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Decadal trends in precipitation and flow in an unregulated eastern slope river

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Summary

The Elbow River Watershed flows through Rocky Mountain foothills into the prairie before joining the Bow River in Calgary. As an important water resource which supplies about 40% drinking water for the citizen of Calgary, there is a growing concern about potential climate change impacts on future water availability. What's more, flooding is severe issue that persists in the Elbow River (Abboud, Ryan and Osborn, 2018). Comprehensive analysis of historical trends in meteorology and discharge parameters in the Elbow River Watershed and understanding of how climate change influenced the river flow in the past records are needed for long-term water resource protection and water shortage prevention, as well as avoiding economic loss and damages from potential flooding in context of climate change. The objectives of this study are determining factors that affecting peak flow rate and the timing of peak flow and identifying historical variability of Elbow River discharge and watershed climate.

Changes with time in both hydrological parameters and meteorological parameters were determined using the Mann-Kendall statistical analyses and non-parametric Spearman's Rho correlation. Throughout the watershed, annual total precipitation was significantly increased, and annual mean maximum temperature decreased significantly in all watersheds. Only the lower watershed had significantly increased annual mean minimum temperature. Significantly increased annual maximum snow pack water equivalent was observed in the upper watershed. Both the middle and the lower watersheds had significantly delayed snow melt timing. Significantly increased annual maximum, mean and median discharge were observed in both the middle watershed and the lower watershed, while only the lower watershed has significantly delayed peak flow occurrence. No significant trends in discharge were observed in the upper watershed, perhaps because increased precipitation is transmitted to the lower watershed via groundwater aquifers.

Method

The unregulated stretch of the Elbow River watershed (i.e. above the Sarcee Bridge gauging station, which is upstream of Glenmore Dam) was chosen for the study in order to evaluate natural (as opposed to regulated) flow and river reaches with significant stormwater. Water diversion still occurs in the river reach studies, however. The Elbow River watershed above the Sarcee Bridge was further divided in to three sub-catchments according to the locations of the three hydrometric stations. The 436 km^2 Upper Elbow River Watershed draining through front range of Canadian Rockies to the Elbow Falls, the 351 km^2 Middle Elbow River Watershed draining from Elbow Falls to the Bragg Creek and 377 km^2 Lower Elbow River Watershed draining from Bragg Creek and prairie to the Sarcee Bridge.

Daily discharge for the Above Elbow Falls (1967-1995) station, Bragg Creek (1979-2014), and Sarcee Bridge (1979-2014) in the study area were collected from Environment Canada. Daily maximum and minimum temperature, daily precipitation and daily SWE (snowpack water equivalent) for each grid within every sub-catchment were interpolated and compiled from Alberta Agriculture and Forestry's database.

Non-parametric tests were performed to detect the presence or absence of historical long-term significant trends and conduct median comparison in hydrometric and meteorological data in this study. The statistical test for identifying trends in hydro-climatic variables separately for each of sub-watersheds utilized in this study is the Mann-Kendall non-parametric rank-order test for Trend (Mann, 1945; Kendall, 1975; Burn 1994; Valeo et al., 2003). These tests apply to independently and identically distributed random variables and can compute Kendall's tau rank correlation coefficient with p-value for significance of the trend, standard normal deviate Z and statistic S. Statistically significant trends over time were identified by p-value less than 0.1. The slope and intercept of Kendall's line describing trend is also provided (USGS Report, 2005). However, impacts on trend detection from serial correlation, spatial correlation and residuals from the LOWESS smooth were not eliminated in this study.

To consider the correlation between the hydrologic variables and the meteorological variables, the non-parametric Spearman's rho was calculated in MATLAB. Correlations between antecedent precipitation and peak flow, Julian day of annual maximum 2-day cumulative precipitation and Julian day of peak flow, annual maximum 2-day cumulative precipitation and peak flow were tested in this study. Statistically significant correlations over time were identified by p-value less than 10%. Rho values close to one and minus one indicates a perfect positive correlation and a perfect negative correlation respectively.

Results, Observations, Conclusions

Available flow records common to all three sub-watersheds (April to October; 1979-1995) showed that on average the upper watershed contributed 65% (59% to 73%), the middle watershed 28% (24% to 34%), and the lower station 7% (4% to 11%) of the annual flow reaching Calgary. Increased average monthly baseflow (between 0.019 m^3/s and 0.04 m^3/s per year) was observed in every month during November to March in middle watershed. Average annual precipitation increased in the upper and middle watersheds (5.18 mm/year) and upper, middle and lower watersheds (3.91 mm/year). Daily SWE was significantly decreased in the upper watershed (-6.2 mm/year) while increased in upper and middle watersheds (2 mm/year). Although earlier snowmelt (0.43 days/year) was observed in the upper watershed, later snowmelt was observed in both upper and middle watersheds (0.34 days/year) and upper, middle and lower watersheds (0.37 days/year).

Peak daily flow increased with time in middle (1.32 m^3/s per year) and lower (1.92 m^3/s pear year) gauging stations, and occurred later with time (0.44 days/year) at the lower gauging station. Peak daily flow was positively correlated with the maximum 48-hour antecedent precipitation before peak daily flow. The upper 90^{th} percentile of peak daily flows all occurred within 2 days of the maximum 48-hour precipitation amount at all three stations. Annual maximum 48-hour antecedent precipitation amount was significantly increasing in watersheds above middle and lower gauging stations, while decreasing in upper watershed. In addition, maximum 48-hour antecedent precipitation occurred later in watershed below middle and lower gauging station.

Novel/Additive Information

1. Most of the flow in the Elbow River that reaches Calgary is generated in the Front Ranges and Foothills.
2. Peak daily flow was significantly increased at middle and lower gauging stations, and occurred later with time at the lower gauging station. Trends in the lower gauging station may be due to increased snowpack, and its later melt.
3. Greater than 90^{th} percentile peak daily flow occurred within two days of the annual maximum 48-hour antecedent precipitation.

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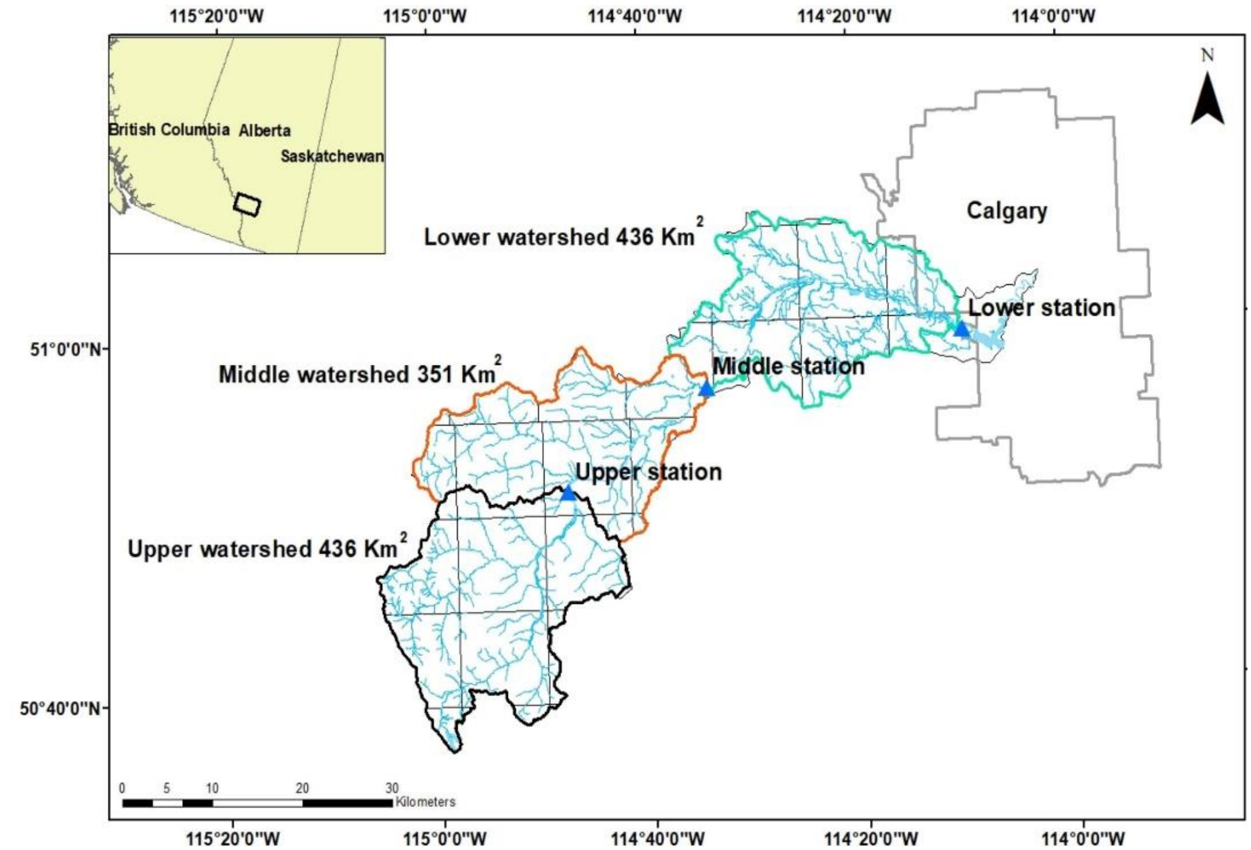

Figure 1. Elbow River watershed above the Sarcee Bridge with river gauging station locations (upper station, middle station and lower station); Inset map showing location of the Elbow River watershed.