From: bob jamieson
Sent: March-15-10 8:13 AM
To: Living Water Smart ENV:EX

Subject: water issues in the East Kootenay
Attachments: Upper Columbia River Watershed Hydrometric Analysis Phase 1.pdf

Ian:

As per our telephone discussion, I will not be able to to attend your discussions on the Water Act, later in April.

I have attached a recent report, produced by the Col. Basin Trust, working with the Columbia Wetland Stewardship Partners and Wildsight, that identifies water issues in the Upper Columbia Basin (above Mica dam basically).

This work identifies several problems that are relevant to your work on revising the Water Act.

1. There is a lack of basic water flow data in this area that might be useful for addressing local water supply issues. The first stations on the Columbia (and Kootenay) River systems are 150-180 km downstream from their sources. **We need some kind of federal/provincial/municipal cost sharing agreement for installing and running more such stations in this area.**

2. There is only one federal long term water quality monitoring station in the Upper Columbia (again 150 km downstream).

3. The only other ongoing water quality monitoring in this area, is a Wildsight run and funded project monitoring water quality in Windermere Lake. **Funding for this work is basically year to year, with minimal government support.**

4. Groundwater monitoring is close to non-existent except in the Invermere area, as indicated in the attached report.

5. We had in the past entertained the notion of developed a water budget for this watershed. This report identifies the major problem **that small water users, mostly ranchers in this area, are not required to monitor their actual use of water.** It is therefore impossible to develop a credible water budget. This problem is compounded by the fact that the ranching sector is basically a negative return endeavour at present, so any additional costs to ranchers would not be well received.

Although we have many people and organizations in this area that are concerned with water issues, we can do very little that is constructive or science based, since there is no useful information on which to base decisions around water in this watershed. We are further road blocked in terms of funding, since local and regional funding agencies are unwilling to fund projects that are seen as downloading of federal and provincial management responsibilities.

Unless there is some serious provincial funding in the offing, for a water program on the scale of that in Alberta and Ontario (and throughout the USA), we see few options for progress on water issues in this area.

Regards,

Bob Jamieson
CWSP

Upper Columbia River watershed hydrometric analysis - phase 1

Photo by Larry Halverson

Report Prepared for: The Columbia Basin Trust

Report Prepared by: Ryan MacDonald, M.Sc (LOTIC Environmental) and Nick Berzins P. Eng (Thunderwater Engineering and Construction, Inc).

Letter of Transmittal

November 23, 2009

Kindy Gosal
Director – Water and Environment
Columbia Basin Trust
Box 393
512 – 8th Avenue North
Golden, BC
V0A 1H0

RE: Upper Columbia hydrometric analysis – phase 1

Dear Kindy.

Please find attached the final report for phase 1 of the upper Columbia River hydrometric analysis. This report was completed based on the terms of reference outlined on July 14, 2009 and comments from Bob Jamieson and Heather Leschied. Comments were addressed to the best of the authors' abilities. If you have any questions or concerns please contact me at your convenience.

Sincerely,

Ryan MacDonald, M.Sc
LOTIC Environmental

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Abstract

There are concerns that environmental change (climate and landscape) could adversely impact water resources in the upper Columbia River watershed upstream of Donald, BC. This study identifies current water related issues in the upper Columbia River watershed through an analysis of hydrology, meteorology, groundwater, water allocation, and water quality. This work suggests there is an observable climate warming signal in the meteorological records in the region. These signals are similar to those found using larger data sets for the province of British Columbia. However, this observed climate warming signal is not as well demonstrated in the available hydrological records to date. Data from the Columbia River at Fairmont, the only station in the upper watershed with a long-term record, suggest water supply in the upper regions of the study area may have declined as significant decreasing trends are shown in late season streamflow for this station. Data from stations in the lower portion of the watershed (Golden area), on the mainstem and tributaries, do not provide any clear indication of change in streamflow. The limited water demand data available suggest the watershed is not presently over allocated; however, these data are not representative of actual use. There is a lack of water use data in the entire study area. Simulations of the water balance would be difficult without better monitoring of climate, streamflow and actual use under present water licenses. This study provides recommendations on which data would be required to simulate historical and future conditions with a hydrological model, and demonstrates that, for simulating a detailed water balance in headwater streams (upstream of Radium Hot Springs), there are inadequate hydrological and meteorological data. Hydrological simulations of the lower portion of the watershed are feasible given there are a number of relatively good observed datasets, however, streamflow in this portion of the watershed does appear to be declining and actual consumptive human use is comparatively small.

1.0 Introduction

Mountainous regions of North America are expected to endure some of the most significant impacts from environmental disturbance as these regions are ecologically complex and highly susceptible to even slight changes in environmental conditions (Barnett et al., 2005). Perhaps the most prominent problem facing water resources in mountain regions is climate change. It is expected that climatic change will enhance the hydrological cycle, with warmer temperatures, increased evapo-transpiration, higher storm frequency, and increased extreme events (Huntington, 2006). These changes may augment current trends in an earlier onset of spring snowmelt (Cayan et al., 2001) and reduced streamflow (Rood et al., 2005). The impacts from climate change on water resources will be compounded as human development increases and landscape disturbance becomes more prevalent.

An area of special concern for water users is the upper Columbia River watershed above Mica dam and Donald, B.C. (Figure 1). The Columbia River has been identified, by the Intergovernmental Panel on Climate Change, as vulnerable to the effects of increased atmospheric temperatures as water supply is dependent on the melt of snow and ice (Field et al., 2007). This watershed supports a number of unique ecosystems and a relatively large human population (in the southern portion of the watershed), and is one of the largest suppliers of hydro-electric power in North America, making water resources in this region particularly important. Studies have identified that the Columbia River system cannot balance the demands of both hydro-electric generation and the needs of aquatic species (Barnett et al., 2004). Hamlet and Lettenmaier (1999) suggest that there will be a shift towards an earlier peak streamflow and decreased late season streamflow under future warming. These conditions could be detrimental for a number of water users, including the sensitive Columbia Wetlands in the upper portion of the basin.

Better management strategies may be needed to maintain sustainable water resources in the upper Columbia River watershed. Lepsoe (2009) shows that information is lacking for both water supply and demand in the Invermere region. In order to properly manage this important resource, water quantity and quality issues must be identified. This study is a follow-up report to MacDonald and Bisset (2009), and is directed towards gaining an increased understanding of water quantity and quantity issues in the upper Columbia River watershed between Canal Flats, at the headwaters of the Columbia River and Donald, British Columbia (Figure 1). In addressing this general question four key objectives have been set:

1. Assess the current state of the watershed through an analysis of historical hydrological and meteorological data.

2. Assess the quality and quantity of hydrometeorological data for assisting managers and communities in adapting to changes in human use and changes in climate in the Upper Columbia River watershed.

3. Provide recommendations for increased hydrometeorological monitoring with the objective of providing data for credible modelling in the Upper Columbia watershed for future management.

4. Assess the current state of knowledge on water quality data within the study area.

These four objectives were met by conducting a detailed analysis of data available mainly from online sources. The methods used in each of the analyses are described in each sub-section of this report. The analyses included:

- Identifying historical trends in hydrological and meteorological records.
- Comparing water availability to demand during low flow periods (late summer, potentially early winter) in the upper watershed above Edgewater.
- Estimating seasonal demand for different kinds of uses and licenses.
- Identifying water demand vs water supply issues for Windermere Creek.
- Assessing the state of our understanding of the interactions between deep aquifers in the Invermere area, Lake Windermere, the nearby tributaries (Toby Creek) and the Columbia River floodplain.
- Determining if a hydrological model can be applied to make adequate predictions of future water availability.
- Providing recommendations on where and what types of data should be collected to enable communities to adequately adapt to changes in water supply.

2.0 Study area and local physiography

The study area is from the headwaters of the Columbia River at Columbia Lake to the town of Donald, B.C (Figure 1). The topography in the study area is dominated by the broad deep valley of the Rocky Mountain Trench. The physiography of the Columbia River valley is typical of a glaciated valley (Walker, 1926). The wide U-shaped valley is intersected by several hanging valleys including Toby Creek and Horsethief Creek enter from the west, north of Invermere. The west side of the valley is formed by the Purcell Mountains and the east side is formed by the Kootenay, Brisco and Stanford Ranges. Relief from the height of land on each side of the trench ranges from 610 meters (m) to 1525 m (530 to 3540 meters above sea level). The Columbia River valley is 4.8 to 9.6 kilometers (km) wide and is located within the Rocky Mountain Trench. The channel and floodplain within this valley that contains Lake Windermere, Columbia Lake and the

Columbia Wetlands is 1.2 km wide and is 30-50 m below the general elevation of the valley.

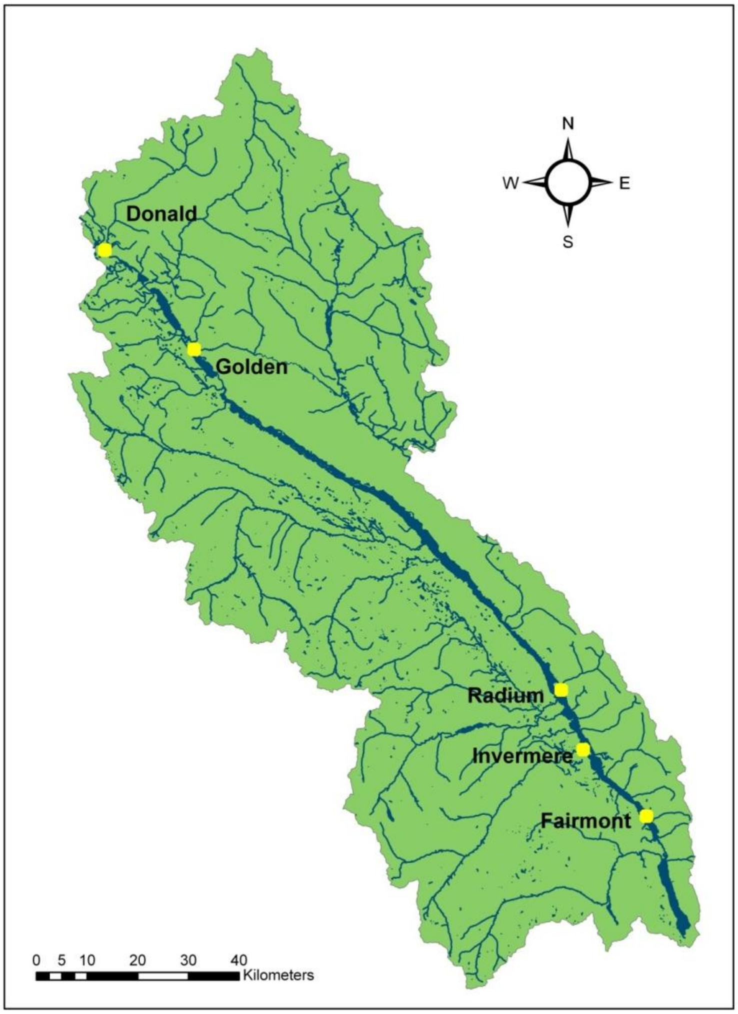

Figure 1 Study area map

The Columbia River originates in springs near Canal Flats flowing north into Columbia Lake. Columbia Lake in turn flows into the Columbia River, through Fairmont Hot Springs Resort and the Riverside golf Course, before entering a floodplain wetland complex (Mud Lake reach, which in turn flows into Lake Windermere). From the north end of Lake Windermere north to Radium, the central valley bottom is occupied by the floodplain of the north-flowing Columbia River. This floodplain is composed of alluvial deposits from side tributaries, multiple meandering channels of the river, naturally formed levees in many areas, and large numbers of floodplain wetlands. This same floodplain complex occurs from Radium to north of Golden (Jamieson and Hennan, 1998).

From Canal Flats north to Edgewater, the wetland occupying the central trench depression is flanked by glaciolacustrine silt terraces. These terraces which dip at low angles toward the central valley bottom are bisected by numerous gullies and are commonly overlain by alluvium and aeolian deposits.

3.0 Meteorological analysis

Figure 2 shows eight meteorological stations that were identified in the upper Columbia River watershed by MacDonald and Bisset (2009). A temporal analysis was conducted to determine how temperature and precipitation have changed in the watershed over the last several decades. An inter-watershed comparison of meteorological data availability was also conducted to identify key areas of interest for augmenting the current meteorological station network.

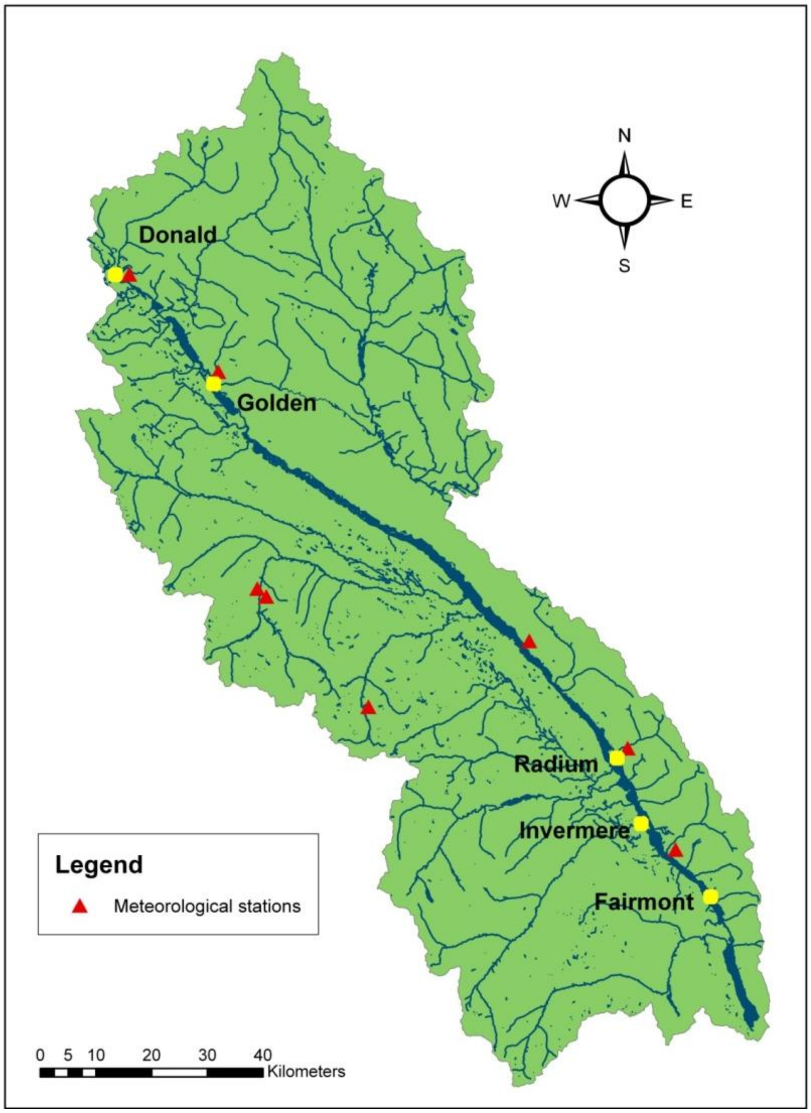

Figure 2 Meteorological stations in the upper Columbia River watershed

3.1 Temporal analysis

Only four stations were used for this analysis, as they were the only stations available that had data available for a sufficient length of time to detect long-term trends. Two higher elevation stations were also included, even though the period of record is short, they provide critical information about the upper elevation regions of the watershed. Three analyses were conducted on each of the stations. The first was an analysis of mean annual air temperature over time. The second was a time series analysis of annual precipitation, and the third was an analysis of the ratio of rain to snow. All of the analyses applied linear relationships between the year of record and the variable to show changes in the variable (temperature and the rain to snow ratio) over time. Mean annual air temperature inherently provides a good indication of climate warming. The proportion of rain to snow provides an indicator for changing precipitation regimes, as it is well documented that with increased warming, there is likely to be an increase in the proportion of the annual precipitation accounted for by rain (Knowles et al., 2006). This is important for water supply in snow-dominated regions, as increases in the proportion of rain to snow leads to decreased storage of water (in the form of snow) and increased winter runoff. These changes in hydrological regime pose a problem for water managers, as the seasonal distribution of streamflow has been relied upon for planning and water allocation for a long time. Both analyses provide indication of the types of changes in climate that could be occurring in the watershed and demonstrate the conditions that are likely to occur in the future if trends continue.

3.1.1 Golden

This station is located in the main valley at low elevation at the north end of the valley. Climate at this site is generally wetter than at stations at the upper end of the drainage (B. Jamieson, pers. comm.). Mean annual temperature is calculated for the years 1908 to 2008. Mean annual precipitation was calculated from 1909 to 2006 with no missing years. The annual ratio of rain to snow was calculated from 1909 to 2006. Precipitation data from 2006 to 2009 were not available from Environment Canada (2009).

Significant increasing trends are observed in both mean annual air temperature (slope = 0.015, $p < 0.0001$) and the ratio of rain to snow (slope = 0.007, $p = 0.002$) for the time series analyzed (Figure 3 and Figure 5), where slope is the change (degrees Celsius) per year and p is the significance level ($p < 0.05$ is a significant trend). A non-significant trend in mean annual precipitation is observed for mean annual precipitation (Figure 4).

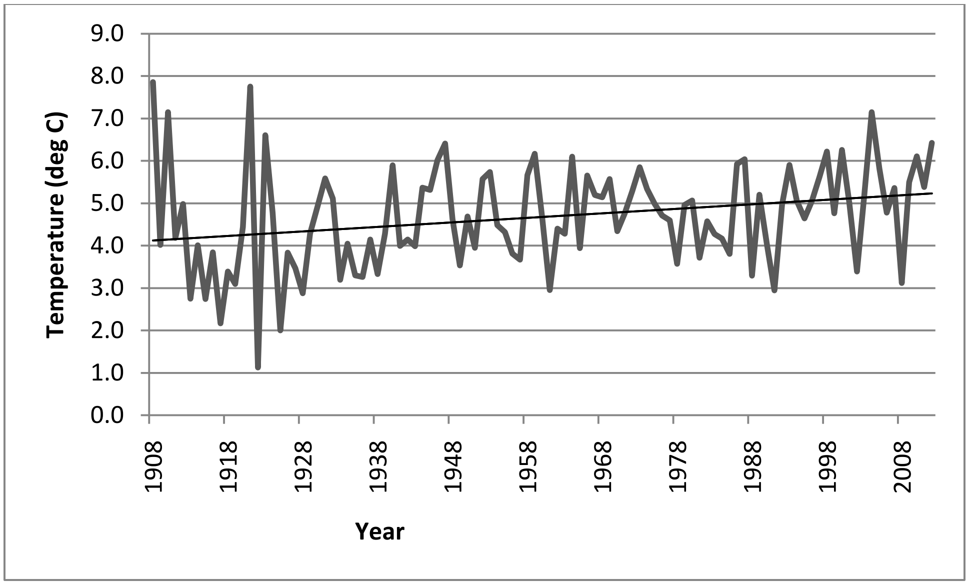

Figure 3 Time series of mean annual temperature at Golden

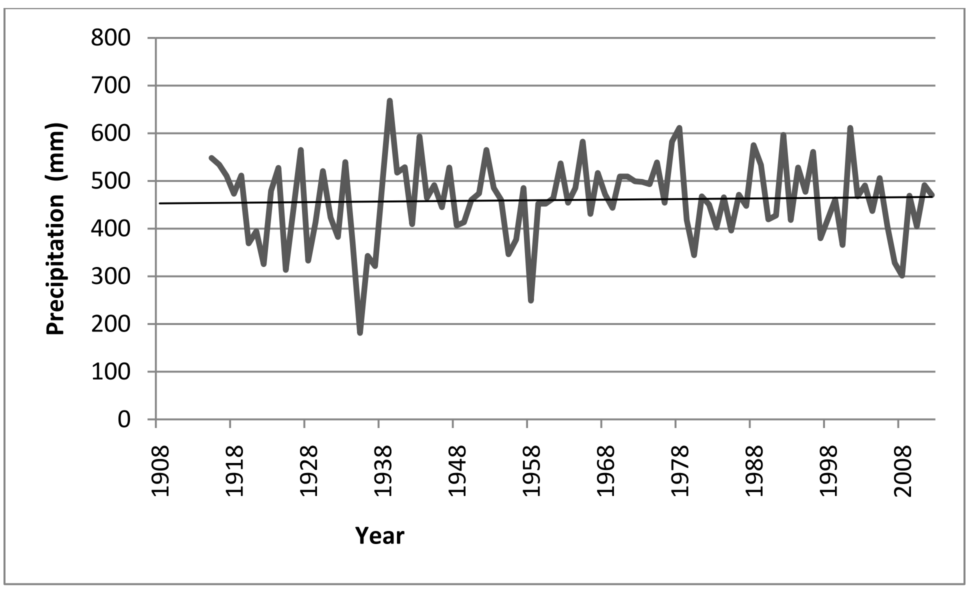

Figure 4 Time series of mean annual precipitation at Golden

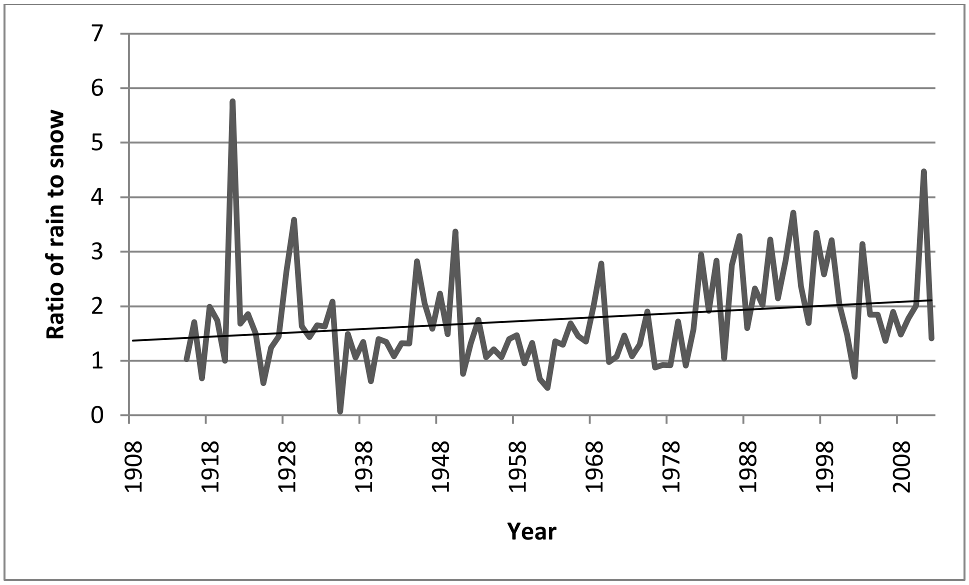

Figure 5 Time series of the annual ratio of rain to snow at Golden

3.1.2 Brisco

This station is located at low elevation, midway between Golden and Invermere. For the Brisco station, only mean annual precipitation and the ratio of rain to snow were calculated, as there were insufficient temperature data to derive long-term trends. The ratio of rain to snow was calculated from 1924 to 2003 with missing values from 1994 to 1997. This station is no longer in operation. A significant increasing trend in annual precipitation is observed (slope = 1.01, $p = 0.02$) for the time series analyzed (Figure 6). A significant increasing trend is observed in the ratio of rain to snow (slope = 0.017, $p < 0.0001$) for the time series analyzed (Figure 7).

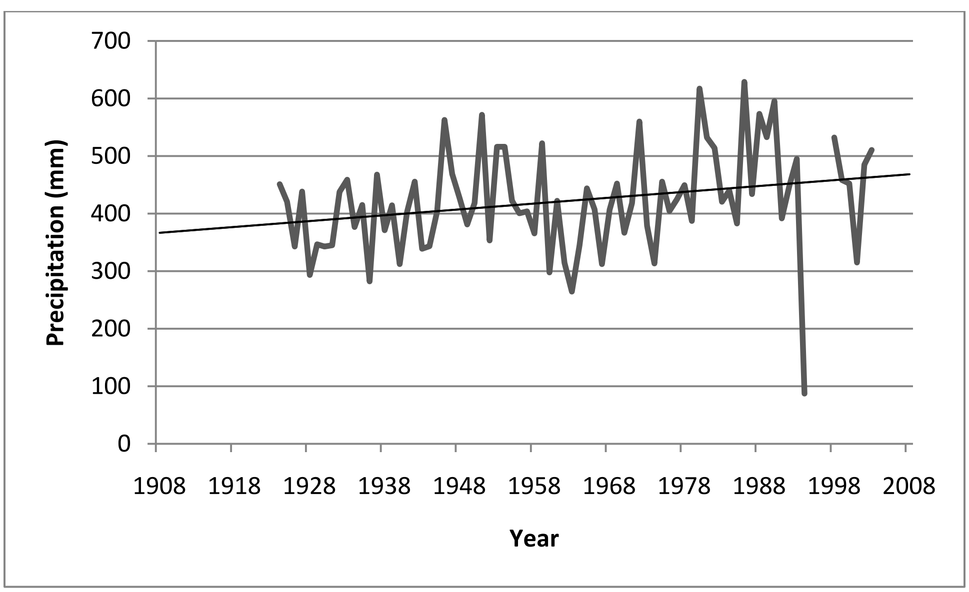

Figure 6 Time series of mean annual precipitation at Brisco

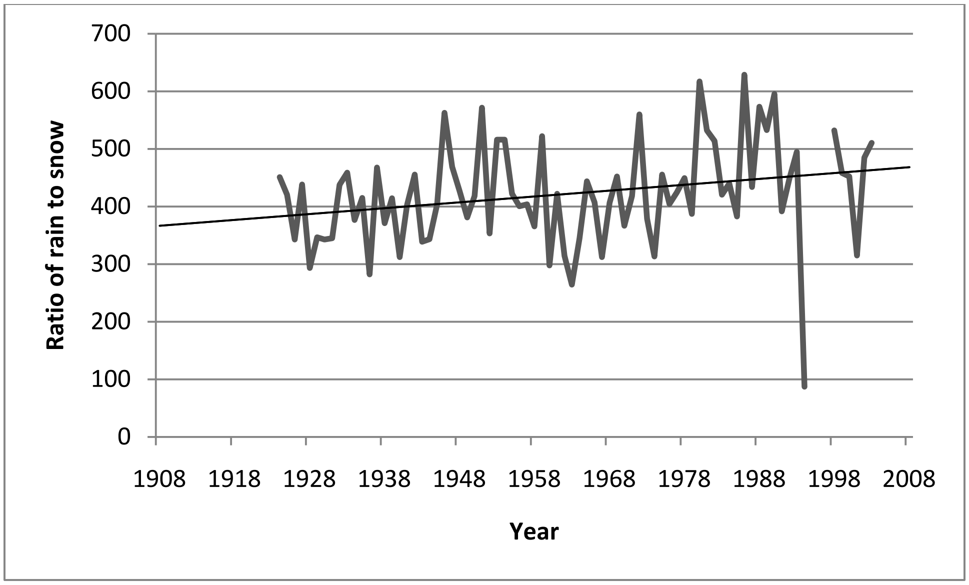

Figure 7 Time series of the annual ratio of rain to snow at Brisco

3.1.4 Kootenay west gate

This station is located at Radium Hot Springs in the drier portion of the watershed. Mean annual precipitation, air temperature and the ratio of rain to snow were analyzed for the Kootenay park west gate meteorological station from 1969 to 2006 Significant increasing trends in both mean annual air temperature (slope = 0.034, p = 0.003) and the ratio of rain to snow (slope = 0.066, p = 0.003) were observed (Figure 8 and Figure 10). A non-significant increasing trend in mean annual precipitation is observed (Figure 9). This station is in operation; however, data from 2007 to 2009 were not available from Environment Canada (2009).

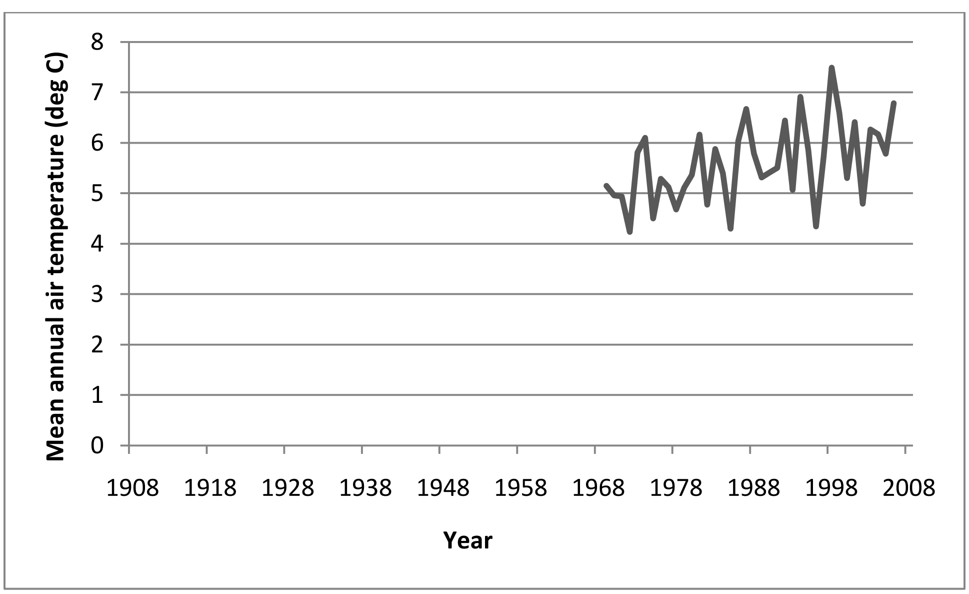

Figure 8 Time series of mean annual temperature at Kootenay west gate

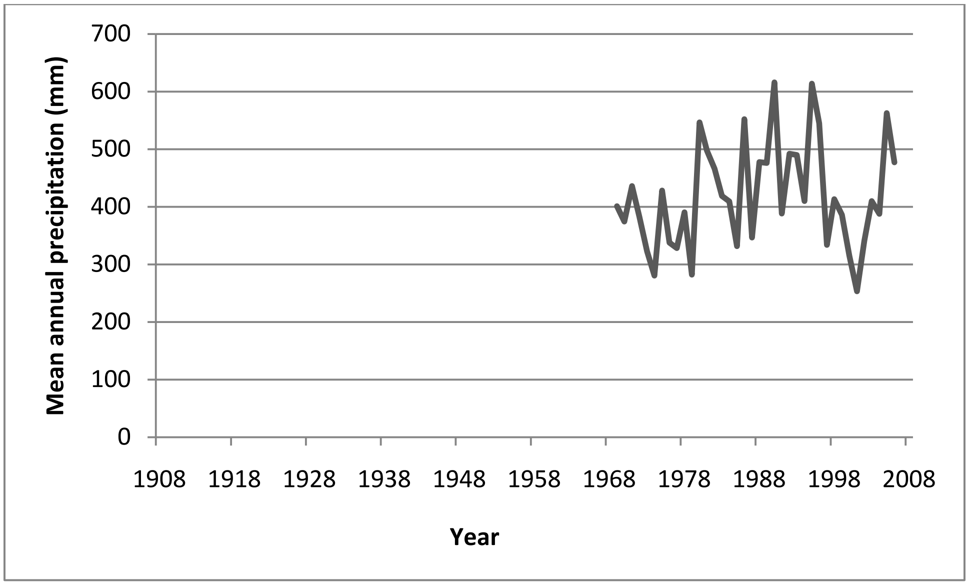

Figure 9 Time series of mean annual precipitation at Kootenay west gate

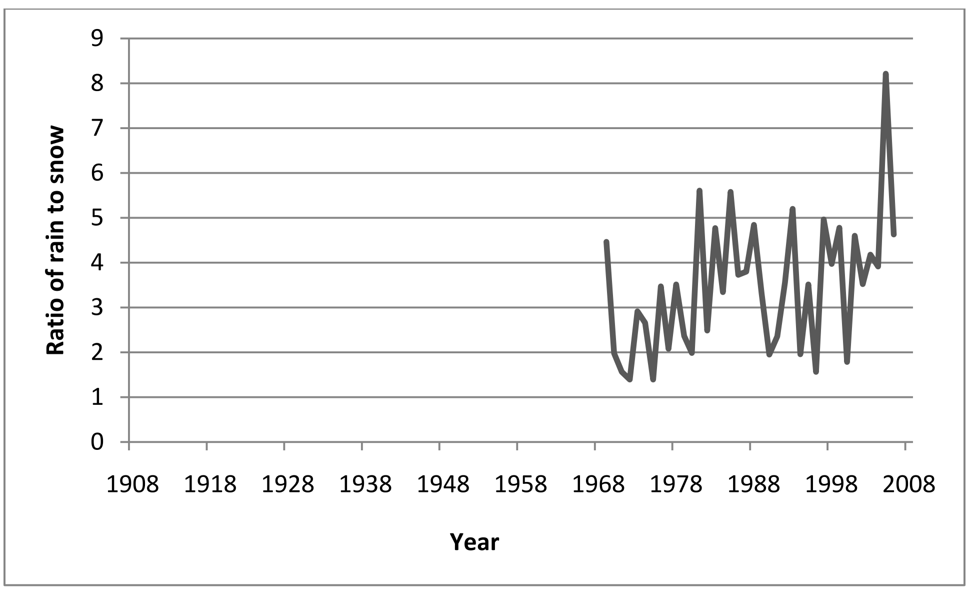

Figure 10 Time series of the annual ration of rain to snow at Kootenay west gate

3.1.3 Bugaboo Creek Lodge

The Bugaboo lodge station was established by Hans Gmoser when he started heli-ski operations there in the 1960's (B. Jamieson. Pers. Comm.). It has sufficient data for 1973 to 1996 only; therefore, long-term trends are not established. However, this is a relatively high elevation station (1494 m) therefore, provides meaningful information about the mountainous portions of the watershed. There are non-significant increasing trends for both air temperature, and the ratio of rain to snow show (Figure 11 and Figure 13). An analysis of mean annual precipitation demonstrates a non-significant decreasing trend (Figure 12). The non-significance of these trends is likely due to the relatively short period of record.

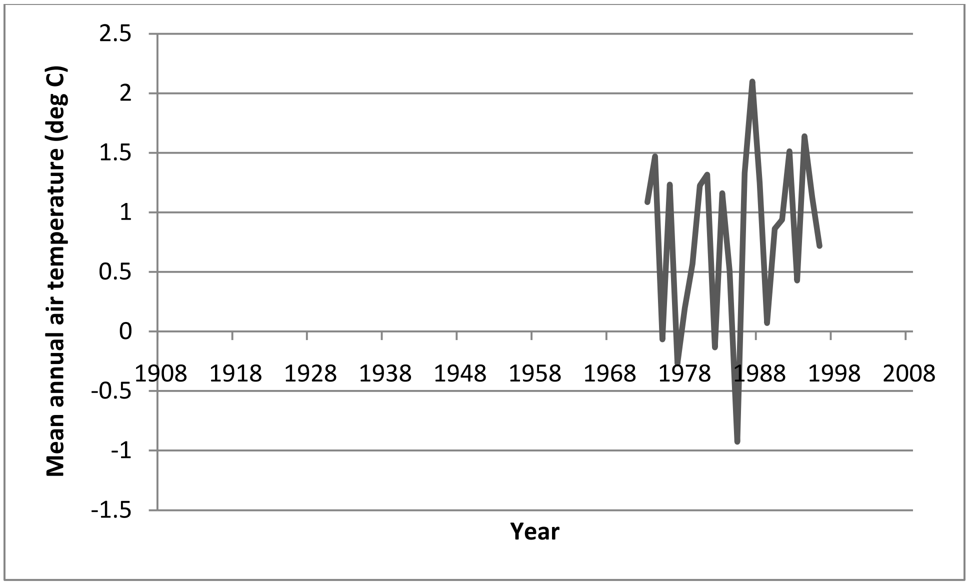

Figure 11 Time series of mean annual temperature at Bugaboo lodge

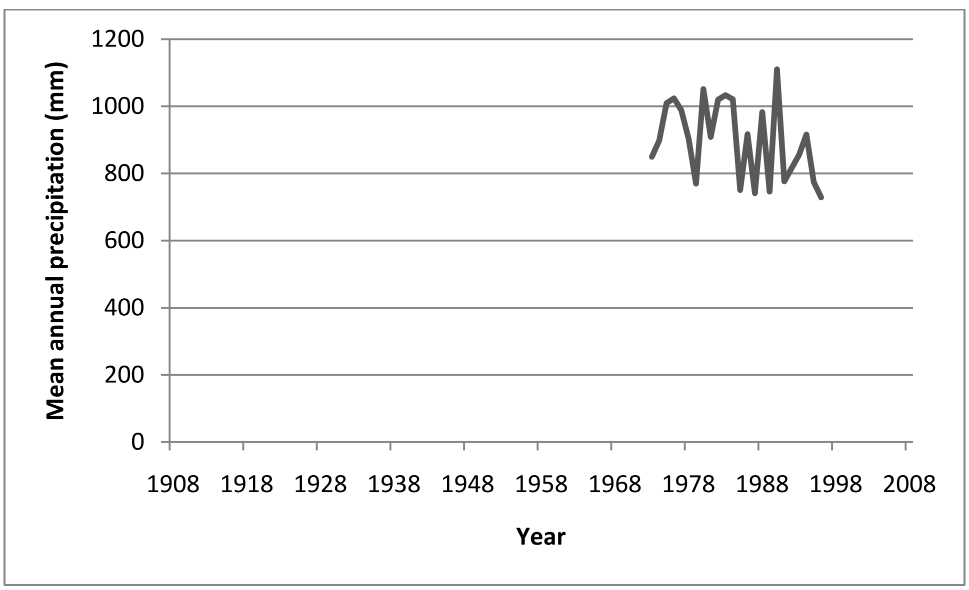

Figure 12 Time series of mean annual precipitation at Bugaboo lodge

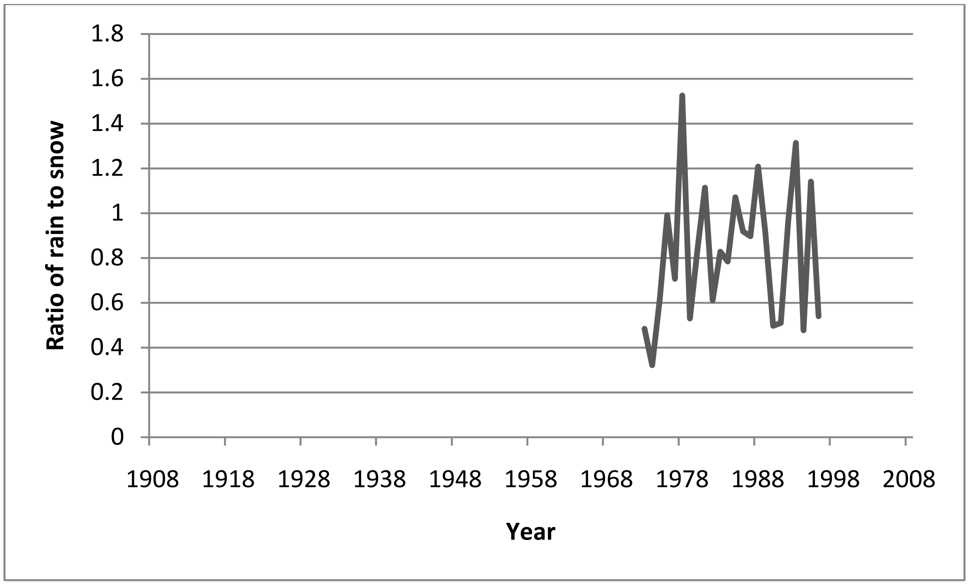

Figure 13 Time series of the annual ratio of rain to snow at Bugaboo lodge

3.1.5 Bobbie Burns

This station is also at higher elevation (1370 m), again at a heli-skiing lodge. Mean annual precipitation, mean annual air temperature, and the ratio of rain to snow were analyzed for the Bobbie Burns station from 1981 to 2000. A significant increasing temperature trend is observed (slope = 0.084, $p<0.0001$) for the time series (Figure 14). There is a non-significant decreasing trend in mean annual precipitation (Figure 15). To support this increase in temperature, a slight non-significant increasing trend is observed in the ratio of rain to snow (Figure 16).

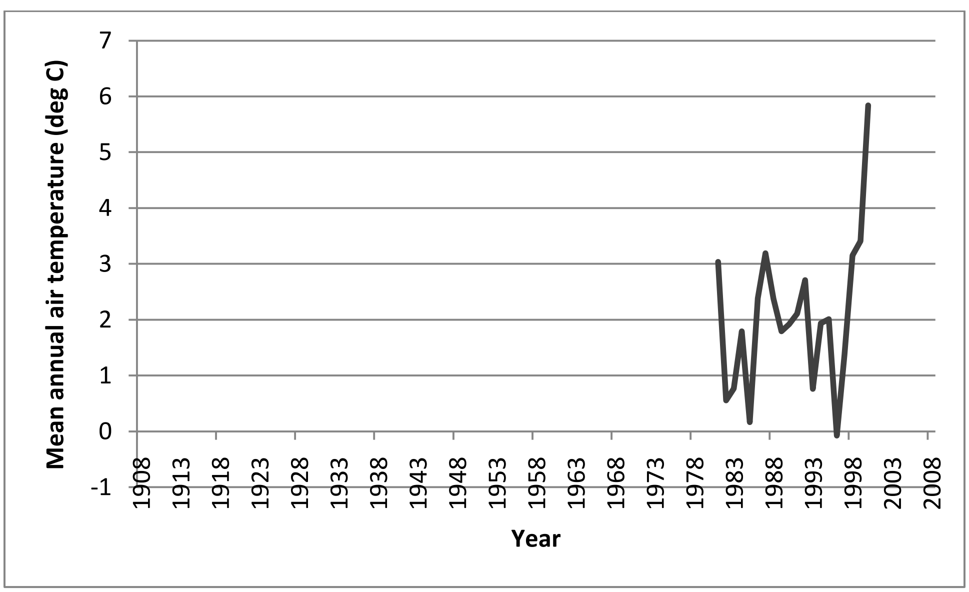

Figure 14 time series of mean annual air temperature at Bobbie Burns

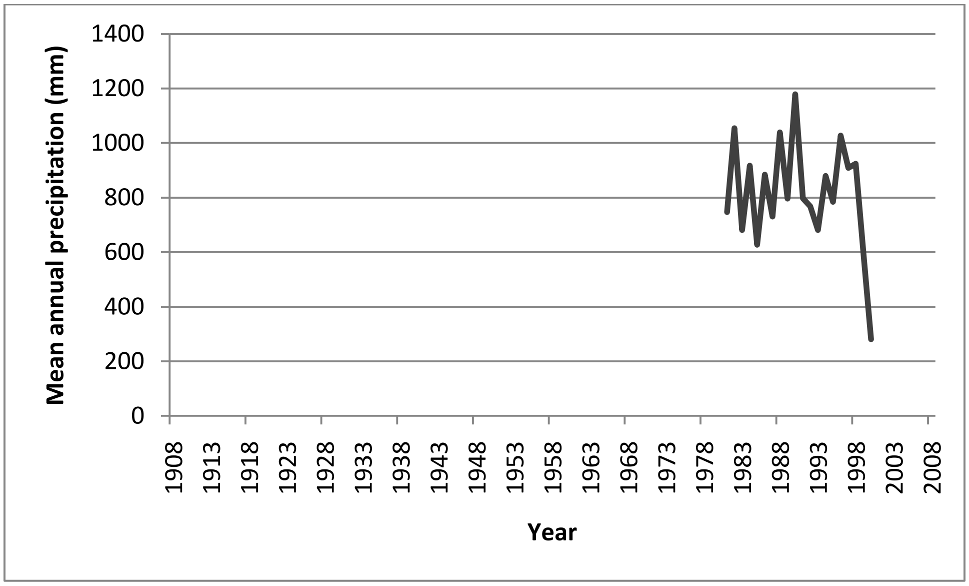

Figure 15 Time series of mean annual precipitation at Bobbie Burns

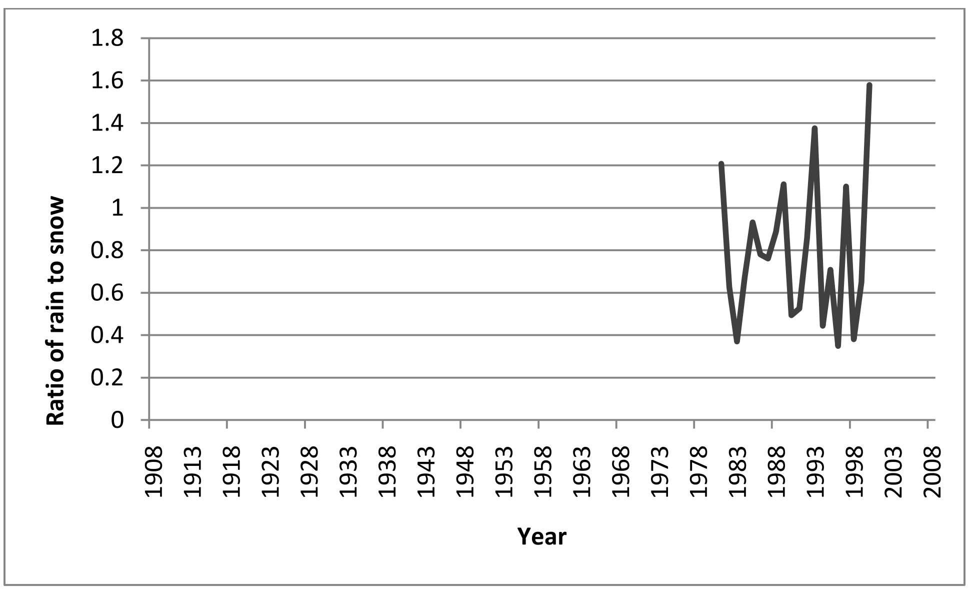

Figure 16 Time series of the annual ratio of rain to snow at Bobbie Burns

3.2 Spatial analysis

There are a number of records in and surrounding the watershed that could be used for modelling. Not all data for modelling must be in the study area, as relationships can be generalized over large regions of similar topography. All meteorological stations within and around the watershed are presented in Table 1 as well as in MacDonald and Bisset (2009).

Table 1 Meteorological stations in the watershed (Me = met station, T = temperature, P = precipitation, H = humidity)

Station name	Station type	Variables	Length of Record	Elevation (m)
Donald	Me	T, P	1891 - 1972	783
Golden Air Port	Me	T, P, H	1902 - present	784
Windermere	Me	T, P	1987 - 1989	802
Invermere	Me	T, P	1913 - 1993	810
Spillimacheen	Me	T, P	1958 - 1980	818
Brisco 1	Me	P	1924 - 1983	823
Brisco 2	Me	T, P	1984 - 2004	823
Kootenay National Park (West Gate)	Me	T, P	1970 - present	899
Kootenay National Park (Radium)	Me	T, P	1925 - 1968	1088
Kootenay National Park (Kootenay Crossing)	Me	T, P	1965 - 2000	1170
Bobbie Burns	Me	T, P	1981 - 2000	1370
Bugaboo Creek Lodge	Me	T, P	1972 - 2006	1493

There is a significant lack of data at higher elevations (Figure 17 and Table 1). Elevations above 2000 m represent a significant portion of the watershed, and likely supply a large portion of the snowpack. With no measurements above 2000 m, it is not possible to adequately verify simulations of temperature, precipitation or snowpack. Snow course and snow pillow data are available from Ministry of Environment (2009a).

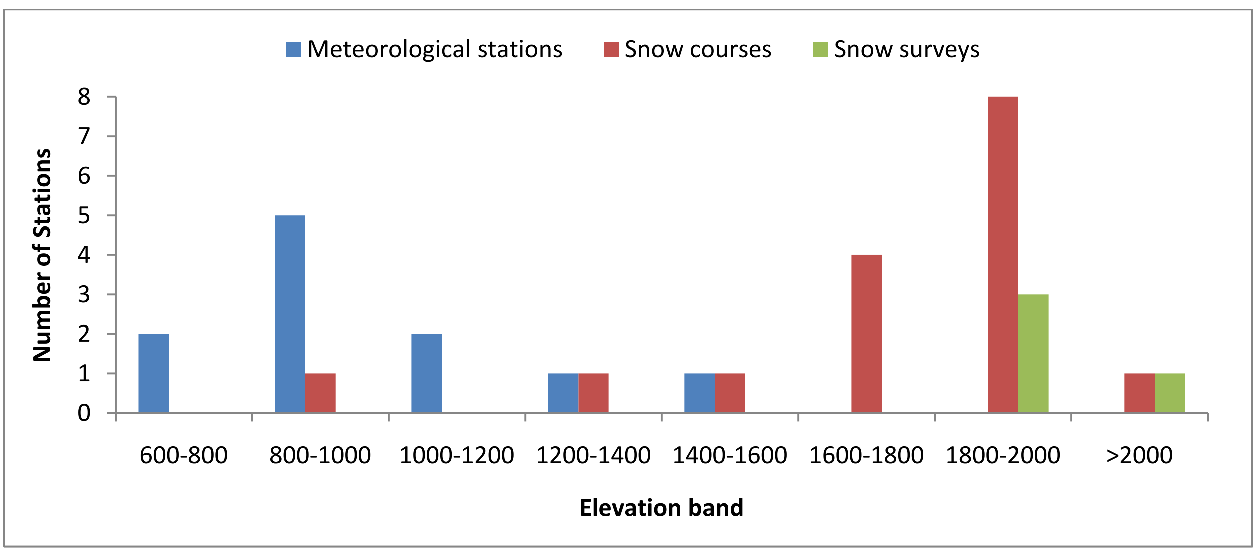

Figure 17 Number and type of meteorological station plotted against elevation band

3.3 Summary

All stations in the Trench appear to represent the same general climate, however, on average stations in the northern portion of the watershed tend to have higher precipitation relative to the southern watershed. The upper elevation stations of Bobbie Burns and Bugaboo have substantially wetter and colder climates. There is a clear indication that the upper Columbia River watershed has experienced warmer temperatures over the past few decades, and a change in the ratio of snow to rain, as one would expect. The data on total precipitation are more variable. These trends are similar to those observed in a report by the Ministry of Environment (2007a), where they show that since 1950 average air temperature has increased at a number of stations across British Columbia. Hamlet and Lettenmaier (1999) suggest these trends will continue as climate warms in the Columbia River watershed.

There is a lack of air temperature and precipitation observations, especially at higher elevations and in the southern portion of the watershed (Figure 3 and Figure 18). Given there is little known about the meteorological conditions in the mountainous portions of the watershed, augmenting the current monitoring network would provide the opportunity to further describe trends and potential threats to water supply from changes in climate. Important regions lacking data are the upper Blaeberry River west of Donald, the upper Kicking Horse River, east of Donald, and high elevations in the Toby, Dutch, Horsethief Creek basins. It must be recognized, however, that meaningful analyses demonstrating changes in climate can only be conducted on long-term datasets.

4.0 Hydrological data analysis

The hydrology of the upper Columbia River watershed was assessed using a number of techniques. First, the hydrological setting was determined through a visual analysis of hydrographs and flow duration curves for eight hydrometric monitoring sites. A hydrograph is simply streamflow volume plotted against time. The hydrographs of streams dominated by groundwater have slow recession curves and relatively low variability in late season streamflow, whereas surface water dominated streams show steeper recession curves and baseflows that are not always well maintained. A flow duration curve shows the percentage of time that a given flow rate is equaled or exceeded. Flow duration curves with a steep recession and lower flows at the tail end of the curve demonstrate streams with relatively low groundwater contribution (Figure 19). Flow duration curves with shallow recession and higher flows at the tail end of the curve demonstrate groundwater dominated stream (Figure 23). The curve is constructed by plotting the exceedence probability of a given streamflow volume against streamflow, where the exceedence probability is calculated by:

$$EXCEEDENCE\ PROBABILITY = 100 * (Rank/(n+1)) \qquad \text{(Eq. 1)}$$

A trend analysis was conducted on seven of the eight stations as these were the only stations with sufficient data records. Trends were also determined for the Illecillewaet River (representing a significant glacial stream to the west of the study area) in Roger's Pass and the Kootenay Crossing station on a tributary of the Kootenay River (representing a non-glacial stream to the east of the study area). Trends were determined on a seasonal basis where, winter is December, January, February; spring is March, April, May; summer is June, July, August; Fall is September, October, November. Trends were derived using the Mann-Kendall trend non-parametric test, as this test is a widely used statistical analysis for non-normal hydrological data (Burn and Elnur, 2002). The important analysis of the Mann-Kendall test is the Sen's slope estimate, as this represents the change in streamflow over time expressed as a percentage (i.e. 0.2 equals 20% decline over the time period). These analyses were conducted using all available data from each of the streams. Although this does not provide consistency between stations, it provides better context for observing long-term trends where data are available and many of the stations do not have long time series.

4.1 Variability of watershed types in the upper Columbia

The flow regime of all creeks and rivers in this analysis is typical of mountainous environments, with peak streamflow occurring in the spring from snowmelt and rain.

However, there are clearly differentiable characteristics of each of the streams, largely driven by the underlying topography and geology. Three examples of hydrographs for the years 1975 to 1979 are given to outline these differences. Flow duration curves were derived for the entire period of record for each station.

The first example is at the far north end of the study area, Blaeberry River station number 08NB015, located below Ensign Creek. The shape of the hydrograph for this stream exhibits characteristics of a quick response to input, meaning there is little storage time between an event (rain or snowmelt) and the streamflow response (Figure 18). This low storage capacity infers there is relatively little groundwater influence in Blaeberry River above Ensign Creek. This is supported by the fact that the watershed is composed of large areas of rocky alpine topography, and a relatively narrow valley. Given these features, in addition to the fact that the watershed is glaciated, this river may be very susceptible to changes in climate and glacial recession.

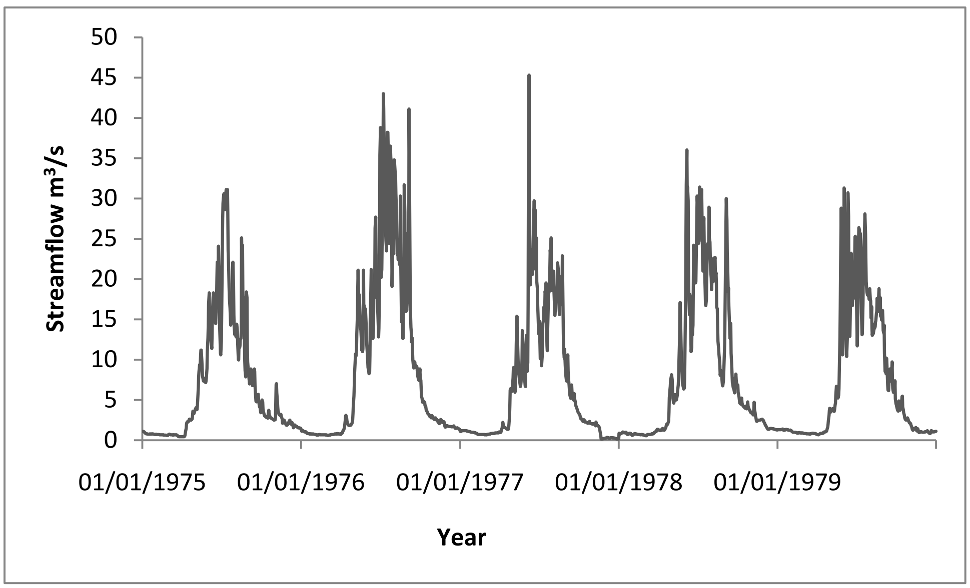

Figure 18 Five year hydrograph for the Blaeberry River

The flow duration curve for Blaeberry River is also indicative of low groundwater contribution (Figure 19). This is demonstrated by a steep recession curve and the fact that the curve approaches very low flows roughly 50% of the time.

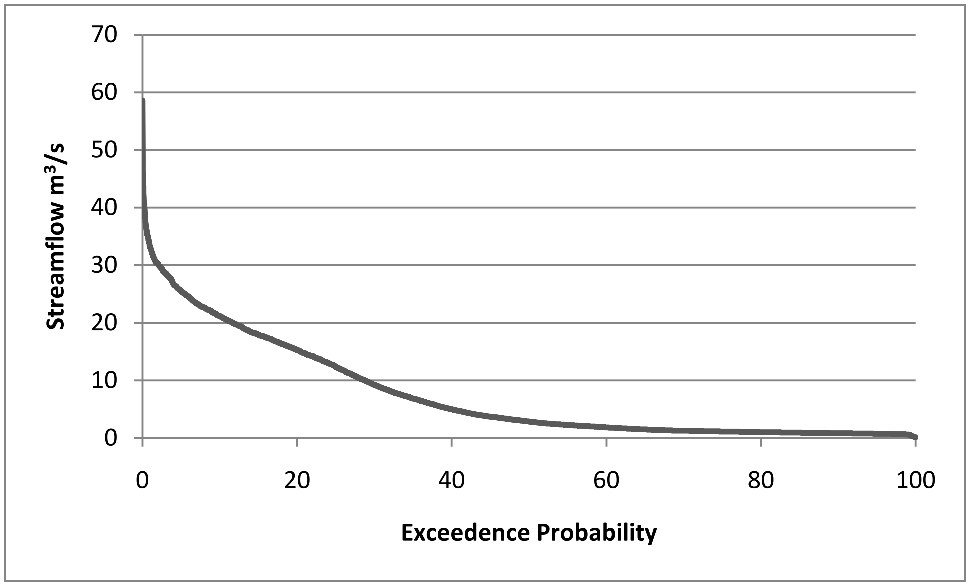

Figure 19 Flow duration curve for the Blaeberry River

The Columbia River station number 08NA045 at Fairmont is used for the second example. This hydrograph demonstrates little variability in streamflow response post-spring flooding, with the exception of late season streamflow (Figure 20).

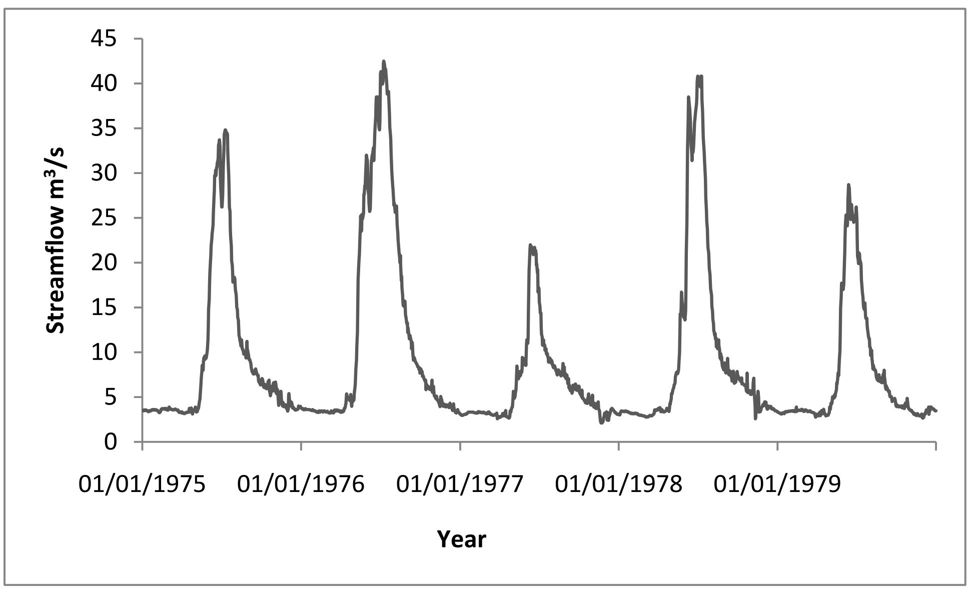

Figure 20 Five year hydrograph for the Columbia River at Fairmont

The flow duration curve for the Columbia River demonstrates a combination of characteristics, with a relatively steep recession curve and a reasonably well maintained tail of the curve (Figure 21). This indicates that this station is affected by a range of hydrological regimes. This could be due to the fact the station monitors flows from a non-glacial watershed (Dutch Creek) and has flow modulated by variations in the level of Columbia Lake.

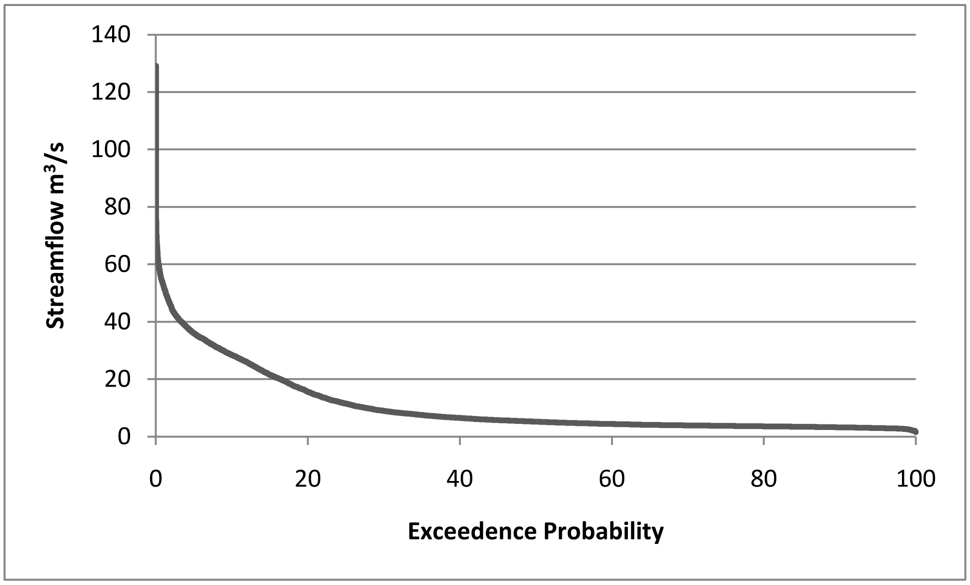

Figure 21 Flow duration curve for the Columbia River at Fairmont

To represent a relatively small stream, Windermere Creek station number 08NA024 located near Windermere was selected for the final example of flow characteristics in the region. The hydrograph for Windermere Creek is indicative of a creek dominated by groundwater influence, with very slow recession curves and relatively low variability in early and late season streamflow (Figure 22). This is characteristic of small mountain streams where groundwater plays a significant role in governing water supply, especially during late season.

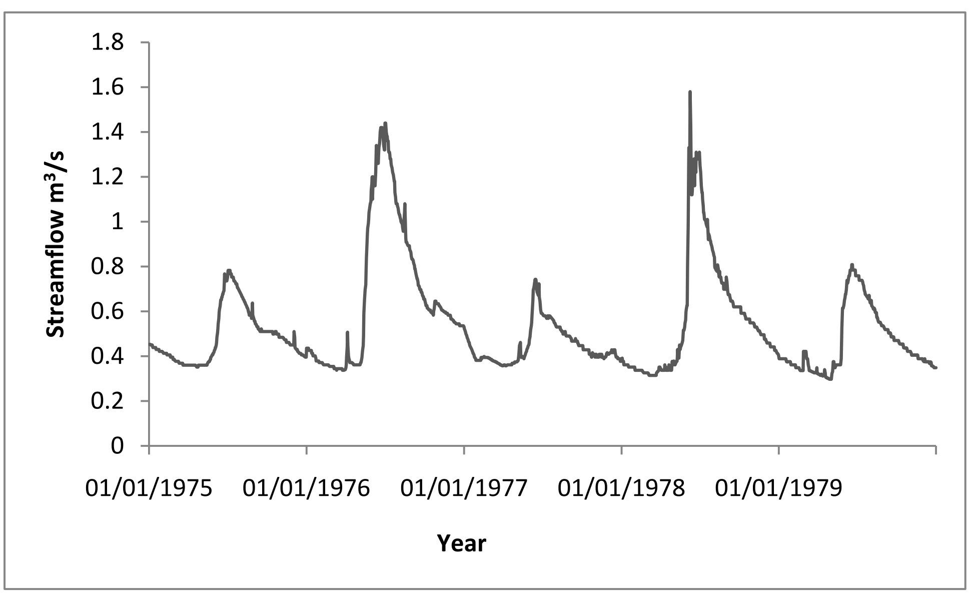

Figure 22 Five year hydrograph for Windermere Creek

The flow duration curve for Windermere Creek supports the characteristics of the hydrograph, with very well maintained baseflow and a relatively shallow recession curve (Figure 23). Both the flow duration curve and hydrograph are supportive of the description of hydrogeological conditions described in section 5.

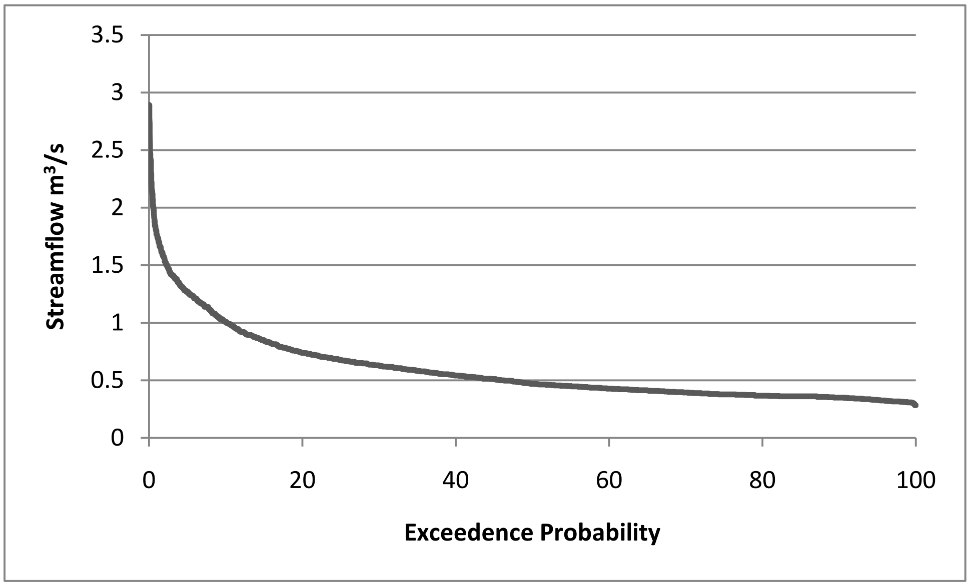

Figure 23 Flow duration curve for Windermere Creek

4.2 Trend analysis

This study attempted to identify seasonal trends at one station in the upper portion of the watershed (the only station available) and at several stations lower in the watershed near Golden.

4.2.1 Columbia River at Fairmont – 08NA045

A trend analysis was conducted from 1945 to 1994 inclusive. Figures 24, 26, and 27 show that there are significant decreasing trends in mean winter, summer, and fall and winter streamflow at the 99, 90, and 95 % confidence levels respectively (Sen's slope estimates =, -0.02, -0.01, and -0.13 respectively). There was no significant trend in spring streamflow (Figure 25).

This is the farthest upstream location on the mainstem Columbia. This is an important station due to the fact that it provides the only long-term hydrological record in the upper watershed and it is a good measure of flows in streams without a glacial contribution. This station is, however, is not active and therefore, does not capture the most recent changes in hydrological conditions in the upper watershed. There are also concerns of the quality of the data from this station due to the fact that there are two major floodplain wells are located near the stream gauge (B. Jamieson, pers. comm.) and were established during the period of record. Assuming these problems have not affected the data from this station, significant decreasing trends in summer, fall, and winter streamflow may be attributed to warming temperatures and increased evaporation, as these periods represent baseflow conditions.

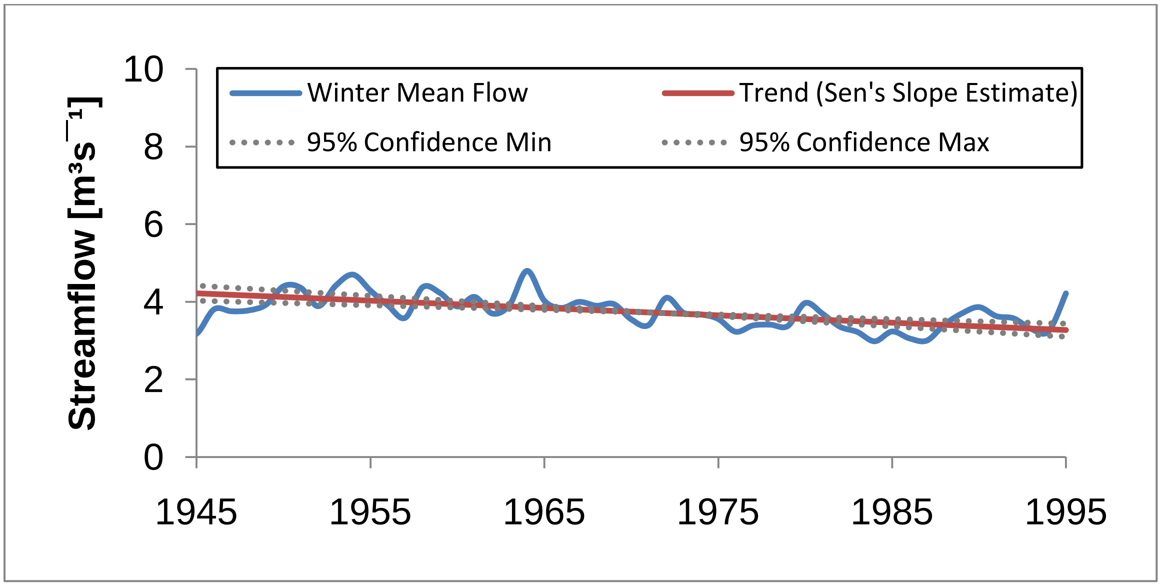

Figure 24 Winter trend analysis for the Columbia River at Fairmont

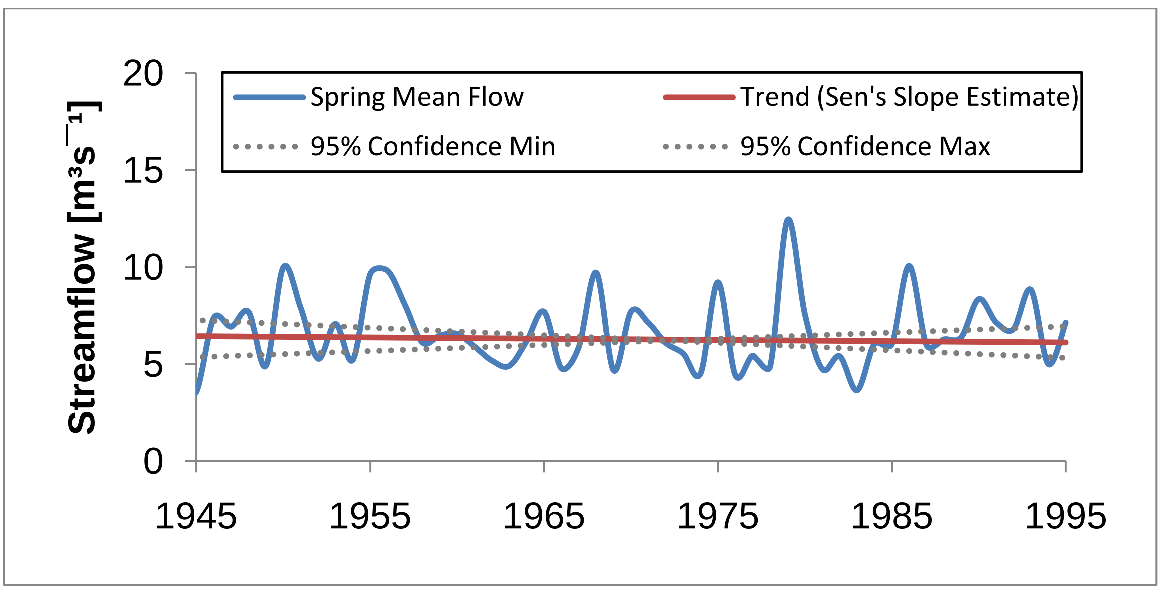

Figure 25 Spring trend analysis for the Columbia River at Fairmont

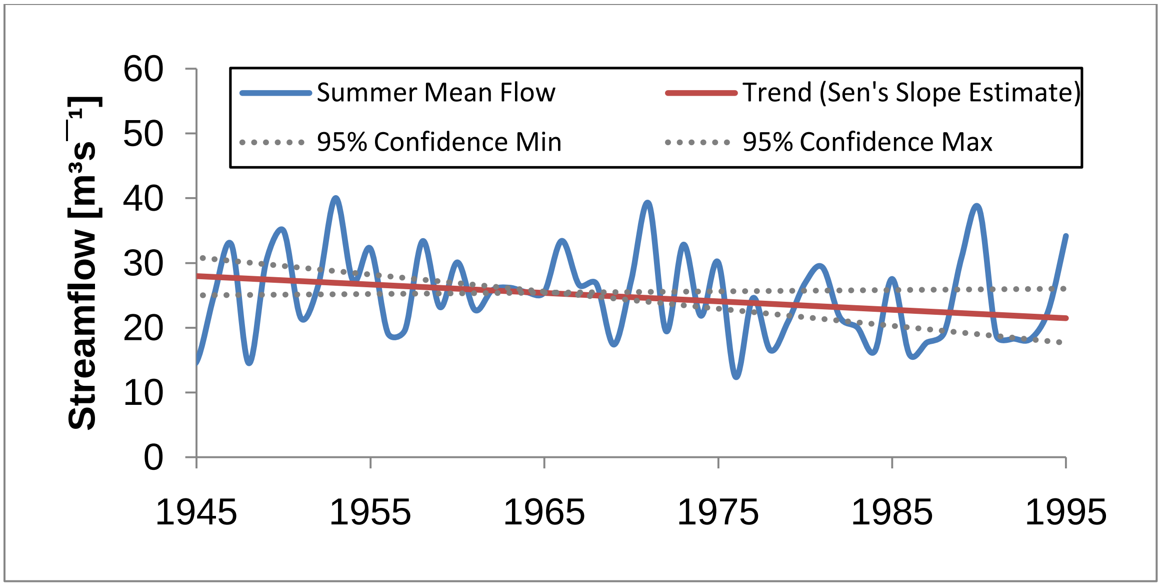

Figure 26 Summer trend analysis for the Columbia River at Fairmont

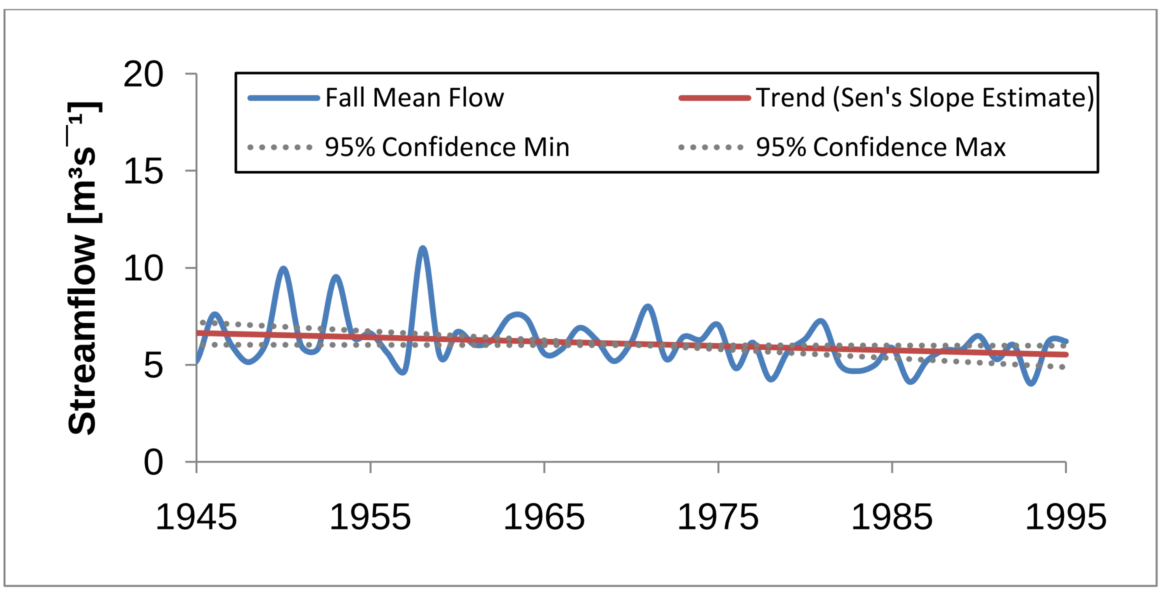

Figure 27 Fall trend analysis for the Columbia River at Fairmont

4.2.2 Spillimacheen at Spillimacheen – 08NA011

The Spillimacheen River is the major tributary to the Columbia, entering above the Nicholson station. A trend analysis was conducted from 1961 to 2008 inclusive, with missing years from 1984 to 1995. Figures 28, 29, 30, and 31 demonstrate that there are no significant seasonal trends for the 35 years of data in the streamflow record.

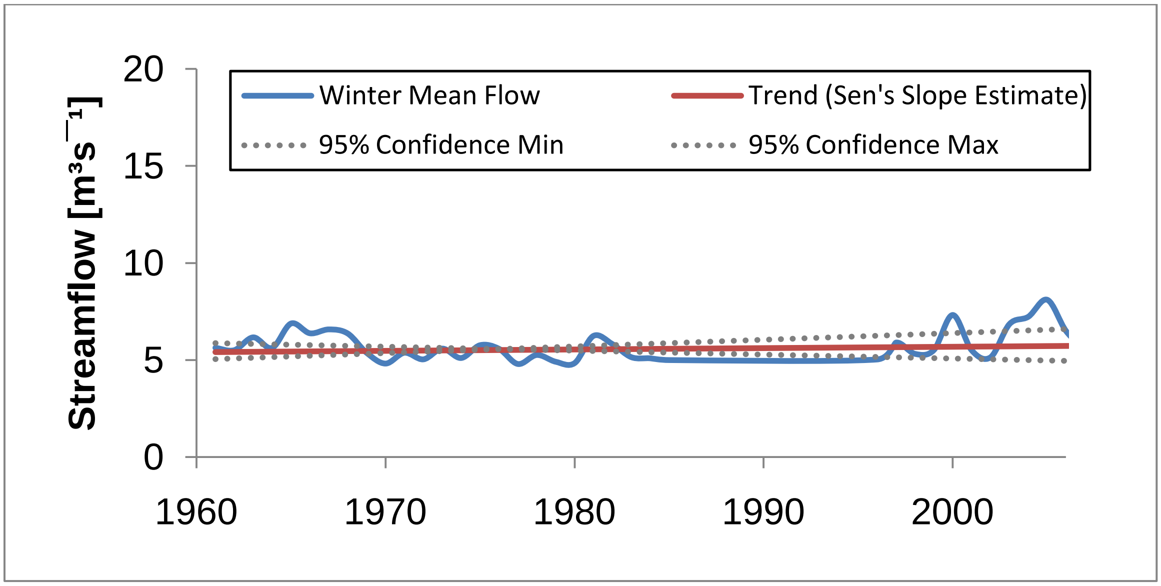

Figure 28 Winter trend analysis for the Spillimacheen River at Spillimacheen

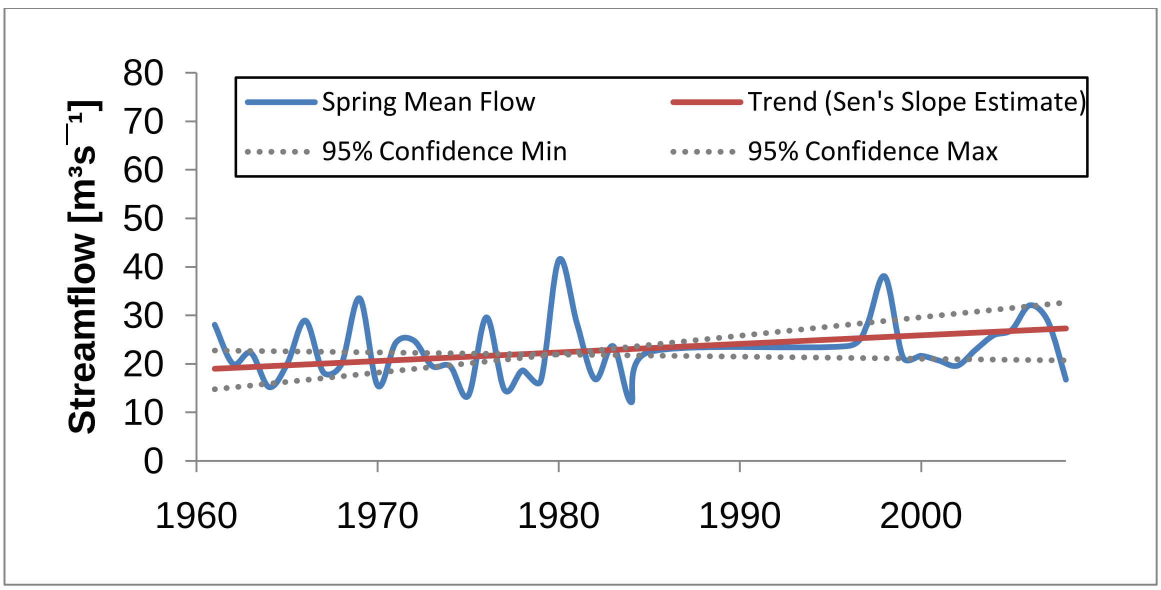

Figure 29 Spring trend analysis for the Spillimacheen River at Spillimacheen

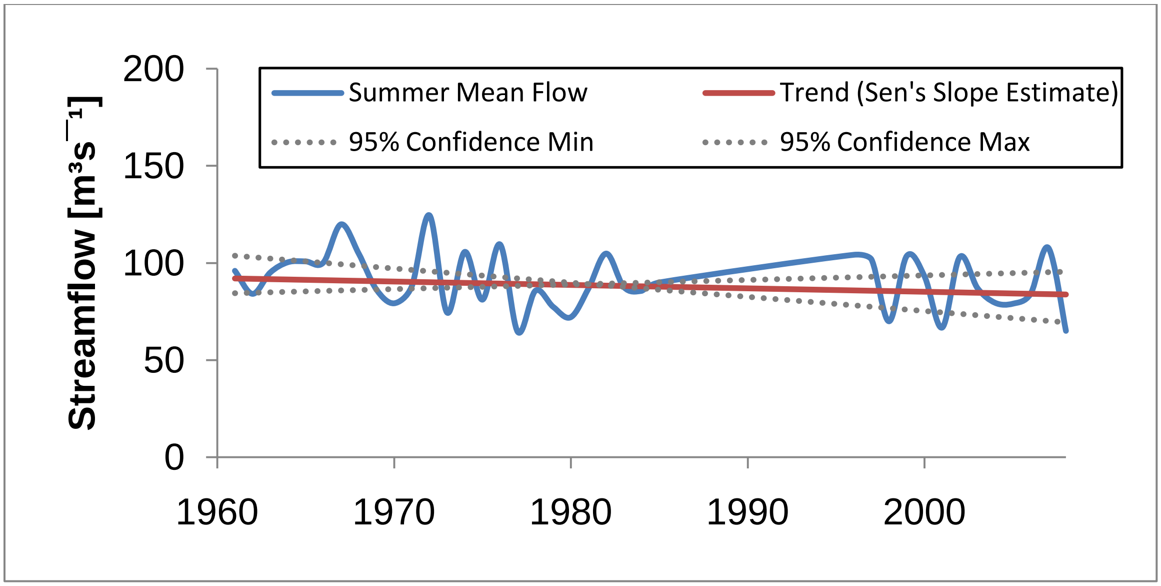

Figure 30 Summer trend analysis for the Spillimacheen River at Spillimacheen

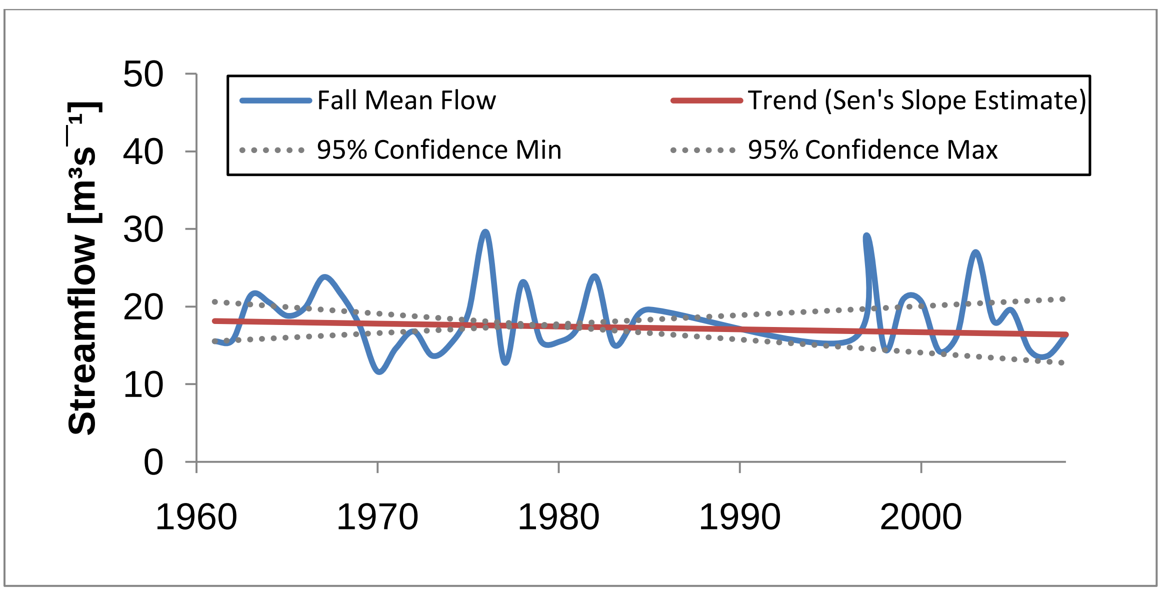

Figure 31 Fall trend analysis for the Spillimacheen River at Spillimacheen

4.2.3 Columbia River at Nicholson – 08NA002

A trend analysis was conducted from 1917 to 2007 inclusive, with data from the year 1971 missing. This station measures flows for the entire river from the Spillimacheen river inflow upstream. Figure 32 demonstrates that there is a significant increasing trend in mean winter streamflow at the 90% confidence level (Sen's slope estimate = 0.03). There no significant trends in spring, summer or fall mean streamflow (Figures 33, 34, and 35).

This is the longest record available in this watershed; therefore, it should provide an excellent indication of long-term trends. The significant increasing trend in spring mean streamflow could be attributed to an increase in snowmelt and an increase in spring precipitation.

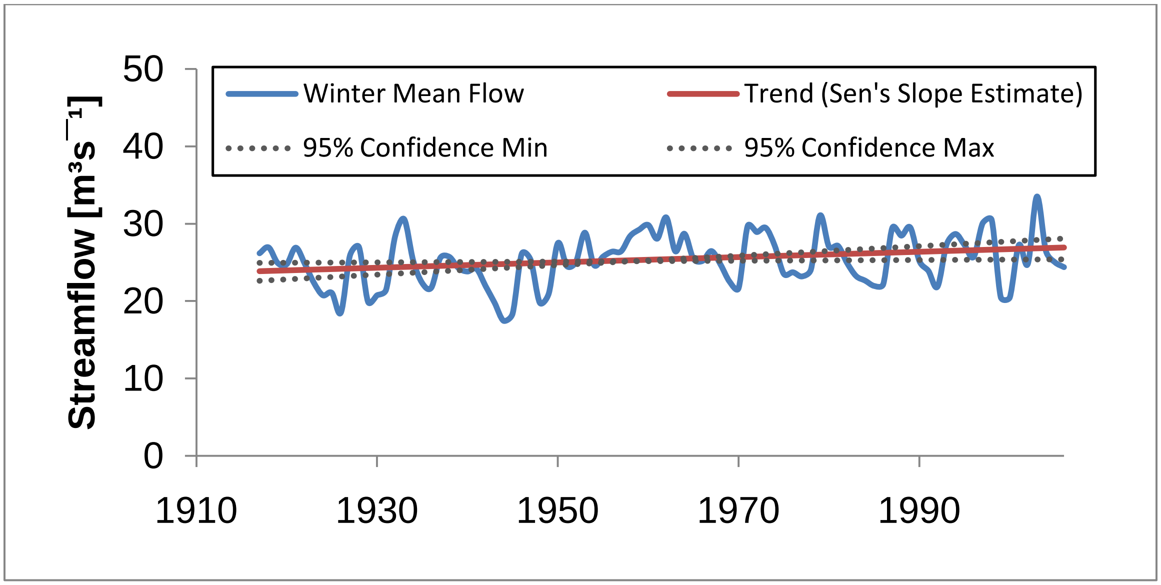

Figure 32 Winter trend analysis for the Columbia River at Nicholson

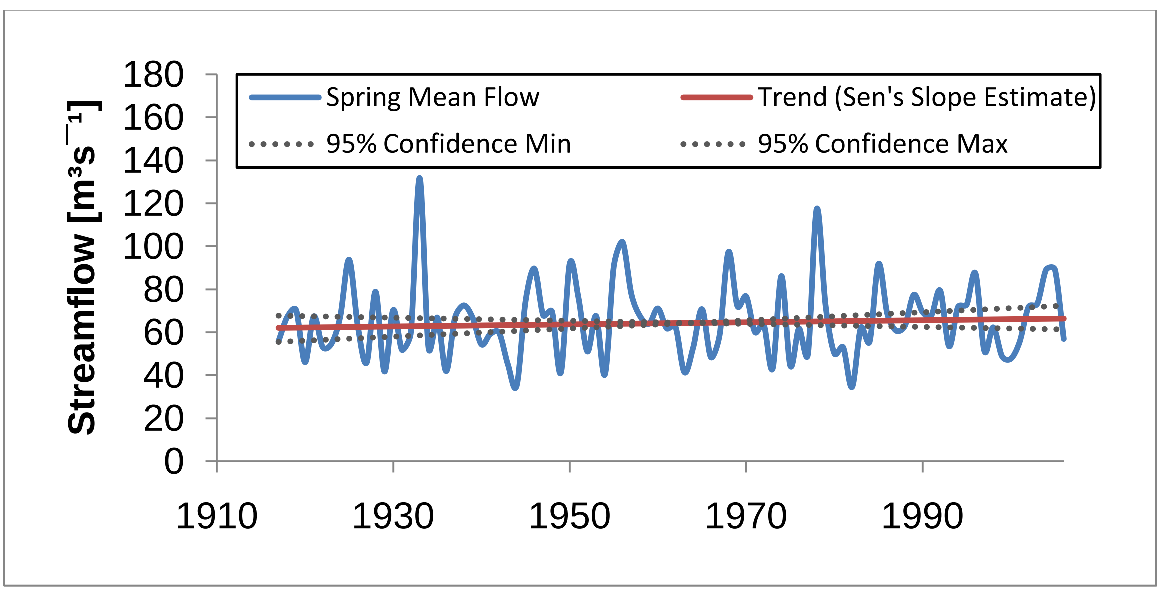

Figure 33 Spring trend analysis for the Columbia River at Nicholson

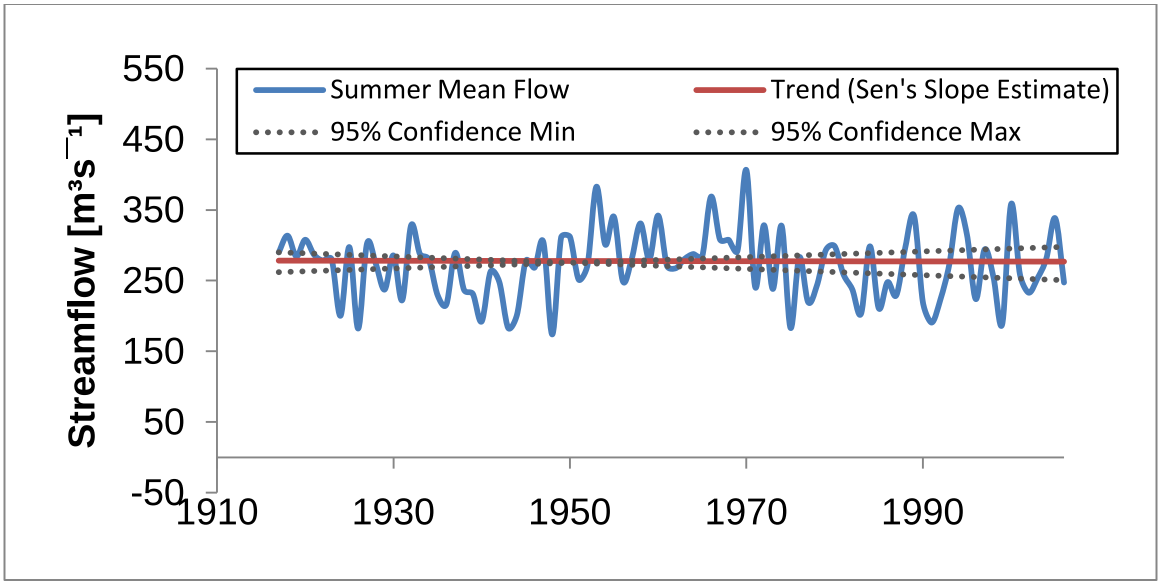

Figure 34 Summer trend analysis for the Columbia River at Nicholson

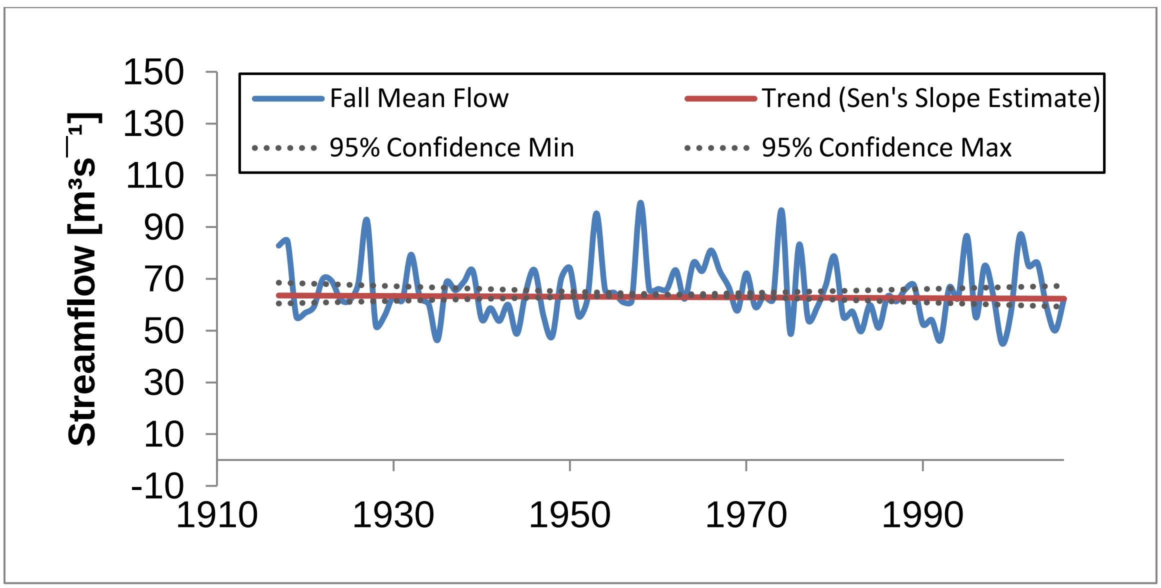

Figure 35 Fall trend analysis for the Columbia River at Nicholson

4.2.4 Kicking Horse River at Golden – 08NA006

The Kicking Horse River is a major tributary flowing out of the Rockies and entering the Columbia at the town of Golden. A trend analysis was conducted from 1975 to 2006 inclusive. There are no significant seasonal trends observed at the kicking horse station (Figures 36, 37, 38, and 39).

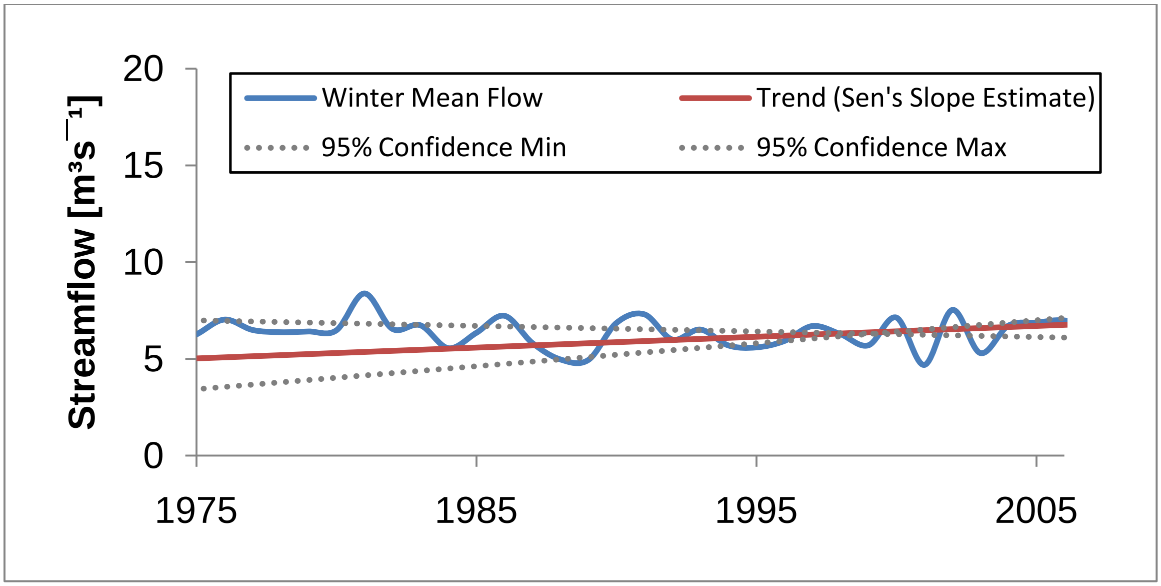

Figure 36 Winter trend analysis for the Kicking Horse River at Golden

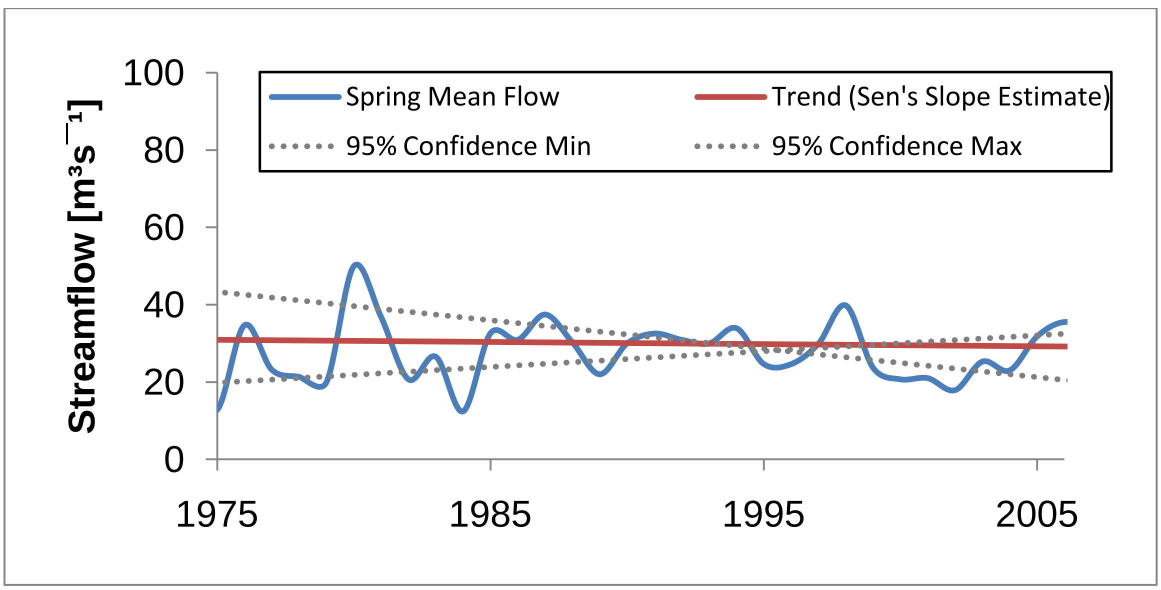

Figure 37 Spring trend analysis for the kicking Horse River at Golden

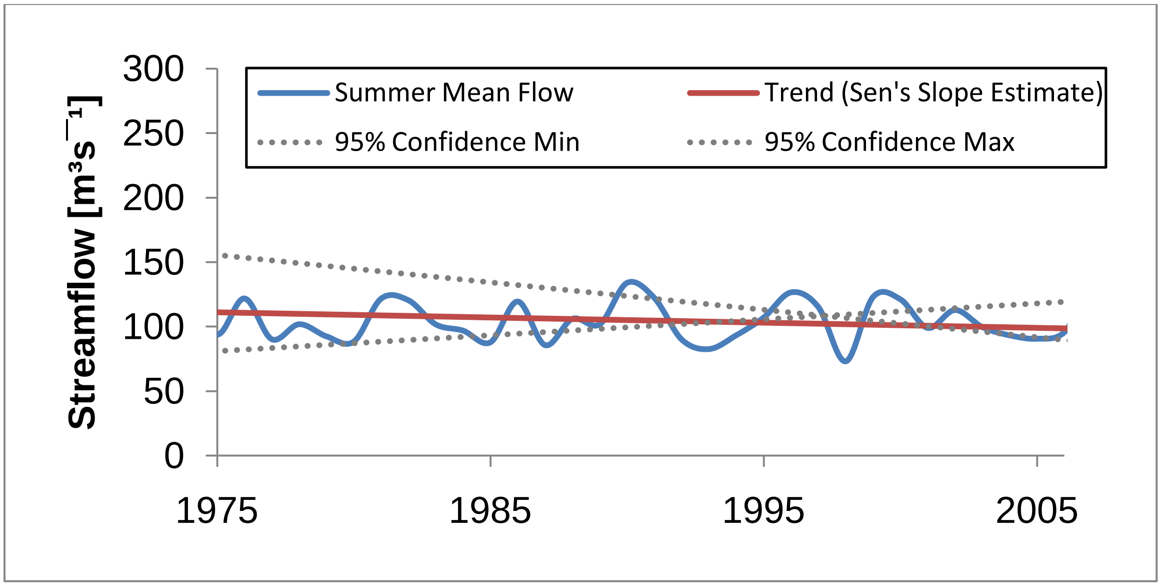

Figure 38 Summer trend analysis for the Kicking Horse River at Golden

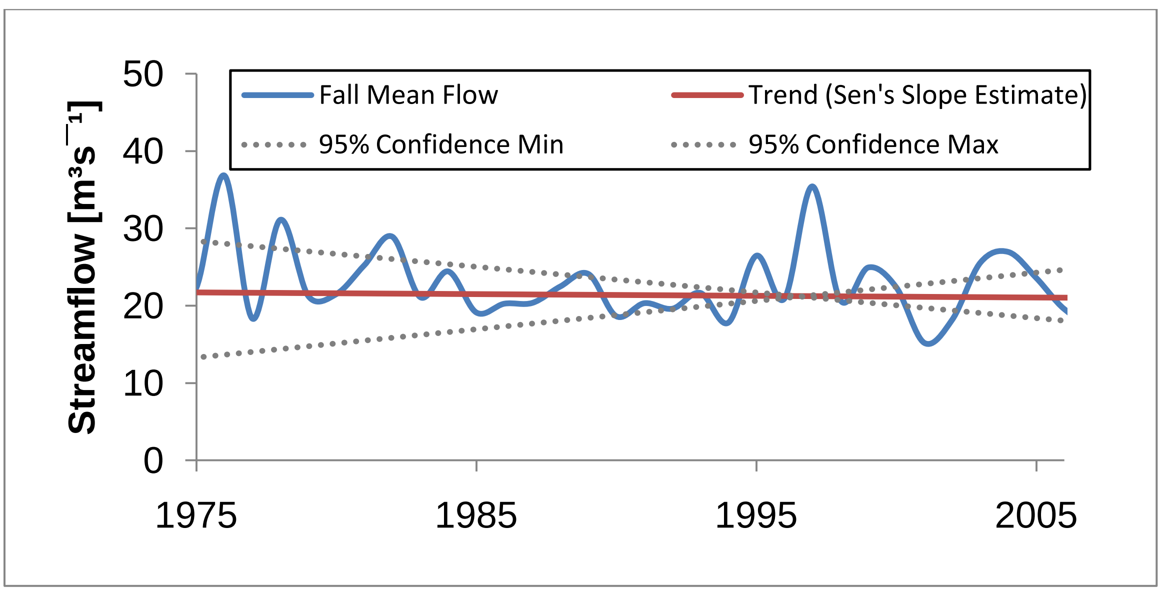

Figure 39 Fall trend analysis for the Kicking Horse River at Golden

4.2.5 Blaeberry River above Willowbank Creek – 08NB012

The Blaeberry has two stations with data, over different time periods and recorded at different sites. The station above Willowbank Creek has the longest time series, therefore, is used for the trend analysis. The analysis was conducted for data from 1971 to 2008 inclusive (37 years). There were no trends observed in the seasonal streamflow at this site (Figures 40, 41, 42, and 43).

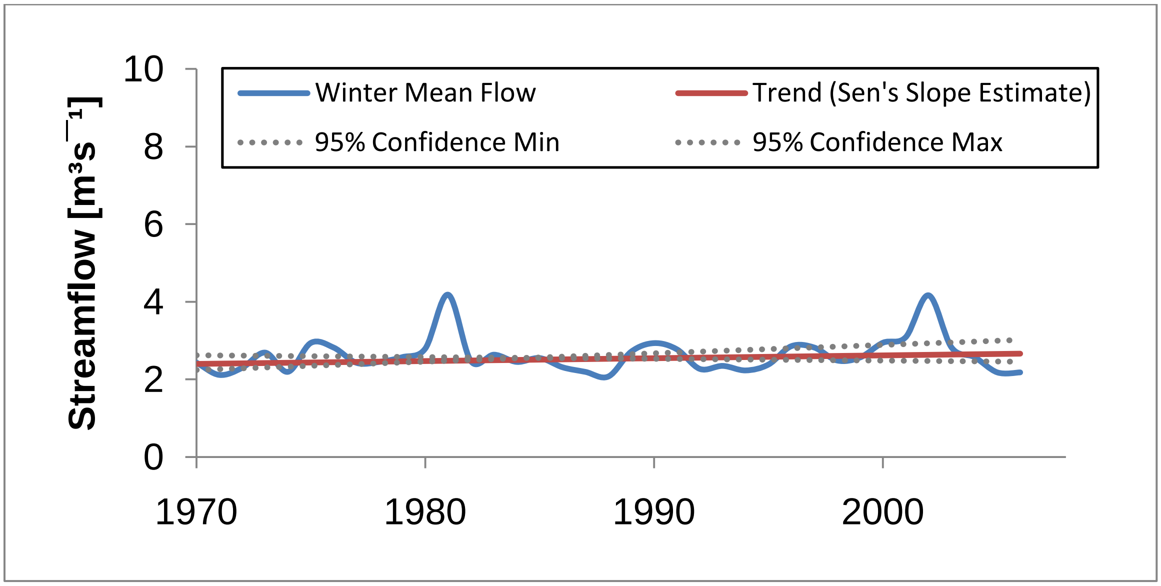

Figure 40 Winter trend analysis for the Blaeberry River above Willowbank

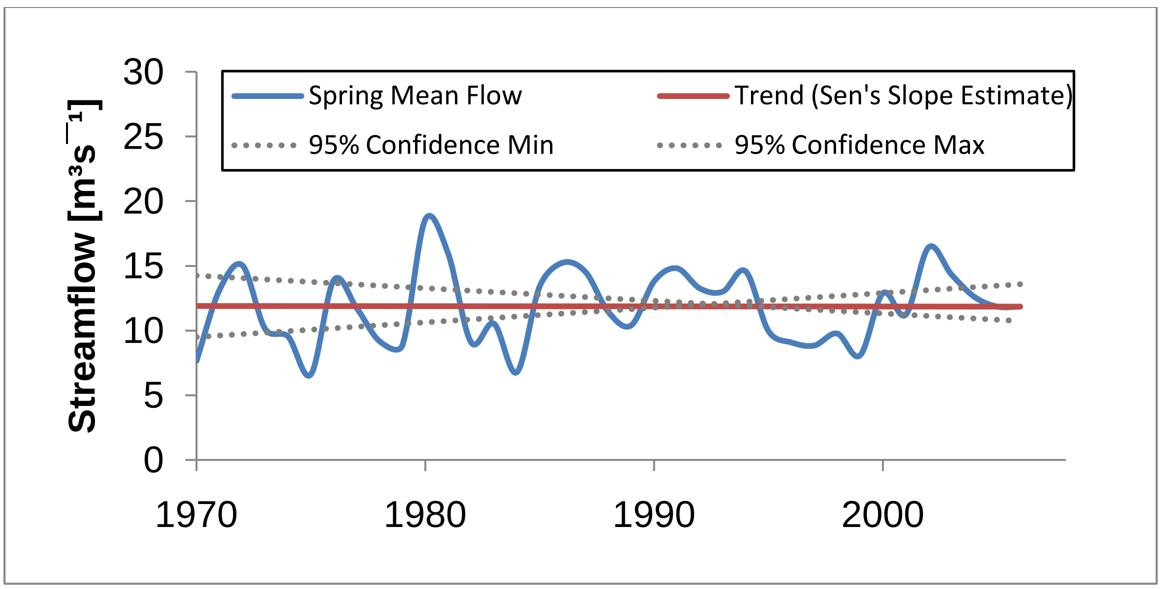

Figure 41 Spring trend analysis for the Blaeberry River above Willowbank

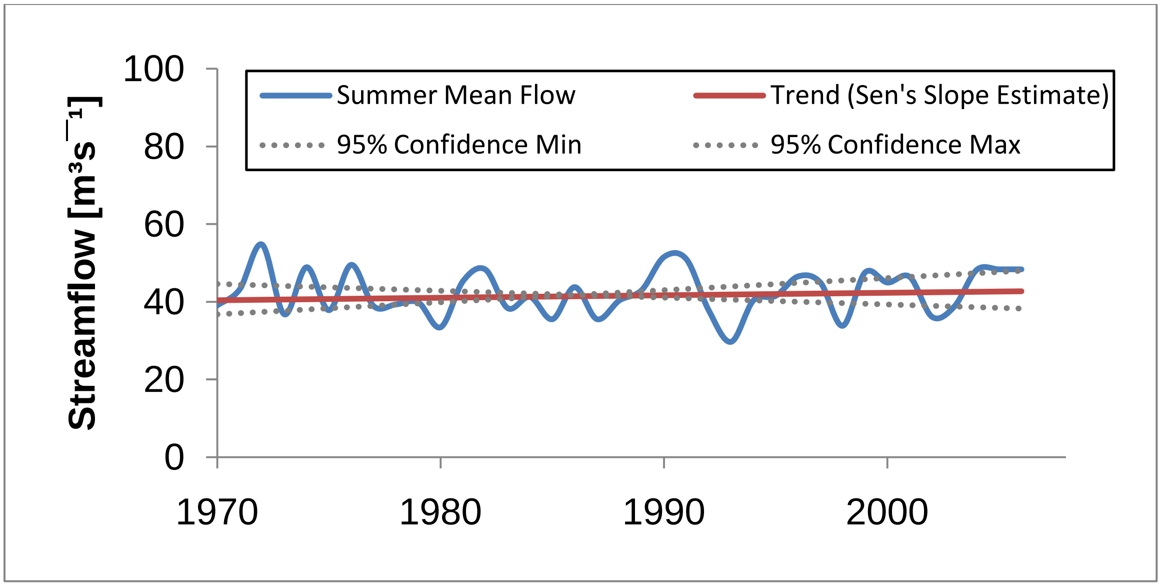

Figure 42 Summer trend analysis for the Blaeberry River above Willowbank

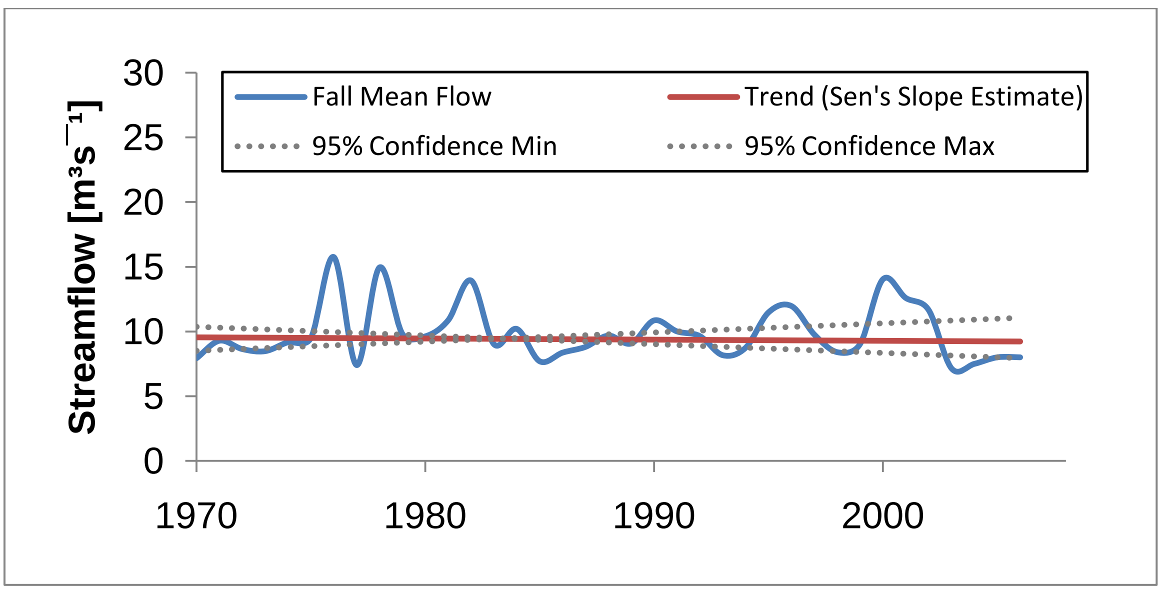

Figure 43 Fall trend analysis for the Blaeberry River above Willowbank

4.2.6 Columbia River at Donald – 08NB005

This station represents the lowest portion on the Columbia River, and accounts for flows from large tributaries including the Spillimacheen, Kicking Horse, and Blaeberry Rivers. A trend analysis was conducted from 1961 to 2008 inclusive. There are no significant trends observed in mean winter, spring, summer or fall streamflow at the Columbia River at Donald station (Figures 44, 45, 46, and 47).

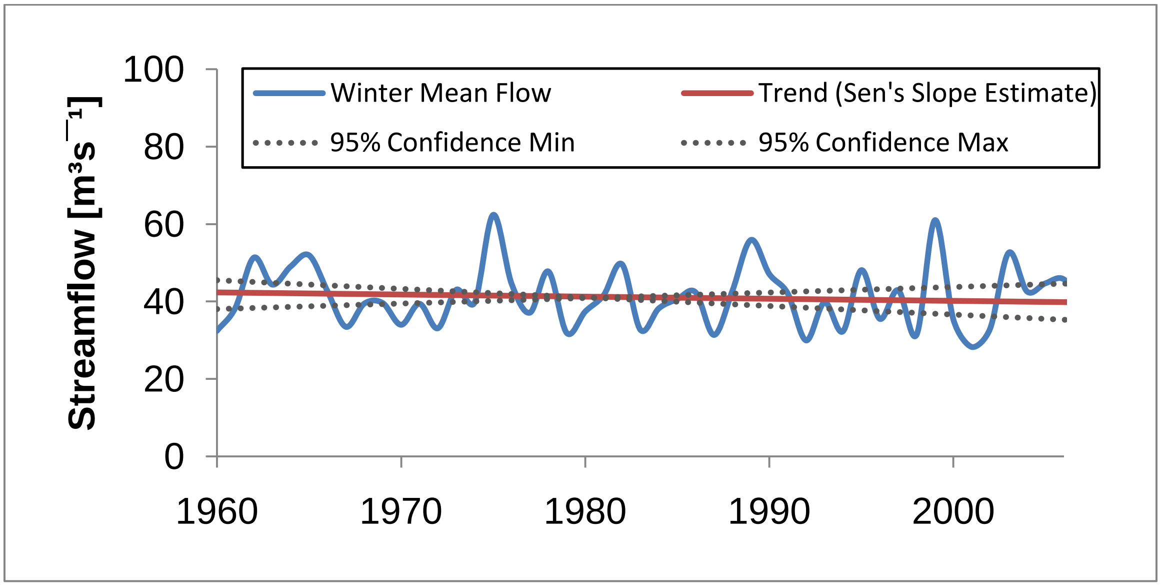

Figure 44 Winter trend analysis for the Columbia River at Donald

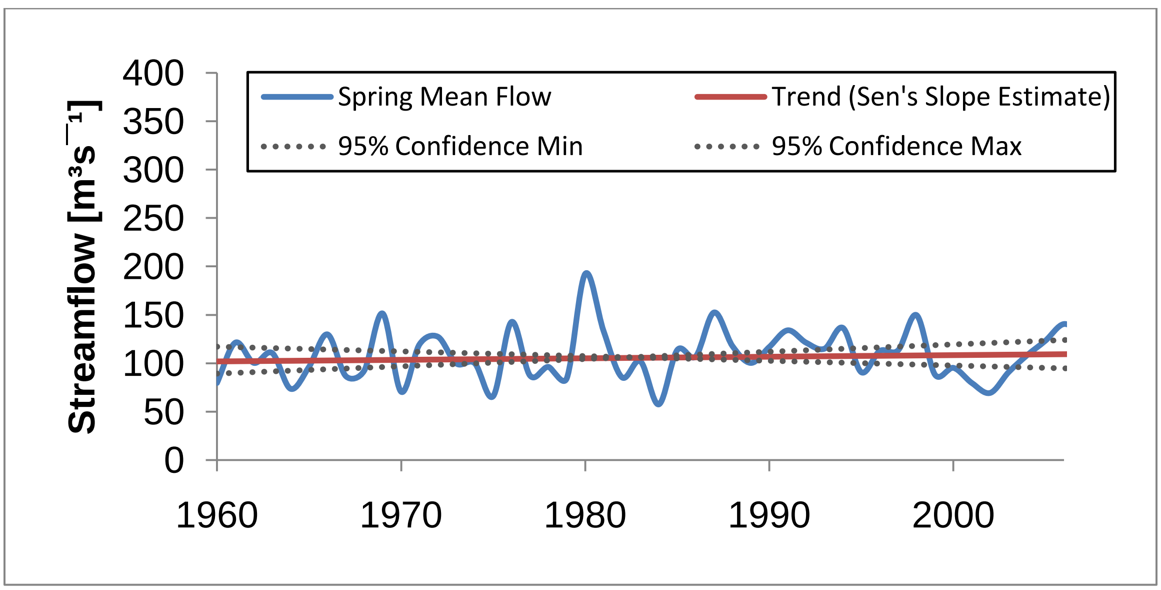

Figure 45 Spring trend analysis for the Columbia River at Donald

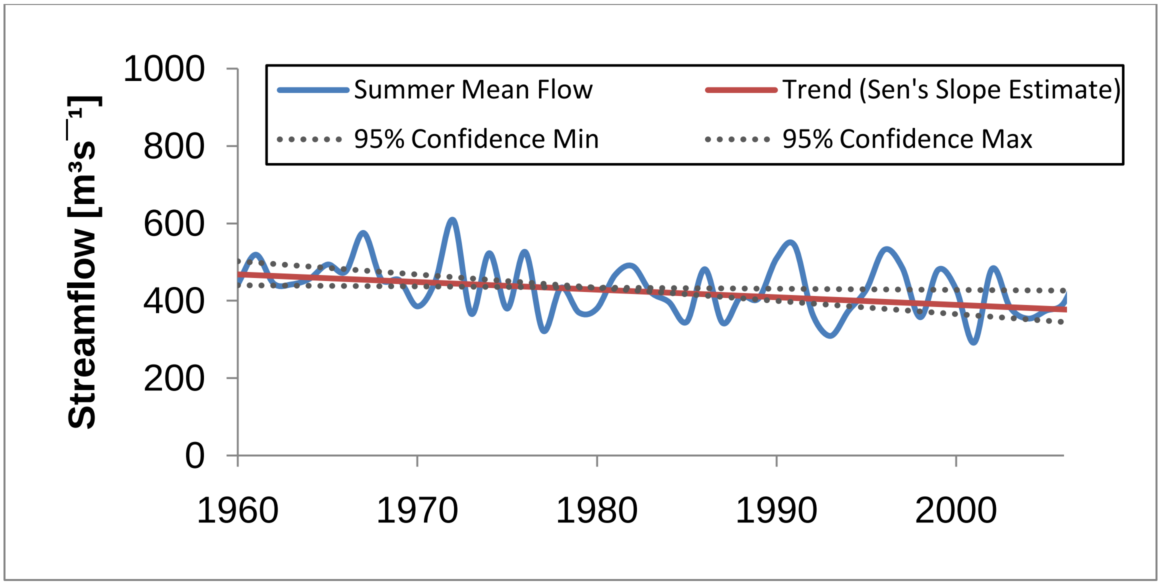

Figure 46 Summer trend analysis for the Columbia River at Donald

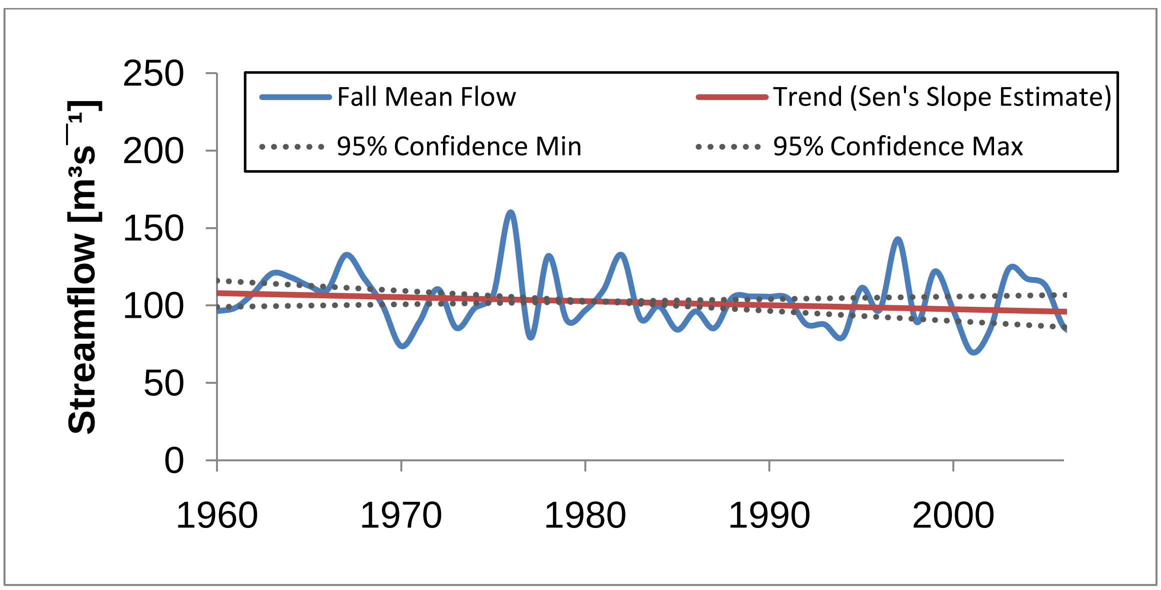

Figure 47 Fall trend analysis for the Columbia River at Donald

4.2.7 Illecillewaet River at Greeley – 08ND013

This station is west of the Upper Columbia watershed and represents a basin with flows from several large glaciers. Trend analyses from 1964 to 2008 inclusive were conducted on the Illecillewaet River. Figure 49 shows a significant increasing trend in spring mean streamflow is observed at the 90% confidence level (Sen's slope estimate = 0.27). Figure 50 demonstrates there is a significant decreasing trend is observed in summer mean streamflow at the 90% confidence level (Sen's slope estimate = -0.44). There are no trends observed in winter or fall mean streamflow (Figure 48 and Figure 51).

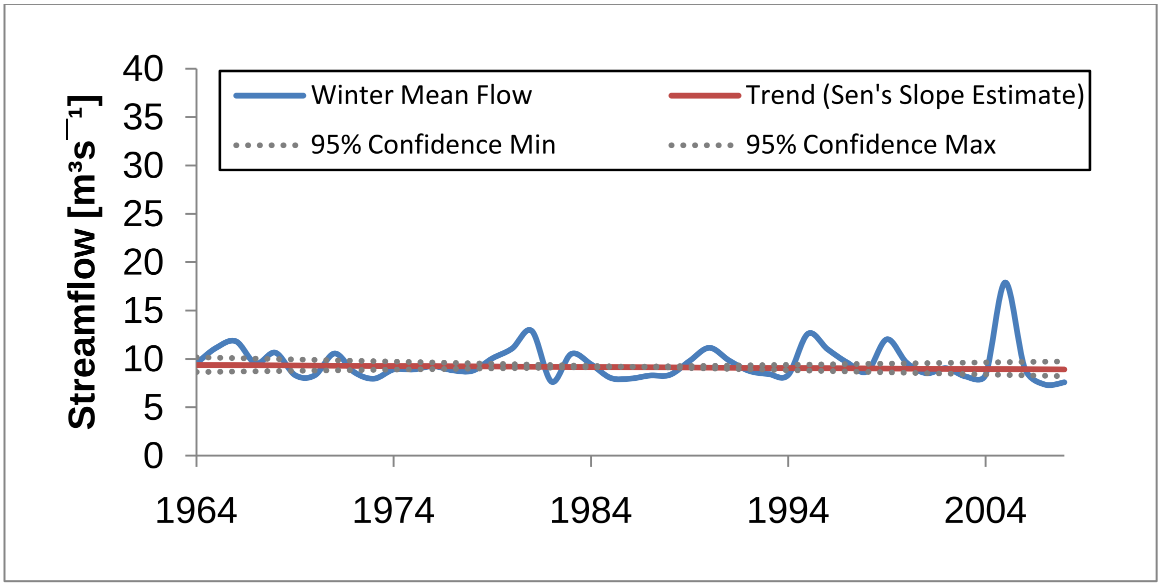

Figure 48 Winter trend analysis for the Illecillewaet River at Greely

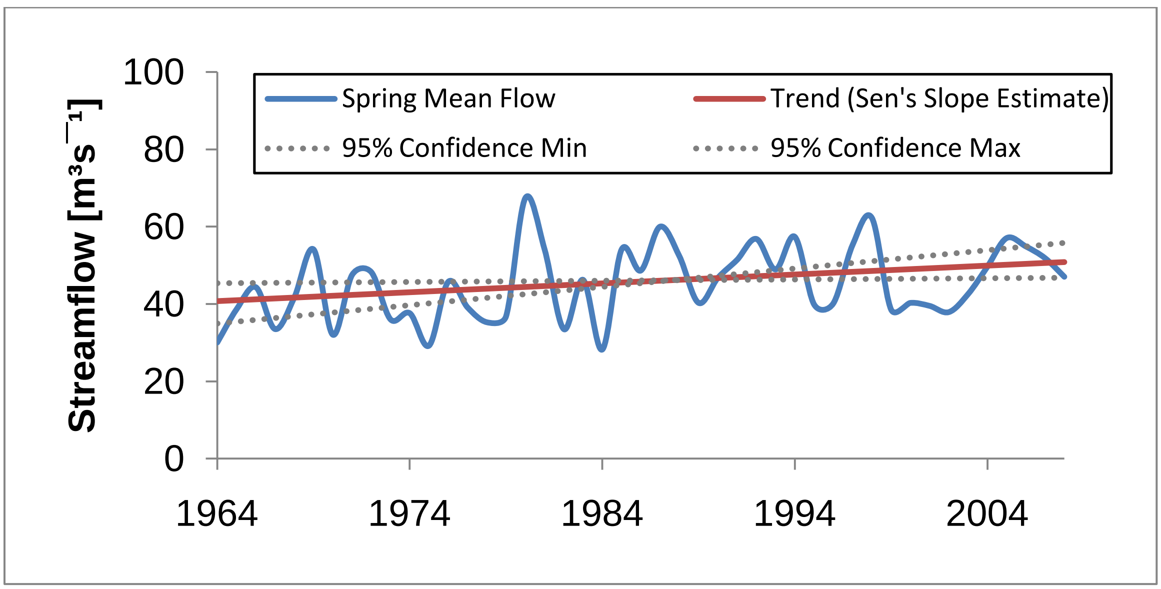

Figure 49 Spring trend analysis for the Illecillewaet River at Greely

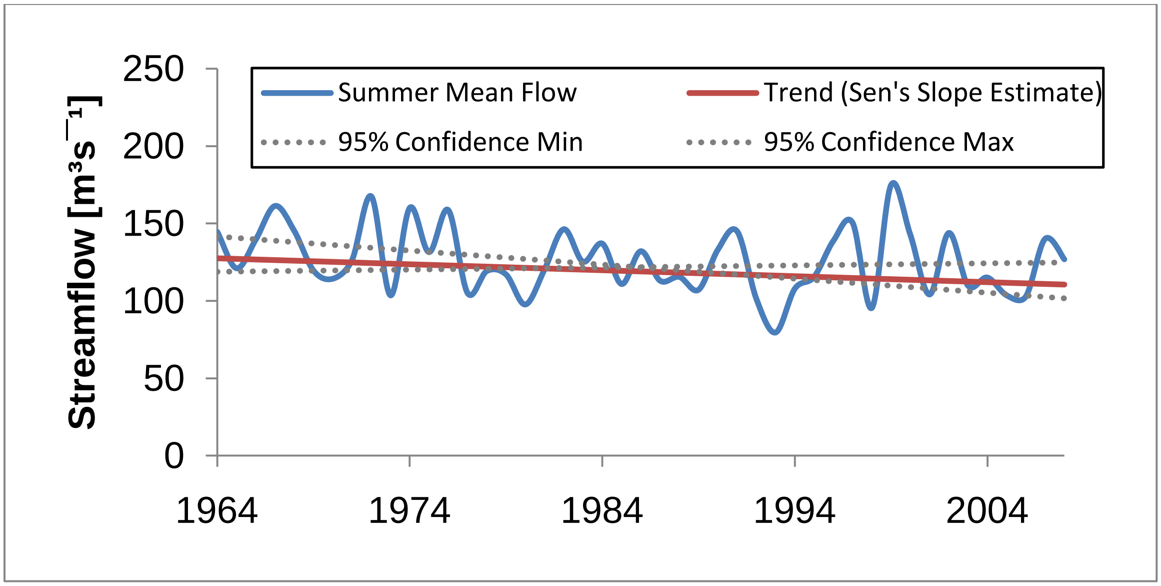

Figure 50 Summer trend analysis for the Illecillewaet River at Greely

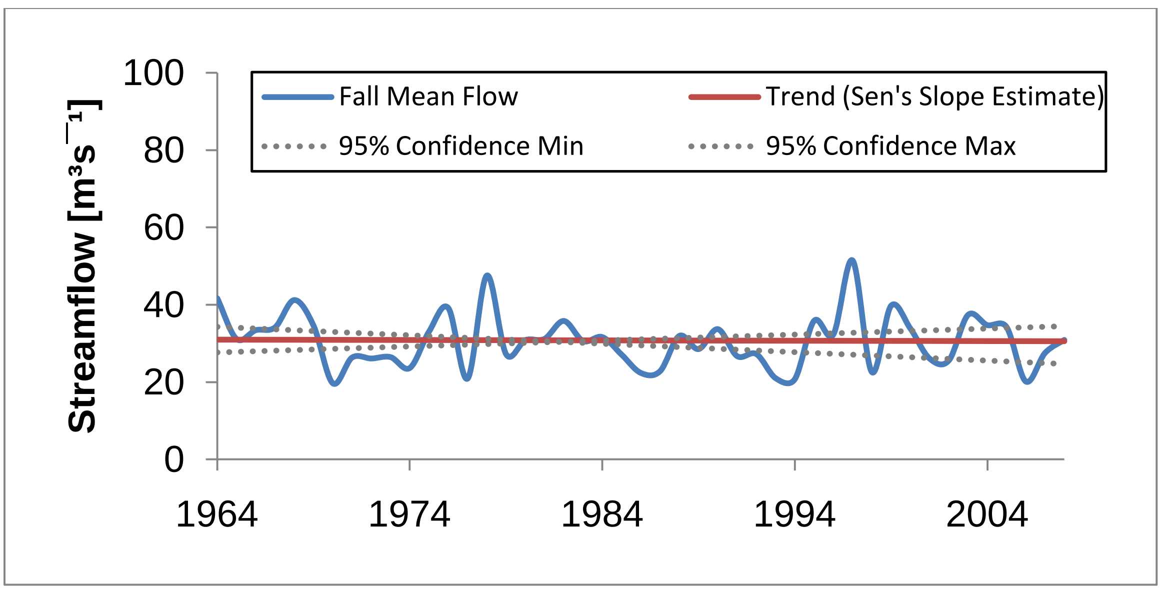

Figure 51 Fall trend analysis for the Illecillewaet River at Greely

4.2.8 Kootenay River at Kootenay Crossing – 08NF001

This station is located in a small watershed in the Upper Kootenay River, east of the Upper Columbia drainage. This dataset is included here since it is the only available and current data in the region for a stream without any glacial contribution to its flows. A trend analysis was conducted from 1961 to 2008 inclusive for the upper Kootenay River. No significant trends were observed for any of the seasons in this time series

(Figures 52, 53, 54, and 55). This lack of trend is contrary to that found for the Fairmont Hot Springs data set (Figures 24-27, p 21-22).

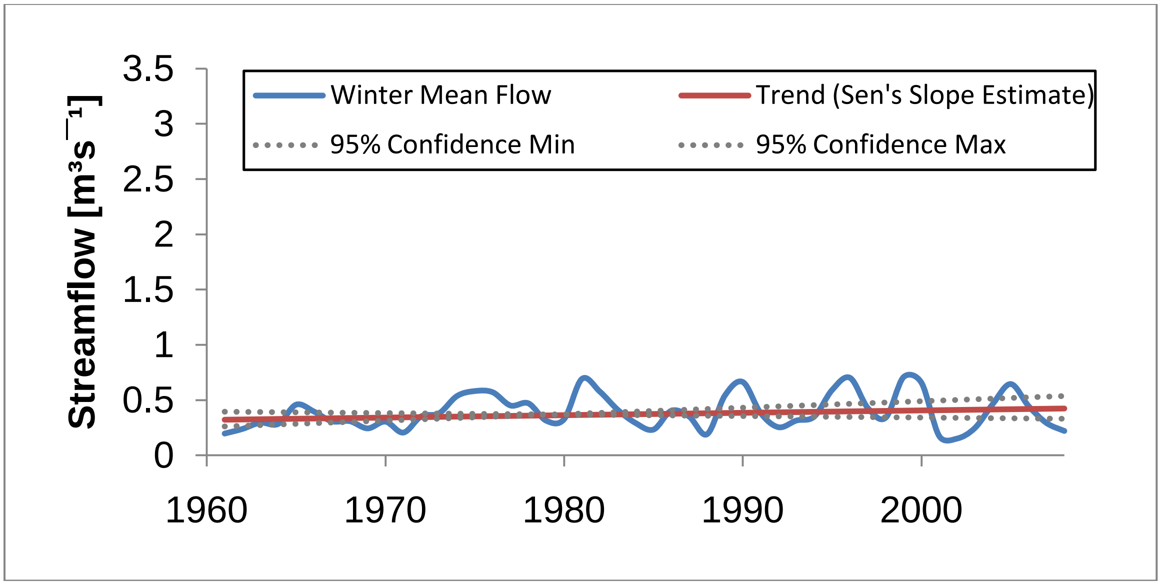

Figure 52 Winter trend analysis for the Kootenay River at Kootenay Crossing

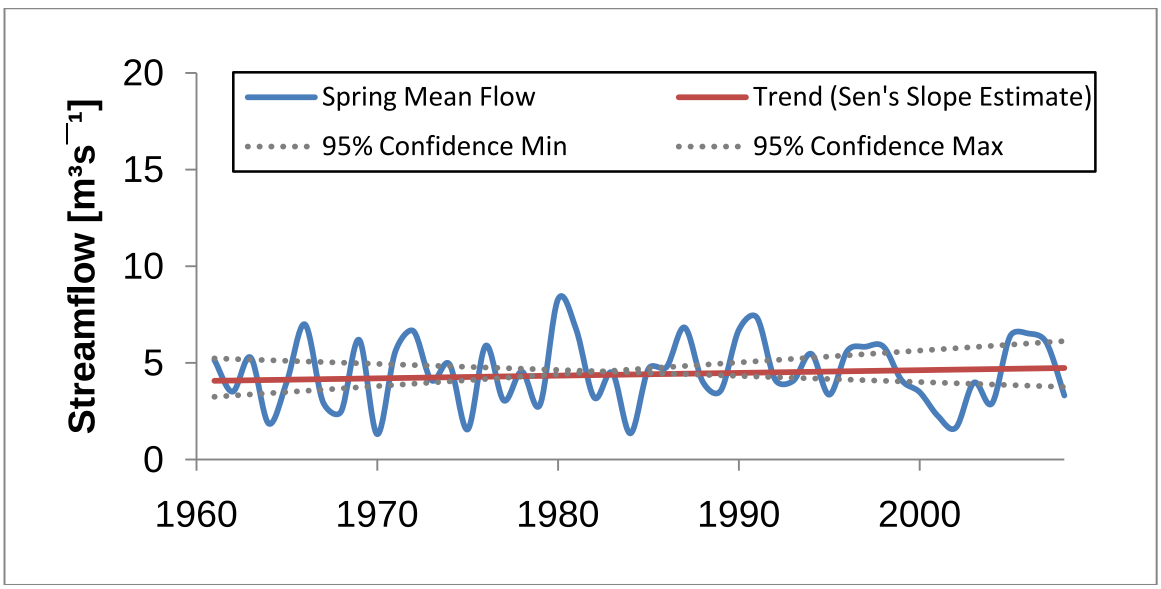

Figure 53 Spring trend analysis for the Kootenay River at Kootenay Crossing

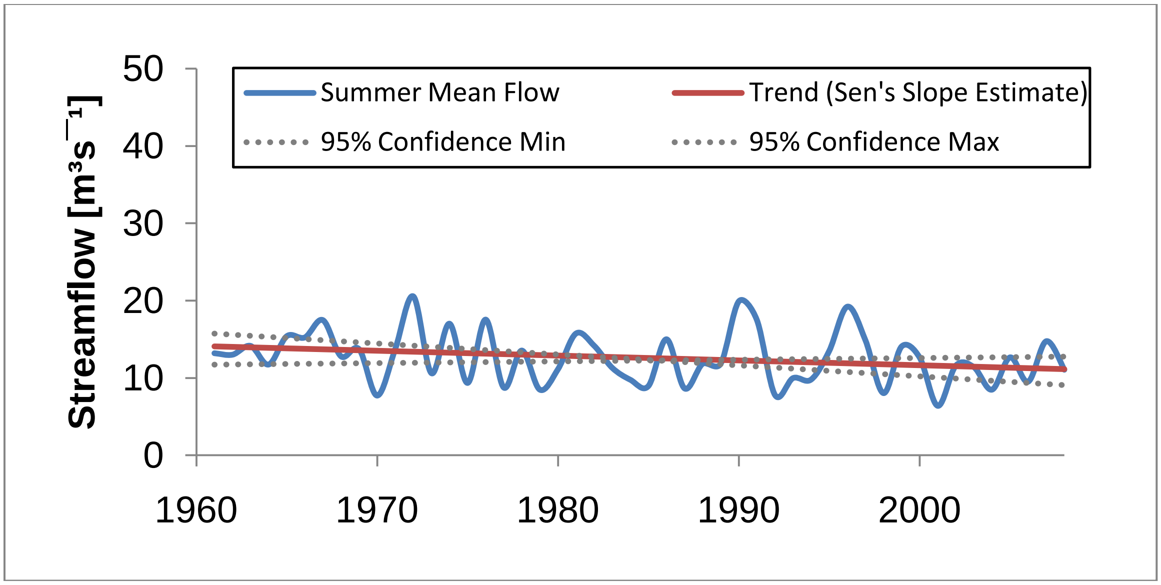

Figure 54 Summer trend analysis for the Kootenay River at Kootenay Crossing

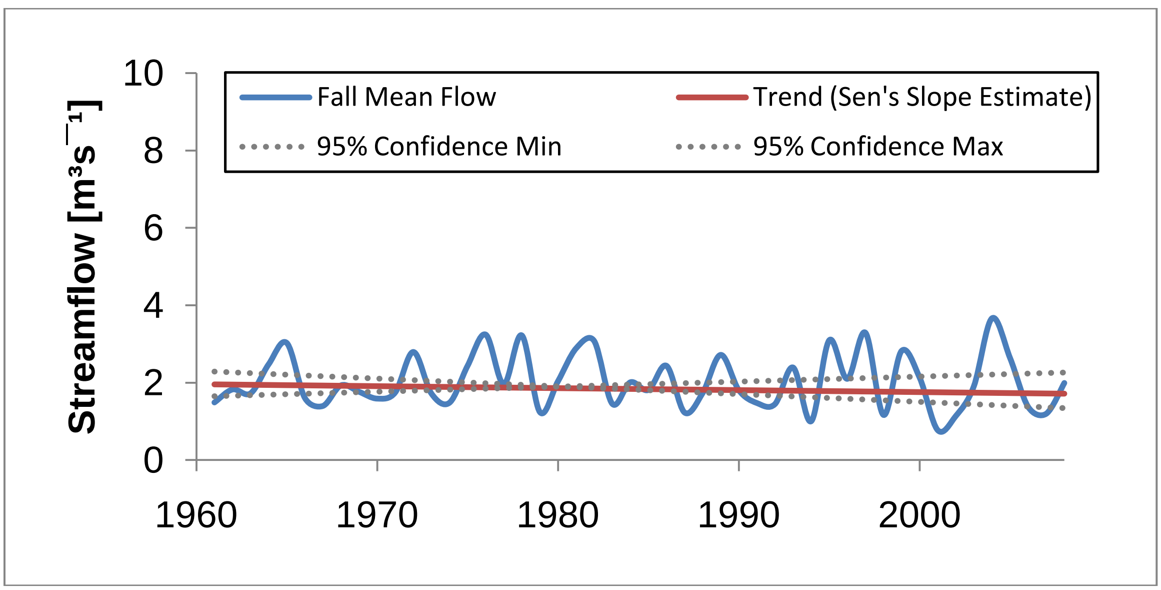

Figure 55 Fall trend analysis for the Kootenay River at Kootenay Crossing

4.3 Water demand

Annual water allocation data were available from (Ministry of Environment, 2009). These data have been characterized for each type of water use (Table 2); no further explanation of the type of use is available from the Ministry of Environment. Each stream with a total annual allocation exceeding 500, 000 m^3 was also identified and summarized in Table 3.

Table 2 Annual water allocation for each type of use in the watershed.

PURPOSE	Annual License(m^3/yr)
POWER-GENERAL	290,225,024.2
IRRIGATION	41,776,266.0
WATERWORKS LOCAL AUTH	12,846,828.3
STORAGE	7,234,371.0
PONDS	4,950,965.3
IRRIGATION LOCAL AUTH	3,731,899.3
WATERING	2,909,364.3
POWER-RESIDENTIAL	2,593,272.2
POWER-COMMERCIAL	2,366,450.2
CONSERV.-STORED WATER	2,188,196.8
LAND IMPROVE	1,550,600.4
MINERAL TRADING-BATH	1,050,073.2
PROCESSING	1,037,594.2
BOTTLE SALES	690,837.6
DOMESTIC	636,606.9
WATERWORKS (OTHER)	522,549.6
ENTERPRISE	459,407.0
SNOW MAKING	363,877.1
STOCKWATERING	82,347.8
DUST CONTROL	69,083.8
FIRE PREVENTION	68,761.0
STORAGE-POWER	58,298.1
INCIDENTAL - DOMESTIC	27,633.5
RES. LAWN/GARDEN	27,257.5
GREENHOUSES	4,835.9
INSTITUTIONS	4,145.0
PUBLIC FACILITIES	3,108.8
CHURCHES/COMM. HALLS	1,381.7
FIRE PROTECTION	690.8
Total Annual Water Allocation =	**377,481,727.5**

Table 3 Waterbodies with greater than 500, 000 m3 annual water allocation.

WATER BODY	Annual License(m^3/yr)
Watersheds above Radium Hot Spgs	
Dutch Creek	5,435,170.0
Shuswap Creek	3,531,758.3
Dry Gulch Creek	933,858.0
Fairmont Hot Springs	856,638.7
Forster Creek	3,800,423.8
Horsethief Creek	1,492,513.0
Windermere Creek	2,746,889.2
Windermere Lake	4,516,756.8
Boker Brook	801,763.2
Watersheds from Radium to Spilli	
Fraling Creek	809,177.3
Goldie Creek	6,414,147.8
Brady Creek	985,453.9
Bunyan Lake	1,110,133.7
Cold Spring Creek	2,149,266.4
Spillimacheen River	268,291,360.5
Earnest Brook	801,763.2
Kindersley Creek	1,852,986.1
Kreuter Creek	801,763.2
Madias Creek	1,681,039.6
Marion Creek	1,195,108.6
McKeeman Creek	623,503.1
McMurdo Creek	705,514.7
Nelson Creek	294,457.0
Rogun Lake	1,356,830.0
Salter Creek	2,072,611.8
Spring Creek	1,620,526.0
Tatley Creek	1,327,424.8
Thorold Creek	872,678.6
West Marion Creek	1,160,571.1
Wilmer Creek	653,745.4
Watersheds from Spilli to Golden	
Birchlands Creek	564,639.1
Templeton River	702,591.4
Bugaboo Creek	22,325,001.9
Canyon Creek	724,670.6
Carbonate Creek	1,688,687.3
Luxor Creek	844,661.6
Macaulay Creek	2,860,631.0
Watersheds below Golden	
Blaeberry River	859,591.6

4.3.1 Windermere Creek supply vs demand- east side of valley

To assess the potential water supply issues for creeks on the eastern portion of the upper Columbia watershed, annual water supply vs. water demand was analyzed on Windermere Creek. Data used to assess water supply vs. water demand on Windermere Creek included the 1960 to 1980 streamflow record and water license data collected from (Environment Canada, 2009; Ministry of Environment, 2009). Monthly averages of daily flow volumes were calculated, as an average represents the condition most likely to occur (Table 4).

Table 4 Mean streamflow for Windermere Creek (1960-1980)

Windermere Creek 1960-1980 mean monthly streamflow	
Month	**mean flow (m^3/day)**
Jan	34,994
Feb	32,272
Mar	31,102
Apr	31,468
May	44,614
Jun	101,713
Jul	85,229
Aug	65,619
Sep	55,064
Oct	48,062
Nov	42,956
Dec	38,722
Annual	**51,051**

The water allocation data for Windermere Creek from the Ministry of Environment (2009) is summarized in Table 5. The assumption that the annual license applies to each day during the year is made, it is also assumed that irrigation allocations are only being used from late April to mid September.

Table 5 Windermere Creek annual water license allocation

Windermere Creek Total Annual Water Allocation	
PURPOSE	**Annual License(m³/yr)**
DOMESTIC	6,908
IRRIGATION	2,609,073
PROCESSING	1,824
RESORT WATERING	129,084
Total Annual Water Allocation =	**2,746,889**

At the annual scale, 14% of the streamflow in Windermere Creek is allocated (Based on the 1960 to 1980 average). With the assumption that irrigation is conducted between late April and mid September, 12% of the streamflow in Windermere Creek is allocated to irrigation during the spring, summer and fall periods. It is recognized that these values are limited by the available data, as well as the period of record and whether or not farmers are actually using or exceeding their allocation.

As demonstrated in the hydrological analysis of individual streams in section 4.1, Windermere Creek is dominated by groundwater. This flow regime likely enables this creek to withstand significant demand during low flow periods. It must be recognized, however, that not all of the creeks on the eastern side of the watershed are groundwater dominated. Windermere Creek is part of a complex of small streams draining the ranges east of the valley from Canal Flats to Brisco that occur in the drier portion of the system. In those drainages without a groundwater contribution providing maintained summer flows, there may be significant supply/demand problems.

Caution must be taken when interpreting these results and flow monitoring on all other creeks with significant allocations should be conducted to determine the hydrological regime of each individual system. This will be difficult as monitoring of actual use will require water meters records to be kept. Also, understanding actual historical use by irrigators would require discussions with local farmers to identify actual vs. licensed use over time.

4.3.2 Upper watershed low flow supply vs demand - west side of valley

Flow data from Toby Creek and Horsethief Creek were used for this analysis. Toby Creek has two significant water users, irrigation and snow making, while Horsethief Creek is only used for irrigation (Ministry of Environment, 2009). Average streamflow conditions were derived for the periods 1943 to 1951 and 1943 to 1984 for Horsethief and Toby Creeks respectively. For the winter period, December, January, February, and March values were used, for the summer period, July and August values were used. The Toby Creek record, however, had significant gaps between 1943 and 1984. These results are, therefore, not representative of current conditions, however, they provide some context for water supply and demand issues in the upper watershed. Results from this analysis are presented in Table 6.

Table 6 Supply and demand for Toby and Horsethief Creeks

	volume of water (m^3)	% allocation
Toby Creek total supply for irrigation and snow making	**6,285,980**	21%
Irrigation use	354,707	6%
Snow making use	119,640	15%
Horsethief Creek total supply for irrigation	**5,414,609**	
Irrigation use	1,492,513	28%

4.4 Glacial contributions to flows

The contribution of glacier meltwater to headwater streams is important for the maintenance of river and groundwater water levels (Schindler and Donahue, 2006). Glaciers are responsible for the maintenance of streamflow levels in the period of the late summer and fall seasons where snowmelt and rainfall precipitation contributions are minimal (Hall and Fagre, 2003). This is particularly important in western Canada, where glacial contribution to streamflow is important for water supply for irrigation, drinking water, ecosystem health and hydro-electric power generation needs (NWRI, 2009).

An increase in annual mean temperature is expected to impact glaciated areas, reducing the areal ice extent with negative consequences for areas dependent on glacial runoff for the maintenance of baseflows (Field et al., 2007). The Canadian Cordillera has been identified as an area where a reduction in glacial ice extent will result in problematic consequences for the maintenance of late-summer and fall baseflows (DeBeer and Sharpe, 2007; Barnett et al., 2005). Stahl and Moore (2006) observed, in recent decades, declining trends in late summer streamflow in glacier-fed streams across British Columbia. Stahl et al. (2008) investigated glacier and streamflow response to climate change in a heavily glaciated Bridge River watershed in British

Columbia (Coastal Range) and concluded that glacial area and summer streamflow declined under conservative estimates of future climate change.

In a recent inventory of glaciated terrain in British Columbia, Menounous et al. (2007) concluded that the Selkirk-Columbia Mountains (just west of the Purcells) lost 18.09% of their area since the 1980's. In the Illecillewaet Basin, Rango and Martinec (1995) concluded that an increase in precipitation would not compensate for the loss of glaciated terrain due to warmer temperatures.

The impact that climate change will have on the glaciated regions of the Columbia River watershed have not yet been extensively investigated, in part due to a lack of hydro-meteorological and glaciological data presently available (Hirose and Marshall, 2009). Figure 56 of the Vowell glacier in Bugaboo Provincial Park demonstrates the significant decline in glacial ice that has occurred from 1997 to 2008. This is common among many of the glaciers located in the Rocky and Selkirk mountain ranges. The streamflow trend analysis supports these increases in glacial melt with increased fall and winter streamflow in a number of watersheds. Presently, the National Water Research Institute (NWRI) is investigating the net change in glacial resources in the Columbia River system and will use modelling to forecast the impact that climate change will have on water resources in the future (NWRI, 2009).

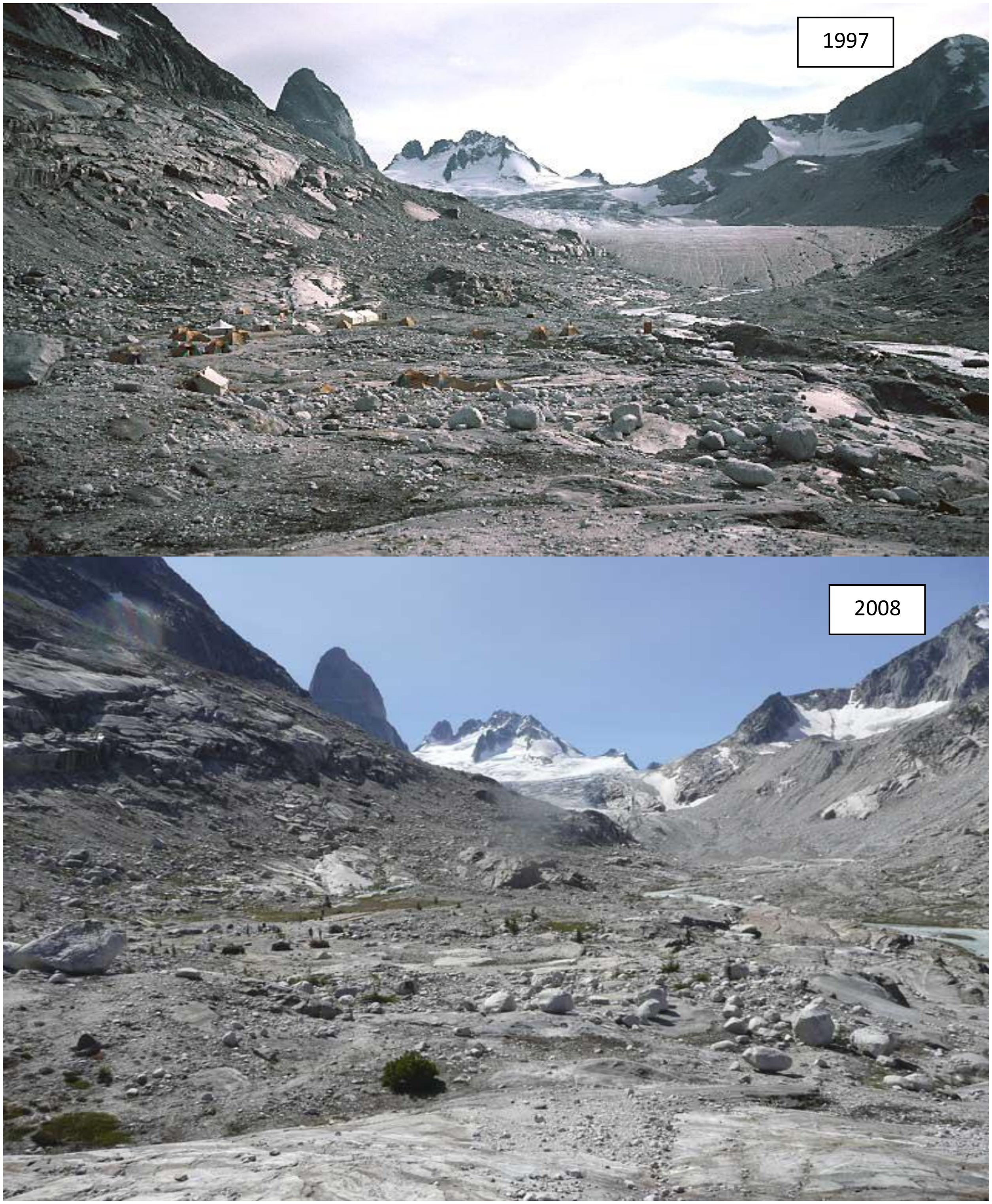

Figure 56 Vowell Glacier, 1997 and 2008 (photo by: Brad Harisson)

4.5 Summary

There is little data collected on a number of the smaller tributaries in the upper Columbia River, above the confluence of Bugaboo Creek. The upper Columbia River watershed possesses a number of streams with different flow characteristics. Results from both the hydrological assessment and trend analysis demonstrate the complexity of this region and susceptibility of the upper Columbia River watershed to a range of possible environmental changes. It does, however, appear that the upper watershed above Radium Hot Springs/Edgewater could be experiencing significantly more change relative to the lower portion of the watershed, as demonstrated by the trend analyses at Fairmont and Kootenay Crossing. The Fairmont station had demonstrable significant decreasing trends in late season streamflow, where the Kootenay Crossing station represented non-significant decreasing trends in late season streamflow. These differences could be attributed to either changes in climate or human use (in the case of the Fairmont data) however, further insight into actual use in this region would be required to appropriately quantify this observation.

To contrast this finding, the only long-term streamflow dataset is available at Nicholson, and suggests there are no seasonal trends observed over the last 100 years. Data from the tributaries in the lower portion of the watershed also suggest there are no significant seasonal trends in the streamflow records. However, all of these stations are located in glaciated watersheds. Therefore, it could be that the late season streamflow trends observed at Fairmont (a non-glaciated watershed) are being negated by increased glacial melt contribution to streamflow.

Water allocation in the region doesn’t appear to be posing a significant stress, as only a relatively small fraction of total water available above Donald is allocated. However, caution must be taken with this interpretation as data on actual use, updated streamflow, and potentially water allocation are limited. This study assumes the information gathered is correct and has attempted to obtain the most current data available. However, there is no means of verifying whether the water allocation values obtained are up to date since there is no requirement for water users (other than community water suppliers and large volume users (resorts) to document their actual water use. Since agricultural use for irrigation is the major use in most watersheds (Table 2), and such users are not required to meter their use, there is no credible way to assess overall water use in these watersheds. With the limited available water use data, it is not possible at this time to reliably assess the basin water balance; large assumptions would have to be made to derive hypothetical scenarios.

There appears to be little known about glacial retreat in this specific region, mainly due to the expertise and logistics required to study glaciers. However the Illecillewaet Glacier is relatively close and has been studied extensively, therefore, provides an excellent surrogate for the changes that should be expected in the study area. Perhaps the most effective means of studying glaciers in this region would be through remote sensing. Studies using remotely sensed data have much promise and have proven to be an effective means of monitoring glacial retreat (Bolch et al., 2009). Next steps in this area would appear to be a remote sensing analysis of overall glacial coverage in the Upper Columbia watershed and the use of historical air photos to document change in a representative sample of glaciers in the watershed. This would provide some sense of the changes occurring, however moving from estimates of changes in area to changes in ice volume and storage loss will be problematic. The costs and expertise associated with using remote sensing technology limit its applicability for most studies, therefore, research institutions should be considered for this assessment. Also, in the mid-term, data on trends for the nearby Illecillewaet region provide good indication for what can be expected in the upper Columbia River watershed.

5.0 Groundwater

This section provides an overview of the surface geology, bedrock geology and hydrogeology of the Upper Columbia Valley between Canal Flats and Edgewater as shown in Figure 1. The objective of this section is to present the state of understanding of the interactions between the deep aquifers in the Invermere area, Lake Windermere, the nearby tributaries (Toby Creek) and the Columbia River floodplain.

5.1 Geology

The surface geology is primarily a result of erosional and depositional events which took place approximately 60 million years ago. The "Laramide orogeny" as it is called, resulted in the formation of the Rocky Mountains, the Purcell Mountains and the young Rocky Mountain Trench. Following this period, a cycle of erosion and sediment deposition occurred that deposited extensive and deep sediments in the Trench. Since the Cenzoic era (60 million years ago to present) the trench was glaciated at least three times. Each glacial event shaped the topography and left unconsolidated sediments on the trench floor.

The preservation of glacial sediments deposited in straight parallel ridges trending north-south in wide portions of the trench opposite tributary valleys indicates that when the ice cover began to recede, the tributary valley glaciers receded before the main trench glacier. The observation that some valleys, such as Toby Creek, are hanging valleys substantiates this conclusion. The absence of end moraines and ice thrust ridges suggest that the glacial retreat was continual and gradual.

As the climate became more temperate, melting of the glacier ice caused the glacier to retreat north. Meltwater was produced and carried to the front of the glacier in channels where it was discharged dropping its sediment load to form outwash aprons and meltwater channels. As the glacier withdrew from the trench, glaciofluvial channels and associated deposits were exposed as eskers and channel deposits. With continued recession of the glaciers, meltwater continued to modify the exposed glacial till through erosion and deposition.

At some point, the trench trough was dammed, possibly by sediment or ice, at Canal Flats. Meltwater flowing from the glacier north of Canal Flats collected to form Glacial Lake Invermere which extended 80 miles north to the present site of Parson. Meltwater streams feeding the lake deposited large quantities of silt to depths exceeding 100 feet on the valley floor. Eventually the dam at Canal Flats was broached and the waters of the lake flowed south eroding a deep channel through the glaciolacustrine silts. (thus the white clay slopes on sees at sites such as the Athalmer bridge). Deposition, throughout the trench, by streams and surface runoff produced alluvial and colluvial fans, deltas, channel deposits and granular deposits. Erosion by streams and rivers produced terraces, fluvial channels and gullies. The glaciolacustrine deposits in the centre of the valley were eroded producing glaciolacustrine silt terraces flanking a central depression. Continued fluvial sedimentation produced deltas and fans which dammed portions of the trench at Canal Flats, Dutch Creek and Toby Creek forming Columbia Lake, Lake Windermere and the Columbia River floodplain.

After deglaciation a complex history of erosion and deposition produced the current landscape. Organic rich wetlands are generally the youngest deposits. These organic rich deposits developed in the restricted subaqueous or water saturated portions of the Columbia River floodplain.

Although the Columbia River presently flows north from its headwaters in Columbia Lake and the Kootenay River flows south past Canal Flats, Haughton (Haughton, 1978) concluded that there have probably been several reversals of these rivers since deglaciation of the area.

All of these processes have created a deep and very complex mix of gravel deposits overlain by thick silt deposits that define the groundwater processes we see at play in the valley today. This complexity makes the study of groundwater resources difficult in this valley.

5.2 Groundwater Hydrogeology

A summary of the groundwater exploration in the study area is presented in Figure 57 (Ministry of Environment, 2009). This figure presents the location of water wells that are recorded within the provincial database. The following text provides a generalization of the data available from these well records.

Groundwater exploration on the silt terraces that flank the Columbia River typically encounter varying thickness of silt and till deposits overlying bedrock. These deposits usually less than 30 metres in thickness are typically marginally suitable for supplying single family residential development and are typically limited by water quality or quantity issues. Yields are typically less than 1 Imperial gallon per minute and deeper wells into bedrock exhibit undesirable characteristics including elevated hardness and dissolved metals concentrations.

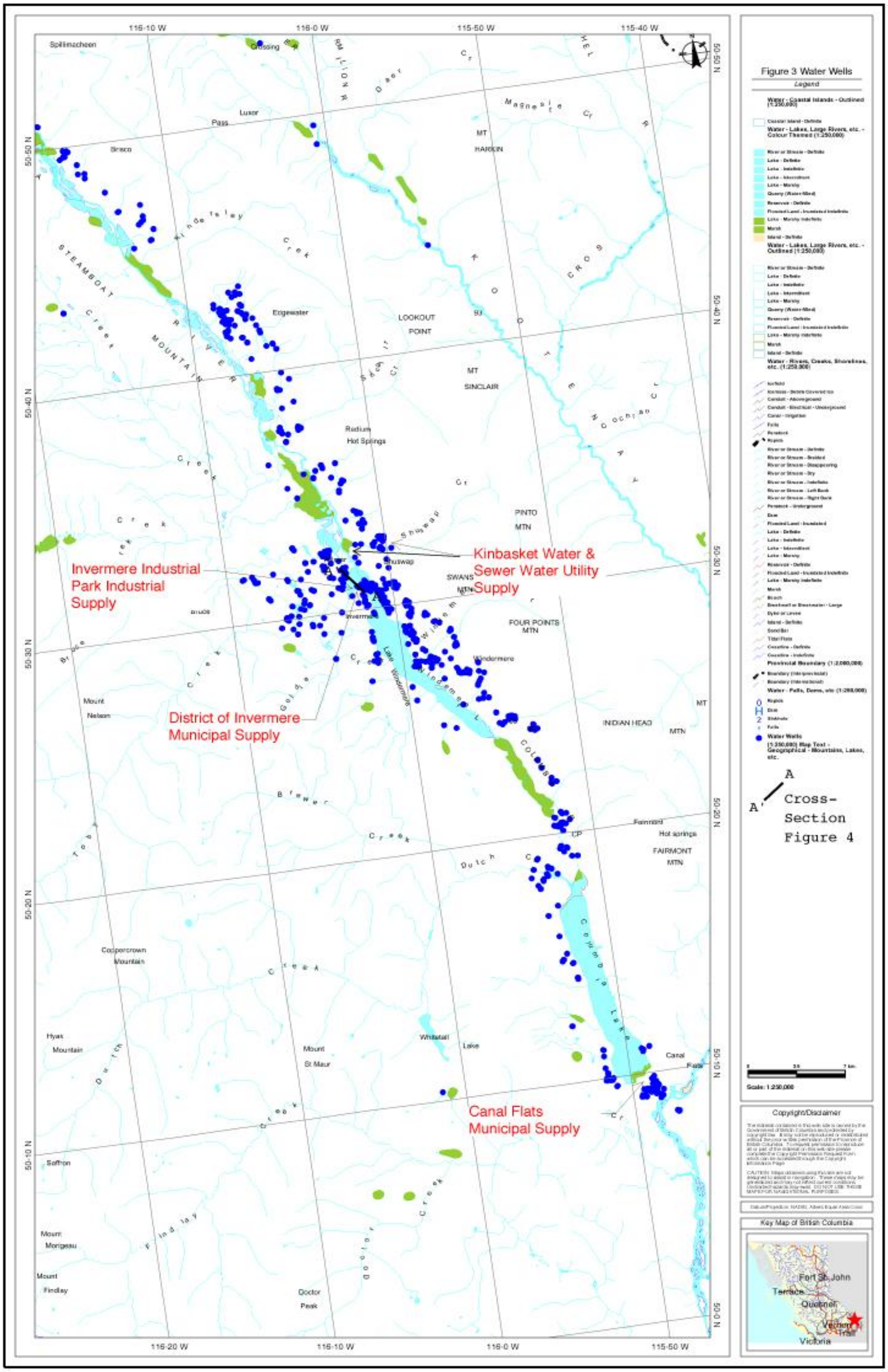

Figure 57 Groundwater wells

In the lower ends of creek drainages like Shuswap Creek and Windermere Creek more prolific wells have been drilled into the alluvial deposits that infill within the glaciolacustrine terrace deposits and above the bedrock outcrops. These shallow wells produce higher yields of groundwater; however this groundwater is typically classified as “groundwater under direct influence” (GUDI) of surface water. In other words, these groundwater sources are very dependent on surface flows in nearby creeks and the flows in the headwaters of these creek drainages. Similar deposits are encountered along Abel Creek and Goldie Creek west of Lake Windermere.

5.2.1 Groundwater in the Canal Flats area

The Village of Canal Flats has drilled three municipal supply wells to depths of approximately 10 m below ground surface. These wells rated to 330 Imperial gallons per minute intersect a high yield unconfined gravel aquifer at depths of 5 m to 10 m below ground surface. This aquifer has a pronounced hydraulic gradient trending north - northwest from the Kootenay River to Columbia Lake apparently indicating a subsurface flow from the Kootenay River system into Columbia Lake and the Columbia River system (Golder Associates, 2007). The Village’s current average daily demand is approximately 67 Imperial gallons per minute.

5.2.2 Groundwater in the Windermere Lake/Toby Creek area

Within the Trench, near the District of Invermere, the majority of well drilling has been to shallow depths sufficient to produce water for a single family residence. Approximately 41 residential wells (see Kafer well and Westergaard well as shown on Figure 57) are drilled into a shallow unconfined aquifer at depths of 30 m or less (Golder Associates, 2003). These wells typically target shallow sands and gravels associated with the alluvial fan of Toby Creek and the static water levels appear to closely relate to the static water level of Lake Windermere.

The District of Invermere utilizes a dual source municipal water supply system. The District has a historic surface water source from Goldie Creek and the Paddy Ryan Lake system that until 2009 was the sole source of municipal water. In 2009, the District connected a “deep aquifer” groundwater well into their supply system. This groundwater well is located within Athalmer (see Town of Invermere MW01-04 well on Figure 58) and extracts water from a gravel deposit located approximately 60 m below ground surface. The well is rated at approximately 800 Imperial gallons per minute capacity; however the District is not currently pumping the well at this extraction rate. Golder Associates Ltd. has classified this aquifer as semi-confined (Golder Associates

2004). Golder Associates also summarized that *"the similarity in major ion chemistry between the groundwater and surface water samples in the area suggest that both the groundwater and surface water are likely originating from the same sources. The concentrations of calcium, magnesium, potassium, hardness and total dissolved solids suggests that the Lake Windermere water is groundwater diluted by precipitation and runoff."* Golder concluded that the deep aquifer was suitable for a municipal water supply, provided the District *"develops and implement groundwater protection measures for the aquifer"*.

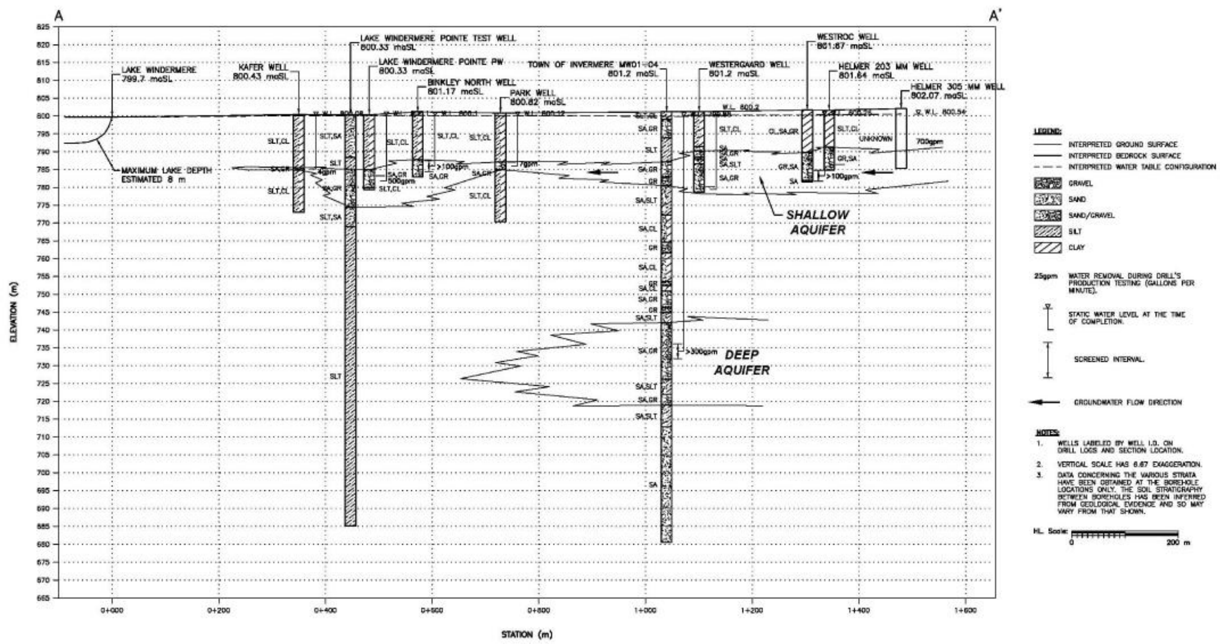

Figure 58 Conceptual cross-section through Toby Creek Alluvial Fan Complex (Waterline Resources, 2005)

During drilling to identify a groundwater supply the District investigated alluvial and glaciolacustrine deposits at one location within the Athalmer area to a depth of approximately 240 m below ground surface without encountering bedrock. This borehole did not encounter coarse granular deposits below a depth of 60 m; however it did indicate that the thickness of saturated sediments in the valley centre exceeds 240 m. These thick deposits from depths of 60 m to 240 m were generally classified as silts and fine sands at this one drilling location, however they may vary across the Trench floor and may include coarser fractions at other locations.

Within the Invermere Industrial Park, there are a number of high yield groundwater wells that encounter gravel deposits at depths of less than 30 m below ground surface. These wells have been rated for extraction up to 700 Imperial gallons per minute (see

Helmer wells and Westroc well on Figure 57); however the extraction is typically less than this and is seasonal in nature related to dust control, washing of aggregate and concrete production.

5.2.3 Groundwater in the Shuswap Reserve area

The Kinbasket Water & Sewer Company provides water supply and wastewater treatment services on the east side of the Columbia River, east and northeast of the District of Invermere. The water supply is derived from a series of groundwater wells to depths of approximately 35 m located in the vicinity of Shuswap Creek. Kinbasket Water & Sewer Company has drilled additional groundwater exploration wells on a terrace within the valley floor north of Invermere. These wells intersect gravels and sands at depths of approximately 60 m below ground surface and reportedly have high yields in excess of 200 Imperial gallons per minute. However, they are not connected to the utility system at this time.

5.2.4 Contributing Groundwater Recharge or Replenishment

Municipal wastewater treatment within the study area typically provides some recharge or replenishment of the near surface groundwater system. The Village of Canal Flats, Fairmont Hot Springs, the District of Invermere, and the Village of Radium Hot Springs operate wastewater treatment systems that involve land application of treated effluent, typically via infiltration basins. It is believed that private utility operators including Kinbasket Water & Sewer and Windermere Water & Sewer, a newly formed utility operating on the east side of the Columbia River, also utilize land application of treated effluent. From a water quality perspective, sewage treatment facilities are, in some cases (Invermere) upstream (in terms of groundwater flows) of the source wells and we are depending on natural processes within these deep gravel beds to remove any E. Coli or other contaminants (B. Jamieson, pers. comm).

5.3 Summary

The glacial deposition environment, the migration of glaciers and associated outwash features, and the interaction with intersecting alluvial deposits from Dutch Creek and Toby Creek create a complex hydrogeology within the study area. However, based on a review of the geology and hydrogeology data within the study area, it appears that in general the groundwater extractions from the current residential, municipal, industrial, and water utility consumers within the valley floor are ultimately connected, through layers of varying permeability and through varying flow paths, to the surface water elevations within the Columbia River floodplain and tributaries to the floodplain.

In the longer term, local communities and other water users need to recognize that even if their water supply comes from floodplain wells, that changes in surface flow in the Columbia River and its tributaries will ultimately affect that water supply and they need to be concerned about the fate of surface water flow in streams such at Toby Creek.

6.0 Water Quality Monitoring

MacDonald and Bisset (2009) and Oliver (2002) outlined the general water quality issues in the upper Columbia watershed. The objective of this report is not to re-state these issues, but to provide a more comprehensive search of water quality monitoring programs being conducted in the study area. Oliver (2002) has provided an extensive list of water quality monitoring sites in the upper Columbia River watershed. Table 7 presents another literature search. Table 7 shows that most of the water quality monitoring studies are conducted above Radium. Table 8 outlines potential threats to water quality in the region, also presented in Oliver (2002). Both this study, and Oliver (2002) show that there are no water quality datasets at one site for more than ten years and suggest long-term water quality monitoring programs be maintained in the upper Columbia River watershed over longer time frames to document changes over time.

Table 7 Water quality monitoring in the upper Columbia River watershed

WQ MONITORING PROGRAM	PERIOD	VARIABLES	COMMENTS	SOURCE
Invermere & Radium Sewage Plants	1977-78	Sewage effluents	new treatment plant in '76; quality improved in '77	Ministry of Environment (1981)
Columbia & Windermere Lakes WQ	1975-78	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	Columbia Lake alkaline, hard, high o2; Windermere Lake oligotrophic	Ministry of Environment (1981)
Jumbo Creek & Toby Creek	1975-78	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	Treated sewage from Invermere causing agal growth, High Barium levels from Mtn Minerals	Ministry of Environment (1981)
Sinclair Creek	1975-78	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	High Arsenic loads from Radium Hot Springs Resort	Ministry of Environment (1981)
Fairmont Creek	1975-78	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	High Arsenic, Chlorine, and other minerals from Fairmont Hot Springs Resort	Ministry of Environment (1981)
Windermere Creek	1976-78	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	High dissolved solids, solids, and hardness	Ministry of Environment (1981)
Columbia and Windermere Lakes, Columbia River, and Windermere Creek Study	1972-83	PH, Metal, Minerals, Hardness, Alkalinity, Fecal Coliforms, etc	Intensive study/summary of both soils and water quality building on the Kootenay Phase I & II reports	McKean and Nordin (1985)
Windermere Lake Leachate Detection Study	1987	Lechate inflows from onsite wastewater disposal	Positive flurometer responses most frequent along developed shoreline	Wiens and Noone (1987) from Masse & Miller (2005)
Reconnaissance Survey of Windermere Lake	1994	Fish sampling	Abundance of Kokanee in Windermere Lk & Westslope Cutthroat Trout in Windermere Ck	Griffith (1994) from Masse & Miller (2005)

Windermere Lake Water Quality Monitoring Program	1999	Water quality and macrophyte abundance	Eutrophication in Windermere Lake	Courtney (1999) from Masse & Miller (2005)
Benthic Macroinvertebrates in Windermere Creek	1999	Benthic invertebrates	species diversity and abundance decreased	Westcott (1999) from Masse & Miller (2005)
Windermere Lake Quality over past 300 years	1998	Historical water quality from sediment core	Diatom levels and algal production increase after settlement in 1950s	McDonald (2000)
Windermere Ck Water Resources Inventory Report	1999	Automated water quality and quantity	Hardness, Conductivity, Metals, & Fecal Coliforms all exceeded standards	Westcott et al. (2000) from Masse & Miller (2005)
Lake Windermere Management Strategy	1971-99	Summarized monitoring results over 30 years	Windermere Lake Oligotrophic tending to mesotrophic	Urban System's Ltd (2001) from Masse & Miller (2005)
Upper Columbia Monitoring Program	2002-03	Effluents from treatment plants, tailings from mines, Lake water quality	Results not published at time of Masse & Miller	Masse & Miller (2005)
Windermere Lake Source to Tap assesment	2005	Water quality and quantity	Results not published at time of M&M report	MOH & MOE (2005) from Masse & Miller (2005)
Kicking Horse River above Field, BC	2000, 2006	Water Quality 2000 & Benthic Macroinvertebrate monitoring 2006	No environmentally significant changes in water quality; benthic results not included	MOE, Env Can & Yukon dept of Env (2007)
Wildsight Lake Windermere Project	2005-09	Monitoring Water Quality at Windermere Lake, Windermere Creek, Columbia River (Faimont), Holland Creek, Abel Creek, Goldie Creek, Brady Creek	Results not published yet, being analyzed by MOE	Rachel Darvill and Heather Leschied (personal communication, 2009)
CBT Water Quality Monitoring Group	2009	Horse Creek and Hospital Creek	Results not published yet, being analyzed by MOE	Heather Leschied (personal communication, 2009)

Table 8 Potential threats to water quality in the upper Columbia River watershed

Potential Threats to Water Quality	Comments	Sources
Radium Hot Springs Resort and Fairmont Hot Springs Resort	Water downstream of the resort in high in mineral content, including arsenic, chlorine and salts that make it unsuitable for human consumption and food-crop irrigation	Masse & Miller (2005), Ministry of Environment(1981)
Ski Resorts	3 Ski Resorts in the basin contribute to effluent discharges and significant water withdrawals for sanitation and snowmaking: Kicking Horse Mountain, Panorama, Fairmont, + Jumbo Glacier (proposed)	Masse & Miller (2005), Jumbo wild (2009)
Golf Courses	8 Golf courses in the Upper Columbia Basin affect water quality and quantity through the use of fertilizers, pesticides, herbicides and irrigation requirements: Greywolf, Eagle Ranch, Copper Point, Riverside, Mountainside, Windermere Valley, Spur Valley, Golden	Columbia Valley Golf (2009), Masse & Miller (2005), Env.Can. (2004)
Lakeside Developments	shoreline development and associated recreational and waste disposal activities threaten water quality. Concern over discharge from septic systems on water-bodies	Masse & Miller (2005), McKean and Nordin (1985), Ministry of Environment (1981), McDonald (2000), Wiens (1987), Westcott (2000), Env.Can. (2004)
Agriculture	Significant water withdrawals and nutrient loading	Masse & Miller (2005), McDonald (2000), McKean and Nordin (1985), Wiens (1987), Env.Can. (2004)
Canadian Pacific Railway	Rail line that runs along water bodies in Columbia Valley presents a danger of spills into waterbody	Masse & Miller (2005)
Forestry	Significant Forestry Operations in Area that affect the state of the basin, Further Research Needed	Env.Can. (2004)
Mining	Gypsum mining in Windermere Creek area causes high levels of dissolved solids, hardness and sulphate. Decommissioned Mountain Minerals Mine site and tailings on Jumbo & Toby Creeks	Masse & Miller (2005), Ministry of Environment (1981), McKean and Nordin (1985), Westcott (2000), Env.Can. (2004)
Dams/Diversions	Spillimacheen Dam; Kootenay River Diversion (proposed and denied twice in early 80s and 2008-09). Changes to flow regime have the potential to produce major changes in water quality	Ministry of Environment (1981),Wildsight (2009), Env.Can. (2004)

6.0 Conclusions and recommendations

This study has identified current trends in hydrometeorological conditions, described the hydrological and hydrogeological settings, outlined water supply issues, and provided a limited assessment of water quality monitoring in the upper Columbia River watershed. Positive trends in mean annual air temperature and the ratio of rain to snow suggest the Columbia River watershed is experiencing a shift towards a warmer climate. Streamflow trends are much less conclusive. Data from the only stream gauge in the upper watershed, on the Columbia River at Fairmont, suggest environmental change in the upper watershed have altered the hydrological regime of this system. This analysis provides context for potential adaptation measures that will be required. However, there are insufficient data to clearly identify streamflow trends over the entire study area. An analysis of water supply vs water demand also provides context for adaptation, however, results are not strong due to the lack of data for both water supply and demand in the upper tributaries of the Columbia River.

The upper watershed (Above Radium Hot Springs) is likely the portion of the watershed most sensitive to climate change. This region also faces the largest water demand issues. To reliably simulate each individual watershed within this region a significant increase in both water supply data (hydrology, meteorology) and demand (actual water use) data would be required. This increase in monitoring would likely not be feasible given at least five to ten of years of data would be required to make the data useful in any type of management context. This provides a significant challenge for the upper Columbia Region.

To reliably simulate the water balance in the study region, accounting for both water supply and demand, a number of datasets would be required. Outlined below are the specific recommendations of data that would be very important in calculating the most realistic water balance:

- Given the hydrological regime is dominated by snowpack; the most significant data gap is reliable snow observations, as there are no long term snow data in the study area. It would be useful to install two snow pillows, one on each side of the upper watershed. At each snow pillow, temperature and wind data should also be collected. Monthly snow surveys would be useful for determining the overall volume of snow over the season. Snow pillows and snow surveys, however, require a significant amount expertise to install, maintain and conduct.

- If snow pillows are not feasible, then high elevation temperature data should be collected. Data are often available from fire towers, however, temperature data loggers can be purchased and installed at a very reasonable cost and with little expertise. These data would be very useful for detecting changes in temperature at high elevations and the potential consequences for glaciers and snowpack.

- With the range of streamflow conditions in the watershed, streamflow at a series of representative streams should be monitored in the upper portion of the study area. There are adequate data on the mainstem of the Columbia River and for the main tributaries at the north end of the study area. The most significant hydrological data gaps are on the tributaries at the upper end of the drainage. It would be useful to augment the current network to include tributaries on both sides of the watershed. Streams should be defined by:

    - Current and future water use (irrigation, snow making, human consumption).
    - Hydrological regime (glacial fed, groundwater dominated, surface water dominated).
    - Include small watersheds on the east side of the valley (e.g Shuswap Creek) and the larger watersheds (e.g Toby Creek, Dutch Creek) on the west side.
    - These two attributes will enable generalizations to be made for other streams being affected by the same types of issues. It would be useful to include a range of uses and hydrological regimes to capture the variability in potential issues facing the watershed. The watersheds identified as data lacking are highly constrained to the upper reaches of the study area. Key watersheds are outlined in Figure 59 where augmented hydrometeorological data collection would be beneficial. The orange and red watersheds represent those with little and no hydrometric data respectively.
    - The stream gauge at Fairmont should also be re-installed if there are no significant issues at the site.

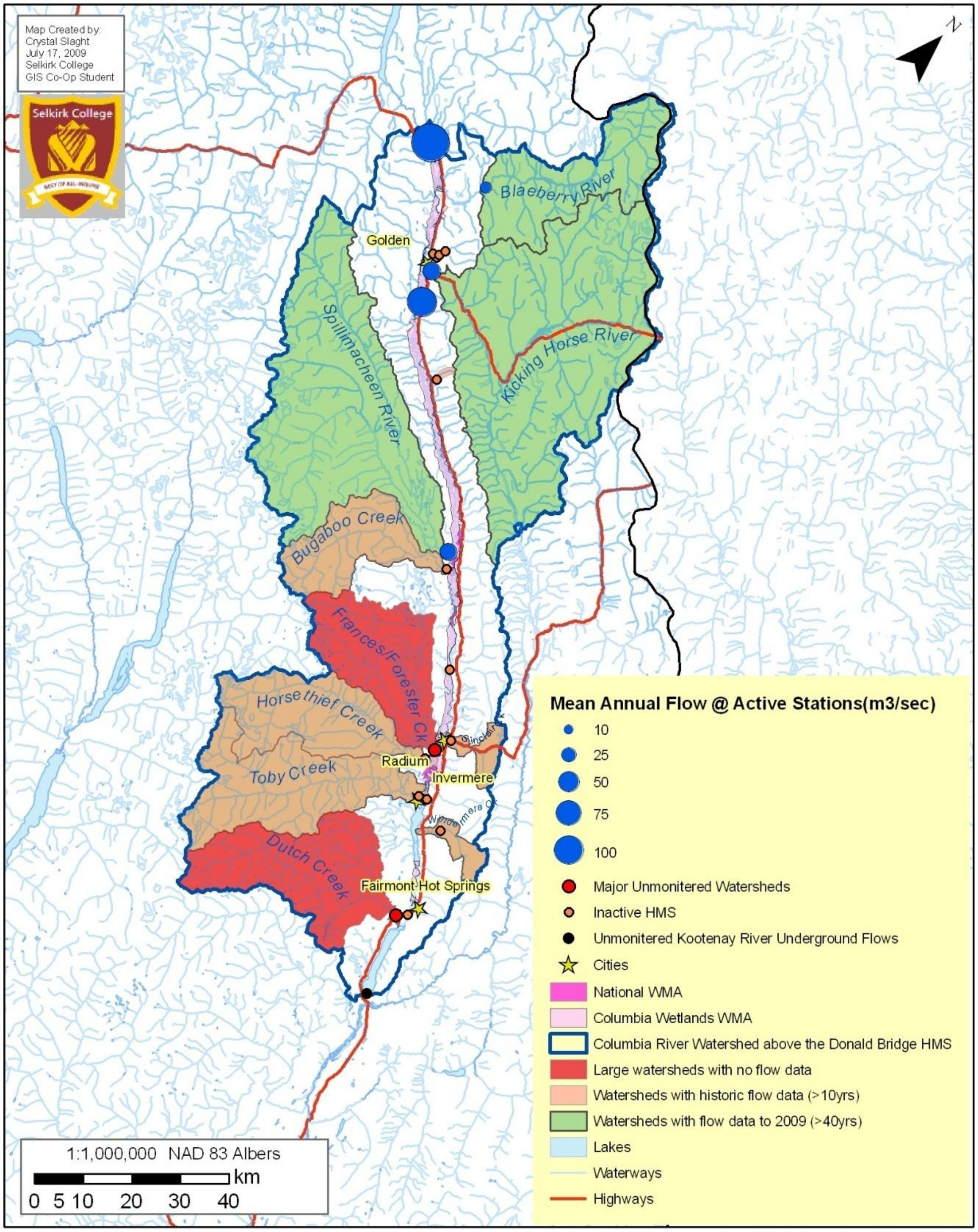

Figure 59 Watersheds outlined based on data record (by: Crystal Slaught)

- Data on water demand is significantly lacking, both for allocation and actual water use. Further work is required to determine all of the potential water users, as it is unknown whether the data available from the BC water atlas (Ministry of Environment, 2009) are up to date or if these data approximate actual use. Effective monitoring of actual use by water users would be required for a relatively long period (roughly 10 years) before a detailed water balance could be calculated. Also, until there are data available to determine the relationship between irrigation water licenses and actual use of water, water demand estimates will be difficult, these issues should be discussed with local ranchers and other users.

The current state of knowledge on water quality data is limited. There is a relatively good dataset being established at the Nicholson bridge on the Columbia River, this site should be maintained. The Wildsight Lake Windermere project provides an excellent opportunity to increase and continue water quality monitoring in this watershed. The project is presently being expanded upstream along the Fairmont reach of the river and into Columbia Lake.

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