Modeling the Response of Glaciers to Climate Change in the Upper North Saskatchewan River Basin

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ABSTRACT AND INTRODUCTION

The objective of this M.Sc. research is to quantify historical and potential future impacts of climate change on glacial contribution to streamflow in the Upper North Saskatchewan River (UNSR) basin, Alberta, Canada. The physiically-based General System of Earth Surface Systems (GENESIS) hydro-meteorological model will be used to analyze the regional impacts of historical data, and to forecast future trends in the hydrology and climatology of selected watersheds within the basin. The model will be successfully applied to the St. Mary River watershed, Montana, and the UNSR basin (DeBeer et al. 2009; MacDonald et al. in press; Byrne et al. in review). Hydro-meteorological processes were simulated at high temporal and spatial resolutions over complex terrain. GENESIS will be applied to the mountain snow-water equivalent (SWE) and the timing of spring melt. A glacier mass balance model is currently in development for incorporation into GENESIS to more accurately gauge the effects of climate change on glaciated areas located in the UNSR basin. The GENERIC Circulation Model (GCM) scenarios will be applied to develop meaningful projections of the range of future hydrologic change under reduced glacial conditions in the basin through 2100.

STUDY AREA

The UNSR flows northeast from its headwaters on the eastern slopes of the Canadian Rocky Mountains through Edmonton, Alberta (Fig. 1), eventually entering Hudson Bay. The upper watershed area (Fig. 2) is dominated by mountainous terrain, ranging in elevation from about 1200-3550 m asl. The Bighorn Hydroelectric Dam built in 1972 created Abraham Lake and serves as the sour point for the study basin. Although this area is only ~14% of the total watershed area above Edmonton, it is responsible for ~40% of average annual streamflow due to the large volume of water derived from snow and ice melt. The climatic regime can be characterized as continental, experiencing cold dry winters with warmer summers (Fig. 3). The hydrology of the glacier snow-melt dominated with peak flows usually occurring in late spring/early summer (Fig. 4). Seven percent of the area is glaciated, and includes parts of Columbia Icefield in its northeastern extent (Fig. 2). Peyto Glacier (~12 km²) is located in the southeast region of the UNSR basin (Fig. 2). This is one of the most intensively studied glaciers in North America, and being the primary benchmark glacier for the Canadian Rocky Mountains it offers continuous mass balance measurements since 1965 (Dumith & Keller, 2006). The detailed records of Peyto Glacier’s mass balance and length variations will allow for verification of a mass balance model that will be applied to the watershed as a whole. Peyto experienced significant declines (~495 mm w.e. a⁻¹) in mass balance during the 20th century (Fig. 5).

GENESIS HYDRO-METEOROLOGICAL MODEL

The GENESIS model will be spatially estimate the climate variables required to calculate glacier mass balance on a watershed scale. Byrne et al. (in review) simulated SWE over the entire complex of the UNSR basin for the period 1960-2010 using GCM derived climate warming scenarios. Monthly temperature and precipitation lapse rates were derived from 1971-2000 PRISM climate normals, similar to a method used by MacDonald et al. (2009). SWE was simulated on a daily scale (Figs. 9 & 10) and compared well with observed conditions at the Bighorn Dam. Future simulations showed a significant change in the timing of the onset of snowmelt across the basin.

CLIMATE CHANGE IN THE UPPER NORTH SASKATCHEWAN BASIN

Alpine glaciers act as barometers of climatic change, responding directly to long-term changes in temperature and precipitation with changes in mass balance and length. Glacier mass balance is defined as the difference between accumulation and ablation during the hydrologic year. A physically based distributed mass balance model is currently being developed for incorporation into the UNSR. GENESIS snowpack simulations will be used to calculate glacier accumulation and ablation. The model uses GENESIS (TIs) to spatially simulate hydro-meteorological variables across the watershed. The incorporation of elevation-based Glacier Response Units (GRUs) will allow the model to simulate the daily mass balance of ice volume across glacier surfaces (Fig. 14). Once the seasonal snowpack has been depleted, glacier ice will be melted with a hybrid degree-day model, using melt factors derived by Shea et al. (2009). Initial glacier volumes are calculated using the area-volume relationship defined in DeBeer & Sharp (2007). Snowpack that remains at the end of the hydrologic year will be converted to ice volume and will be spatially redistributed to lower glacier elevations for use in the following year’s calculations. The model will be calibrated with Peyto glacier mass balance measurements and glacial extents derived from satellite imagery.

DISCUSSION

During the 20th century glaciers across the globe experienced a severe decline (Lemke et al. 2007), including alpine glaciers in the Canadian Rocky Mountains. By 1985, Peyto Glacier had lost approximately 25% of its 1960 volume (Fig. 15), and about 50% of its 1980 volume (Demuth et al. 2009). Similarly, Jiskoot et al. (2009) found that the Clementeau Icefield and Chaba Group glaciers, located just northwest of the study area, retreated an average of 14 m per year from 1850-2001. The Saskatchewan and Athabasca Glaciers in the CIU also experienced severe declines in recent decades (Fig. 16). Evidence suggests that recent warming has caused a change in glacier mass balance in the UNSR basin that is unprecedented during the Holoene (Cornau et al. 2009). Based on analysis of projected climate indices (Figs. 10-13) it is expected that glaciers in the region will continue to decline over the next century. The earlier onset of spring melt forecasted by GENESIS will result in a lengthening of the ablation season and a further reduction in glacier mass balance.

REFERENCES

Bighorn Hydroelectric Dam

Total Annual Precipitation based on NCAR-10 A

Total Annual Precipitation based on NCAR-15 A

Total Annual Precipitation based on UNI

Total Annual Precipitation based on PRISM 75

Total Annual Precipitation and the mountaneous snowpack in the St Mary River watershed, Montana. (2009). Glacier contribution to the North and South Saskatchewan Rivers. Data Sources: (1) 1971-2000 PRISM climate normals, used by MacDonald et al. (2009); (2) 1960-2010 Regional Climate Studies, used by Byrne et al. (in review); (3) 1980-2009 PRISM climate normals, for spatially representative values, derived in Byrne et al. (2010). Model output for the UNSR basin was analyzed using climate-change indices developed by the WMO (Alexander et al. 2006). Figures 10-13 show decadal trends in Total Annual Precipitation (PRCP) and Ice Days (ID) between 1960 and 2100, based on the NCAR-B1 and MIRO-A1B scenarios. These two indices are important for monitoring glacier health in the basin. PRCP drives the mass balance of glaciers by contributing to ice accumulation, while ID can be used as a proxy for the length of the glacial ablation period. Results show significant trends in PRCP and ID for both climate scenarios, with greater rates of change at high elevations.