IS PEAK SNOWPACK IN THE NORTH CASCADE MOUNTAINS DECREASING OVER TIME?

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ABSTRACT

Snowpack records have been kept within the North Cascade Mountains for the past 60 years or more. Analysis of long-term records at selected stations show a dramatic downward trend in peak snowpack accumulations. Data analysis, potential causes and probable effects will be addressed.

INTRODUCTION

Washington State is an area of extreme climatological differences. As an example, historic records *(Western Regional Climate Center - Reno, NV)* show temperature extremes of 118° F to –48° F, annual precipitation ranging from 185 inches to only 2.6 inches and total winter snowfall of 1140 inches.

Record Highest Temperature (degrees F)	118	5 Aug 1961	Ice Harbor Dam
Record Lowest Temperature F	-48	30 Dec 1968	Mazama & Winthrop
Highest Average Annual Temperature F	55.6		Lower Granite Dam
Lowest Average Annual Temperature F	36.5		Mt. Spokane Summit
Record Maximum Annual Precipitation inch	184.56	1931	Wynoochee Oxbow
Record Minimum Annual Precipitation inch	2.61	1930	Wahluke
Record Maximum 24-hour Precipitation inch	14.26	23-24 Nov 1986	Mt. Mitchell #2
Highest Average Annual Precipitation inch	137.21		Quinalt Rngr Stn
Lowest Average Annual Precipitation inch	6.84		Priest Rapids Dam
Record Maximum Winter Snowfall inch	1140.0	1998-99	Mount Baker Ski Area
Record Maximum 1-Day Snowfall inch	52.0	21 Jan 1935	Winthrop
Highest Average Annual Snowfall inch	680.0		Rainier Paradise RS

Washington records, as compared to other states in the Western US, indicate that this state leads the west in extreme accumulations. The following table lists the top ten individual climate stations in the categories of extreme precipitation and snowfall.

Highest Average Annual Precip. (inches)		Most Days >= .01 Inches Precip in a year	
		1. Long Beach Exp Stn, WA	215
1. Quinalt Rngr Stn, WA	137.21	2. Forks 1 E, WA	212
2. Aberdeen 20 NNE, WA	132.64	3. Quillayute, WA	209
3. Valsetz, OR	130.57	4. Astor Exp Stn, OR	206
4. Tillamook 13 ENE, OR	126.50	5. Willapa Harbor, WA	201
5. Spruce, WA	125.31	6. Stampede Pass, WA	200
6. Laurel Mtn, OR	124.20	7. Tolt S. Fk Res., WA	200
7. Nehalem 9 NE, OR	122.25	8. Tatoosh Island, WA	198
8. Port Orford 5 E, OR	120.90	9. Dryad, WA	197
9. S Olympic Tree Fm, WA	120.78	10. Grays River, WA	196
10. Forks, WA	119.08	10. Naselle, WA	196

ACCUMULATED SNOWFALL EXTREMES (inches) (Stations with at least 10 years of data)	
1. Rainier Paradise Rngr Stn, WA	679.4
2. Crater Lake, OR	529.3
3. Alta, UT	515.6
4. Stevens Pass, WA	493.2
5. Soda Springss-CSSL, CA	470.1
6. Santiam Pass, WA	453.3
7. Spirit Lake RS, WA (8 yrs)	445.1
8. Snoqualmie Pass, WA	439.9
9. Stampede Pass, WA	438.7
10. Wolf Creek Pass 1 E, CO	434.3
11. Chiwawa River, WA	417.1
12. Silver Lake-Brighton, UT	412.9
13. Echo Summit-Sierra Ski Rch, CA	412.2
14. Twin Lakes, CA	400.5

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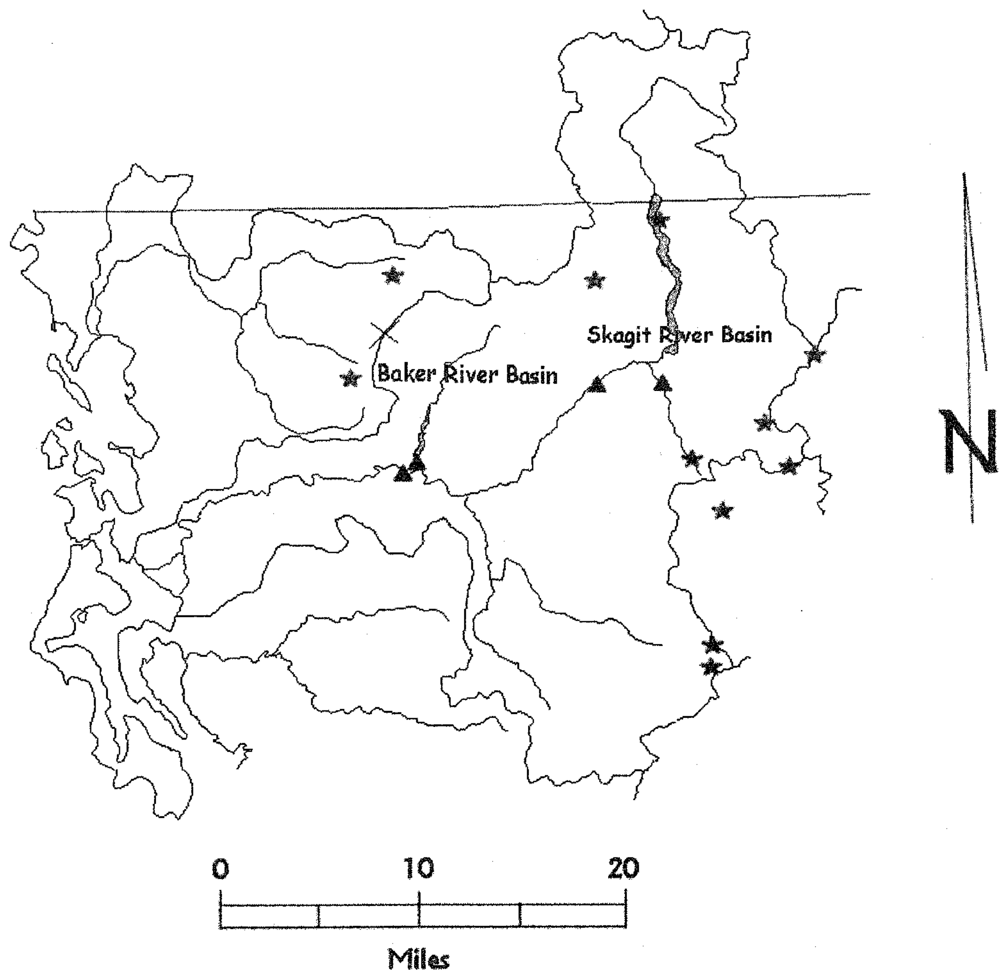
STUDY AREA

The area studied consists of the Skagit and Baker river basins located in the Northwest corner of Washington State. *(fig. 1)*

The Skagit River Basin is primarily fed by the Skagit River from the North, Granite Creek from the South East, Thunder Creek from the South and Beaver Creek to the West. There are a total of 19 snow survey stations, two river gages, four cooperative precipitation stations and three lake elevation gages in the basin *(fig. 2).* Snowpack information is used primarily to manage hydro power generation reservoirs. Data is available as far back as 1928 however, the 1936 to present data sets are more complete and were used in this analysis.

The Baker River Basin, located on the East flank of Mount Baker, stores water for power generation and recreation at two reservoirs. There are nine snow survey stations, two stream gages and two cooperative precipitation stations *(fig. 3)* with data available from 1959 to present.

The National Park Service has been conducting mass balance studies on five glaciers within the study area. The North Cascade National Park is home to some 300 plus glaciers, approximately one-third of the total number of glaciers in the lower 48 states *(Post et. Al 1971).*



(Figure 1, Regional map of study area.)

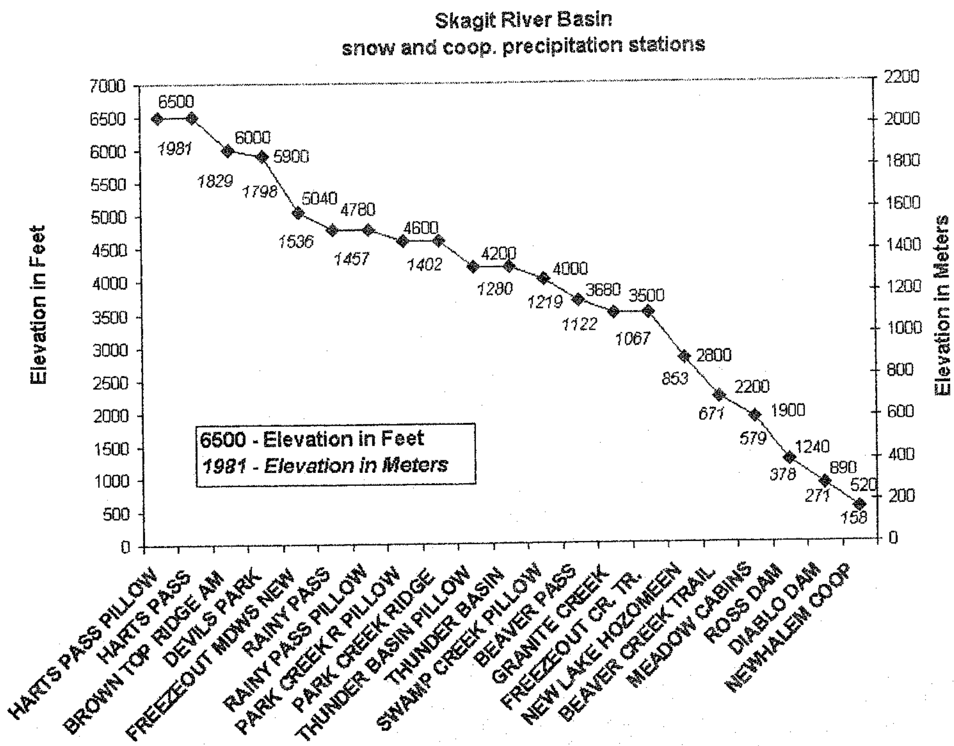


Figure 2, List of Skagit River snow and coop. precipitation stations

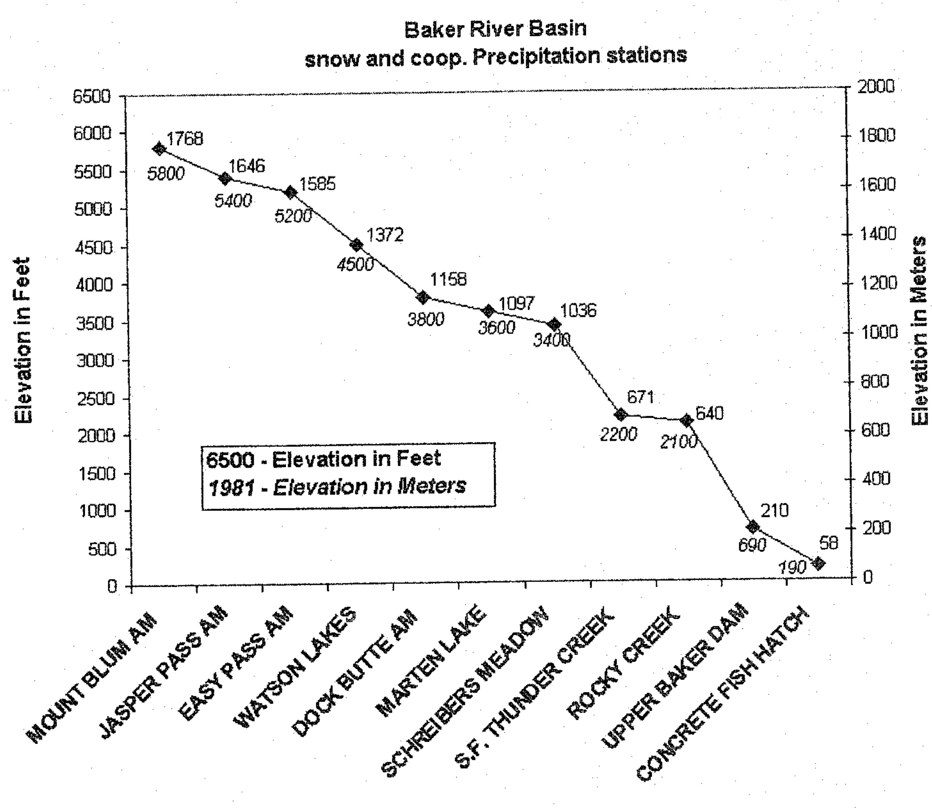


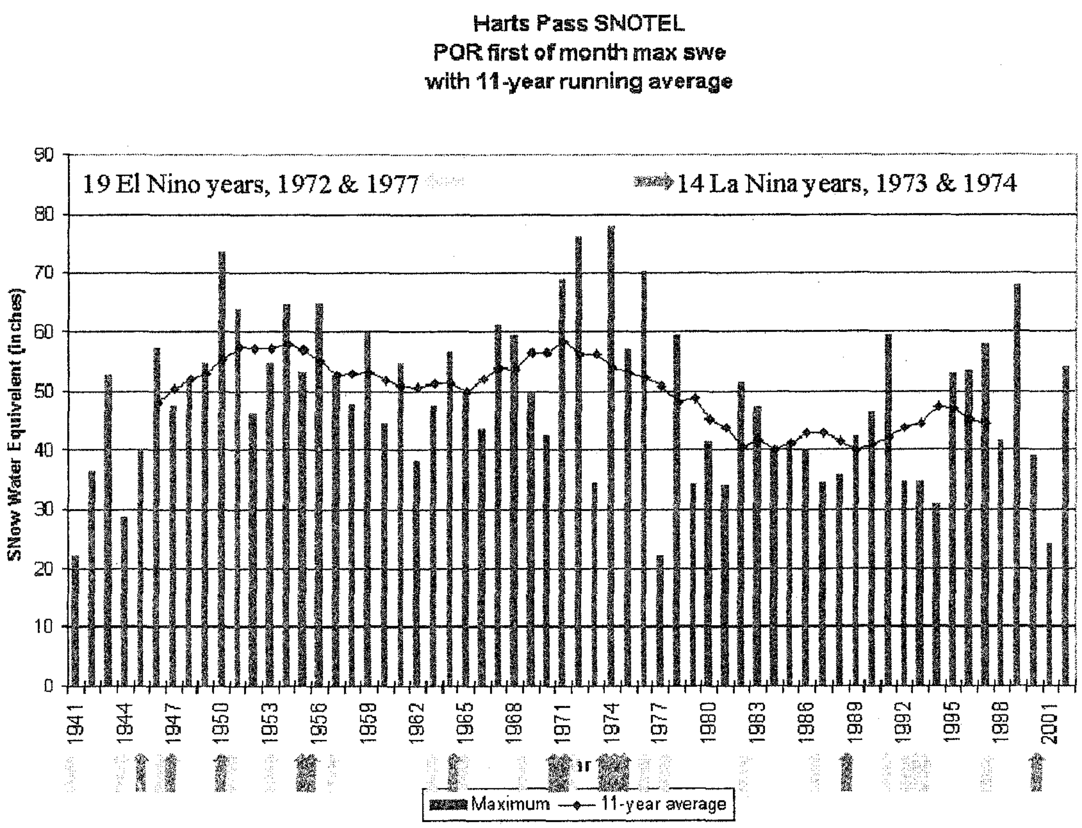
Figure 3, List of Baker River snow and coop. precipitation stations

METHODOLOGY and COMPARATIVE RESULTS

The primary objective of this analysis is to determine if peak annual snow water equivalent (SWE) is in fact decreasing over time. Many variables can play into the validity and accuracy of the study. Change in canopy, longevity of data collection, inconsistent human factors, El Nina & La Nina, and site accessibility are but a few.

This particular study explores the long-term data collected at each site without adjustment for the factors listed above. However, sites with less than ten years of consistent data were not used in the analysis.

Known Enso years were also explored on a minor scale. Comparison of Enso years to maximum SWE accumulation at Harts Pass *(fig. 4)* shows the variability of Enso by Southern Oscillation Index (SOI) influence. High and low snowpack seasons can be experienced in both El Nina and La Nina years. In example; 1972 and 1977 were both considered El Nina years with 1972 being the highest SWE on record and 1977 the lowest on record. La Nina years 1973 and 1974 show a like comparison.

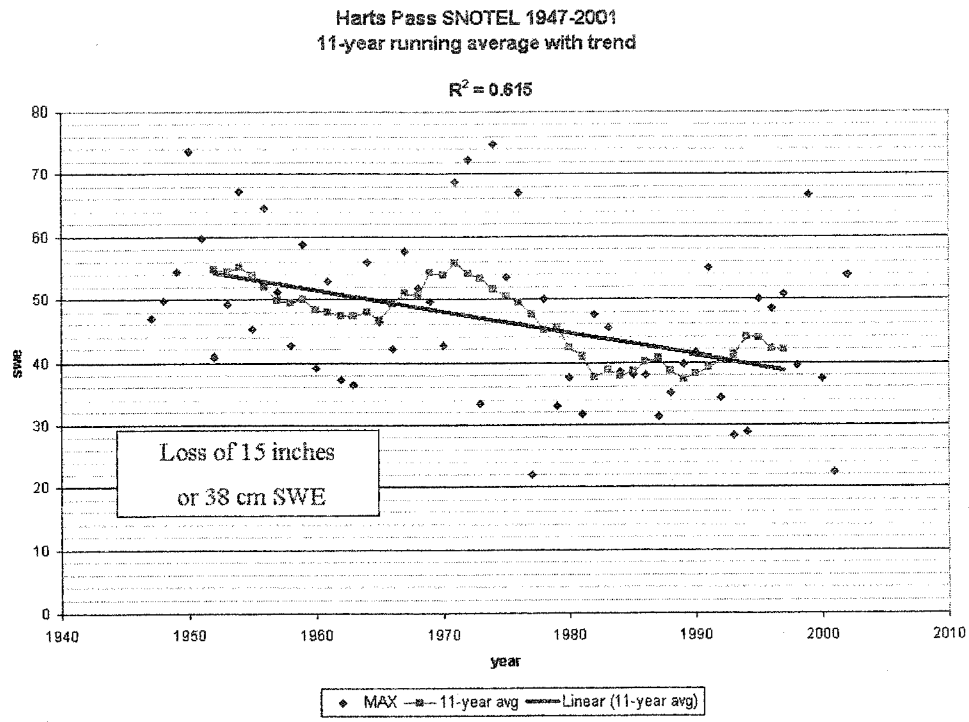


(Figure 4, Enso effects on maximum SWE at Harts Pass)

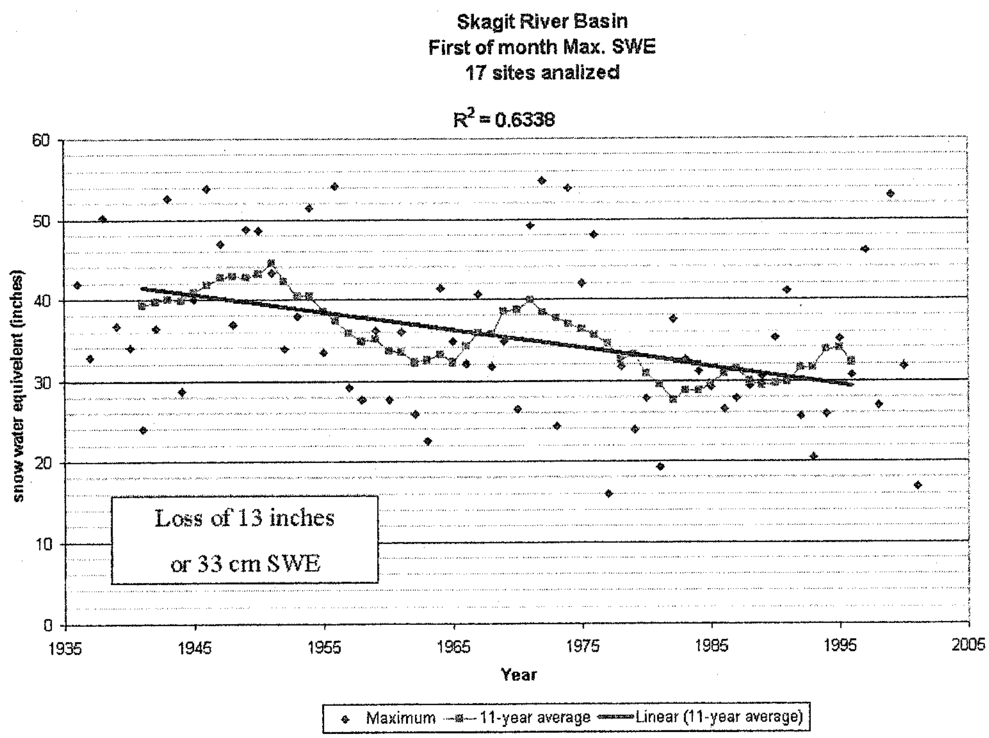
Historic site data was polled for maximum first of month snow water equivalent. Most sites have been and continue to only be manually measured once per month with occasional readings taken at mid month. SNOTEL data was not introduced until approximately 1978 with more automated stations being added throughout the span of 20+ years. There are now six SNOTEL sites being monitored within the Skagit River Basin, however only four of them have enough snowpack data (minimum 10 years) and/or were co-located with long term snow courses to be of much use. The Baker River system has no SNOTEL at this time. Thus, the majority of the data used in both basins was collected at manual and aerial sites.

Short term (less than 20 years) SNOTEL precipitation and temperature data was reviewed but not used in the analysis. Correlation's between this data, SWE and streamflow didn't appear to have a strong influence over the results of the study, nor did National Weather Service (NWS) valley precipitation.

Maximum SWE for each site and basin grouping of sites were than processed with an 11-year average to smooth the data. These averages were then graphed to show linear trend and regression*(Fig 5 & 6).*

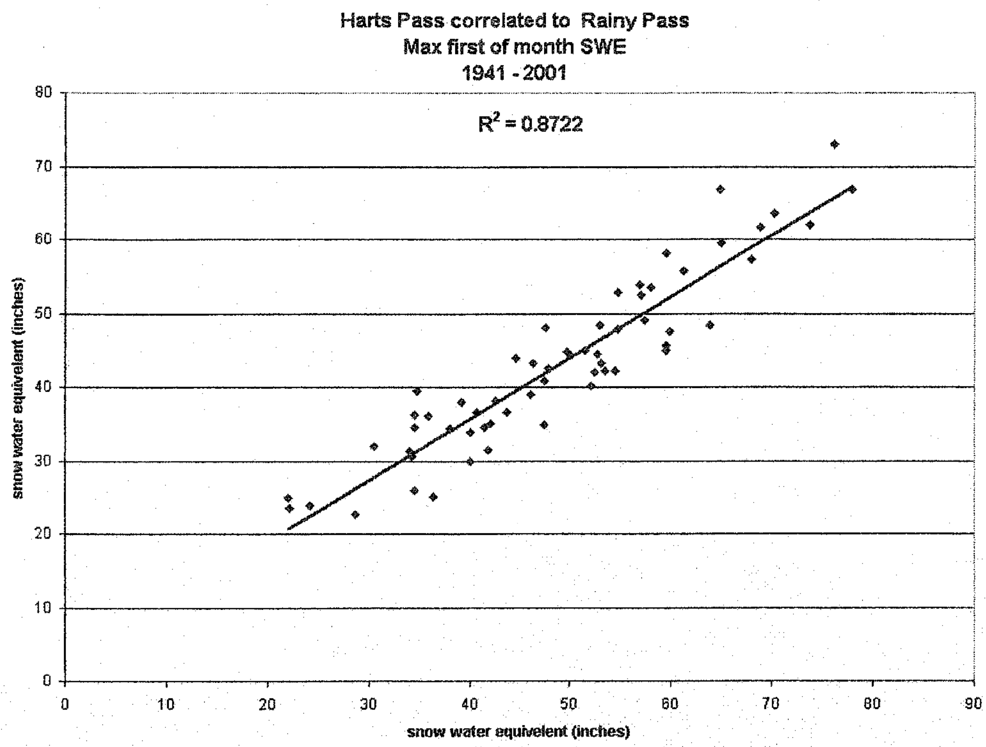


(Figure 5, Linear trend of Harts Pass)



(Figure 6, Linear trend of 17 Skagit River sites with at least 10 years of data)

Site-to-site correlation's of the 11-year moving average were also run to determine the consistency of data within each basin . An example of two sites with a strong correlation is presented in *(fig. 7)*. Many sites within the respective basins showed good to excellent correlation's though there were a few poor representations *(fig. 8)*. These poor correlation's can mostly be attributed to elevation differences. It is found that the lower elevation sites tend to be more transitory in nature and are susceptible to rain-on-snow events that may create a wider degree of margin in maximum accumulation. In contrast, mid to upper elevation sites collect and keep the snowpack throughout the entire winter, except on rare occasions.



(Figure 7, linear correlation of Rainy Pass and Harts Pass SWE)

SKAGIT RIVER												
R sq.	Harts	Rainy	Park	Thunder S	Beaver Ck	Beaver PS	Brown Top	Devils	Freezout t	Freez Med	Granite	Hozom
Rainy	0.87											
Park	0.78	0.85										
Thunder SC	0.56	0.68	0.70									
Beaver Ck	0.51	0.55	0.67	0.66								
Beaver ps	0.66	0.69	0.75	0.78	0.81							
Brown Top	0.85	0.90	0.80	0.68	0.63	0.81						
Devils	0.77	0.86	0.71	0.65	0.44	0.61	0.88					
Freezout t	0.62	0.71	0.76	0.76	0.81	0.87	0.81	0.62				
Freez med	0.64	0.72	0.68	0.57	0.59	0.67	0.77	0.66	0.76			
Granite	0.71	0.80	0.79	0.80	0.71	0.80	0.79	0.74	0.88	0.78		
Hozom	0.52	0.57	0.68	0.71	0.84	0.80	0.71	0.50	0.90	0.69	0.83	
Meadow c	0.26	0.34	0.37	0.46	0.50	0.37	0.40	0.31	0.54	0.38	0.65	0.61
Thunder ST	0.60	0.60	0.62	0.69	0.38	0.55	0.64	0.50	0.67		0.75	0.60

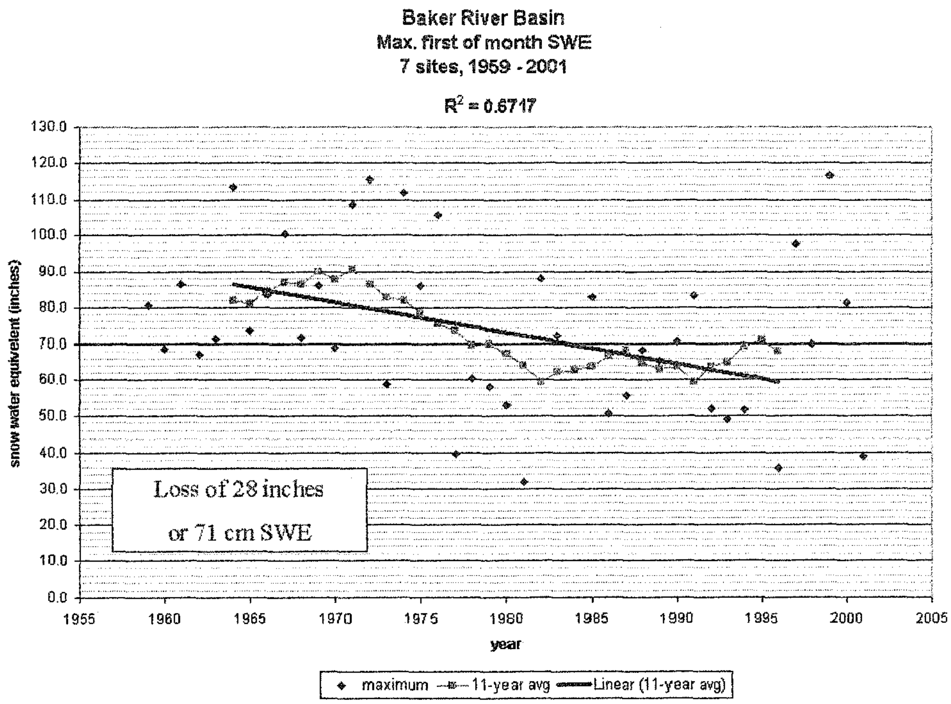
BAKER RIVER								
	Dock	Easy	Jasper	Martin Lk	Mt. Blum	Rocky	Schreib	SF Thund
Easy	0.74							
Jasper	0.83	0.87						
Martin LK	0.92	0.82	0.88					
Mt. Blum	0.64	0.76	0.70	0.74				
Rocky	0.67	0.54	0.52	0.67	0.48			
Schreib	0.92	0.70	0.79	0.89	0.61	0.73		
SF Thund	0.53	0.39	0.40	0.47	0.26	0.61	0.49	
Watson	0.93	0.79	0.86	0.94	0.63	0.69	0.91	0.53

(Figure 8, table of site correlation's by R^2, all sites not represented)

BASIN ANLYSIS

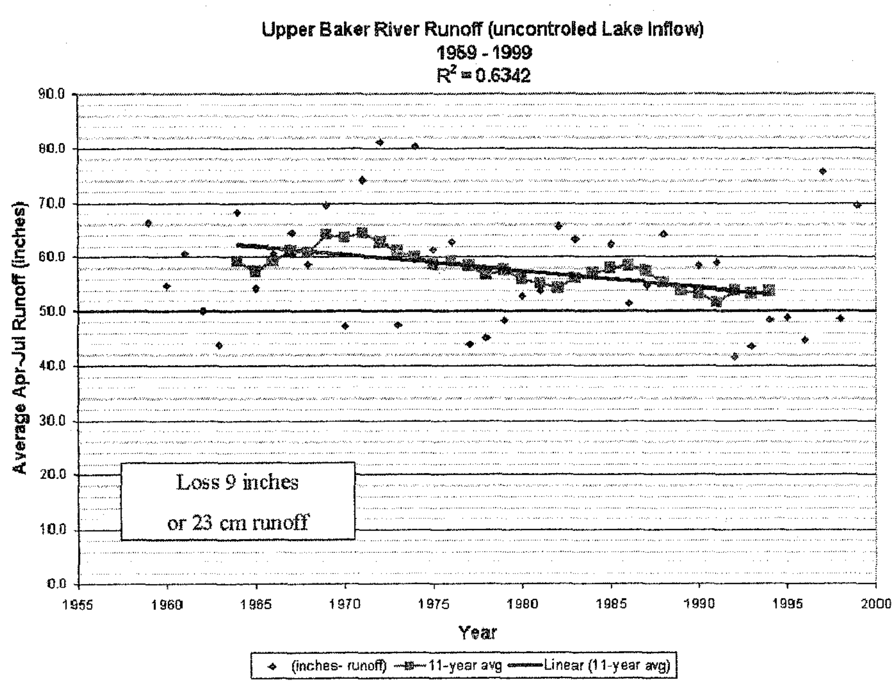
The Baker River was selected for a more complete analysis of maximum snowpack as compared to precipitation and streamflow because of the availability of complete and balanced data sets. The Baker River has reliable and consistent data sets starting in 1959, through the present.

As a start, maximum first of month SWE was analyzed as described above with the resulting R^2 coefficient of .67 *(fig. 9)*. Seven snowpack stations showed an apparent loss of 28 inches (71 cm) total maximum SWE over a 42-year period. Accounting for a 68% decrease.

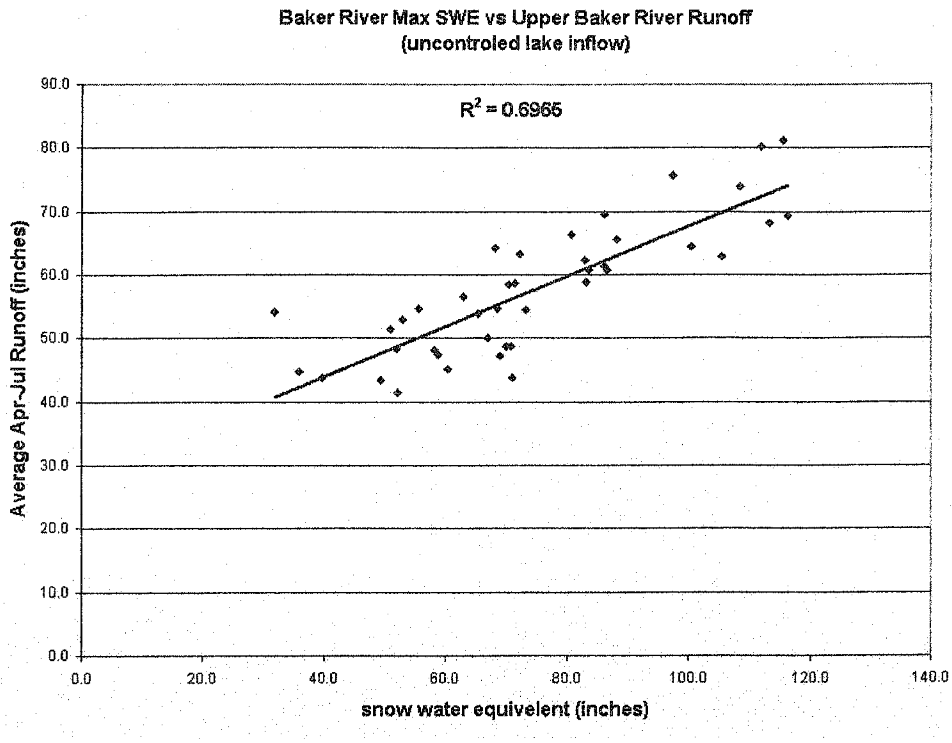


(Figure 9, Baker River Basin SWE linear trend)

Following a like trend, the Upper Baker River runoff (April – July, uncontrolled lake inflow) showed a reduced flow of 9 inches (23 cm) over the same period *(fig 10)*. As would be expected, there is a significant correlation between basin maximum SWE and uncontrolled runoff, R^2=.70 *(fig. 11)*.

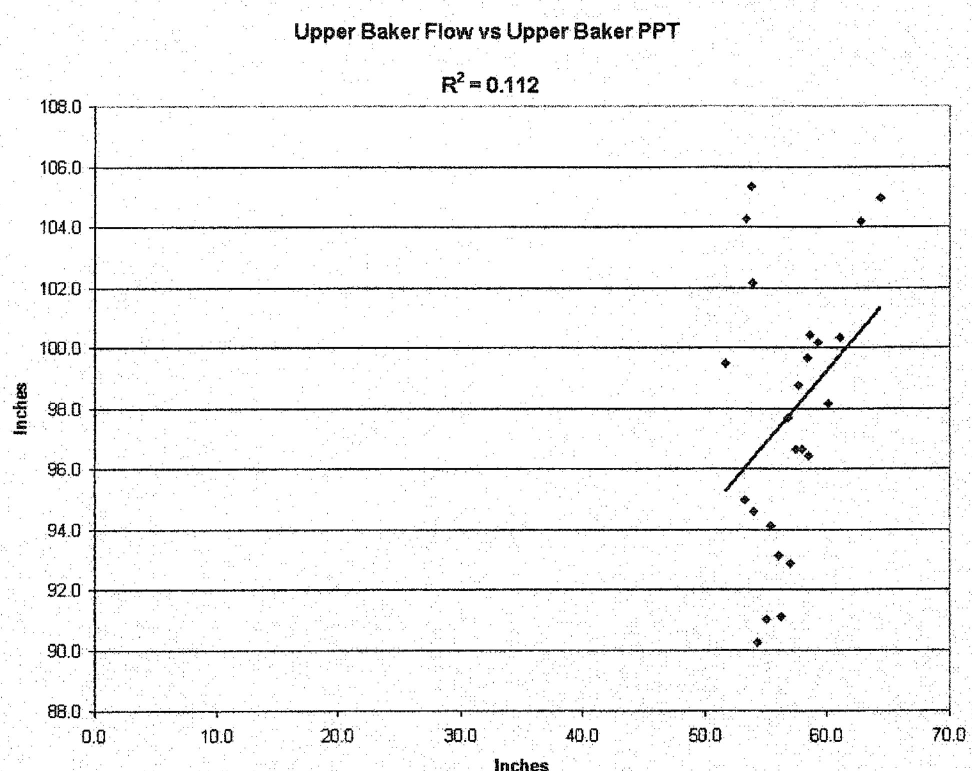


(Figure 10, Upper Baker River average April-July runoff)



(Figure 11, maximum SWE as compared to runoff)

In contrast, when runoff at Upper Baker River was compared to basin precipitation at both the Concrete Fish Hatchery and Upper Baker Dam, the analysis showed R^2 correlation's as low as .35 and .11 respectively (fig. 12). Analysis of basin precipitation indicated no significant change over the period 1959-present. Precipitation stations within the Baker and Skagit basins showed reasonable correlation with each other but did not indicate a significant role in peak runoff. Nor did basin precipitation show positive correlation with basin SWE.



(Figure 12, Upper Baker River runoff as compared to Upper Baker Dam precipitation)

NORTH CASCADE GLACIER STUDY

The National Park Service began monitoring glaciers in North Cascades National Park in 1993. Goals for this program and additional data can be found at North Cascades National Park home page at http:/www.nps.gov/noca/massbalance.htm.

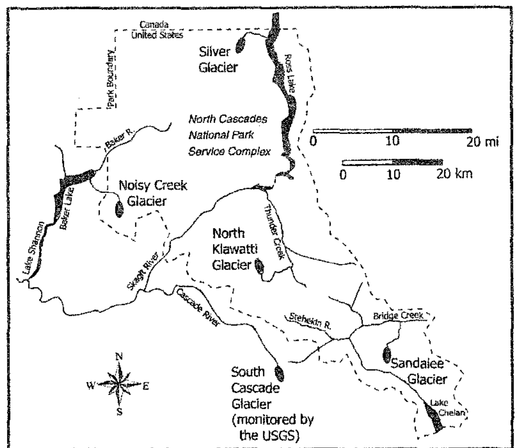


Figure 1. Glaciers monitored in North Cascades N.P.S. Complex.

The four glaciers monitored are located at the headwaters of four park watersheds, each with large hydroelectric operations *(Figure 1)*. The glaciers represent a range in elevation from 8500 to 5700 feet, and a range in climatic conditions from maritime to continental.

Estimates of glacial contribution to runoff for three watersheds are based on the mass balance measurements (figure 2) and GIS analysis to determine glacier area within 165 ft elevation bands *(Table 2)*. Glaciers reduce the variation of flow in these watersheds by providing meltwater from ice in dry/warm years, and by storing water in wet/cool years. Glacial contribution to streamflow in these watersheds varies by as much as 100% annually. Magnitude of glacial contribution to streamflow is large, but varies by the amount of glacial cover in each watershed. Thunder Creek is 13% glaciated, while Baker River and Stehekin River are 6% and 3%, respectively (Post and others, 1971).

Relative importance of glacial contribution to streamflow increases from west to east. For example, glaciers annually contribute a higher percentage of meltwater to streamflow in the Stehekin watershed than in the Baker, despite the fact that the Baker is more glaciated. This is due to lower snowfall east of the hydrologic crest of the North Cascades. In this high accumulation year, we anticipate that glacial contribution to summer runoff will be below average in these watersheds.

	Mean Glacial Runoff	Range of Glacial Runoff		Percent Glacial Runoff to Total Summer Runoff	
		Minimum	Maximum	Minimum	Maximum
Noisy Creek Glacier	1.6	1.1	2.1	---	---
Baker River Watershed	74	51	93	6	14
North Klawatti Glacier	3.9	2.8	4.8	---	---
Thunder Creek Watershed	102	80	135	23	45
Sandalee Glacier	0.4	0.4	0.5	---	---
Stehekin River Watershed	68	54	91	6	16

Table 2. Glacial contribution to summer stream flow (May 1 to Sept. 30) for three watersheds. Runoff units are thousands of acre-feet. Data from 1993-2001 except the Sandalee Glacier and Stehekin River Watershed (1995-2001).

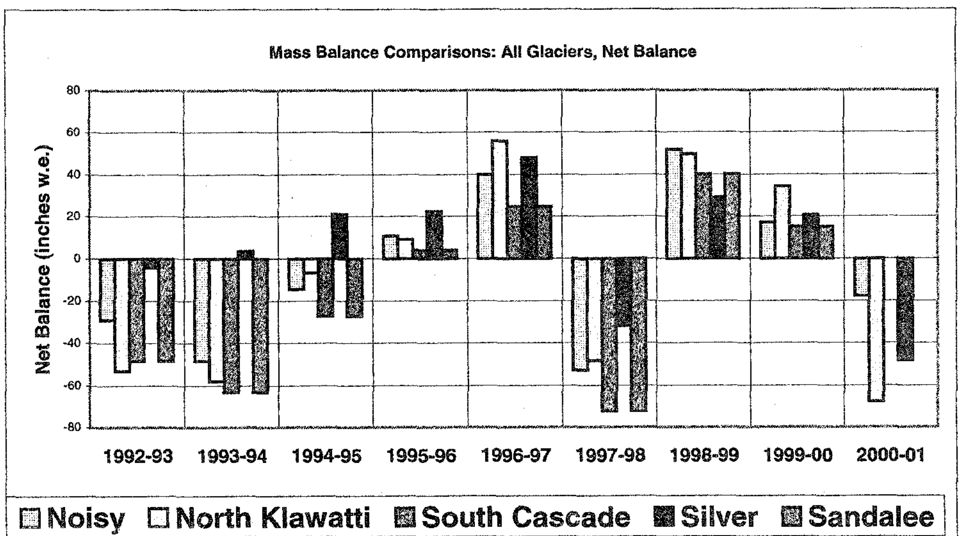


Figure2. Net annual mass balance for the five glaciers monitored in the North Cascades

SUMMARY

This rudimentary analysis indicates that maximum annual snowpack in the North Cascade Mountain Range could in fact be decreasing over time. Reductions in summer runoff are also evident, however summer runoff does not appear to show the dramatic reductions that appear in the snowpack. This may be attributed to added glacier contributions during low snow years, helping to balance river basin runoff.

Annual precipitation appears to be holding steady or showing slight increases, though the lack of long-term, high elevation data may reduce the statistical viability of it's use. Analysis confirms that these basins are snowpack driven which may raise concerns regarding reservoir management in future years.

The cause may be attributed to any number of arguable climatic and hydrologic concerns such as global warming or climate change. The fact remains that there appears to be a dramatic downward trend in maximum snowpack, warranting further in-depth study.

REFERENCES

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http://www.nps.gov/noca/massbalance.htm

US Geological Service, Tacoma, WA
http://www.usgs.gov

Seattle City Light, Skagit River Project

Puget Sound Energy, Baker River Project