Examining the Effects of Climate Extremes on the Water Supply-Demand System of Two British Columbia Watersheds

LWS 548 Major Project

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Executive Summary

An analysis on the water supply-demand system was examined to better understand the effects of climate extremes on the Chapman Creek Watershed in the Sunshine Coast and on the Norrish Creek Watershed in the Abbotsford-Mission region. Both regions are facing a challenge where the population is continuing to increase, and climatic changes are becoming more unpredictable. Precipitation, temperature, and discharge data was obtained and used to identify climatic trends for both watersheds. These trends are a direct result of climate change where both Sunshine Coast and Abbotsford-Mission region are experiencing a decrease in summer precipitation, an increase in extreme temperatures, unpredictable changes in streamflow during extreme events, and a decrease in snowpack. There is clear evidence of a shift in earlier snowmelt and earlier spring freshet. These changes and their implications influence the water consumption and the water supply for both watersheds. Both systems are noticing an increased demand for water during the summer where precipitation is low, and temperatures are high. As climatic models continue to predict future trends, both watersheds will require careful management in order to supply enough water and to meet the water demand during peak seasons. Emphasis should be placed on conservation management techniques as this is the most feasible and cost-effective option. It will be crucial to understand the impacts of climate change on the water supply and demand of these smaller communities which may provide future insight into managing larger systems.

Introduction

Climate change and its impact on our world is becoming unpredictable, and this instability will expose our systems to more extreme climatic threats. During the last century, there was a rapid increase in our world's population along with significant industrial and agricultural growth. These ecological and social changes have introduced a threat to our global water security, where our present-day living standards keep increasing water demand. This effect will be seen across every region and will further impact our water supplies. According to a report by the International Panel on Climate Change (IPCC), (Hoegh-Guldberg et al., 2018), the population facing water scarcity have increased from 250 million people in the 1900s to 3.8 billion people in the 2000s.

The increase from 15 percent of the global population to almost 60 percent of the global population (Hoegh-Guldberg et al., 2018) means that more than half of the global population will be living in water-scarce conditions. Climate change and population growth are the main reason for this change. This percentage will only increase more as our water consumption behavior has exacerbated due to higher water stress in several semi-arid and arid regions such as California (Mehran et al., 2015), and has caused a serious water shortage in South Asia, North Africa, and in the Middle East (Kummu et al., 2016). It will be crucial, over the next few decades, to predict how changes in population and how extreme climatic fluctuations will affect our water resource availability.

In Canada, it is expected that extreme climatic events such as floods and droughts will occur more frequently and with greater intensity. Changes in climatic variables such as temperature and precipitation, will increase the risk of these extreme climatic changes across Canada (Burch et al., 2010). The IPCC (Hoegh-Guldberg et al., 2018) has stated that there is a greater than 90 percent probability that these heat waves and heavy precipitation events will continue to occur. Much of Southern British Columbia will experience a longer duration of summer heat and droughts and there will be significant reductions of summer precipitation (Haughian et al., 2012). British Columbia will also see fewer, but larger rainfall events during the winter that will have severe consequences for different ecosystem functions and services (Knapp et al., 2008). B.C. is strongly influenced by its glaciers and snow accumulation and by changes in its mean temperature and energy balance shifts (Loukas et al., 2001). The increase in future annual temperature in B.C., which is projected to increase by 1 to 3 degrees Celsius by 2050 (Murdoch & Spittlehouse, 2011), and the large decrease in annual snowfall will reduce the amount of snowpack. The melting of these snow-packs is occurring earlier than expected and at a quicker rate, and the spring snowmelt is followed by a longer and drier summer in several parts in south coastal B.C. (Pike et al., 2010). There are several papers that are suggesting that we shift our focus towards examining the potential significance of these event timings (Burn, 2002; Dery, 2009; Zhang et al., 2001; Whitfield &Cannon, 2000).

Most research focuses on managing water supplies under future climatic modeling scenarios, but there seems to be a lack of data available and a limited amount of research on water consumption. In B.C., watershed managers and policy-informers are emphasizing that there should be more investments and resources going towards water supply infrastructures. Updating these infrastructures such as pipes, dams, and reservoirs will take an economic hit and will require an enormous amount of time. One report (Schreier, 2016) suggested that we should try to change our consumption pattern, particularly during the summer peak season, which will help with managing the demand-side through water conservation.

Understanding these extreme climatic changes and their impacts on our water supply-demand system will allow us to compare and to recommend different possible management strategies for smaller communities in British Columbia. This report will aim to examine these climatic impacts along with the implications it has on our water supply-demand system for two B.C. watersheds; the Chapman Creek System in the Sunshine Coast region and the Norrish Creek System in the Abbotsford-Mission region.

The population of the Sunshine Coast region is approximately 32, 200 (Statistics Canada, 2022) and similarly, the population of Abbotsford-Mission metropolitan area is approximately 195, 700 (Statistics Canada, 2022). The population of both regions are increasing at a rapid rate where there was a seven percent population increase for the Sunshine coast region since 2016 (Statistics Canada, 2022) and an eight percent population increase for the Abbotsford-Mission region since 2016 (Statistics Canada, 2022). This rapid increase in population growth poses a social challenge for watershed managers and policy makers to deal with. These land-use and socioeconomic changes are occurring concurrently with the extreme climatic variability that these systems are experiencing. This makes existing watershed and water resource management practices more difficult to manage. Thus, decision-makers must start shifting their focus on ensuring a reliable water supply-demand system where future extreme climatic impacts are also considered. This report will complement the existing work that has been done to examine the effects of extreme climatic changes on the water supply-demand system of both Chapman Creek System and Norrish Creek System.

The objectives of this report are to:

- Review historical and current climatic and hydrologic data records for both Chapman Creek, from the Gibson climate station, and Norrish Creek, from the Abbotsford Airport and the Mission Abbey climate station.
- Analyze and make a comparison of changes in temperature, precipitation, and discharge between the Chapman Creek and Norrish Creek during the dry and wet season with an emphasis on recent extreme years; 2015, 2017, & 2021.
- Examine the long-term trends and implications from these climatic and hydrologic variables on the water supply-demand system for both Chapman Creek and Norrish Creek.
- Recommend future management strategies for both regions by utilizing different policy frameworks that have been effective in B.C or in other regions.

Methods

Climate Data Records

The climate data records for both Chapman Creek Watershed and Norrish Creek Watershed were obtained from the Environment Canada's climatic data base. For both watersheds, the data included a record of key climatic variables: such as maximum, minimum, and mean annual and monthly temperatures (degrees Celsius), total precipitation (mm), and total snow accumulation (cm). For the Chapman Creek Watershed, the Gibson Gower Point climate station (ID: 1043152; latitude of 49.39 & longitude of -123.54) was used for collecting and analyzing the raw monthly and annual temperature and precipitation data from 1971 to 2021. This station is 34 meters elevated above sea level and was used in several past studies that have assessed the water supply and demand characteristics of Chapman Creek (Chapman & Rekstan, 1991). Although the Gibson climate station is at a 34-meter elevation, the water reservoir is located at a 1500-meter elevation. This means that the conditions for the water supply are different at higher elevations. Thus, the climate record from the Gibson Gower Point station was useful in providing insight into understanding the historical and current climate pattern. It also allowed for a comparison of different extreme years which helped with examining the impacts of these climatic variables on the Chapman Creek's water supply and demand.

The climate data records for the Norrish Creek Watershed in Abbotsford-Mission were provided from two different stations. The Abbotsford Airport climate station (latitude of 49.03 & longitude of -122.36) was used to review the monthly temperature and precipitation data of Abbotsford-Mission from 1945 to 2021. This climate station was also used for comparing the trends in summer temperature and precipitation. Similarly, the Mission-West Abbey climate station (ID: 1105192, elevation of 197 meters above sea level) was used to show the trend in total snow accumulation from 1963 to 2007. This station did not provide data for snow accumulation from 2008 to 2021, but was still used, based on its elevation, to show the general trend of decreasing snowfall. Thus, both the Abbotsford Airport climate station and the Mission-West Abbey climate station were representative of the headwater conditions for Norrish Creek.

Hydrological Data Records

The hydrological data records were collected from the Water Survey of Canada website for the Chapman Creek and for the Norrish Creek. The archived data records for Chapman Creek were taken from two stations which provided data on monthly average discharge. The first station (ID: 08GA060) provided monthly discharge data for the Chapman Creek above the Sechelt Diversion from 1971 to 1988. The second station (ID: 08GA078) provided monthly discharge data for the Chapman Creek below the Sechelt Diversion from 1993 to 2003. There was no discharge data provided between 1989 to 1992. Both these stations were in the same region, and both had a drainage area of 64.5 km square.

The discharge data for Norrish Creek was taken from the Norrish Creek station near Dewdney (ID: 08MH058) which had a total drainage area of 117 km square. The data set provided average monthly discharge from 1960 to 2006. For both Chapman Creek's and Norrish Creek's discharge date records, there were a few missing gaps in recording discharge measurements for some months. This will influence the average monthly discharge during the respective time period for both watersheds. The lack of data for discharge, for both Chapman Creek and Norrish Creek, over the last decade did not allow for a full picture of the implications from recent climatic events on these watershed systems.

Water Demand (Consumption) Records

For the Chapman Creek, the water demand was summarized in tables that showed the consumption pattern of the region. This table was taken from the Sunshine Coast Regional District report on water demand analysis and projections (Rosenboom, 2018). This table provided a summary of water demand characteristics from 2003 to 2018 which allowed for comparing this demand with the region's water supplying capacity.

There was no raw data to interpret or any summary tables that provided meaningful trends for the Norrish Creek in the Abbotsford-Mission area. The Abbotsford-Mission Master Water Plan in 2017 provided a graph that showed a general decreasing trend in water consumption for the Norrish Creek Watershed from 2007 to 2017, but this figure alone cannot support the water demand trends for the area. However, this Master Water Plan report provided specific future water demand and supply targets that was compared with its current target. This may provide a bit of evidence in understanding how the Abbotsford-Mission Water System tends to reach those targets as it has considered them under a changing climatic modelling scenario.

Results & Discussion

Overview of Sunshine Coast Regional District

The Sunshine Coast Regional District (SCRD) consists of several communities that are located on the South Coast of British Columbia. The Chapman Creek Watershed lies within the SCRD and is the primary water supplier for approximately 32, 200 residents (Statistics Canada, 2022). The watershed, which is approximately 73 km square in size (Mukai et al., 2016), covers the region between Langdale and Earl's Cove including the District of Sechelt and the Town of Gibson; both being popular tourist destinations during the summer. Approximately 90 % of the drinking water supplied to residents in the SCRD comes from the Chapman Creek Watershed (Mukai et al., 2016).

The main storage reservoirs for drinking water for SCRD are Chapman Lake and Edwards Lake. Both Chapman Lake and Edwards Lake act as a headwater storage reservoir for the SCRD and are in the Tetrahedron Provincial Park. When establishing the Tetrahedron Provincial Park, the primary goal was to maintain the Chapman Creek Watershed characteristics, particularly its water quality, along with enhancing recreational opportunities. Water flows from Chapman Lake through the Chapman Creek, which is approximately 17 km long and is a third order stream (Mukai et al., 2016), and empties into the Georgia Strait.

The Chapman Creek Watershed is classified into three bio-geoclimatic zones: the Coastal Western Hemlock, the Mountain Hemlock, and the Alpine Tundra (Mukai et al., 2016). These bio-geoclimatic zones are useful when determining the amount of precipitation that falls in the form of rain, snow, or a mix of rain-snow as the elevation increases in the watershed. As elevation increases, the annual precipitation increases in the watershed. This is due to the orographic effect of the Coast Mountains in B.C. where precipitation is falling towards the mountain windward side and this forces air in an upward direction (Pike et al., 2010).

Precipitation & Temperature Data Analysis of Chapman Creek

The watershed experiences its highest precipitation in the form of rain during winter, especially in November and December, and its lowest precipitation during July and August (Chapman & Rekstan, 1991). Most precipitation, approximately 95 %, in the Chapman Creek Watershed precipitates as rain (Mukai et al., 2016). Approximately 75 % of SCRD annual precipitation is received between October and March (Chapman & Rekstan, 1991). This is crucial for the water storage reservoirs in the SCRD as the freshwater-supply source recharges from the abundant precipitation and the deep snowpack. The average annual temperature in the watershed is 10 degrees Celsius, where the coldest temperature occurs during January and the warmest month is July with an average temperature of 17 degrees Celsius (Chapman & Rekstan, 1991). There seems to be a correlation as the elevation increases in the watershed, the mean temperatures during the winter months decreases (Chapman & Rekstan, 1991).

Figure 1 below shows the annual total average monthly precipitation from 1971 to 2021 and similarly, Figure 2 below shows the average monthly temperature from 1971 to 2021 from Gibson climate station.

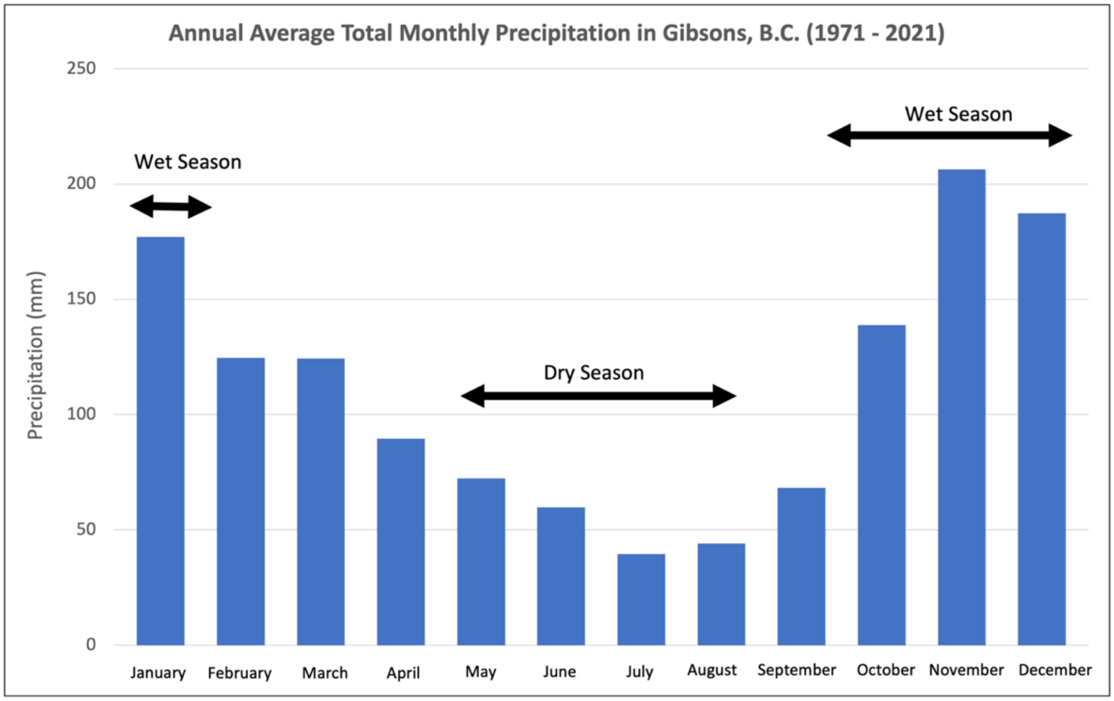

Figure 1: Annual Total Average Monthly Precipitation in Gibson (1971 – 2021)

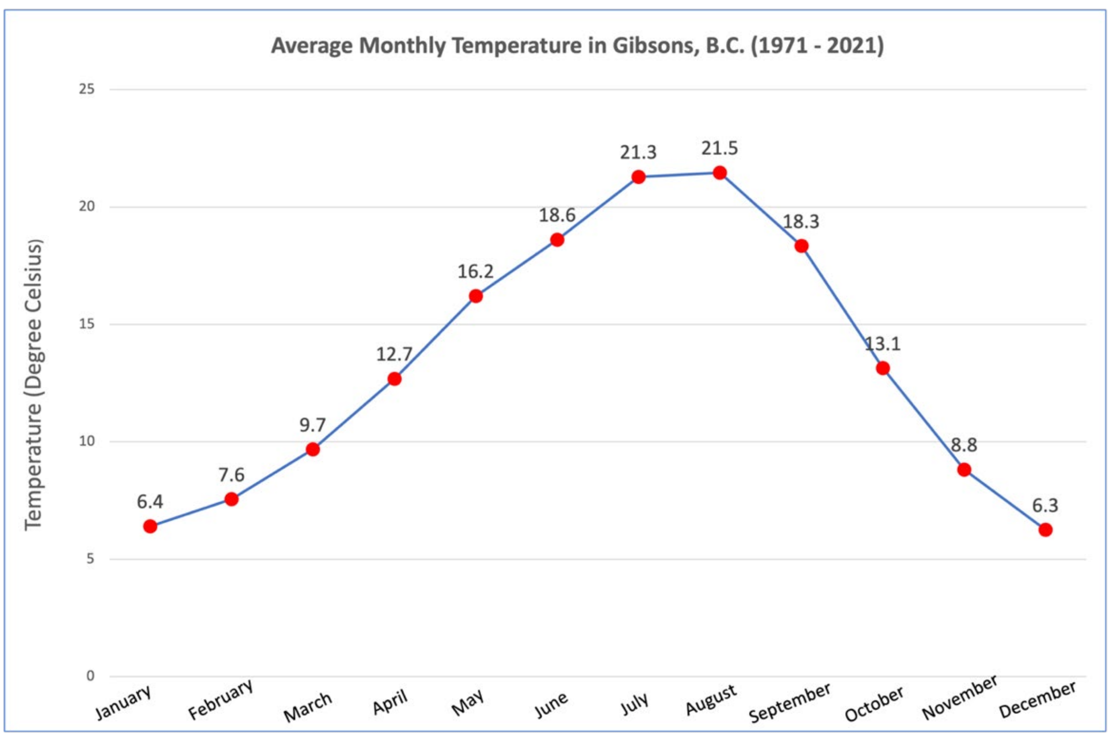

Figure 2: Average Monthly Temperature in Gibson (1971 – 2021)

Figure 1 shows that the dry season (May to August) receives the least amount of precipitation, while the highest precipitation is received during the wet season (October to January). Similarly, Figure 2 shows how the average monthly temperature in Gibson rapidly increases as the seasons shift from winter towards summer where July and August have the highest average temperature.

Figure 3 below shows the annual maximum temperature for the Gibson climate station from 1971 to 2021. From Figure 3, there is a projected trend where the maximum temperature of the Chapman Creek Watershed will increase in the years to come. Figure 4 further supports this evidence as it shows the average maximum temperature from May to August in Gibson (1971 to 2021) increasing in a linear trend. The highest maximum temperature that the watershed has experienced was shown in the recent years; 2015, 2017, and 2021 from Figure 4.

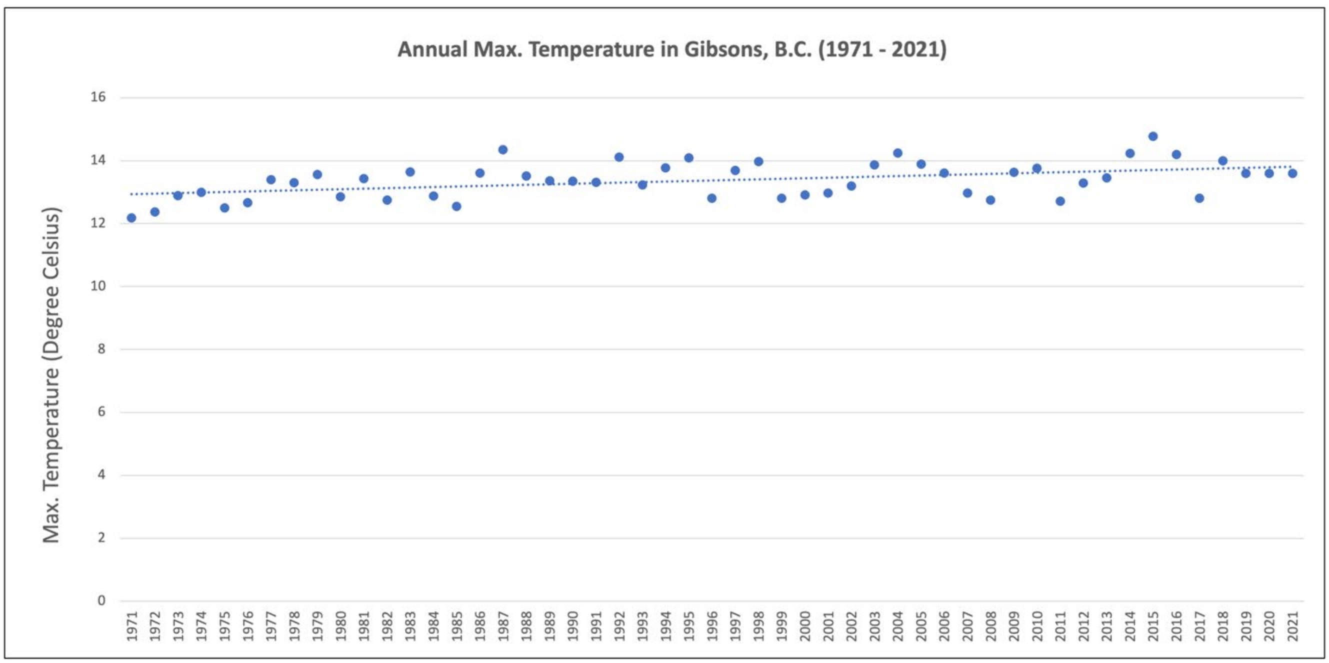

Figure 3: Annual Maximum Temperature in Gibson (1971 -2021)

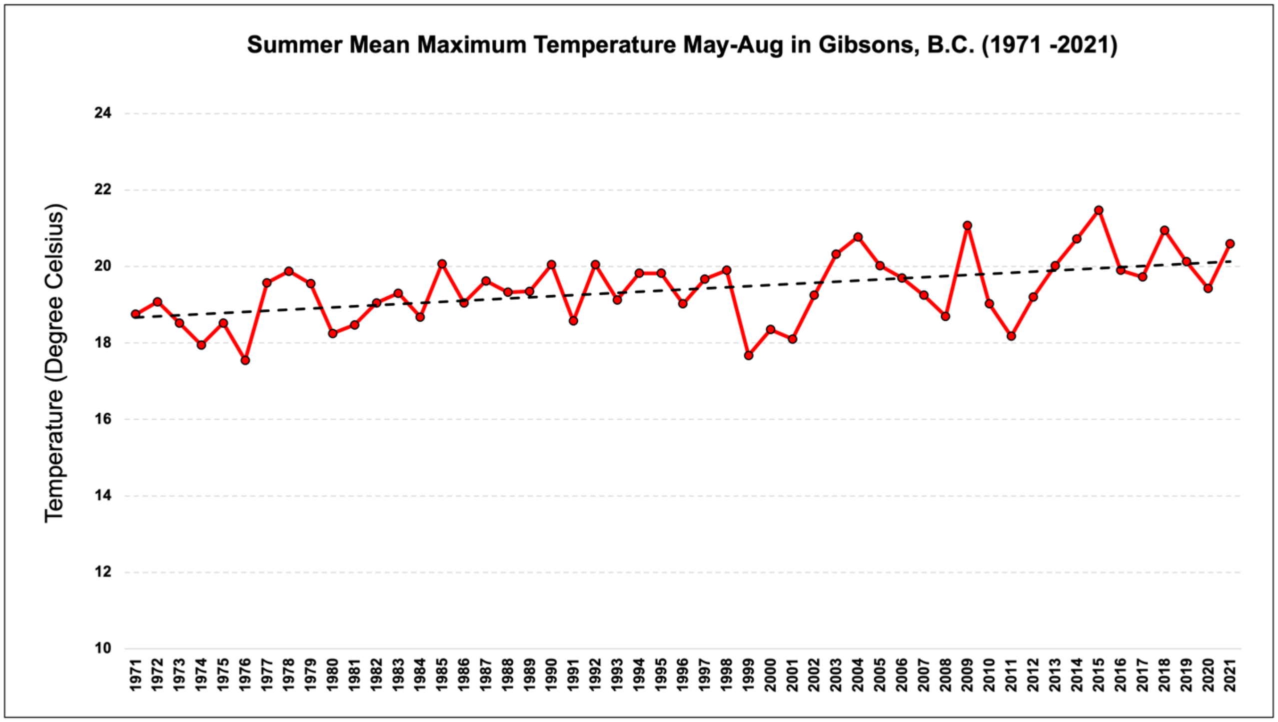

Figure 4: Summer Mean Maximum Temperature in Gibson (1971 – 2021)

These trends are supported from a similar study (Murdock & Spittlehouse, 2011), where the projected average summer temperature for most of British Columbia is expected to increase between 1-3 degrees Celsius. The study also predicts a 1-4 degree Celsius range increase for the winter months in B.C. (Murdock & Spittlehouse, 2011). However, this trend is not the same in Chapman Creek Watershed if we examine the annual precipitation in Gibson. Figure 5 shows how there is a decreasing trend in annual precipitation from 1971 to 2021 and similarly, Figure 6 shows that the Chapman Creek Watershed is experiencing a significant decrease in precipitation during its summer months. In B.C., most of the southern areas are expected to see a 15 % decrease in its summer precipitation (Murdock & Spittlehouse, 2011) compared to an increase in summer precipitation in Northern B.C. From Figure 6, the mean summer precipitation from 1971 to 2001 was 243 mm whereas, the mean summer precipitation from 2002 to 2021 was 175 mm. There was a 28% decrease between these periods which supports the trend of decreasing summer precipitation in southern B.C.

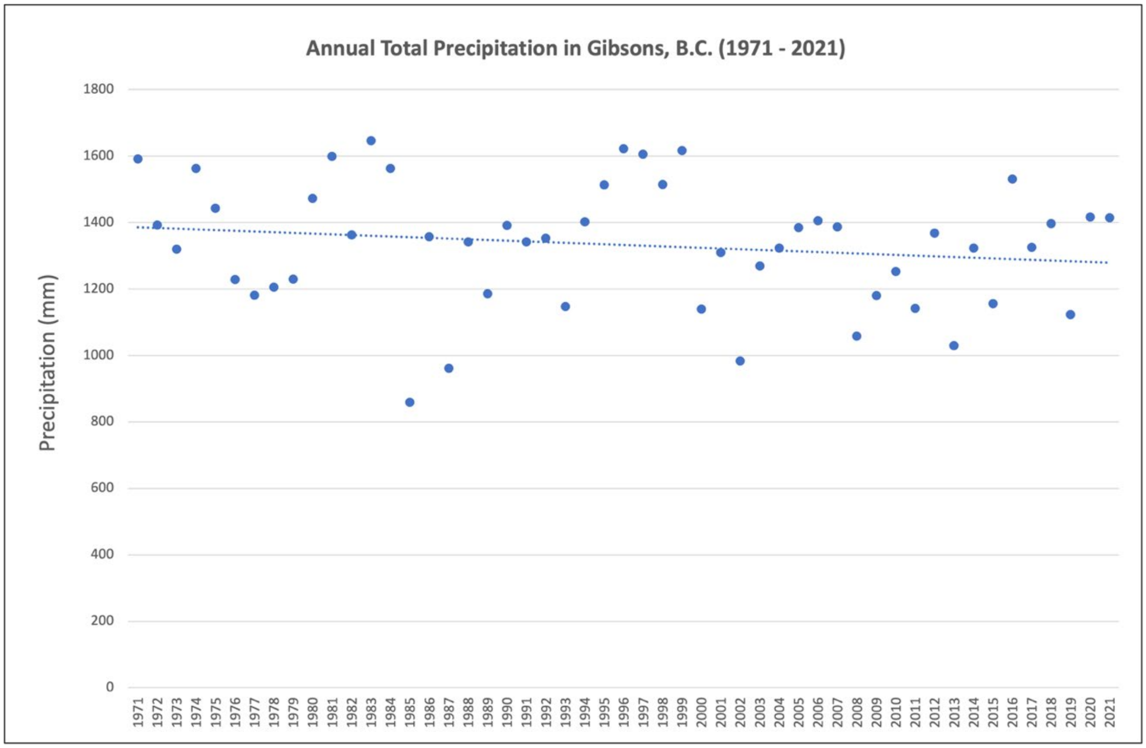

Figure 5: Annual Total Precipitation in Gibson (1971 – 2021)

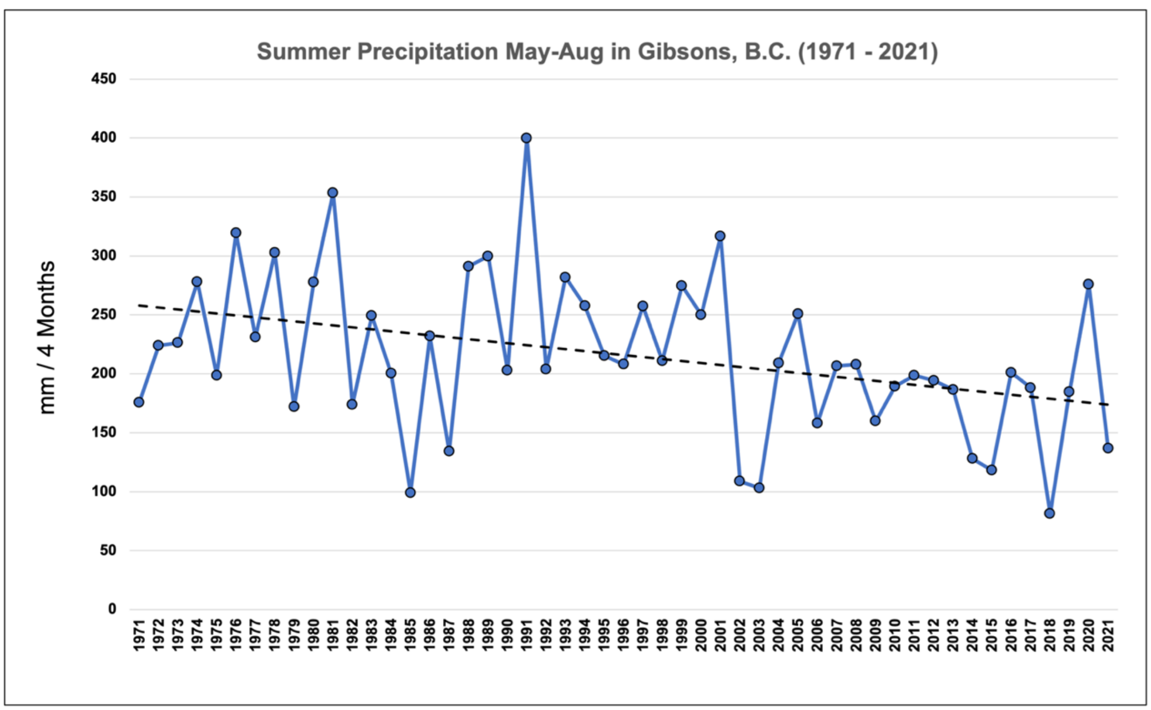

Figure 6: Summer Precipitation May – August in Gibson (1971 – 2021)

Figure 7 shows the decreasing trend in total snow accumulation in the Chapman Creek Watershed, during the November to March period, from 1971 to 2021. This trend in snow decline shows that there will be less snow in this region for the future and it may suggest that there will be an earlier snowmelt, hence a longer dry season.

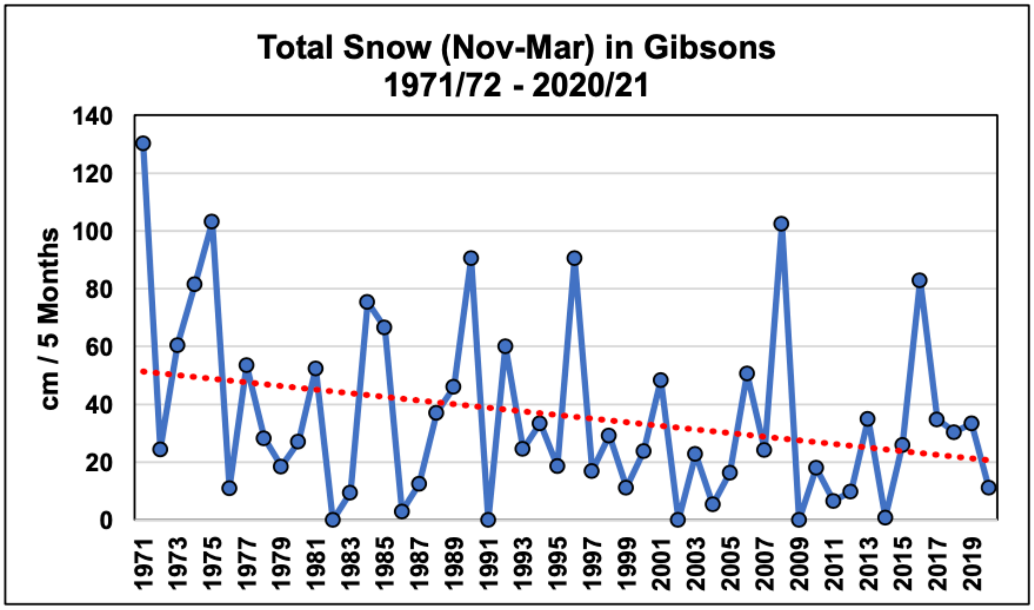

Figure 7: Snow Accumulation, Nov–Mar, in Gibson (1971 – 2021)

Hydrologic Data Analysis (Discharge) of Chapman Creek

Approximately 80 % of the annual precipitation that the Chapman Creek Watershed receives goes into the Chapman Creek as run-off and leaves the watershed as streamflow (Triton Environmental Consulting Report, 2006). Streamflow is measured frequently by the SCRD, however there are several gaps in previous and current hydrologic data records for the Chapman Creek. Extreme high peaks or data values are generally seen during September to January for the Chapman Creek where the excess amount of rainfall produces an overland flow that may be hazardous due to erosion and bed-load transport (EBA, 2000). There have been high turbidity pulse events in the Chapman Creek Watershed and the SCRD has faced challenges when dealing with its drinking water quality. The summer months mostly experience the low flows which has a strong correlation with the low summer precipitation in the watershed (Triton Environmental Consulting Report, 2006). During these low flow periods, the surface water mainly comes from higher-elevated (greater than 1000 meters) catchments where it fulfills the system's demand for providing drinking water to the residents (Carson, 1999).

Figure 8 shows the annual average monthly discharge from 1971 to 2003 of the Chapman Creek. The figure shows the low flows occurring in the summer months however, the highest flow period occurs in May during the Spring freshet. This is because the watershed is highly influenced from the climatic regime of the South British Columbia Mountains. Burns (2002) has observed that April and May tend to have the highest flow due to the shift in the timing of the spring run-off. This shift in spring run-off timing has been shown in a similar study in B.C. by Dery (2009), where this earlier onset of the spring freshet is followed by a significant decrease in summer streamflow and then by a small delay in the onset of increasing fall-winter flows. This detection of an earlier onset of the spring freshet has supported the shift from several snow-dominated watersheds becoming more rain-dominated in B.C. (Dery, 2009; Burns, 2002).

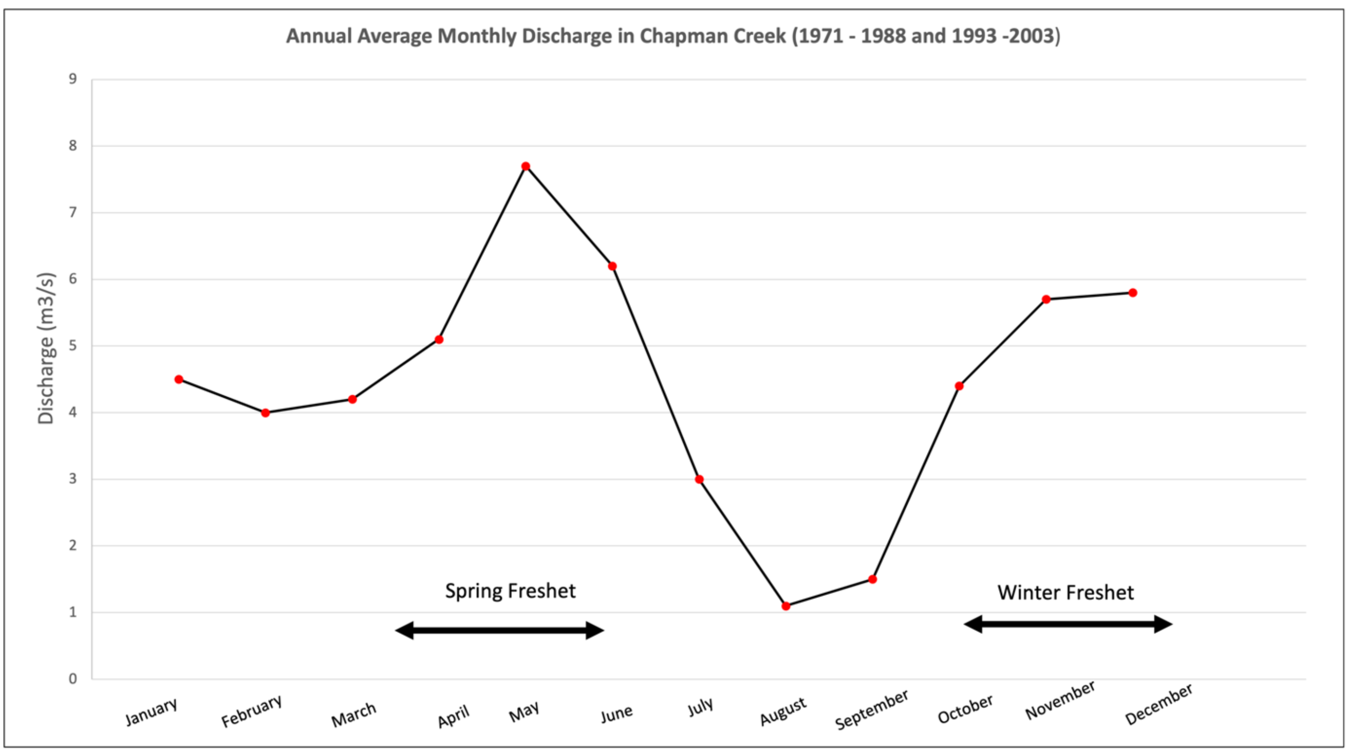

Figure 8: Average Monthly Discharge in Chapman Creek (1971-1988 & 1993-2003)

Figure 9 below shows the annual one-day extreme flow events that the Chapman Creek has experienced from 1970 to 2003. It is interesting to notice the month in each year where these one-day extreme flow events have occurred; usually takes place from October to January. This indication will be crucial for the SCRD to consider when implementing future watershed management goals.

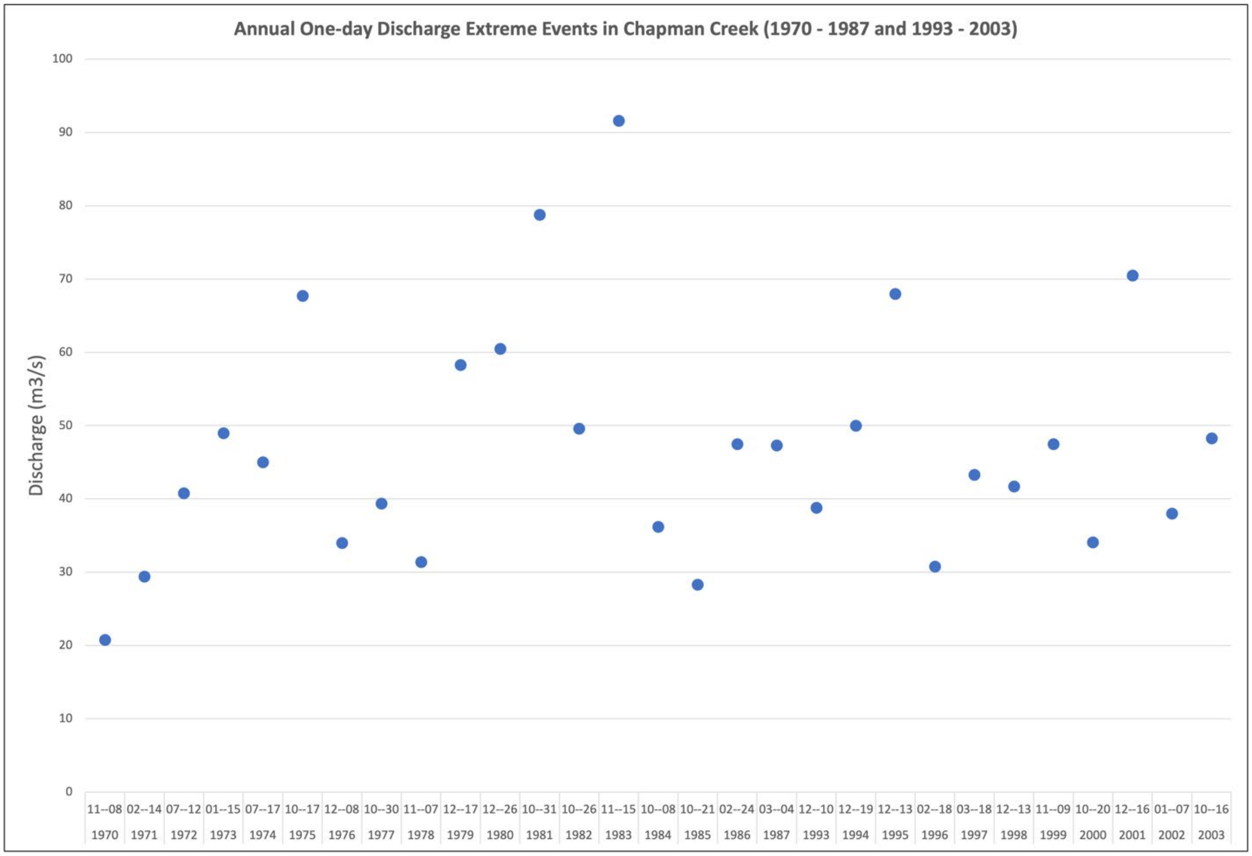

Figure 9: Annual One-day Extreme Flow Events in Chapman Creek (1970-2003)

Implications on the Water Supply-Demand System of Chapman Creek Watershed

Chapman Lake is the largest surface water reservoir where large influxes of rainfall allow the lake to annually supply drinking water to its residents. The SCRD has released several annual water use reports that shows a general pattern of water usage increasing. In 2004, the watershed reported to have consumed approximately 1.1 billion gallons from Chapman Creek (Triton Environmental Consulting Report, 2006) which was 95 % of its total supply that year. Changes in temperature, precipitation, and discharge can influence the watershed’s ability to supply enough potable water while ensuring that the demands of the residents are met. The water demand for Chapman Creek Watershed is highest in August, approximately 0.25 m^3/s, and this high demand is during the low flow months (Triton Environmental Consulting Report, 2006). It will be important for the SCRD to adapt to future extreme climatic variability to better regulate and manage their water supply infrastructures and to reduce the summer peak water demand.

The main challenge for the Chapman Creek Watershed is to supply enough water during the summer months where the watershed experiences maximum average temperatures, low amounts of total precipitation, and low flows. These specific climatic changes are associated with being more prone for experiencing prolonged drought periods and water scarcity. These climatic threats can result in a lower quality of water supply to meet the needs of multiple water users and can cause the SCRD to use its water reserve supplies. The current tactic that the SCRD is utilizing to supply water during summer months are to divert water from Chapman Creek to a back-up reservoir during periods of high precipitation and high streamflow and to supply water from the back-up reservoir to the Chapman Creek Water Treatment Plant. This will ensure that the water being supplied are in alignment with the domestic water demand and with the ecological flow requirement (Rosenboom, 2018). Figure 10 shows an example of the water supply deficit based on the reference year, 2017. From the figure, there was more demand for water in July, August, and September than water being supplied.

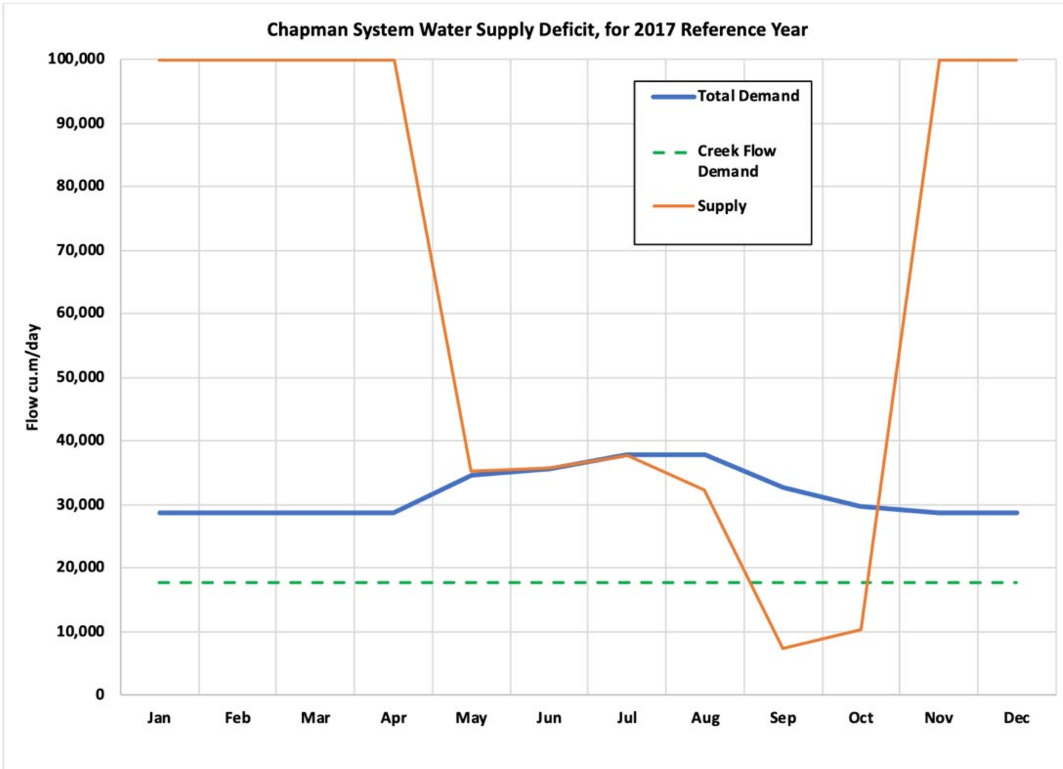

Figure 10: Water Supply Deficit; Reference Year 2017

Source- Rosenboom, 2018

Another option for the SCRD is to reduce the water demand during the summer peak season to counter-balance the water supply. Extreme climatic and hydrologic changes, particularly during the summer, has little direct association with the increase in water demand in the SCRD. The main driver for this increase comes from a rapid population growth, especially the tourism that the SCRD receives during summer. Figure 11 summarizes the trend in water demand for the watershed. There seems to be a slight reduction in water demand in 2017 compared to 2003 water demand and this may be due to the current summer water use restrictions that are in place.

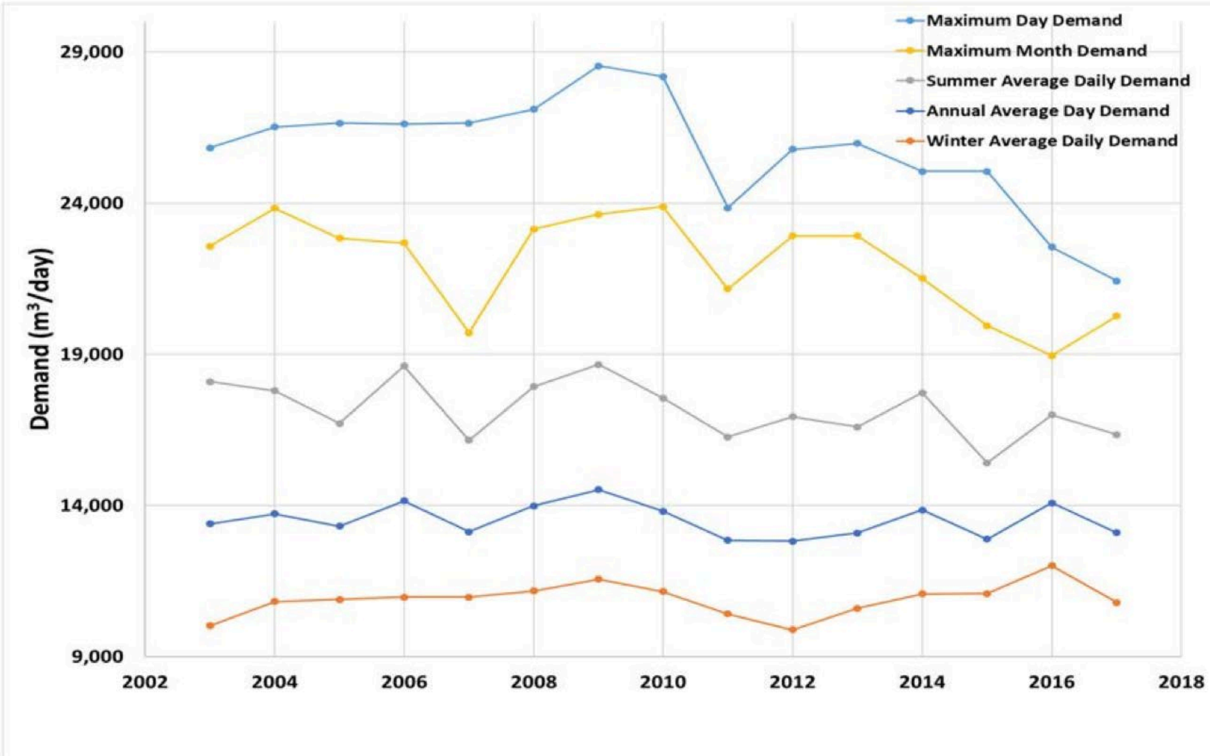

Figure 11: Annual & Maximum Water Demand; Chapman Creek Watershed (2003-2017)
Source – Rosenboom, 2018

Table 1 shows the different water demand characteristics for Chapman Creek Watershed from 2003 to 2017 and it is interesting to observe a slight reduction in the average annual daily demand (AADD). The table shows a declining trend in the summer average daily demand (SADD) due to the SCRD's recent summer water restrictions and this reduces the maximum month daily demand (MMDD). However, there is no noticeable reduction in the winter average daily demand (WADD), and this may be the reason for the fluctuating numbers for the AADD in this watershed. The SCRD has also summarized the amount of reduction in its two main water demand characteristics, AADD and MMDD, when using 2010 as a reference year. Table 2 shows a 13% reduction in its AADD in 2017 and a 21% reduction in its MMDD in 2017, using a 2010 base year comparison. The reduction in the SCRD's AADD in Table 1 shows a slight decline while in Table 2, the AADD has decreased more than expected. This is due to the time period that these tables are summarizing where in Table 2, the SCRD used the year 2010 instead of the year 2003 as a base reference. Furthermore, Table 2 is also useful as it shows a rapid increasing population rate in the watershed.

Table 1: Summary of Water Demand Characteristics of Chapman Creek (2003-2017)

Year	AADD (m^3/day)	WADD (m^3/day)	SADD (m^3/day)	MMDD (m^3/day)	MDD (m^3/day)	MWDD (m^3/day)
2003	13,390	10,026	18,099	22,581	25,833	-
2004	13,728	10,819	17,801	23,833	26,519	-
2005	13,316	10,888	16,715	22,846	26,646	-
2006	14,156	10,970	18,618	22,684	26,616	-
2007	13,130	10,968	16,157	19,711	26,652	-
2008	13,986	11,170	17,929	23,142	27,108	-
2009	14,521	11,561	18,666	23,628	28,543	-
2010	13,817	11,151	17,550	23,883	28,188	-
2011	12,849	10,411	16,262	21,168	23,848	-
2012	12,823	9,883	16,938	22,919	25,780	-
2013	13,096	10,598	16,594	22,922	25,980	-
2014	13,848	11,074	17,731	21,513	25,056	23,606
2015	12,884	11,081	15,409	19,946	25,056	21,261
2016	14,086	12,008	16,996	18,959	22,550	21,113
2017	13,106	10,793	16,345	20,274	21,427	21,243
2018	-	-	15,958	19,266	22,800	21,498

Where: AADD = Average Annual Daily Demand
SADD = Summer Average Daily Demand (May – September)
WADD = Winter Average Daily Demand (October – April)
MMDD = Maximum Month Daily Demand
MDD = Maximum Day Demand
MWDD = Maximum Week Daily Demand

Source - Rosenboom, 2018

Table 2: Reduction in Water Demand in Chapman Creek (2010 – 2017)

Year	Population Model	Annual Average Day Demand (AADD) (m^3/capita/day)	Reduction From 2010 (%)	Maximum Month Daily Demand (MMDD) (m^3/cap/day)	Reduction from 2010 (%)
2010	**20,639**	**0.67**	**0**	**1.16**	**0**
2011	20,814	0.62	7	1.02	12
2012	21,090	0.61	9	1.09	7
2013	21,357	0.61	9	1.07	8
2014	21,629	0.64	4	0.99	14
2015	21,903	0.59	12	0.91	22
2016	22,173	0.64	4	0.85	27
2017	22,500	0.58	13	0.90	21

Source - Rosenboom, 2018

Overview of Norrish Creek Watershed System

The Norrish Creek Watershed lies within the Abbotsford-Mission region which is becoming a desirable community to live in. This attractive region is being more urbanized, and its economy is significantly growing which allows it to have a resilient water supply system. However, with population increase and climate change, the demand for water is increasing. Thus, it will be crucial for both Abbotsford and Mission municipalities to collaborate with one another to protect the current and to enhance future water resource management.

The Abbotsford-Mission water system consists of two surface water sources; Norrish Creek where water is fed from Dickson Lake, and Cannell Lake. There are 19 additional groundwater wells that are used alongside these two surface water sources to meet peak water demands. The Norrish Creek Watershed is near the North side of the Fraser River and is approximately 120 km squared in land area where 80 km square of that land area is the water supply source (Lee & Brubacher, 2017). Water flows from

Dickson Lake into Norrish Creek which ultimately becomes the Nicomen Slough and flows into the Fraser River. Norrish Creek is made up of steep riverbanks and is non-alluvial (Lee & Brubacher, 2017). The watershed varies a lot in its elevation; the range is roughly between 250 meters to 1500 meters (Lee & Brubacher, 2017).

<u>Precipitation & Temperature Data Analysis of Norrish Creek</u>

Unlike the Chapman Creek Water System, precipitation in the Norrish Creek Watershed precipitates as both rain and snow. Figure 12 shows the annual total precipitation for Abbotsford-Mission area where there is a decreasing trend in total precipitation. Similarly, Figure 13 shows the average summer precipitation (May to August) for Abbotsford-Mission and there is a significant decrease in average summer precipitation in the more recent years. The extreme precipitation events are projected to increase by 10% especially in the fall and winter while it is projected that there will be a 15% decrease in summer precipitation for the Norrish Creek Watershed (Lee & Brubacher, 2017).

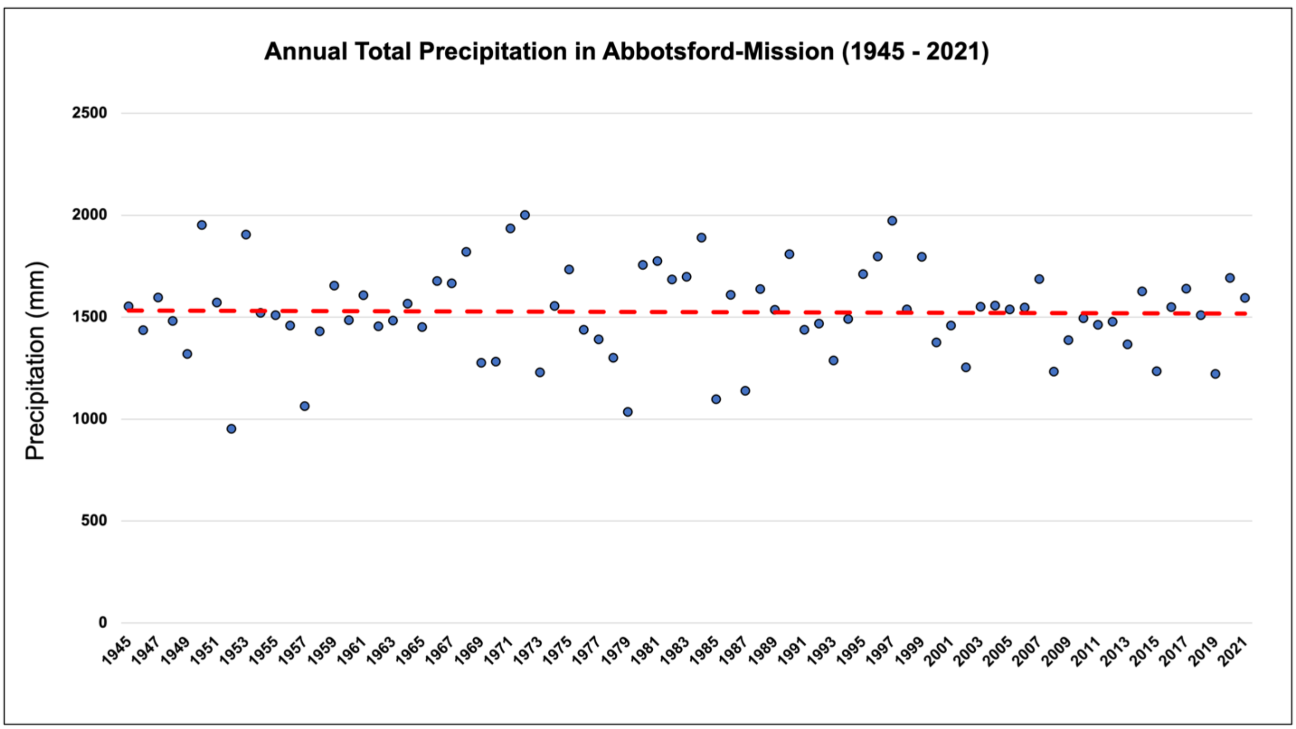

Figure 12: Annual Total Precipitation Abbotsford-Mission (1945-2021)

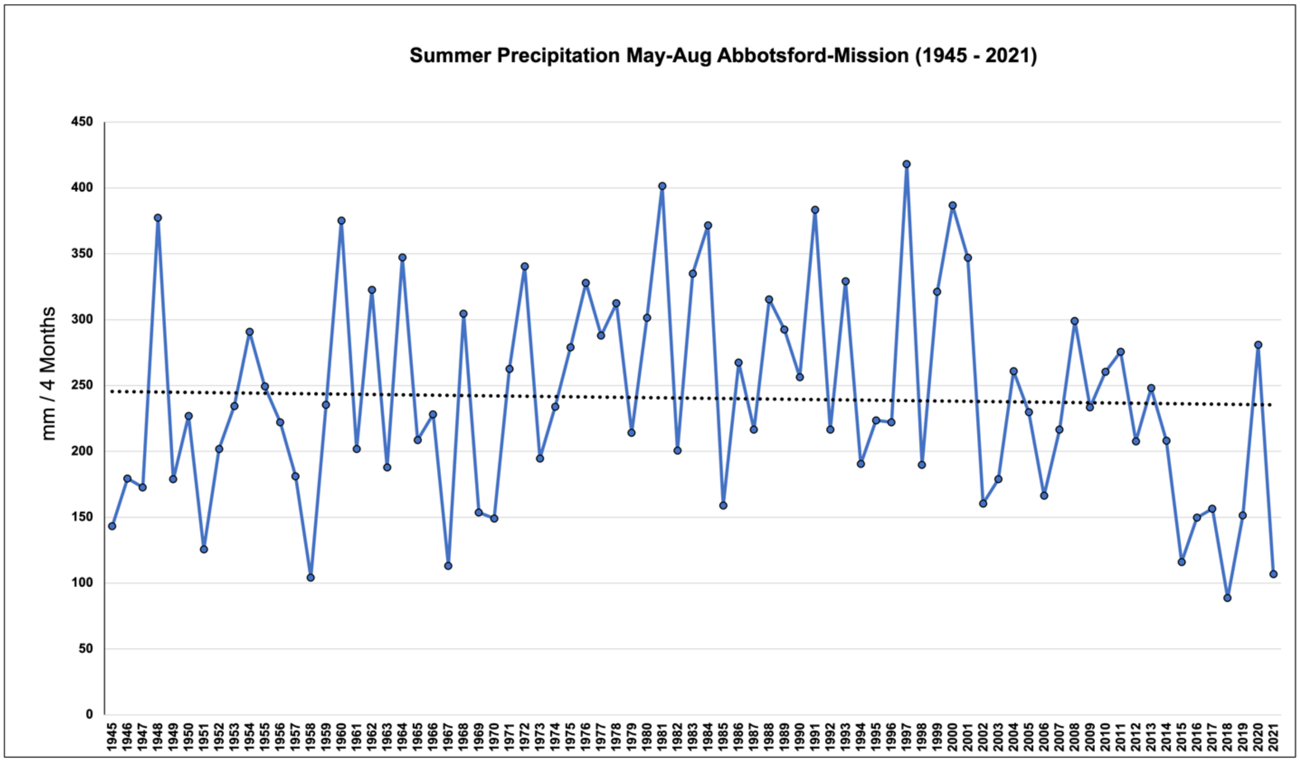

Figure 13: Summer Precipitation May-August; Abbotsford-Mission (1945-2021)

The annual mean summer precipitation from 1945 to 2001 was 253 mm and from 2002 to 2021, the annual mean summer precipitation was 207 mm. There was a 18% decrease in precipitation during these time periods. As summer precipitation in Abbotsford-Mission is decreasing, this will place additional stress on the surface water storage reservoir, Dickson Lake. This decreasing trend will further impact the streamflow of Norrish Creek where the Abbotsford Commission Council has previously struggled in meeting its legislative requirement of maintaining a minimum flow for its aquatic species.

The average annual temperature of Abbotsford-Mission will increase by 2 degrees Celsius by 2050 (Rodenhuis et al., 2007). Figure 14 represents an increasing trend in average maximum summer temperature (May to August) in Abbotsford-Mission. This will lead to a quicker evaporation rate from Dickson Lake and Cannel Lake (Lee & Brubacher, 2017). Furthermore, increasing temperatures during the summer will be problematic for the watershed as it strongly correlates with a forward shift in the watershed's annual hydrograph (Lee & Brubacher, 2017). This will result in the onset of an earlier spring freshet and similar to the Chapman Creek Watershed, there will be a shift towards a more rain-dominated hydrological regime.

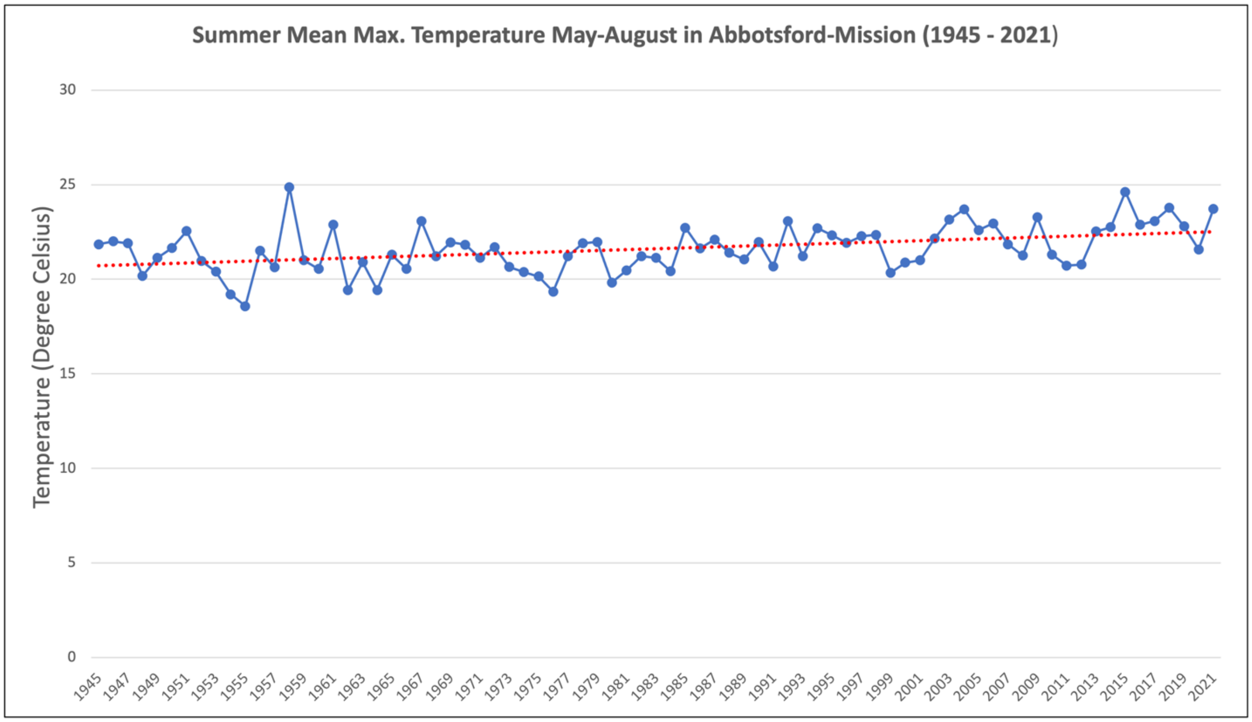

Figure 14: Average Maximum Summer Temperature; Abbotsford-Mission (1945-2021)

Figure 15 shows that there is a decreasing trend in total snow accumulation, between November to March, in the Abbotsford-Mission region from 1963 to 2007. The Mission West Abbey station is higher elevated, thus was useful in showing the decreasing trend in snow accumulation during fall and winter.

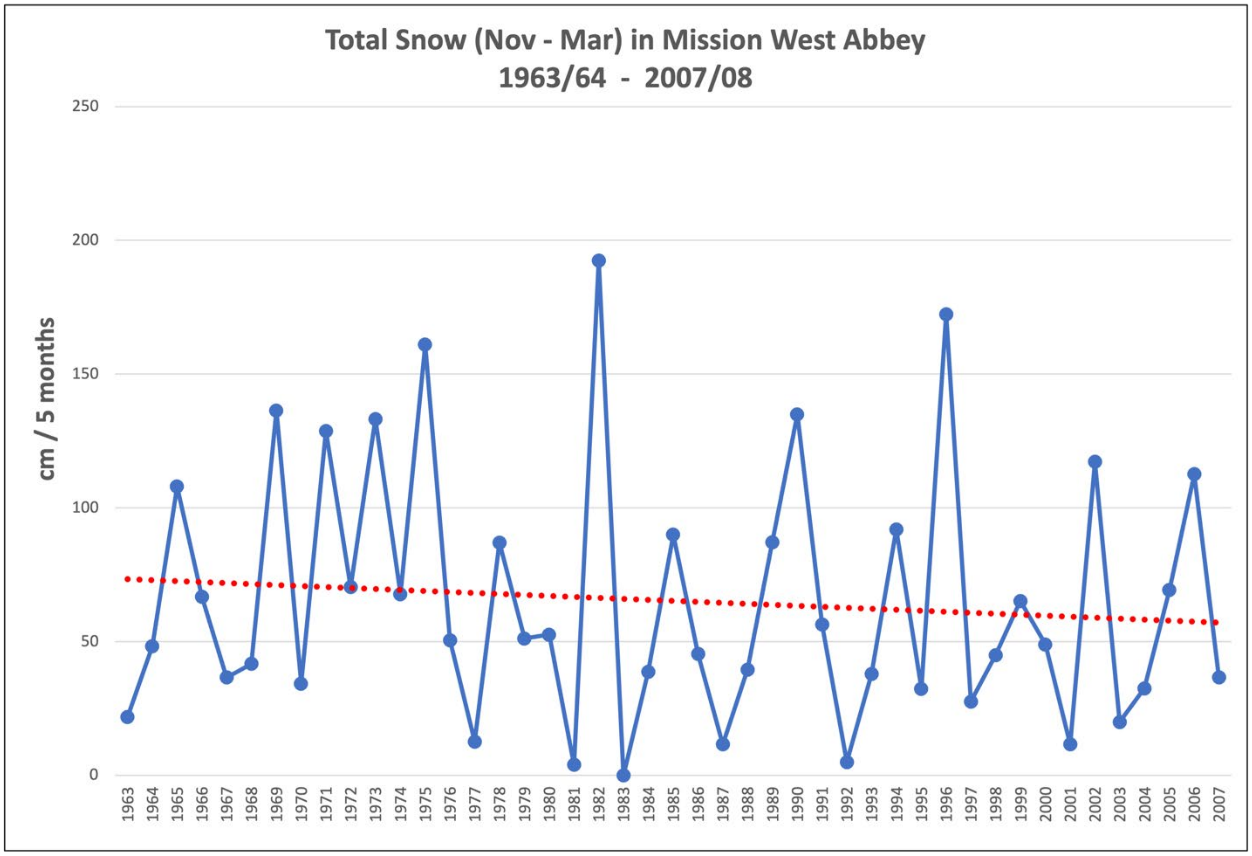

Figure 15: Snow Accumulation, Nov–Mar, in Mission West Abbey (1963 – 2007)

Hydrological (Discharge) Data Analysis of Norrish Creek

The peak flows in Norrish Creek are dependent on whether it receives precipitation as snow or as rain. Generally, the highest peak flows in the Norrish Creek are in the fall and these flows remain relatively high during the winter and tends to spike in the spring freshet. Figure 16 shows the annual average monthly discharge from 1960 to 2006.

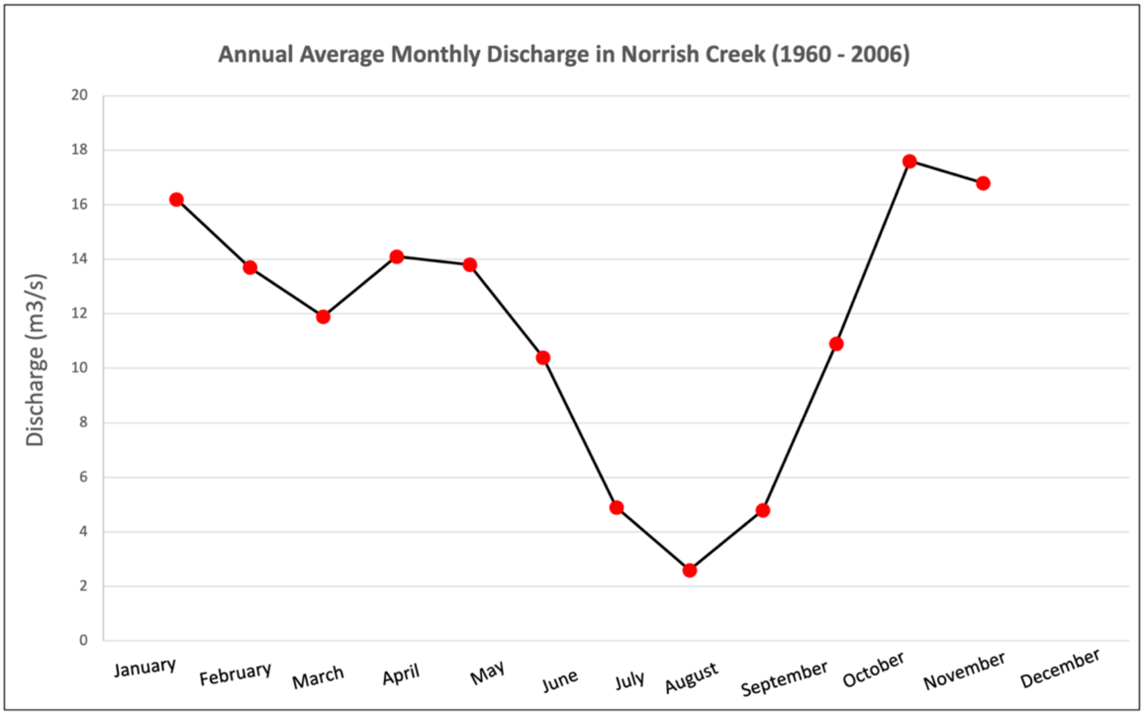

Figure 16: Annual Average Monthly Discharge; Norrish Creek (1960-2006)

Implications on the Water Supply-Demand System of Norrish Creek Watershed

The Norrish Creek Watershed is capable of supplying 90 MLD and can fulfill 100% of its annual daily demand (ADD) during the winter and spring (Lee & Brubacher, 2017). However, the watershed is not able to independently fulfill the maximum daily demand (MDD) due to the size of the water supply pipelines in the region. When there is a peak in water demand in the summer, where temperatures are at its maximum and where there is little precipitation, then there needs to be upgrades to the supply and demand management programs. This will ensure that the future demand per capita consumption does not exceed the water supplying capacity. It is projected that Abbotsford-Mission will be capable of supplying 140 MLD by 2035 which will help with adapting to droughts during summer (Lee & Brubacher, 2017). In B.C., there are models that predict a 25% to 50% annual decrease in snowpacks (Pike et al., 2010), and this will affect the flow period during the spring freshet. The annual decrease in snowpack will result in less water available for storage in Dickson Lake and may cause a delay in groundwater recharge (Lee & Brubacher, 2017). Currently, the Norrish Creek

Watershed experiences enough precipitation to fill its storage reservoirs, however with the future increase in water demand along with the summer low flows and the insufficient snowpack run-off, there will be a shortage of water resources. These water resources must be carefully managed, especially in the summer, as Abbotsford-Mission heavily relies on water for not only its residents, but for other agricultural demands. Figure 17 shows the water consumption pattern in Abbotsford-Mission from 2006 to 2017. There was a significant decrease in maximum daily demand from 2006 to 2011 due to the region's summer water restrictions. However, the trend in water use is starting to slightly increase from 2011 to 2017 and this result may be a combination of both population increase and extreme climatic variability. Due to the lack of available data and access on water consumption in Abbotsford-Mission, this limits our findings and assumption on what the demand would have looked like from 2017 to 2021. With the recent flood event in Abbotsford during 2021 November, the demand and supply sources would have been severely impacted.

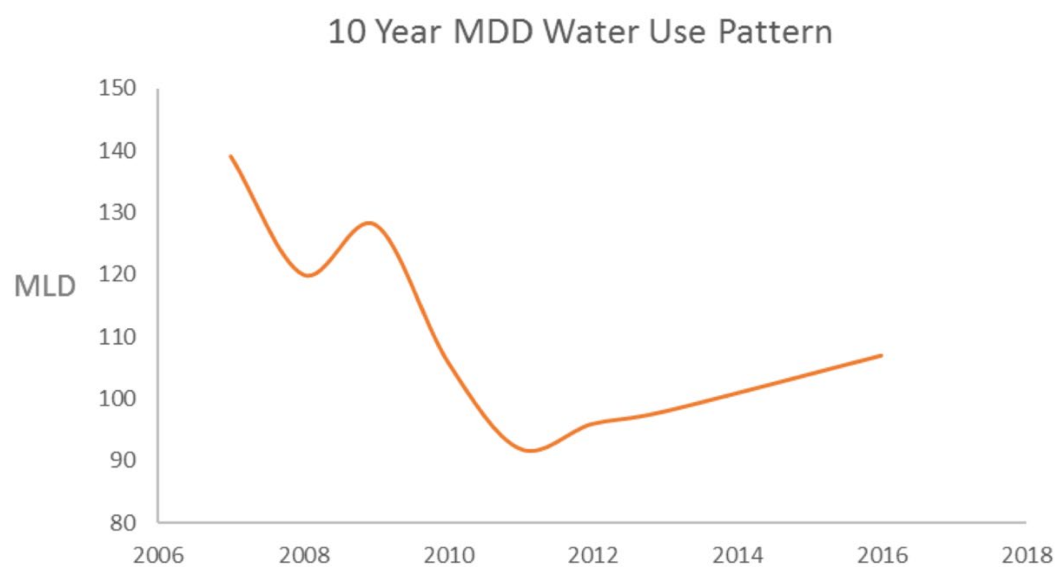

Figure 17: Water Consumption Pattern; Abbotsford-Mission (2006-2017)
Source – Lee & Brubacher, 2017

<u>Extreme Climatic Years Comparison for Chapman Creek & Norrish Creek</u>

Table 3 summarizes and compares the precipitation and temperature during the summer season for three extreme climatic years (2015, 2017, & 2021). These specific years have experienced summers of extremely low precipitation and of extremely high temperatures.

Table 3: Summary of Recent Extreme Climatic Years for Chapman & Norrish Creek

	Chapman Creek		**Norrish Creek**	
Year	Precipitation (mm)	Temperature (Degrees C)	Precipitation (mm)	Temperature (Degrees C)
2015	118 mm	22 Degrees	116 mm	25 Degrees
2017	188 mm	20 Degrees	157 mm	23 Degrees
2021	131 mm	21 Degrees	107 mm	24 Degrees

The extreme rainfall events are best shown in Figure 18. This figure shows the recent flooding event in Abbotsford where there was a significant amount of daily precipitation on specific 1-day intervals (November 14th and 27th). It is crucial for both Chapman Creek Watershed and Norrish Creek Watershed to plan and prepare for future rainfall events which are followed by longer periods of extremely high summer temperatures.

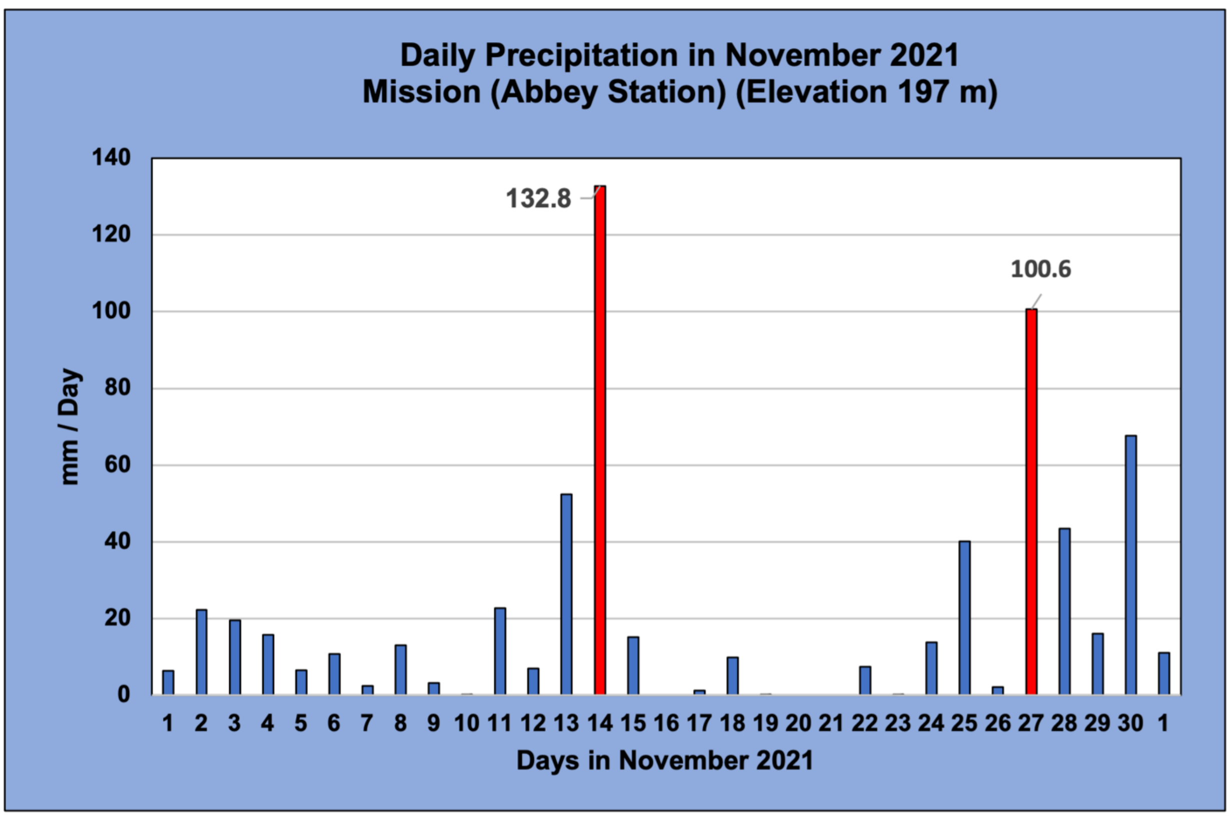

Figure 18: November Flood Event in Abbotsford, 2021

Source – Schreier, 2021

Water Supply-Demand Management Strategies for both Chapman & Norrish Creek

There are four main options for dealing with the uncertainties in the water supply-demand system for both watersheds. The first option focuses on enhancing the current water storage reservoir and its capacity. However, this option has many constraints and is costly. Another option is to find new alternative water source pathways. This strategy will be difficult for several small communities as our water sources are finite and have many constraints. The third option for managing water resources is the re-use of our water. This option is restricted unless there is a water treatment facility in the region that can help with supplying re-used water and would also require major changes in the plumbing infrastructure. The final option is for communities to focus on water conservation that can help with managing both the supply and demand side. This will be the most cost-effective strategy but will require major changes in human behavior. Watershed managers should not fully rely on these conservation methods as these methods and their outcomes are more short-term.

For dealing with the Chapman Creek's and the Norrish Creek's water supply issues, it is important to understand that in order to supply enough water to the residents, the system heavily relies on Winter rain and snow accumulation. With the current climatic changes that both watersheds are experiencing such as less snow, an earlier snowmelt, higher temperatures, and lower summer precipitation, it will be crucial for implementing water conservation strategies sooner than later. Similarly, during periods of heatwaves and droughts, the main challenges in dealing with water demand issues are population growth, higher water usage in the Summer, and the amount of water loss through leakages.

Watershed managers and policy-informers must shift their focus on introducing water conservation options for both watershed systems. During the Winter season, the water demand is not as high as it is during the Summer. Thus, conservation options for indoor water use include having water efficient appliances (low-flush toilets, dual-flush toilets, horizontal-axis washing machines, hot water pipe insulations, etc.), reducing water pressure in certain household items (shower flow restrictors, pressure-reducing valves in toilets, etc.), and re-using greywater. During the Summer, when there is a peak demand for water, conservation strategies for outdoor water use include roof-water harvesting, xeriscaping through water efficient plants, effective irrigation techniques, and implementing water use restrictions. The most economically feasible option for water conservation is to adopt the idea of universal water metering which will help with managing the water supply-demand system, especially when our watersheds are experiencing extreme climatic changes. One research paper (Brooks, 2006) studied the benefits of water metering and pricing where the paper emphasized that larger water users should pay more. Some of these benefits of water metering and pricing are that it allows for volumetric pricing compared to a flat rate, allows for water-supplying companies to obtain money from their customers to recover from their costs, and educates users on alternatives for more efficient domestic water usage (Brooks, 2006). Another potential conservation strategy is for residents to install “Smart” Water Meters which will help with dealing with conserving water during peak seasons rather than forcing water-use restrictions on residents. It will be important for smaller watersheds such as Chapman Creek and Norrish Creek to practice these water conservation strategies and to educate their residents on the current climatic issues.

Conclusion

The purpose of this report was to understand how changes in climatic and hydrological variables (temperature, precipitation, and discharge) will influence the water supply and demand system of two B.C. watersheds. Both watersheds are experiencing a rapid population increase and have experienced extreme climatic events. Examining these climatic events allows for a comparison of key current and future climatic trends that are predicted for most of B.C. The increase in winter rainstorms, the decrease in summer precipitation, the increase in summer temperature, the change in the hydrological rain-snow regime, and the shift of an earlier spring freshet are all indicators of climate change that B.C. is experiencing. The results from reviewing and analyzing historic data records allowed for a better understanding of examining these indicators and their implications on the water supply and demand system for both Chapman Creek Watershed and Norrish Creek Watershed.

The impacts from climate change on the water supply-demand system for both watersheds are similar. Extreme floods and droughts have a significant effect on the water supply infrastructures and on the water-supply sources due to the rapid change in streamflow. These extreme events, particularly droughts during the summer, changes our water consumption behavior, not directly from changes in temperature or precipitation, but from our desire to use more water. We need to start realizing how scarce our water resources are becoming and change our behavior to adapt to future climatic uncertainty.

Recommendations

In this report, the agricultural water use was not analyzed nor examined for both watersheds. Both regions, particularly for the Abbotsford-Mission region, the agricultural sector is expanding where farmers are promoting a healthier food production system and are strengthening their food productivity. However, several farmers are facing challenges in meeting their crop production requirements as water resources are under pressure from climatic changes and population growth. For achieving food security, the agricultural water usage should be further examined for both systems. Furthermore, this report did not examine the climatic effects on aquatic and terrestrial habitats and species. Both Chapman Creek and Norrish Creek have separate plans and targets for maintaining their minimum streamflow for protecting their species. This should be further investigated as our water consumption pattern and supplying capacity will influence the creek's flow thresholds.

A list of current and future recommendations from the SCRD Watershed Report and the Abbotsford-Mission Master Water Plan provides mitigating efforts on enhancing the water supply-demand system.

For the Chapman Creek, these recommendations include:

- Future universal water metering installation and pricing updates in all towns
- Implementing of a mandatory stage 2 or stage 3 sprinkling restrictions during the summer season to reduce domestic water use
- Repairing and better detection of leaks in water supplying infrastructures
- Introducing incentive programs such as rainwater harvesting (launched in 2018 for SCRD) and the use of water efficient appliances

- Promoting effective irrigation controls for lawns, gardens & farms
- Investing more into public education and outreach programs
- Updating the availability and access to hydrometric data for the public to reduce the inconsistencies and gaps in discharge measurements
- Future population model analysis during the summer where tourism is high in the SCRD

For the Norrish Creek, these recommendations include:

- Continue to meter all customers in Abbotsford and implement universal metering in Mission
- Increase the use of declining block rates for customers; pricing should be based on the amount of water consumption, which results in behavioral changes
- Maximize the durability of existing water supply infrastructures to accommodate demand growth
- More construction of green infrastructures and incentives for low-impact development
- Implement fixture rebates for toilets and washers, a gradual conservation strategy
- Implement free irrigation-landscape audits, an opportunity for significant reduction in water use in some towns
- Better social engagement and marketing workshops to educate and inform residents of climate issues

Acknowledgement

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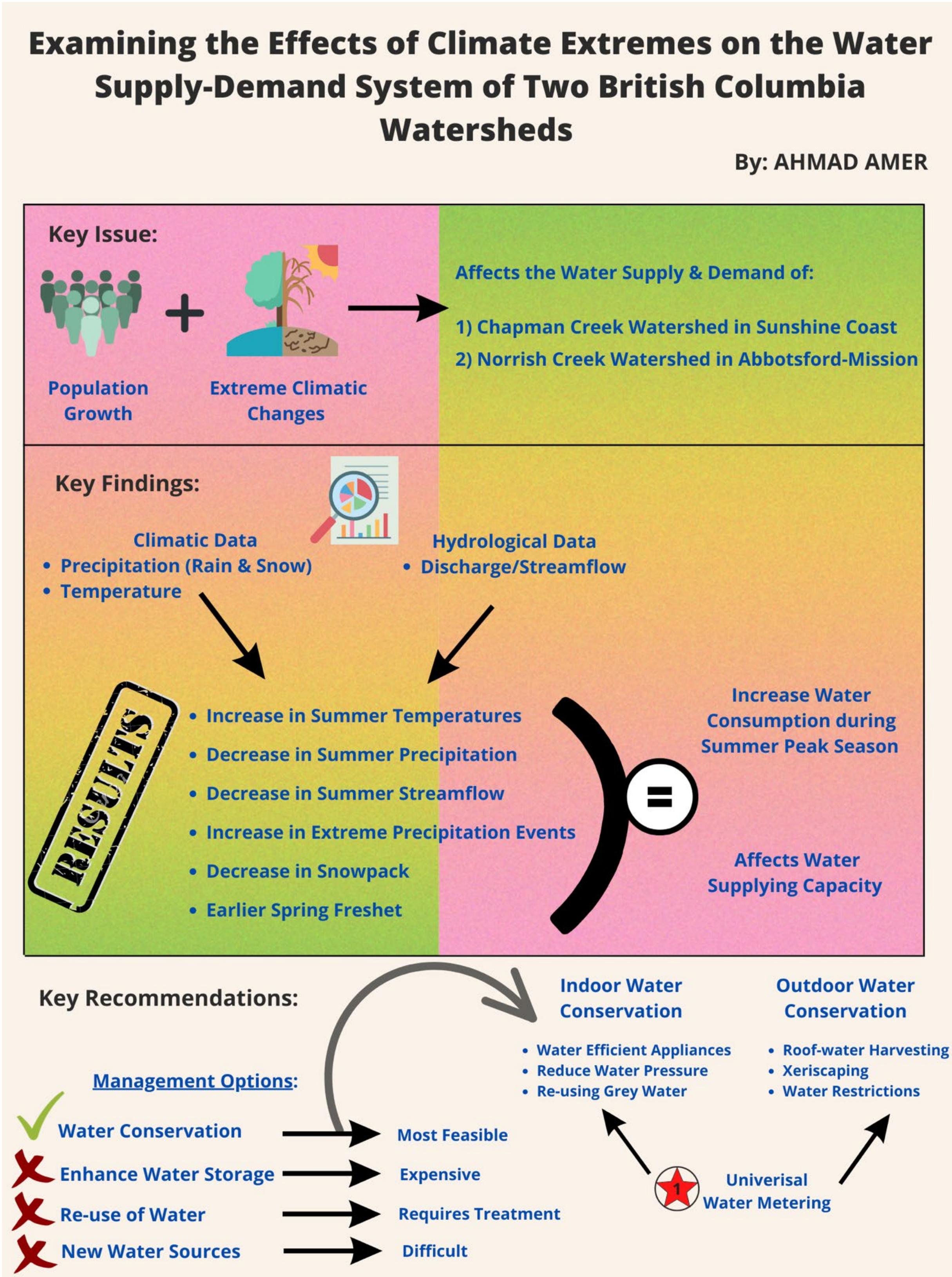
Attached to this page is my Communication Feature (Visual Abstract) for my major project:


Examining the Effects of Climate Extremes on the Water Supply-Demand System of Two British Columbia Watersheds
By: AHMAD AMER
Key Issue:
Population Growth
+
Extreme Climatic Changes
Affects the Water Supply & Demand of:
1) Chapman Creek Watershed in Sunshine Coast
2) Norrish Creek Watershed in Abbotsford-Mission
Key Findings:
Climatic Data
• Precipitation (Rain & Snow)
• Temperature
Hydrological Data
• Discharge/Streamflow
RESULTS
• Increase in Summer Temperatures
• Decrease in Summer Precipitation
• Decrease in Summer Streamflow
• Increase in Extreme Precipitation Events
• Decrease in Snowpack
• Earlier Spring Freshet
=
Increase Water Consumption during Summer Peak Season
Affects Water Supplying Capacity
Key Recommendations:
Management Options:
Water Conservation
Most Feasible
Enhance Water Storage
Expensive
Re-use of Water
Requires Treatment
New Water Sources
Difficult
Indoor Water Conservation
• Water Efficient Appliances
• Reduce Water Pressure
• Re-using Grey Water
Outdoor Water Conservation
• Roof-water Harvesting
• Xeriscaping
• Water Restrictions
1
Univerisal Water Metering