Ernst Kerhoven, July 2014

Wapiti River Watershed Climate Change Assessment

Introduction

Several datasets were used in this study to assess historical trends and future climate projections for temperature, precipitation, and river flow in the Wapiti River Basin. Environment Canada's CanGrid dataset provides monthly temperature and precipitation data at a 50 km grid scale over most of Canada from 1900 to 2009. This data was used to analyze historical trends in temperature and precipitation in the Wapiti River Basin. Mbogga et al. (2009) developed downscaled meteorological data for the Canadian Prairie Provinces (ClimatePP) for five 30-year time periods, two historical: 1961-1990 and 1971-2000, and three future projection periods: 2010-2039, 2040-2069, and 2070-2099. Future projections for six climate scenarios for the Wapiti River Basin were accessed from the Pacific Climate Impacts Consortium (PCIC) website: HAD A1B, CGCM34 A2, CGCM35 A2, HAD A2, ECHAM B1, MRI B1, and HAD A1B. River flow data from the Water Survey of Canada (WSC) hydrometric station Wapiti River near Grande Prairie (07GB001) was used for analyzing historical river flows. No hydrologic studies on potential impacts of climate change on river flows in the Wapiti River Basin have been conducted; however, Schnorbus et al. (2011) conducted a high quality assessment of potential impacts of climate change on the Upper Peace River Basin. This study includes projections for the Pine River, the headwaters of which are in the same mountains as the headwaters of the Wapiti River. The Pine River and the mountainous region of the upper Wapiti River (which is the source of 80% of the Wapiti River's flow) have very similar hydrologic behavior in terms of annual flow volumes per square kilometre (Figure 1) and the seasonal variation of their hydrographs (Figure 2). The projected changes in flow for the Pine River from Schnorbus et al. (2011) therefore provide a reasonable guide to the likely change of flow for the Wapiti River.

Temperature Trends and IPCC Projections

Figure 3 shows the historical average temperatures in the Wapiti River Basin from Environment Canada's CanGrid dataset (black dots), the ClimatePP historical normals (green dots), and the ClimatePP projected climate change scenarios (red dots). The solid line indicates the long term trend of the CanGrid data, while the dashed lines indicate the range within which 95% of the annual data is expected to occur. The historical temperature trend from 1900 to 2009 is +1.76, plus or minus 0.73, degrees Celsius per century. The probability that a stable climate would produce a trend of this size by random chance alone is 1.5×10^{-6} ($+1.76 \pm 0.73$ ^{o}C/100yr, $p = 1.5 \times 10^{-6}$). All trends in this study were evaluated with a two-tailed least-squares trend test, adjusted for serial co-relation using the effective sample size method. Trends are usually considered statistically significant when the "p-value" is less than 0.05. The temperature trend in the Wapiti River Basin is therefore statistically extremely significant. The ClimatePP projections for future climate show that this trend can be expected to continue through the rest of the 21st century, with some potential for acceleration in the latter half of the century. By the end of the century, four of the six projections show average temperatures being higher than the warmest year on record (1944).

Figures 4, 5, 6, and 7 are similar to Figure 3, except they show the seasonal temperature trends and projections: Winter (December to February), Spring (March to May), Summer (June to August), and Autumn (September to November). The seasonal figures are also as change in temperature with respect to the 1961 to 1990 average temperature for the CanGrid data. The seasonal trends are highly significant, except for the autumn season. The winter trend is +2.68 ± 2.08 ^{o}C/100yr, p =0.01, the spring trend is +1.68 ± 1.24 ^{o}C/100yr, p =0.0065, the summer trend is +1.76 ± 0.52 ^{o}C/100yr, p =1.4 x 10^{-11}, and the autumn trend is +0.85 ± 1.22 ^{o}C/100yr, p =0.16. The projections are largely consistent with these trends, although summer temperatures are expected to accelerate in the latter half of the 21st century (Figure 6).

Precipitation Trends and IPCC Projections

Figure 8 shows the historical and projected precipitation in the Wapiti River basin as percent difference with respect to the 1961 to 1990 baseline. The historical CanGrid data shows a statistically non-significant increasing trend (+9.0 ± 13.7 %/100yr, p = 0.19), as with the temperature data, the future climate projections are largely consistent with this historical trend, although most of the projections predict some acceleration in the latter half of the 21st century (3 of 6 scenarios are well above the extrapolated trend line, while the other three are all clustered near the trend line).

Figures 9 and 10 show the historical and projected changes in rainfall and snowfall, respectively. Almost the entire increasing trend in annual precipitation is due to increases in rainfall. From 1900 to 2009, rainfall has increased with a statistically non-significant trend of (+10.5 ± 15.1 %/100yr, p = 0.15) while snowfall has essentially no trend (+0.2 ± 19.8 %/100yr, p = 0.99). The rainfall trend is largely consistent with the ClimatePP projections with some acceleration (Figure 9, most of the red dots lie above the extrapolated solid trend line, but well below the upper dashed line). The snowfall trend is also consistent with the ClimatePP projections (Figure 10).

Stream Flow

Stream flow trends and projections are more difficult to assess than for temperature and precipitation because long-term data sets of 100 years or more are rare in Western Canada. Flow data for the Wapiti River near Grande Prairie is available from 1961 to 2010, which is one of the longer continuous records in Northern Alberta. Figure 11 shows the historically observed annual flows in the Wapiti River (black dots). Over this period, flows have decreased with a statistically significant trend (-43.0 ± 31.2 %/100yr, p = 0.04). This indicates a rapid rate of decline that is not consistent with Climate Change projections from the PCIC climate change simulations for the Upper Peace River Basin, which is expected to undergo similar changes in temperature and precipitation as the Wapiti River Basin (2040-2069 mean annual changes from 1961-1990 baseline, Peace River Basin: +2.4 ^{o}C and +12% precipitation, Wapiti River Basin: +2.3 ^{o}C and +5% precipitation).

In the Wapiti River Basin, over the period 1961 to 2009, rain and snow have both declined at a rate that is not consistent with the long term trend for the 20th century. Annual rainfall has been decreasing very slowly (-0.4 ± 48.0 %/100yr, p = 0.87) rather than increasing, and snowfall has declined rapidly (-52.3 ± 30.9 %/100yr, p = 0.02) rather than remaining stable. This departure from the long-term trend is most likely due long-term ocean circulation patterns, such as the Pacific Decadal Oscillation (PDO), which is known to regulate the supply of moisture from the Pacific Ocean to Alberta over periods of many decades. PDO was in a cool/wet phase for most of the 1960s and 1970s, and in a warm/dry phase in the 1990s and 2000s. PDO has been observed to have varied between wet and dry cycles across the 20th century and long term-cycles are a fundamental source of bias in trend estimates from observed data. To reduce this bias, the flow record of the Wapiti River was extended to the CanGrid data period with the following simple annual flow model:

$$Q_i = 0.189Q_{i-1} + 0.348P_s + 0.193P_R - 3.07T - 26.8$$

Where Q is the annual flow in year 'i' in m^3/s, P_R and P_S are the CanGrid annual rainfall and snowfall in mm for year 'i', and T is the mean annual temperature degrees Celsius in year 'i'. This equation was used to produce a "Simple Model" time series of annual Wapiti River flows near Grande Prairie based on observed CanGrid data (blue dots in Figure 11).

Although the Simple Model cannot reproduce the detailed yearly variation of observed annual flows in the Wapiti River, it does do a good job of reproducing the trend and range of year-to-year variation in flow (Figure 11, compare the purple and black lines from 1961 to 2009; Figure 12, compare the 10 year moving averages for the observed and modelled data). This provides some confidence that the trend and range of year-to-year variation of the extended series is representative of what has occurred in the Wapiti River over the 20th century.

The long term trend from the Simple Model, the ClimatePP Climate Change Scenarios (based on the Simple Model and the ClimatePP projections for annual rain, snow, and temperature), and the PCIC Upper Peace River projections translated to the Wapiti River Basin all provide consistent predictions: a slight increasing trend, with a continued wide range of annual variation. The principal uncertainty is snowfall. For the most part, increased evaporative losses due to increased temperatures are expected to be offset by increased rainfall leaving changes in annual flow to be largely determined by changes in snowfall (compare the red dots in Figure 10 with those in Figure 11).

Conclusions

Historical trends in temperature, precipitation, and stream flow in the Wapiti River basin were compared with future climate change projections from General Circulation Models (GCMs). The Wapiti River Basin has undergone significant warming and a slight increase in precipitation over the past 100 years, although precipitation (particularly snowfall) has decreased since the 1970s. GCM projections predict that 21st century temperature and precipitation are expected to follow closer to the long-term century long trend rather than the more recent trends since the 1970s. Stream flow trends have largely followed the long term trends in temperature, rainfall, and snowfall and are expected to continue to do so in the 21st century. Long-term average flows over periods of 30 years) are expected to remain within the range of historical annual variation for the 21st century, however by the end of the century the large range of uncertainty of future snowfall produces a large range of uncertainty in future river flows. For the next 30 years, river flows are expected to remain more or less in the same range as they have for the past 50 years.

This analysis is based on historic temperature, precipitation, and stream flow data; a very simple empirical hydrologic model; and sophisticated hydrologic modelling results from a nearby basin. The information in this report represents the most that can be provided without conducting a watershed specific modelling exercise similar to Schnorbus et al. (2011).

References

Mbogga, M., Hamann, A. and T. L. Wang. 2009. Historical and projected climate data for natural resource management in western Canada. Agricultural and Forest Meteorology 149: 881-890.

Schnorbus, M.A., K.E. Bennett, A.T. Werner and A.J. Berland, 2011: Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada. Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 157 pp.

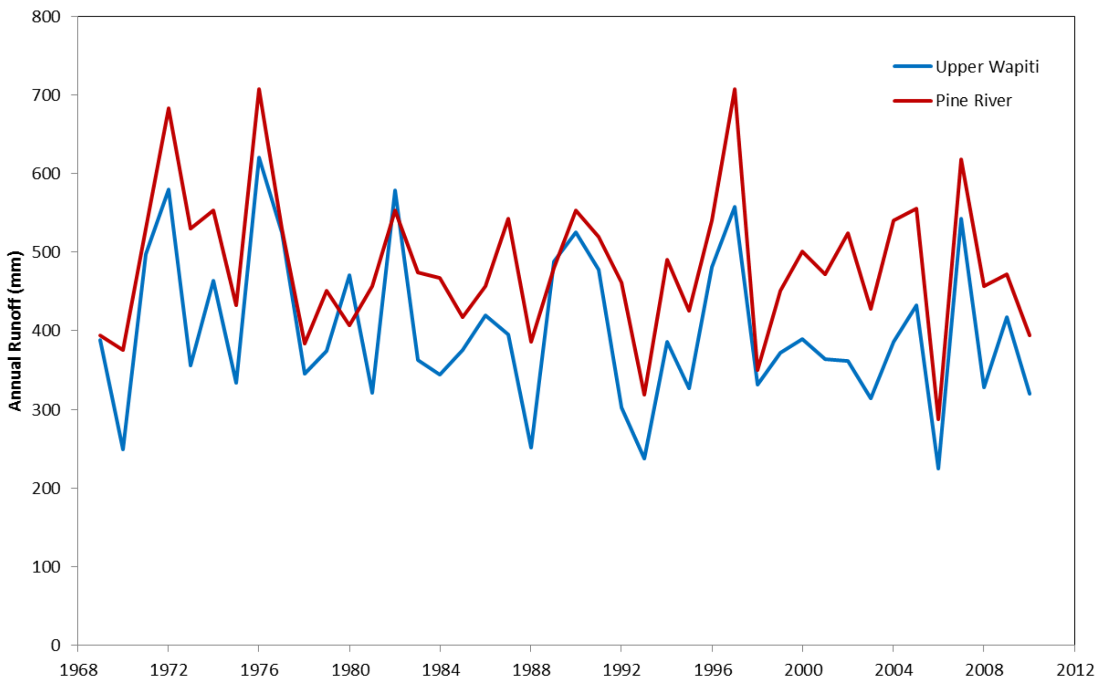

Figure 1 – Average annual runoff depths for the Upper Wapiti (above Pinto Creek) and Pine River watersheds.

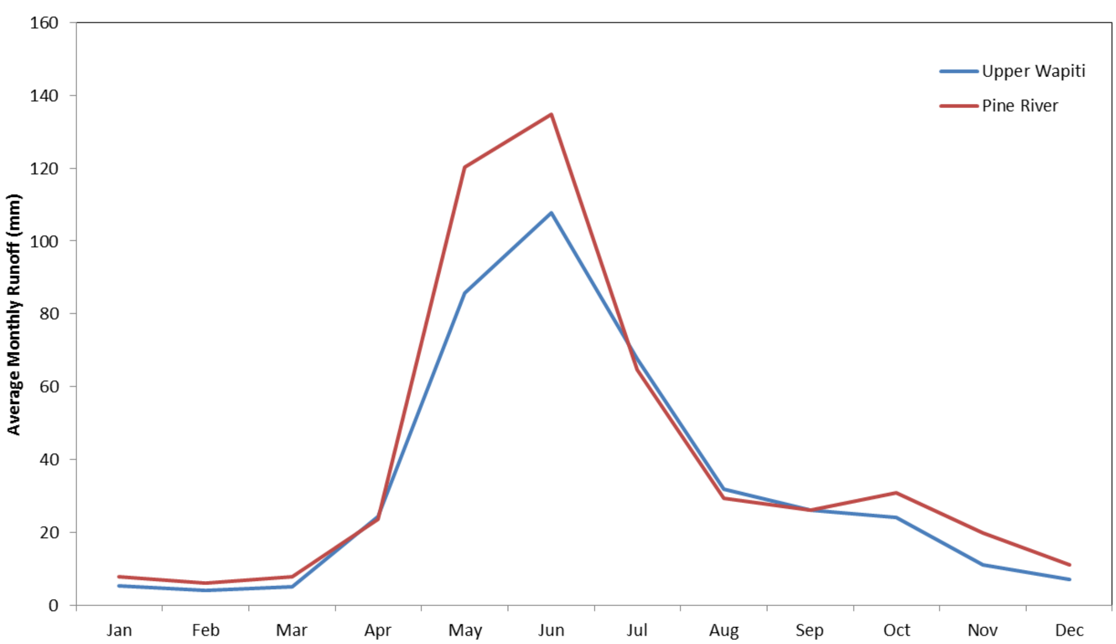

Figure 2 – Average monthly runoff depths for the Upper Wapiti (above Pinto Creek) and Pine River watersheds.

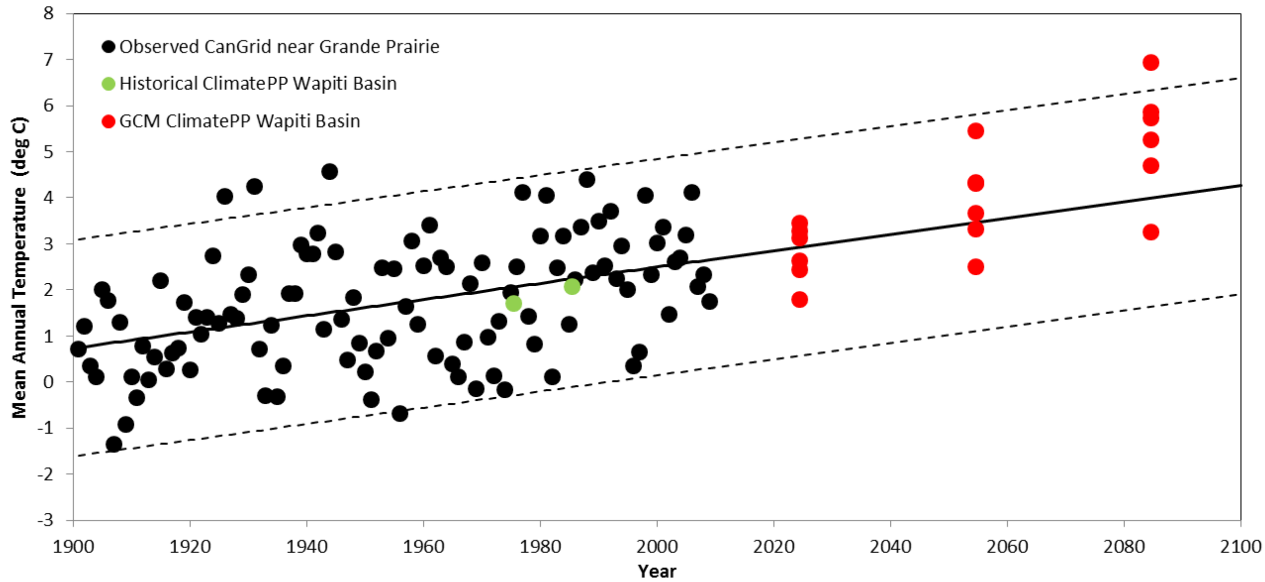

Figure 3 – Annual Temperature trends and Climate Change projections in the Wapiti River Basin. Black dots are Environment Canada (CanGrid data), green dots are 30-year averages from the ClimatePP database, and red dots are for six ClimatePP 30-year projections. The solid line represents the historical trend and the dotted lines represent the two standard deviation range of annual variability about the trend.

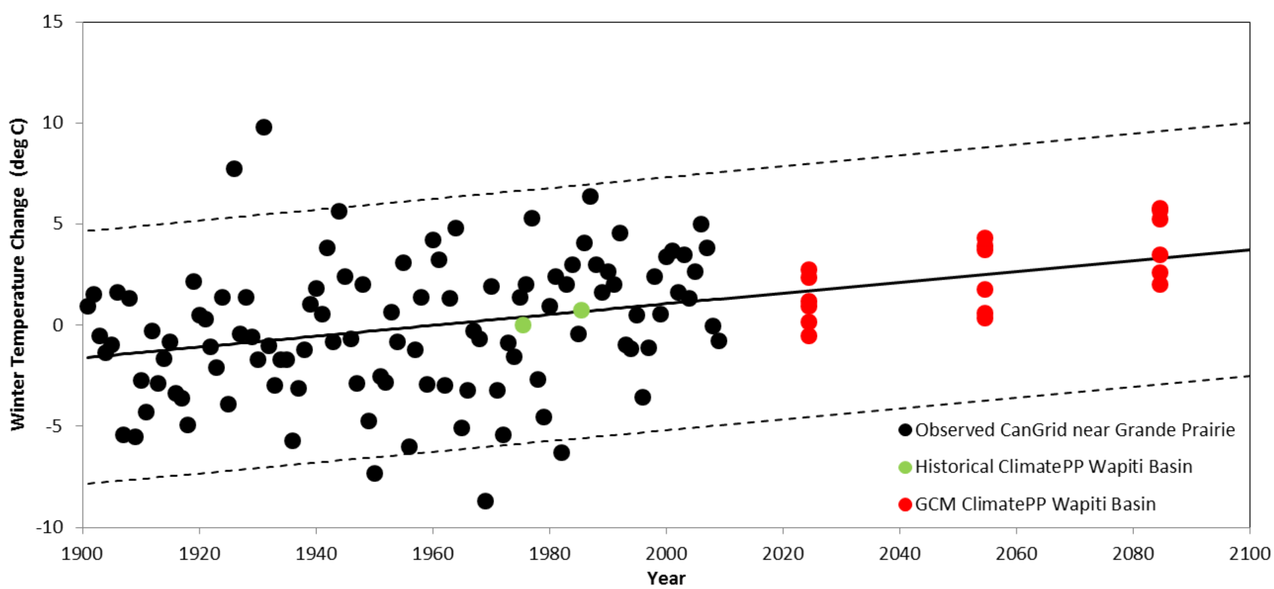

Figure 4 – Winter Temperature trends and Climate Change projections in the Wapiti River Basin

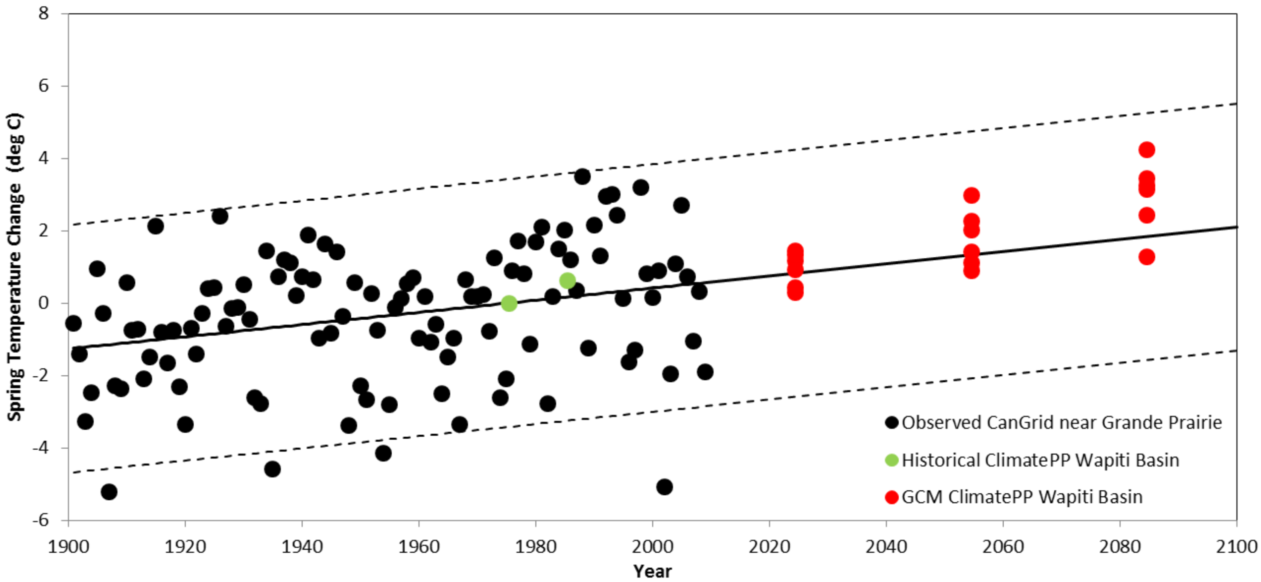

Figure 5 – Spring Temperature trends and Climate Change projections in the Wapiti River Basin

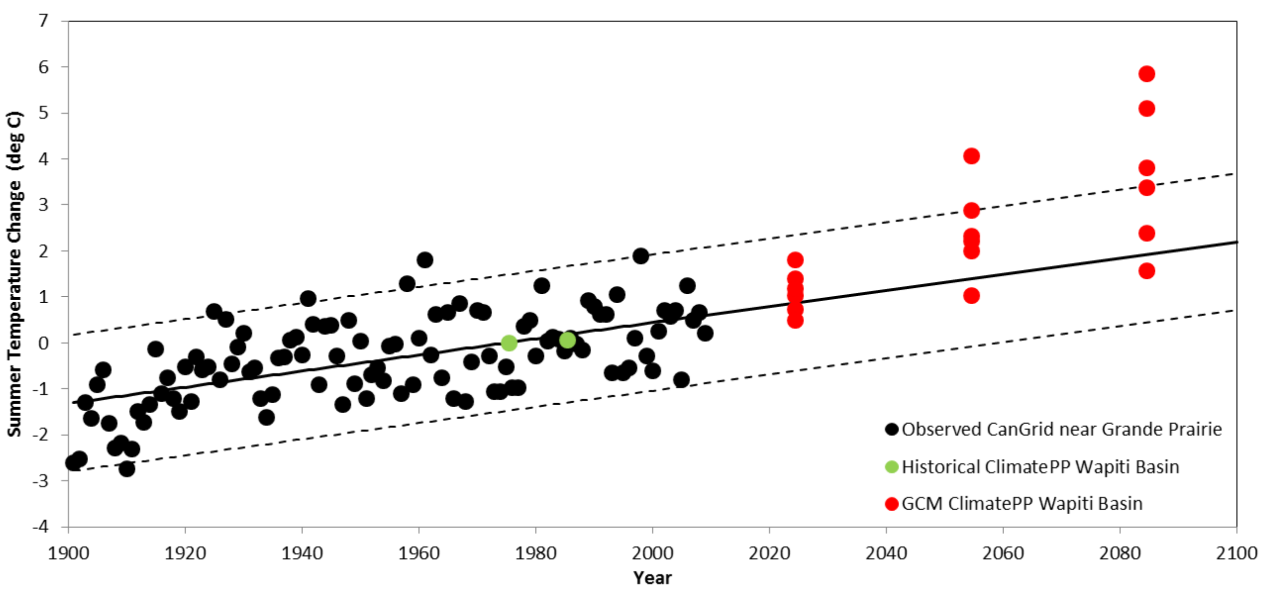

Figure 6 – Summer Temperature trends and Climate Change projections in the Wapiti River Basin

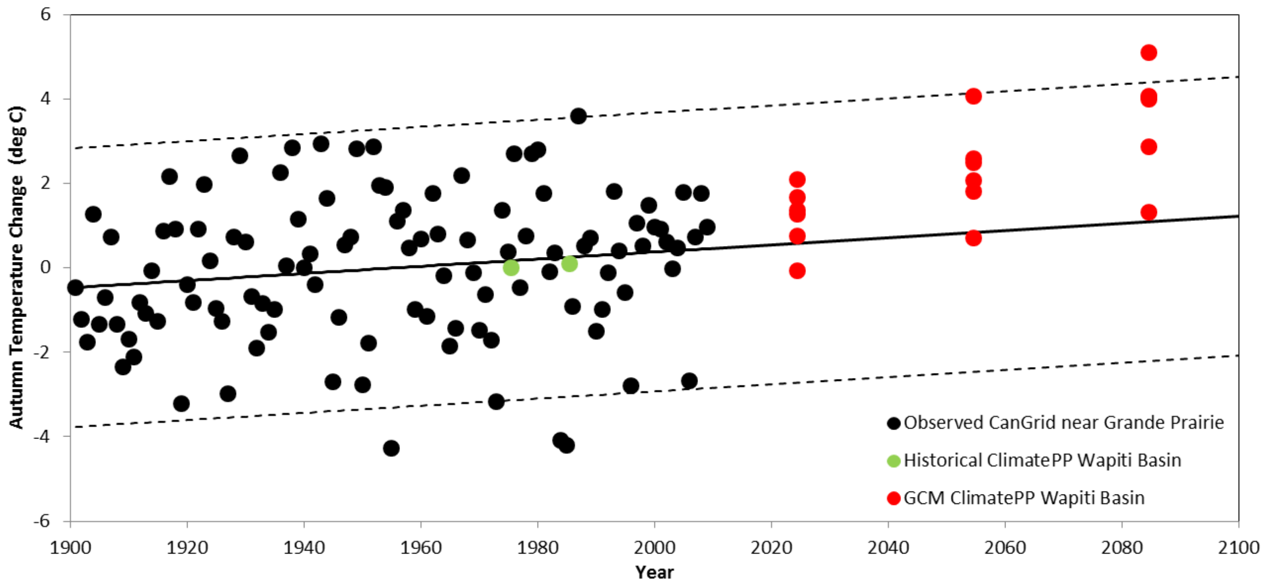

Figure 7 – Autumn Temperature trends and Climate Change projections in the Wapiti River Basin

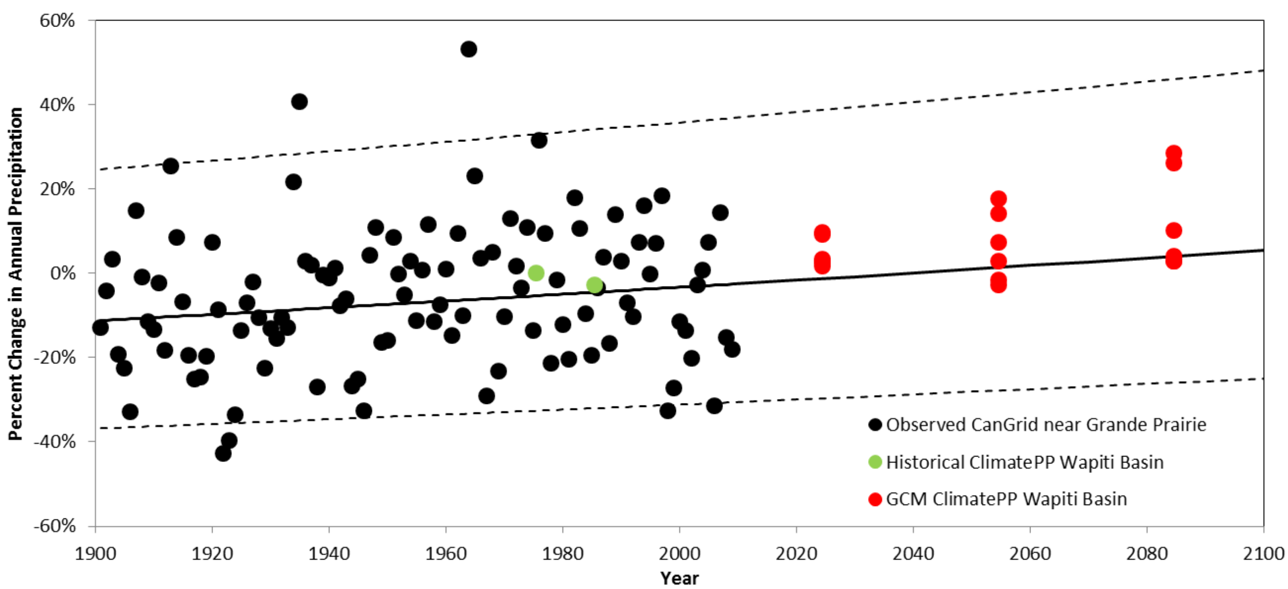

Figure 8 – Annual Precipitation trends and Climate Change projections in the Wapiti River Basin

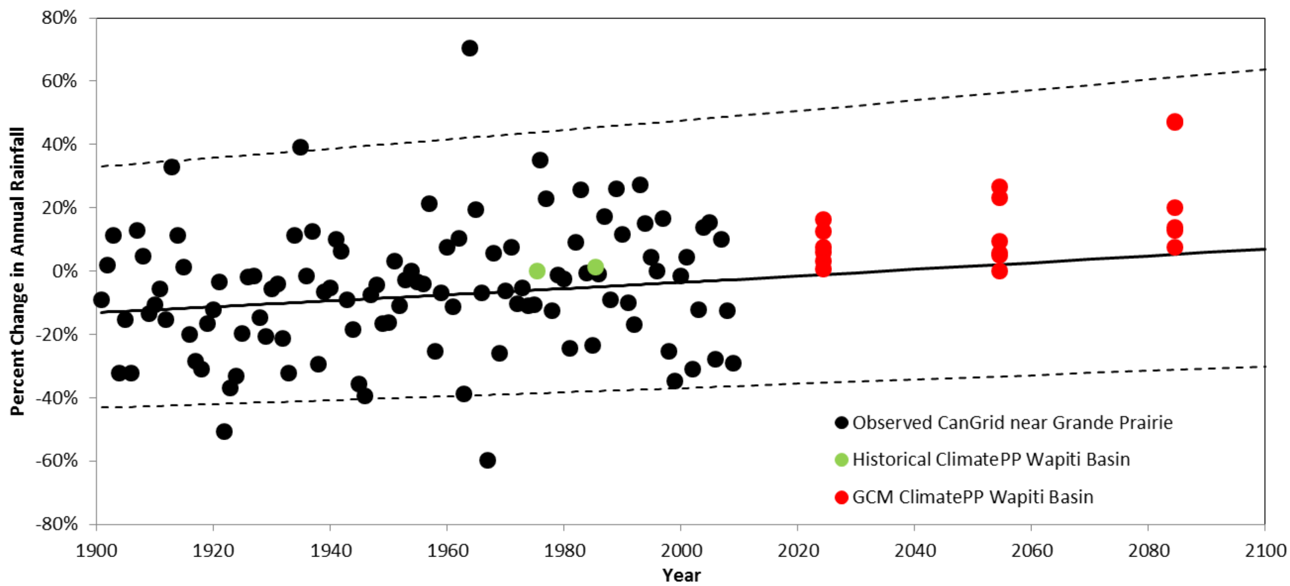

Figure 9 – Annual Rainfall trends and Climate Change projections in the Wapiti River Basin

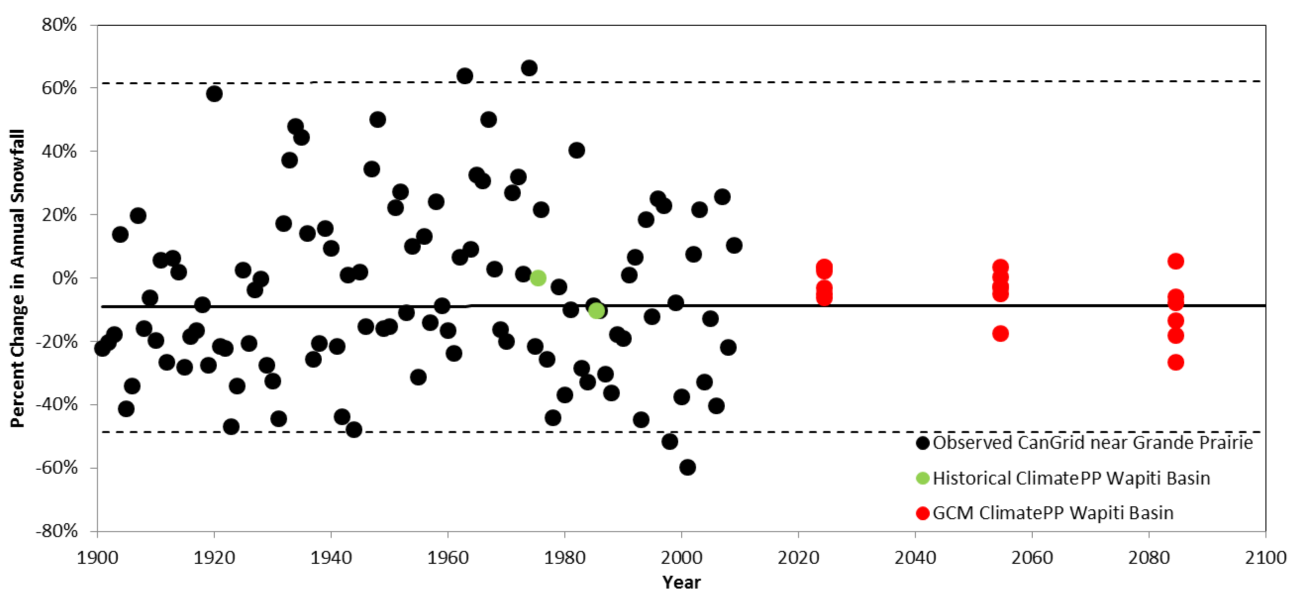

Figure 10 – Annual Snowfall trends and Climate Change projections in the Wapiti River Basin

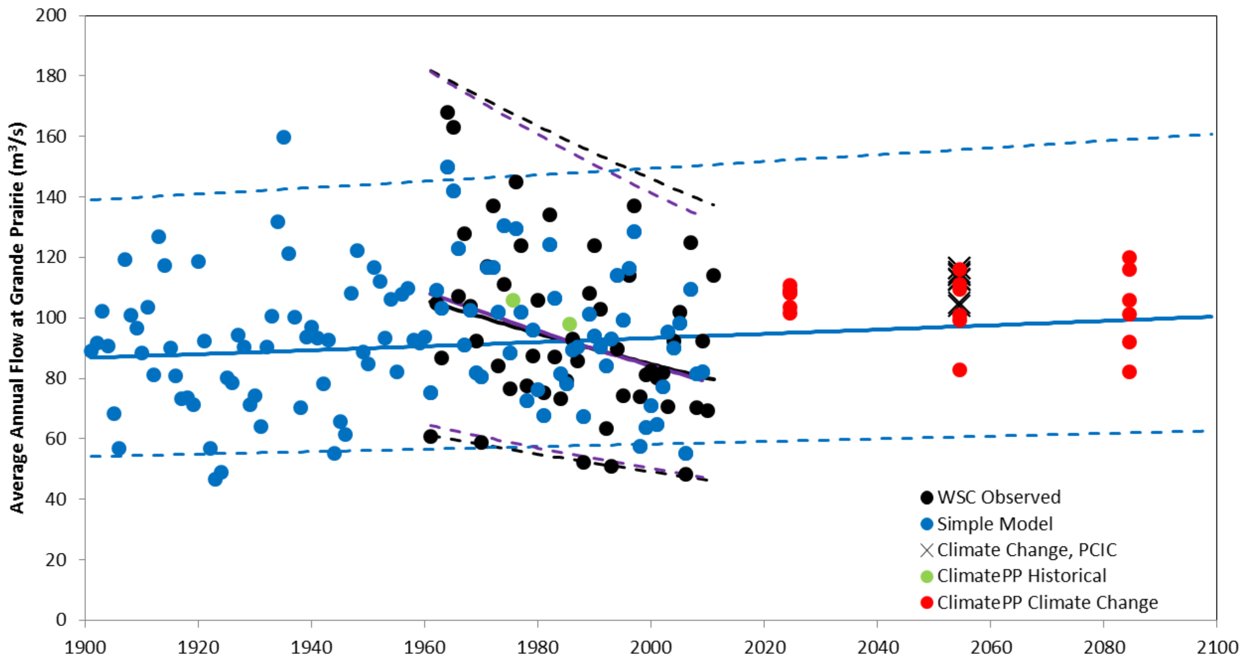

Figure 11 – Annual Flow trends and Climate Change projections in the Wapiti River Basin. Black dots are observed annual flows from Water Survey of Canada station 07GE001. Blue dots are estimated flows from CanGrid temperature and precipitation data, and red dots are estimated flows from ClimatePP projections. Black Xs are climate change projections based on results from the PCIC Peace River study for the upper Peace River applied to the Wapiti River Basin. Black lines indicate the 1961-2010 flow trend (solid) and annual range of variation (dotted) for the observed data. Blue lines are the trends for the simple model for the period 1901-2009. Purple lines are for the simple model for the period 1961-2009.

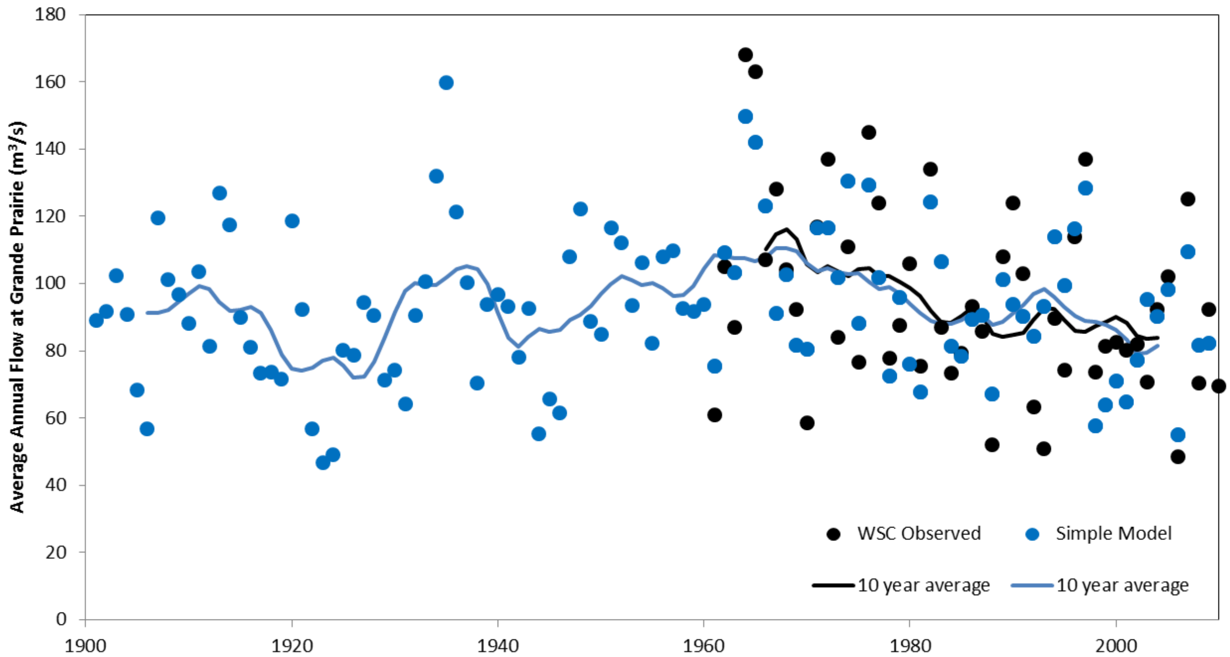

Figure 12 – Annual Flow trends and Climate Change projections in the Wapiti River Basin. Black dots are observed annual flows from Water Survey of Canada station 07GE001. Blue dots are estimated flows from CanGrid temperature and precipitation data. Lines indicate the 10-year moving average for observed flows (black) and modelled (blue).