment, accessed online January 2016.

- Regonda SK, Rajagopalan B, Clark M, Pitlick J 2005. Seasonal Cycle Shifts in Hydroclimatology over the Western United States. *J Climatology* 18 (2):372-384.
- Reynoldson TB, RH Norris, VH Resh, KE Day and DM Rosenberg 1997. The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. *J. N. Am. Benthol. Soc.* 16: 833-852.
- Rodenhuis D, KE Bennett, AT Werner, TQ Murdock and D Bronaugh 2009 (revised): *Climate Overview 2007: Hydro-climatology and Future Climate Impacts in British Columbia*. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 132 p.
- Schnorbus M, A Werner and K Bennett 2014. Impacts of climate change in three hydrologic regions in British Columbia, Canada. *Hydrologic Processes* 28:1170-1189.
- Schreier H, M Hampstead, E Paré and N Klassen 2016. *Evaluation of Community Water Conservation Efforts in the Columbia Basin 2009 to 2015* 78 p.
- Stahl K and Moore RD 2006. Influence of watershed glacier coverage on summer streamflow in British Columbia, Canada. *Water Resources Research* 42 (6):W06201.
- Stewart IT, Cayan DR, and Dettinger MD 2005. Changes toward Earlier Streamflow Timing across Western North America. *J Clim* 18 (8):1136-1155.
- Utzig G, J Boulanger and RF Holt 2011. *Climate Change and Area Burned: Projections for the West Kootenays*. Report #4 from the West Kootenay Climate Vulnerability and Resilience Project. Available at: www.westkootenayresilience.org.
- Utzig G and D Schmidt 2011. *Dam Footprint Impact Summary - BC Hydro Dams in the Columbia Basin*. Report prepared for the Fish and Wildlife Compensation Program (Columbia Basin).
- van der Kamp D, RD Moore and J Trubilowicz 2012. *Estimating Snow Disappearance Dates at Snow Course Sites*. Poster presentation, Department of Forest Resources Management, UBC.
- Wang T, A Hamman, DL Spittlehouse and TQ Murdock 2012. ClimateWNA—High-resolution spatial climate data for Western North America. *J. Appl. Meteorol. Climatol.* 51:16-29.
- Whitfield PH, Moore RD, Fleming SW, Zawadzki A 2010. Pacific Decadal Oscillation and the Hydroclimatology of Western Canada—Review and Prospects. *Canadian Water Resources Journal* 35 (1):1-28.

Personal Communications

Brian Menounos. Email communication August 19, 2016.

.

Appendix 1

Definitions

Aquifer. A saturated underground layer of water-bearing permeable rock or unconsolidated material that can transmit significant quantities of water.

Atmospheric water. Water held within the atmosphere in gaseous, liquid and solid forms.

Catchment. An area of land over which all surface runoff drains to one common point.

Climate. The long-term average (over at least several decades) of factors such as temperature, precipitation, humidity, solar radiation, frost-free period and growing-degree days, in a given region. It also includes the frequency and intensity of extreme events such as high intensity rainfall and droughts.

Freshet. The springtime flood of rivers resulting from snow and ice melt, particularly in the northern latitudes of North America.

Global climate model. A specific class of computer-driven models for weather forecasting, understanding climate and projecting climate change. It is also referred to as a general circulation model.

Glacier. A body of ice formed by the compaction and re-crystallization of snow over multiple winter seasons that is massive enough to deform and flow under its own weight.

Groundwater. Water located beneath the ground's surface. It is found in aquifers, in the pore spaces of rocks, in sediment, as permafrost and as soil moisture. In some locations, it can be saline.

Hydrograph. A graph showing the rate of flow (discharge) versus time past a specific point in a channel.

Hydrology. The scientific study of the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere.

Lake. A naturally occurring body of standing water with at least two metres of summer depth. If inflows or outflows are regulated, the seasonal pattern of water levels in the lake are generally similar to those prior to regulation.

Precipitation. Water in liquid or ice form that falls from the atmosphere when water vapour condenses and coalesces into droplets heavy enough to fall to the Earth's surface.

Ramsar. The Convention on Wetlands, also called the Ramsar Convention, is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.

Reservoir. An artificially created body of standing water subject to regulated outflows.

Snowpack. The quantity of accumulated snow in an area.

Snow-water equivalent. The amount of water contained within the snowpack expressed as the equivalent depth of water from melting the snowpack instantaneously.

Stream. A body of water with a current, confined within its bed and banks (including rivers and creeks).

Streamflow. The rate of water volume flowing past a point in a stream.

Surface water. Water that is naturally open to the atmosphere, such as streams, lakes, reservoirs and wetlands.

Trust Region. The region served by the Trust, as defined in the *Columbia Basin Trust Act*. The region primarily consists of all land in British Columbia that drains to the Columbia River within Canada. The region does not include major watersheds that drain to the Columbia River in the United States, such as the Kettle and Okanagan watersheds. See map on page vi.

Water quality. The physical, chemical and biological characteristics of water, usually at a particular location.

Water quantity. The temporal variation in the amount of water present, usually at a particular location. This may include aspects such as inputs (e.g., precipitation and snow), storage in wetlands, aquifers, lakes and reservoirs, and flow rates.

Water resources. Surface water, groundwater, atmospheric water and their elements: streams, lakes (and reservoirs), wetlands, aquifers, glaciers and precipitation (including snow).

Wetland. An area where soils are water saturated for sufficient time each year that excess water and low oxygen determine vegetation and soil development. Wetlands may or may not exhibit standing water at any particular time of the year. Wetlands include areas of standing shallow water under two metres in depth.

Acronyms used:

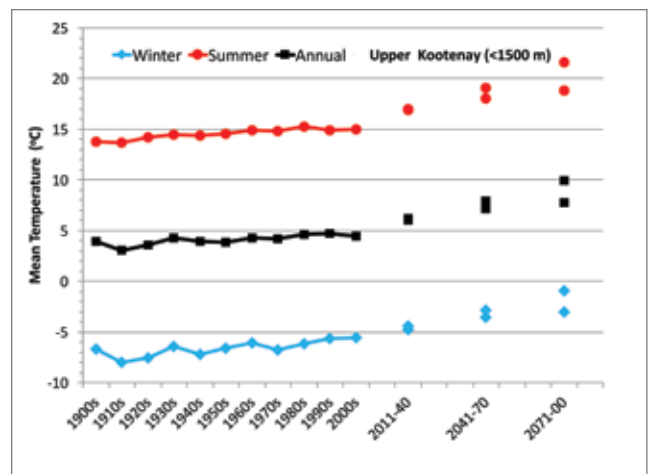
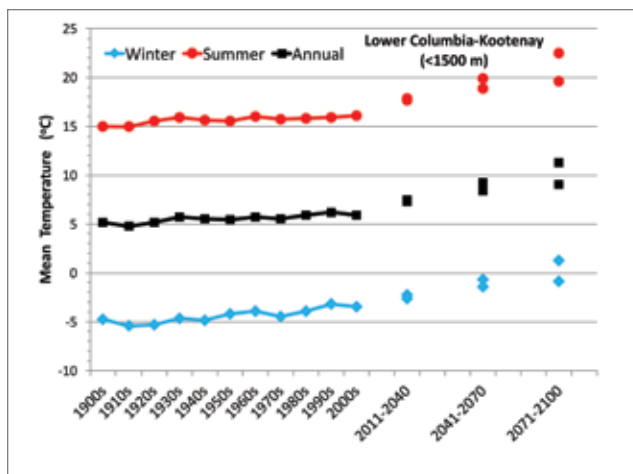
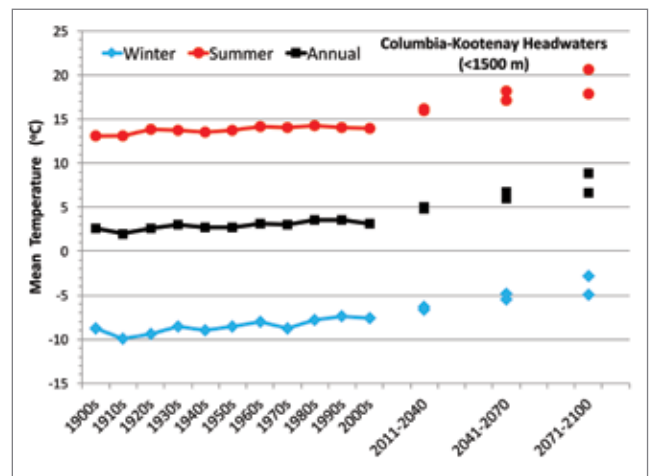
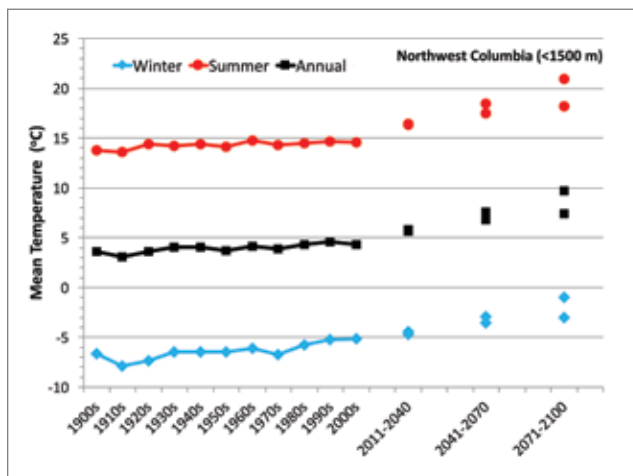
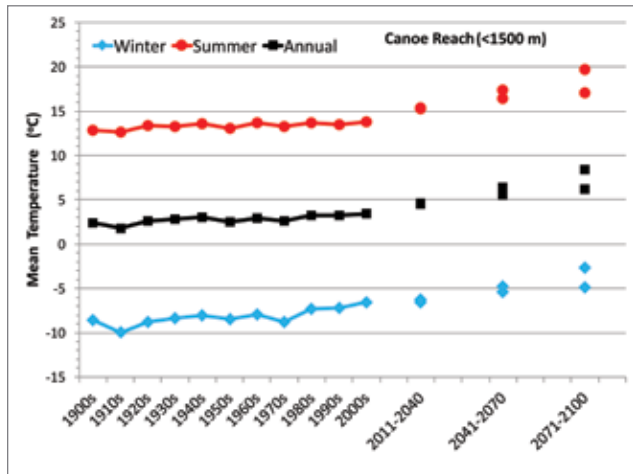
CABIN	Canadian Aquatic Biomonitoring Network
CBWN	Columbia Basin Watershed Network Society
CBWQMP	Columbia Basin Water Quality Monitoring Program
CRIEMP	Columbia River Integrated Environmental Monitoring Program
ECCC	Environment and Climate Change Canada
ENSO	El Niño Southern Oscillation
FWCP	Fish and Wildlife Compensation Program
GCM	Global Climate Model
IHA	BC Interior Health Authority
IPCC	Intergovernmental Panel on Climate Change
MoE	BC Ministry of Environment
MoFLNRO	BC Ministry of Forests, Lands and Natural Resource Operations
MoTI	BC Ministry of Transportation and Infrastructure
PDO	Pacific Decadal Oscillation
PCIC	Pacific Climate Impacts Consortium
WQMSD	Water Quality Monitoring and Surveillance Division
WSC	Water Survey of Canada

Appendix 2

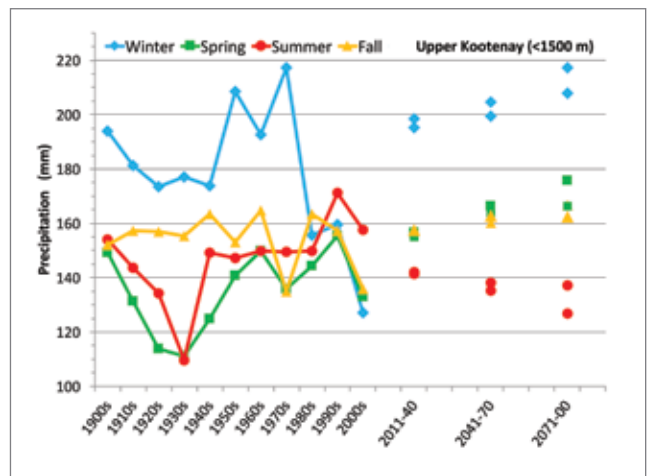
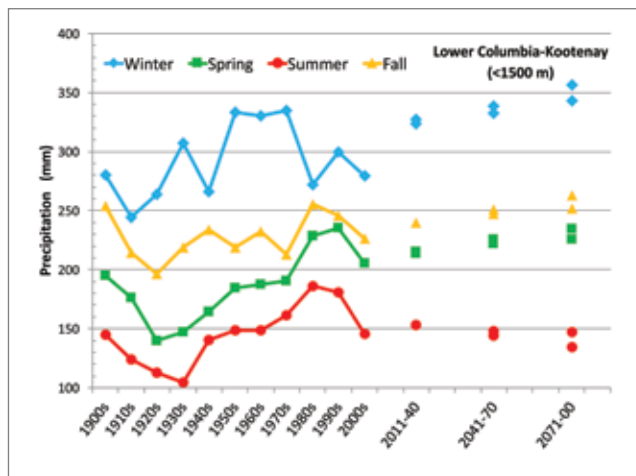
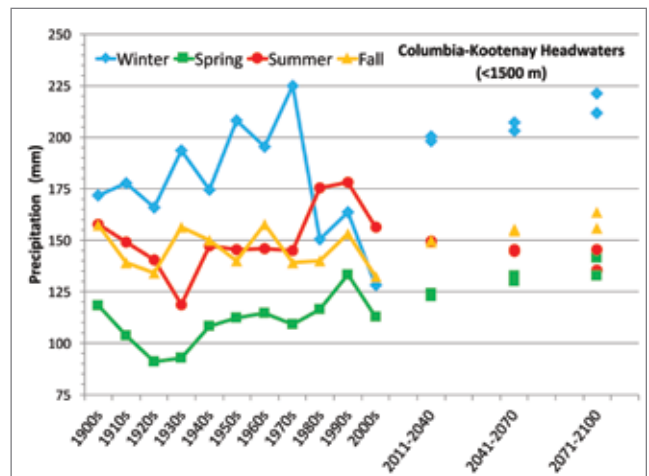
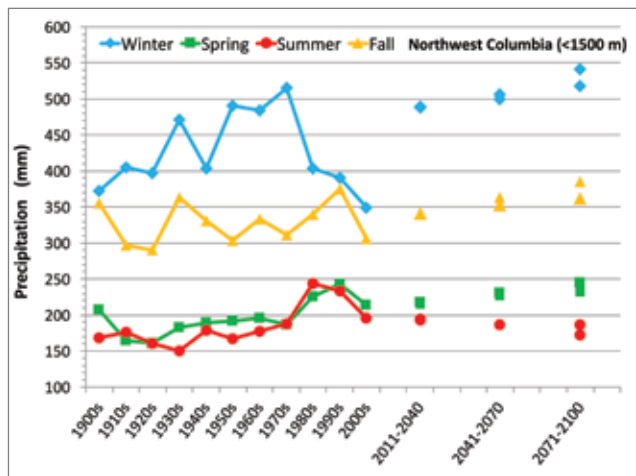
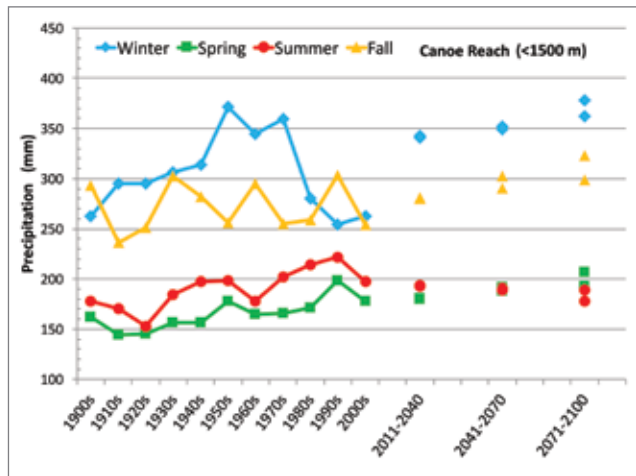
Seasonal Historic and Projected Climate for Selected Hydrologic Regions

The following pages provide comparisons of seasonal historic and projected climate for five of the Basin's ten hydrological regions. All projections are based on AR5 15 GCMs, means of e4.5 and e8.5.

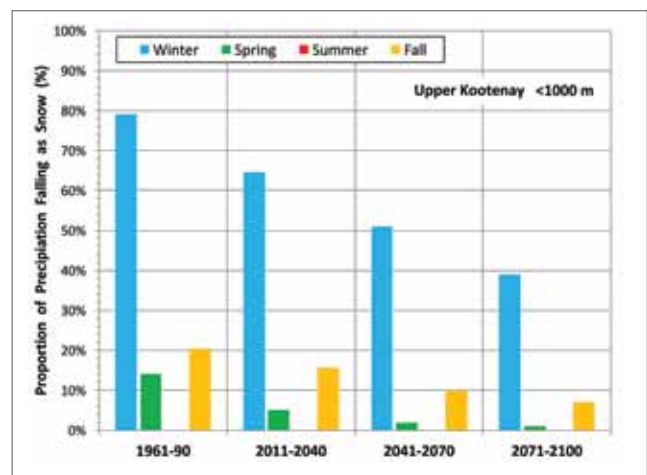
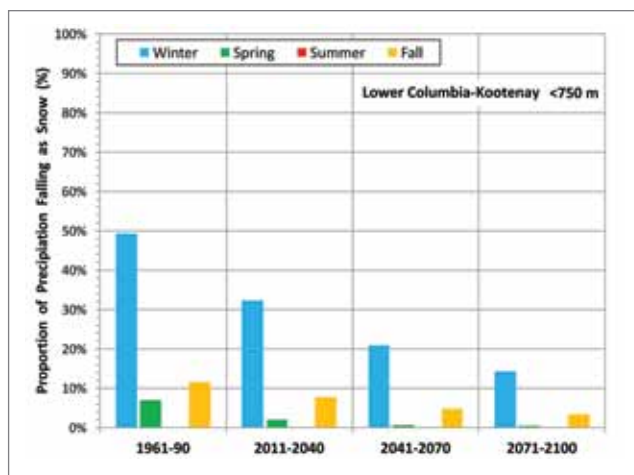
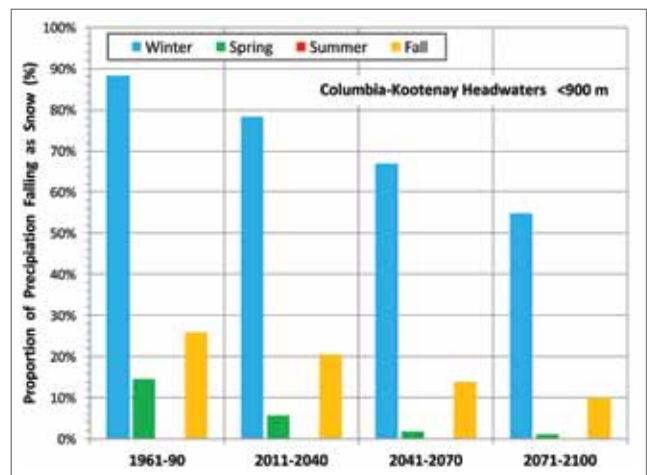
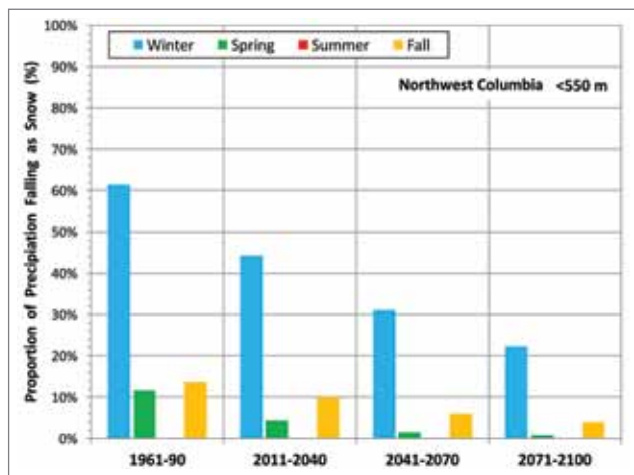
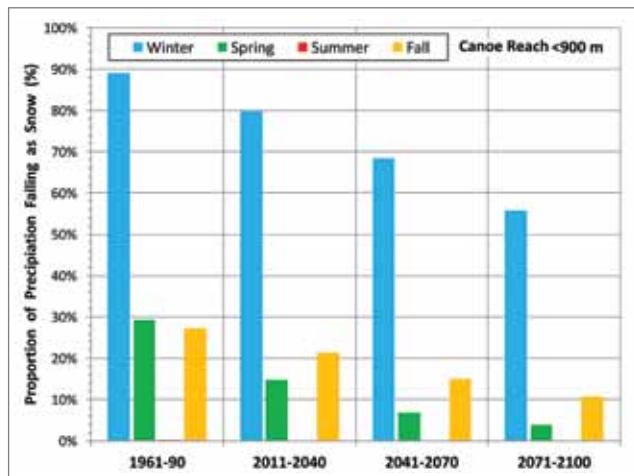
a) Mean temperature



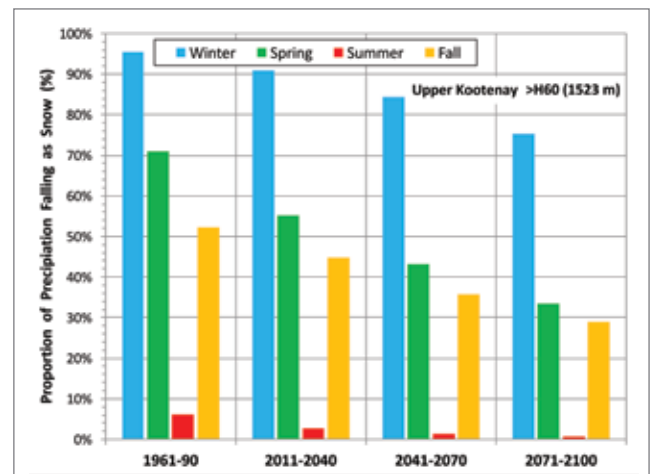
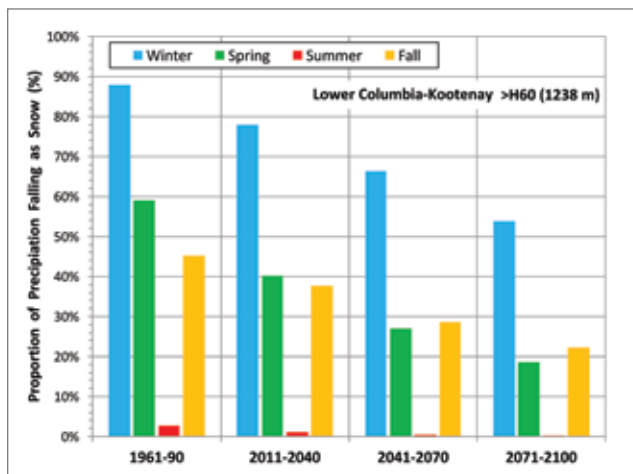
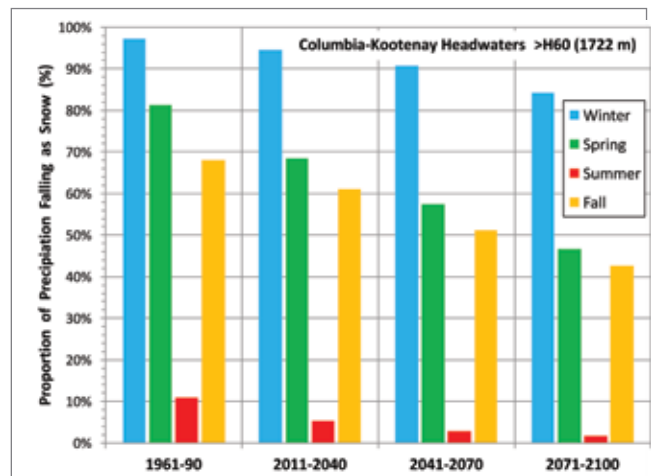
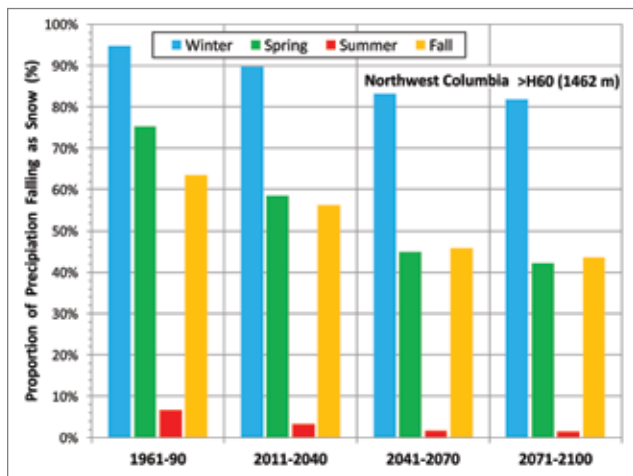
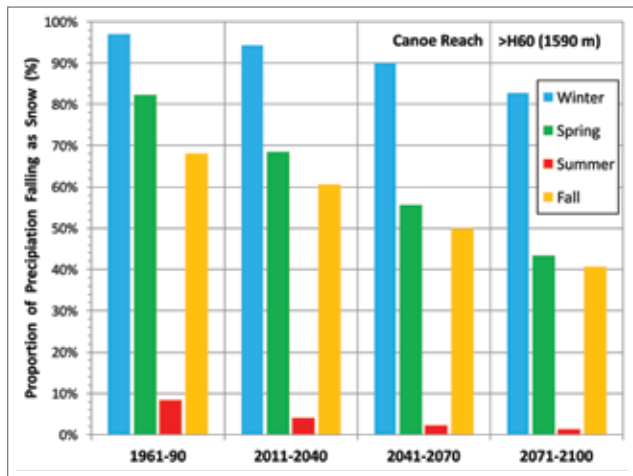
b) Mean precipitation



c) Proportion of precipitation falling as snow (%) at valley bottom



d) Proportion of precipitation falling as snow for the upper 60 per cent area by elevation (H60)





Head Office, Southwest Basin

300–445 13 Avenue
Castlegar, BC V1N 1G1

1.800.505.8998
250.365.6633
info@cbt.org

Northeast Basin Office

512 8 Avenue North, PO Box 393
Golden, BC V0A 1H0

1.800.505.8998
250.344.7065
info@cbt.org

Northwest Basin Office

220 Broadway, PO Box 220
Nakusp, BC V0G 1R0

1.800.505.8998
250.265.9936
info@cbt.org

Southeast Basin Office

201–828 Baker Street
Cranbrook, BC V1C 1A2

1.800.505.8998
250.426.8810
info@cbt.org