WATER SCIENCE SERIES

Cowichan River: A Summary of Historical Disturbances, Water Use Pressures and Streamflow Trends

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BRITISH
COLUMBIA

No. 2017-05

The **Water Science Series** are scientific technical reports relating to the understanding and management of B.C.'s water resources. The series communicates scientific knowledge gained through water science programs across B.C. government, as well as scientific partners working in collaboration with provincial staff. For additional information visit: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-science-data/water-science-series.

ISBN: 978-0-7726-7178

Citation:

Pike, R.G., E.L. Young, J.D. Goetz and D.L. Spittlehouse. 2017. Cowichan River: A Summary of Historical Disturbances, Water Use Pressures and Streamflow Trends. Water Science Series. WSS2017-05. Prov. B.C., Victoria B.C.

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Cover Photograph:
Cowichan River below the highway bridge, near Duncan, B.C. - June, 2011. Photo: Robin Pike.

ACKNOWLEDGEMENTS

The authors thank the following peers for their thoughtful and careful reviews of this report: Mike Wei, Klaus Rathfelder, Pat Lapcevic, Neil Goeller, Sylvia Barroso, John Baldwin, and Celine Davis. The authors also thank the editors of the Water Science Series for their publication assistance.

EXECUTIVE SUMMARY

The Cowichan River basin is home to nearly 50,000 people and is part of the traditional territory of the Cowichan First Nation. The climate of the basin is a mixture of Maritime and Mediterranean style climates. Mean monthly temperatures are lowest in December and January (2.7°C), while the warmest month on average is August (18°C). Mild-winters result in substantial snow accumulation occurring only in the upper elevations. Precipitation levels vary throughout the basin and it is generally drier in the eastern portion, wetter in the west and wettest in the uppermost mountainous areas.

Prior to the 1850's, the Cowichan River was most likely in a natural state with limited amounts of disturbances along its riparian areas and within the stream channel. At the time, the Cowichan River was described as a long and tortuous river that was exceedingly rapid, except for smooth water in the canyon section. In this time period, the Cowichan River was characterized to be 56 km long, dropping 170 m, with 130 rapids and 30 sets of falls that were up to 5 m high.

The first large-scale disturbance of the Cowichan River was a period of log driving from 1890 to 1908. To facilitate log driving, explosives were used to remove rocks, hang-ups or other impediments to downstream log movement. This resulted in major changes in channel morphology of the Cowichan River; 29 waterfalls were eliminated, leaving only one major falls (Skutz), and the number of rapids were reduced from 130 to approximately five.

Blasting to facilitate log driving was not the only modification that was potentially affecting the stability of the Cowichan River in the early part of the 1900's. For several decades up until the mid-1960's, dredging was performed as a flood control measure in the lower river floodplain, near the town of Duncan. Materials dredged from the streambed were deposited on the channel banks to act as dikes during floods. These materials likely cut off many side channels, thereby affecting access to important fish habitat. One of the most significant alterations of the flow regime of the river, however, occurred in the late 1950's with the installation of a weir at the outlet of Cowichan Lake. The installation of the weir provided storage in Cowichan Lake and the ability to augment the summer low flow regime of the Cowichan River.

Analysis of pre- and post-weir streamflow data demonstrated that summer low flows became less severe after weir construction with a post-weir September median discharge of 7.50 cubic metres per second (cms) compared to a pre-weir September median discharge of 3.62 cms. Low flows during the pre-weir control period went down as low as 0.425 cms (September 10, 1944) which is almost an order of magnitude lower than the minimum flow observed in the post-weir period. Controlled releases of water from the weir have eliminated the extreme lows that occurred previously in the system.

Weir control, however, has not been the only recent influence on streamflow. Surface water diversions have increased substantially over the last 65 years. The number of surface water licences has tripled, from 167 licences in 1954 to 501 licences by 2012. Similarly, the number of groundwater wells increased from 445 wells in 1954 to 2843 wells by 2012. In addition to water diversions, there are also several effluent inputs to the Cowichan River from sewage and aquaculture operations.

These disturbances and water pressures in the Cowichan River basin have had a cumulative influence on the hydrologic regime of the river. Two Water Survey of Canada (WSC) stations on the Cowichan River, called the 'Upper Station' (08HA002, near Lake Cowichan) and the 'Lower Station' (08HA011 near Duncan), were analysed for streamflow characterization and trends in this report. Analysis of the hydrometric data uncovered some interesting relationships between the stations. The Upper Station has a lower mean annual discharge than the Lower Station (45 cms vs. 53 cms). This is expected as the Lower Station has a bigger catchment area. Monthly mean discharges are always highest at the Lower

Station, for all months except for June through September, possibly reflecting the seasonal recharge to the aquifers under the river and withdrawal pressures downstream of the Upper Station. Typically, low flows are lowest, both annually and on a monthly basis, for the Lower Station; illustrating streamflow losses from the surface water system downstream. Specifically, the biggest difference can be seen in August, where at 7 cms, the Upper Station exhibits this flow (or lower) nearly 40% of the time. In contrast, the Lower Station recorded this level (or lower) 85% of the time (August 85th percentile=7.08 cms) from 1965–2015. While smaller in drainage area, the Upper Station has higher flow volumes for 7-day and 30-day low flows return periods (i.e., is less severe). The 7-day, 10-year low (7Q10) at the Upper Station is 4.9 cms, whereas the Lower Station is 3.5 cms, demonstrating a loss of water between the two WSC stations. Similarly, the 30-day statistic illustrates the same pattern; the Upper WSC Station 10-year, 30-day low is 5.2 cms, whereas the Lower Station is 3.7 cms.

Human pressures on groundwater resource use from industrial, aquaculture, agricultural and urban developments have also been increasing in the Cowichan basin. In general, groundwater levels in the lower Cowichan basin display a seasonal fluctuation that is in a synchronous pattern with surface water discharge. BC State of Environment reports groundwater levels (mean) measured at two local Provincial Observation Wells to be in declining trends over the long-term period of record.

This study analysed trends from 1965–2015 for various surface and climate variables for the Cowichan basin. For the trending period, this study found statistically significant trends in rising annual, January, June and July air temperatures. While no statistically significant trends were detected in this time period for changes in the amount of precipitation, some patterns were found in a greater occurrence of days with higher daily total rainfall amounts in the latter half of the trending period. No snow data of similar length of time to the trend period were available to analyse in the report.

Trends in groundwater levels as detailed in the 2015 BC State of Environment report (2015a, 2015b) from two wells in the Provincial Observation well network below Duncan, BC detail that groundwater in these observation wells are generally in a state of decline over their respective periods of record. A more detailed description of the groundwater resources and relationships in the Cowichan basin can be found in Lapcevic et al. (in press). Surface waters in the Cowichan basin are exhibiting a similar trend, with decreases over the trending period for July, August and September hydrologic summary statistics. Statistical trends in flow variables highlight a tendency for decreasing dry weather flows over the trending period, particularly in the latter half of the period where there may have been a step shift in the climate-streamflow regime (vs. continuous linear trend).

The large scale channel modifications that have occurred since the late 1800's in the Cowichan basin have set in place an important legacy of stream channel disturbances that continue to this day. Water use in the basin has increased steadily through time, putting further pressures on aquatic habitat. As a result of the various water stressors, water use pressures and climate drivers, streamflow has been changing in the Cowichan River. While this report does not attribute causal mechanisms for this decline, the end result is the Cowichan River will require increased attention in the future to mitigate existing water stressors, habitat disturbances, continued water pressures and ever changing natural drivers.

CONTENTS

1. INTRODUCTION

The Cowichan River basin is home to nearly 50,000 people (Cowichan Valley Regional District 2015) and is part of the traditional territory of the Cowichan First Nation. In the heart of the basin lies the Cowichan River, a highly valued water course that is designated both as a Provincial, and as a Canadian Heritage River (http://www.env.gov.bc.ca/bcparks/heritage_rivers_program/). Within the basin, there are many activities that compete for water resources that make the maintenance of water supply for healthy ecosystems challenging. These activities include fisheries, urban/rural development, industrial activities (e.g., pulp and paper production), agriculture, aquaculture, domestic use, recreation, and cultural values. The Cowichan River basin has a long history of disturbances and pressures that have led to significant changes in the river's flow regime. This report summarizes some of the major disturbances and water use pressures that the Cowichan River has faced over the last century, and presents a characterization of water and climate as well as associated trends for the area.

1.1 Location

The Cowichan River basin is located on southern Vancouver Island, British Columbia (Figure 1). The river originates in Cowichan Lake and flows primarily east towards the city of Duncan, discharging into the estuary at Cowichan Bay and then into the Salish Sea. Major tributaries to the Cowichan River include the Koksilah River, Bear Creek, Somenos Creek, and Holt Creek. The river's largest tributary, the Koksilah River, was not included in the statistical analysis of this report because it joins the Cowichan River near the estuary at the basin outlet below the lower Water Survey of Canada hydrometric station. Elevations in the basin range from sea level to over 1500 m (Mt. Landale). Cowichan Lake is located in the centre of the basin and is supplied by the tributaries flowing into it from the surrounding mountains.

Figure 1: Cowichan River basin on Southern Vancouver Island, British Columbia.

2. HISTORIC DISTURBANCES AND CHANNEL CONDITION

2.1 Pre-Disturbance River Condition

Prior to the 1850's, the Cowichan River was most likely in a natural state with limited disturbances along the riparian areas and within the river channel. The only development in, or near, the river would likely have been traditional First Nation fish weirs and limited localized forest clearing adjacent to settlements. Early accounts of riparian and stream conditions are interesting to contrast to present day. One early account of the historical conditions of the Cowichan River comes from the report of an expedition led by Robert Brown in 1864 (as detailed in Saywell 1967). In that expedition, Brown characterized the Cowichan as a long and tortuous river that was exceedingly rapid, except for some smooth water in the canyon section. Brown documented a river with few bars, banks that were treed to the water's edge, and a river divided into multiple channels in many places with a breadth varying from 6 m to 12 m. He noted that below Squitz (Skutz) falls, the bed materials were largely rounded, well-worn stones (Saywell 1967). In reviews of early written records (Saywell 1967, Drushka 1992), the Cowichan River (at that time period) was characterized to be 56 km long, dropping 170 m, with 130 rapids and 30 sets of falls that were up to 5 m high. These early channel conditions are very different from what exists today, likely a direct result of a history of channel disturbances over the last 150 years.

2.2 Disturbance History

The first large scale disturbance of the Cowichan River was a period of log driving that occurred from 1890–1908. At this time, log driving was the only means to transport massive volumes of timber cut from the hillsides surrounding Cowichan Lake down the river to the estuary. To facilitate log driving, explosives were used to remove rocks, hang-ups or other impediments to downstream log movement, and channel diversions were minimized or blocked to ensure that logs stayed on course and that jams did not occur (Drushka 1992). As part of the preparation for log driving, a sluice dam was constructed at the outlet of Cowichan Lake to control water levels and flow rates in the river. Cut logs of fir and cedar approximately 18 m in length and up to 2 m in diameter were stockpiled behind the dam within 'boom sticks' until water levels were right for log driving (Drushka 1992, Saywell 1967). Further details about the operation of the dam and to what extent it may have affected lake and river levels are unknown.

The first log drive down the Cowichan River occurred in the winter of 1890/1891. This initial attempt was deemed a failure as a bridge was destroyed and much timber was lost along riverbanks and to log jams (Drushka 1992, Saywell 1967). Several successful log drives occurred after this date with one of the largest occurring in 1906 (13 million board feet) with an estimated 4-5 million board feet lost in the process (one board foot is a one foot wide by one foot long by one inch thick piece of lumber) (Rajala 1993). During this drive, four 30 m boom sticks broke free and caused a large log jam in the canyon below Skutz Falls. The jam was released with dynamite, and as a result, the white bridge in Duncan (Figure 2) was nearly destroyed. The last log drive down the Cowichan River occurred in 1908 with the anticipated completion of the rail line to Cowichan Lake in 1913 (Drushka 1992, Rajala 1993). However, the legacy of blasting used to facilitate log driving was likely responsible for the major changes in channel morphology of the Cowichan River; 29 waterfalls were eliminated, leaving only one major falls (Skutz), and the number of rapids were reduced from 130 to approximately five.

Figure 2: White bridge (Presently the site of the Allenby Road bridge) over Cowichan River, Somenos Village, circa 1910. (Image courtesy of Cowichan Valley Museum and Archives, CVM 1988.10.7.2).

With the completion of the rail lines, and later a road network, the forest industry was no longer dependent on the Cowichan River as a transportation corridor for harvested timber. Over the course of many decades, much of the old growth timber was harvested within the Cowichan basin. Because the majority of the basin is held and managed as private forest lands, information on the historical rate of removal and equivalent harvested area could not be included in this report. However, in present day, the majority of the Cowichan basin is covered in a mixture of silvicultural openings and regenerating second growth forests with valley bottoms covered in a mixture of forest, agriculture, residential and urban landscapes.

Forestry was not the only modification that was potentially affecting the stability of the Cowichan River in the early part of the 1900’s. For several decades, up until the mid-1960’s, dredging was performed as a flood control measure, near the town of Duncan. Materials dredged from the streambed were deposited on the channel banks to act as dikes during floods. These deposited materials cut off many side channels, thereby affecting fish access to off channel habitat. In the mid 1980’s, a more permanent dike structure was constructed on the lower Cowichan River. The above modifications straightened the river channel which accelerated flow rate. Removal of large woody debris and other navigation hazards in this area also reduced and simplified the quantity and quality of main channel aquatic habitat.

Perhaps, one of the most significant alterations to the flow regime of the river occurred in the late 1950’s with the installation of a weir at the outlet of Cowichan Lake. Construction of this weir was authorized in June 1956 when the Crofton Mill was granted a licence, under the *B.C. Water Act*, permitting the storage of 39.5 million cubic metres (m^3) of water (Water Licence CLW23085). The purpose of this weir was to store water in Cowichan Lake for release into the river during the low flow season as a more reliable water supply for the mill. The typical period of use for the weir is between April 1st and October 31st each year. In January 1965, another water licence was issued to the Crofton

Mill authorizing modifications to the weir and additional storage of 22 million m^3 (Water Licence CLW29542). This licence stated that "…construction had already begun and must be completed by December 31, 1966", as such, the exact date of weir completion is not known. The diversion structure for withdrawal of surface waters from the Cowichan River is located near the town of Duncan (Figure 4, see Catalyst Paper Corp Licence) approximately, 39 kilometres downstream from the outlet of Cowichan Lake.

3. HISTORIC AND CURRENT WATER USE PRESSURES

The Cowichan River has always been a highly valued system for its water resources and fisheries. Use of water from the river has steadily increased since the early 1900's. More recently with the installation and continued use of the weir at Lake Cowichan, as well as an increase in both surface and groundwater use, pressures on the Cowichan River have and continue to intensify. To help highlight the increased water demands in the Cowichan basin, this section compares the surface and groundwater uses in 2012 with those in 1954 (prior to any known construction/operation of the Cowichan Lake weir).

3.1 Surface Water Licenses

Surface water licences authorize the diversion of water from a surface water body (e.g., lake, river, stream) for many different uses. Surface water diversions within the Cowichan basin have increased substantially over the last century. According to Provincial Water Licence Data (BC Geographic Warehouse 2015a), the number of surface water licences has tripled, from 167 total licences in 1954 to 501 total licences by 2012 (Table 1).

The highest proportion of licences, both past and present, are allocated to supply domestic needs and divert approximately 0.000026 cubic metres per second (cms) or less, which is the equivalent usage of one household (approximately 500 imperial gallons per day, per single family household)(Table 1). However, the biggest increase between the two time periods in the number of licences has been for large users (0.0014 and 0.0395 cms) which equates to 51 to 1500 household equivalents. This category nearly quadrupled from six licences to 22 in 2012. Also notable, is the recent appearance of licences authorized to divert over 0.0395 cms (1500 household equivalent or greater). Prior to weir installation, there were no licences in this category, with the largest authorized withdraw for the City of Duncan at 0.014 cms (530 household equivalent). Today, there are three authorized withdraws in this category, with the largest at 2.832 cms (108,000 household equivalent) for Catalyst Paper Corporation for use at the Crofton Mill, as well as sharing with the Municipality of North Cowichan and TimberWest Forest Limited (BC Geographic Warehouse 2015a).

Table 1: Number of active surface water licences in the Cowichan River basin in 1954 and 2012 (B.C. Geographic Warehouse 2015a).

Authorized Amount	# of licenses in 1954	# of licenses in 2012
<= 1 household equivalent (<= 0.000026 cms)	108	328
2 – 50 household equivalent (0.000027 - 0.0013 cms)	53	148
51 – 1500 household equivalent (0.0014 – 0.0395 cms)	6	22
> 1500 household equivalent (> 0.0395 cms)	0	3
Total Active Licenses	**167**	**501**

The spatial distribution of surface water licences has also shifted between the 1954 and 2012 time periods (Figures 3 and 4). In 1954, surface water licences were relatively spread out with a few small clusters (Figure 3). In 2012, surface water licences covered a wider area across the lower basin and near the lower quarter of Cowichan Lake (Figure 4). Very few of these water licences (past and present) are located directly on the Cowichan River's main stem; most are on lakes and tributaries that feed into the Cowichan River. The distribution of the largest two categories of licences (51 household equivalents or more) has also changed dramatically. Prior to the weir's establishment in 1954, there were a total of six of these large users, with only one of them on main stem (e.g., the City of Duncan). In 2012, there were 25 large users, with five withdrawing directly from the main stem, including the three the largest users.

Exact water usage data were unavailable for this report; consequently the actual amount of water diversion is unknown. The data only represent the number of legal provincial water licences; there may be other water users unaccounted for in this report. Please see Appendix A for licence analysis methodologies and assumptions.

In addition to water diversions, there are also several permitted effluent discharges to the Cowichan River from sewage and aquaculture operations. These include discharges from the Town of Lake Cowichan sewage treatment plant, Duncan-North Cowichan Joint Utilities Board Sewage Lagoons, Cowichan Tribes Hatchery, Vancouver Island Trout Hatchery, and Marine Harvest Canada Hatchery (Lapcevic *et al.* in press).

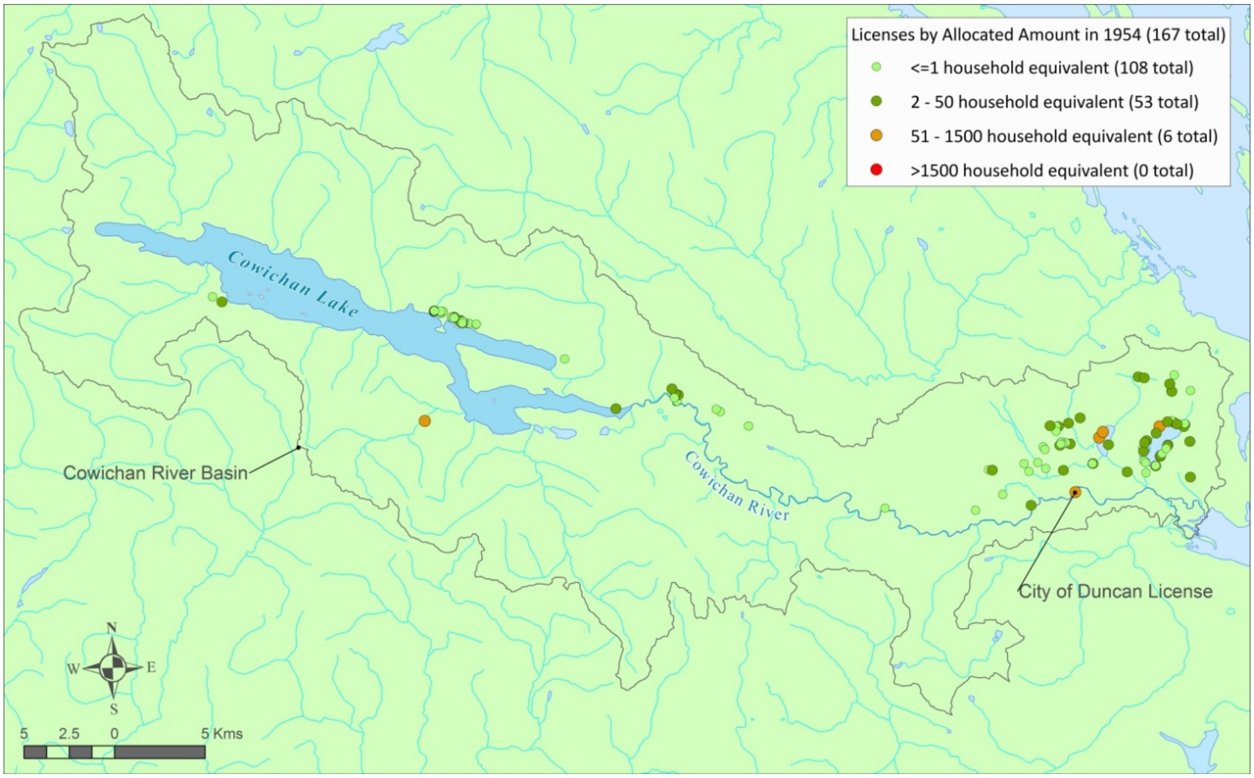

Figure 3: Cowichan River basin surface water licences in 1954 prior to weir construction, categorized by authorization amount.

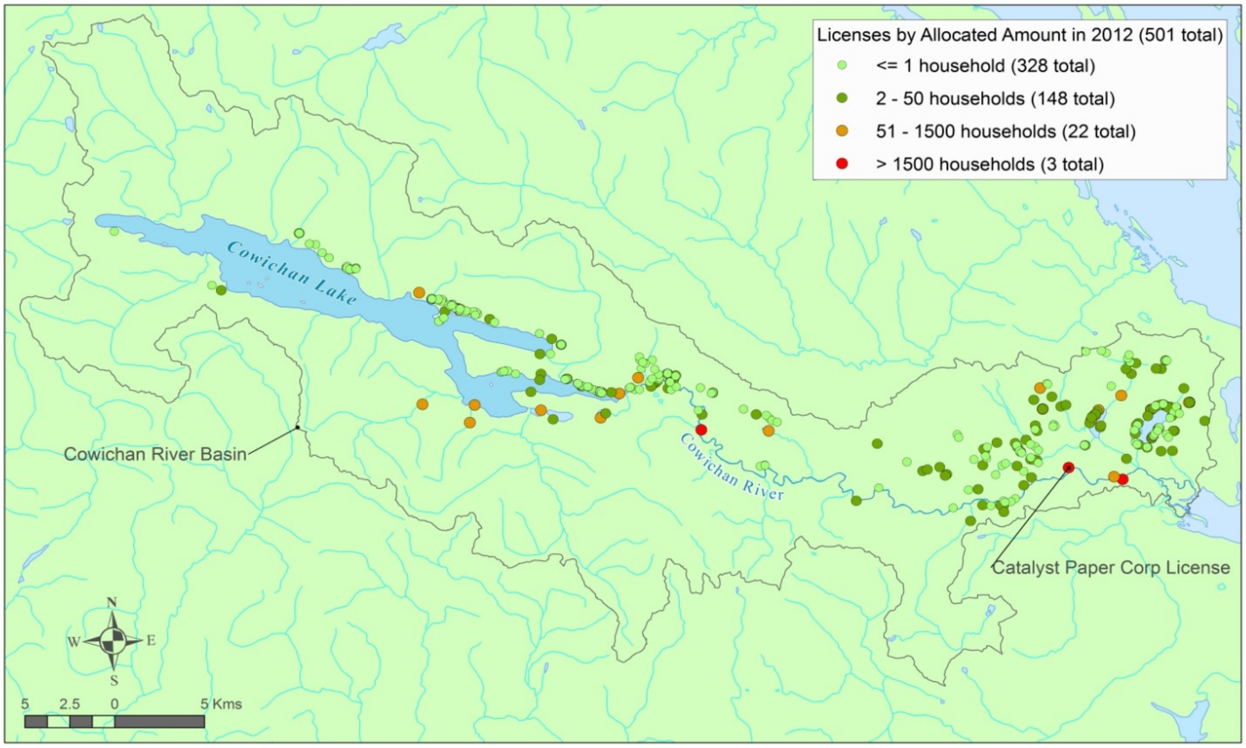

Figure 4: Cowichan River basin surface water licences in 2012, categorized by authorization amount.

3.2 Groundwater Wells

There was a significant increase in the number of groundwater wells between 1954 and 2012 based on data extracted from the Provincial observation wells database (WELLS) (BC Geographic Warehouse 2015b). According to WELLS, there were 445 known wells in the Cowichan River basin in 1954. By 2012, that number had increased to 2843 wells. This increase in number of wells significantly intensified the density of groundwater wells in certain locations in the Cowichan basin. As shown in Figures 5 and 6, groundwater wells have spread out considerably throughout the valley bottom and are clustered heavily in the lower floodplain region. The colour categories used in these figures align with the three levels of demand as categorized in the *BC Aquifer Classification System*; light (less than 4 wells per km^2), moderate (4 to 20 wells per km^2), and heavy (greater than 20 wells per km^2) (for more information see, Berardinucci and Ronneseth 2002).

Prior to the 2016 enactment of the *Water Sustainability Act,* the submission of well construction reports (records) was not mandatory. Therefore, the number of wells used in this analysis may underestimate the total number of wells in the basin. Additionally, groundwater diversion and well pumping rates can vary by several orders of magnitude between different wells and are not submitted on the well construction report. For further information on the history of groundwater resources and use in the Cowichan basin, see Lapcevic *et al.* (in press) and Appendix A for well data methodologies and assumptions.

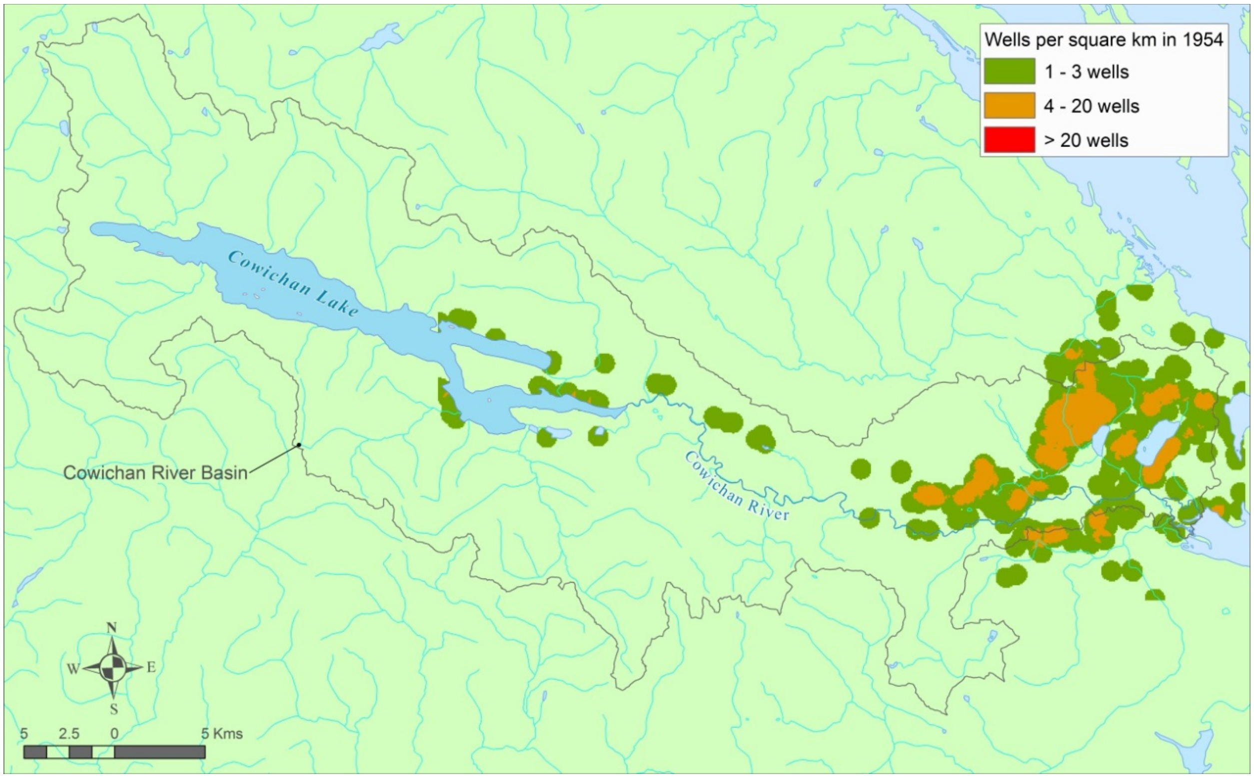

Figure 5: Cowichan River basin groundwater well density in 1954.

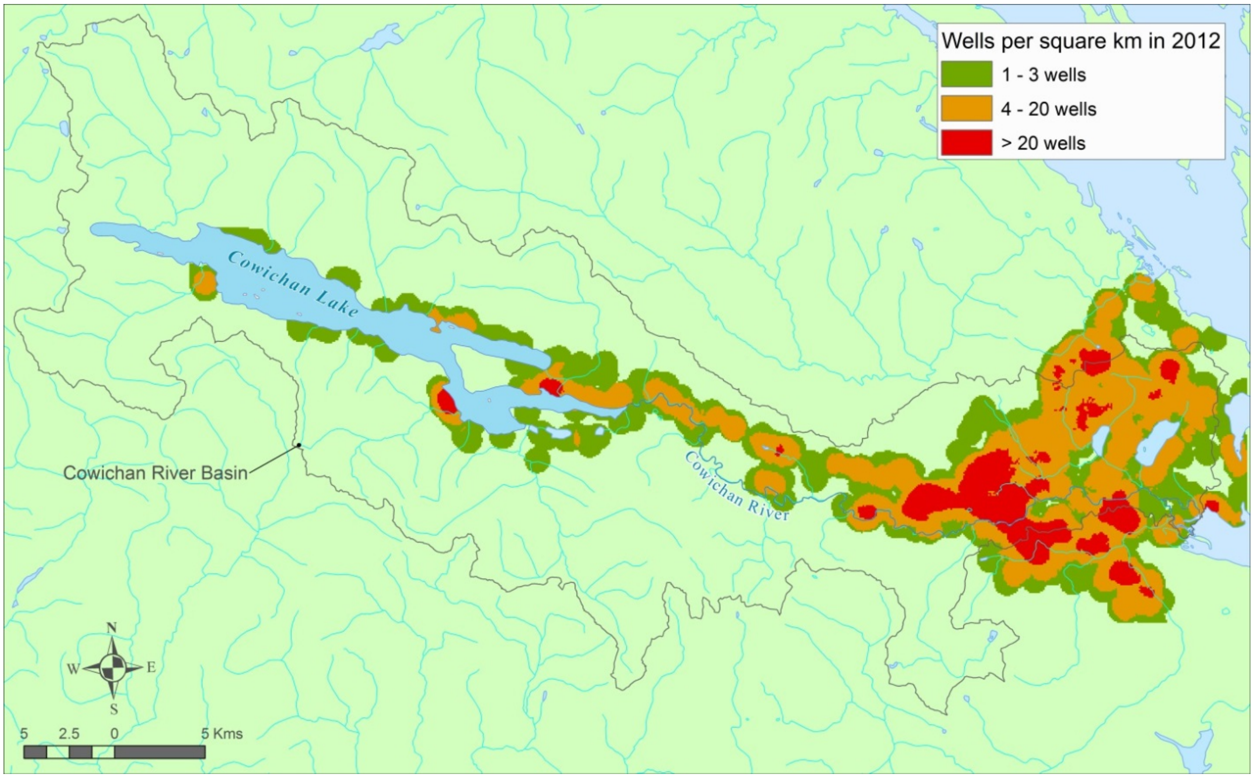

Figure 6: Cowichan River basin groundwater well density in 2012.

4. CLIMATE

The climate of the Cowichan basin is a mixture of Maritime and Mediterranean style climates, resulting in mean annual temperatures of 9.7°C and a long growing season. This results in mild winters with seasonal snow accumulation only occurring in the upper elevations of the basin. Precipitation levels vary throughout the basin and are generally lower in the eastern portion with 750–1000 mm annually, compared with 1000–2500 mm in the western and greater than 4000 mm in the upper wet mountainous portions (data source: Climate BC - http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna).

Between various climate monitoring stations, there are over 100 years of daily weather data (maximum and minimum air temperature and total precipitation as rain or snow) for the Cowichan basin. The first recorded measurements started in October 1913 in the Cowichan Bay area. Daily weather data were first measured in the Lake Cowichan area in 1924 and have continued at various sites until the present, though the separation of precipitation into rain and snow is largely not available. Unfortunately, long-term records from a single station are not available. Consequently, many stations were combined to create a single, long-term record to determine the seasonal and inter-annual variability of an area (see: Spittlehouse 2017). While combining records together may increase the uncertainty in the daily data, particularly when using weather stations that may have a large spatial separation, uncertainty tends to be reduced as the data are averaged over longer time steps (e.g., monthly).

The following section summarizes some of climate variables using the dataset compiled for Spittlehouse (2017) with a focus on the 1965–2015 time period for the Cowichan Lake Forestry climate station. Details of the assembly of the data set, the comparison between stations and regression equations used to adjust data and the evaluation of the record using an independent long-term weather station record are detailed in Spittlehouse (2017). Readers are also referred to this report for decadal trends for annual and seasonal temperature and precipitation and derived variables for Cowichan lake Forestry, 1902–2016 and 1951–2016.

4.1 Average Temperatures

Average air temperatures, as represented by Cowichan Lake Forestry climate station, in the Cowichan basin are mild, in comparison to other parts of British Columbia. Mean monthly temperatures are lowest in December and January (2.7°C), while the warmest month is August (18°C) (Table 2). The basin does experience both hot and cold extremes periodically (Table 2). Air temperatures greater than 30°C have been recorded in May through September while <0°C conditions have been observed in all but the summer months of June, July and August (Table 2).

Table 2: Cowichan Lake Forestry Climate Station historical mean, maximum and minimum, monthly and long-term annual temperatures, 1965–2015 (°C*).*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Long-term*
Mean °C	2.7	3.9	5.5	8.0	11.8	14.9	17.8	18.0	15.0	10.0	5.4	2.9	*9.7*
Min °C	-16.1	-13.5	-10.0	-5.0	-1.1	0.6	1.7	4.4	-0.6	-5.5	-15.0	-15.0	*-16.1*
Max °C	14.4	18.5	22.5	28.0	33.0	35.7	37.9	38.2	36.0	28.5	18.3	16.0	*38.2*

4.2 Precipitation

Precipitation in the Cowichan basin is typically a mixture of rain in valley bottoms and winter snow accumulation in the higher elevations. Average annual precipitation for the 1965–2015 period of record for the basin was approximately 2200 mm (Table 3). The wettest months coincide with the months that experience the highest runoff volumes (November through February) while most late springs and summers are relatively dry. In some years, monthly precipitation has been recorded to be almost absent from June through September, while in other years, significant amounts of precipitation have fallen (Table 3).

Table 3: Cowichan Lake Forestry Climate Station historical mean, maximum and minimum, monthly and long-term annual precipitation, 1965–2015 (mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Long-term*
Mean(mm)	334	244	240	135	77	49	33	45	77	223	356	361	*2174*
Min (mm)	35	22	40	19	10	3	1	1	1	20	120	69	*1229*
Max (mm)	696	644	492	287	206	126	101	254	260	597	865	626	*2922*

5. STREAMFLOW

5.1 Background

Cumulative disturbances and water pressures in the Cowichan basin have had an influence on the flow regime of the river. Historical streamflow data from two Water Survey of Canada (WSC) hydrometric stations were downloaded for analysis to characterize historical flows and to identify recent trends (Data Source: Water Survey of Canada). The “Upper Station”, 08HA002 (Cowichan River at Lake Cowichan), is situated near the outlet of Cowichan Lake and represents an area of 594 km^2, while the “Lower Station”, 08HA011 (Cowichan River Near Duncan), is located in the lower end of the basin near Duncan with an area of 826 km^2 (Figure 7). The Upper Station has a continuous record from 1941–2016, as well as some additional data from March 1913 to September 1919. The Lower Station has a continuous record from 1965 to 2016, with some data gaps from 1961–1964. The following section first compares pre- and post-weir construction streamflow characteristics at the Upper Station. Characterization and comparisons of the Upper and Lower Stations are then detailed for the period of 1965–2015, when continuous data were collected for both stations. Further information on data gap filling and processing specifics for these two stations are presented in Appendix A.

5.2 Pre-Weir and Post-Weir Construction Streamflow Characteristics

The purpose of the licenced weir at Cowichan Lake is to store water in the lake for release into the river during the summer low flow season. This section compares Upper Station streamflow records prior to known construction of the weir (1913–1954) with records after weir construction was completed and operations were underway (1965–2015). The period between 1955–1964 was excluded, as this was a time of transition to weir control.

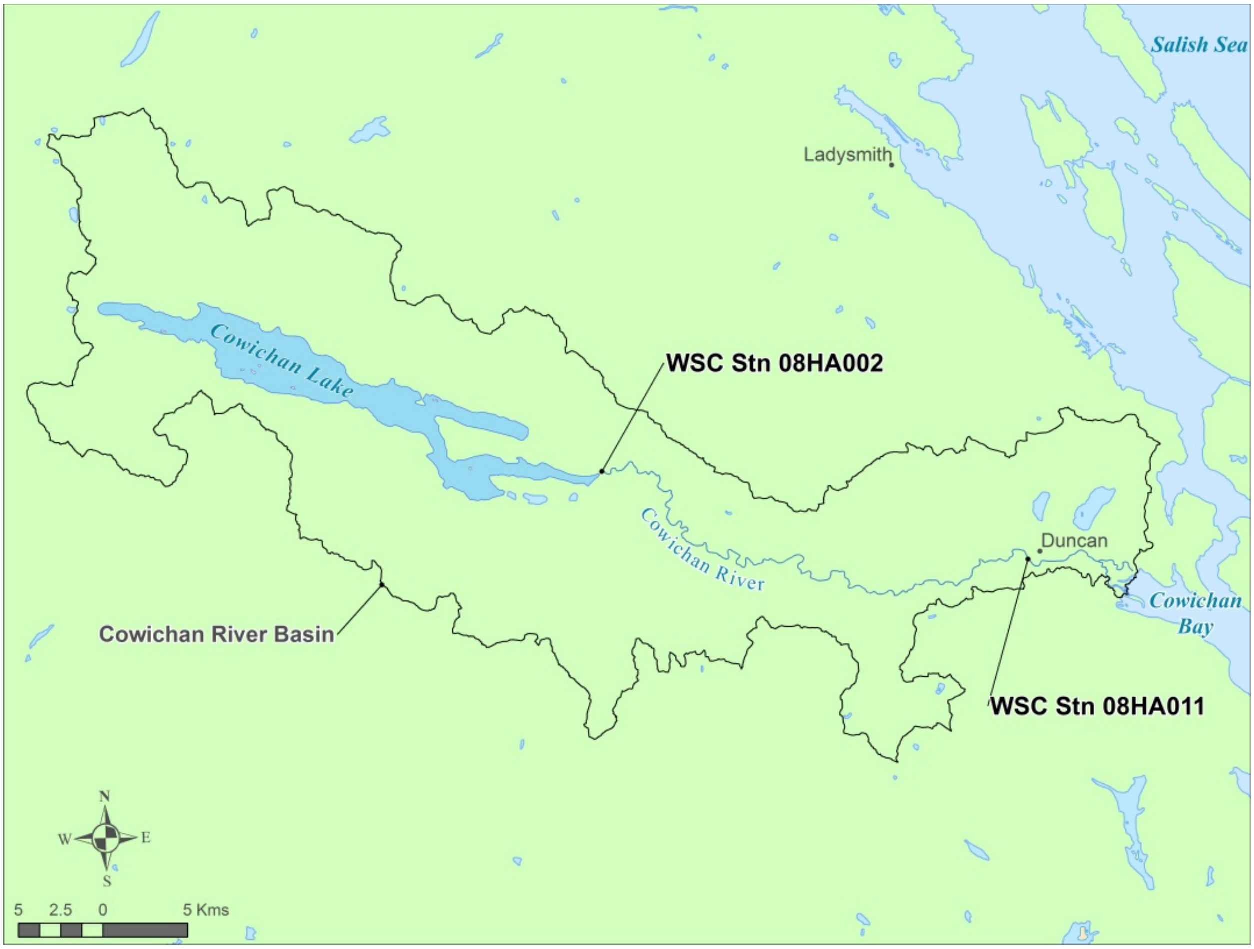

Figure 7: Location of two Water Survey of Canada hydrometric stations in the Cowichan basin.

The analysis of pre- and post-weir streamflow data shows that summer low flows became less severe (i.e., flow levels increased) after weir construction with post-weir September median discharge of 7.50 cms in contrast to pre-weir September median discharge of 3.62 cms (Figure 8). Conversely, spring and early–summer streamflow levels (between April and July) declined after weir installation; this is likely due to the holding back of water specifically for release later during the low flow summer months (Figure 8). This effect can be seen in the analysis of pre- and post-weir, monthly minimum (daily mean) discharges (Figure 9). With respect to daily average, low flow extremes, the monthly minimum daily discharges in July, August and September are relatively constant in the post-weir control period, with the lowest flow level of 3.5 cms (Figure 9). During the pre-weir control period, low flows went down to as low as 0.425 cms (September 10, 1944) which is almost an order of magnitude lower than the minimum flow observed in the post-weir period. The installation of the weir had a significant effect in redistributing flows between months and in augmenting low flows in the system (Figures 10 and 11) resulting in a “flattening” of typical low flows due to controlled releases from the weir that effectively eliminated extreme lows that previously occurred (Figure 11).

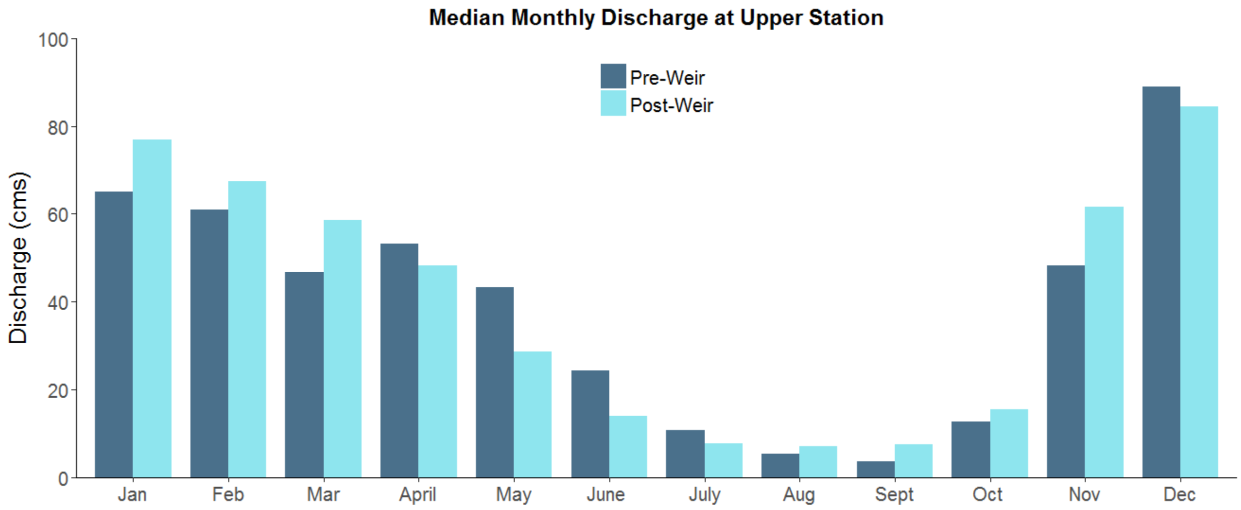

Figure 8: Upper Station comparison of pre- and post-weir median monthly discharges.

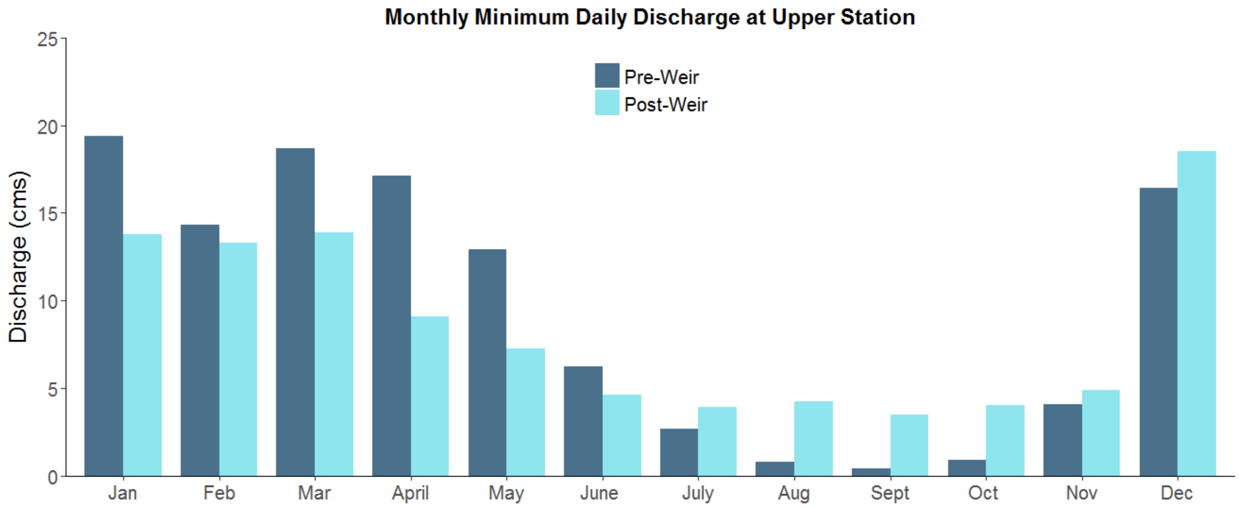

Figure 9: Upper Station comparison of pre- and post-weir monthly minimum daily discharges.

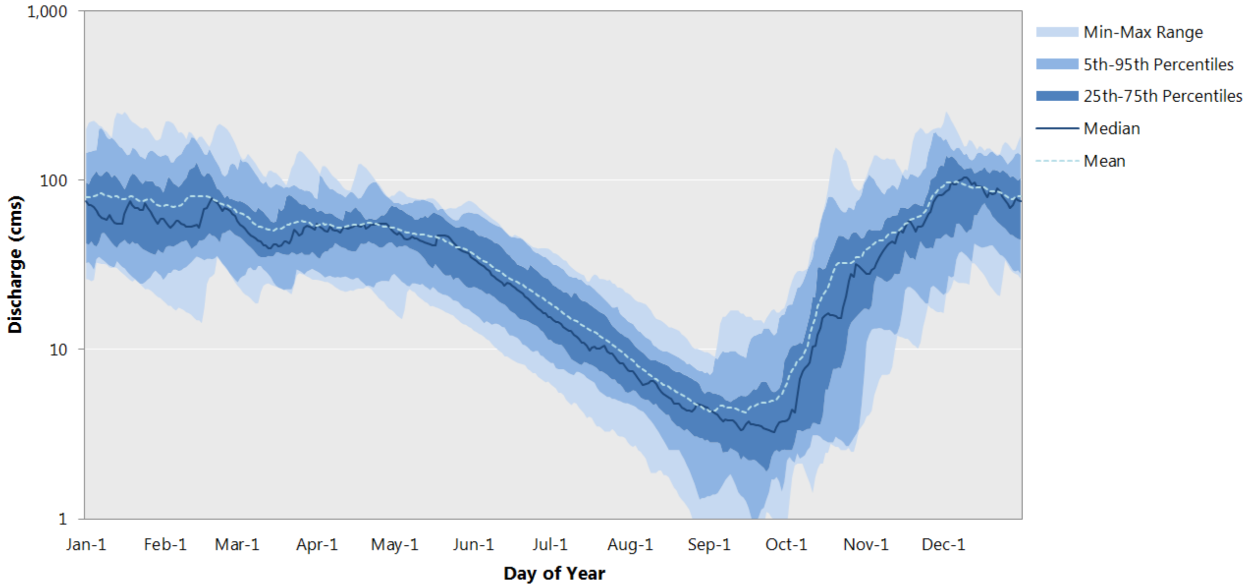

Figure 10: Daily mean discharge Upper Station (08HA002), pre-weir 1913–1954.

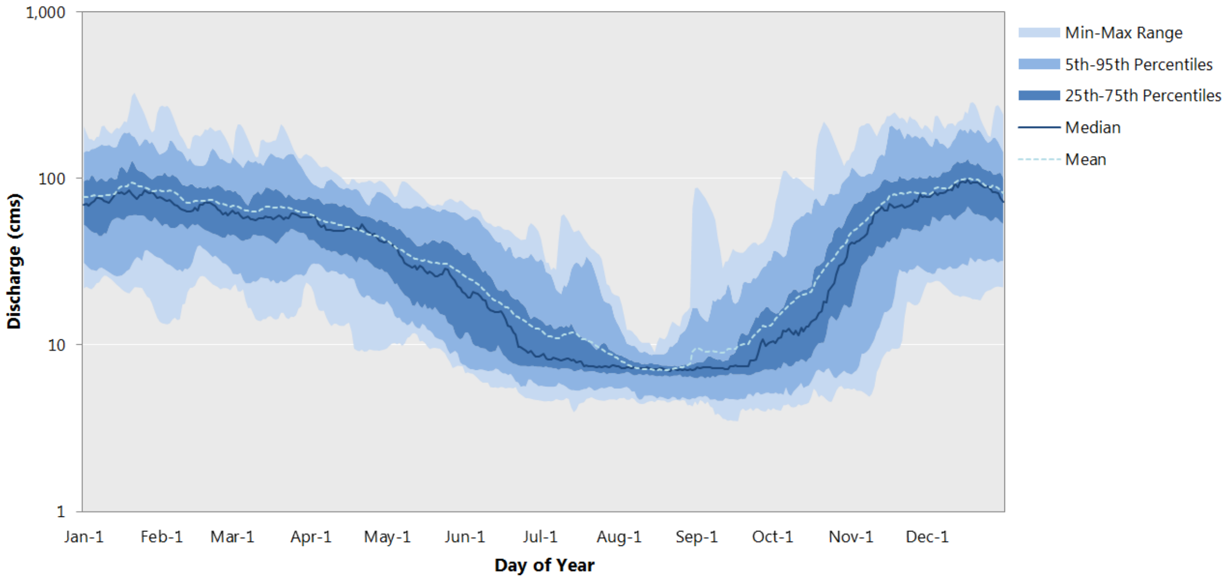

Figure 11: Daily mean discharge Upper Station (08HA002), post-weir 1965–2015.

The lowest average discharge measured during 30 consecutive days (30-day mean low flow) also changed as a result of weir control. The low flows are distinctly different in the pre-weir and post-weir periods with a calculated 30-day mean low flow of 3.34 cms prior and 6.83 cms after weir control (Figure 12). Prior to weir control, 15 out of 19 years with data had 30-day mean low flows less than 4 cms. The resulting effect of the weir was a near doubling of volume of the 30-day low and elimination of 30-day low flows less than 4 cms. The first 30-day mean low flow that was greater than 7 cms in the historical record didn't occur until 1954. The frequency of extremes (7-day and 30-day) low flows was substantially reduced as well; the 7Q10 (7-day consecutive low flow with a ten year return frequency) was 1.09 cms for the 1913–1954 period (Table 4), whereas post-weir 7Q10 was 4.87 cms for 1965–2015 time period (Table 9).

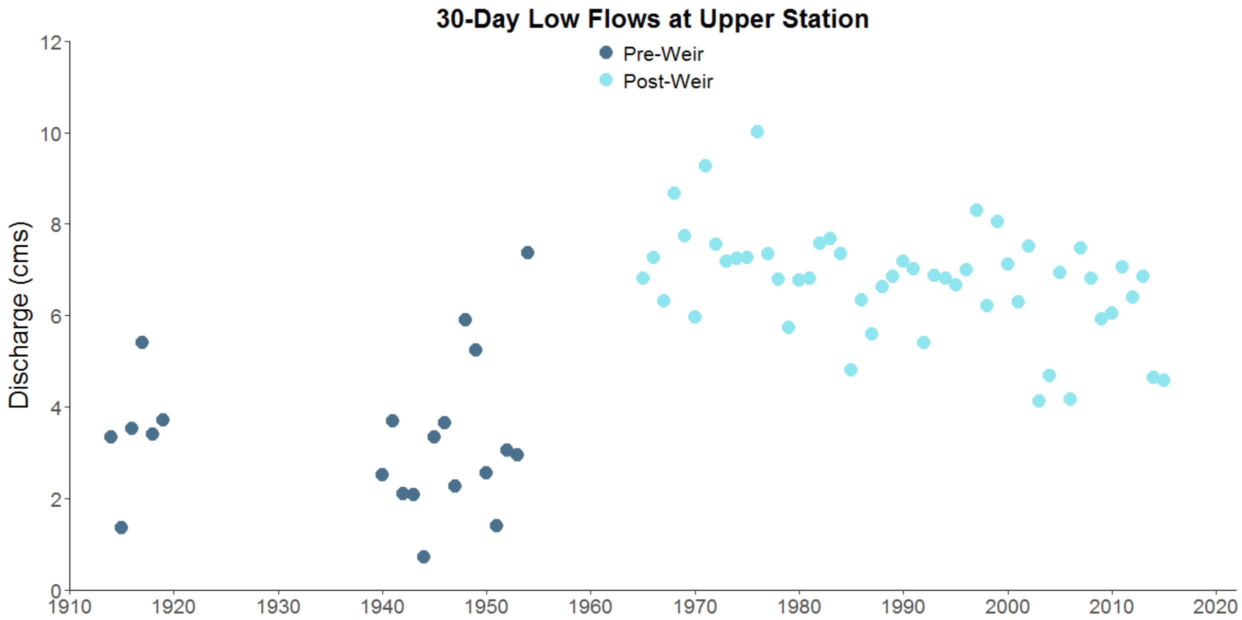

Figure 12: Upper Station Comparison of Pre- and Post-weir annual 30-day Mean Low Flows.

Table 4: Upper Station annual 7-day and 30-day low flow frequency, pre-weir 1913–1954.

Return Period (Years)	Probability	7-day low flow (cms)	30-day low flow (cms)
2	0.50	2.682	3.243
5	0.20	1.528	1.947
10	0.10	1.086	1.448
25	0.04	0.727	1.032
50*	0.02	0.550	0.818
100*	0.01	0.421	0.659

*Statistics extrapolated beyond length of record.

5.3 Upper and Lower Station Streamflow Characterization

5.3.1 Monthly and Annual Comparisons

Monthly data summaries were compiled from daily mean discharge data for each of the WSC stations (Table 5). Mean monthly data is the average of all daily average values, median is the 50th percentile of all daily average data sorted per month and maximum and minimum values represent the extreme daily averages over the data time series per month (Table 5). The Upper Station has a long-term mean annual discharge of 45 cms and median discharge of 34 cms, and the Lower Station has a long-term mean annual discharge of 53 cms and median discharge of 37 cms (Table 5).

Some interesting observations can be made on the monthly summary data for both stations (Table 5). For both stations, monthly maximum daily discharges are typically highest during the winter (October through March), yet high monthly maximum daily discharges (more than 60 cms) statistically can occur at any time of the year including the summer months (Table 5). Mean monthly discharges are higher at the Lower Station for all months except for June through September vs. the Upper Station.

Table 5: Upper Station and Lower Station annual and monthly hydrologic summary statistics (cms), 1965–2015.*

	Upper Station (WSC 08HA002)				**Lower Station (WSC 08HA011)**			
	Mean	**Median**	**Maximum**	**Minimum**	**Mean**	**Median**	**Maximum**	**Minimum**
Jan	84.282	76.800	326	13.800	108.059	96.100	450	15.600
Feb	74.982	67.450	273	13.300	91.736	80.750	303	14.700
Mar	65.261	58.600	211	13.900	78.115	69.700	359	15.800
Apr	51.003	48.250	135	9.120	57.574	53.500	154	8.670
May	32.878	28.600	96	7.270	34.654	30.600	121	6.440
Jun	17.982	14.100	70	4.630	17.765	13.350	73	2.990
Jul	10.587	7.780	61	3.950	9.444	6.590	65	2.850
Aug	7.474	7.190	87	4.280	5.946	5.500	88	2.550
Sep	10.325	7.495	88	3.490	8.998	6.040	85	2.580
Oct	25.201	15.600	219	4.030	27.310	14.600	312	2.820
Nov	70.530	61.600	249	4.890	84.428	71.150	407	3.280
Dec	90.900	84.500	286	18.500	113.643	104.000	425	17.900
Annual	***44.975***	***33.700***	***326***	***3.490***	***52.982***	***36.900***	***450***	***2.550***

*Note: Mean is the average of all daily average values, median is the 50th percentile of all daily average data sorted per month and maximum and minimum values represent the extreme daily averages (per month) over the data time series.

Monthly mean discharges in the wettest part of the water year (October through May) are higher at the Lower Station than at the Upper Station, as would be expected from the larger drainage area of the Lower Station (Figure 13). However, in the summer months (July through September) discharges are less at the Lower Station. This reversed relationship reflects a loss of water (change in the magnitude of streamflow) between the two stations during the summer months, likely due to a combination of recharge along losing sections of the river to alluvial aquifers adjacent and underlying the river, and withdrawals of surface water and groundwater.

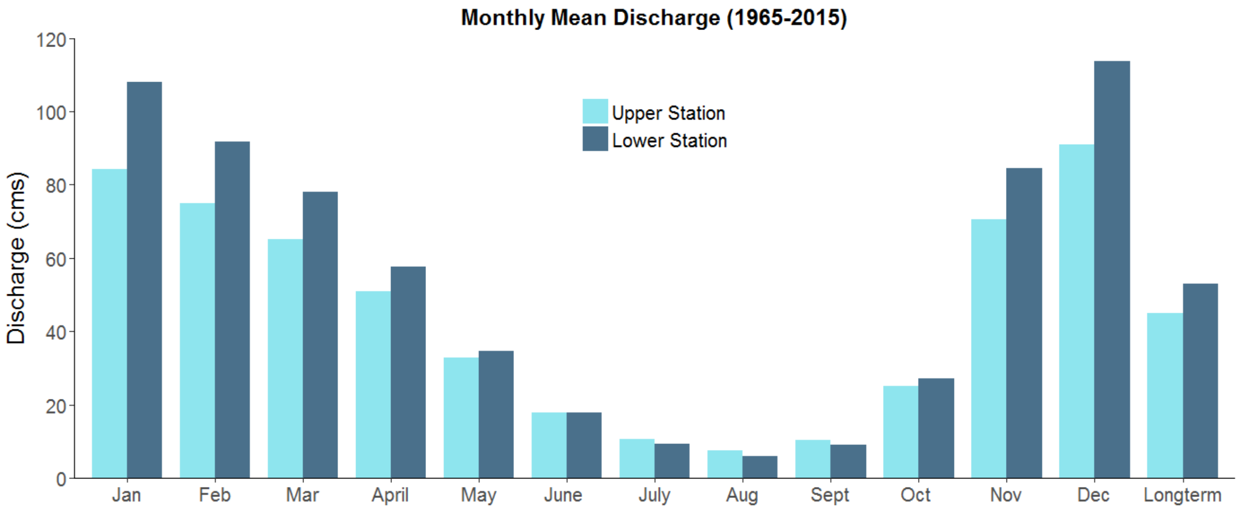

Figure 13: Upper and Lower Station monthly and long-term mean discharges between 1965 and 2015.

Tables of monthly and long-term percentiles statistics were generated for the two Cowichan River hydrometric stations (Tables 6 and 7). Percentile statistics show the percent time that flows less (or more) than certain magnitudes are observed in the system, often on a monthly / annual basis (i.e., 10P = 10% recorded observations below and 90% observations are above that defined level).

Table 6: Monthly and long-term percentiles for the Upper Station, 1965–2015. Discharge values <= 7 cms are highlighted.

Percen-tile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Long-term*
1	21.900	20.117	14.880	13.000	7.956	5.530	4.660	4.574	4.023	4.420	6.538	21.160	*4.710*
2	22.900	22.300	17.660	14.858	9.216	5.646	4.762	4.660	4.190	4.768	8.215	23.460	*5.155*
5	27.000	29.595	24.500	22.345	10.300	6.470	5.290	4.820	4.690	5.590	13.400	27.400	*6.240*
10	34.700	37.400	30.100	26.900	12.100	7.090	6.250	5.750	5.600	6.540	21.500	37.800	*6.960*
15	41.600	41.400	36.200	29.200	14.100	7.424	6.510	6.070	6.044	7.140	30.435	45.200	*7.389*
20	48.600	45.380	41.300	31.800	15.100	7.658	6.760	6.320	6.310	7.840	33.700	51.200	*7.900*
25	54.500	49.300	44.700	34.825	17.300	7.960	6.950	6.560	6.600	9.030	38.500	57.200	*9.600*
30	58.800	53.170	47.900	37.370	19.400	8.470	7.140	6.770	6.870	10.100	42.500	62.900	*12.700*
35	62.700	56.500	51.000	40.000	22.100	9.543	7.280	6.900	7.030	11.300	47.215	69.100	*16.000*
40	67.400	59.820	53.700	42.260	24.800	10.900	7.400	6.980	7.190	12.700	51.560	74.200	*21.500*
45	72.000	63.600	56.100	45.105	26.800	12.600	7.540	7.080	7.350	13.800	57.515	79.800	*27.400*
50	76.800	67.450	58.600	48.250	28.600	14.100	7.780	7.190	7.495	15.600	61.600	84.500	*33.700*
55	82.400	71.490	61.700	51.300	31.200	15.300	8.100	7.280	7.670	17.400	68.190	90.000	*40.000*
60	87.500	77.120	64.600	54.700	35.400	16.600	8.580	7.390	7.990	20.000	74.800	95.100	*46.060*
65	92.600	82.700	68.000	57.670	38.500	18.600	9.470	7.470	8.610	22.400	80.700	101.000	*52.700*
70	97.800	87.430	73.200	61.030	41.000	20.400	10.500	7.560	9.403	27.500	85.200	108.000	*59.000*
75	106.000	92.300	79.500	64.575	44.200	22.600	11.600	7.690	11.100	31.100	91.775	115.000	*66.400*
80	116.000	99.740	87.400	68.920	49.300	25.700	12.800	7.960	13.400	38.800	98.800	124.000	*75.600*
85	128.000	108.000	95.900	74.765	54.700	31.065	15.000	8.440	15.500	46.000	107.000	137.000	*86.400*
90	141.000	124.000	108.000	81.610	60.000	37.700	18.000	9.070	18.200	57.200	123.000	150.000	*99.940*
95	169.000	145.000	131.000	89.665	68.500	47.165	25.300	10.400	23.855	76.100	169.000	180.000	*127.000*
98	195.000	169.440	147.000	97.100	74.500	54.226	35.700	12.900	35.700	99.640	208.420	210.000	*161.000*
99	208.000	192.830	168.200	103.000	77.420	59.300	39.620	14.820	40.326	111.000	223.710	224.200	*189.000*

Table 7: Monthly and long-term percentiles for the Lower Station, 1965–2015. Discharge values <= 7 cms are highlighted.

Percen-tile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Long-term*
1	21.860	23.534	20.660	13.429	7.196	3.950	3.098	2.890	2.863	3.137	5.009	21.280	*3.232*
2	24.980	29.278	24.760	16.316	8.652	4.527	3.346	3.006	2.975	3.589	6.798	24.700	*3.900*
5	31.100	36.295	29.500	23.390	9.840	5.240	4.050	3.380	3.273	4.390	11.325	32.300	*4.730*
10	40.200	43.600	37.400	28.300	11.900	6.150	4.560	4.080	4.196	5.270	20.780	42.600	*5.400*
15	47.900	48.885	42.600	32.300	13.900	6.490	5.050	4.450	4.580	5.810	30.800	49.500	*5.950*
20	56.100	53.900	47.600	36.000	15.700	6.828	5.320	4.720	4.940	6.810	36.500	57.100	*6.810*
25	64.800	59.175	51.500	39.000	17.600	7.450	5.510	4.930	5.160	7.770	42.000	65.100	*8.650*
30	69.400	63.100	55.900	41.900	20.500	7.980	5.700	5.070	5.300	9.022	46.870	73.200	*11.800*
35	76.000	67.400	59.400	44.000	23.000	8.870	5.920	5.210	5.480	10.600	51.745	81.300	*15.900*
40	82.200	72.260	63.100	46.100	25.800	10.300	6.150	5.320	5.620	11.900	57.200	88.200	*22.100*
45	89.600	75.900	66.400	49.505	28.300	11.800	6.370	5.400	5.830	13.200	64.805	94.900	*29.700*
50	96.100	80.750	69.700	53.500	30.600	13.350	6.590	5.500	6.040	14.600	71.150	104.000	*36.900*
55	103.000	87.590	72.500	57.100	33.100	15.000	6.930	5.620	6.263	17.070	79.100	111.000	*44.000*
60	109.000	93.880	76.800	60.600	36.000	16.300	7.470	5.730	6.742	20.000	87.040	118.000	*51.500*
65	118.000	99.635	81.100	64.255	39.400	18.400	8.210	5.880	7.420	24.100	94.870	127.000	*59.900*
70	126.000	106.000	87.100	68.300	42.500	20.000	9.340	6.080	8.380	28.600	103.000	137.000	*68.000*
75	137.000	113.000	95.400	72.800	48.100	22.500	10.400	6.340	9.930	32.800	110.000	148.000	*77.075*
80	150.000	121.000	104.000	77.700	53.500	26.000	11.700	6.650	12.200	40.500	120.000	160.000	*89.800*
85	165.000	133.000	115.000	85.000	58.500	31.700	14.000	7.080	14.300	51.180	133.650	175.000	*105.000*
90	190.000	153.200	131.000	93.210	65.000	38.810	17.000	7.950	16.800	65.760	159.100	199.000	*124.000*
95	237.000	186.050	160.000	106.000	72.500	48.400	24.700	9.490	23.510	90.930	207.100	237.000	*162.000*
98	280.800	228.440	185.400	119.000	78.560	56.726	35.400	11.400	34.684	124.000	280.420	282.400	*212.000*
99	320.200	244.610	207.400	130.710	83.500	63.100	40.020	13.140	37.900	154.780	304.000	316.200	*250.000*

The 50th percentile (median flow) of the Lower Station is 36.9 cms while the Upper Station is 33.7 cms. This confirms that the Lower Station annually records greater discharge than the Upper Station. However, Tables 6 and 7 also show that the typical low flows measured are the least, both annually and on a monthly basis, for the Lower Station, again illustrating the losses from the surface water system downstream. Specifically, annual flows of less than 7 cms occur about 10% of the time at the Upper Station, whereas they only occur 20% of the time, annually at the Lower Station. The largest difference is in August, where at 7 cms, the Upper Station exhibits this flow (or lower) nearly 40% of the time whereas the Lower Station recorded this level (or lower) 85% of the time for the period of record analysed (Table 7, August 85th Percentile=7.080 cms).

In examination of annual data statistics, the Lower Station has the highest annual maximum daily discharges and the least annual minimum daily discharges in comparison to the Upper Station. Annual maximum daily discharges at the Lower Station have been observed to be up to 246 cms higher than at the Upper Station and, are on average 87 cms higher overall (Table 8). The difference between the two station's annual maximum daily discharges has been as little as 12 cms. On average, annual maximum daily discharges at the Lower Station are 49% higher than at the Upper Station, but have ranged from 15% to 160% higher in any given year depending on flow generation mechanisms (Table 8; Figure 14).

Table 8: Differences between Lower and Upper WSC station's annual minimum and maximum daily discharges (cms and %).

	Difference in Annual Minimum Daily Discharge (Lower Station minus Upper Station)		Difference in Annual Maximum Daily Discharge (Lower Station minus Upper Station)	
	(cms)	**(%)**	**(cms)**	**(%)**
Mean	-1.540	-26	86.920	49
Min	0.260	4	11.700	160
Max	-3.020	-47	246.000	15

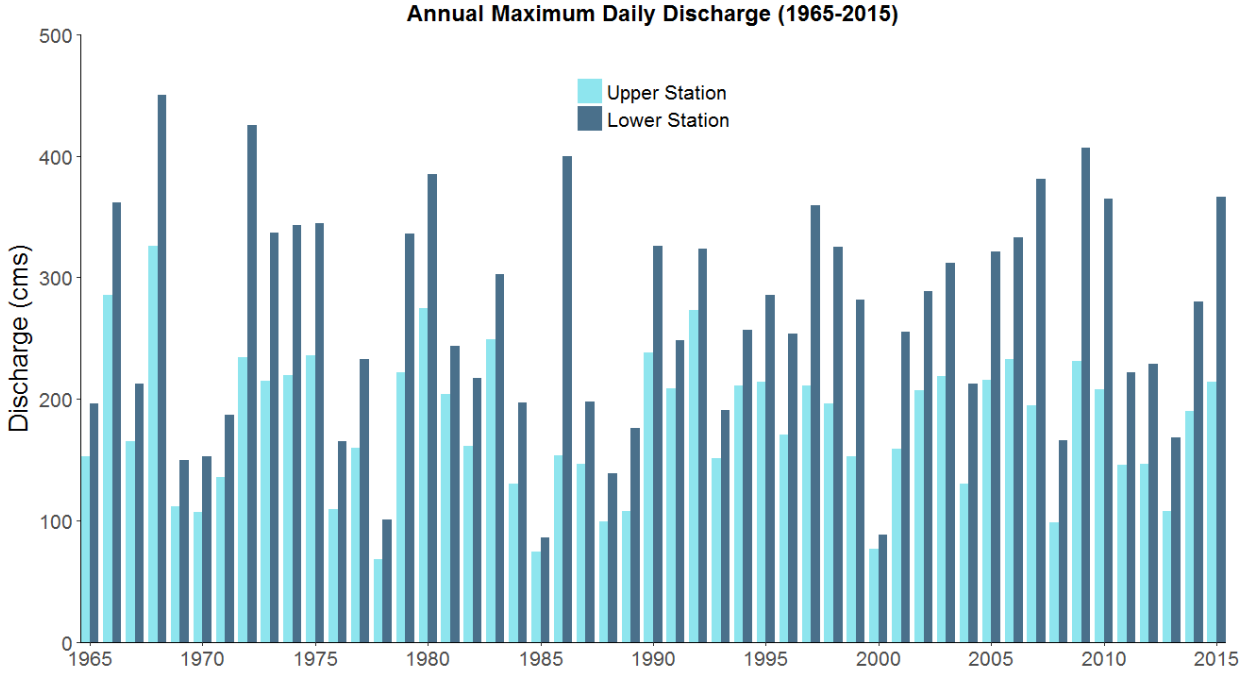

Figure 14: Upper and Lower Station annual maximum daily discharges, 1965–2015.

Annual minimum daily discharges at the Lower Station have been observed to be up to 3.02 cms less than at the Upper Station with an average of 1.5 cms less overall. On average, annual minimum daily discharges at the Lower Station are 26% less than at the Upper Station, but can range from + 4% to – 48% less in any given year (Figure 15).

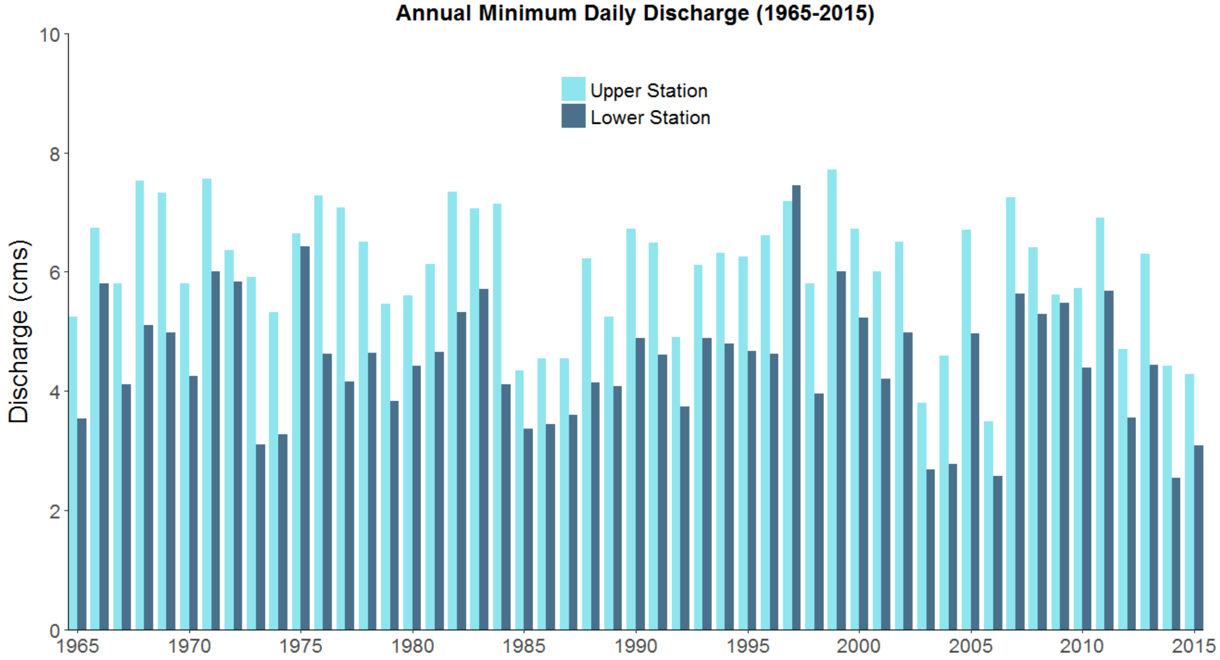

Figure 15: Upper and Lower Station annual minimum daily discharges, 1965–2015.

The frequency of extreme low flows also differs between the Upper and Lower stations (Tables 9 and 10). Annual 7-day and 30-day minimum values were fit to a Log-Pearson Type III distribution. While smaller in drainage area, the Upper Station has a higher discharge for the 7-day and 30-day low flow return periods. The 10-year, 7-day low flow at the Upper Station is 4.9 cms, compared to 3.5 cms at the Lower Station indicating a loss of water between the hydrometric stations. The 30-day statistics illustrate the same pattern; the 10-year 30-day low flow at the Upper Station is 5.2 cms (Table 9), compared to 3.7 cms at the Lower Station (Table 10).

Table 9: Upper Station annual 7-day and 30-day low flow frequency, 1965–2015.

Return Period (Years)	**Probability**	**7-day low flow (cms)**	**30-day low flow (cms)**
2	0.50	6.413	6.795
5	0.20	5.420	5.747
10	0.10	4.866	5.191
25	0.04	4.268	4.606
50	0.02	3.887	4.237
100*	0.01	3.550	3.913

*Statistic extrapolated beyond length of record.

Table 10: Lower Station annual 7-day and 30-day low flow frequency, 1965–2015.

Return Period (Years)	Probability	7-day low flow (cms)	30-day low flow (cms)
2	0.50	4.802	5.203
5	0.20	3.912	4.221
10	0.10	3.470	3.745
25	0.04	3.022	3.270
50	0.02	2.749	2.982
100*	0.01	2.514	2.737

*Statistic extrapolated beyond length of record.

6. GROUNDWATER

6.1 Background

Groundwater pressures have been increasing long before the installation of the weir at Lake Cowichan. Several other authors have comprehensively studied the groundwater resources of the Cowichan basin and readers are referred to these reports for more comprehensive details on the aquifers and groundwater resources (Janicki 2011, Barroso *et al.* 2013, Carmichael 2014, and Lapcevic *et al.* in press). This section provides a brief summary of historical groundwater level trends based on the available Provincial Groundwater Observation Well data and information from the BC Ministry of Environment and Climate Change Strategy, State of Environment Website (*http://www.env.gov.bc.ca/soe/indicators/water/wells/index.html*). Identified trends presented are in absence of a discussion of likely causal mechanisms.

The Provincial Groundwater Observation Well Network lists seven active observation wells in the Cowichan basin (Table 11). Historically, there have been an additional eight observation wells that are now inactive in the basin (Barroso *et al.* 2013). Four of the active observation wells (428, 429, 430 and 431) were omitted from this report's analysis as they were recently installed and the data time series was too short for trend analysis. Therefore, this report focuses on three observation wells (204, 211, and 318) (Figure 16).

Table 11: Provincial Groundwater observation wells in the Cowichan basin.

Obs Well #	Status	Dates of Operation	Well Depth	Aquifer Lithology
204	Active	1977 – present	9 m	Sand and Gravel
211	Active	1976 – present	32 m	Sand and Gravel
318	Active	1993 – present	30 m	Sand and Gravel
428	Active	2013 – present	87 m	Sand and Gravel
429	Active	2013 – present	45 m	Sand and Gravel
430	Active	2013 – present	78 m	Bedrock
431	Active	2013 – present	27 m	Sand and Gravel

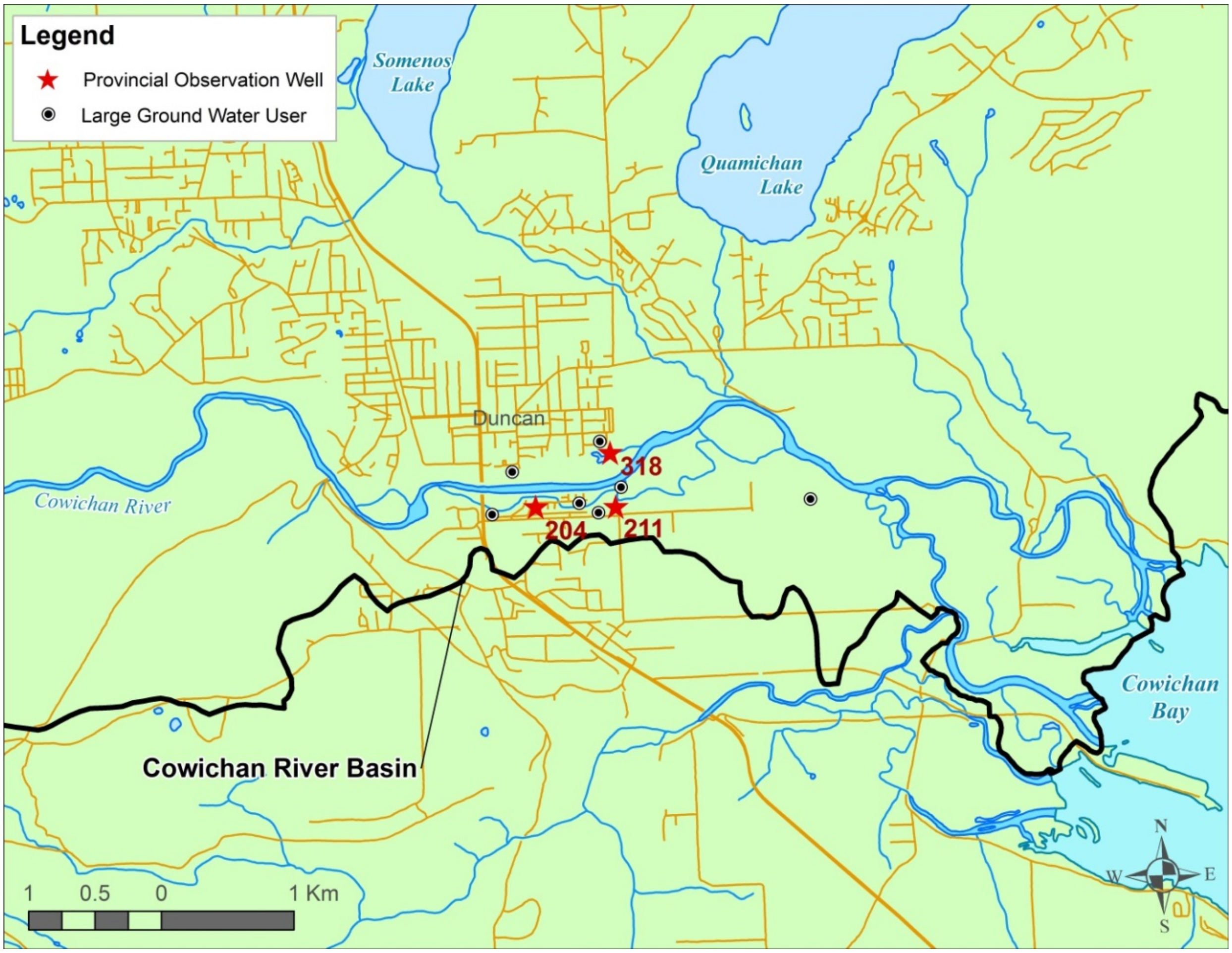

Figure 16: Location of Provincial Groundwater observation wells with measurements pre-dating 1993, in the lower Cowichan River basin.

6.2 Groundwater Level Characterization

In general, groundwater levels in the lower Cowichan basin display a seasonal fluctuation that is in a synchronous pattern with surface water discharge (Figure 17). For example, water levels in observation wells 204 and 211 are shallowest (nearer the ground surface) in the winter (November through January) and deepest in the summer (June through September). In contrast, observation well 318 shows late summer water levels (July through September) are also deeper (around 4.5 metres below ground surface) but it does not *"…follow a typical seasonal variability, reflecting precipitation inputs to aquifer recharge, and instead appear to reflect periods of high water use"* (Barroso *et al.* 2013: 20). Hydraulic connectivity of the Cowichan River to the surrounding aquifer has been reported by several authors (Barroso *et al.* 2013, Foster and Allen 2015, Lapcevic *et al.* in press) and as inferred from the groundwater level regime as in Figure 17.

Groundwater level trends presented below are summarized from the BC State of Environment report (2015a, 2015b) using data from the Provincial Observation Well network. B.C. State of Environment reports groundwater levels at observation wells 204, 211, 318 to be declining over their long-term period of record (BC Ministry of Environment 2015a; 2015b). However, only two out of the three wells reported statically detectable trends (p values < 0.05). For this summary section, Provincial Observation well #318 was therfore omitted due to nonsignicant p-value statistic. Of the two remaining observation wells, 211 (Figure 18) is categorized as showing a moderate rate of decline (-0.0342 m/yr) whereas 204 (Figure 19) is also declining but categorized as stable (- 0.0258 m/yr). It is noted that these calculated trends represent the respective period of record analysed (as noted in Figures 18, 19) and do not match the streamflow/climate trending period (1965-2015). This report stresses the importance of considering the time period of analysis in the context of trend detection.

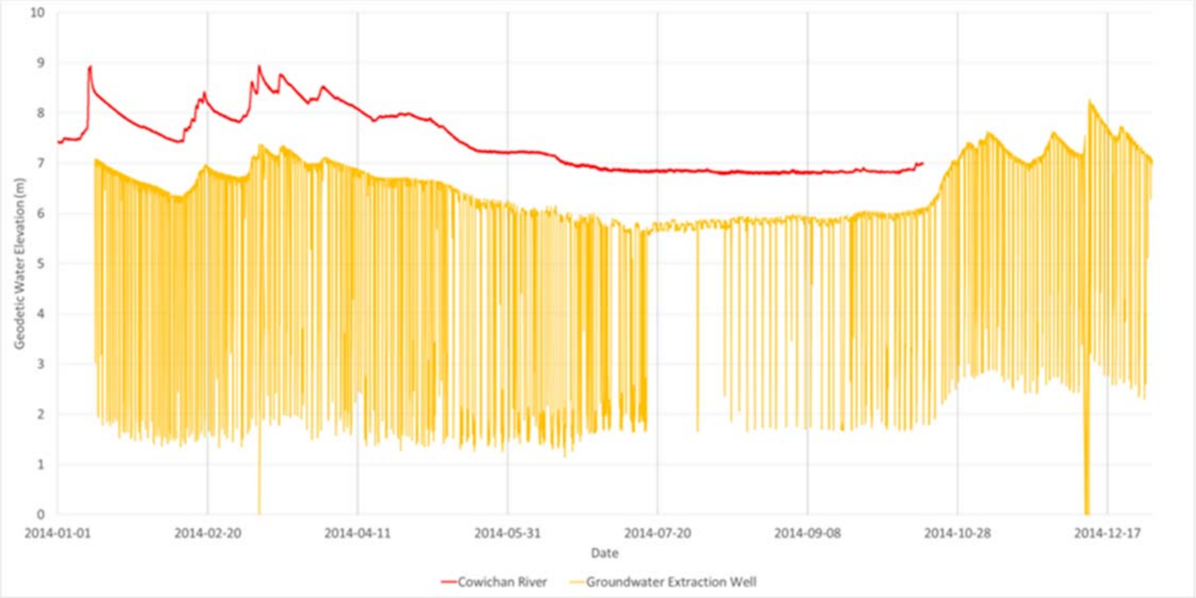

Figure 17: Relationship between groundwater and surface water levels demonstrate the synchronous behaviour high and low water levels. Vertical yellow lines represent the cyclical drawdown of groundwater level in monitoring well (CR1A) close to a high capactiy production well. (Image: Neil Goeller, FLNR, Nanaimo, BC).

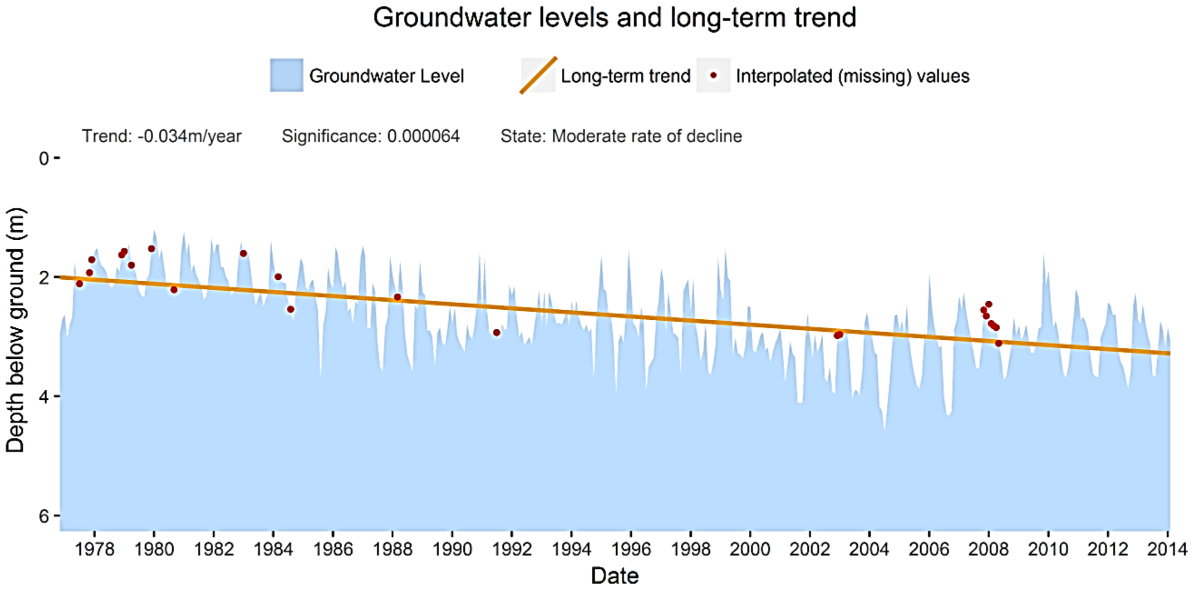

Figure 18: Observation Well #211, Duncan (Marine Harvest Canada Boys Rd.) groundwater level trend, 1976–2014. (Significant p= 0.000064). Source: http://www.env.gov.bc.ca/soe/indicators/water/print_ver/2014_GWL_Trends_print_ver.pdf

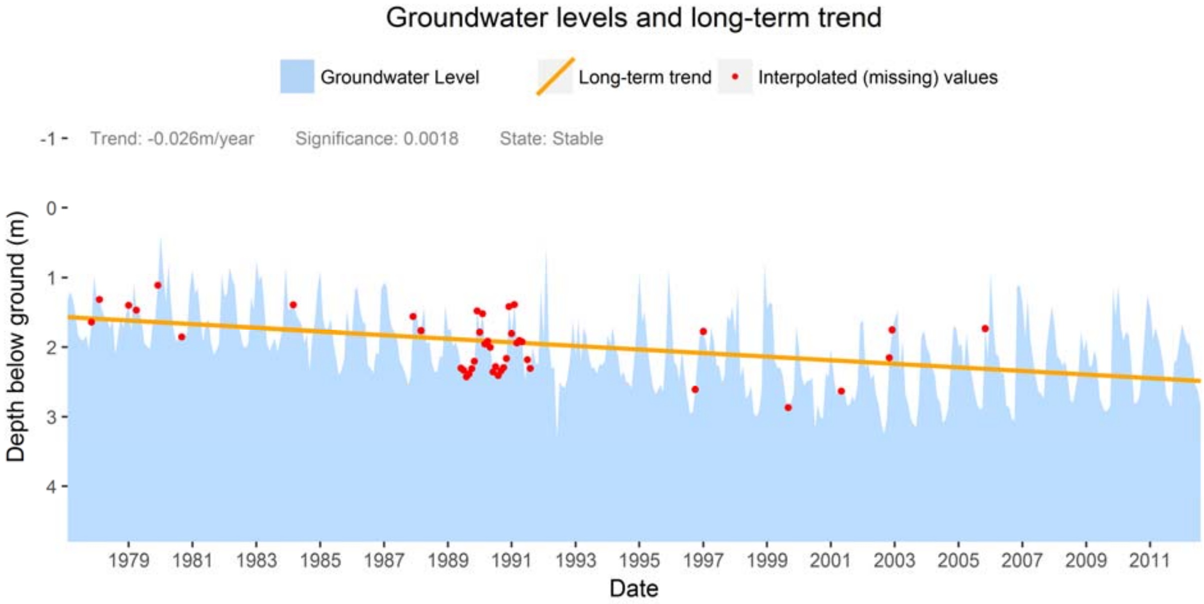

Figure 19: Observation Well #204, Duncan (Duncan Rv Park North Boys Rd.) groundwater level trend, 1977–2012. (Significant p= 0.0018). Source: http://www.env.gov.bc.ca/soe/indicators/water/print_ver/2014_GWL_Trends_print_ver.pdf

7. TRENDS: CLIMATE AND SURFACE WATER (1965-2015)

The following sections discuss the overall trends in the surface water and climate variables for the Cowichan basin from 1965–2015. Information on projected future climate for the Cowichan basin can be found in a report by the Cowichan Valley Regional District (2017). Because trends analyses are sensitive to selected time periods, the entire time period from 1965–2015 was analysed as a single analysis unit (Table 12). It is important to note that differing time periods of analysis usually result in different trends and associated magnitude and statistical significance.

Trends are presented in absence of any causal explanations of dominate controlling drivers, such as disturbances, water use pressures, etc. Some of the trends discussed are likely due to the regulation of flows after weir installation and others due to modes of climate variability or other disturbances. However, identification of the specific cause of the trend is beyond the scope of this report as the resulting trends are the cumulative effect of all land-use changes, withdrawals, and climate variations. A trending of groundwater data from the observation well record was not included in this section, because the record length does not span the desired time period (1965–2015) and was covered previously.

Trending was performed using the R programming language Version 3.1.3, in the RStudio IDE Version 0.98.1103 (R Core Team 2015) using the ‘zyp’ package (Bronaugh and Werner 2013) and Microsoft Excel 2010. In ‘ZYP’, non-parametric trends were calculated using the Yue and Pilon method where initial trend slopes are estimated using the Thiel–Sen approach, which are then corrected for serial correlation effects, and then finally assessed using the Mann-Kendall test for significance (p-value) of the trend (see Bronaugh and Werner 2013 for further explanation). Trends are reported as significant if the p-value was <0.05. Table 12 presents the calculated trends over the entire period (1965–2015) and calculated p-value (the p-values are noted as *** if < 0.001, ** if < 0.01, or *if < 0.05). Blank values indicate no statistically detectable trend in the analysed time series period (i.e., p >= 0.05).

Table 12: Cowichan basin trend analysis results (red is a decreasing trend, green is increasing), 1965–2015 using the Yue-Pilon method. Only statistically detectable statistics (p<=0.05) are reported.

Period	Measure	Surface Water-Upper Station (08HA002) 1965–2015	Surface Water-Lower Station (08HA011) 1965–2015	Air Temp 1965–2015
JAN	Mean			+1.97°C (Mean Temp)**
	Min			+ 1.7°C (Mean Tmin)**
	Max			+2.4°C (Mean Tmax)***
FEB	Mean			
	Min			
	Max			
MAR	Mean			
	Min			
	Max			
APR	Mean			
	Min			
	Max			
MAY	Mean			
	Min			
	Max			
JUN	Mean			
	Min			+1.1 °C (Mean Tmin)*
	Max			
JUL	Mean	-4.037 cms (Mean) ** -3.245 cms (Median)**	-3.296 cms (Mean) ** -3.345 cms (Median)**	+1.2 °C (Mean)*
	Min	-1.646 cms **	-1.286 cms**	+1.2 °C (Mean Tmin)**
	Max	-5.738 cms **	-6.290 cms*	
AUG	Mean	-2.004 cms (Mean) **	-1.510 cms (Mean) *	
	Min	-1.020 cms*		
	Max	-2.936 cms **	-2.797 cms*	
SEP	Mean	-3.659 cms **	-3.218 cms*	
	Min	-1.870 cms**	-1.615 cms*	
	Max			
OCT	Mean			
	Min			
	Max			
NOV	Mean			
	Min			
	Max			
DEC	Mean			
	Min			
	Max			
Annual	Mean			+0.70 °C (Mean Temp)*
	Min	-1.004 cms (Annual) * -0.998 cms (7-day Avg low)* -1.354 cms (30-day Avg low)**	-1.153 cms (30-day Avg low)*	
	Max			
Oct_to_Sep	Mean			
	Min			
	Max			
JFM	Mean			
	Min			
	Max			
AMJ	Mean			
	Min			
	Max			
JAS	Yield	-57.47mm***	-35.236 mm**	
	Min			+1.03°C (Mean Temp)**
	Max			+1.33°C (Mean Tmax)*
OND	Mean			
	Min			
	Max			
AMJJAS	Mean			
	Min			
	Max			

*p-values are *** < 0.001, **< 0.01, *< 0.05, JFM: January, February, March, AMJ: April, May, June, JAS: July, August, September, OND: October, November, December, AMJJAS: April to September.*

7.1 Climate Trends: Precipitation and Air Temperatures

The trends in air temperature and absence of significant trends in precipitation (Table 12) are similar to the results reported by Spittlehouse (2017) for the 1951-2016 period for Cowichan Lake Forestry climate station. No snow data was available for the entire trending period to analyse.

An exploration of the frequency of days with rain greater than defined thresholds (i.e., 20, 30, 50, 80, 100 mm) was conducted. Extreme daily rain fall totals (i.e., 100 mm plus per day), show no statistical detectable trends, but plots of the occurrence of these days indicates a shift with more frequent occurrence of daily exceedances in the latter half of the trending period (Figure 20) with 18 daily total occurrences from 1985 onwards versus five prior to 1985.

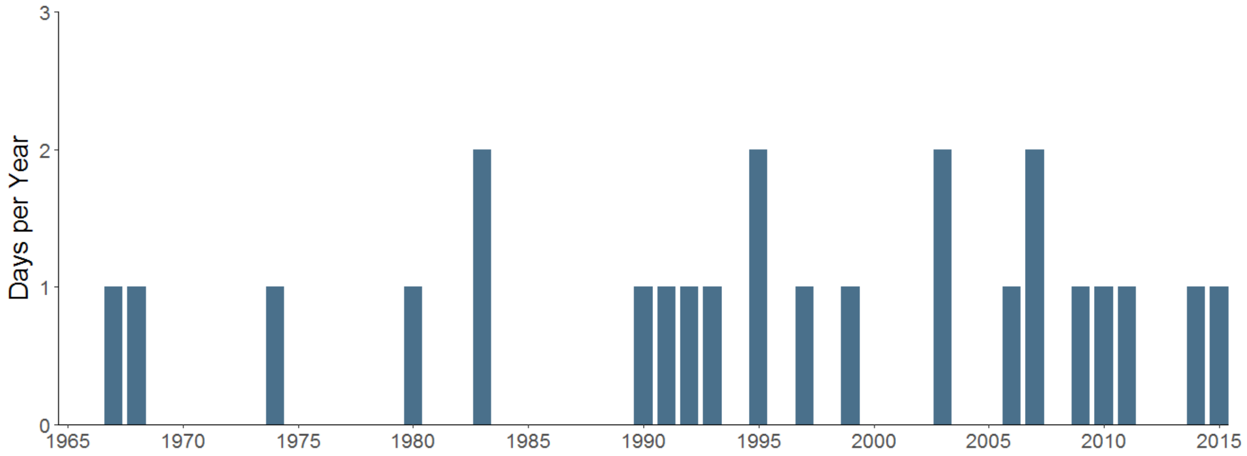

Figure 20: Number of days/year daily precipitation > 100 mm, Cowichan Lake Forestry Climate Station.

Monthly, seasonal and annual air temperature data (average, maximum and minimum) were also analysed over the trending periods. Trend analysis for the 1965-2015 period found a statistically detectable increase in the mean annual air temperature of 0.7 °C (Figure 21). This rate (0.14 °C /decade) is close to the rise (0.18 °C /decade, 1951-2016) reported by Spittlehouse (2017).

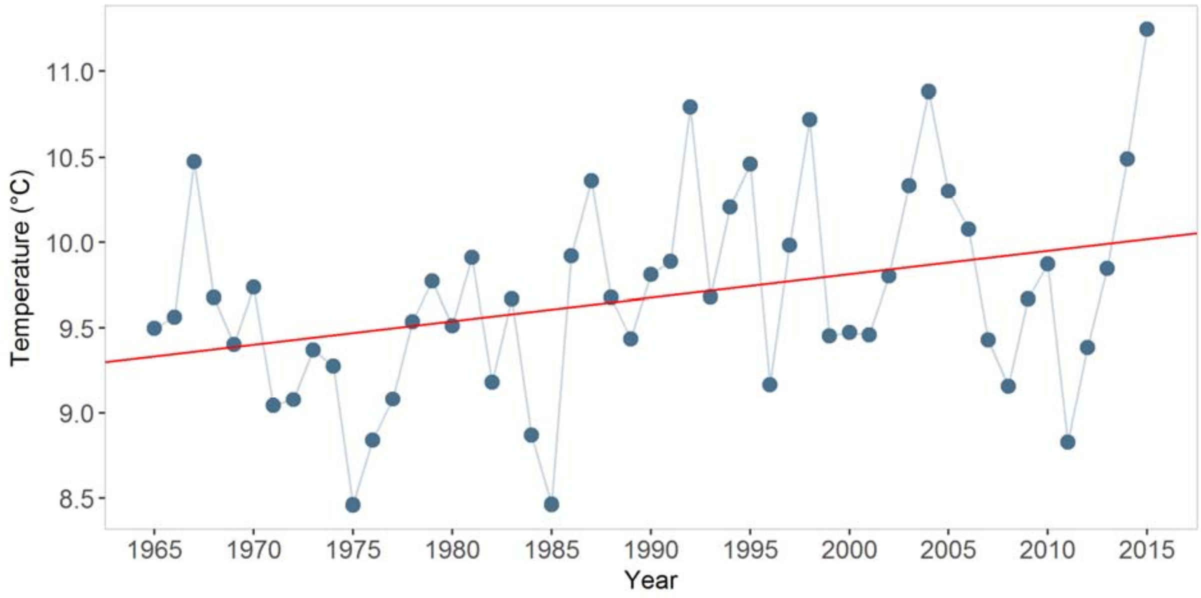

Figure 21: Annual average air temperature trend (1965–2015), Cowichan Lake Forestry Climate Station (p=0.034).

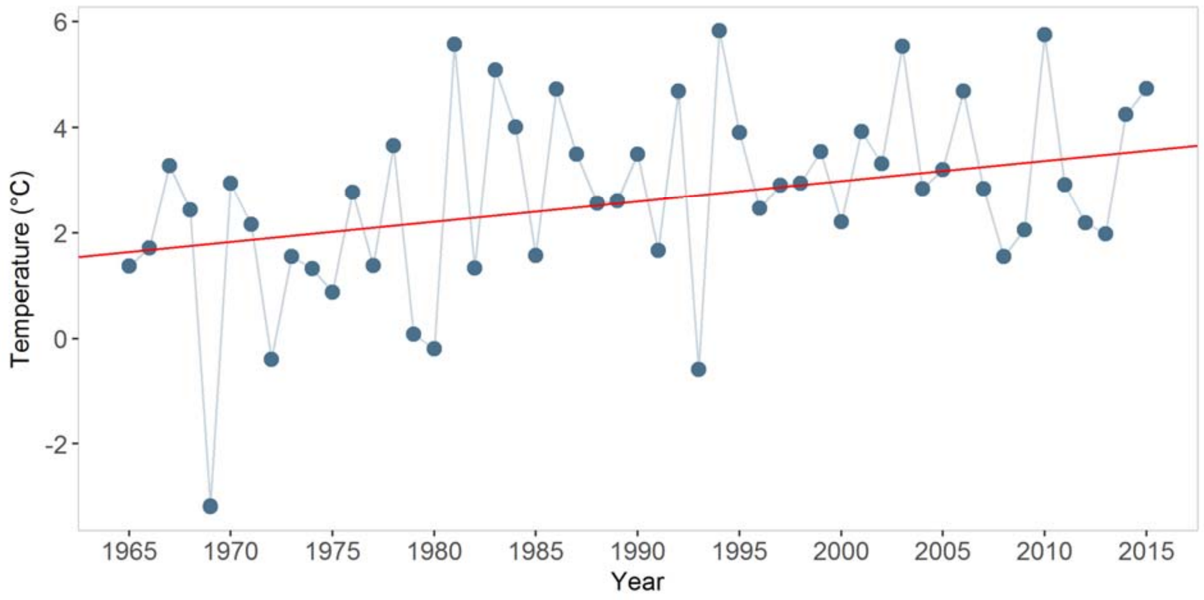

Figure 22: January average monthly air temperature trend (1965–2015), Cowichan Lake Forestry Climate Station (p= 0.002).

Monthly trends of increased temperatures were also detected in January and June / July (Table 12). January mean minimum, mean maximum and average temperatures all demonstrated an increasing trend over the trend period (+1.7°C, +2.4°C and +2.0°C, respectively) (Table 12, Figure 22). Similar to January, the same June and July summary statistics showed similar rising trends of approximately 1.2 °C (Table 12) over the trending period. While the trending time periods differ from Spittlehouse (2017), the directions of trends are consistent. Readers are directed to Spittlehouse (2017) for further information on climate trends for the Cowichan basin.

7.2 Surface Water Trends

Data analysis was also performed for the Upper and Lower Stations to determine if there were any detectable surface water trends. For each hydrometric station, 104 different statistical variables were calculated and then analyzed (see: Appendix A). The analysis identified statistically significant trends in reduced streamflow for many variables calculated in the July through September time period (Table 12). Specifically, there has been a decrease in the median July discharge of approximately ~ -3.3 cms for both stations, with maximum (-5.7/-6.3 cms) and minimum (-1.6/-1.3 cms) decreasing flows for the Upper and Lower Stations, respectively (1965–2015). Decreases in flows for August were also observed for the mean daily flow (-2.0/-1.5 cms, Figure 23) and maximum daily flows (-2.9/-2.8 cms) for the Upper and Lower stations respectively, and -1.0 cms for the minimum daily flow over the trend period for the Upper station only (Table 12). Only mean and minimum trends were detected for September flow variables. Overall, decreases in these monthly flow statistics is also reflected in a reduction in the water yield (total outflow discharge × time/basin area) of -57 mm and -35 mm July through September (Figure 24, Upper Station, -57 mm). It is noted that this trend is not strictly linear and 'step shifts' (regime changes) are visible in many of the plots (Figures 23 and 24) occurring in the mid-1980s, again highlighting the sensitivity of trends analysis results to chosen trending period and other drivers of trends (i.e., modes of climate variability and human disturbances).

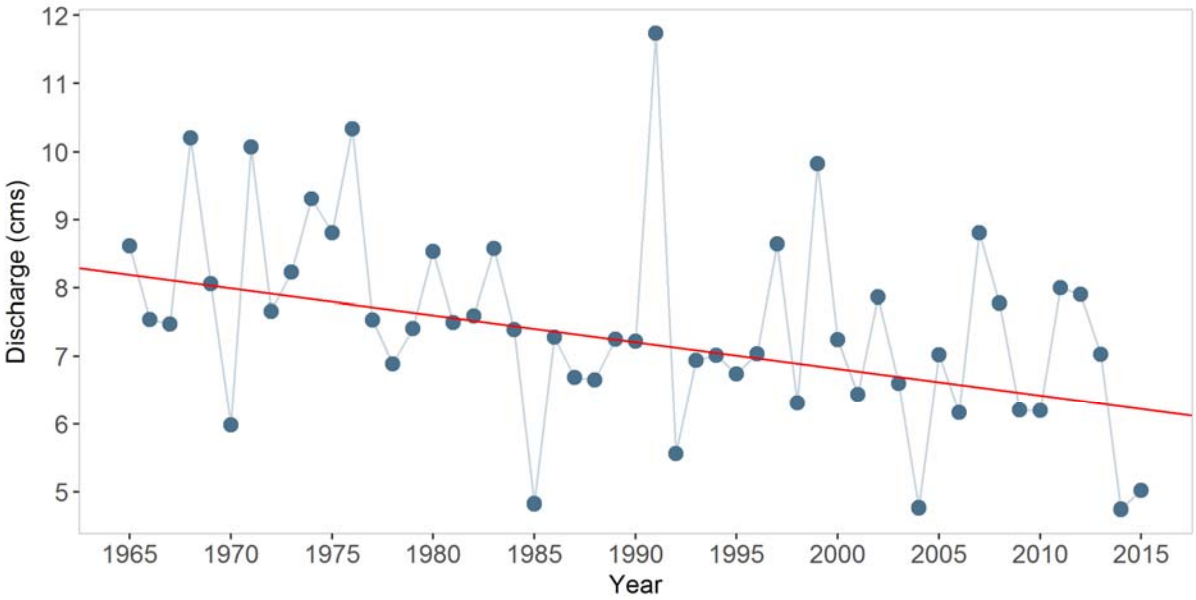

Figure 23: August mean discharge trend for Upper Station, 1965–2015 (p=0.001).

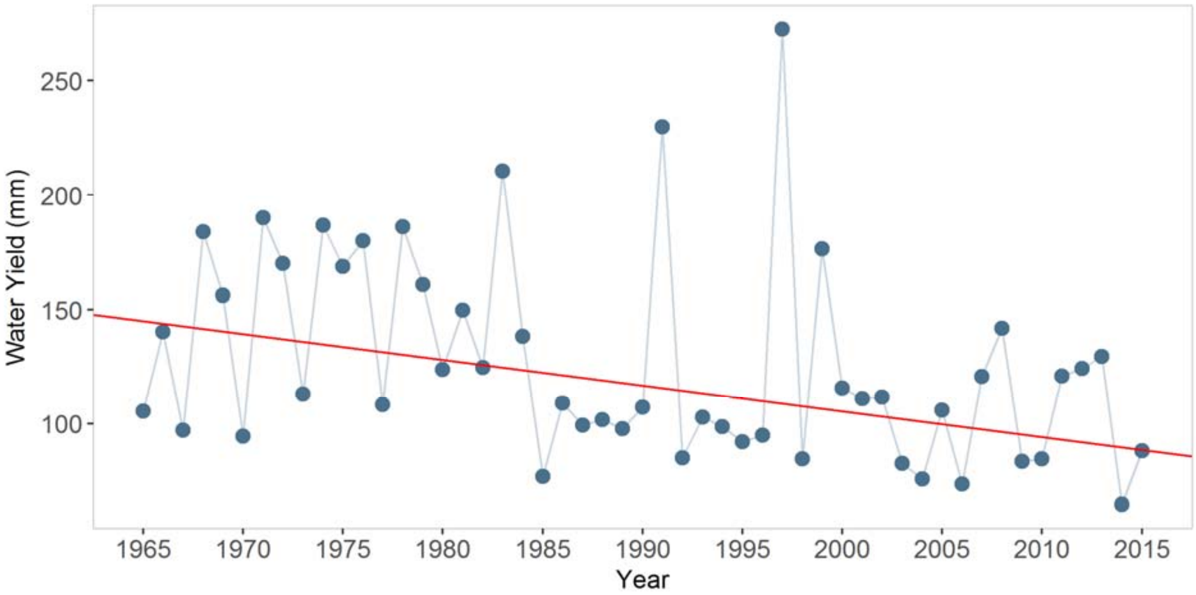

Figure 24: July through September declining water yield trend for the Upper Station, 1965–2015 (p=0.000).

On an annual basis, there was no detectable statistical significance in the trending period for the higher flow summary statistics analysed (Appendix A). Trends in the annual, 7-day and 30-day average low flows summary statistics (-1.0, -1.0, -1.4 cms respectively; Table 12) were detected for the Upper Station (Figure 25). For the Lower Station, only trends in the 30-day low flow (-1.2 cms) were statistically detectable (Table 12).

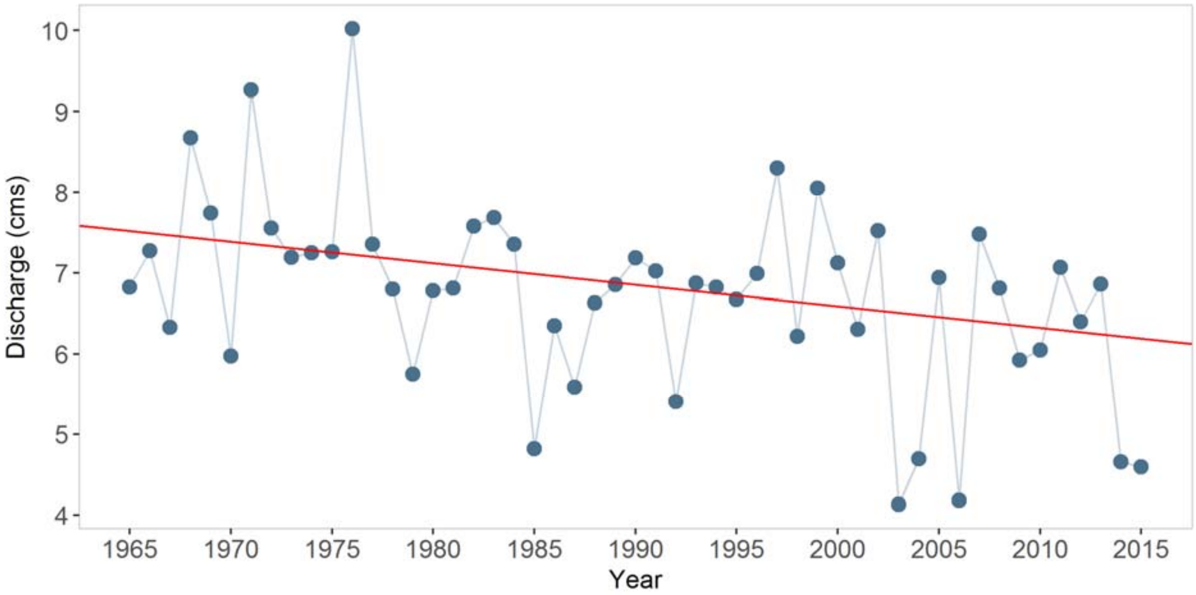

Figure 25: 30-day average low flow trend for the Upper Station, 1965–2015 (p=0.003).

Daily percentiles for the period of record were calculated and annual data was compared to the 'normal' range by summing the number of days per year below daily 25th, and above, 75th percentiles. The number of days with discharge below the 25th percentile (with data over the 1965–2015 period) was found to increase (66.5 more days) over the time period (Figure 26). This is consistent with other summer time variables that display a trend of decreasing flow (increased number of low flow days).

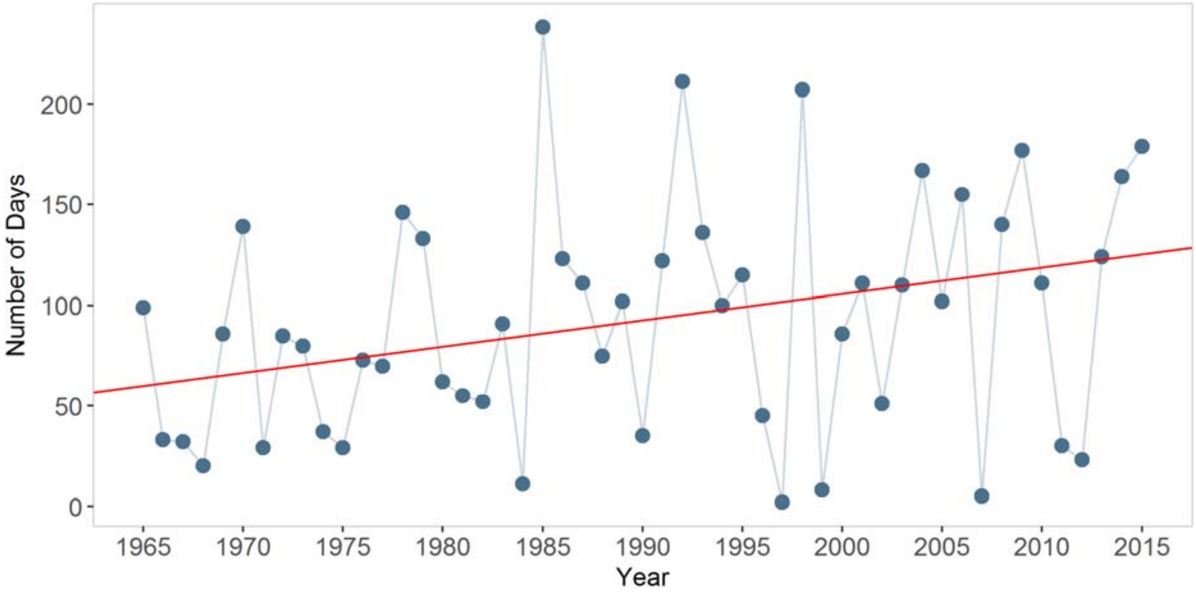

Figure 26: Number of days below the 25th percentile discharge trend for the Upper Station, 1965–2015 (p=0.034).

7.3 Trends Summary

For the trending period (1965–2015), this study found statistically detectable trends in rising annual, January and June/July air temperatures. While no trends were detected in this time period for changes in the amount of precipitation, some trends were found to show a greater occurrence of days with higher daily rainfall amounts in the latter half of the trending period. In terms of snow amounts, no data within the trend period were available to analyse, but Spittlehouse (2017) did report a decrease (-10 mm per decade) in an estimate of precipitation as snow. The increase in warming (air temperatures), is likely having an effect on not only the form of precipitation, but on evaporative demand as well (e.g., -5 mm per decade, Spittlehouse 2017).

Observations of groundwater levels from the Provincial Observation Well network show that groundwater in two Provincial Observation Wells are declining. Further discussion of basin wide trends over different time periods can be found in Lapcevic *et al.* (in press). Surface water discharges are exhibiting a similar trend, with statistically significant decreases over the trending period for July, August and September summary statistics. Statistical trends in flow variables highlights a tendency for decreasing summertime flows over the trending period, particularly in the latter half of the period where there may have been a step shift in climate-streamflow regime. These shifts can occur as a result of a sudden switch to a different dominate climate pattern (see Moore *et al.* 2010 for more details), and therefore, statistical trends as stated in this report, may actually represent an abrupt change to a different climate regime vs. a more gradual, continual change over the trending period.

8. CONCLUSIONS

The large scale channel modifications that have occurred since the late 1800’s in the Cowichan basin have set in place an important legacy of stream channel disturbance that continues to this day. Importantly, channel modifications via blasting, dredging, and others have altered river flow regimes and natural channel habitat features. Water use in the basin has increased steadily through time, putting further pressures on water resources in the Cowichan basin. Groundwater extraction and well density in the lower basin has increased through time to present day. Surface water extractions have also increased over the period of analysis. The installation of the weir near the outlet of Cowichan Lake to control water released in the spring and summer to the river has fundamentally changed the timing and magnitude of low flows in the system compared to the pre-weir flow conditions.

Climate and precipitation data available for the Cowichan basin allowed for the identification of statistically detectable trends for the period of 1965–2015. While no trends were detected in the time period for precipitation, trends of rising air temperatures are likely changing the amount of precipitation that falls as snow that has the potential to influence the amount and timing of water delivery to ground and surface waters in the basin.

As a result of the cumulative impact of various water stressors, water use pressures and climate drivers, water availability has been changing in the Cowichan basin. Surface water discharge trends are declining, particularly in the low flow season from July through September. While this decline is not attributed to any specific causal mechanism, the cumulative effects of the stressors indicate that the Cowichan River will require increased attention in the future to mitigate these trends.

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APPENDIX A: METHODOLOGIES AND ASSUMPTIONS

The follow appendix materials describe the data analysis methodologies for surface water and groundwater well summaries and data filling procedures for streamflow data gaps.

A.1 Surface Water Licences

Provincial water licence data was accessed through the BC Geographic Warehouse (BC Geographic Warehouse 2015a). The following protocol was used to determine final water licence data used in this report:

- Only licences that were authorized to divert water between 1914 to present were included; excluding any licences or applications that were abandoned, expired, pending, and refused.
- All 'storage' licences were examined; those where the allocated diversion amount was captured in another licence were excluded (licence purpose definitions are found at *http://www.env.gov.bc.ca/wsd/water_rights/licence_application/cabinet/water_purpose_definitions-2013.pdf*).
- Non-consumptive licences were excluded; these are flagged with 'TF' in the 'units' field and indicate that total flow is authorized to pass through the licenced works, but no water is diverted from the stream (Abbreviations found at *http://www.env.gov.bc.ca/wsd/wrs/query/licences/help/all.htm*).
- Licences flagged with 'm' in the quantity field were excluded; these are licences with multiple points of diversion that have a combined maximum diversion amount (Abbreviations found at *http://www.env.gov.bc.ca/wsd/wrs/query/licences/help/all.htm*).
- Licence data was collected for two time-based snapshots, one from the end of 1954 and one from the end of 2012 (these were based on their 'priority date').
- Cancelled or abandoned licences were removed; the 'cancelled date' was used for cancelled licences and the 'status date' was used for abandoned licences. The 'status date' is the date that the abandonment was updated in the provincial e-licensing system and thus the 'status date' was the date, or close to the date, that the licence was actually abandoned.
- Licences were categorized based on allocated diversion amount. Amounts were converted into cubic metres per second and then categorized.

A.2 Groundwater Wells

Wells data was accessed through the BC Geographic Warehouse (BC Geographic Warehouse 2015b). The following methodologies were used to estimate final well data used in this report:

- Only wells within Cowichan basin (excluding Koksilah watershed) were included.
- Only wells drilled before 2013 were included.
- Assumed all wells are in use, but actual status of all wells is unknown.
- Well records in WELLS are voluntarily submitted, which could lead to an underestimation of actual number of wells in the Cowichan basin.
- 56 wells were excluded from analysis as there was insufficient data to determine active status.
- 7 observation wells were excluded.
- Wells were categorized into the two time periods based on their 'construction date.'
    - 65 of the total 2851 wells did not have a construction date, so were arbitrarily included in the first time period.

  - 370 of the 2851 wells had an arbitrary construction date of '1950-01-01'; this date was applied to old well records with an unknown construction date. It was assumed all wells with this arbitrary date were drilled prior to or near 1950.
- A point density analysis was completed using GIS to determine the number of wells per square kilometer.

A.3 Surface Water Data Gap Filling Methods

Historical streamflow data from two Water Survey of Canada hydrometric stations were downloaded (January 11, 2017) for analysis to characterize historical flows and to identify recent trends (Water Survey of Canada 2017). Data gaps that exist in the Lower Station's 2003 record were filled by regressing the Upper Station to the Lower Station ($Y=1.0138x-1.3628$, $r^2= 0.9608$). Records of instantaneous discharges are not as complete as the records for daily average discharges. Therefore, daily average discharges were used to calculate monthly and annual values for mean, median, maximum and minimum for both stations. Data analysis was performed using the R programming language Version 3.1.3, in the RStudio IDE Version 0.98.1103 (R Core Team 2015 and Microsoft Excel 2010).

A.4 Analysed Surface Water Summary Statistics (104 variables)

Annual Min Discharge (cms)
Date of Annual Min Discharge
Minimum of Annual 3-day avg (cms)
Date of Min Annual 3-day avg
Min Annual 7-day avg (cms)
Date of Min Annual 7-day avg
Min Annual 30-day avg (cms)
Date of Min Annual 30-day avg
Annual Min Discharge (cms)
Annual Max Discharge (cms)
Annual Mean Discharge (cms)
Annual Total Discharge (m^3)
Annual Water Yield (mm)
Cumulative Sum of Annual Daily Q (cms)
Date of 25% of Annual Cumulative Discharge
Date of 50% of Annual Cumulative Discharge
Date of 75% of Annual Cumulative Discharge
Jan/Feb/Mar Total Discharge (m^3)
Apr/May/Jun Total Discharge (m^3)
Jul/Aug/Sep Total Discharge (m^3)
Oct/Nov/Dec Total Discharge (m^3)
Jan/Feb/Mar Water Yield (mm)
Apr/May/Jun Water Yield (mm)
Jul/Aug/Sep Water Yield (mm)
Oct/Nov/Dec Water Yield (mm)
Jan Min Discharge (cms)
Feb Min Discharge (cms)
Mar Min Discharge (cms)
Apr Min Discharge (cms)

May Min Discharge (cms)
Jun Min Discharge (cms)
Jul Min Discharge (cms)
Aug Min Discharge (cms)
Sep Min Discharge (cms)
Oct Min Discharge (cms)
Nov Min Discharge (cms)
Dec Min Discharge (cms)
Jan Max Discharge (cms)
Feb Max Discharge (cms)
Mar Max Discharge (cms)
Apr Max Discharge (cms)
May Max Discharge (cms)
Jun Max Discharge (cms)
Jul Max Discharge (cms)
Aug Max Discharge (cms)
Sep Max Discharge (cms)
Oct Max Discharge (cms)
Nov Max Discharge (cms)
Dec Max Discharge (cms)
Jan Mean Discharge (cms)
Feb Mean Discharge (cms)
Mar Mean Discharge (cms)
Apr Mean Discharge (cms)
May Mean Discharge (cms)
Jun Mean Discharge (cms)
Jul Mean Discharge (cms)
Aug Mean Discharge (cms)
Sep Mean Discharge (cms)
Oct Mean Discharge (cms)
Nov Mean Discharge (cms)
Dec Mean Discharge (cms)
Jan Median Discharge (cms)
Feb Median Discharge (cms)
Mar Median Discharge (cms)
Apr Median Discharge (cms)
May Median Discharge (cms)
Jun Median Discharge (cms)
Jul Median Discharge (cms)
Aug Median Discharge (cms)
Sep Median Discharge (cms)
Oct Median Discharge (cms)
Nov Median Discharge (cms)
Dec Median Discharge (cms)
Jan 20th percentile Discharge (cms)

Feb 20th percentile Discharge (cms)
Mar 20th percentile Discharge (cms)
Apr 20th percentile Discharge (cms)
May 20th percentile Discharge (cms)
Jun 20th percentile Discharge (cms)
Jul 20th percentile Discharge (cms)
Aug 20th percentile Discharge (cms)
Sep 20th percentile Discharge (cms)
Oct 20th percentile Discharge (cms)
Nov 20th percentile Discharge (cms)
Dec 20th percentile Discharge (cms)
Jan 10th percentile Discharge (cms)
Feb 10th percentile Discharge (cms)
Mar 10th percentile Discharge (cms)
Apr 10th percentile Discharge (cms)
May 10th percentile Discharge (cms)
Jun 10th percentile Discharge (cms)
Jul 10th percentile Discharge (cms)
Aug 10th percentile Discharge (cms)
Sep 10th percentile Discharge (cms)
Oct 10th percentile Discharge (cms)
Nov 10th percentile Discharge (cms)
Dec 10th percentile Discharge (cms)
Oct to Mar Total Discharge (m^3)
Apr to Sep Total Discharge (m^3)
Oct to Mar Water Yield (mm)
Apr to Sep Water Yield (mm)
Number of Days Below 25th Daily Percentile
Number of Days Above 75th Daily Percentile
Number of Days Outside 25th/75th Daily Percentiles