CALIBRATION OF A HYDROLOGIC AND DYNAMIC GLACIER MODEL TO THE NOOKSACK RIVER BASIN USING GRIDDED SURFACE CLIMATE DATA

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1. Introduction

The Nooksack River drains an approximately 2000 km^2 watershed in the North Cascades in Whatcom County, Washington (Figure 1) and is a valuable freshwater resource for regional Tribes, municipalities, industry, and agriculture, and provides critical habitat for endangered salmon species. Nooksack River streamflow is largely influenced by precipitation and snowmelt in the spring, and glacial melt throughout the warmer summer months when precipitation is minimal. Mt. Baker has the largest contiguous network of glaciers in the North Cascades, which have shown a significant retreat in recent decades (Pelto and Brown, 2012; Figures 2 & 3).

Concern has grown over the effects that climate variability and change might have on glaciers and water resources in general in the Nooksack basin. Regional climate projections through the end of the 21st century indicate an increase in average annual air temperature, a decrease in summer precipitation, and an increase in winter precipitation. We will employ publically available statistically derived gridded surface data and numerical modeling techniques to simulate the effects of forecasted climate change on the Upper Nooksack River with an emphasis on late summer low flows. Here, we focus on calibration and validation of the model for the North, Middle, and South Fork Nooksack Basins.

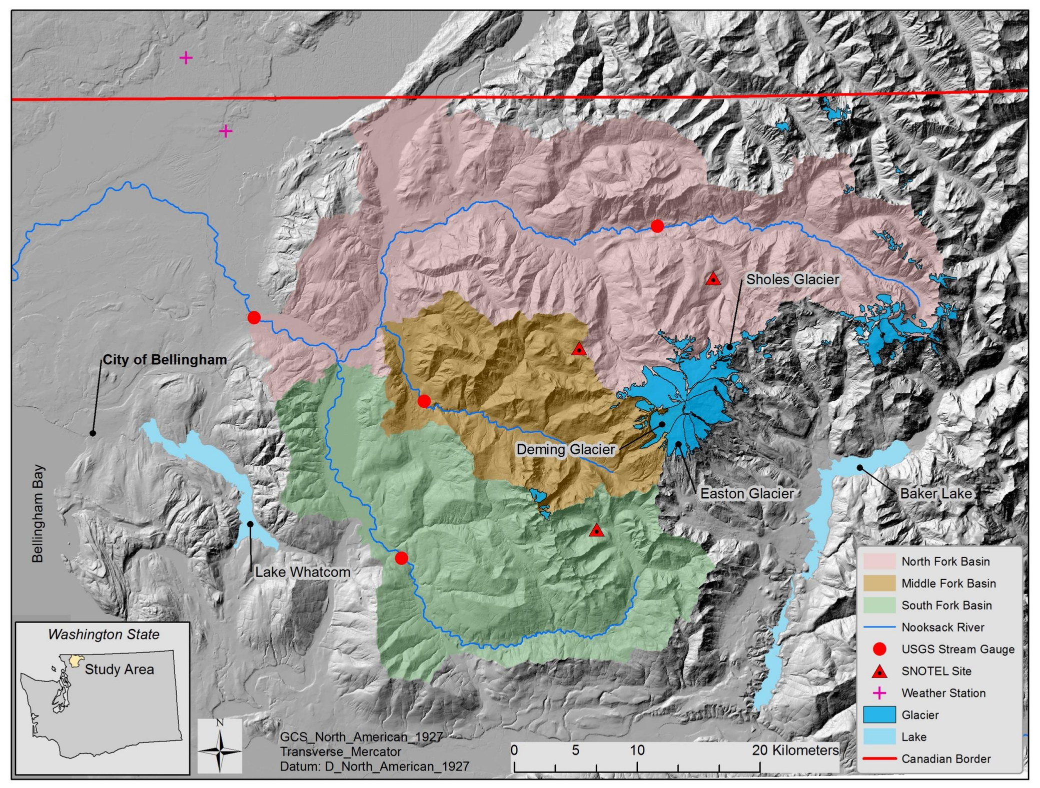

Figure 1. Location of the North, Middle, and South Fork basins in the upper Nooksack River watershed, northwest WA State.

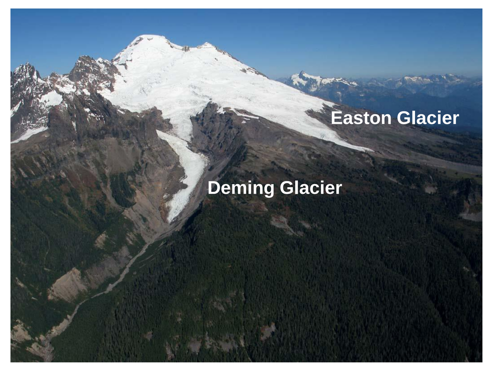

Figure 2. Mt. Baker and the Deming and Easton Glaciers (photo by John Scurlock).

Figure 3. Coleman Glacier terminus in the North Fork Nooksack basin (photo by John Scurlock).

2. Project Objectives

Predict the effects of Pacific Northwest climate change on streamflow

Ultimately, the goals of our project are to assess the impacts of climate change on Nooksack basin hydrology using the Distributed Hydrology Soil Vegetation Model (DHSVM) version 3.2 with an integrated glacier dynamics model, forced with downscaled future climate data developed using the multivariate adaptive constructed analogs method (MACA; Abatzoglou and Brown, 2011). The MACA downscaled data incorporates 20 global climate models of the CMIP5 using RCP4.5 and RCP8.5 forcing scenarios.

Before simulating the hydrology and glacial response to climate change, we have to calibrate the DHSVM to the Nooksack basin using historical observed meteorological data. Due to a lack of spatially distributed long-term historical weather observations in the basin, we apply publically available statistically derived gridded surface data developed by Livneh et al. (2013; Figure 4). The advantage of the Livneh data, is that it was used to train the MACA data set that we will apply for future climate forcings.

Livneh Gridded Surface Data

The Livneh dataset was created by incorporating daily observations from National Weather Service Cooperative Observer stations across the USA and monthly precipitation from the Parameter-elevation Regressions on Independent Slopes Model (PRISM; PRISM Climate Group). Temperatures are adjusted with elevation using a 6.5ºC/km lapse rate. The resulting daily data includes minimum and maximum temperature, precipitation, and wind speed from 1950-2011. For this project, the Livneh grids are disaggregated to 3-hr time-steps for use in the DHSVM.

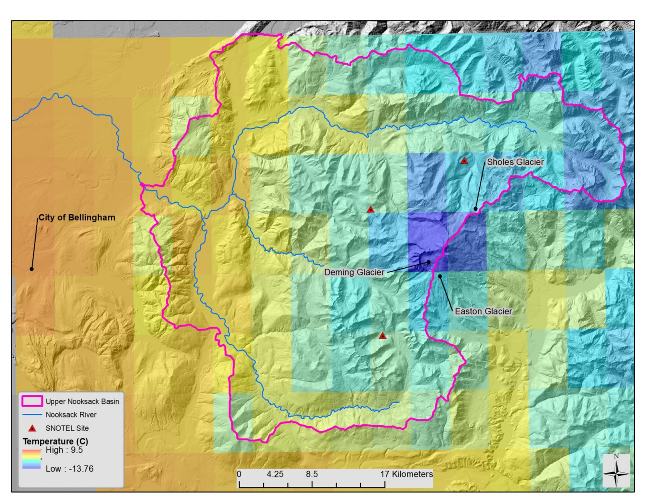

Figure 4. Example gridded Livneh daily temperature in the Middle Fork basin for December 15, 1987.

Daily Livneh Data
Max temperature
Min Temperature
Precipitation
Wind Speed

Processed and disaggregated → for the DHSVM input using VIC

3-hr DHSVM Input
Temperature
Precipitation
Wind Speed
Humidity
Shortwave Radiation
Longwave Radiation

VIC = variable infiltration capacity model (Liang et al., 1994)

3. Modeling Tools

Distributed Hydrology Soil Vegetation Model

The DHSVM developed at the University of Washington and Pacific Northwest National Laboratory, uses meteorological and spatially distributed physical data to simulate a water and energy balance at the pixel scale of a digital elevation model (Figure 5; Wigmosta et al., 1994). The model predicts snowpack evolution, evapotranspiration, soil infiltration and storage, saturated subsurface flow, and surface runoff, for each pixel over a user-defined time step.

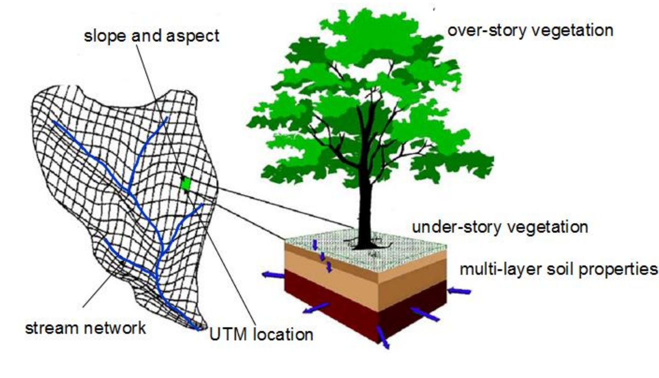

Figure 5. Conceptual model of DHSVM structure (from Wigmosta, et al., 1994).

DHSVM Setup

Physical model inputs (Figure 6) to the DHSVM include a stream network and the following 50-meter resolution GIS data sets:

- Digital Elevation Model (USGS)
- Soil Thickness (generated in ArcInfo AML)
- Soil Type (STATSGO database)
- Landcover (NOAA Landsat)
- Stream Network (generated in ArcInfo AML)
- Solar/Shadow Map (generated in ArcInfo AML)

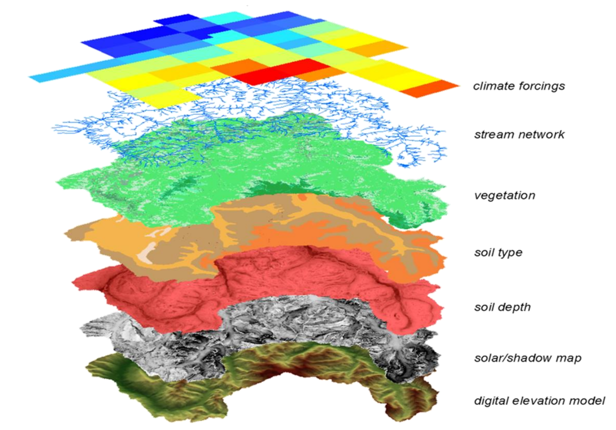

Figure 6. Input grids for the DHSVM.

Glacier Dynamics Model

A recently developed glacier dynamics model is integrated into the DHSVM (Naz et al., 2014). On a monthly time step, the glacier dynamics model estimates the (Figure 7):

- Mass balance (ice accumulation and ablation) for each grid cell covered with a glacier.
- Flow of ice as determined by the surface mass balance fluctuations.
- Updated thickness and extent of glacier ice in response to the simulated dynamic ice flow.

Glacier ice melt contribution to streamflow can be estimated by subtracting the stream discharge results of a simulation with no glacier from one incorporating glacial processes.

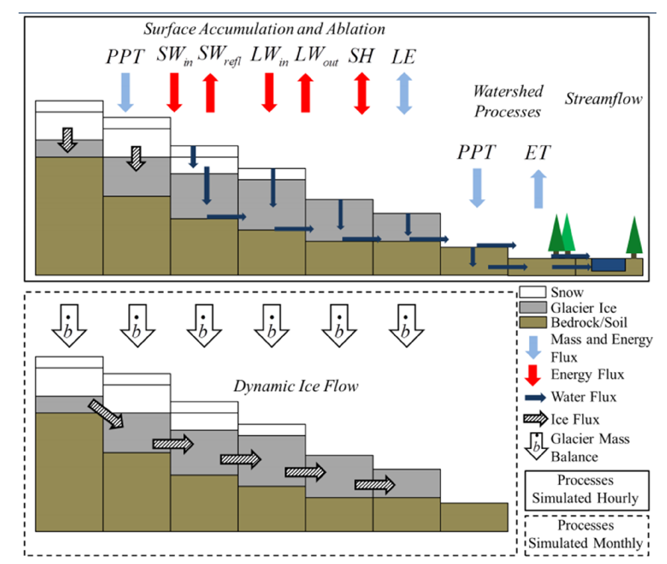

Figure 7. Glacier model processes (Naz et al., 2014).

4. Model Calibration

Calibration requires the adjustment of model parameters to achieve a reasonable comparison between predicted and observed values. The DHSVM is calibrated to observed 1) glacial mass balance and aerial extent, 2) streamflow, and 3) snow-water equivalent (SWE) in the Nooksack basin (Figure 1). Calibration is performed for each of the three sub-basins separately in an effort to better capture local variability due to the complex topography of the Mt. Baker area. Here, we report the calibration to the North, Middle, and South Fork basins of the Nooksack River.

We are using processed meteorological data (see Project Objectives) from Livneh observational data grid points for the calibration. In addition, we are incorporating monthly (30-year normals) PRISM datasets to capture the variable precipitation lapse rates at a higher resolution (800 m; PRISM Climate Group, 2004).

Statistical tests are used in addition to graphical comparisons to assess the accuracy of DHSVM results with respect to observations. The Nash-Sutcliffe (1970) model efficiency coefficient and R^2 test statistics are examined for each model run to assess the predictive capability of the DHSVM.

5. Preliminary Glacier Calibration Results

North Fork

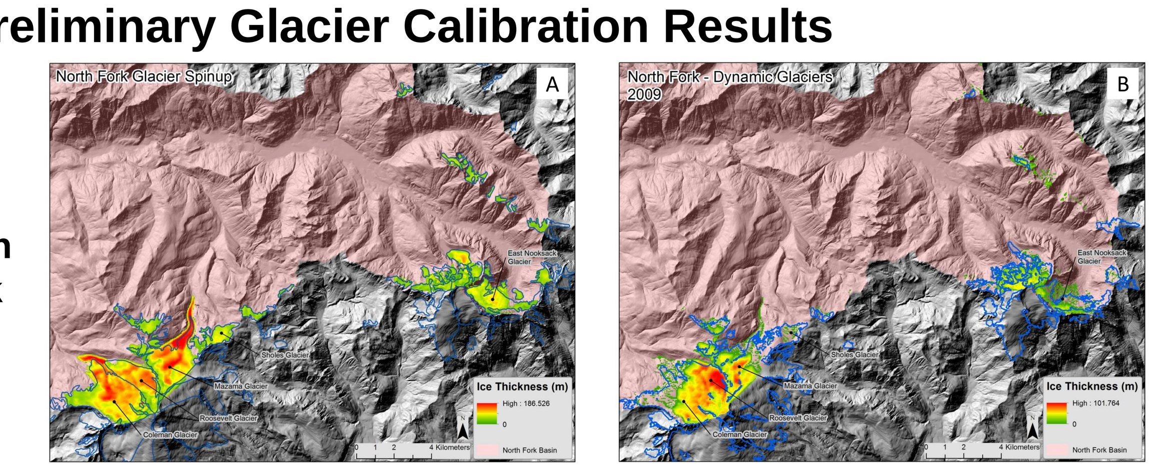

Figure 8. (*A*) Ice thickness and aerial extent of glaciation generated by 1000 year spinup simulation using an estimated annual mass balance for the North Fork basin. Blue outlines are GLIMS 1950 aerial ice extent. (*B*) Preliminary results of dynamic glacier simulation from 1950-2009. Blue outlines are digitized glacier extent from 2009 Landsat imagery.

Middle Fork

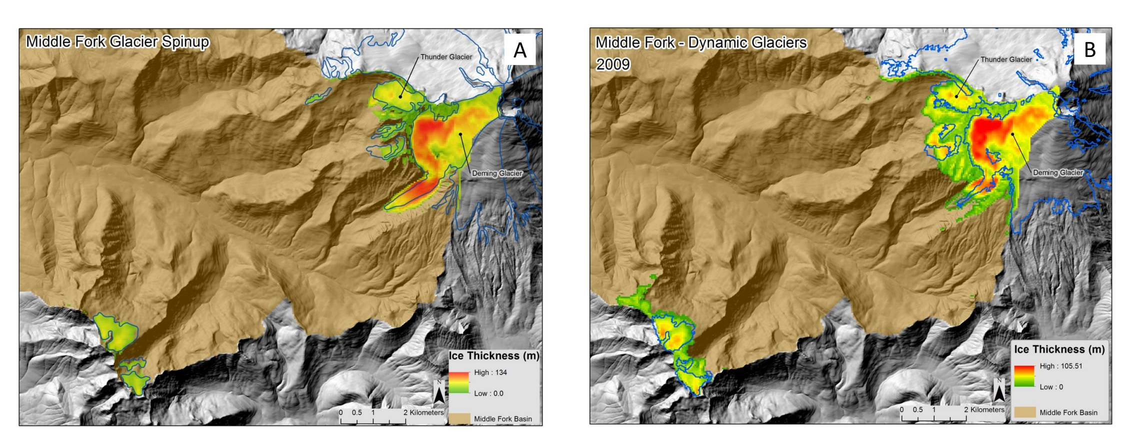

Figure 9. (*A*) Ice thickness and aerial extent of glaciation generated by 1000 year spinup simulation using an estimated annual mass balance for the Middle Fork basin. Blue outlines are GLIMS 1950 aerial ice extent. (*B*) Preliminary results of dynamic glacier simulation from 1950-2009. Blue outlines are digitized glacier extent from 2009 Landsat imagery.

6. Preliminary Hydrology Results

North Fork

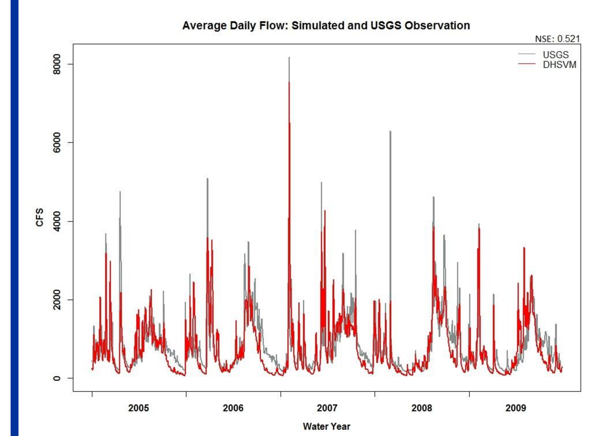

Figure 10. Preliminary DHSVM calibration results for North Fork Nooksack average daily streamflow for water years 2005-2009 at the USGS stream gauge below Cascade Creek near Glacier, WA. Nash Sutcliffe efficiency score is shown in the upper right corner.

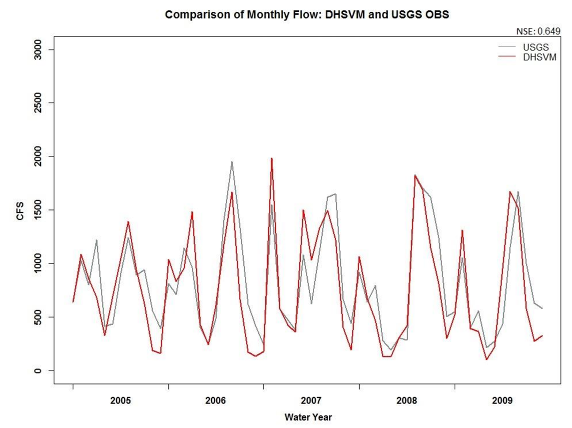

Figure 11. Preliminary DHSVM calibration results for North Fork Nooksack average monthly streamflow for water years 2005-2009 at the USGS stream gauge below Cascade Creek near Glacier, WA. Nash Sutcliffe efficiency score is shown in the upper right corner.

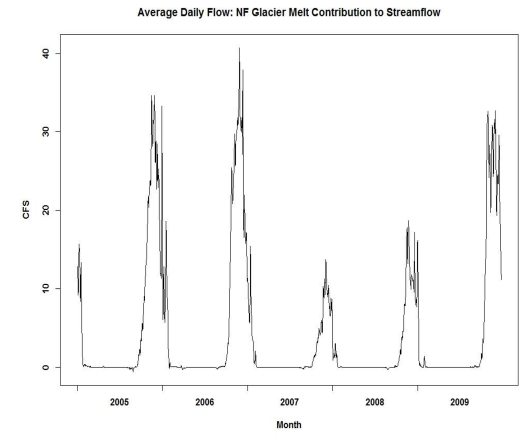

Figure 12. Preliminary simulated glacier melt contribution to streamflow in the North Fork basin for water years 2005-2009.

Middle Fork

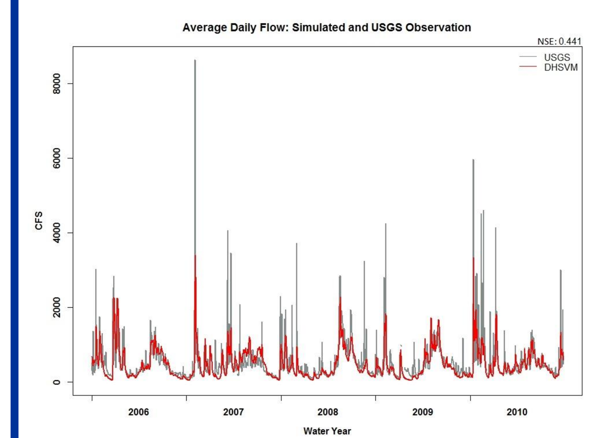

Figure 13. Preliminary DHSVM calibration results for Middle Fork Nooksack average daily streamflow for water years 2006-2010 at the USGS stream gauge near Deming. Nash Sutcliffe efficiency score is shown in the upper right corner.

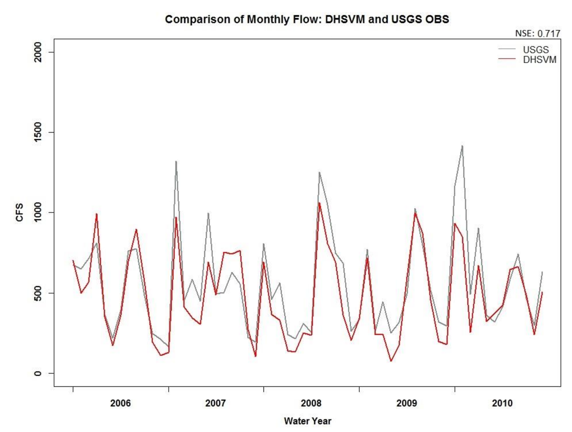

Figure 14. Preliminary DHSVM calibration results for Middle Fork Nooksack average monthly streamflow for water years 2006-2010 at the USGS stream gauge near Deming. Nash Sutcliffe efficiency score is shown in the upper right corner.

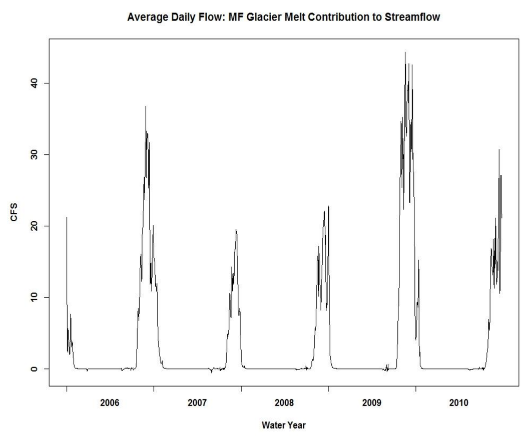

Figure 15. Preliminary simulated glacier melt contribution to streamflow in the Middle Fork basin for water years 2006-2010.

South Fork

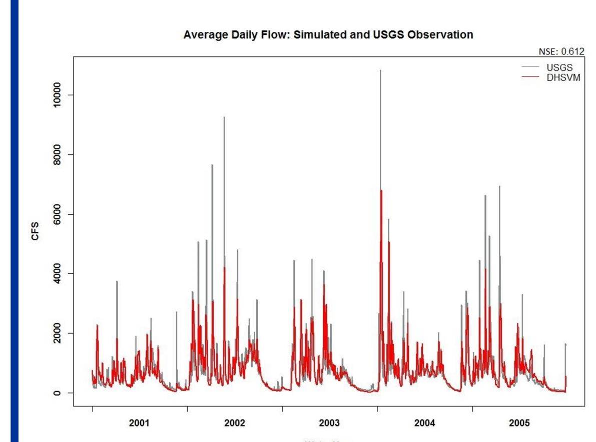

Figure 16. Preliminary DHSVM calibration results for South Fork Nooksack average daily streamflow for water years 2001-2005 at the USGS Wickersham stream gauge. Nash Sutcliffe efficiency score is shown in the upper right corner.

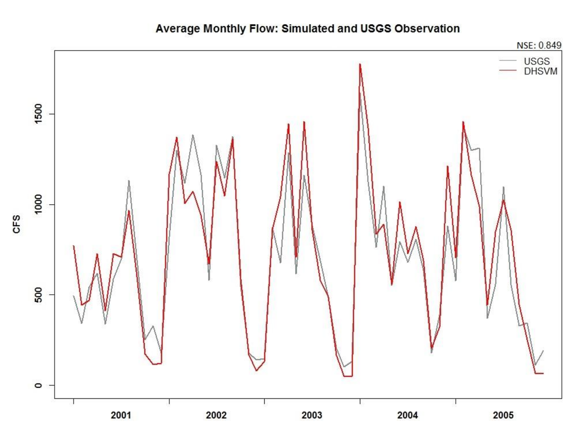

Figure 17. Preliminary DHSVM calibration results for South Fork Nooksack average monthly streamflow for water years 2001-2005 at the USGS Wickersham stream gauge. Nash Sutcliffe efficiency score is shown in the upper right corner.

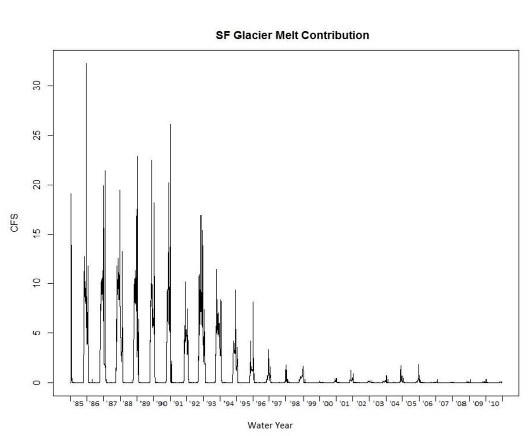

Figure 18. Simulated glacier melt contribution to streamflow from previously existing small glaciers in the South Fork basin for water years 1985-2010.

Discussion and Further Modeling

Additional calibration is needed in the North and Middle Fork Nooksack basins, particularly with regard to glacier ice extent. Attempting to calibrate SWE, ice extent, and streamflow simultaneously has proved challenging as improving one often has a negative impact on the others. Initial ice extent adequately captures the estimated 1950s historical extent but additional calibration is needed to better simulate the observed change in glacier extent through the beginning of the 21st century. Modern day glacier coverage in the South Fork basin is minimal and does not contribute significant melt to streamflow. Thus, model runs into the 21st century will not consider any glacier coverage in the South Fork basin. Glacier melt in the Middle and North Fork basins however, is a significant contributor to streamflow in the drier late summer months throughout the period of simulation.

South Fork hydrology has generally been well captured with the model but peak flows during large storm events are consistently under-simulated, lowering the Nash Sutcliffe efficiency score significantly. In the Middle and North Fork basins, peak flows are underestimated like in the South Fork basin, but summer streamflow is generally underestimated as well. This is likely due, at least in part, to the glacier ice extent not being properly calibrated. Further calibration will largely focus on altering temperature lapse rates and soil conductivities to improve glacier and streamflow results respectively.

Acknowledgements

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