Assessment of the vulnerability and potential impacts of climate Change on local small watersheds in British Columbia

LWS 548 Major Project
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Executive Summary

Watershed management has been deployed as an important approach for planning and managing water with flexible frameworks. Understanding the implication of climate change on watershed is essential to protect each eco-aquatic system. However, due to resource limitations, it has been extremely challenging to plan and manage watersheds under accelerating climate change for each individual case. The objective of this project is to conduct an assessment on watershed vulnerability with potential impacts on exposure and sensitivity in local watersheds in British Columbia, the Mission/Wagg Creek in North Vancouver and the Fishtrap Creek in Kamloops.

The major climate changes in both watersheds are increased annual temperature and precipitation with seasonal variabilities. Summer seasons will be longer, warmer and drier while winter seasons will be wetter and warmer. The frequency and intensity of extreme weather events are likely to increase, stressing the infrastructure in the Mission/Wagg creek and bringing wildfire threats to the Fishtrap Creek. The overall water quality of both watersheds won't be negatively impacted, following the drinking water standards. For the Mission/Wagg Creek, based on the results from the semi-distributed SWMM (storm water management model), the drainage and sewage system can handle the increased rainfall intensity and runoff simulations with necessary partial upgrade on certain infrastructure. The costs to upgrade the infrastructure for future would not be excessive even considering both climate changes and urbanization. For the Fishtrap Creek, the water quantity and quality will decrease due to climate change, especially for the years following forest fire. The increase in temperature and decrease in seasonal precipitation will help spread the wildfires, resulting in worsening or longer fire season. Planning for Fishtrap Creek should focus on reducing the

likelihood and impacts of wildfires, such as developing recovery plans. Due to limitation of time, no quantitative analysis was conducted for the Fishtrap Creek. Overall, a great vulnerability was indicated for both watersheds, requiring more efforts and quantitative analysis on the impacts of climate change regarding watershed management in the future.

Introduction

Water nurtures all ecosystems and creatures to live, grow and flourish. With the rapid pace of population growth and worsening environmental conditions, it is of unprecedented significance to value and manage this fundamental resource of life. To secure the supply of safe and adequate water for all sectors in the future under the increasing challenges brought about by climate change, we must better manage and monitor water supply systems on various scales (Fraser Basin Council, 2011). One management unit is watershed, which has been deployed as an important approach for planning and managing water with flexible frameworks.

The watershed management process involves characterizing existing conditions, identifying problems, setting priorities, developing protection strategies based on objectives within the watershed, implementing protection strategies, and revising the management plan (EPA, 2008). This is of paramount importance especially due to the upcoming threats posed by climate change. The watershed-based approach addresses problems in a comprehensive and holistic manner while involving all stakeholders in the strategies; each watershed planning is unique based on the features and the issues of the watershed and the stakeholders' interest (Fraser Basin Council, 2011). However, due to resource limitations, it has been extremely challenging to plan and manage watersheds under accelerating climate change for each individual case.

Understanding the implication of climate change on watershed is essential to protect each local eco-aquatic system. Key parameters to consider when defining climate change are temperature, precipitation, humidity, and wind (Haley, D. & H. Auld, 2000). Any changes in the above parameters that persist over a period of decades can be identified as climate changes. According to ABCFP Climate Change Position Statement (2017), for the province of British Columbia, average annual temperature will increase by 1-3 °C with more extreme temperatures in the summer. Precipitation is predicted to increase 20% in most parts. Consequently, snowfall will decrease in amount and intensity during the winter seasons (Intergovernmental Panel on Climate Change, 2007). The changes in each watershed will bring significant impacts on the water resources in their vicinity.

As part of the BC Regional Adaptation Collaborative (RAC), Fraser Basin Council published Rethinking Our Water Ways: A Guide to Water and Watershed Planning for BC Communities In The Face Of Climate Change And Other Challenges (ROWW) in October 2011, aiming to reduce risks in the water sector and make adaptations to seize opportunities. According to ROWW, both long-term and year-round climate changes would influence water resources greatly in terms of watershed hydrology and geomorphology, water quantity and quality, aquatic ecosystems and infrastructures. We must prepare to mitigate conflicts between water consumption by humans and the natural environment created by the changing quantity and quality in water supply.

Water supply quantity will be impacted by climate change due to increased frequency of extreme temperature and precipitation events. Changes in rain precipitation can directly cause abnormal stream flows at certain locations, hence altering hydrology due to increased or decreased frequency and volume of water discharge (Furniss et al., 2013). Moreover, reduced precipitation or water supply over a long period of time can change forest fire patterns. Elongated duration of the dry and fire season will directly result in loss of biodiversity, leading to higher and faster runoff. Water supply quality will also be impacted because of climate changes, leading to insufficient supply of clean water for drinking, agricultural, commercial and industrial purposes. Relating to water quality, aquatic ecosystems will be altered by chronic stresses on fish migration patterns in certain watersheds due to higher water temperatures and lighter stream flows (Nelitz et al., 2009).

As discussed above, climate change has multiple parameters which all impact watersheds in various aspects. It is important to understand the changes in each parameter and how they affect local watersheds and their interconnected components, since the impacts on watershed health and water resources vary greatly depending on different geographical and topographical features. For example, rain dominated watersheds will behave differently from coastal watersheds, the latter of which would suffer from the impact of sea level rise (EPA, 2008). It is important for small regions with limited resources to study their local watersheds' response towards climate change to effectively prevent water insecurities and maximize watershed values.

Among established papers, most research focuses on the qualitative relationships between hydrologic parameters and climate change data. However, there exists a knowledge gap where quantitative study on the relationship between climate change data and hydrologic parameters are severely lacking. There are two main types of hydrologic models: simple models which only considers the water input and stream output and spatial models which consider the groundcovers such as vegetation. The latter is more complicated with higher accuracy and require advanced modeling software. Given the timespan of this study, only simple regression model was conducted.

The first case study is the Mission/Wagg creek which is two streams that drain a substantial portion of the city of north Vancouver as well as a small section of the district of north Vancouver. The Mission/Wagg creek system can be classified as an extensively urbanized area with more developments and redevelopments to take place in the future. The climate of southwest British

Columbia is generally maritime, typically wet and mild winters and dry and warm summers. The coast mountains cause most of the moisture carried from the ocean to precipitate. Cloudy wet weather predominates from October to April and is caused by strong frontal systems that originate in the North Pacific Ocean. Summer months rains are also caused by weak frontal storms. Runoff quantity and runoff quality are main concerns in the watershed regarding stormwater management as well as the drainage infrastructures.

The second study site is in Fishtrap Creek. Located in the Interior Plateau of British Columbia, the Fishtrap Creek is approximately 50 km north of Kamloops. Fishtrap Creek joins the North Thompson River just south of Barriere, as a tributary to the North Thompson River. The major land use of the Fishtrap Creek is mainly forest and harvest. Fire is the major concern in the watershed due to its largest spatial extent and hazardous influence. One of the severe fire in recent history for British Columbia, the McLure Fire, near Barriere B.C. burnt over 26,420 hectares in 2003 (Ministry of Forest and Range B.C., 2009). The 2003 McLure fire will be studied as an example to analyze the impact of wildfire.

To be more detailed, two goals shall be defined to characterize the vulnerability of the watershed (Nelitz et al., 2013). First is to measure the spatial and temporal changes in water quantity and quality under the exposure of climate change parameters. Second is to study how human communities and freshwater ecosystems within a watershed respond to climate-related stress and how to plan for it. For each watershed, it is expected to identify their values that can be put at risk by climate change, including their hydrology and geomorphology, water quantity, water quality, aquatic ecosystems and infrastructure. After the assessment, identifying implications for watershed and risk management processes would be suggested for watersheds of interest.

Methodology

To better visualize the relationship between climate change and watershed vulnerability, 2 case studies are selected: Mission Wagg Creek in North Vancouver and the Fishtrap Creek at Kamloops. Mission/Wagg Creek watershed is highly urbanized in the Greater Vancouver Area while the Fishtrap Creek is located in the McLure Forest with little human intervention.

The first step is to identify the conceptual framework for vulnerability assessment depending on the characteristics of watersheds. It is expected to obtain data from official platforms such as the Ministry of Environment's databases to gain basic hydrological and climatic information of the watersheds.

The second step is to evaluate the hydrologic variations and climate change for both watersheds individually. It is expected to identify the climate change and hydrologic changes separately and the find the connections between climate change and watershed performances. Historical and real-time climate and hydrologic data can be obtained from online platforms like Environment Canada and BC Water Tool. Platforms such as Plan2Adapt will provide information regarding future climate conditions. Visualization and comparison of the data will also be included. Qualitative assessment will be conducted by comparing the trends in selected parameters with supervision and guidance. For example, the semi-distributed storm water management model (SWMM) can be used for the Mission/Wagg Creek watershed. The last procedure in this step is linking the changes to the response in the water resource.

The third step is to assess the vulnerability in both watersheds using a literature-based class definition. Assuming mean annual flow is representative of water availability, the watershed will be considered vulnerable if flow value falls below historical values. A similar scheme will be applied to runoff and discharge. Water quality will be considered vulnerable if the values fall below government established standards for municipal and drinking water. After the assessment, I will provide implications for future management practices based on the dominant controls on vulnerability of local watersheds.

Results & Discussion

Mission/Wagg Creek

Climate Change Data

The climate change data of selected watersheds are obtained from the Climate Atlas of Canada, an interactive tool that contains temperature and precipitation data with mapping and images. The original data is collected analyzed by Pacific Climate Impacts Consortium using statistical models and techniques. To generate future climate scenarios, the most import inputs of Global Climate Models (GCM) is the concentration of greenhouse gases such as carbon dioxide, nitrous oxides and methane. Two carbon scenarios were used to simulate 24 GCMs: one high Representative Concentration Pathway (RCP) assumed GHG emission rate continue to increase at current rate and one low RCP assumed GHG emission rate will decrease drastically and be stable by the end of the century. The results were reported and analyzed as 10^{th} percentile, mean and 90^{th} percentile over the 1976-2005, 2021-2050 and 2051-2080 periods. Table 1 is the summary of climate change data in Vancouver.

Table 1 Climate projections for North Vancouver

Climate Atlas Report of Vancouver							
		RCP 4.5: Low Carbon Future			RCP 8.5: High Carbon Future		
Variable	Period	1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Precipitation (mm)	annual	1780	1831	1920	1780	1837	1865
Precipitation (mm)	spring	372	384	396	372	381	392
Precipitation (mm)	summer	201	190	181	201	186	178
Precipitation (mm)	fall	541	556	595	541	571	572
Precipitation (mm)	winter	666	700	750	666	700	721
Mean Temperature(°C)	annual	6.9	8.7	10.6	6.9	8.5	9.5
Mean Temperature (°C)	spring	5.8	7.6	9.3	5.8	7.4	8.4
Mean Temperature (°C)	summer	14.4	16.4	18.6	14.4	16.1	17.2
Mean Temperature (°C)	fall	7.3	9	10.8	7.3	8.7	9.6
Mean Temperature (°C)	winter	0	1.7	3.5	0	1.4	2.5

For North Vancouver, under both scenarios, although precipitation will increase annually, the seasonal variability is more drastic. The precipitation will decrease in the summer, yielding drier summers. Winter seasons will have the most amount of increase in precipitation at 5% while the precipitation will only decrease by 7% in the summer. Temperature wise, mean temperature will increase both annually and seasonally with an increasing amount of very hot days (>30 °C). For both high carbon and low carbon climate future, the number of very hot days double in the 2021-2050 period and triple in 2051-2080 period. The dates of last spring frost prepone and the dates of first fall frost postpone under both scenarios, resulting in longer frost-free seasons.

When studying the precipitation values in seasonal changes, the pattern is not uniform across the months. From the monthly total precipitation plot, it is obvious that the largest increases in winter precipitation are in December and January while July and August will have less precipitation over time. Such trend suggests longer and dryer summers and wetter winters for years to come. Two global climate patterns, the Pacific Decadal Oscillation and the El Nino-Southern Oscillation (ENSO), regulate the variability of precipitation in BC from year to year. ENSO would induce warmer and dryer summer and spring while PDO results in cooler and wetter spring and winter. The magnitudes and cycles of the two patterns will determine the climate changes in BC.

Precipitation will influence the availability and quality of water supply. Significant indicators of precipitation include maximum precipitation, snowpack and dry spells. Dry spells measure the number of consecutive days with precipitation less than 1mm daily, reflecting the stretch of dry days in a year. The historical average longest dry spell duration is 21 days while the number is expected to grow to 26 days by the 2050s and 29 days by the 2080s on average. According to the Climate Projection, for Metro Vancouver, snowpack will decrease over the winter and early spring. Compared to historical average winter snowpack depth of 266 cm, it is projected to have a 56% decrease by the 2050s and a 77% decrease by the 2080s, which will lead to significantly lower spring and summer snow levels.

Hydrologic Data

The most available data for the North Vancouver area is from BC Water Tool is located at Montroyal Boulevard. Climate data of Mackay Creek at Montroyal Boulevard is captured by Water Survey of Canada at station ID 08GA061. The drainage area is 3.63 km^2 and the mean annual discharge is 0.233 m^3/s. The gauging station has been collecting data since 1970 for the watershed. To show the impact of climate change on streamflow, seven-day flow data is plotted over time along with historical median. Although daily discharge varies, later years with higher temperature have larger streamflow during all year round with earlier freshets.

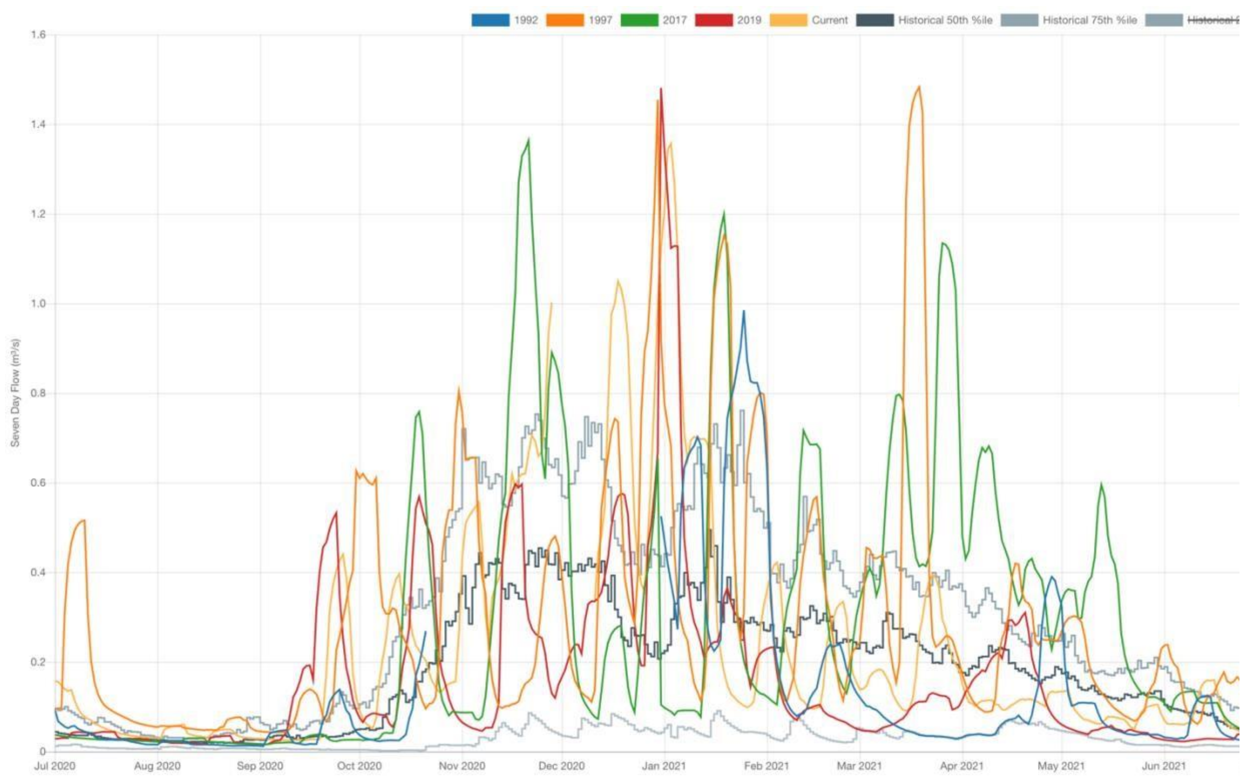

Figure 1 Seven-day flow for Mackay Creek in year 1992, 1997, 2017 and 2019 with historical values

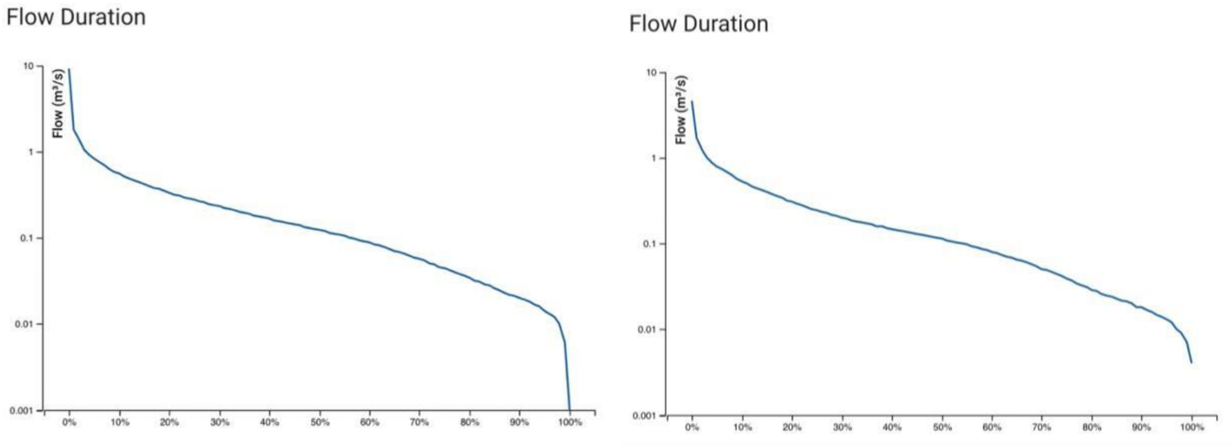

Figure 2 The flow duration curve between 1970-1999(left) and 2000-2017 (right) for the Mackay Creek watershed

Table 2 Historical median monthly flow of Mackay Creek ($m^{3/}s$)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970-2017	0.25	0.22	0.19	0.16	0.12	0.07	0.03	0.02	0.03	0.08	0.3	0.26
1970-2000	0.24	0.26	0.19	0.18	0.13	0.07	0.04	0.02	0.03	0.07	0.31	0.28
2000-2017	0.25	0.18	0.20	0.15	0.10	0.06	0.02	0.02	0.03	0.11	0.27	0.23

To study the impact of climate change, the data was divided into two periods: 1970-2000 and 2000-2017. It is obvious that warmer years have less monthly flow all year round, especially in the winter months such as December and February. The flow duration curves are also shown in figures 2, which are plots of discharge versus percent of time and the area under the curve represents the average daily flow. From the flow duration curves, we can deduct the ability and characteristics of the watershed to provide flows at varying levels. The upper region of the curve indicates the basin's flood regime whereas the lower region suggests the ability of the basin to sustain lower flows during dry seasons.

Water quality in Mission/Wagg Creek is closely monitored by the city of Metro Vancouver and enforced by Vancouver Coastal Health. According to the annual water quality report, water quality in the watershed is safe as drinking water tested on a biweekly basis by Metro Vancouver. Tests include parameters from microbiological, chemical and physical and radiological groups under the Guidelines for Canadian Drinking Water Quality Guidelines. Figure 3 summarizes the microbiological evidence, turbidity, Halo acetic acids, trihalomethanes and water temperature tests' results. It is obvious that all THM and HAA concentrations are substantially lower than the value suggested by the guideline with lowest values in the summer months. Turbidity is caused by rainfall events and are more stable nowadays because of universal filtrations in North Shore sources. In generally, the turbidity data falls below the allowable limits with exception from watermain replacement programs occasionally.

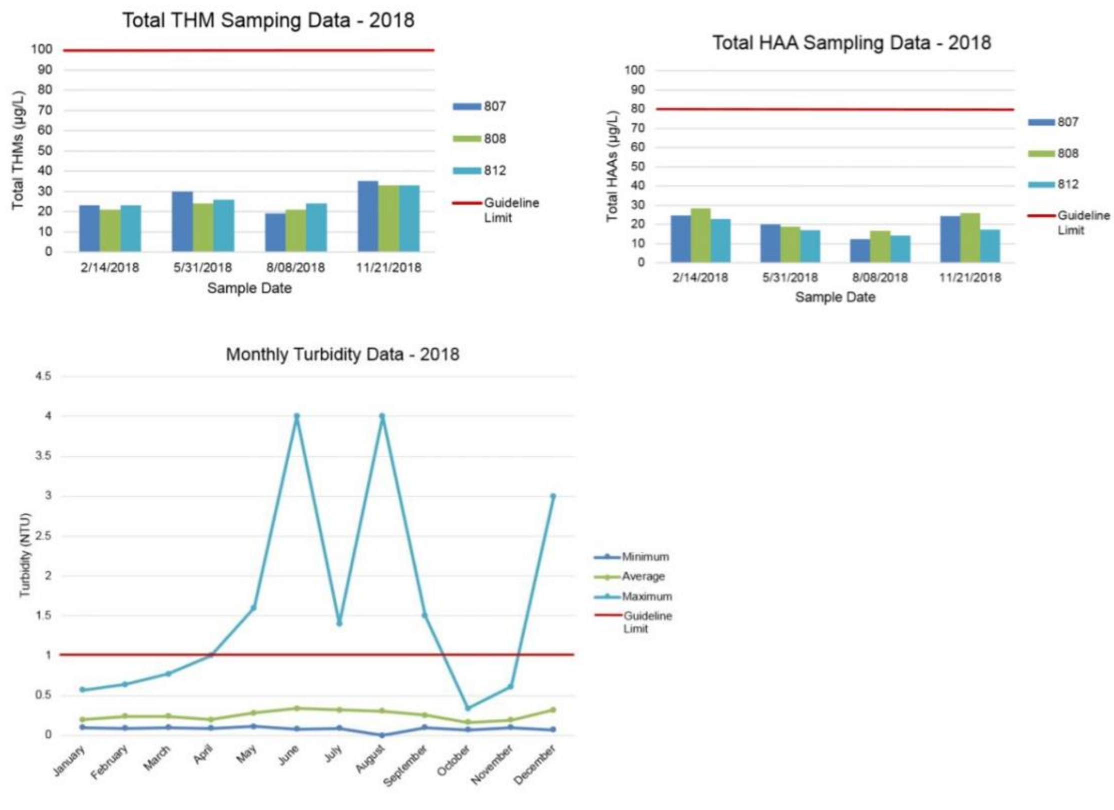

Figure 3 Water quality data in North Vancouver.

Discussion and Recommendations

As a result of climate change, the increase of methane, nitrous oxide, ozone and CFC will increase the atmospheric convective activity, enhancing the hydrological cycle and increasing short-duration rainfall intensity. Warmer atmospheres hold more moisture, leading to non-linear increase of water vapor in atmosphere. To be more accurate, 1 degree temperature rise can increase saturation vapor pressure over the sea by 10%, inducing more convection rain and short durations precipitation. Accordingly, non-convective activity will decrease, resulting in fewer large-scale stratiform rain and higher number of dry days and fewer light rainfall days (Whetton et al., 1993). In addition, shorter return period is expected for North America. Using Canadian Climate Center GCM (CCCGCM2), current return period of 20 years was reduced to approximately 1 in 10 years frequency (Zwiers and Kharin 1998).

Changes in variability and new frequency of extreme events increase in variability leads to bigger change in tail of the distribution. However, according to Karl and Knight (1998), from the results of Kendall’s t statistical test, no trend could be found in the time series of annual maximum daily precipitation. Lucero(1998) linear regression to investigate the evolution of time series of annual rainfall and maximum daily rainfall of two gauge stations.

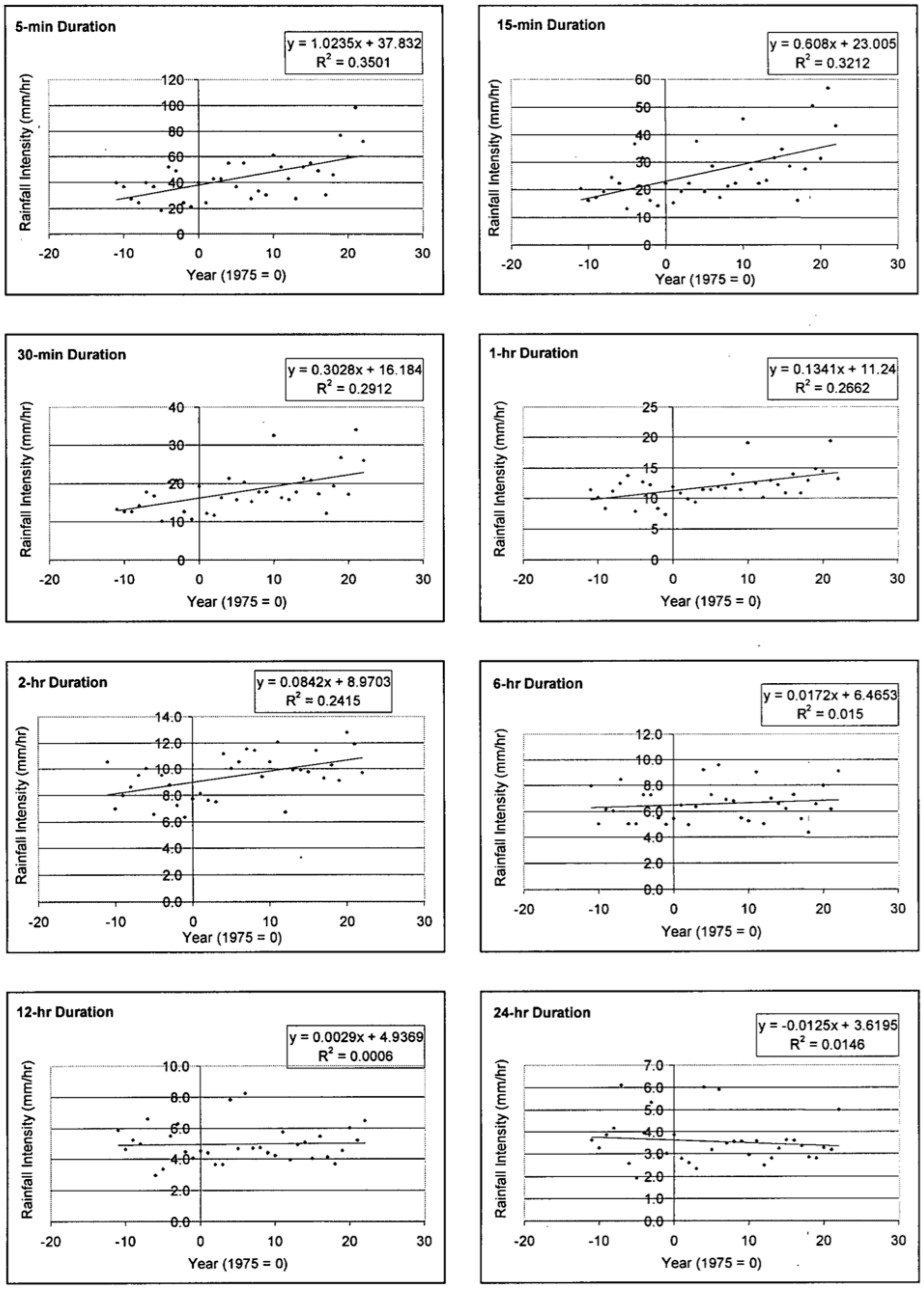

Figure 4 North Vancouver Short-Duration Rainfall Trends using linear regression models. The confidence levels of 5-minute, 15-minute, 30-minute, 1-hour and 2-hour duration trends are 95%. Source: KWL, 1999

For the design of urban infrastructure of North Vancouver, the rainfall design is based on the intensity, duration and return period. In the design, it is assumed that statistical parameters of hydrological variables remain constant over time; rainfall is a function of only time and has uniform distribution over entire catchment, ignoring spatial variability and storm movement. Kerr Wood Leidal(KWL) Associates designed a stormwater management strategy for the Mission/Wagg Creek in 1999, focusing on drainage system using SWMM model. The Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for individual or continuous simulations of runoff quantity and quality. According to EPA, it is mostly used to design and size of drainage system units and to control combined sewer overflows and sanitary sewer overflows. In addition, it can also model the inflow and infiltration within the sanitary sewer systems and map the floodplain of natural channel systems. The results from KWL study provides foundation for this project with design scheme and management recommendations.

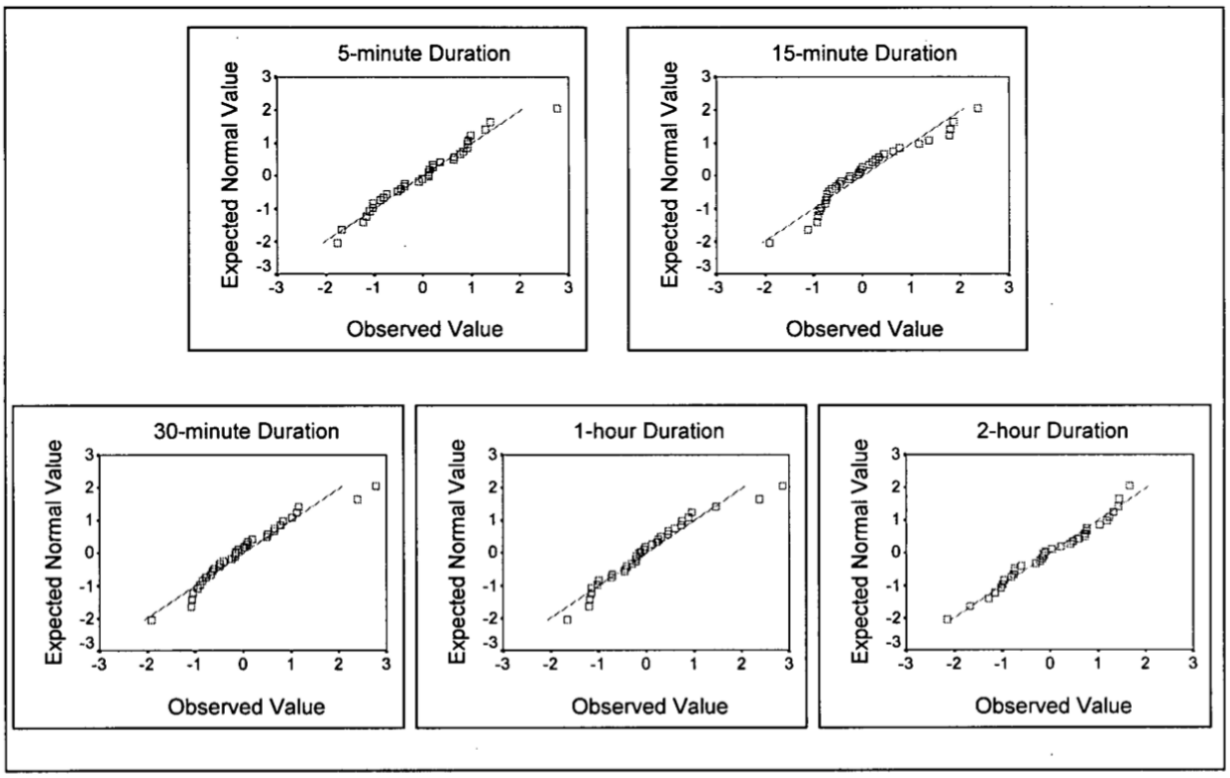

Figure 5 Standardized residuals of North Vancouver.

As a result of climate change, greenhouse gases will enhance the atmospheric vapor saturation and pressure and increasing short-duration rainfall intensity. In addition, shorter return period is expected for North America, current return period of 20 years was reduced to approximately 1 in 10 years frequency. To interpretate the precipitation data, Loukas and Quick(1996) determined uniform time distribution with least-square regression lines was appropriate for BC, excluding convective summer storms from 175 storms studied. From the SWMM model, 5-minute, 15-minute, 30-minute, 1-hour and 2-hour durations all show significantly increase trend at 95% level. 6-hr also increase but also at 95% level.

12-hr duration rainfall has a slope of almost zero while 24-hr duration is weakly decreasing. QQ plots verify that linear regression model can detect non-stationarities in the study. Non-parametric test would be more appropriate for testing samples without compliance to normal distribution requirements.

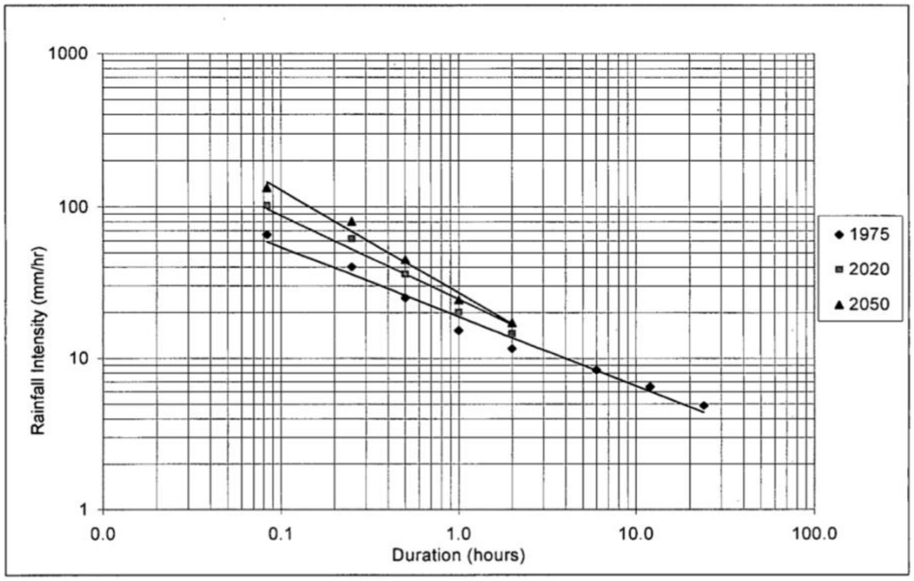

Figure 6 North Vancouver Present and Projected 10-year return period intensity-duration curves.

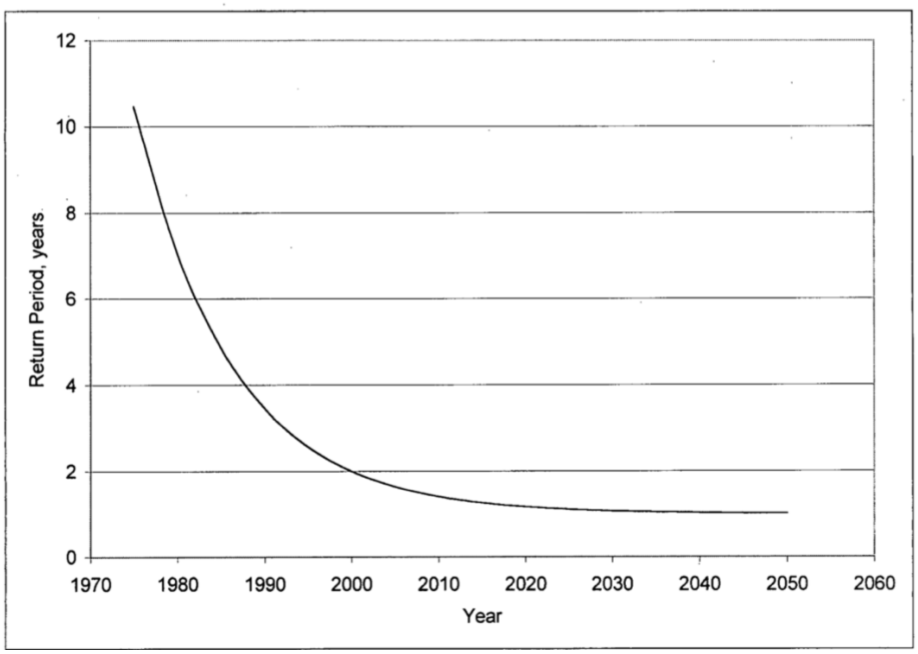

Figure 7 Return Period changes for a storm of intensity = 15.5 mm/hr and duration = 1hr.

From the IDF (intensity-duration-frequency) curves, the average storm recurs 1.5 years in 2020 and 1 year by 2050. It is necessary to upgrade surcharging major drainage sewers which were undersized. Culverts are the hydraulic structures which allow water to flow under artificial stream barriers such as roadways or embankments. In North Vancouver, its designed to handle 200-year peak flows. Two out of seven culvers in North Vancouver are considered inadequate with headwater level higher than road elevation. Such inadequacy may lead to flooding of the downstream streets and properties, even washing out of the roads in worst cases. To be more specific, from the results of SWMM simulation, 220 meters of the 15th street trunk sewer should be upgraded from 600 mm diameter to 750 mm and 120 meters along 23rd street need to be upgraded from 915 mm diameter to 1050 mm.

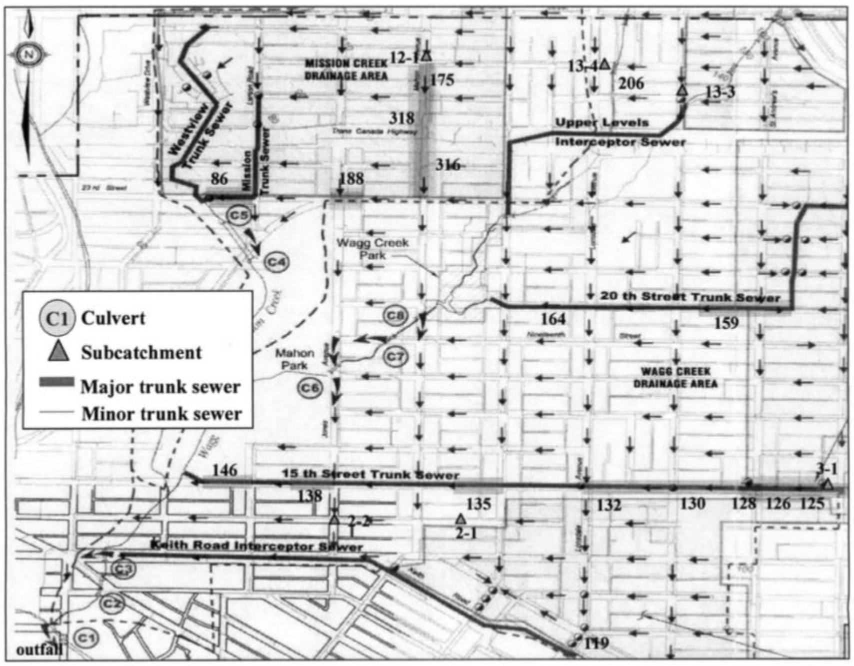

Figure 8 SWMM Results of Mission/Wagg creek. Source: KWL 1999

Climate change would only increase rainfall intensity which yields a marginal impact on the infrastructure, but the results are site-specific and cannot be used for other watersheds. Runoff amount generated by storm determines the infrastructure-upgrade plan and quantify environment impacts. For North Vancouver, no statistically significant trend can be observed. Due to time constraints, continuous simulation is not used. However, KWL (1999) conducted a 1-year continuous simulation with similar results from storm simulations. Runoff amount generated by storm determines the infrastructure-upgrade plan and quantify environment impacts. Calculated climate change equivalent TIAs. The present level of imperviousness would have to be reduced to 27% by 2020 and 18% by 2050. However, it is not achievable since current TIA is 44.5% and more developments are expected to happen in the future. In the future, it is recommended to encourage Best Management Practices to the averse the impacts. To be more specific, we need mitigation measures to manage stormwater runoff, including structural and non-structural strategies, replacing the water capacity of soil by paving pervious surfaces. Better infrastructure design requires detailed analysis of runoff mechanism of watershed. There exist no universal measures that can be applied to multiple watersheds, varying due to site constraints and non-structural strategies. Another possibility is to use computer models such as BMPSOFT to generate more cost-benefit analysis for each watershed.

Regarding the temperature changes, hot summer indicators and winter temperature indicators can help us identify the new normal for temperature in the watersheds of interest. For example, heating degree days is an indicator of number of days on which heating is required to compensate for the cold weather. Therefore, the fewer heating degree days, the less energy required for heating purposes. On the contrary, cooling degree days measures how hot it is and how hot days last. Historically, air conditioning system is rarely required in BC. However, the number of cooling degree days is projected to have a 380% increase by the 2050s and 784% increase by the 2080s, which is a significant departure from the past and creates huge energy demands for mechanical cooling in the summer. In addition, it might also pressure the design of current building, energy systems, heating, ventilation and air conditioning (HVAC) and related infrastructure.

As discussed above, SWMM model is only one of the numerous models that study vulnerability of watersheds and has its limitations. Its assumption on constant hydrological variables parameters may not hold in many cases since statistical models will likely change as climate changes and urbanization develops. There is also no consideration of spatial changes in the precipitation or runoff. It is possible that the data were collected as local maximum or minimum, inducing error in simulation results. SWMM model solves continuity equations and momentum equations in a simplified version in each conduit, assuming that friction force is balanced by gravity. Therefore, backwater effects, entrance/ exits losses and pressurized flow cannot be taken accounted for. Another limitation is that SWMM cannot be used with highly aggregated rainfall data, which is against the increasing trend of short-term rainfalls. It can only be used as an analysis tool but not an automated design tool for city planning. For instance, it is suggested to consider surrounding topography, location, and current structural condition of each culver, which is not considered in SWMM simulations.

New thresholds and occurrence of extreme weather events will pose challenges on local infrastructure such as drainage and stormwater infrastructure. Water supply and demand, sewage and drainage, ecosystems and agriculture, air quality and human health, building and energy systems and transportation, recreation and tourism are all impacted by climate change.

Fishtrap Creek

Climate Change Data

Table 3 Climate projections for Kamloops

Climate Atlas Report of Kamloops							
		RCP 4.5: Low Carbon Future			RCP 8.5: High Carbon Future		
Variable	Period	1976-2005	2021-2050	2051-2080	1976-2005	2021-2050	2051-2080
Precipitation (mm)	annual	306	321	325	306	321	340
Precipitation (mm)	spring	55	59	61	55	59	63
Precipitation (mm)	summer	92	91	88	92	93	92
Precipitation (mm)	fall	74	80	81	74	78	86
Precipitation (mm)	winter	85	91	94	85	91	99
Mean Temperature(°C)	annual	8	9.7	10.7	8	10	12
Mean Temperature (°C)	spring	8.5	10.3	11.4	8.5	10.6	12.4
Mean Temperature (°C)	summer	18.8	20.7	21.8	18.8	21	23.3
Mean Temperature (°C)	fall	7.7	9.1	10.1	7.7	9.4	11.3
Mean Temperature (°C)	winter	-3.2	-1.7	-0.5	-3.2	-1.4	0.5

Climate data of the Fishtrap Creek watershed are retrieved from BC Water Tool and documented by Environment Canada. The station is located near McLure with station ID 1165030 and elevation of 366 m. Climate data cover the span of 26 years with 4 years missing for temperatures and 1 year missing for precipitation. Percentages of possible observations are over 93 and 99 % respectively for temperature and precipitation. Hence, the data collected from the station are considered reliable. The historical data are available from 1967 to 2009. The nearest station that has up-to-date data is in Kamloops, which unfortunately is not representative of the Fishtrap Creek Watershed.

For Kamloops, the change in precipitation and temperature is slightly different due to the type of climate. The precipitation will increase annually and seasonally with minimal to no decrease in summer precipitation. Temperature and very hot days will increase under both scenarios and frost-free seasons will prolong as a result. The mean temperature will exceed 20 °C in the summer. In addition, tropical nights might appear which means the temperature will be higher than 20 °C at night. The 90th percentile generated by 24 models indicates 1 and 8 tropical nights in the 2021-2050 and 2051-2080 periods.

The climate of the Fishtrap Creek Watershed is semi-arid climate since it is in the rain shadow of the Coast Mountains. Winters are short cold in general with mean temperature of -4.5 ºC in January. Most summers are warm with mean temperature of 19.7 ºC in July and maximum temperatures exceeding 27.9 ºC. The watershed receives on average 439.4 mm of total annual precipitation, with 443.6 mm pre-fire and 408.6 mm post-fire respectively. Precipitations are relatively higher in summer and winter months due to convective thunderstorms in the summer and the clash of opposing warm and cold air masses in the winter. The maximum precipitation average is in June at 55 mm and lowest average precipitation is 23.4 mm in February. The maximum annual precipitation is in 1997 with a value of 618 mm and the lowest value is in 1973 of 220.2 mm. From stacked bar chart, it is obvious that the snow precipitation is less significant compared to rain precipitation in the past three decades with the deepest surface snow of 15.5 cm in 1993.

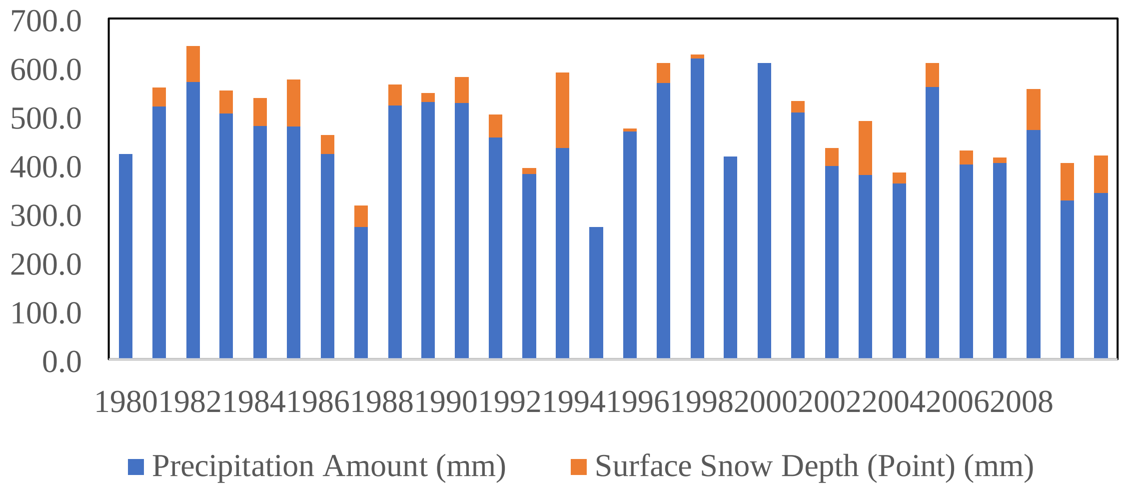

Figure 9 Stacked column figure of annual precipitation and surface snow depth

From 2000 to 2003, the annual precipitations are significantly smaller than previous years, which might have led to the fire combined with other climatic effects. After the fire, the interception of precipitation decreases, and the evapotranspiration of the vegetation and litter layer also decreases. Combined effect may lead to increase water yield according to Moody and Martin (2001).

Hydrologic Data

Hydrometric data of the Fishtrap Creek are obtained from the Water Survey of Canada website at gauging station (08LB024) near Westsyde Road. The gauging station has been reporting daily discharge values of Fishtrap Creek continuously since 1971. One exception period is from July 2003 to March 2004 since the McLure fire burnt the station, but it was rebuilt in March 2004 and collected data post-fire. The data from WSC include daily mean discharges from consistently recorded streamflow every 15 minutes. The gross drain area is around 135 km^2 at 1200 m above sea level. The data source is consistent and of high credibility and used for further analysis. The main incident happened in the Fishtrap Creek is the 2003 McLure forest fire, which posed significant impacts on the water quality and water quantity in the watershed because of both human intervene and climate changes. Therefore, some analysis on the data focus on the before and post fire changes.

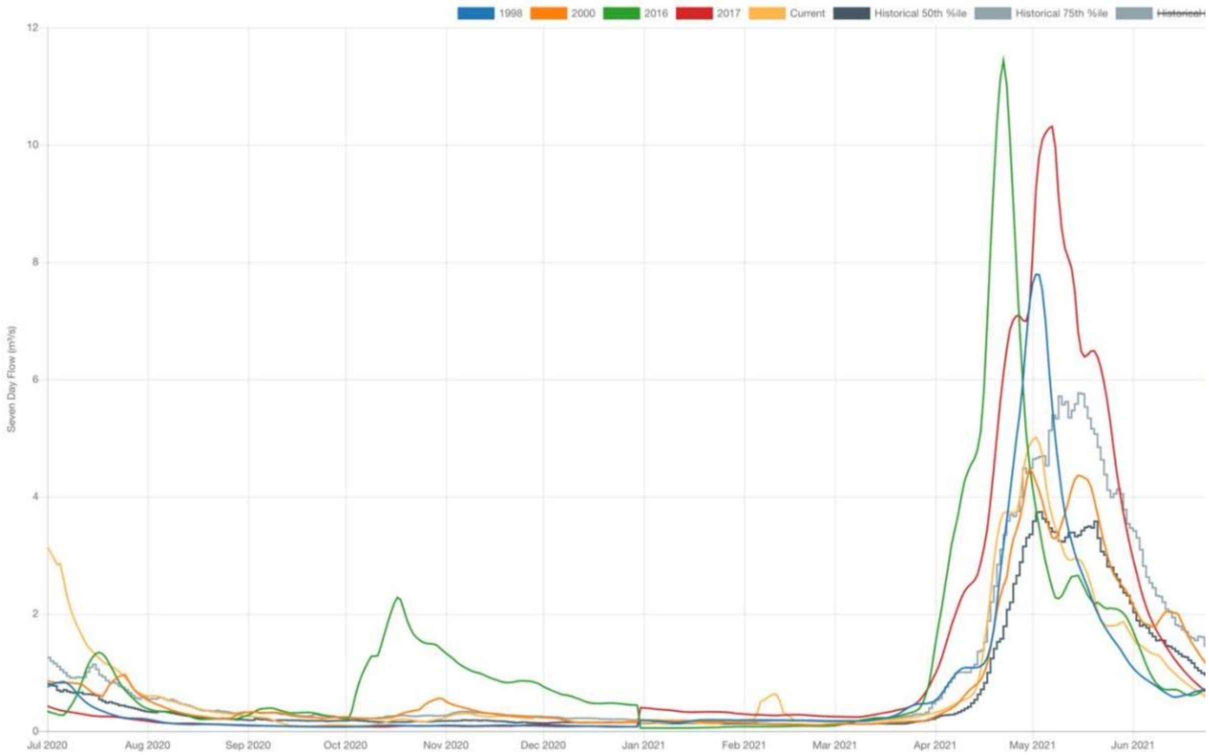

Figure 10 Freshet-season hydrographs of 7-day discharge.

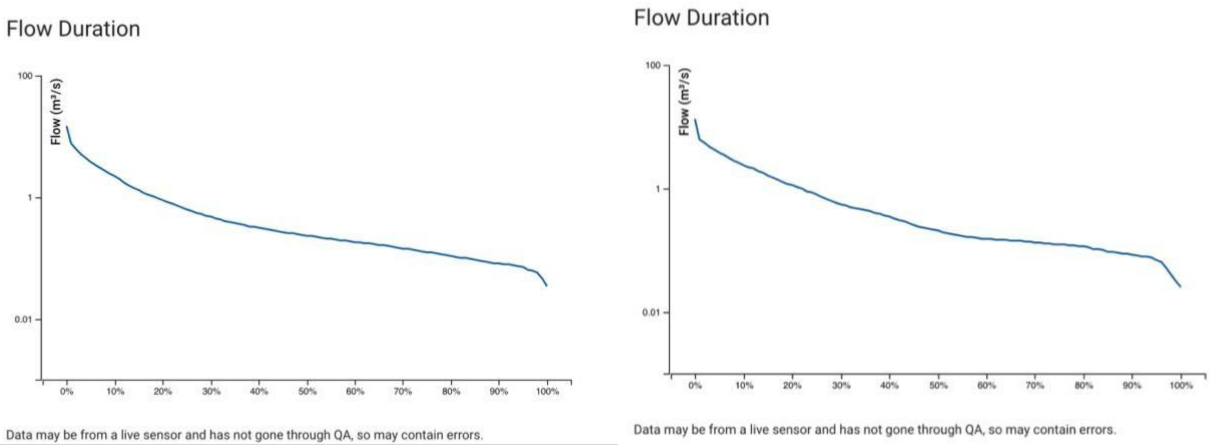

Figure11 The flow duration curve between 1970-1999(left) and 2000-2017 (right) for the Fishtrap watershed

Table 4 Historical median monthly flow of Fishtrap Creek ($m^{3/}s$)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970-2017	0.13	0.11	0.13	0.88	3.21	1.21	0.53	0.24	0.18	0.16	0.17	0.15
1970-2000	0.13	0.12	0.13	0.61	3.31	1.18	0.59	0.28	0.21	0.18	0.18	0.15
2000-2017	0.13	0.11	0.13	1.64	3.08	1.23	0.5	0.19	0.15	0.15	0.15	0.14

The highest instantaneous discharge value was recorded on May 15,1997 at 15.3m^3/s and the daily average maximum is 14.9 m^3/s. The lowest discharge occurred on May 14, 2001 with values of 3.13 m^3/s and 2.97 m^3/s for instantaneous and average daily discharges respectively. The long term mean daily discharge of the Fishtrap Creek Watershed is 7.53 m^3/s. A return period of approximately 5 years is observed for flows greater than 10 m^3/s.

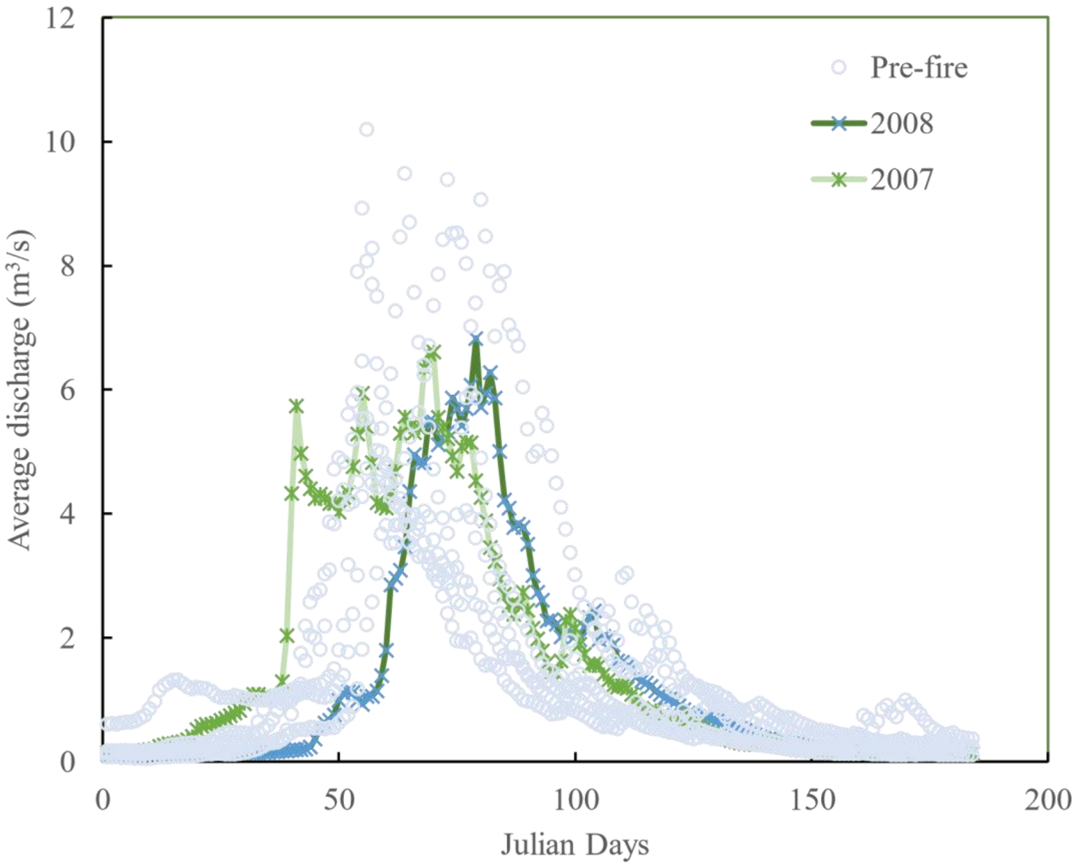

Figure 12 Freshet-season hydrographs of daily mean discharge. Pre-fire examples are in light blue and post fire years (2008 and 2007) are shown in markers connected by lines.

The timing and magnitudes of the peaks are shown in Figure 12. At Fishtrap Creek, no significant higher peak flow was observed after the fire. After the fire, maximum discharges occur two weeks earlier than pre-fire years. This phenomenon might be caused by the earlier time of the snow melt due to fewer vegetation disturbance (Silins et al., 2009). Pre-fire peak occurred during the month of May in general and mean date was May 15th. These observations are addressed in previous research as well. This might have resulted from the desynchronized snowmelt after the fire. According to Figure 12, multiple discharge peaks are observed in freshets while only one peak pre-fire. According to Eaton (2010), snow in the burnt and logged portions of the watershed melt earlier than that under undisturbed canopy in the fire.

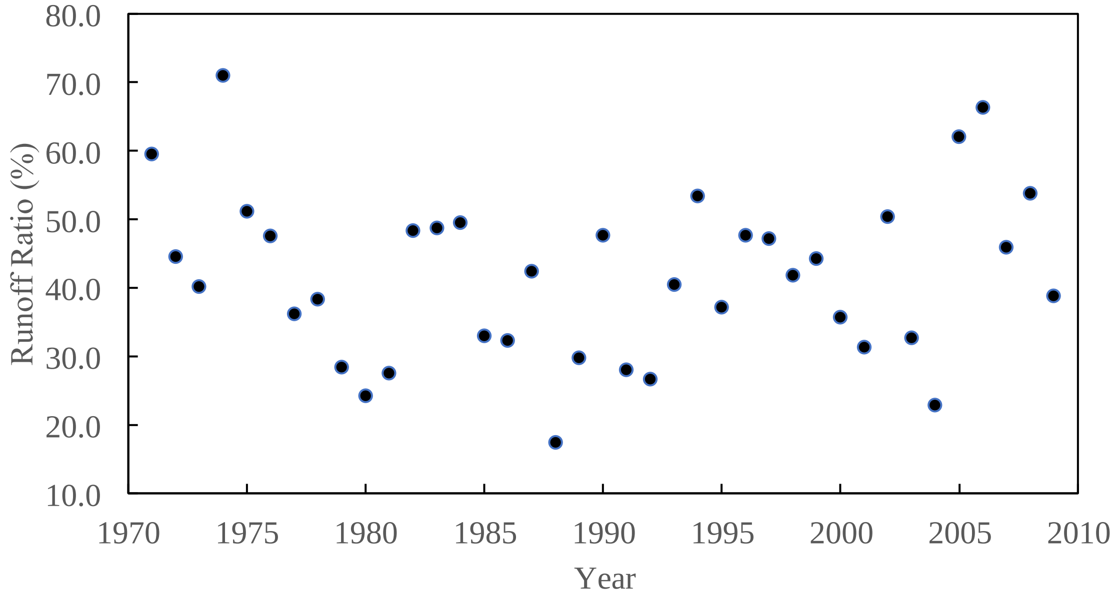

Figure 13 Scatter plot of runoff ratios versus year.

During the period of study, the average runoff ratio is 41.6% and the post-fire runoff coefficient is 46.0%. it is apparent that runoff increases after the fire due to logging activities in the areas that were burnt in the fire. According to Shakesby and Doerr (2006), fire might reduce infiltration of water and enhance soil water repellency, leading to an increase in runoff. To be more specific, they state that the highest runoff would occur the first year after the fire and drops sequentially. In the case of the Fishtrap Creek, the runoff ratio is 62% in 2005 and 63% in 2006, following the trend Shakesby and Doerr proposed. Research study of Moody and Martin (2001) also indicate that runoff would decline after the first couple years following the fire.

Table 5 summarizes the mean values of precipitation, discharge and runoff. The increased runoff ratios are consistent with decreased interceptions. However, there is no significant variation in discharge in post-fire years. According to Moore and Giles (2010), the morphology of stream channel change after the fire. The original morphology of the watershed is laterally stable plane-bed and after fire it becomes laterally active riffle-pool morphology with twice the width in some places. The fire damaged the internal stability of the watershed and steam boundaries, but the sediments supply to the Fishtrap Creek was not altered significantly with only increase from bank failures.

Table 5 Average values of precipitations, discharges and runoff ratios

Water Year Range	Precipitation Amount (mm)	Discharge (mm)	Runoff Ratio (%)
1971-2009	439.4	181.0	41.6
1971-2003	443.6	178.6	40.4
2004-2009	408.9	183.6	46.0

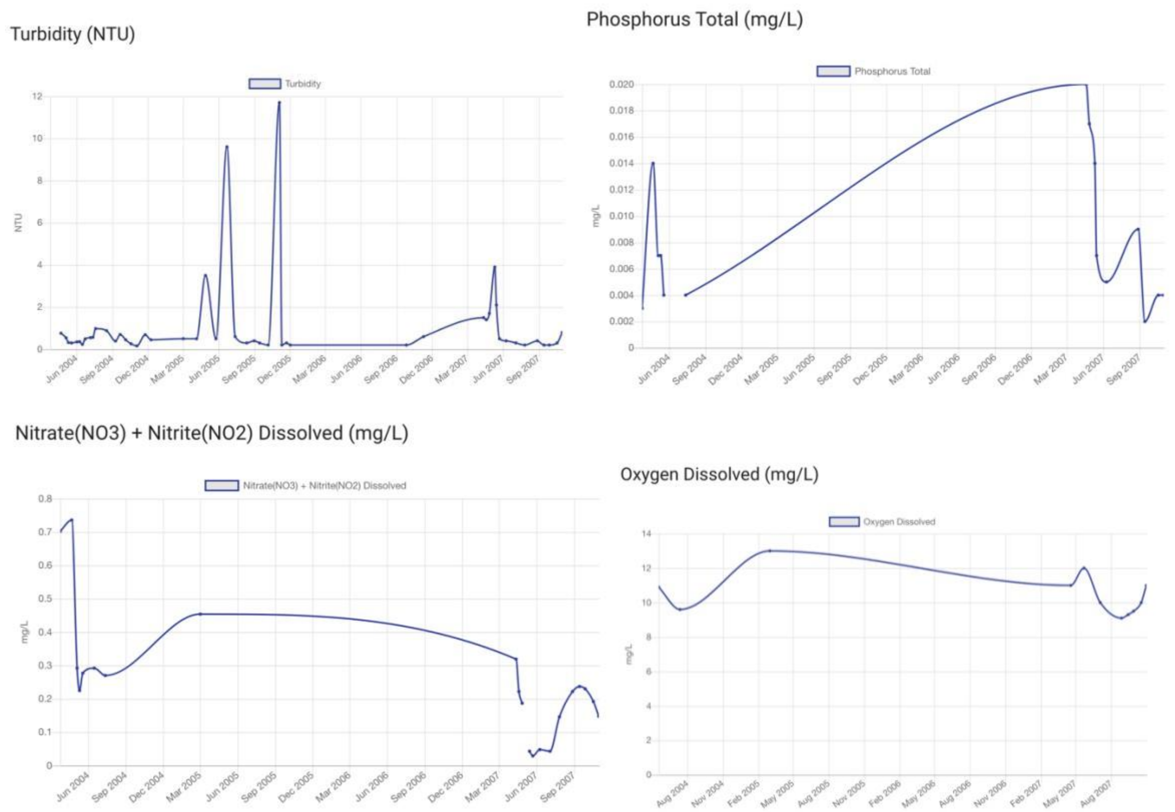

Figure 14 Post-fire turbidity, phosphorus, nitrogen and oxygen dissolved record (2004-2007)

Turbidity, a physical parameter, measures the clarity of the water and the concentration of suspended materials in the water such as soil particles, algae, microbes and other substances. The commonly used units for turbidity measured from a calibrated nephelometer are called Nephelometric Turbidity Units (NTU). In forest management, turbidity is important since harvesting and logging activities impact systematic erosion and sediment delivery directly. And turbidity reflects the changes effectively. For reference, many California watersheds monitor turbidity to assess management effectiveness and protect water quality (Harris, Sullivan, Cafferata, Munn and Faucher, 2007). From Figure 14, the turbidity is significantly higher in 2005 which might be caused by organic matter or inorganic particles. For raw drinking water without further treatment, the increase in turbidity from background should not exceed 1 NTU while the background should not be greater than 5 NTU. In the years following the fire, the water in the Fishtrap Creek shall not be considered a source of drinking water.

Nitrogen limits terrestrial and aquatic productivity. According to Meays (2009), the water quality guidelines for nitrate, nitrite and phosphorus are summarized in Table 6. From the data retrieved, the concentration for both nutrients are within the standards for freshwater aquatic life. However, the concentrations for nitrite are not separated and evaluated individually. In the Fishtrap

Creek, the pH is around 8 and ammonia won't be a major source of N since it is not stable in water when pH is less than 9. In addition, ammonium would be rapidly utilized in plants or fixed in soils and would be below detection limits.

Table 6 Standards of selected chemical parameters established by BC Ministry of Environment & Climate Change Strategy

Water Use	Nitrate (mg/L)	Nitrite (mg/L)	Total P(µg/L)
Drinking Water	10 (maximum)	1 (maximum)	10
Freshwater aquatic life	31.3(maximum)	0.06 (maximum)	n/a
Freshwater aquatic life	3(average)	0.02 (average)	5 -15

Dissolved oxygen measures the total amount of oxygen in the water through diffusion, aeration and photosynthesis. Dissolved oxygen is critical for most aquatic organisms and should be above critical values. According to BC aquatic life water quality guidelines, Long-term average for dissolved oxygen is 8 mg/L for all life stages and 11 mg/L for buried embryo and alevin. From figure 14, the dissolved oxygen concentration meets the standards for aquatic life following the fire.

Discussion and Recommendations

According to Canada's Changing Climate Report (CCCR2019), led by Environment and Climate Change Canada, the likelihood of some type of extreme events will increase due to anthropogenic climate changes. Both the frequency of intensity of extreme events will increase considerably due to both climate change and human activities brought by population growth. To be more specific, the extreme events include drought, flooding, cold and warm extremes, arctic sea ice and wildfires. For example, the intensity of the 2003 McLure Forest Fire was amplified by the dryer and hotter summer weather. However, it is hard to identify changes in daily and short-duration climate events due to their internal highly variable nature.

Climate changes won't directly cause wildfires, but they are highly linked to one another. The longer and drier summer will contribute to longer wildfire seasons as fire can only start and spread in a dry and hot weather. According to Flannigan(2017), there will be a 50% increase in the number of days with dry and windy environment which can start and spread the fire in the western Canada. First, the increasing temperature is making the environment more fire-prone, drying out vegetation more quickly and thoroughly. When vegetation that can withstand fire dry out, they become fuels for wildfires to consume, allowing more fires to start and spread further and wider.

The number of very hot days is critical when it comes to the start of a fire. Even with downpours or flooding, only a few hot days is sufficient to create fire conditions. For instance, the 2017 fire season in British Columbia followed a spring of rainstorms and floods. According to the ClimateAtlas of Canada's prediction, the forests will be more flammable across the country.

Another contributing factor to fire is lightning. More than half of forest fire are caused by lightning and unfortunately rising temperatures may lead to the development of lightning-producing storms. Based on the study of Natural Resources Canada, 80% increase in the lightning strikes is a conservative prediction by the end of the century. According to Canadian Council of Forest Ministers, 7000 forest fires was the average number since 1990 and the number might rise to 9,000 fires per year by the end of the century.

Although not discussed quantitatively in climate changes in Kamloops, wind is also an important indicator of climate change and as well as a determinant element in wildfire. Wind both spread the wildfires rapidly and hinders the putting out process. The rising temperature of the Arctic leads to drier and windier weather in southern Canada. As the Arctic warms up, the jet stream from the Arctic will slow down and meander in the south from the far north. Therefore, the weather would stay longer in the region. In the case of hot and dry weather, the chances of starting and spreading wildfires are drastically increased by the persistent weather conditions.

While land use, climate change and forest management affect wildfire risks, wildfires also influence the natural environment and health. As a natural part of ecosystems, wildfire produce greenhouse gases and aerosols and remove carbon from the atmosphere by plants, resulting in a net neutral impact on climate carbon emission. However, if the fires burn more frequently, the greenhouse emitted during the burning processes cannot be removed from the atmosphere sufficiently since plants cannot grow to maturity before wildfires. With more people relocating to wild lands, the life, property and health of the public is also put at risks. Smokes can lead to eye and respiratory illness. The short-term influence on water quality is discussed above, damaging the health of the ecosystem and aquatic life.

It is important for the Fishtrap Creek to build fire resilience facing the irreversible trend of increasing wildfire hazards. Similar to the 2003 McLure fire, both water quality, quantity and ecosystem will be negatively influenced by wildfires in the future. To reduce the likelihood and impacts of forest wildfires, more consideration should be given when developing residential areas near fire-prone forests. For example, the space between structures and nearby tress should be increased; new developments should incorporate fire-resistant features and materials; the resources allocated to firefighting and prevention should also be increased.

CONCLUSIONS

To summarize, the main climate changes to expect in both watersheds are increasing temperatures, decreases in snowpack, longer summer month, more precipitation in fall, winter and spring seasons and more intense extreme events. Climate change will have various impacts in local

BC watersheds on multiple scales. Larger temperature difference between daytime and nighttime will result in heavier precipitation in the winter months as well as stronger snowpack. Hence, drier and warmer summer along with reduction in summer snowpack will lead to insufficient supply of water in summer.

For the Mission/Wagg creek, the main impact of climate change is the burden on the sewerage and drainage systems, especially caused by extreme short-duration rainfalls. The unexpected frequency and intensity of extreme events might exceed the original designing plan. Flooding, damaging to infrastructure and property and human health will be under great if the current sewerage and drainage systems fail. To be more detailed, the storm sewers might overflow during extremely intense rainfalls since combined sewers will be overload and directly discharge into the nearest water body with diminished treatment efficiency.

For the Fishtrap Creek, the main concern regarding its land use and climate change is the fire hazards. The combined variations in both precipitation and temperature increase the risk of extreme wildfires and the evolvement in the future. According to CCCR2019, the Canadian Forest Fire Weather Index System characterizes fire risk utilizing data gathered daily. The larger the FWI indices values, the increasing likelihood and potential of hazardous wildfire. Based on the study of Flannigan et al., (2019), both FWI indices and fire season will increase due to higher temperature and less precipitation in the future. For the future planning of the watershed, it is important to focus on strengthening the fire resilience through comprehensive wildfire protection plans.

RECOMMENDATIONS

Due to the limitation of time, the quantification of hydrologic response of selected watersheds to changing climate may not be fully available. However, quantifying the changes and vulnerability is essential for decision makers to guide the modelling process for future management. In the future, it is recommended to quantify the response and response, to apply more advanced models and algorithms such as exploratory modelling to assess more accurate response to better protect the economic and ecologic health of watersheds. In the future, a proper model can be selected for the Fishtrap Creek with sufficient guidance. For instance, as discussed in the study of Deshmukh and Singh (2016), hydrologic models can quantify the vulnerability using established facts. They applied the exploratory modelling framework to determine maximum tolerance for selected hydrologic indicators using the CART (classification and regression trees) algorithm. Other potentially useful models include CLASS (Canadian Land Surface Scheme), CRHM (Cold Regions Hydrology Model), PLAN2ADAPT, etc, A detailed list of tools for climate change vulnerability can be found in the study of Nelitz et al. (2013, p.92-100). It is feasible to quantify the vulnerability using a similar modelling approach.

Although there are no universal tools that can be applied to all watersheds, it is still worth studying the climate change impacts on individual watersheds to better manage the resources in the region and prepare for future development. The climate change is the inevitable future, but the pace of change can be slowed by joint effort of mankind. Another limitation of this study comes from the variability of the climate change projections. As discussed previously, the numbers used in this study is the average or mean values generated by 24 Global Climate Models with different input and assumptions. The most common assumption is that GHG emission rate will continue to increase at current speed or even faster. The Representative Concentration Pathway is conservatively assumed to be 8.5 but it's not impossible to achieve a lower GHG emission or even zero net carbon emission in the future. While it is important to consider and plan under worst case scenarios, it's equally valuable to reverse or slow down climate change when it's still feasible.

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