

Chapter 8 - Recommendations for Future Work

Recommendations to refine this study:

One of the more difficult tasks in this study was accurately determining the 1998 extent of the glaciers. Glacier outlines for this year were drawn using uncorrected aerial photography. Boundaries were drawn by determining their position relative to topographic features appearing in both GIS relief layers and the photos. Because of time and budget limitations, no photometric work was done to determine boundary positions with greater precision. Furthermore, very few ground observations were available to test the accuracy of the outlines.

Though I have confidence in the methods used to produce the 1998 glacier outlines, I recommend acquiring additional aerial photography and digital orthoquad (DOQs) to further test their accuracy. Additional aerial photography, both vertical and oblique, could be used to check the classification of snow and ice and confirm the disappearance of several small glaciers. Additional DOQs could be used to confirm the location of glacier outlines drawn from the currently available aerial photography. At the time this thesis is being written DOQs based on 1998 aerial photography exist for only one quadrangle in the complex.

Recommendations for expanding this study:

The glacier coverage of the basins inside the park complex is incomplete, making it impossible to accurately determine the impact of glacier change on runoff for several watersheds. Since both the Skagit and Stehekin basins contain several hydroelectric facilities and provide water for agriculture and several cities, extending this study to include all of the basins in the park complex is an important contribution to managing the water resources of the region. In addition, I recommend extending this study to include all of the North Cascades as well as the Nooksak and Skagit watersheds north of the Canadian Border.

A major limitation with the collection of glacier inventories for the North Cascades is that they are a very sparse temporal record. Currently, only two regional inventories of the North Cascade glaciers exist. Post et al. (1971) defines the 1958 glacier extent for the entire North Cascades Range and this study which describes glaciers in the National Park Complex for 1998. This temporal sparseness makes it difficult to correlate regional glacier change with mass balance variations on benchmark and secondary glaciers. Furthermore, because of a lack of information about annual glacier spatial changes, the impact of glacier change on runoff is done using extremely coarse annual averages of glacier volume change. Since complete vertical aerial photography of the park complex exists for 1967 and 1974, additional GIS glacier data for these two years could be produced to create a more detailed temporal portrait of glacier change in the complex. Additional GIS coverage could also be produced using DOQs and aerial photography available from the U.S. Forest Service and Washington State Department of Natural Resources.

During the time that this thesis was being written, an event took place that could impact glacier change in the North Cascades. During the winter of 1998, a record snowfall was recorded at Mt. Baker. Climate data from the Cascade West division showed that winter to be wetter and colder than average. This climate change is reflected in a positive net balance for South Cascade Glacier during the 1998 water year. The previous year, which had been drier and warmer than average, was accompanied by a negative net balance at South Cascade. If this climate change were to continue, it would seem reasonable to expect an expansion of the region's glaciers. While this may be a brief reversal of past trends, the questions are how significant of a reversal it is and long will it continue? One approach to answering these questions is to compare 1998-2001 area /volume changes for South Cascade and the four USNPS monitored glaciers to pre 1998 area /volume changes. In this analysis trends in pre-1998 to post-1998 variations in area and mass balance could be used as a proxy for the entire study area. Regional area variations could be determined by incorporating satellite imagery into the current GIS

database. A trial analysis involving a SPOT image of the North Cascades taken in July 1992 showed that it is possible to quickly extract snow and glacier cover from such an image. The primary advantage to this approach is a savings in time. Furthermore, because many satellite images have such a low view angle, spatial distortion is at a minimum, making orthorectification largely unnecessary. Currently the expense and resolution of this imagery limits its use for glacier monitoring. However, as higher resolution imagery becomes available at lower cost, using satellite images could greatly streamline glacier map production.

One additional question raised by this study is how glacier change in the National Park Complex compares to glacier change on a regional level (the Pacific Northwest). Glacier inventories currently exist for Mt. Rainier (Nylen, in process), Mt. Baker (Harper, 1992), and the Olympic Mountains (Spicer, 1986). With the completion of an inventory for glaciers in the Oregon and Southern Washington Cascades (Pinotti, *in process*) it will be possible to create a digital inventory of all glaciers in the Pacific Northwest for several time periods. What is problematic about this task is that the current collection of inventories have little temporal consistency. This study and the Post et al. (1971) inventory show regional glacier cover for only two time points, 1958 and 1998. While the other inventories show more years, these years are often not synchronous with each other. Consequently, a major task in assembling a regional glacier inventory would be to use the existing digital data and available remote sensing imagery to construct regional maps for at least two years. Once assembled, these digital maps could be used to assess glacier change in the same way as was done in this study.

One final question is how glaciers will change during the next two centuries given projected changes in global climate. A simple model of glacier change in four selected watersheds (chapter 6) indicates that given current rates of glacier change, the last of the glaciers in the complex would disappear in 209 to 610 years. However, these forecasts are based on determining rates of area change for entire basins and using these rates to forecast annual areas. A major problem with this approach is that it ignores increases in rates of change as glaciers become smaller. Furthermore, the model

constructed in this study does not take into account projected changes in regional and global temperature. Therefore, a more robust model would determine regional glacier change by determining changes for individual glaciers. Rates of change would be scaled to glacier size and adjusted on the basis of projected temperature change. Once completed, such a model would provide a useful tool for assessing the impact of projected climate change on the water resources of western Washington.