Lyman Glacier: a Century of Change

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ABSTRACT

Lyman Glacier, North Cascade Range, Washington, has retreated a distance of 1310 m from 1890-2008 and is currently 440-m long and a 75% reduction in glacier length. Glacier area has declined from 1.41 km^2 to 0.20 km^2 from 1890-2008, an 86% decline. The volume has declined 93% during this same period, to a current volume of 9.8 million m^3. Lyman Glacier continues to have negative mass balances even in years in which mass balance is generally positive on all other North Cascade glaciers observed, such as in 2008. From 1984-2008 the mean accumulation area ratio (AAR) has been 25, whereas a minimum AAR of 60 is needed for equilibrium. The glacier occasionally calves small icebergs into a lake that the terminus rests in, further raising mass loss. The glacier is thinning and receding across the entire accumulation zone. This indicates a lack of a persistent accumulation zone. Without a persistent accumulation zone the glacier will not survive. At current rates of retreat, areal loss and volume loss the glacier will disappear in 25-40 years. The continued retreat will continue to reduce late summer runoff into Lyman Lake and Railroad Creek.

Keywords: glacier retreat, Lyman Glacier, North Cascades

INTRODUCTION

The global retreat of mountain glaciers is one of the clearest signals of ongoing climate change (Haeberli and Hoezle, 1995; Oerlemans, 2000). Glaciers are part of the Global Climate Observing System (Haeberli et al. 2000). Terminus observations have long been the hallmark of glaciologic observations (Oerlemans, 1994). Terminus observations identify the response of the glacier to recent climate changes. The change in glacier length as a result of climate change is a strongly smoothed and delayed, but also an enhanced signal, while mass balance is the direct and undelayed reaction to the local weather conditions during a year (Haeberli and Hoelzle, 1995). Lyman Glacier has the most complete records of retreat of any glacier in the North Cascades (Freeman, 1941; Long, 1955; Pelto and Hedlund, 2001, Jumpponen, et. al, 1998). The simple topographic setting, well-preserved Little Ice Age trimlines, multiple USGS maps from 1940 and 1979 aerial photographs, and repeated photographs from 1907-2008 further allow for reconstruction of its mass loss through time.

Lyman Glacier is at the headwaters of Railroad Creek and has been an important source of water for the Town of Holden, Railroad Creek, and Lyman Lake. The glacier has a northward orientation on the flanks of Chiwawa Peak. The glacier is fed by direct snowfall and avalanching off Chiwawa Peak. In 1890 the glacier was fed by two high elevation arms one descending from Spider Gap at 2150 m, the other from the west ridge of Chiwawa Peak at 2380 m (Figure 1). The glacier descended the slopes of Chiwawa Peak to the current nearly flat glacial lake basin at 1810-1840 m. The glacier then extended 1500 m across this flat region.

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Today this flat region has been exposed by 1310 m of retreat exposing four new proglacial lakes (Figure 1). The Little Ice Age end moraines are still well preserved and provide a marked transition from mature to immature alpine vegetation (Jumpponen, et al., 1998). LIA lateral moraines are also evident due to the transport of iron oxidized metamorphic rock from Chiwawa Peak by the glacier. Photographs of the glacier in 1907 indicate the glacier within 30 meters of the Little Ice Age moraine. Photographs from 1921 indicate the two high elevation feeders are still strongly connected to the glacier and the lateral margins of the glacier can again be pinpointed (Figure 2). In 1940 USGS photographs were used to create a topographic map. A map of the margins of Lyman Glacier was completed in 1955 by William Long during his work with the Forest Service. Based on 1979 aerial photographs the USGS updated the topographic map for the area. Satellite imagery in 2006 and field mapping in 2008 provide the final measures of the glacier margins.

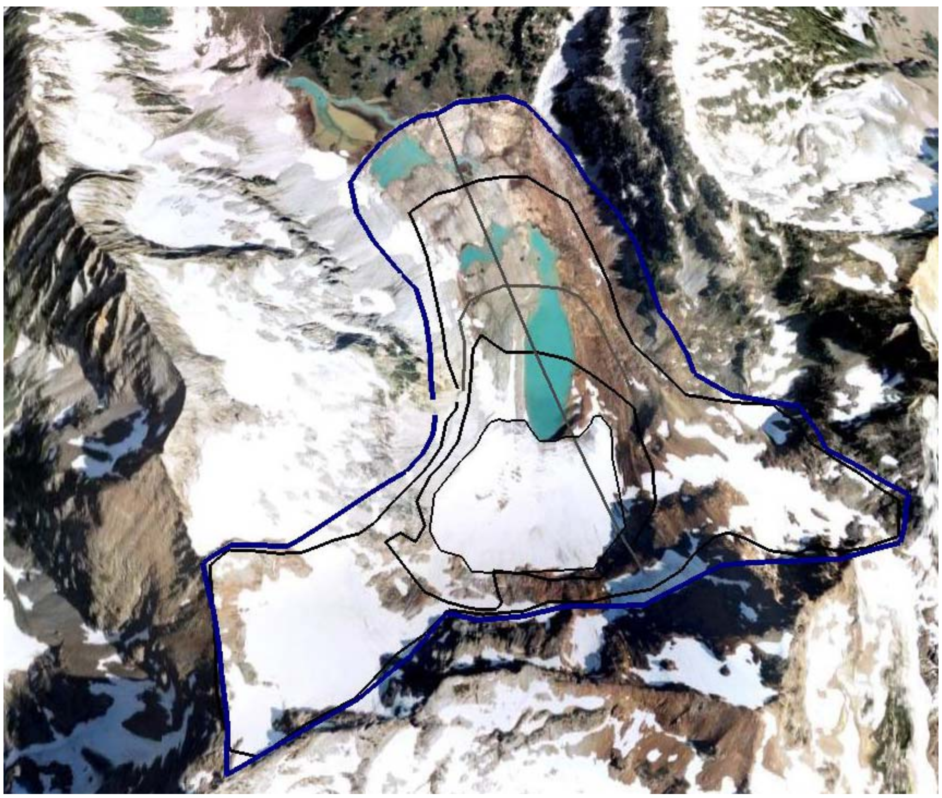

Figure 1. SPOT satellite image of Lyman Glacier from 2005 indicating the Little Ice Age extent of the glacier, newly formed proglacial lakes of the 20th century, and terminus positions of 1890, 1921, 1958, 1979 and 2008.

NORTH CASCADE TERMINUS CHANGE

Since the maximum glacier advance during the Little Ice Age (LIA) there have been three climate changes in the North Cascades sufficiently large to substantially alter glacier terminus behavior. During the LIA mean annual temperatures were 1.0-1.5^{o}C cooler than at present (Burbank, 1981: Porter, 1986; Pelto and Hedlund, 2001). The lower temperatures in the North Cascades led to a snowline lowering of 100 to 150 m during the LIA (Porter, 1986; Burbank, 1981). North Cascade glaciers maintained advanced terminal positions from 1650-1890, emplacing one or several terminal moraines.

This first substantial climate change following the LIA was a progressive temperature rise from the 1880's to the 1940's. The warming led to ubiquitous rapid retreat of North Cascade Range alpine glaciers from 1890 to 1944 (Rusk, 1924; Burbank, 1981; Long, 1955; Hubley, 1956). The average terminus retreat of 38 North Cascade glaciers from their LIA moraines to their 1950 positions was 1215 m (Pelto and Hedlund, 2001).

The second substantial change in climate in the Northern Cascades began in 1944 when conditions became cooler and precipitation increased (Hubley 1956). Hubley (1956) and Long (1956) noted that many North Cascade glaciers began to advance in the early 1950s, following 30 years of rapid retreat. The advance was limited to glaciers with rapid response times, typically those with high accumulation rates, high elevation accumulation zones and steeper slopes (Pelto and Hedlund, 2001). All of the glaciers on Glacier Peak, 15 miles west of Lyman Glacier advanced during this period.

At the Lyman Lake USDA snotel site, 150 m in elevation below the glacier April SWE averaged 1.76 m from 1945-1976. The third climate change was towards warmer conditions. For the North Cascades a 0.6°C summer temperature rise and 0.9 °C rise in winter temperature (Mote, 2003). The warming led to a reduced SWE-precipitation ratio indicating increased winter rain events (Pelto, 2008 and Mote, et. al., 2008) and a warming. For the 1977-2006, period April 1 snowpack was 18% lower, 1.46 m swe at Lyman Lake. These changes led to ubiquitous glacier retreat and prompted significant negative mass balances (Krimmel, 1994; Pelto 1993 and 2006). The NCGCP had been monitoring the terminus position of 47 glaciers from 1984-2007, all have retreated substantially. By 2008, five had disappeared: David Glacier, Lewis Glacier, Spider Glacier, Lyall Glacier and Milk Lake Glacier; in each case no glacier ice mass exceeding 0.01 km^2 remains (Pelto, 2006). Spider Glacier is adjacent to Lyman Glacier. The head of the former Spider Glacier reached Spider Gap at the head of Lyman Glacier.

TERMINUS OBSERVATIONS

For Lyman Glacier photographic records along with direct terminus measurements provide an accurate time sequence of glacier retreat from the Little Ice Age moraines to the present. The terminus of Lyman Glacier was observed in 1898 and 1907 to still be nearly in contact with its Little Ice Age moraine (Freeman, 1941; Rusk, 1924; Jumpponen, et. al., 1998). In 1907, the glacier still terminated in the glacial lake impounded by the LIA terminal moraine, Lyman Glacier was approximately 30 m from the LIA moraine. Lyman Glacier was observed by Washington Water Power Company (WWPC) from 1929-1940, at the time they collected photographs of the glacier from 1907 and 1915. Photographs from 1921 from a Mountaineers Expedition (Univ. Washington Library), provide the best visual record of glacier extent. By 1921 the glacier had retreated beyond the southern edge of this first proglacial lake (Figure 2 and 3). Companion photographs with the same perspective from 200 and 2008 follow (Figure 4 and 5). By 1929 the glacier had receded notably from the lake exposing a large bedrock knob that has been used subsequently as a benchmark for terminus retreat measurements (Freeman, 1941, Long, 1955). In 1988 NCGCP visited Lyman Glacier with William Long he identified the marker used by WWPC. This marker was used as a field check on the GIS based retreat assessment for the 1979-2008 period. WWPC measurements identified a retreat of 337 m, 15 ma^{-1} from 1907-1929 and 196 m from 1929-1940, 18 ma^{-1} (Freeman, 1941).

William Long observed the terminus position of Lyman Glacier in 1944, he noted a new glacial lake being exposed at the terminus that is not evident in the 1940 aerial photographs (Long, 1955). For all assessments of retreat from the 1940 position to present, the retreat distance is the mean of measurements at three points. The measurements are made perpendicular to the ice front from the centerline and from 200 m right of the centerline and left of the centerline. Subsequent USGS mapping and aerial photographs from 1958, 1970, 1972 (Figure 6) and 1979 further document the terminus position. Until 1979 the glacier ended in a relatively shallow proglacial lake. An overlay of the 1958 and 1979 vertical aerial photographs on the USGS topographic map indicated a retreat from 1940 to 1958 of 183 m, 10 ma^{-1}. An additional 240 m of retreat occurred from 1958 to 1979, 11 ma^{-1}.

Since 1979 retreat has extended a deepening lake basin (Figure 7). The depth of the lake at the calving front has been measured at 12 to 18 m from 2002-2008. Beginning in 1984 the North Cascade Glacier Climate Project (NCGCP) has monitored the glacier, recording terminus position in 1986, 1988, 1990, 1992, 1995, 1999, 2000, 2002, 2006, 2007 and 2008. During each of these years mass balance measurements were also completed. In 1986 a large landslide that descended onto the glacier in 1926 began to spill off the glacier front. This mound of debris had reduced ablation and terminus retreat on the eastern side of the terminus. This debris has also filled in what would otherwise be a wider proglacial lake. By 2002 this mound of debris had largely been shed by the glacier. The distance travelled by this debris pile indicates a mean annual velocity of 5 ma^{-1}. An additional large debris pile has been deposited on the western side of the glacier likely in the winter of 2002 and is being exposed now. Continued observation of its position will provide future velocity measurements.

From 1986 to the present NCGCP has surveyed the terminus on 10 occasions through 2008. Total retreat during the period has been 256 m, 11 ma^{-1}. The retreat has been most pronounced at the glacier center in the last 20 years as the ice front has developed a substantial ice cliff that calves. This ice cliff extended 12 m above the water line in 1986. In 2002 and 2008 the ice cliff extended 28 m above the waterline and approximately 16 m below the water line at the centerline. The depth of the water was determined from a handheld sonar device. The retreat rate has been relatively constant over the last 68 years between 10 and 11 ma^{-1} (Figure 7). The Lyman Glacier has retreated a distance of 1310 m since 1890, a 75 % reduction in glacier length. With the current retreat rate of 11 ma^{-1}, the 440 m long glacier will be gone in 40 years.

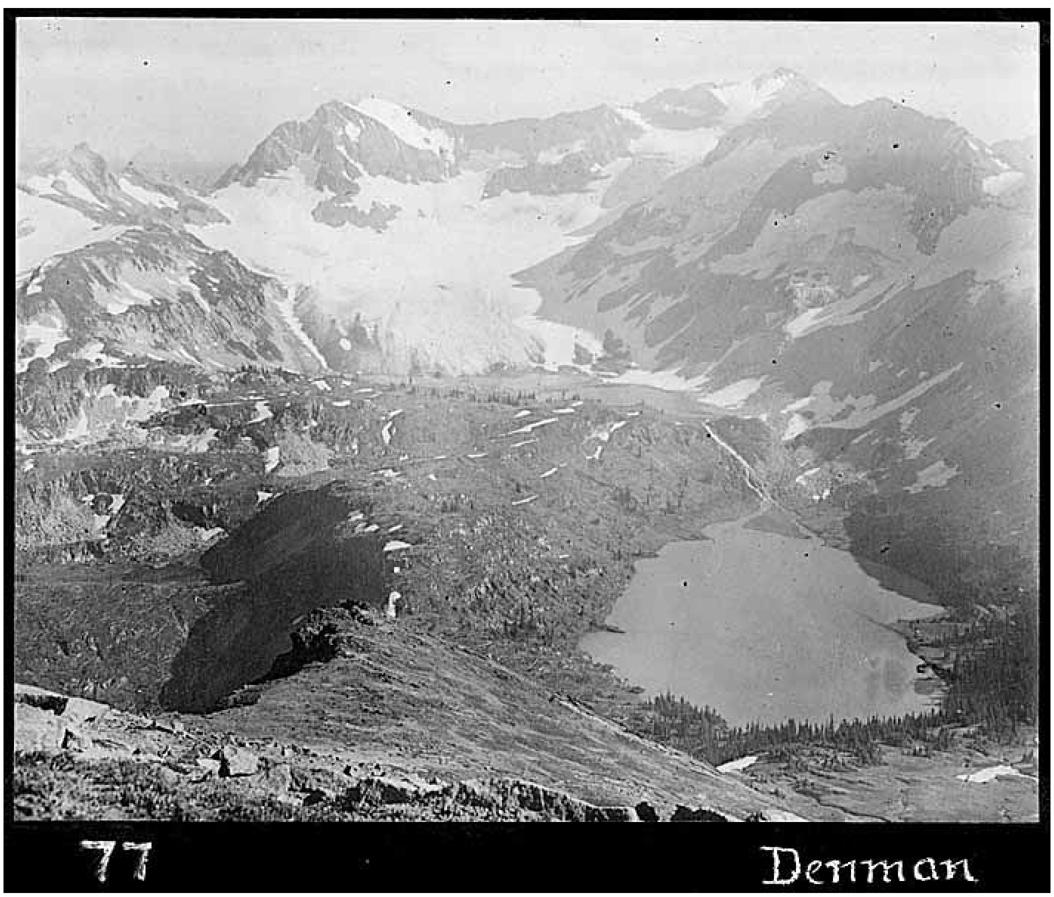

Figure 2. Lyman Glacier in 1921 from north of Cloudy Pass, note the glacier smoothly transitions into the tributary glaciers toward Spider Pass and the western ridge of Chiwawa Peak.

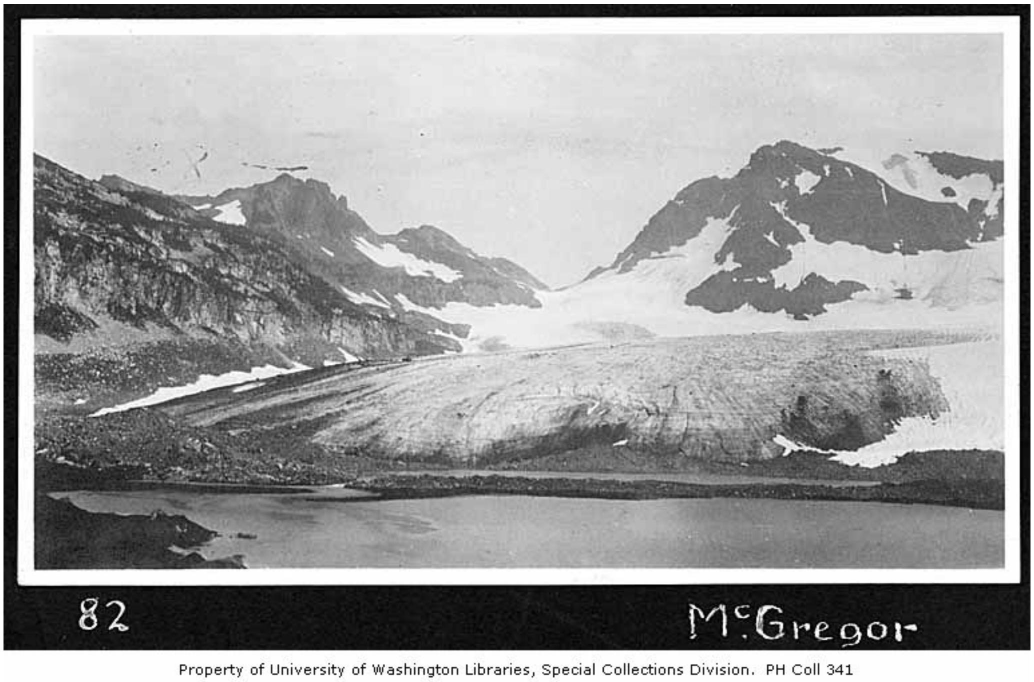

Figure 3. Lyman Glacier terminus in 1921.

Figure 4. Lyman Glacier in 2005 from approximately the same location as in 1921 north of Cloudy Pass.

Figure 5. Terminus of Lyman Glacier in 2008. The calving front extends 26 m above the water line and 16 m below the water line at the center of the glacier. The landslide deposit seen at the snowline in 1972 is largely gone from the glacier front.

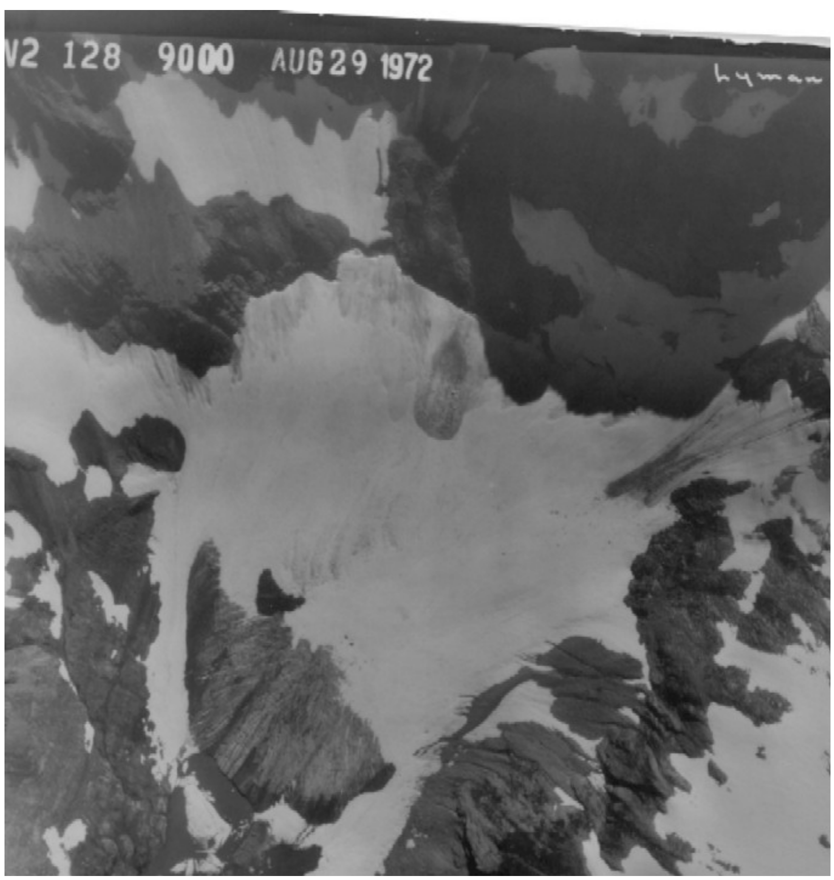

Figure 6. Vertical aerial photograph of Lyman Glacier in 1972, previous to formation of calving front. Note 1926 landslide deposit at the snowline.

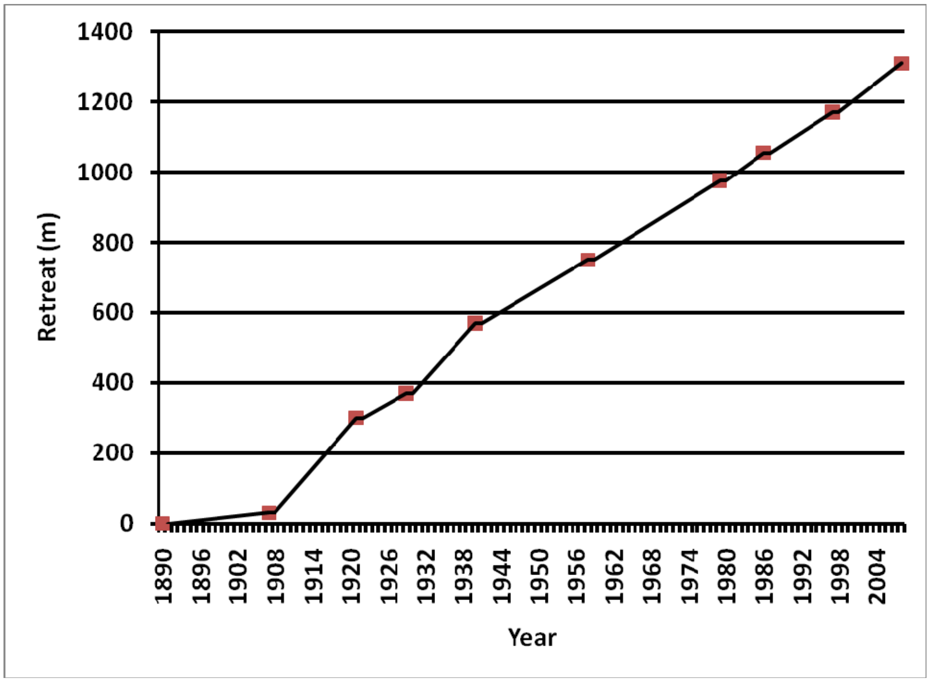

Figure 7. Retreat rate of Lyman Lake 1898 to 2008. Since 1940 the retreat rate has been constant.

AREAL EXTENT

Reduction in aerial extent is based on the LIA moraines which the glacier was observed to be nearly reaching in the 1890's (Freeman, 1941; Long, 1955). Additional photographs from 1921, 1940, 1955 and 1979 allow accurate mapping of glacier area (Jumpponen et al., 1998). SPOT satellite imagery from 2005 also provides an outline of the glacier area that was used in ground reference for the 2008 survey. In 2008 the perimeter of the glacier was mapped using differential GPS. The trunk glacier area has declined from 1.41 km^2 to 0.20 km^2, an 86% decline, a best fit to the exposed bedrock on the headwall and the exposed basal topography of the flat outwash plain, to provide basal topography beneath the glacier (Figure 8). A glacier cross section indicates the observed and reconstructed basal and surfaces of Lyman Glacier for the five points in time (Figure 8). The volume of the trunk glacier has declined by 93% from 150 million m^3 in 1890 to 10 million m^3 in 2008. The volume of the glacier system has been reduced from 189 m^3 in 1890 to 13 million m^3 in 2008, a 93% decline as well. The rate of volume loss of 0.50 million km^3a^{-1} has been relatively constant over the last 53 years. At this rate the 10 million km^3 remaining will be lost in 20 years. For the entire glacier system with the tributary feeders from Spider Gap and Chiwawa Ridge yields an area of 2.31 km^2 in 1890 and 0.28 km^2 in 2008, an 88% reduction. The retreat of the peripheral areas was most rapid from 1921-1944. William Long visited the glacier in 1944 and noted the main trunk glacier had separated from the Spider Gap arm and the Chiwawa Ridge arm (Long, 1955). These were critical feeders to the Lyman Glacier. By 2005 the separated Spider Gap section had melted away. Loss in area has been relatively consistent since 1955, with a loss of 0.008 km^2a^{-1}. A continuation of this rate will eliminate the glacier in 25 years.

VOLUME LOSS

Glacier volume is the product of areal extent and mean depth. In the case of the Lyman Glacier previous USGS maps from 1940 and 1979 and evident LIA trimlines allow reconstruction of the surface profile of the glacier (Figure 9). The bedrock topography is also evident in the deglaciated region. Many glaciated cirques and valleys have a parabolic shape. Lyman Glacier occupies the head of a parabolic shaped glaciated valley.

An equation for the parabolic shape was derived from the exposed bedrock of the cirque basin walls. The parabolic profile was extended under the glacier to reconstruct the bed profile beneath the current glacier. The slope of the glacier has been observed to have remained relatively constant, with slow steepening. The 1921 photographs indicate a consistent surface slope from the terminus to the base of Chiwawa Peak. The 1940 based USGS maps indicate a surface slope of 14o. In 1979 the mean surface slope from the terminus to a point 500 m above the terminus was 15o. In 1986 the slope was measured at 16o for the lowest 400 m. In 2002 and 2008 the mean surface slope from the terminus to a point 200 meters above the terminus was 17o. The reduced profile length corresponds to the reduced glacier length, to keep the sampled region the same. The lack of a significant slope change argues for the lack of complex topography beneath the current glacier.

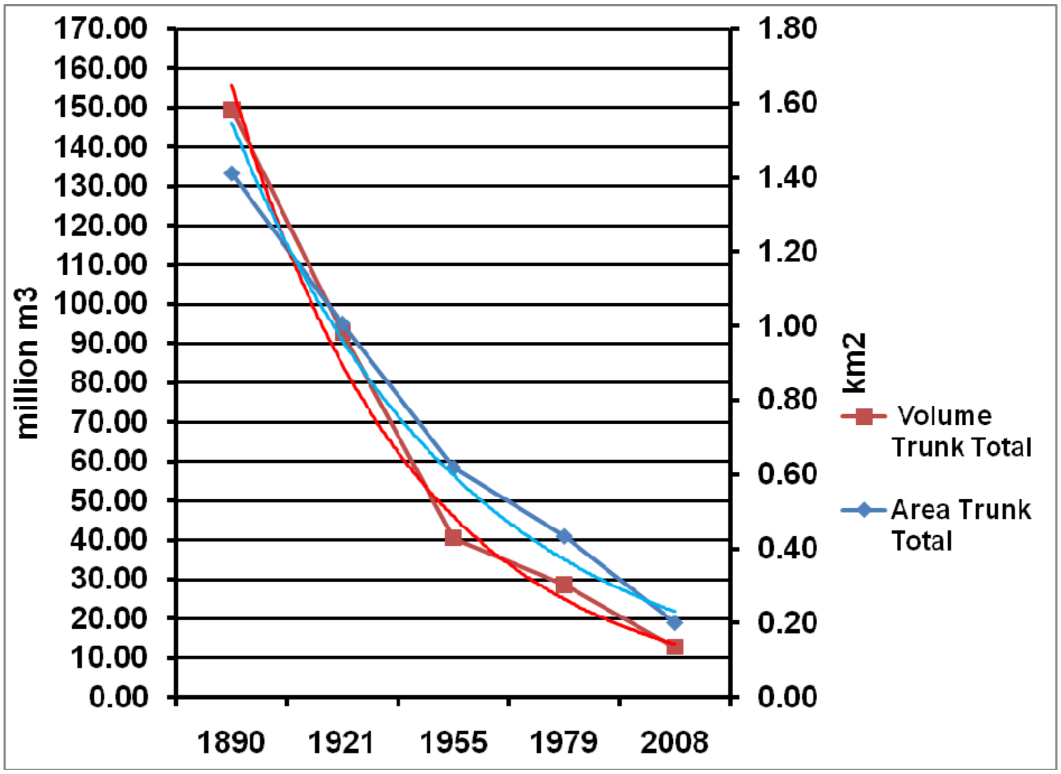

Figure 8. Areal and volume extent loss of Lyman Glacier.

MASS BALANCE

Mass balance observations have been completed during 15 of the last 25 years and AAR observations have been made in 23 of the 25 years, forest fires blocked access in two years. Only two years 1991 and 1999 featured a positive mass balance. Mean annual observed surface mass balance has been -1 ma^{-1}, this is compared to -0. ma^{-1} for ten North Cascades glaciers assessed during those same years. In addition the glacier occasionally calves small icebergs into a lake that the terminus rests in, further raising mass loss. The mean AAR has been 25. A minimum AAR of 60 is needed for an alpine glacier to be in equilibrium (Porter, 1975). Based on the volume loss, mass balance has averaged -1.3 ma^{-1} since 1955. A continuation of the retreat and volume loss rate will lead to the loss of this glacier with present climate by 2040. In recent years mass balance observations have indicated that the glacier AAR averages 25, as opposed to a minimum of 60 needed for equilibrium (Porter, 1975). Ablation measurements on Lyman Glacier from 1986-2008 indicate mean daily ablation in August of 0.034 $mday^{-1}$. The result of glacier area loss is reduced glacier runoff, the observed ablation indicates 370,000 m^3 and 210, 000 m^3 of glacier runoff in August from Lyman Glacier in 1986 and 2008 respectively, this is considerably reduced from the estimates of WWPC of over one million m^3 of runoff in August in the 1920's. The reduced summer runoff fits the pattern noted for other east side North Cascade glacier fed stream such as Stehekin River (Pelto, 2008), with substantial increases in winter streamflow and reductions in summer streamflow.

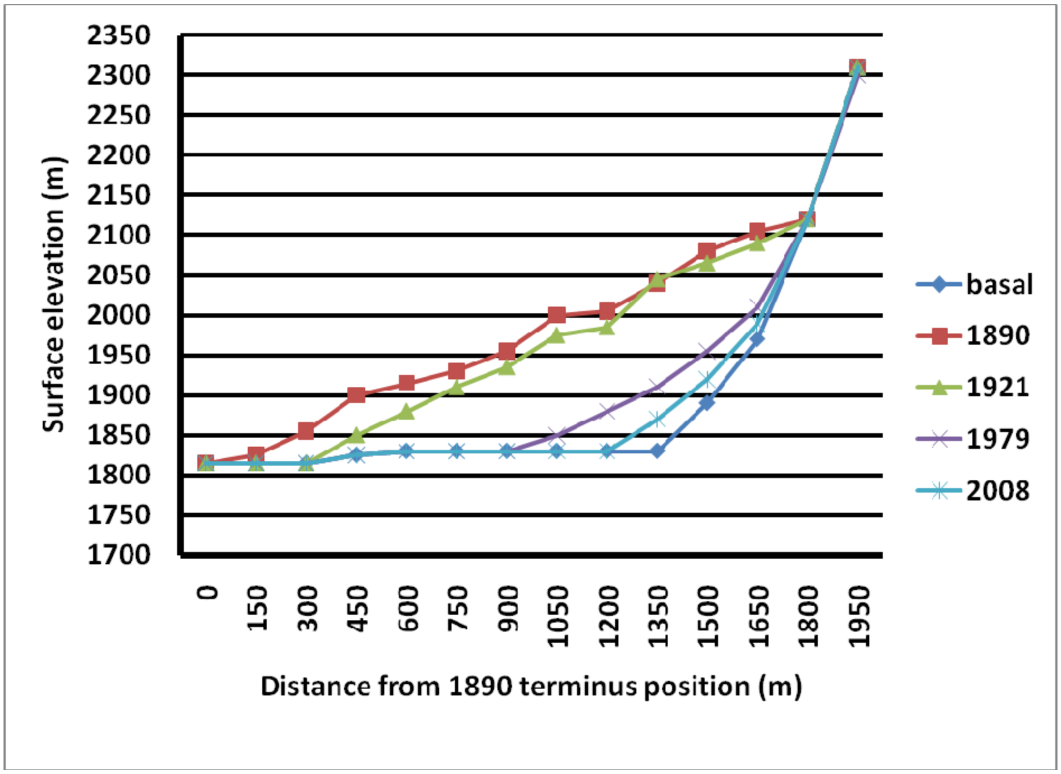

Figure 9. Profile of the Lyman Glacier surface and basal topography. The basal topography is reconstructed under the current glacier, dashed section, using a fitted parabola. The surface topography from 1890 is based on the readily observable Little ice Age trimlines, note the 1921 terminus photograph.

FORECAST

During the entire period from 1890-2008 Lyman Glacier has not approached equilibrium despite a 90% reduction in area. This indicates the glacier remains in disequilibrium with current climate. A glacier in disequilibrium will melt away without substantial climate change favoring positive mass balance (Pelto, 2008). The margin of the glacier in the accumulation zone has been receding around the entire perimeter. This indicates the lack of a persistent accumulation zone, as seen in Figure 3. Mass balance measurements further indicate the near complete loss of snowcover in 2001, 2003, 2004 and 2005. Without a persistent accumulation zone a glacier will not survive (Pelto, 2006; Paul et al., 2004). From 1955-2008 Lyman Glacier has been: 1) Retreating at 10 ma^{-1}, a rate that will lead to glacier loss in about 40 years. 2) Areal extent loss at a rate of 0.08 $km2a^{-1}$, leading to glacier loss in 25 years. 3) Volume reduction has been 0.5 million m^3a^{-1}, leading to glacier loss in 20 to 25 years. All of these factors indicate that with present climate Lyman Glacier should survive another 20-40 years.

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