Skykomish River, Washington Impact of Ongoing Glacier Retreat on Streamflow

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ABSTRACT:

Glacier retreat and changes in summer runoff have been quite pronounced in the Skykomish River Basin, North Cascades, Washington. In the Skykomish River watershed from 1958-2009 glacier area has declined from 3.8 km^2 to 2.1 km^2. Columbia, Foss, Hinman and Lynch Glacier the primary glaciers in the basin declined in area by 10%, 60%, 90% and 35% respectively since 1958. Annual mass balance measurements have been completed from 1984-2009 on Columbia, Foss and Lynch Glacier. They have lost -13.3 m, -14.2 m and -11.7 m respectively, an average of 14 m of ice thickness. The glacier retreat has and is exposing new alpine lakes. Despite 15% higher ablation rates, the 46% reduction in glacier area has led to a 40% reduction glacier runoff between 1958 and 2009, 50,000 m^3/day. Examination of USGS streamflow records indicate that Skykomish River summer streamflow (July-September) from 1950-2006 has declined 35% in the watershed, spring runoff (April-June) has declined 15%, while winter runoff (November-March) has increased 11 % due to increasing winter rain and melt events reducing snowpack storage efficiency. The 40% reduction in glacier runoff has not led to a significant decline in the percentage of summer runoff contribution, given the 35% decline in total summer streamflow. The impact on river discharge of glacier runoff decline is limited as the percentage of total streamflow, since glacier runoff peaks at close to 3-5% in August. The loss of glacier area will continue to lead to reduced glacier runoff and late summer streamflow, with limited impact on the flow of the main stem of the Skykomish River except during periods of critically low flow when glaciers currently contribute 10% of the streamflow.

Keywords: glacier runoff, glacier retreat, snowpack, stream discharge, North Cascades

INTRODUCTION

Glaciers act as natural reservoirs storing water in a frozen state instead of behind a dam. Glaciers modify streamflow releasing the most runoff during the warmest, driest periods, summer, when all other sources of water are at a minimum (Fountain and Tangborn, 1985). Annual glacier runoff is highest in warm, dry summers and lowest during wet, cool summers (Rasmussen and Tangborn, 1976). The amount of glacier runoff is the product of surface area and ablation rate (Pelto, 2008). The North Cascade Glacier Climate Project began an annual monitoring program of North Cascade glaciers in 1984 (Pelto, 1996). Mass balance is observed annually on ten glaciers. The cumulative mass balance loss has been 20-30% of the entire glacier volume in 25 years (Pelto, 2010). All 47 observed glaciers have retreated significantly since 1984, five have disappeared (Pelto, 2010). North Cascade glaciers provided 800 million m^3 of runoff each summer in the past, but today this contribution is declining as glacier area available for melting

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declines (Bach, 2002; Pelto, 2008). The glacier retreat and loss of glacier runoff has been quite pronounced in the Skykomish River Basin.

SKYKOMISH WATERSHED HYDROGRAPH

The Skykomish River watershed drains the west slope of the North Cascades (Figure 1). The USGS Skykomish River gaging station at Gold Bar is used in this study. The basin has an area of 1386 km^2, the average elevation of the basin is 1050 m. This station is just downstream of the confluence of the North Fork and South Fork of the Skykomish River. The watershed has sub-watersheds that are dominantly pluvial, nival and glacial. The pluvial segments have peak flows in the winter due to the winter storm events (Dery et al., 2009). Nival streams peak in the May and June with the high snowmelt and glacial flows peak in July and August during peak snowmelt (Fountain and Tangborn, 1985; Dery et al., 2009). The Skykomish River as a whole is a hybrid basin with the various segments reaching a maximum at different times, and reducing the length and duration of the summer minimum flow period. The period from October-March is a storage period with precipitation exceeding discharge and from April-August is a period of excess runoff release (Figure 2).

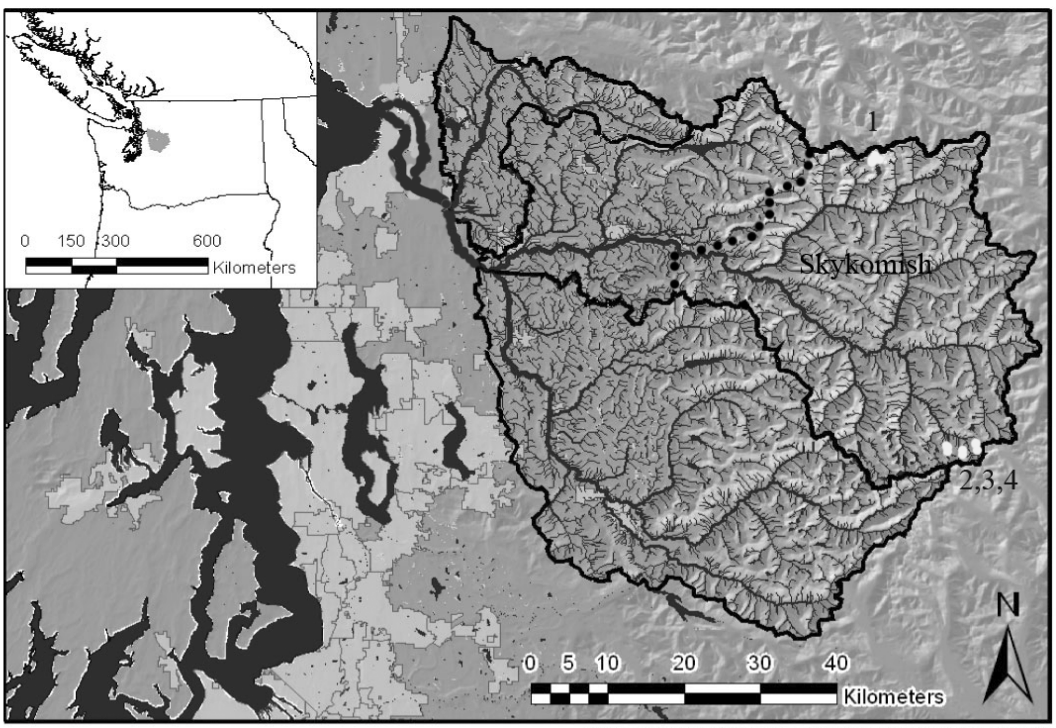

Figure 1. The Skykomish River basin indicating gaging stations and glaciers.

Alpine runoff throughout the mountain range from 1950-2006 has increased in the winter (November-March), 11% in Skykomish Basin (Figure 3) as more frequent rain on snow events enhance melting and reduce snow storage (Mote 2003; Pelto, 2008). The tendency for greater winter flows and greater maximum flows in the winter is consistent with the trends in British Columbia and in the Pacific Northwest (Zhang et al., 2001; Stahl and Moore, 2006; Mote et al., 2008). The earlier release of meltwater in the North Cascades due to warmer spring conditions and reduced winter snowpack has become more pronounced since 1990 when first documented by Pelto (1993). Total spring runoff (April-June) has declined 15% in Skykomish Basin, while many North Cascades basins have not seen a significant spring change (pelto, 2008). The lower mean altitude of the basin versus others examined by Pelto (2008) emphasizes the earlier snowpack melting leading to greater contributions to runoff from snow melt during the winter. Summer runoff has decreased markedly in all six North Cascade basins examined (Pelto, 2008) and in neighboring BC (Stahl and Moore, 2006). The 35% decline in Skykomish River is the largest (Figure 3).

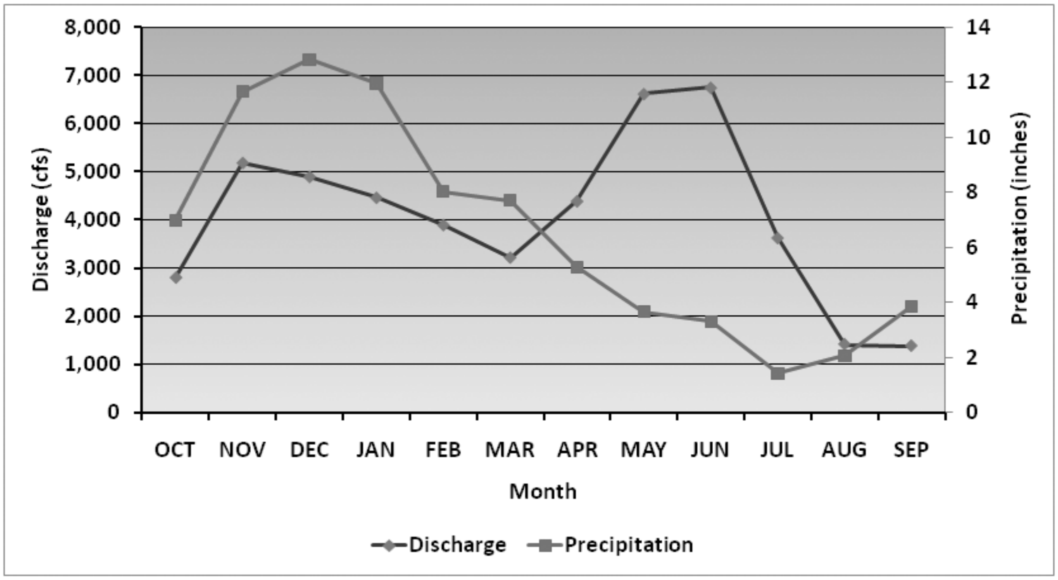

Figure 2. Annual precipitation and hydrograph for the Skykomish River basin. Runoff is at the USGS gaging station on the river at Gold Bar. Precipitation data is from Stevens Pass 1210 m at the headwaters of the basin.

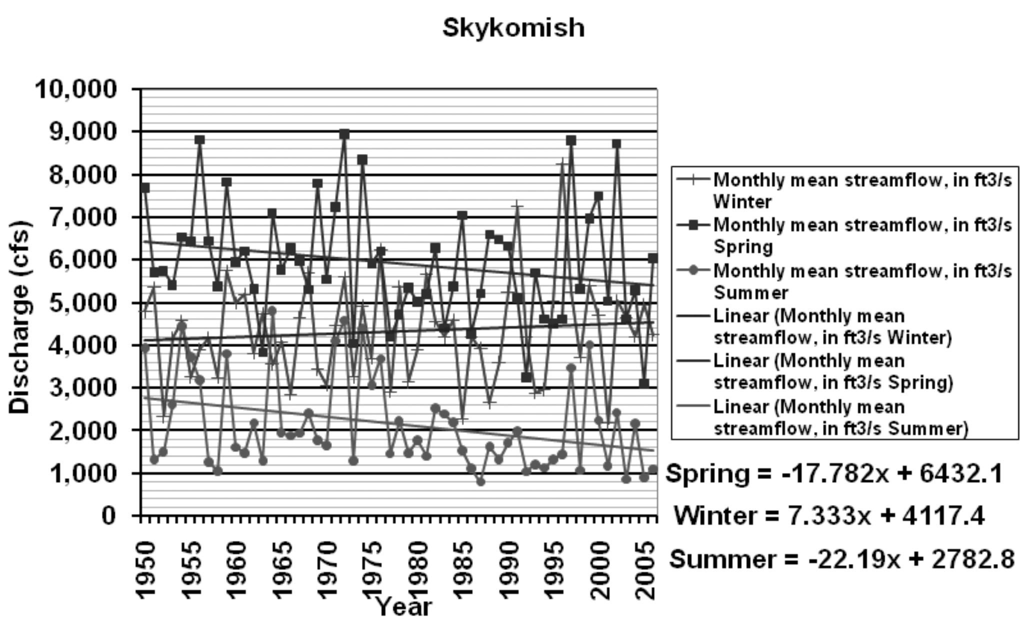

Figure 3. Trends in mean seasonal runoff in the Skymoish River basin 1950-2006. Streamflow at the USGS gaging station on the Skykomish River at Gold Bar. Most notable is the consistently lower summer streamflow since 1976, despite an increase in annual precipitation during this interval.

This decline in summer runoff is apparent in the change in fraction of the total annual runoff. Rasmussen and Tangborn (1976) noted that the basin had just over 40% of the area above 1200 m and had a summer fraction of runoff of 43% May-Sept. for the 1929-1973 period. From 1985-2006 the summer fraction of runoff has declined to 36% of the total runoff. Annual precipitation has risen during this same period in the region and in the basin (Pelto, 2008; Mote et. al., 2008). The most likely cause of the decline in summer fractional flow is the reduced snowpack storage efficiency. Mote (2003) in examining 40 stations in the Washington and British Columbia noted that substantial declines in SWE coincide with significant increases in temperature, and occur in spite of increases in precipitation. A key ratio that can be used to identify the relationship between the snowpack and precipitation is the ratio between winter precipitation (November-March) and April 1 SWE. An increasing ratio indicates a greater percentage of precipitation is falling and remaining as snow. A declining ratio indicates that greater percentages of precipitation occur as rain instead of snow and/or that melt of winter snowpack is increasing. Mote et. al., (2008) noted that the fraction of the precipitation from November-March retained as snow on April 1 had declined by 28% overall in the Cascades of Washington, and 19 and 20% respectively at the two stations closest to the Skykomish River. Pelto (2008) examining snowpack at Stevens Pass in the Skykomish River basin noted a decline in snowpack storage efficiency of 30%.

GLACIER CHANGE

In the Skykomish River watershed from 1958-2009 glacier area has declined from 3.8 km^2 to 2.1 km^2. There are four principal glaciers in the basin comprising 90% of the glaciated area Columbia, Foss, Hinman and Lynch Glacier. Annual mass balance measurements have been completed from 1984-2009 on Columbia, Foss and Lynch Glacier. They have lost -13.3 meters, -14.2 meters and -11.7 meters respectively, this is an average of 14 meters of ice thickness (Figurre 4). Ablation measurements are completed on each glacier, each summer, and changes in glacier area are assessed at least every three years. During the course of the mass balance measurements the glacier boundaries have also been mapped. Their area has declined 10%, 60%, 90% and 35% respectively since the 1958 USGS mapping. An examination of the USGS images of the glaciers from 1958, 1960 and 1964 indicate that the glacier boundaries were accurate in 1958. The glacier retreat has and is exposing new alpine lakes.

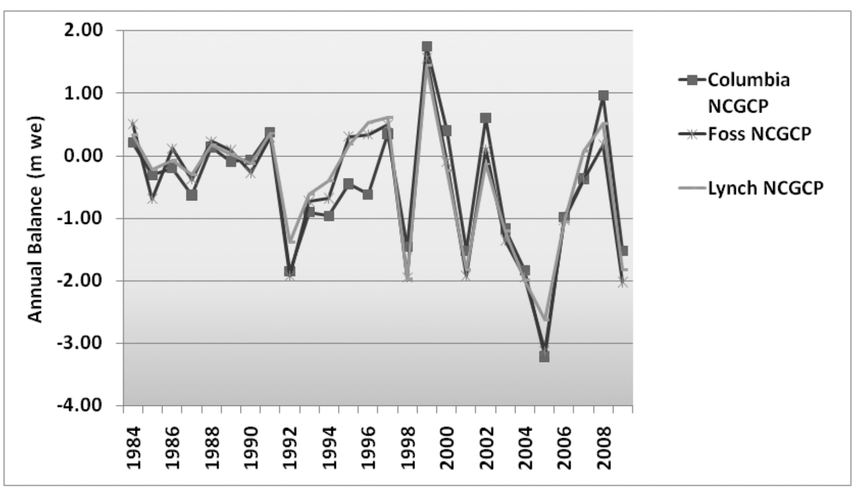

Figure 4. Annual mass balance of Skykomish River basin glaciers 1984-2009.

Lynch Glacier is on the north side of Mount Daniels, the highest point in the Skykomish Watershed and drains into the South Fork Skykomish River. In USGS maps of the region the glacier flows down the mountain ending in basin, with a modest fringe of water showing, this configuration is evident in the 1960 image below. This lake, usually referred to as Pea Soup Lake, expanded rapidly between 1978 and 1983, as the portion of the glacier occupying this basin disintegrated, by 1988 the lake was fully open water. Lynch Glacier retreated 390 m from 1950-1979, almost all of it occurring in a rapid breakup of the glacier in Pea Soup Lake. From 1979-2009 the glacier has retreated 132 m from the lake shore. Annual mass balance measurements indicate the loss of 13 meters of ice thickness on average. More importantly in 2003 on the upper west section of the glacier section a bedrock ridge and scattered outcrops were exposed. The width of the glacier at this elevation has been reduced by 135 m, 15%. The features have continued to expand, indicative of thinning of the glacier in what was its accumulation zone, note the rock outcrop on the upper right portion of the glacier in 2007 in the right image (Figure 5). This is an indicator of a glacier that cannot survive current climate (Pelto, 2010). Lynch Glacier has lost 35% of its area since 1958.

Figure 5. Lynch Glacier, North Cascades in 1960 (Austin Post, USGS) and 2007 (below). There are new rock outcroppings in the accumulation zone on the right side (west side) of the glacier, the width of exposed rock on the ridge on the right side of the glacier has expanded (A and B). On the left side of the glacier the snow connection to the Daniels Glacier which existed up through 1987, is now an exposed ridge (C).

Hinman Glacier is on the west side of Mount Hinman drains into the South Fork Skykomish River. This was the largest glacier in the North Cascades south of Glacier Peak 50 years ago. Today it is nearly gone. Hinman Lake, unofficial name, has taken the place of the lower portion of the former glacier, which still has a couple of separated relict ice masses. In the USGS map based on 1958 photographs the glacier extends from the top of Mount Hinman at 2300 meters to the bottom of the valley at 1525 meters. Hinman Glacier from the west in 1988 is now a group of four separated ice masses, three are significant in size still. A 2009 view from the far end, north end of Lake Hinman up the valley and mountain side that was covered by the Hinman Glacier, now 90% gone compared to 1958 (Figure 6). The new lake is one kilometer long. This is no longer a glacier and is just a few relict pieces of ice as viewed from the 1958 terminus location in 2009, the largest relict has an area of 0.05 km^2.

Foss Glacier is on the Northeast side of Mount Hinman and drains into the South Fork Skykomish River. As recently as 1984 this glacier covered the majority of this mountain face. Today the glacier is rapidly thinning, separating into smaller parts and retreating. Foss Glacier had by the middle of August lost all of its snowcover in 1992, 1993, 1994, 1998, 2003, 2005, and 2009. This has led to thinning of the upper reaches of the glacier. Thinning of the upper reaches, what should be the accumulation zone of a glacier is an indicator of a glacier that cannot survive current climate (Pelto, 2010). The lower section detached from the upper section in 2003 and melted away in 2009. Foss Glacier in 1988, in the middle in 2005 with the 1988 outline, and in 2009 (Figure 7). In the latter two images the snowpack is essentially gone from this dying glacier. Annual balance measurements indicate a loss of over 15 meters of average ice thickness, which for a glacier that averaged 30-40 m in thickness represents 40-50% of the volume of the glacier lost between 1984 and 2009. The reduction in glacier extent has been 40% between 1984 and 2009 and 60% between 1958 and 2009.

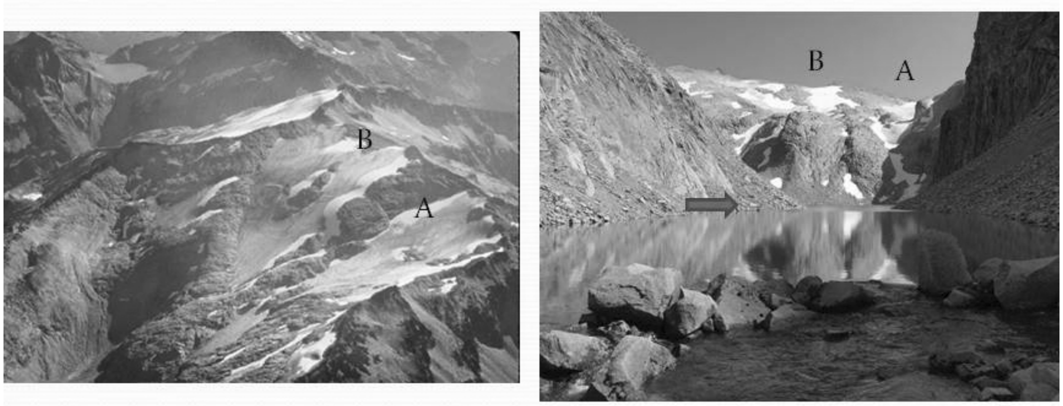

Figure 6. Above, Hinman Glacier from the west in 1988 is a group of four separated ice masses, three are significant in size still. Two ice masses A and B are indicated. Below, a 2009 view from the far end, north end of Lake Hinman up the valley and mountain side that was covered by the Hinman Glacier, now 90% gone compared to 1958. Photograph taken from near the 1958 terminus position, arrow indicates terminus. The lake did not exist in 1958.

Columbia Glacier occupies a deep cirque above Blanca Lake ranging in altitude from 1460 m to 1720 m and is the headwaters of the North Fork of the Skykomish River. Kyes, Monte Cristo and Columbia Peaks surround the glacier with summits over 2200 m. This glacier has the lowest mean altitude of any substantial glacier in the North Cascades. The glacier is the beneficiary of locally heavy precipitation and orographic lifting over the surrounding peaks causing cooling of the air mass greater than that expected from the elevation of the glacier. Facing southeast Columbia Glacier is protected from afternoon sun. During the winters storm winds sweep from the west across Monte Cristo Pass dropping snow in the lee on Columbia Glacier. Avalanches spilling from the mountains above descend onto and spread across Columbia Glacier. The avalanche fans created by the settled avalanche snows are 6 m deep even late in the summer. Columbia Glacier has retreated 134 m since 1984. The head of the glacier has retreated 90 m. The key issue is that the glacier is thinning as appreciably in the accumulation zone in the upper cirque basin as at the terminus (Pelto and Hartzell, 2003). This indicates a glacier that is in disequilibrium with current climate and will melt away with a continuation of the current climate conditions. The glacier has lost 15 m in thickness since 1984, but still remains a thick glacier, over 75 meters in the upper basin and will not disappear quickly (Pelto, 2010). In 2003, 2004, 2005 and 2009 there has been nearly a complete exposure of the glacier surface and the loss of all firn and snowcover on the glacier. This exposed more than 50 annual layers in the 2005 (Figure 8). Glacier runoff measured directly below the glacier in combination with ablation on the glacier indicate a range from 40,000-90,000 m3/day during the summer melt season from this glacier.

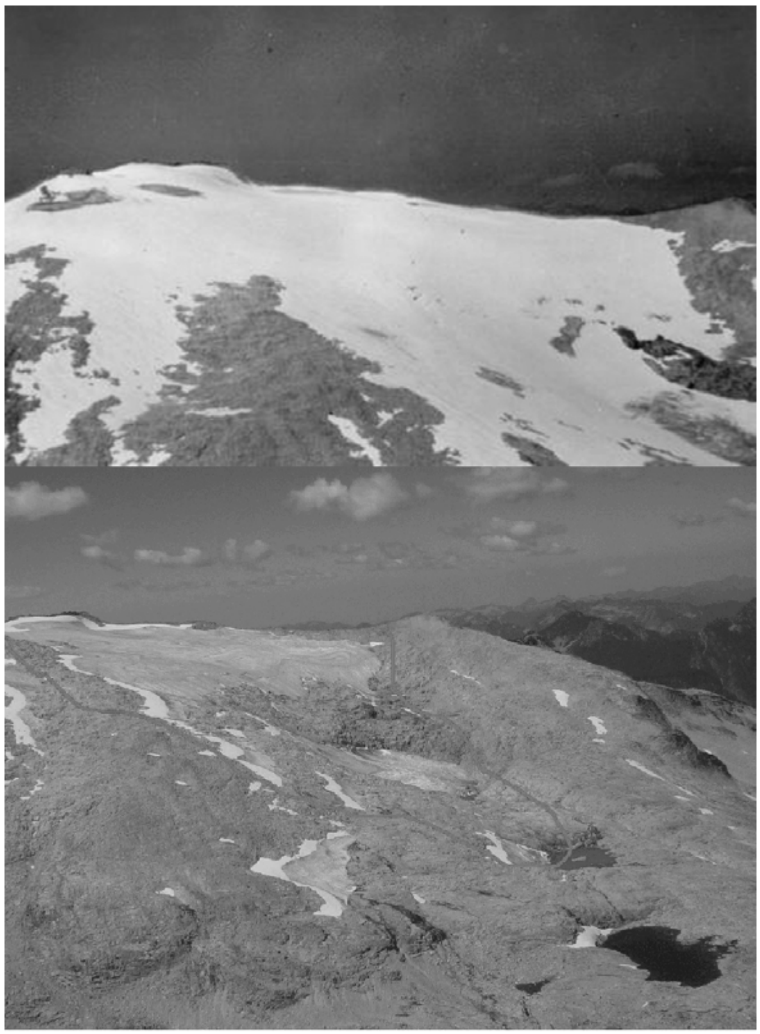

Figure 7. Foss Glacier, North Cascades 1988 and 2005 indicating the change in the extent of the glacier. There is substantial marginal retreat in the accumulation zone and new rock outcroppings in the accumulation zone.

GLACIER RUNOFF

Annual glacier runoff is the product of annual ablation and glacier area a 15% increase in summer mass balance has been observed for the 1959-1983 period versus the 1985-2005 period on South Cascade Glacier (Bidlake). This summer balance is reported in loss per unit area, not volume and hence is a useful measure of the mean summer ablation on a glacier. The correlation coefficient in annual balance for the 1984-2005 period between South Casade Glacier and Columbia, Foss and Lynch Glacier respectively (Pelto, 2007). This suggests that the 15% increase in summer ablation rate is applicable to the Skykomish Basin glaciers as well. The 15% increase in summer ablation is offset by the 46% reduction in glacier area over which the melting occurs leading to a 38% reduction in glacier runoff. August ablation measurements on the three glaciers indicate glacier runoff is 75,000 m^3/day in the basin. This is a 50,000 m^3/day reduction in August glacier runoff from 1958. At the same time as glacier runoff has declined so has overall streamflow, as a result the percentage of streamflow contributed by glaciers has changed little from the 1950-1984 period compared to the 1985-2006 period (Figure 9), despite reduced glacier area. The reduction of the glacial melt component augmenting summer low flows is already resulting in more low-flow days in Skykomish River basin and other area streams. Instream flow levels considered insufficient to maintain short term survival of fish is below 10% of the mean annual flow (Tennant, 1976). In the Skykomish River from 1950-2006 there have been 412 days with flow below 10% of the mean annual flow, 90%, 372 of them since 1985. During several of these low flow periods measured glacier melt indicates that glacier contributions comprise 8-12% of the flow to the river during these lowest flow periods. The low flow periods typically coincide with high ablation periods on the glaciers. It is during these low flow periods that glacier loss will particularly affect streamflow. Stahl and Moore (2006) noted that glacier-fed streams in British Columbia have exhibited a decreasing trend for August streamflow.

Figure 8. Accumulation zone of the Columbia Glacier from the headwall. Notice the number of annual horizons exposed on August 1, 2005. This is the third consecutive year of significant negative annual balances, and follows 2004 when the AAR dropped below 20.

Glacier volume loss can lead to an increase in overall streamflow if the volume is sufficiently large. In the North Cascades in general the glacier volume loss has contributed up to 6% of the August–September stream-flow (Granshaw and Fountain, 2006). The observed net glacier volume loss has been a source of runoff, this is a portion of the observed ablation as well. The -0.50 m/a annual glacier mass balance loss spread over the July-September when glacier volume loss occurs is 0.15-0.25 m^3/s of discharge in Skykomish River, which is less than 1% of the mean summer streamflow. Glacier volume loss has not been mitigating summer low flow in the basin as it has in other more heavily glaciated basins.

CONCLUSIONS

The continued loss of glacier area will lead to an ongoing decline in late summer glacier runoff and streamflow in the Skykomish Basin. Compared to the 30% decrease in total summer runoff the 40% reduction in glacier runoff resulting in a 1.5-2.0% decline in total streamflow is small. Only when streamflow is at critically low levels does the glacier runoff contribution rise to ~10%and potential loss there of become important. The complete loss of glaciers will lead to a further decrease of 2-4% in summer runoff in the basin. Hinman Glacier and Foss Glacier continue to lose area rapidly and will cease to exist within 20 years. Columbia Glacier and Lynch Glacier do not have a persistent accumulation zone but remain thick and will persist and provide runoff to the basin for some time.

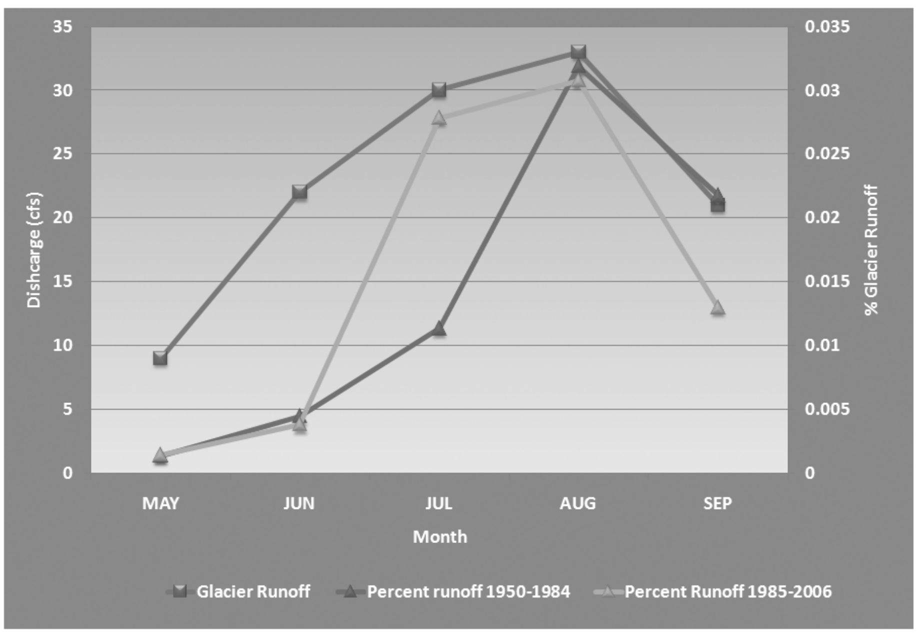

Figure 9. Overall glacier discharge based on ablation measurements and the percentage of the mean August runoff supplied by glacier runoff in the short term 1985-2006 and the long term 1950-1984 for the Skykomish River basin at the Gold bar USGS station.

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