Chapter 7 - Discussion and Conclusions

This study is a contribution to a global effort to determine rates of change of small glaciers. By doing so it looks at both the impact of climate change on glaciers, as well as the impact of glacier change on water resources. My work is similar to glacier inventories for Washington, Oregon, and Western Canada (Nylen, in process; Mennis, 1997; Champoux and Ommanny, 1985*)* in that it uses both remote sensing data and geographic information system technology (GIS) to construct a geospatial portrait of a glacier covered region. It is unique because it provides a detailed baseline for estimating and assessing the impact of glacier change in Western Washington by reinventorying a major portion (25%) of the glaciers of the continental United States. Also, it tests the validity of using detailed data from a single regularly monitored (benchmark) glacier to estimate glacier change for an entire glacial region.

Based on the comparisons made in this study, during 1958 the North Cascades National Park Complex had 321 glaciers having a combined area of 117.3±1.0 km^2, and an estimated total volume of 10.1±0.2 km^3. By 1998 this population had decreased to 316, with the area dropping to 109.1±1.1 km^2 and a volume of 9.3±0.2 km^2. Currently most (93%) the glaciers in the complex have areas less than 1 km^2, 84% have average elevations above 1800 meters, 67% are oriented from northwest to northeast, 86% have average slopes less than 40°, all but nine terminate on bedrock, and 84% have no discernible debris cover.

Between 1957 and 1997, combined glacier area decreased by 7.0% (8.2±0.1 km^2) and combined volume by 7.9% (0.8±0.1 km^3). With fractional area change for individual glaciers ranging from 10% to -100%, mass loss is a nearly universal theme for the entire population. Investigations of climate division data, SOI and PDO show that this change is the result of both increased temperature and decreased precipitation, as evidenced by a high frequency of warmer, drier years (particularly in 1977-1997) during the study period. Comparisons of glacier spatial characteristics to fractional area change indicate that rates of glacier change are primarily influenced by glacier size, orientation, and average elevation. Generally, glaciers with the largest fractional area loss had areas less than 1 km^2, were oriented toward the south, or had low average elevations. Slope, terminus condition, and debris cover had no discernible impact on fractional area change.

Studies of stream flow and glacier change in selected watersheds reveal that streams in the Complex have their peak discharge in early summer. Furthermore, in basins with a large fraction of glacier cover, glacier mass loss has contributed up to 6% to August-September runoff and augmented August-September precipitation by nearly 16%. Given that these two months are the driest of the year and precipitation accounts for only 25 to 35% of the runoff for that period, it can be argued that glacier mass loss is important to water resource management. Tests of the impact of glacier change on the timing and variability of annual runoff failed to produce consistent results, indicating that changes in annual and seasonal precipitation overshadow contributions from glacier mass loss.

A comparison of spatial changes of South Cascade Glacier (the benchmark glacier for the North Cascades) to changes in the glaciers of the National Park Complex portray South Cascade as anomalous. Because this glacier is larger, has a lower average elevation, and a larger fractional area change during 1957-1997, it is tempting to say that data from it cannot be used to estimate glacier change in the region. However, the length of its mass balance record, plus the similarity of its net balance to mass balance records from the four glaciers within the complex show that data from the glacier is valuable for estimating glacier change for most of the glaciers of the complex. Based on this, a method was developed for constructing mass balance histories for glaciers having mass loss that involved scaling the mass balance for South Cascade Glacier by specific volume change for the glacier in question. Tests revealed that this method could not be applied to glaciers that were in equilibrium or grew in size. This method when applied to entire glacier cover of the complex showed a cumulative mass balance of -8.0 m between 1958 and 1998, with 92% of that loss taking place between 1977 and 1998.

The glacier change observed in this study is consistent with changes observed in other inventories and glacier monitoring programs. Like numerous well-studied glaciers in North America, Europe, and Asia, the area of most glaciers in the North Cascades has decreased dramatically during the past century. Estimates of volume change for all small glaciers in the world (Dyurgerov and Meier, 2000) show a net mass balance of -5.5 m (mwe) between 1961 and 1997. This is similar in magnitude and trend to a regional net balance of -5.6 m for the National Park Complex. If glacier change continues at the current rate, it is estimated that it would take between two and six centuries for the North Cascades to become glacier free. If estimates of a 4°C increase in average global temperature over the next century (Ruddiman, 2001) become reality, total deglaciation would probably take less than a century.