Watershed Evaluation of McGillivray Creek Watershed

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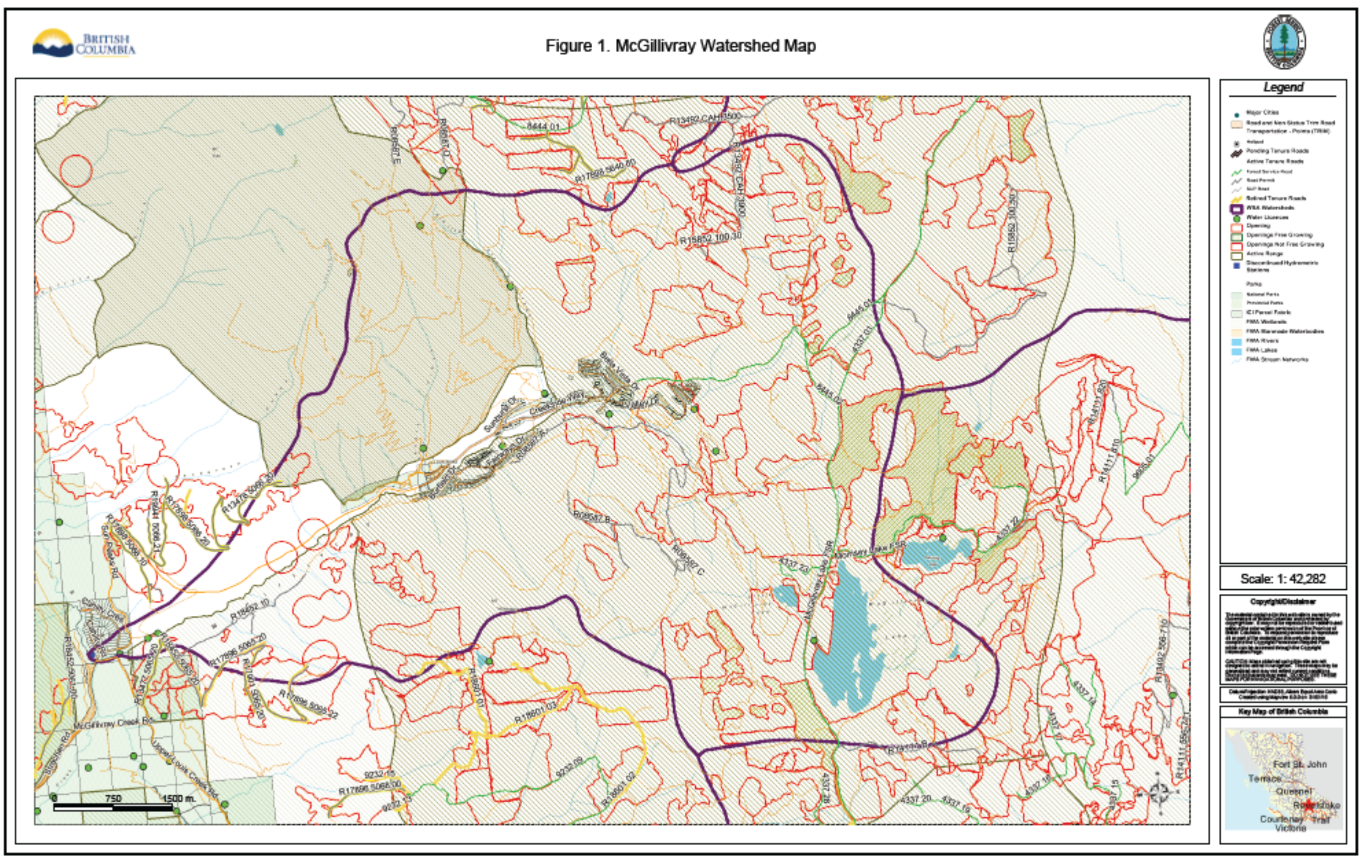
Introduction

The Watershed being reviewed is the McGillivray Creek watershed, an upper headwater hanging valley tributary to the Louis Creek watershed in the Southern Interior of BC (119° 52' 35" W, 50° 53' 5" N). The McGillivray is a significant tributary, and has significant land uses that directly influence the downstream Louis Creek watershed. Within the approximately 5100 hectare McGillivray watershed are; the Resort Municipality of Sun Peaks, 6 range tenures covering 80-90% of the area, and current (Licensee Sun Peaks) and historic forest tenures (FLNR Mapview, 2015; FLNR E-licensing, 2015). The southeastern most corner of the watershed was burnt in the 2003 McGillivray Fire, and there are rural properties and the small community of Whitecroft at the downstream end of McGillivray Creek (FLNR Mapview, 2015).

In 2011, the Ministry of Environment ranked the watersheds in the Thompson Okanagan Region according to water quality risk. Of 182 small watersheds in the region, the Louis Creek watershed was ranked 12th in risk priority due to land use types and watershed characteristics (Cooper, 2011). *Figure 1. McGillivray Watershed Map* shows the McGillivray watershed and associated land uses in the area. The Louis creek watershed, into which McGillivray drains, has high fish values and is currently in the process of being designated as a Sensitive Watershed under a government action regulation. The McGillivray sub-basin is thought to be a significant source tributary to the Lois Creek watershed and is currently being examined more closely (Ptolemy, 1980; McLeary and St. Pierre– personal communication, January 2015). The resort of is situated in the valley bottom at the upper end of McGillivray creek watershed and is currently the most significant impact to the watershed in terms of both quality and quantity.

Figure 1. McGillivray Watershed Map



Seasonal Water Use and Shortages

The area is used as a multi season resort with; downhill skiing, cross-country skiing, snowshoeing, dogsledding, snowmobiling in winter, and golf, hiking, biking and lake activities such as boating and fishing in summer. The area has a regular rural population year round, including ranchers, and residential neighbourhoods, as well as an increased seasonal population in winter.

Water use is year round with the times of stress being fall and winter when both supply is limited and demand is highest. There are 8 water licenses allocated in the McGillivray watershed, allocated to drinking waterworks (for Sun Peaks), private domestic use, irrigation, land improvement, and storage (non-power). The total allocation is 429, 866 cubic meters per year with the breakdown provided in *Table 1. Water Allocations by license, use and season* (FLNR E-licensing, 2015). There are 3 restricted licenses; two are from April 1 to September 30 for irrigation, and the third is for storage from April 1 to June 30. Total allocations for water include 8 licenses on McGillivray Creek and tributaries (FLNR E-licensing, 2015). Water is used for drinking water, agricultural irrigation, snowmaking and irrigation of the golf course (FLNR E-licensing, 2015). The area is currently fully allocated under the Province of BC's Water Act (WA) for surface water allocations.

Table 1. Water Allocations by license, use and season

McGillivray Watershed Area	5105.297	ha's					
PurposeUse	**TermStart**	**TermEnd**	**Quantity**	**Units**	**StreamName**	**PODNumber**	**AverageDemand_m3s**
00A - Waterworks Local Auth	Jan 01	Dec 31	58076.29975	m3/year	Resort Creek	PD48535	0.00185
00B - Waterworks (Other)	Jan 01	Dec 31	111174.631	m3/year	McGillivray Creek	PD48489	0.00353
01A - Domestic	Jan 01	Dec 31	1659.32285	m3/year	McGillivray Creek	PD48492	0.00005
01A - Domestic	Jan 01	Dec 31	829.66325	m3/year	McGillivray Creek	PD48492	0.00003
03B - Irrigation	Apr 01	Sep 30	3700.44	m3/year	McGillivray Creek	PD63895	0.00024
03B - Irrigation	Apr 01	Sep 30	140863.416	m3/year	McGillivray Creek	PD48489	0.00896
04A - Land Improve	Jan 01	Dec 31	0	*Total Flow	Armitage (Five Mile) Creek	PD68204	0
08A - Storage-Non Power	Apr 01	Jun 30	113562.3535	m3/year	Armitage (Five Mile) Creek	PD69190	0.0146
	Total Annual Withdrawals		429,866.13	m3/year			

* Total flow from spring freshet is allocated to storage for snowmaking, but, the discharge from Five Mile creek is not available. Note: Discrepancies between *Figure 1. McGillivray Watershed Map* license locations, and number of allocations listed are a result of abandoned applications on McGillivray Lake, Switchback Creek and an active application for a storage pond shown on the Map but not in allocation database.

Although not within the scope of this project, the Resort also currently accesses groundwater. The groundwater source(s) in use will become regulated shortly under the Water Sustainability Act (WSA). Groundwater sources in the area were initially thought to be quite large, but, the source was not adequately surveyed initially and recent evaluations are showing that groundwater sources will contribute less water than expected in the future (Christian St. Pierre and Christa Pattie, Personal Communication, January 30, 2015).

McGillivray Creek average annual discharge, according to data collected from retired hydrometric station (08LB081) between 1982 and 1996, is approximately 0.366 m3/second, while average low flow discharge is 0.218 m3/second (Environment Canada, 2015). The time period of concern, as mentioned previously is the low flow period from October to February, after long periods of dry weather, and higher withdrawals for the ski season. The time period recorded was reviewed to look at whether there were significant trends during the monthly; low flow period compared to the annual flow, the difference between months in the low flow period, annual over all trends in average monthly flow, and low flow months early in the series compared to late in the series. There were no statistically significant trends, however, in all cases, the monthly flows declined over the time period.

Figure 2. McGillivray Creek Hydrometric Data Annual Monthly Flow shows the monthly variability, especially in the month of June, depending on the year, and also shows that there is little variability for the months of October – February, the low flow period. The low flow time period of October to February is shown in *Figure 3. McGillivray Creek Hydrometric Monthly Data – Low Flow vs Annual Average, comparing the time period to the annual average.*

Figure 2. McGillivray Creek Hydrometric Data Annual Monthly Flow

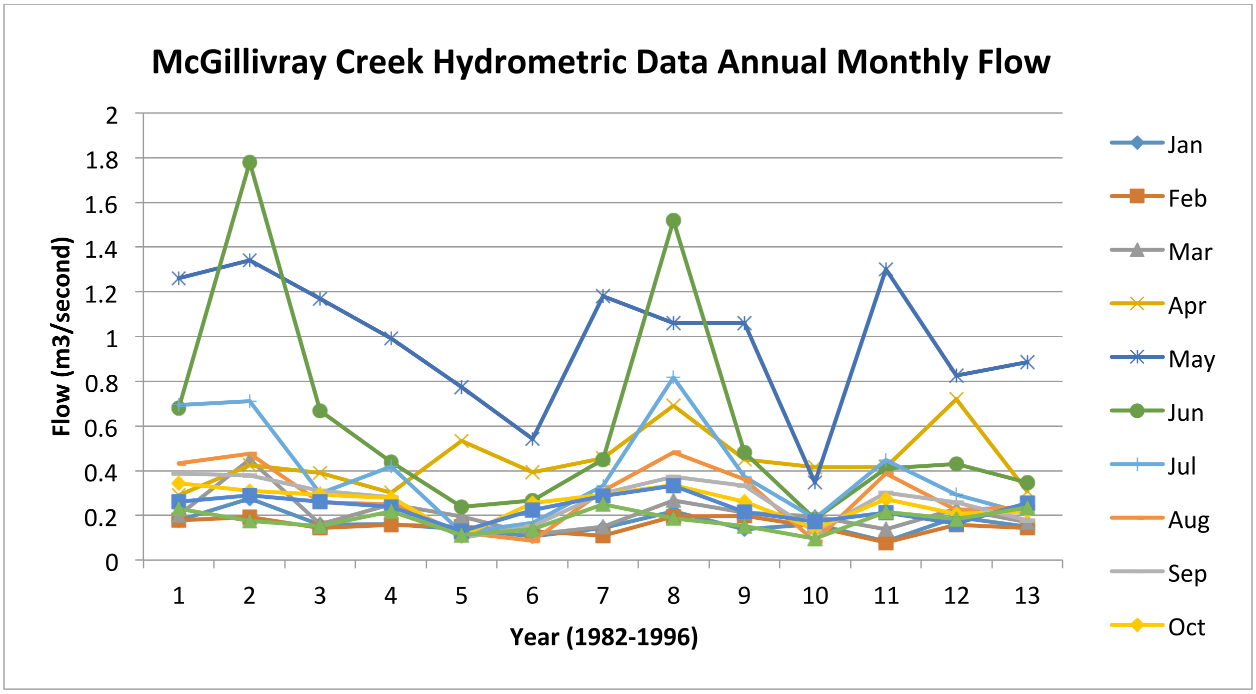
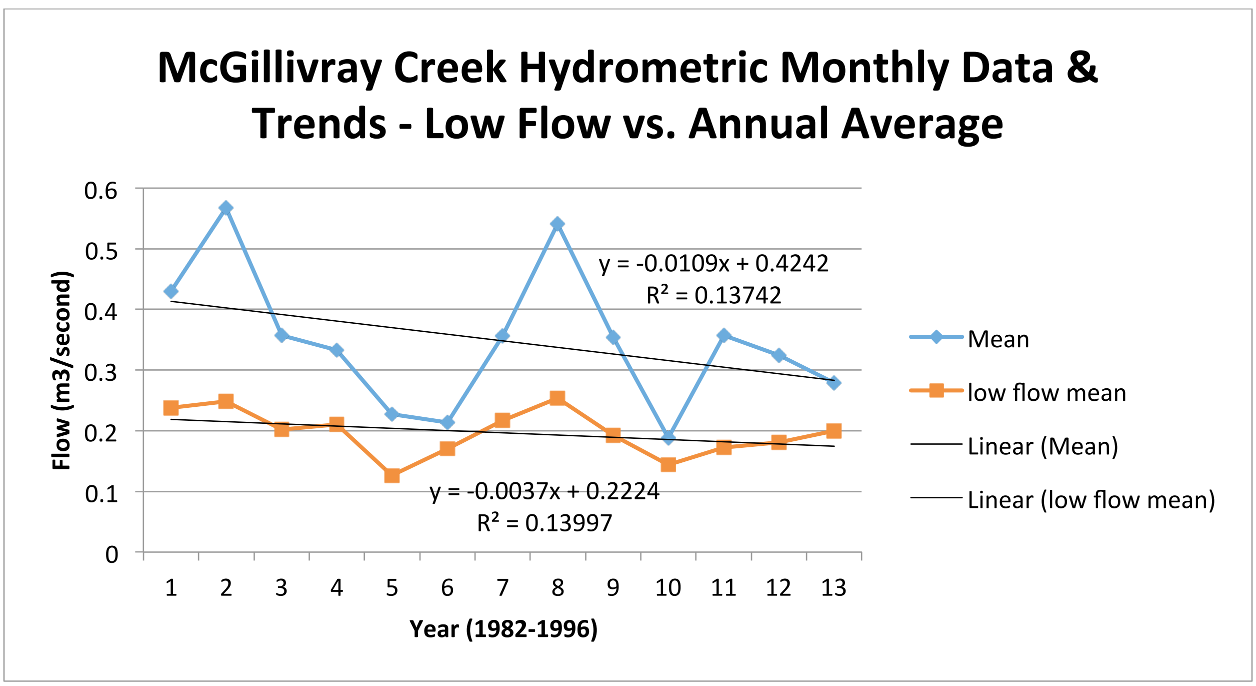


Figure 3. McGillivray Creek Hydrometric Monthly Data – Low Flow vs Annual Average.



The extreme low and high flows were also reviewed. *Figure 4. Extreme Low Flow Events (1982-1996)* shows the trend in extreme low flow events. The extreme low flows have been decreasing over the period from 1982-1996. This is a short time period, but the decrease is showing to be significant with 95% confidence. The possibility that long term decreases are related to; withdrawals at the resort, or climate events should be examined, but data was not found. Of the extreme events, nine of thirteen occur within the low flow period, with the remaining four occurring in August and September.

Figure 4. Extreme Low Flow Events (1982-1996)

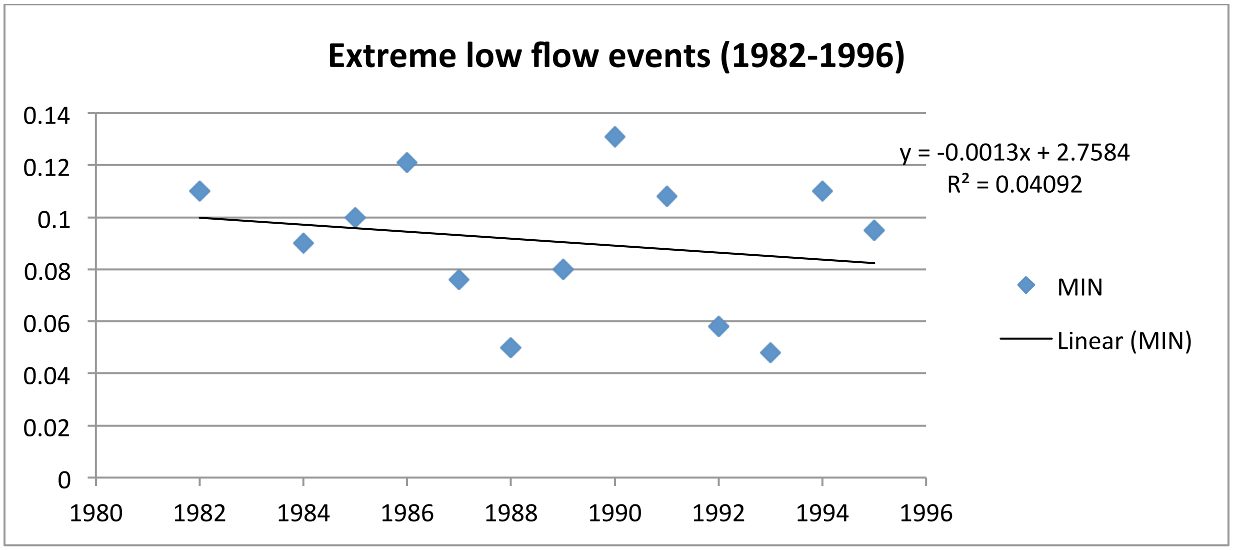
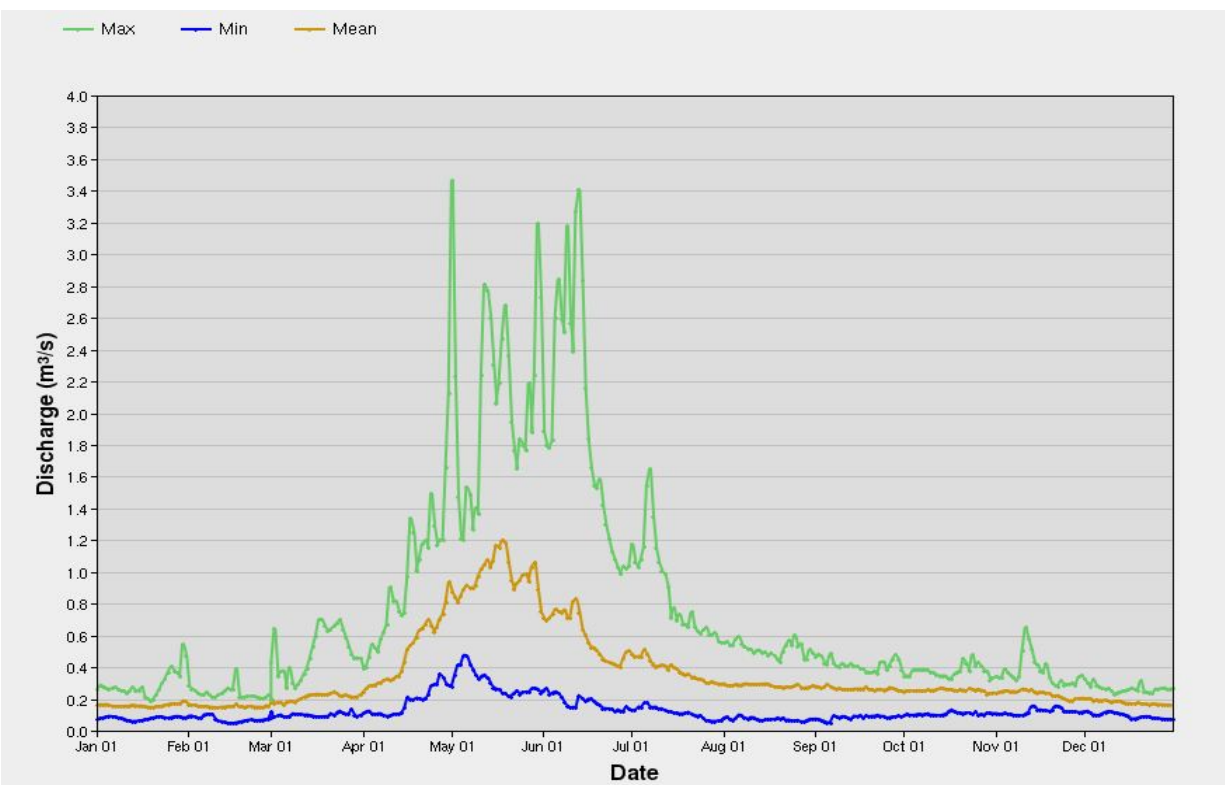


Figure 5. McGillivray Hydrograph shows the variability in peak flows in the spring runoff in both timing and amount, with the remainder of the year being relatively consistent.

Figure 5. McGillivray Hydrograph



The time period of Hydrometric data collected on McGillivray Creek is not sufficient to evaluate trends. Water allocations have been based on ad hoc data sources, as a result of not having a comprehensive source for hydrometric data, and in many cases, insufficient data. Data on surface water sources is limited, and must extrapolated over the long term, which is problematic given climate change. It is also important to keep in mind that although allocated, most water sources are not metered; therefore, the actual use may be above or below the allocation. There are not plans to measure water use in the short term, or with the implementation of the WSA.

There is not climate data for the Sun Peaks area. The Weather Station at Kamloops is probably not representative of the climate at Sun Peaks, with a gain in elevation of approximately 900m from Kamloops to the base of Sun Peaks (Sun Peaks, 2015). However, if trends showing for Kamloops are similar to Sun Peaks, then the resort may experience less precipitation in the form of snow, and warmer temperatures in both the winter and summer months.

Snow data from Sun Peaks is available for 1995 to 2014. In reviewing the data for new snow, and the snow base, there were no significant trends over the past 20 years; however, the snow base does show a decline (SPRC-SH, 2015). The information provided does not indicate whether snow making contributes to the snow base or new snow data.

Seasonal Water Stress

The need for water in the valley was not initially considered in the development of the resort (Christa Pattie - Personal Communication, January 2015). The resort is currently approximately one quarter of its proposed size, with only 59.7Ha of a proposed 233.5Ha's developed in the valley bottom (Ecosign, 2013). The proposal is for the currently ~7500 bed capacity to reach ~23,000. Given that the surface water for the valley is currently fully allocated, there are significant concerns about water availability particularly in the winter at low flows (Ecosign, 2013). The challenge in protecting many environmental services, such as environmental flow needs, is that economic drivers (resort development) are often more effective than environmental arguments where data, monitoring and enforcement, as well as understanding about environmental needs, are limited, as is the case here.

Given that there is not climate data available for the area, the adjacent weather patterns have been considered (Environment Canada, 2015). Environment Canada data for Kamloops shows patterns of winter warming trends, and reduced precipitation in the form of snow. Both of these trends were statistically significant for Kamloops (Appendix 1 – Climate Station Kamloops). As stated, the absolute values will not be relevant, but the trends in weather patterns could be. The most prominent seasonal issues will likely arise in the late summer, as the catchment is small and steep, with little precipitation, warm temperatures in summer, and reduced vegetative cover, and, in winter when demand is highest. Low flows occur throughout the year, with the significant period of concern being when water levels are at their lowest, and visitors and snowmaking are highest.

The main ski area, Mount Tod, is southern exposure, with little to no vegetative cover on the ski runs. The lack of vegetative cover increases evaporation losses in the summer months. The ski slopes experience extended periods with little moisture during the dry period. Maintaining adequate base flow in McGillivray creek is critical. The creek is fish bearing, and salmonid use of the stream could be affected by the seasonal water stress and low flows in fall and winter (Ptolemy, 1981; McLeary –

personal communication, January 2015). McGillivray is also tributary to Louis Creek, which has significant fisheries values (Ptolemy, 1981); and is a water source for domestic and agricultural purposes (FLNR Mapview, 2015).

A summer seasonal water stress for the resort is that there is not currently sufficient water in the surface water system to allocate for irrigation of the golf course. The Municipality had constructed a diversion in McGillivray creek as an addition to the existing water works, however, the diversion has been ordered removed, and it has been determined the existing allocation is not sufficient to provide irrigation services to the golf course. The resort will continue to pursue alternatives, possibly increasing pressure on the already limited supply during the dry period.

The desired future use of additional water for resort expansion and water for snowmaking is also a concern. The resort experiences patchy snowfall particularly in the early part of the ski. The resort is currently making snow for 49.5ha with plans to expand that to 150ha (Ecosign, 2013). The water for current snowmaking is taken from Five Mile creek to fill a 121,133m3 reservoir during spring freshet (Ecosign, 2013; Metric Conversions, 2015). Further snowmaking will require additional water sources, and three additional reservoirs have been proposed (Ecosign, 2013). The first proposed new reservoir source is unclear, but may require more water from Five Mile creek. The other two reservoirs have been proposed to use treated effluent water from existing sewage lagoons (Ecosign, 2013). Based on typical consumption of water required for snow making to a depth of 30cm, and, the proposed expansion from 49.5 to 150 Ha's, the resort could require an additional 528,630m3 of water (Schreier – Personal Communication, 2015). Studies in the Alps have shown that as temperatures increase, the greater the losses to sublimation during snowmaking, resulting in increased water requirements for snowmaking (Schreier – personal communication, 2015).

Water Quality

Data - CABIN Database

The Canadian Aquatic Biomonitoring Network (CABIN) has two sample sites on McGillivray Creek; Site Code: TOP-MCGV-01 (downstream of village location) and TOP-MCGV-02 (upstream of village location). Water chemistry information from two sample periods was reviewed to determine whether there were changes over the two-year period, as well as, looking for contaminants that exceed water quality standards.

Table 2. Water Chemistry McGillivray Creek Sites, shows the increases and decreases in water quality indicators over two sample periods on CABIN site TOP-MCGV-02 and the downstream accumulated water quality impacts from one sample at CABIN site TOP-MCGV-01 (CABIN, 2015).

Changes from the two sample periods are not significant, however, some components could be useful indicators of land use impacts, particularly comparing the downstream site to the sites upstream of the resort village over time (CABIN, 2015). Impacts from forestry, range and non-point source pollution from the resort could be monitored over time using this methodology and building on this data set.

TABLE 2. Water Chemistry McGillivray Creek Sites

Water Chemistry - (CABIN, 2015)								
			decrease from previous sample	increase from previous sample		downstream increase		
Site Code: **TOP-MCGV-02** - Upstream of Sun Peaks Village			Site Code: **TOP-MCGV-02** - Upstream of Sun Peaks Village			Site Code: **TOP-MCGV-01** - Downtream of Sun Peaks Village		
Sample Date: September 17 2007			Sample Date: September 29 2009			Sample Date: September 17 2007		
Silver	0	mg/L	Silver	0.000028	mg/L	Silver	0	mg/L
Aluminum	0.0064	mg/L	Aluminum	0.0229	mg/L	Aluminum	0.0358	mg/L
Arsenic	0	mg/L	Arsenic	0.00021	mg/L	Arsenic	0.0002	mg/L
			Boron	0	mg/L			
Barium	0.0255	mg/L	Barium	0.00755	mg/L	Barium	0.0331	mg/L
Beryllium	0.00003	mg/L	Beryllium	0	mg/L	Beryllium	0	mg/L
Bismuth	0	mg/L	Bismuth	0	mg/L	Bismuth	0	mg/L
Bromide	0	mg/L	Bromide	0	mg/L	Bromide	0.02	mg/L
Cadmium	0.00001	mg/L	Cadmium	0.000017	mg/L	Cadmium	0.00003	mg/L
Dissolved Chloride	1.8	mg/L	Dissolved Chloride	0.5	mg/L	Dissolved Chloride	8.9	mg/L
Cobalt	0.000007	mg/L	Cobalt	0.000059	mg/L	Cobalt	0.000069	mg/L
Chromium	0	mg/L	Chromium	0.0003	mg/L	Chromium	0	mg/L
Copper	0.00096	mg/L	Copper	0.584	mg/L	Copper	0.00121	mg/L
Alkalinity	80.6	mg/L	Alkalinity	98	mg/L	Alkalinity	115	mg/L
Total Organic Carbon	1.7	mg/L	Total Organic Carbon	4.6	mg/L	Total Organic Carbon	2.5	mg/L
Colour	0	Unknown	Colour	0	Unknown	Colour	0	Unknown
Bottom Dissolved Oxygen	9.99	mg/L				Bottom Dissolved Oxygen	9.68	mg/L
pH	8.19	pH	pH	8.12	pH	pH	8.12	pH
TDS (Filterable Residue)	112	mg/L	TDS (Filterable Residue)	120	mg/L	TDS (Filterable Residue)	180	mg/L
Total Suspended Solids	0	mg/L	Total Suspended Solids	0	mg/L	Total Suspended Solids	0	mg/L
Specific Conductance	108	uS/cm	Specific Conductance	201	uS/cm	Specific Conductance	280	uS/cm
Air Temperature	10.5	Degrees C				Air Temperature	11	Degrees C
Temperature	5.5	Degrees C	Temperature	5.76	Degrees C	Temperature	6.59	Degrees C
Turbidity	0.2	NTU	Turbidity	0.6	NTU	Turbidity	2.1	NTU
Lithium	0.00051	mg/L	Lithium	0	mg/L	Lithium	0.00101	mg/L
			Magnesium	2.72	mg/L			
Manganese	0.00485	mg/L	Manganese	0.0291	mg/L	Manganese	0.0235	mg/L
Molybdenum	0.00107	mg/L	Molybdenum	0.00008	mg/L	Molybdenum	0.00179	mg/L
Nickel	0.00168	mg/L	Nickel	0.00029	mg/L	Nickel	0.00035	mg/L
Ammonia	0	mg/L	Ammonia	0.154	mg/L	Ammonia	0	mg/L
Nitrate/Nitrite	0.069	mg/L	Nitrate/Nitrite	0.035	mg/L	Nitrate/Nitrite	0.074	mg/L
TKN (Water)	0.07	mg/L	TKN (Water)	0.08	mg/L	TKN (Water)	0.08	mg/L
Total Nitrogen	0.14	mg/L	Total Nitrogen	0.12	mg/L	Total Nitrogen	0.16	mg/L
Total Organic Nitrogen	0.07	mg/L	Total Organic Nitrogen	0	mg/L	Total Organic Nitrogen	0.08	mg/L
Lead	0.00003	mg/L	Lead	0.00253	mg/L	Lead	0.00008	mg/L
Ortho Phosphorus	0.006	mg/L	Ortho Phosphorus	0.001	mg/L	Ortho Phosphorus	0.009	mg/L
Total Phosphorus (Water)	0.002	mg/L	Total Phosphorus (Water	0	mg/L	Total Phosphorus (Water)	0.007	mg/L
Antimony	0.000016	mg/L	Antimony	0.00004	mg/L	Antimony	0.000035	mg/L
Selenium	0.0004	mg/L	Selenium	0	mg/L	Selenium	0.0006	mg/L
Tin	0.0001	mg/L	Tin	0.00007	mg/L	Tin	0.00004	mg/L
Sulphate	6	mg/L				Sulphate	17.6	mg/L
Strontium	0.128	mg/L	Strontium	0.0918	mg/L	Strontium	0.2	mg/L
Thallium	0.000003	mg/L	Thallium	0	mg/L	Thallium	0.000004	mg/L
Uranium	0.000353	mg/L	Uranium	0.000005	mg/L	Uranium	0.000949	mg/L
Vanadium	0	mg/L	Vanadium	0.0006	mg/L	Vanadium	0.00014	mg/L
Zinc	0.0009	mg/L	Zinc	0.0096	mg/L	Zinc	0.0033	mg/L

McGillivray Creek Water Quality Condition

The sources of chemicals and other water quality indicators in *Table 2* could include; natural geological and hydrological sources, land use sediment generation and associated contaminants, as well as, non-point source pollutants (NPS) from the municipality and surrounding land use. In *Table 2,* downstream increases highlighted in yellow are potential indicators of NPS resulting from the land use activities and municipality upstream. Other potential indicators of land use impacts such as total dissolved solids, conductivity, nitrogen & phosphorous and metals were also be considered with respect to origin and potential effects. Some indicators from CABIN have been checked against the BC Water Quality Guidelines and the RAMP guidelines of Alberta.

Samples from McGillivray Creek for total dissolved solids, specific conductance, and alkalinity are below acceptable thresholds (BC MoE, 2015; RAMP, 2015). Other indicators reviewed against the water quality guidelines include; temperature (well below limits), sulphates (well below limits), nitrate and nitrite (well below limits) (BC MoE, 2015). Aluminum is currently below the level of 0.05mg/L (median value) for freshwater aquatic life, at 0.0358, but, this value increased significantly from 2007-2009, and was higher downstream of the resort (Butcher, 2001). Arsenic is also below acceptable limits for all water uses at 0.2 micrograms/L. At the time of assessment (2007 and 2009), based on the indicators, the water in McGillivray Creek was of good quality for all uses (drinking water, aquatic ecosystems, irrigation etc.) (BC MoE, 2015).

Evaluating trends in water quality, however, are not possible without longer-term data collection. A review of the sites monitored for water quality contaminants in BC shows that there are very few headwater systems that are monitored, particularly over the long term. In the southern interior, there are monitoring stations in the North and South Thompson Rivers, but, it appears that typically water is monitored only for drinking water purposes and most small communities accessing surface water within the Thompson Nicola Regional District (TNRD) provide public data only after water treatment has occurred. Long-term water quality data is very difficult to attain, particularly in small watersheds, and will be required to assess the impacts of development on water quality.

Planning for Water Quantity and Quality Protection Measures

Water management considerations for reducing water quality impacts and water quantity concerns are important in the McGillivray Watershed. Although the water is currently of good quality, it is necessary to focus on reducing the inputs of contaminants and adhering to best management practices for; land use activities in the area, urban non point sources of pollution. The significant concern in this area is for water quantity management and the implementation of some water conservation measures may assist in meeting water demand. Water quantity and quality protection often are interrelated, and many management options provide benefits to both quality and quantity.

Short Term

Short-term strategies for implementation or consideration include; sediment management, riparian best management practices and land use/ resort development considerations.

All land uses in the area should ensure sediment best management practices are followed, as this is likely one of the easiest and most immediate opportunities. Preventing sediment delivery to watercourses is a preventative measure that will reduce impacts to water quality.

Minimising road area within the watershed will reduce the amount of sediment delivery to water. Where roads are necessary for access and development, ensuring appropriate road construction and maintenance practices is critical for preventing sediment delivery to water sources. Maintenance best management practices ensure that water is directed off the road through the use of berms, and into collection areas, such as sumps or areas that are not hydrologically connected to the water source.

Forest/vegetative cover protects soil surfaces from exposure to rain, reducing the erosive potential of rain, which causes sedimentation. Management practices that maintain vegetative cover, forest floor and litter layers, serve as a protective layer to mineral soils are required. In forest harvesting, utilising appropriate methods and techniques that minimise exposure of mineral soil are required.

Timing and methods for forest harvesting, forest clearing for recreational development and grazing should be considered to reduce compaction and resulting reduced infiltration ability of the soil. Best management practices that avoid these outcomes include; avoiding saturated soils, utilising equipment with dispersed weight loads, and avoiding traffic on soil types sensitive to compaction, and effective grazing rotations, that prevent overgrazing and compaction.

Adhering to riparian management practices that retain minimum buffer widths of forest adjacent to streams in both land use and urban and recreational construction will be greatly beneficial to water quality. Maintaining riparian setbacks assists in trapping sediments and reducing the amount reaching the streams. Riparian buffers also act to reduce evaporation and maintain stream temperature. Forested buffers better protect streams from livestock and wildlife, reducing impacts from hoof shear, as well as reducing pathogenic introductions from animal faeces. Trails that are near watercourses can be used as an opportunity to raise awareness with residents and visitors about the critical habitat through the use of signage.

In Resort development, design considerations have the greatest probability of protecting water quantity. There are opportunities for recovery and re-use of water for some purposes, which will greatly affect the available water. When planning ski runs and other recreational trails; snowmobile, snowshoe etc., that allow for retention of trees on sites where it is safe to do so will minimise evaporation losses from ski runs. Promoting treed runs where tree species are appropriate, to the degree necessary to allow snow through fall, while also providing shade, and keeping the ski runs cooler in warmer weather events, perhaps reducing the need for snowmaking and reducing evaporation and sublimation losses.

Sun Peaks Municipality should explore options for the capture, reuse and storage of grey water and rainwater. Water collected within the municipality could be used for irrigation purposes on landscaping and the golf course, or for snow making in the lower portions of the resort, reducing the transport or water, and reducing the pressure on treated water.

Currently there are reservoirs in place, and proposed for development, that take advantage of spring freshet. There is the need to also consider the losses to evaporation during the summer season between water capture and use. The time period varies, but on average there is the potential for significant evaporation losses between June and September, when temperatures are highest (Note: summer temperature data was not available). Reducing evaporation losses could reduce the deficit in water use for snowmaking, which is a concern going forward.

These are some of the obligations and options of land users in the area and should be considered standard practice. The long-term objective is to create a better understanding by all users in the watershed, to ensure water use and protection is optimized. As a municipality and primary land and water user in the area, the Resort has the responsibility to engage the public and community through source water protection strategy development and implementation to assist in water quality and quantity protection measures. This process is difficult and can take some time, but as the watershed is clearly defined and of a manageable size, it is possible to create a realistic plan and vision of a water future.

Long Term

Sun Peaks should address water quality and quantity issues through initiation and development of a Source Water Protection (SWP) Strategy. A SWP is defined by Simms, Lightman, and de Loe, as "…an activity involving; mapping water sources, identifying threats, and instituting risk management strategies." Much of this work is complete, and could be built upon to consider the long term availability and quality of the water; the land uses that now, and potentially could in the future, impact the sources; and, the types of management strategies that could be instituted to protect the source from contamination and overuse.

Due to the complexity of water management and diversity of potential impacts, the protection of water sources needs to be implemented as a multi barrier approach to ensure protection (Simms, Lightman and de Loe, 2010). To be effective, site-specific options for source water protection at Sun Peaks should include the key considerations above, as well as, stakeholder engagement in the process of protection (WHO, 2011). The other land users in the valley must also be included, as they have a stake in the outcome, and play a role in protection. The process would be time consuming, but would provide a more realistic water future in the McGillivray and downstream Louis Creek Watersheds.

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APPENDIX 1 – Climate Station Kamloops

518 Assignment 2 Posted Oct. 1, 2014. Due Date: November 10, 2014.

Increased Climatic Variability

Climate is a multi-dimensional term defined by; weather, wind and storms, rainfall, temperatures, sunny and cloudy days, length of growing season etc. Climate affects living and growing conditions for both ecosystems and social/economic systems in all parts of the world. For this reason, it is critical that we are aware of what the changing climate signals are, and adjust for the potential predicted future.

It is important to be aware that climate data is difficult to interpret given the natural variability in temperatures, precipitation, and other climate factors. Natural variability from one location to the next, whether on a large or small scale, makes extrapolation from climate data difficult. Collection of averages (temperature, precipitation, etc.) of climate data is how we make it possible to collect and consider that information, but, it has limitations.

The use of average data has the effect of masking variability, and, variability exists within even a small geographic area. Therefore, climate data must be considered and interpreted very carefully (Schreier and Pang, 2014). Natural climatic variability, both spatially and temporally, creates uncertainty for prediction/forecasting of future climate without risk of errors. Limited climate stations makes it necessary to extrapolate climate data interpretations over broad regions, which, is not necessarily accurate/feasible, and the use of average temperature and precipitation values results in the cancelling out of extremes (Schreier and Pang, 2014).

Climate Station Kamloops Airport (YKA)

The climate station at the Kamloops Airport was chosen as a sample location. The weather station used is at 345.3m elevation, a valley bottom location (Government of Canada, 2014). Members of the urban community of Kamloops live at valley bottom up to approximately 800m in elevation. Rural population in the surrounding area live up to approximately 1100m in elevation. The topography in the surrounding area is such that the majority of prevailing wind comes from the much higher surrounding mountains, and the majority of precipitation from the pacific, is lost over the Coast Mountains, prior to weather systems arriving in Kamloops.

Anecdotally, I would expect climate data to reflect that there has been a warming trend in the Kamloops area in the winter months. Anecdotal evidence such as; increasing bark beetle activity (mountain pine beetle, Douglas-fir beetle, balsam bark beetle, western bark beetle and spruce bark beetle), forest defoliator insect activity, trends in fire frequency and severity, and localised cases of surface water scarcity. All of these can be indicators of a changing climate, and all are also affected by land management decisions and human interference/intervention.

Climate data from 1951 to 2012, was used initially for winter and summer average maximums and minimums and precipitation to illustrate the difficulty of using averages to show trends. The data for 1952 and 2012 was then compiled and compared for the winter and summer extremes. 2008 data was incomplete so in some instances may be excluded from the analysis. For assessing whether there has been a shift in precipitation, the data for 1960-2012 was used. All climate data used is from the Government of Canada, 2014.

Temperature

Interpreting historic climate data is complicated. When average temperatures are used across broad geographic regions, the result is that higher or lower than normal temperatures cancel one another out and create the perception that changes are not consistent or significant. In one out of three weather stations, data collected and interpreted for the last 50 years will show no statistically significant change in climate variables (Schreier, personal communication, 2014).

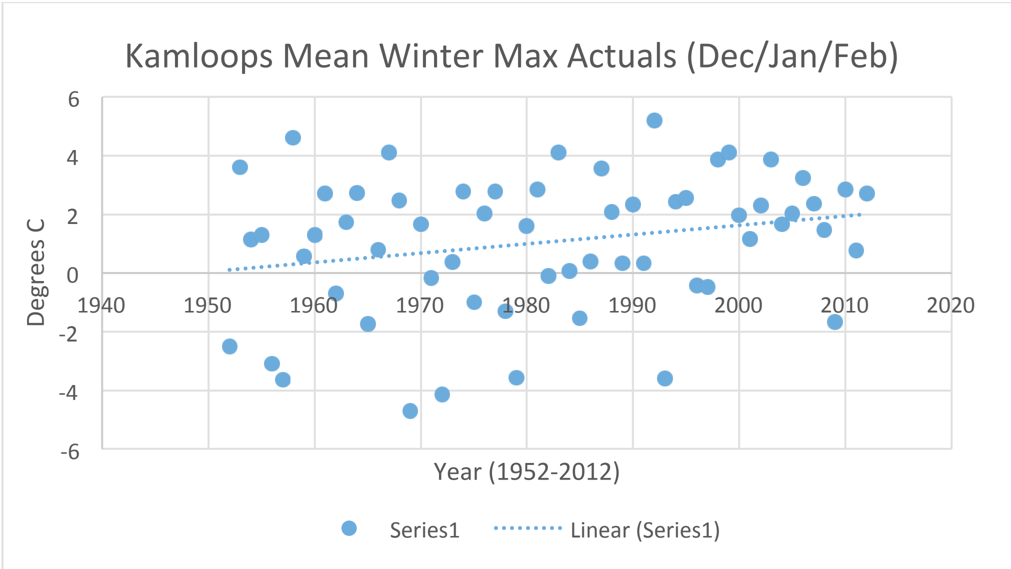
To evaluate temperature, winter and summer should be evaluated during critical periods (Schreier and Pang, 2014). The observations that initially show trends, can then be assessed for their significance. Temperature critical periods assessed are; winter - December, January February, and, summer – June, July, August (Schreier, personal communication, 2014). In some cases the entire period will show trends, in others, they can be evaluated separately. Identification of the significance of the changes are dependent on assessing the appropriate sets of data.

Illustrating the effect of the use of averages

Prior to analysis, it is important to illustrate the effects that the use of averages can have on the outcome of climate data interpretation. The mean winter min and max temperatures were used as an example. The trend in mean winter maximum and minimum temperatures (Figure's 1a and 1b) indicates that the winter temperatures are increasing. Winter maximums appear to be increasing by approximately 1 degree Celsius every 30 years. However, when the statistical significance of the data was tested, it shows that the increase is not statistically significant. With 95% confidence, the trend is between -0.0068 and +0.0612, and, because zero is within that range, we can't be certain that there is definitely an increase in temperature when using average data. Eliminating the extremes, reduces the variability, and the extremes are the events that will cause most disruption to the environment and society. This data manipulation and methodology does not provide certainty that climate is changing, and as a result, can be employed by individuals, corporations or governments whose interests are not served or advanced by the certainty of climate changes.

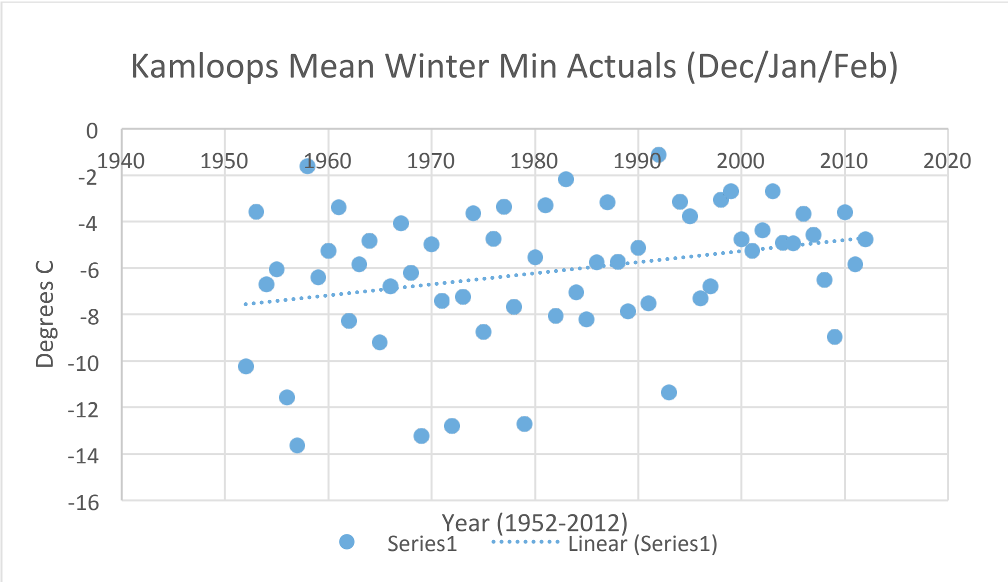
Figure 1a. Actual mean winter max temperatures recorded at Kamloops Airport (1952-2012) and *Figure 1b. Actual mean winter min temperatures recorded at Kamloops Airport (1952-2012)* show the trends of the average climate data for; winter maximum (1a) and minimum (1b) averages (Dec/Jan/Feb), and demonstrate the inability to use mean temperatures to confirm trends in climate. Means show trends, but the lack of statistical significance shows that means are inappropriate due to the natural variability in weather and the limited data collection points. The means will not be the issue in future climate, it will be the extreme climate events that cause problems.

Figure 1a. Actual mean winter max temperatures recorded at Kamloops Airport (1952-2012)



Kamloops Mean Winter Max Actuals (Dec/Jan/Feb)
Degrees C
6
4
2
0
-2
-4
-6
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year (1952-2012)
Series1
Linear (Series1)

Figure 1b. Actual mean winter min temperatures recorded at Kamloops Airport (1952-2012)

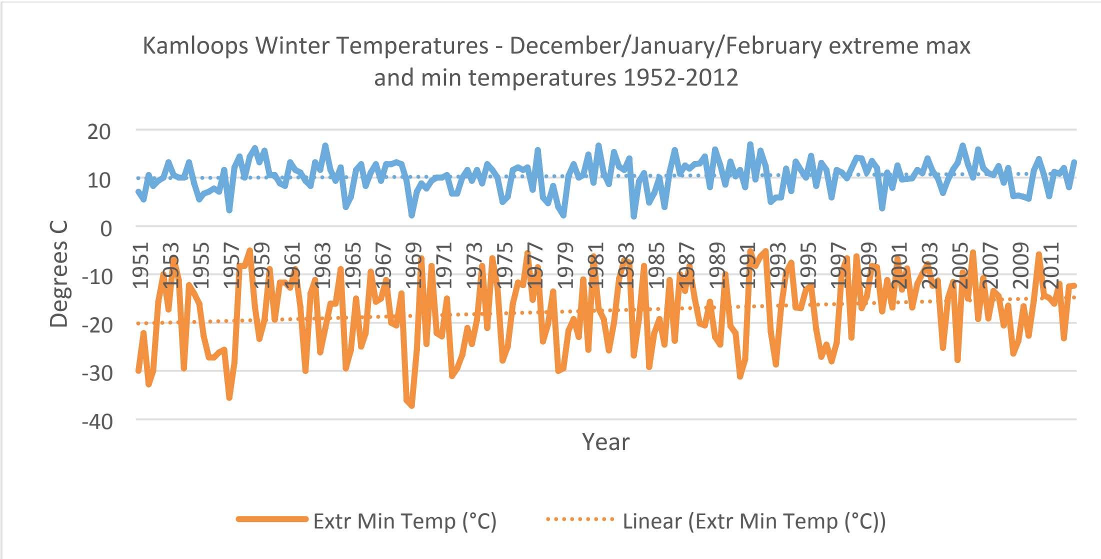


The use of means and lack of statistical significance illustrates the need to use the extreme values to attempt to determine whether there are changes happening in the climate. It is the extreme events that will prove limiting and potentially catastrophic in the future. In the following sections, the extreme temperatures, precipitation events and trends, in both winter and summer are evaluated.

Winter Extreme Temperatures

The extreme winter maximum and minimum temperatures were analysed for Kamloops for December, January and February using Environment Canada data from December 1951 to December 2012. In all three winter months, the minimum winter temperatures appear to be increasing while the extreme maximum temperatures do not appear to show much of a trend. *Figure 2. Kamloops Winter Temperature Trends* shows the combined winter maximum and minimum temperatures for winter months in Kamloops from 1952-2012. The trend shows that over 60 years, the extreme minimum winter temperature has increased by approximately 5 degrees Celsius.

Figure 2. Kamloops Winter Temperature Trends



Figures; 2a. Kamloops December Trend, *2b. Kamloops January Trend*, and *2c. Kamloops February Trend* show the extreme maximum and minimum temperatures and trend from 1951-2012 for each winter month individually. All three months show an increasing trend in the winter minimum temperature, but the change in the minimum January temperatures is most prominent. January shows a trend of an increase of approximately eight degrees Celsius over 60 years. This illustrates that even the winter extreme averages for a winter, rather than by month, can hide a more prominent or extreme change in a certain period.

Figure 2a. Kamloops December Trend

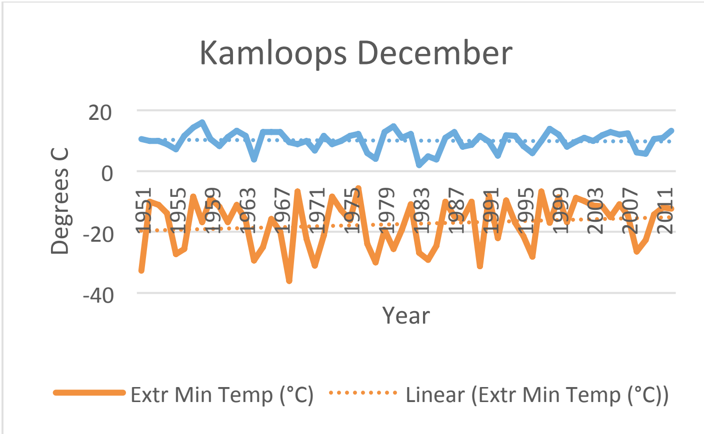


Figure 2b. Kamloops January Trend

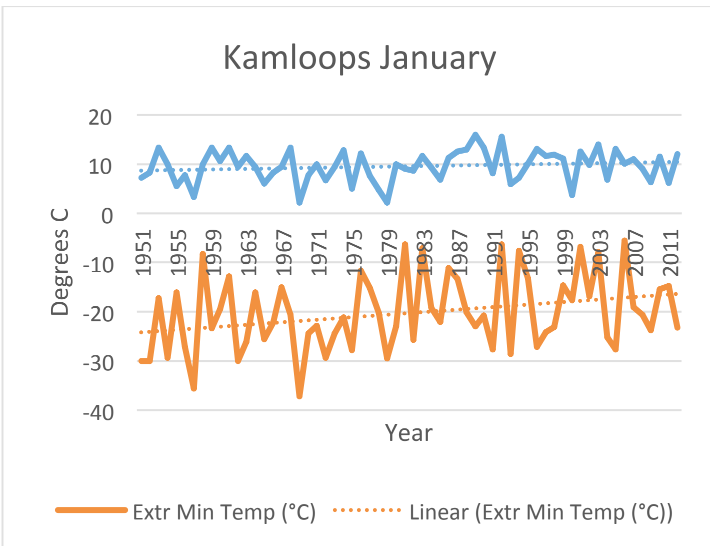
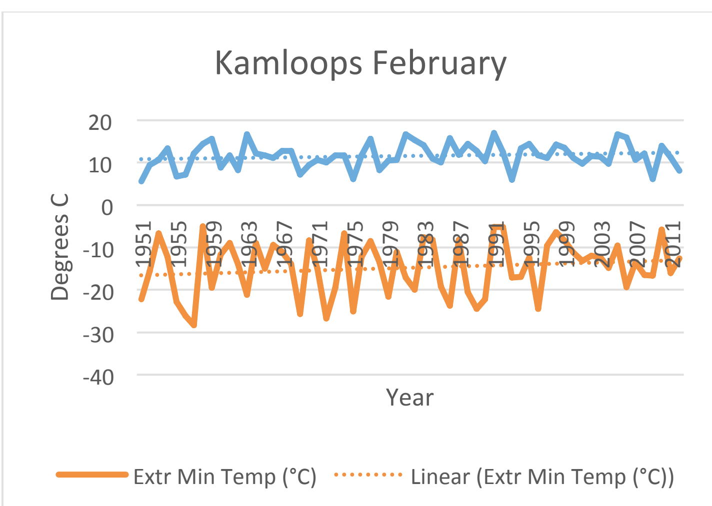
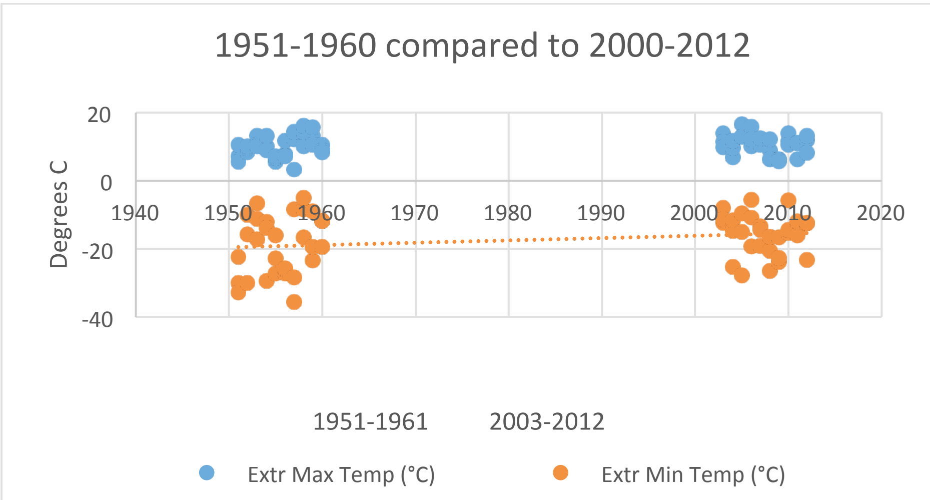


Figure 2c. Kamloops February Trend



To determine whether the change in temperature from a historic time period to the most recent time period is significant, the minimum temperature for the decade 1951-1960 vs 2000-2012 has be assessed. The graph in *Figure 2d. Kamloops 1951-1960 vs 2000-2012 winter extreme max and min,* shows an increasing trend in the minimums. If this trend is shown to be significant, we can infer that the increasing trend will continue into the future.

Figure 2d. Kamloops 1951-1960 vs 2000-2012 winter extreme max and min



Statistical Significance of Winter Trends

The winter maximum temperatures do not show much of a trend, and statistical analysis confirmed that the trends are not significant. In evaluating the winter minimum temperature trends, however, both January alone and the winter period, including December, January and February combined, shows statistically significant trends. Using linear regression, for the three winter months, the R^2 value is 0.0367 and has a P-value of 0.00897 so there would be a 0.8% probability of this being chance. The upper and lower confidence limits show that with 95% confidence the slope will be between +0.0205 and +0.1417, so we can be certain that there has definitely been an increasing trend in temperature 95% of the time.

January alone is also statistically significant with an R^2 value of 0.0918 and a P-value of 0.0303. The upper and lower confidence limits show that with 95% confidence the slope will be between +0.0116 and +0.2257, so we can be certain that there has definitely been an increase in temperature 95% of the time in January.

statistical significance of winter minimum temp

t-Test: Two-Sample Assuming Unequal Variances

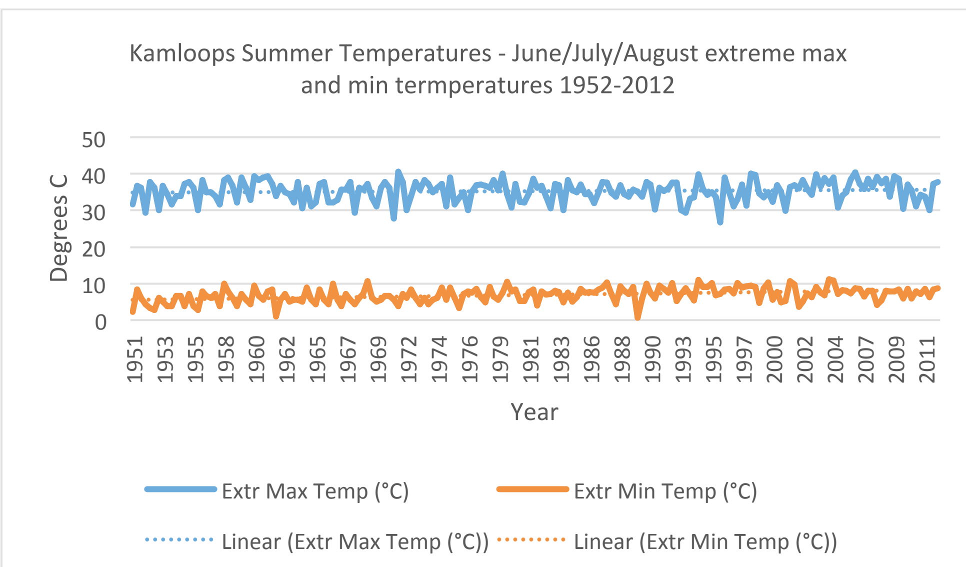
	Variable 1	*Variable 2*
Mean	-19.09	-15.6833
Variance	75.97817	34.08626
Observations	30	30
Hypothesized Mean Difference	0	
df	51	
t Stat	-1.77855	
P(T<=t) one-tail	0.040637	
t Critical one-tail	1.675285	
P(T<=t) two-tail	0.081274	
t Critical two-tail	2.007584	

In *Table 1. Kamloops 1951-1960 vs 2000-2012 statistical significance of winter minimum temp,* the minimum temperature for the decade 1951-1960 compared to 2000-2012 was analysed using an independent samples two tailed t-test in Microsoft excel (Grange, 2011),(Duke, 2010). The change from the first time period to the second time period, is shown to be statistically significant with 95% confidence. We can infer that the change in minimum temperature, by using the P-value of 0.040, indicates that only 4% of the time the temperature change would be random (Grange, 2011), (Wikipedia, 2014), (Hooper, Unk).

Summer Extreme Temperatures

The extreme summer maximum and minimum temperatures were analysed for Kamloops for June, July and August In all three summer months, the minimum temperatures appear to be increasing while the extreme maximum temperature does not appear to show much of a trend. *Figure 3. Kamloops Summer Temperature Trends,* shows the combined maximum and minimum temperatures for summer months in Kamloops from 1952-2012. The trend shows that over 60 years, the extreme minimum summer temperature has increased by approximately 3 degrees Celsius.

Figure 3. Kamloops Summer Temperature Trends



The summer extreme maximum and minimum temperatures for individual months June, July, August shows that the most prominent change is in the extreme minimum temperatures in August. *Figures; 3a. Kamloops June Trend*, 3*b. Kamloops July Trend*, and 3*c. Kamloops August Trend* show the extreme maximum and minimum temperatures and trend from 1951-2012 for each summer month individually. All three months show an increasing trend in the summer minimum temperature, but, the change in the minimum August temperatures is most prominent. August shows a trend of an increase of approximately four and a half degrees Celsius over 60 years. This illustrates that the summer extreme averages can also hide a more prominent or extreme change in a certain period.

Figure 3a. Kamloops June Trend

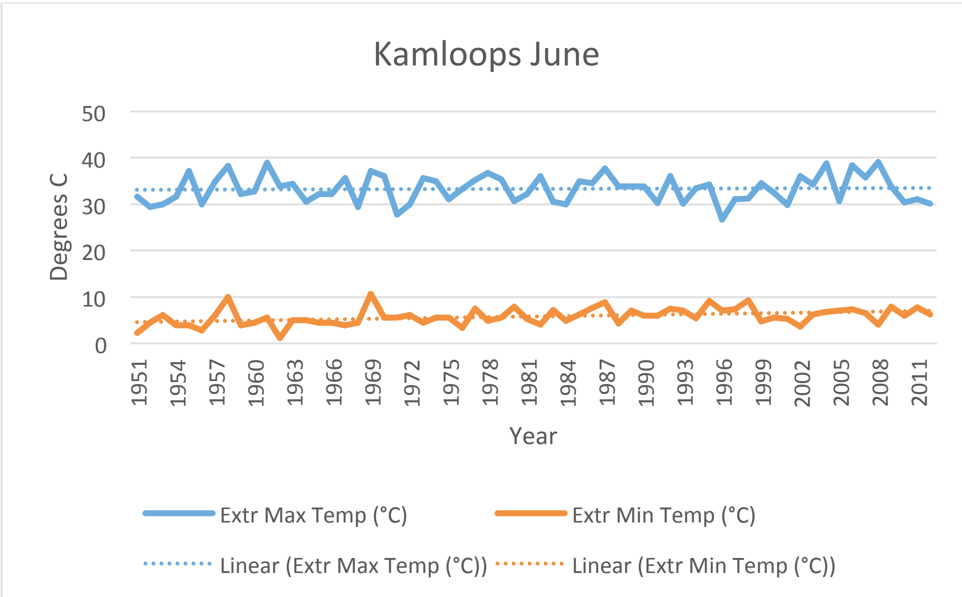


Figure 3a. Kamloops July Trend

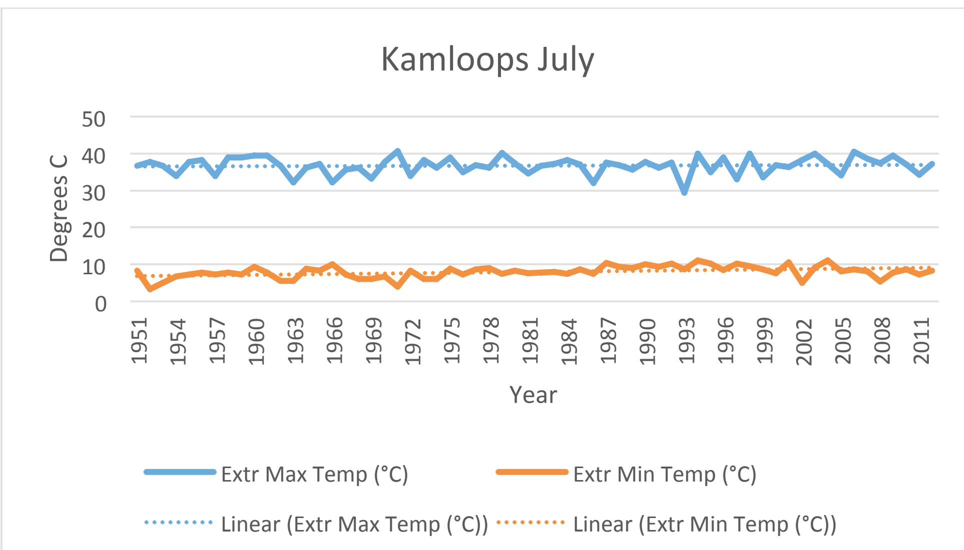
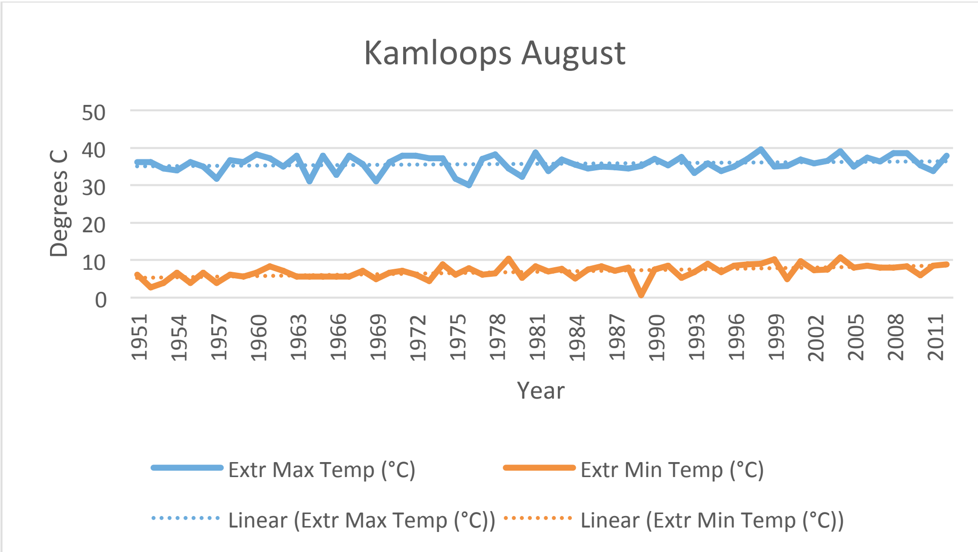


Figure 3a. Kamloops August Trend



Statistical Significance of Summer Trends

To determine the significance of the summer trends over time, linear regression was used to shows that the summer minimum temperatures are increasing. In the case of summer, rather than compare the full summer period to determine whether this pattern can be anticipated to continue, a two-tailed t-test was used for the month of August alone in two time periods. This is a critical time as it is the height of the drought season, and increased minimum temperatures will increase stress on aquatic and terrestrial ecosystems by reducing overnight recovery and increasing losses to evapotranspiration.

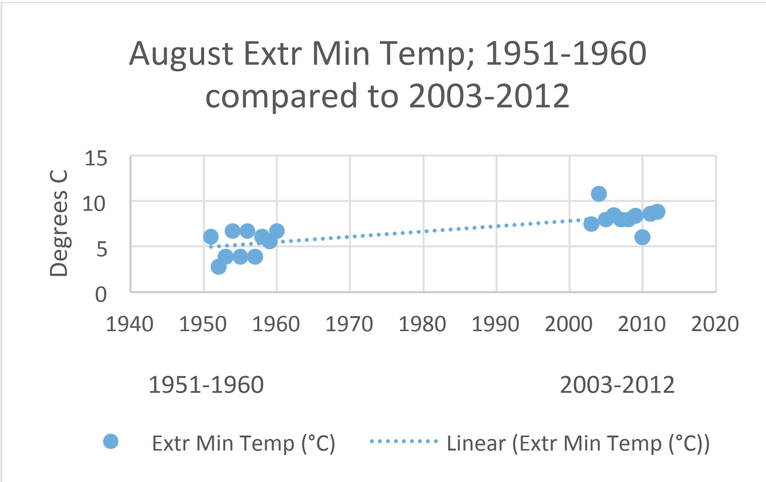
The historic time period for August 1951-1960 was compared to August 2000-2012. *Figure 3d. August Extreme Min Temp,* shows the trend is increasing from the historic decade 1951-1960 compared to most recent 2003-2012. *Table 2. Statistical significance August*, show that the trend is statistically significant and we can expect it to continue (Grange, 2011), (Wikipedia, 2014), (Hooper, Unk).

Figure 3d. August Extreme Min Temp

Table 2. Statistical significance August

t-Test: Two-Sample Assuming Unequal Variances

	1951-1960	*2003-2012*
Mean	5.24	8.26
Variance	2.149333333	1.424888889
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	-5.051451268	
P(T<=t) one-tail	0.00004920	
t Critical one-tail	1.739606726	
P(T<=t) two-tail	0.00009841	
t Critical two-tail	2.109815578	



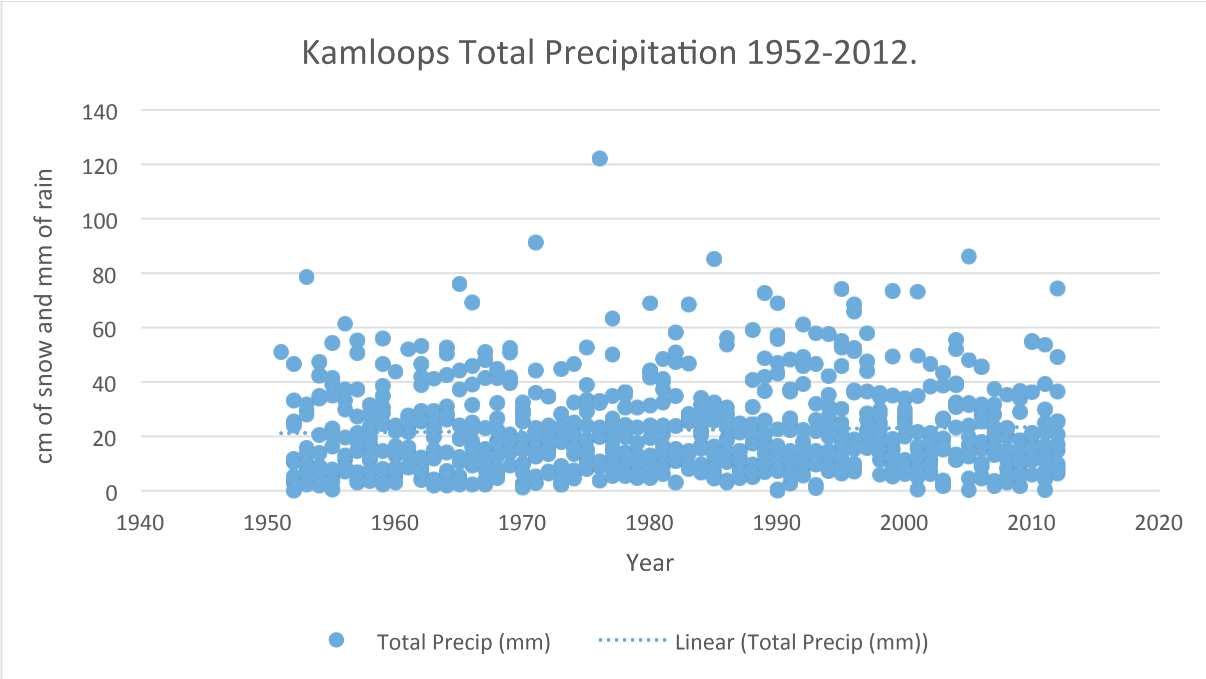
Precipitation

Changes in precipitation are difficult to quantify, as are the effects of those changes on aquatic and terrestrial ecosystems, society and the economy. Precipitation comes in the form of rain or snow and is variable much like temperature. For many reasons the timing of precipitation, as well as the intensity and frequency of precipitation are critical. The frequency and duration of precipitation events, particularly of rain, is of concern given the potential for runoff and flooding as the soils are not able to infiltrate the rain at the rate it is falling. Ideally precipitation events could be reviewed as daily data to identify the extreme events and their change in amplitude and frequency, but, for the purposes of this exercise only total by month data has been analysed.

Total precipitation data can be considered in the context of critical periods to assess if there has been a shift in timing. Winter precipitation needs to be considered for effects on snowpack, and spring replenishment of stressed summer waterways. Summer precipitation is critical for drought impacts and can play a role with fire risk, intensity and severity in fire prone locations like Kamloops.

The total precipitation for Kamloops over the time period 1952-2012 was reviewed. *Figure 4. Kamloops total precipitation 1952-2012* shows the total precipitation data on its own indicates that there has been very little change in the annual precipitation over the 60 year period. This information on its own does not provide any insight into the potential risks associated with changing precipitation regimes. To start to understand the critical periods, both winter precipitation and summer precipitation need to be evaluated on their own.

Figure 4. Kamloops total precipitation 1952-2012



Winter Precipitation

Examination of the trends in winter precipitation for the months December, January and February (form here on referred to as "winter") in *Figure 5. Kamloops Change in Total Winter Precipitation*, show a decreasing trend. However, when the precipitation is shown as either snow in *Figure 5a. Change in Winter Precipitation as Snow*, or, rain in, *Figure 5b. Change in Winter Precipitation as Rain*, the trends are diverging where rain is increasing and snow is decreasing. This can be of particular concern for ecosystems that rely on slow input of meltwater from the mountains to sustain flow and cool them through the summer months. This can also indicate an increase in rain-on-snow events (which can cause early melt of existing snow packs, as well as, creating unstable layers that can cause avalanches in steep terrain), reduced opportunities for recreation that rely on snow (ski hill operations, backcountry recreation), and potential flooding in winter when the ground is frozen and has a reduced infiltration capacity. This trend is not surprising given the confirmed increase in winter minimum temperatures.

Figure 5. Kamloops Change in Total Winter Precipitation

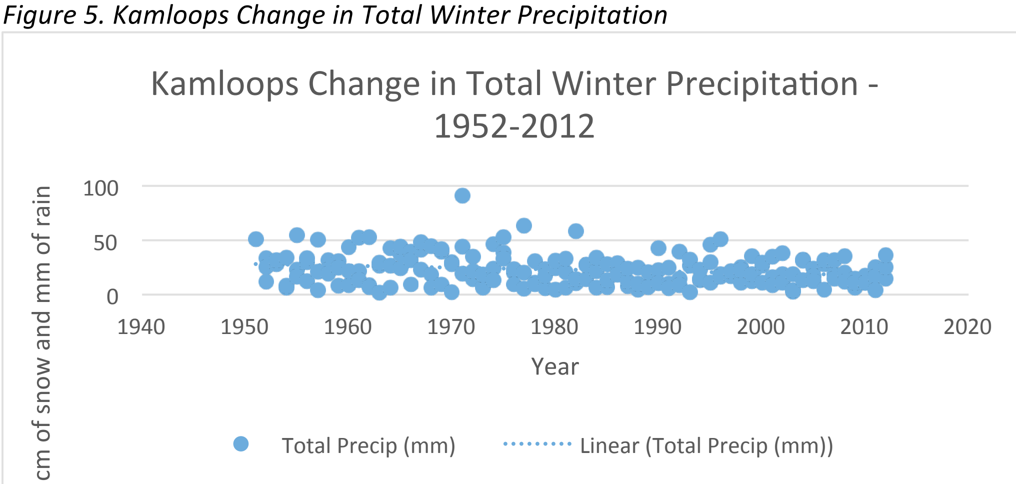


Figure 5a. Change in Winter Precipitation as Snow

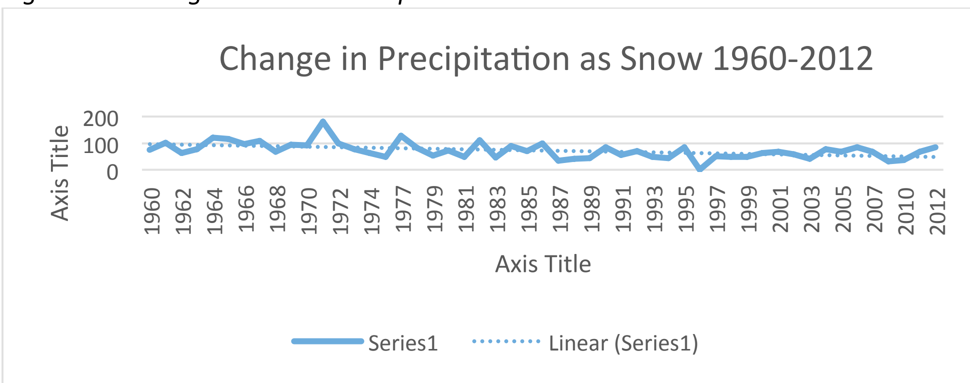
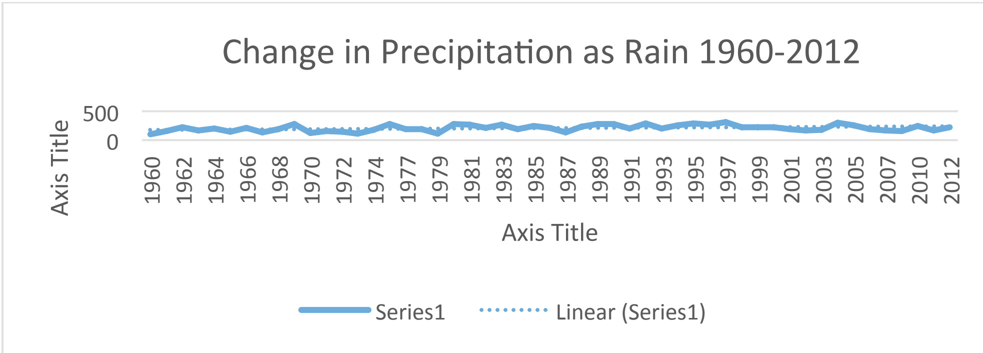


Figure 5b. Change in Winter Precipitation as Rain



Significance of Winter Precipitation

The primary consideration for winter precipitation is the change in precipitation in the form of snow. Historically, this would provide a prolonged source of meltwater for spring replenishment of water courses, and, would provide a thermal blanket keep moisture in the ground and heat out. *Figure 5d. Winter Precipitation as Snow* shows that for the two time periods 1959-1970 compared to 2002-2012, the total amount of snow is decreasing, and *Table 2. Winter Snow Precip t-Test* indicates that this trend is significant and we can predict that it will continue (Grange, 2011), (Wikipedia, 2014), (Hooper, Unk).

Figure 5d. Winter Precipitation as Snow

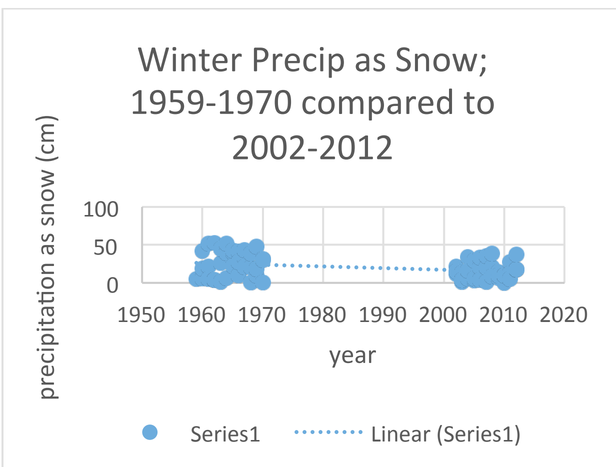


Table 2. Winter Snow Precip t-Test

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	*Variable 2*
Mean	25.25882	15.37576
Variance	298.1352	129.4631
Observations	34	33
Hypothesized Mean Difference	0	
df	57	
t Stat	2.77415	
P(T<=t) one-tail	0.003735	
t Critical one-tail	1.672029	
P(T<=t) two-tail	0.007469	
t Critical two-tail	2.002465	

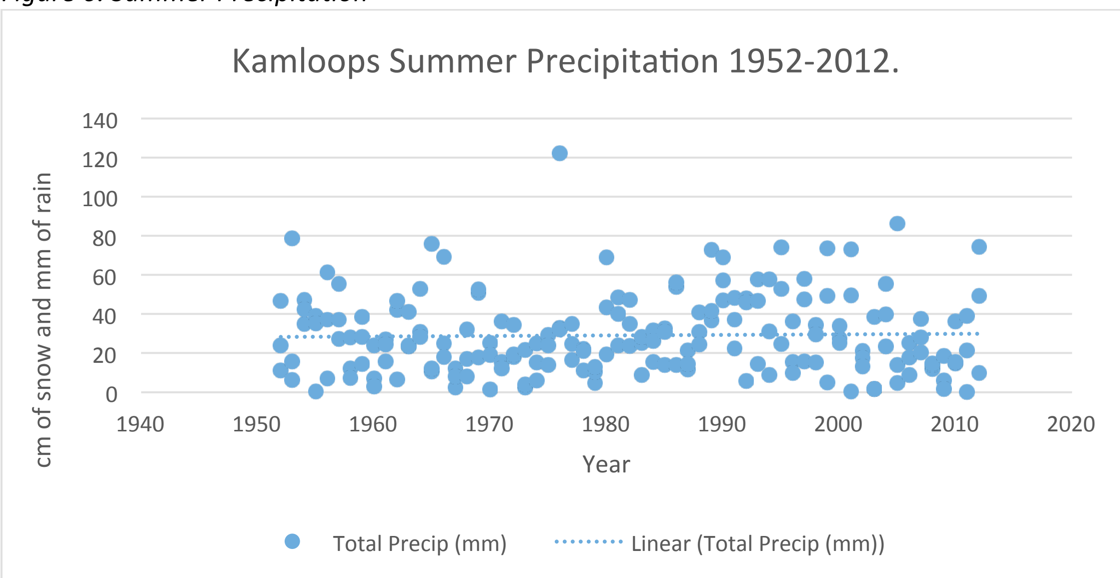
Summer Precipitation

Evaluating the summer precipitation between 1952 and 2012 for the months of June July and August does not appear to show any trend. *Figure 6. Summer Precipitation* does not show a trend. A statistical assessment of summer data was done and the data is not significant.

This is not surprising given that the data used was monthly, and individual precipitation events that are significant are hidden by the use of totals. This masks the significance. As a result, large and unusual rainfall events that can result in; overland flow, reduced infiltration, and sedimentation, are lost in the data set. In order to assess the frequency and impacts of these events it would be necessary to look at the frequency, duration and overall volume of rainfall of every rainfall event over time. The data required would be daily data.

It is likely that if daily data was reviewed, there would be a trend in the frequency and severity of rain events in the spring and summer. There have been a number of these events in the past few years. On July 26, 2011 (Kamloops Daily News, 2011) there was flash flooding that resulted in road closures and debris flows, where some storm flows blew manhole covers off. The most recent, on the 23rd of July, 2014, Peterson creek that runs through the downtown core broke through its banks and damaged Peterson Creek Park trails and infrastructure, as well as, further downstream eroding the foundation from under a house on its bank. The north east area of town, Sun Rivers, is built below silt bluffs and experienced small scale landslides that resulted in the closure of the highway 5a. This is in addition to many other road closures, and damage to personal properties and landscapes. In a climate that is typically dry, has fine textured, and in some cases hydrophobic soils, the impact to infrastructure such as roads and buildings, as well as natural ecosystems, can be severe.

Figure 6. Summer Precipitation



Precipitation Shifts – February to March

To answer the question about whether or not precipitation is shifting from late winter to early spring, the months of February and March were looked at in a number of ways. When you consider the change in precipitation in winter, from snow to rain, and, the increase in winter minimum temperature, the change in precipitation form is not surprising. In order to determine whether there is more precipitation in the spring, the trend in the months of February and March have been looked at. The total precipitation, shown in *Figure 7. Total precipitation Trend* shows that over time the total precipitation has been increasing in February and March combined, for a total increase of approximately 5mm over 50 years. When the individual months are looked at, February shows less of an increasing trend than March. To compare the change, the time period of 1960-1970 has been compared to the time period of 2000-2010, for both months. *Figure 7a. February Precipitation Changes* and *Figure 7b. March Precipitation Changes* show the difference between the historic decade of 1960-1970 and recent decade 2000-2010. Since the total precipitation change in February appears to be less than that in March. Which would imply that a shift in precipitation is occurring. The largest trend is in precipitation in the form of rain in March.

Figure 7. Total precipitation Trend

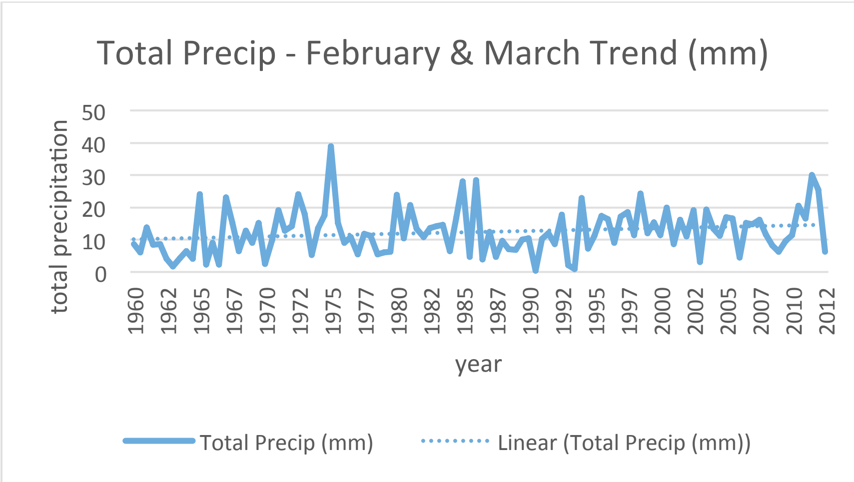


Figure 7a. February Precipitation Changes

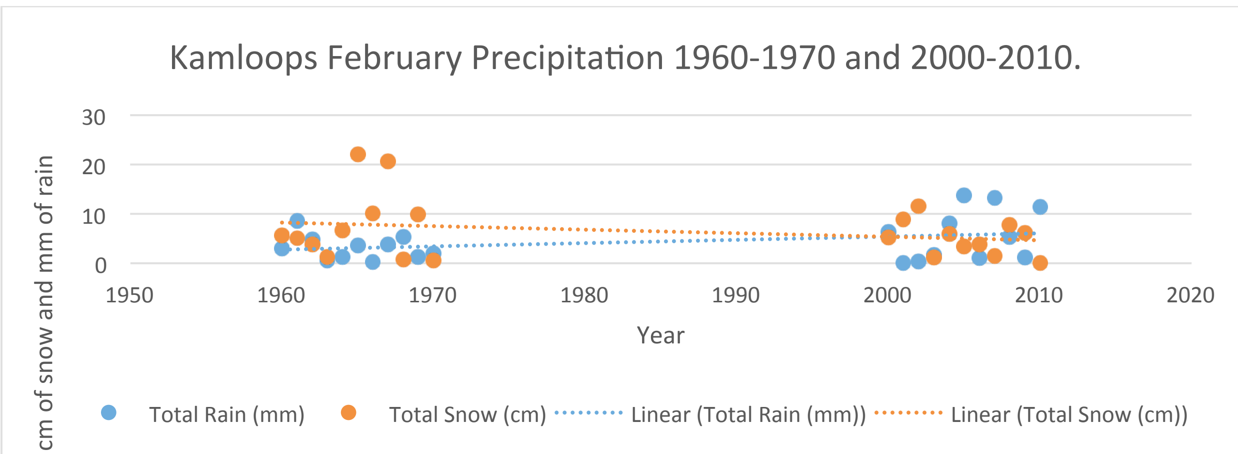
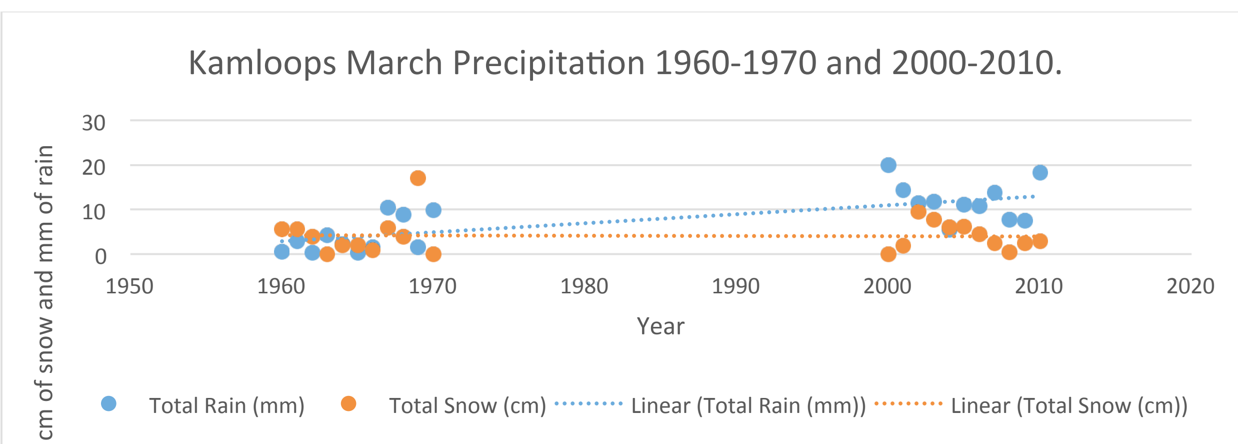


Figure 7b. March Precipitation Changes



Significance of Early Spring Precipitation

The increased precipitation as rain in February and March are both statistically significant. A two tailed t-test was used to compare the historic (1960-1970) and recent (2000-2010) time periods, and showed that the probability of either of these trends being chance are extremely low. Given that it has been established that winter precipitation is decreasing, and that spring precipitation in the form of rain is increasing, we can infer a shift from winter to spring precipitation regimes.

Conclusions

The data assessed has provided a generic set of baseline information. This information could be used to identify starting points to assess the impacts of these significant observed changes. In order to assess the potential impacts of increases in minimum temperatures, the values at risk need to be determined, as do their critical thresholds/tolerances (E.g. Forest seedling tolerances to summer minimum temperature increases).

To assess the impacts of changes and shift in timing of precipitation, it would be necessary to evaluate the extreme daily events in the context of values at risk. This would require that daily data be evaluated over time, in the context the value being considered. For precipitation timing changes in spring, for example, capacity of the environment to absorb the additional water will have a direct impact on spring freshet. The caution is that extrapolation of climate data from one geographic location has inherent risk, and should be done with extreme care and consideration.

Statistical significance of historic data and its use to predict future, is somewhat dependent upon the theory that all other factors remain the same. Increased anthropogenic effects on climate are therefore an important consideration. These effects are widespread and often human activities, that are seemingly innocuous, can affect local climate. Human interactions with the environment are difficult to quantitatively define; have cumulative impacts; and, are increasing. Land management decisions impact the spatial and temporal distribution of forest age classes, impacting resilience and susceptibility to fire and insect regimes. Reduced canopies on insect damaged or killed trees reduce interception cover, and thereby reduce evapotranspiration rates. Fire management, through protection of resource values and communities has inadvertently created decadent forests susceptible to extreme fire behavior. Urbanisation creates heat sources, disrupting natural air circulation patterns. There is increasing demand for withdrawal of surface and groundwater for various domestic and industrial uses that goes relatively unmonitored, but the availability in critical periods is diminishing. All of these contribute to the resilience of natural ecosystems, and result in environmental outcomes that are similar to climate impacts, while also contributing to climate change. Close attention to social and land use trends is required to more accurately predict climate impacts and future trends.

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