Geomorphology Lab: **Glacier Mass Balance**

The purpose of this exercise is to illustrate features about glaciers, glacier change, and effects on the landscape. The glacier of interest here is South Cascade Glacier located on the crest of the North Cascade Range of Washington. It takes about 2.5 - 3 hours to drive to the nearest trailhead from Seattle. The glacier is SE of Mt. Baker and N of Glacier Peak. This glacier is within the Skagit River drainage basin. Just on the other side of the crest, water flows to the Columbia in eastern Washington.

South Cascade Glacier has the longest history of mass balance measurements in North America and second longest in the world, after Storglaciären in Sweden. Mark Meier initially selected South Cascade for long-term study in 1958 after reviewing a number of other candidate glaciers. Favorable features of the glacier (see attached figures) include 1) the glacier geometry is simple and almost all parts of the glacier are accessible; 2) not too large, about 4 km^2 when the study started (note the gauging station at the end of the lake, 3) the glacier is relatively easily accessible by trail; and 4) the glacier resides in a hydraulically well-defined basin. Since 1958, the glacier has been the site of many studies on mass balance, ice flow, and glacier hydrology. As part of the basic monitoring program, yearly measurements are made of mass balance, terminus change, and surface topography. Hourly measurements are made of the weather, and runoff. This is one of 3 sites in the US measured in detail by the US Geological Survey.

A few articles on the glacier include:

Meier, M.F., Tangborn, W.V., Mayo. L.R., and Post, Austin, 1971. Combined ice and water balance of Gulkana and Woverine Glaciers, Alaska, and South Cascade Glacier, Washington, 1965 and 1966 water years. U.S. Geological Survey Professional Paper 715-A, 23 p. The nitty gritty of mass balance calculations, not suitable for children or young adults.

Meier, M.F., and Tangborn, W.V., 1965. Net budget and flow of South Cascade Glacier, Washington. Journal of Glaciology, 5(41), 547-566. This paper in many ways set the stage for how we think about alpine glaciers. Often referenced in textbooks.

The Krimmel series of annual reports starting in 1989, the most recent of which is, Krimmel, R.M. 1999. Water, Ice, Meteorological and Speed Measurements at South Cascade Glacier, Washington, 1998 balance year. US Geological Survey Water-Resources Investigations Report 99-4049. 36 p. Good overview of mass balance methods combining traditional and modern methods, with up to date data for the basin.

Reports will be typed (font 12 pt) and each answer will follow the numbering system of the questions and be in consecutive order. Graphs need to be adequately labeled including axis labels with units. All features in a graph or drawing must be identified. Neatness counts and all pages need to be stapled.

Questions

Examine the map of net mass balance for South Cascade Glacier in 1965. This map is of the same glacier depicted in the photos attached later in the lesson. Note the date, November 2, very late in the autumn. It must have been a very warm autumn. Each point represents the location of a stake where the mass balance was measured. Ignoring the ice patches on the east side of the glacier and the tributary glacier on the west side, our attention will be focused on the main trunk of the glacier.

1. (5 pts) To see the broad changes in mass balance we need to contour the net mass balance measurements. The contour interval is 1.0 meters water equivalent (m weq) and the range starts at -4.0 m weq and ends at 1.0 m weq. Make the contours in solid lines and label each contour. Include a contour for the 1.5 m weq. Note, your map will have two sets of contour intervals, one set for altitude and the other for mass balance.

2. (2pts) Lightly shade in the ablation zone.

Again using the same map, draw a line down the center from the glacier. The line should start at the middle of the glacier where it meets the lake. It should follow the centerline of the glacier in a smooth manner and terminate at the middle of the very top of the glacier. The location of the latter is somewhat arguable. To settle that debate here and now, terminate the centerline profile where the 2150 m contour line meets the glacier boundary right by the latitude mark of $48^{o}21'$.

3. (5pts) Create table of values (two columns) including altitude of the glacier surface in one column and the value of mass balance at that altitude. For consistency, take the altitude only where the centerline profile crosses the altitude contour. You will have to estimate the mass balance at that point based on the contours you constructed.

4. (5pts) Plot the data with elevation on the x-axis and mass balance on the y-axis.

5. (3pts) According to your plot, what is the equilibrium line altitude (ELA)?

6. (5pts) How does this value for the ELA compare to the altitude of the entire equilibrium line on the map? Explain.

Examine the two figures of South Cascade Glacier [[noting the year of photography for each]] and the longitudinal profile of the glacier, which is drawn to scale. The lake, South Cascade Lake, did not exist in 1928 when the glacier almost completely covered it.

On both figures, we can see the snowline. Note the dates of the photos. Clearly they are at the end of the season. We can assume that the snowline is a close approximation of the annual equilibrium line.

7. (3 pts) Draw on each photograph, in colored pencil or ink (not black) the boundary between the accumulation and ablation zones. Ignore the small snow and ice patches away from the main glacier. During the time that has elapsed between the two dates has the equilibrium line remained stationary, or moved to higher or lower elevations? Please note that there may be small year-to-year variations in the ELA without a significant change in ELA. For the purpose of this exercise, you are not concerned with the specific details of the exact ELA position, rather whether the ELA has changed significantly.

8. (10 pts) Please describe how the glacier has thinned over the whole glacier and retreated, identifying features on the photos as evidence. Denote the features on the figure with numbers and lines (or arrows) and refer to these in the text. Include on the longitudinal profile your estimate of the surface of the glacier in 1983.

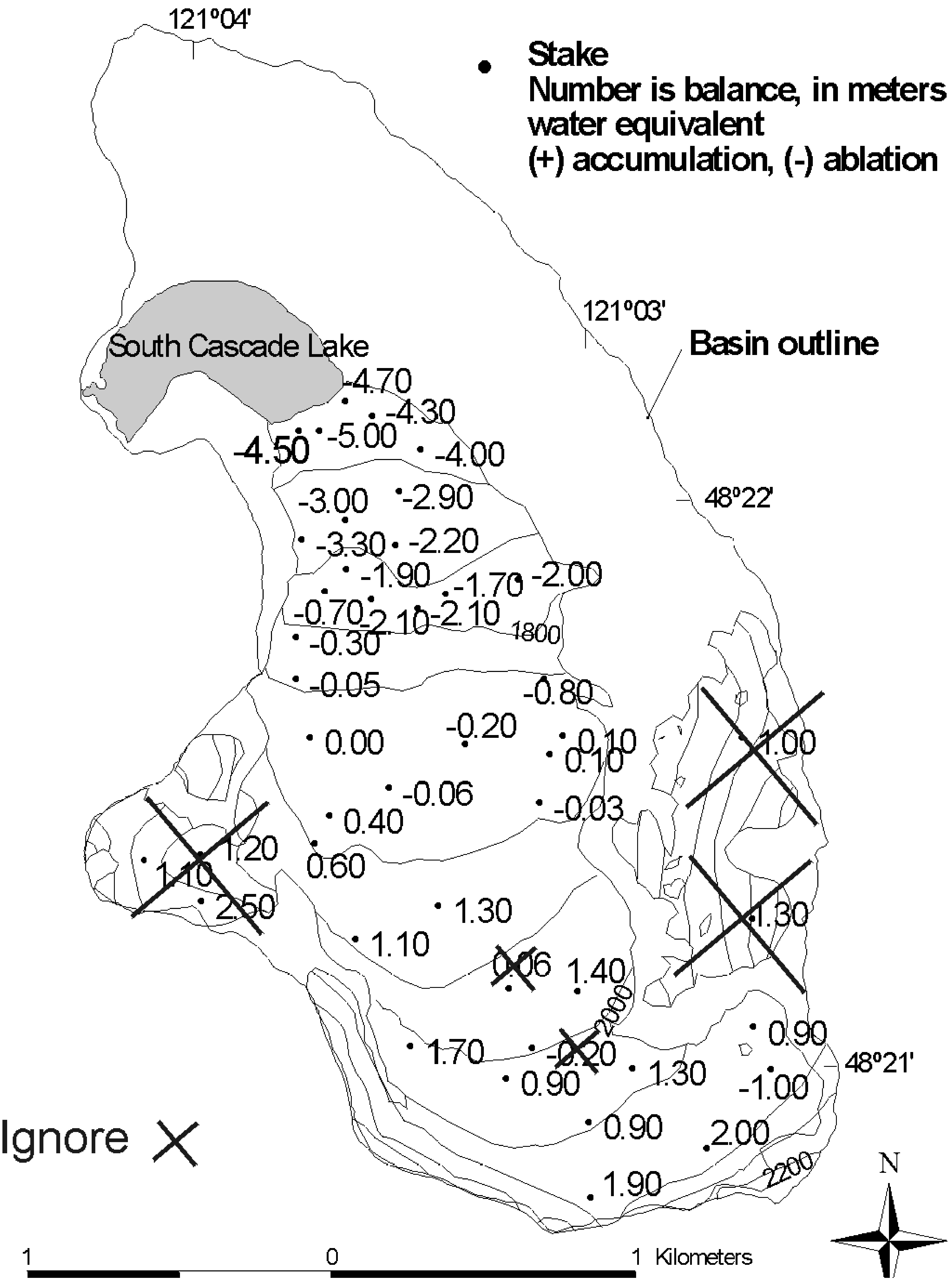
9. (5pts) Based on your answers in (7) and (8.) what is going on climatically? They seem to provide contradictory answers. Or do they? Assume (and correctly so) that there is no late season snow fall that changed the position of the snowline (ELA in this case) just before the photograph was taken.

10. (5pts) Attached is the mass balance data from South Cascade Glacier (Krimmel, 1999). Put these values into a spreadsheet with the columns in the following order: Year, Summer Balance, Winter Balance, and Net Balance. Don't forget the units. Krimmel provides winter [b_m(s)] and net values [b_n]; you need to calculate summer values. Remember, Net Balance = Summer Balance + Winter Balance. Plot the results for the net, summer, and winter balances all on the same graph. Time is on the x-axis and balance is on the y-axis. Explain what this graph is showing.

11. (3 pts) For the years 1961 through to 1983, what was the net mass change for the glacier? Add up all the values of net mass balance from 1961 through 1983. Does this jive with (8)? Explain.

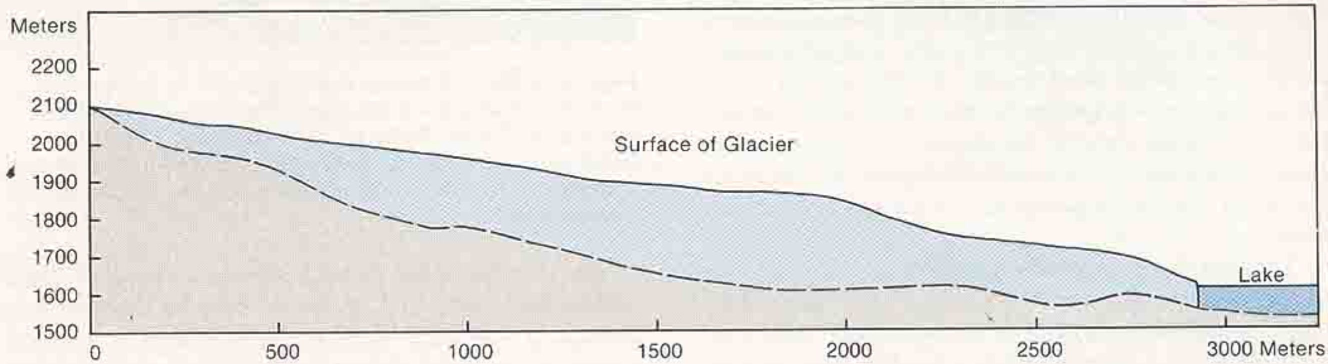
12. (3pts) From 1984 to the present, what is the net mass change? From this value, what is your estimate of what happened to the glacier since the photo taken in 1984?

South Cascade Glacier
November 2, 1965



A

Oblique aerial photographs of the South Cascade Glacier, Washington. (*A*) September 27, 1960; Neg. No. FR6025-50. (*B*) October 10, 1983; Neg. No. 83R1-188. (Courtesy of Andrew G. Fountain, U.S. Geological Survey, Tacoma, Washington.)



Longitudinal profile of the South Cascade Glacier during the 1965-66 budget year. No vertical exaggeration. (Based on U.S.G.S. Professional Paper 715-A, 1971.)

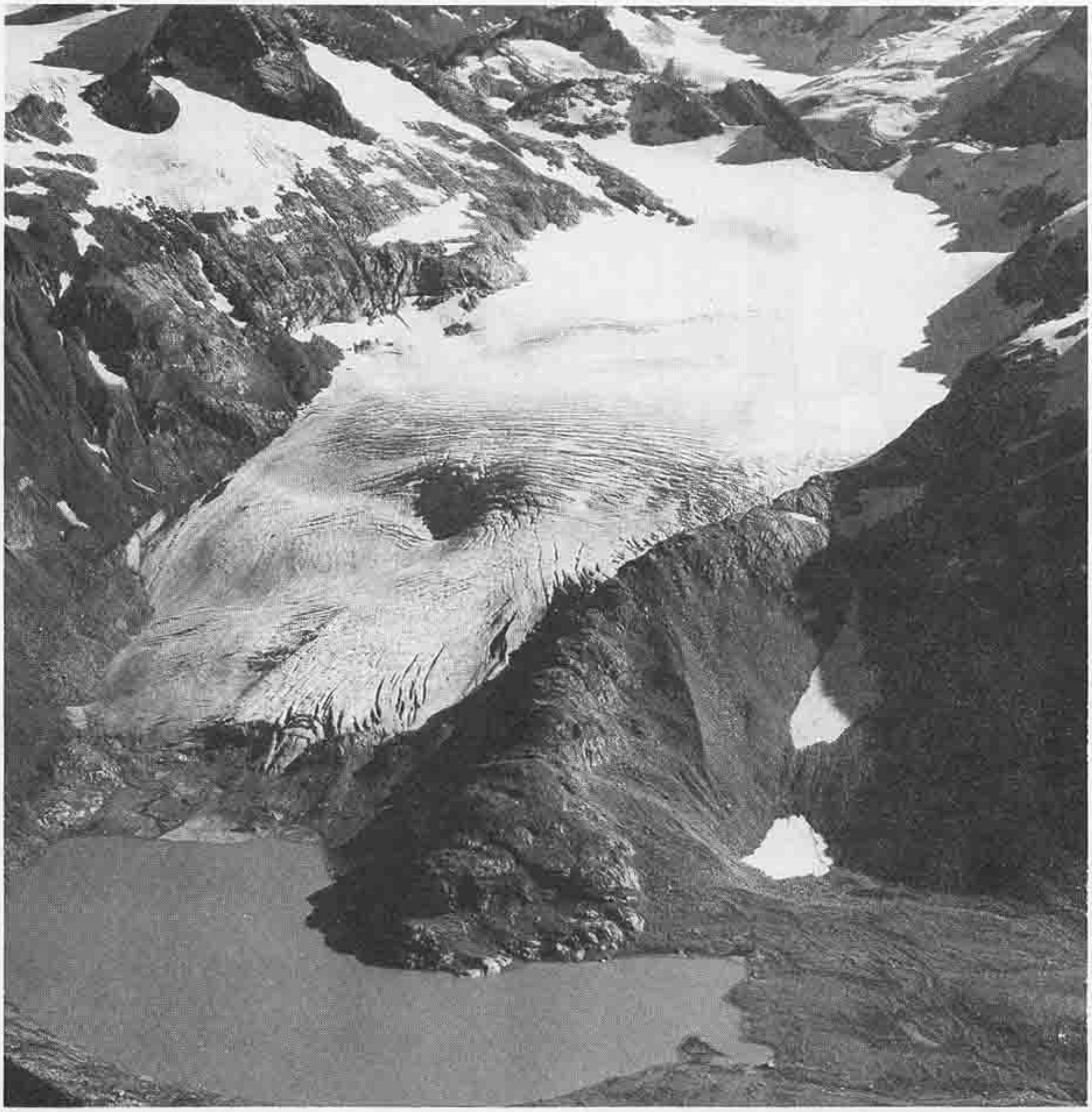

B

TABLE 16. Mass balance time series at South Cascade Glacier

[For years 1986-91, net balance, $\bar{b}_n$, was determined by the index regression method discussed in Krimmel (1989) and has an error of 0.23 m. For years 1959-64 and 1968-82, winter balance, $\bar{b}_m(s)$, was determined from unpublished snow accumulation maps and has an error of 0.12 m. For years 1983-1991, $\bar{b}_m(s)$ was determined using the index station regression discussed in Krimmel (1989) and has an error of 0.23 m. For years 1992 to 1998, $\bar{b}_n$ and $\bar{b}_m(s)$ were determined by the grid-index method (Krimmel, 1996b)]

Year[1]	$\bar{b}_m(s)$ (meters)	$\bar{b}_n$ (meters)	Year[1]	$\bar{b}_m(s)$ (meters)	$\bar{b}_n$ (meters)
[2]1959	3.28	0.70	1979	2.18	-1.56
1960	2.21	-0.50	1980	1.83	-1.02
1961	2.40	-1.10	1981	2.28	-0.84
1962	2.50	0.20	1982	3.11	0.08
1963	2.23	-1.30	1983	1.91	-0.77
1964	3.25	1.20	1984	2.38	0.12
[3]1965	3.48	-0.17	1985	2.18	-1.20
1966	2.47	-1.03	1986	2.43	-0.71
[4]1967	3.29	-0.63	1987	1.88	-2.56
[5]1968	3.00	0.01	1988	1.89	-1.64
1969	3.17	-0.73	1989	2.35	-0.71
1970	2.41	-1.20	1990	2.80	-0.73
1971	3.51	0.60	1991	3.35	-0.20
1972	4.27	1.43	1992	1.91	-2.01
1973	2.21	-1.04	1993	1.98	-1.23
1974	3.65	1.02	1994	2.39	-1.60
1975	3.06	-0.05	1995	2.81	-0.69
1976	3.53	0.95	1996	2.94	0.10
1977	1.57	-1.30	1997	3.71	0.63
1978	2.49	-0.38	1998	2.76	-1.86

1 Balance year (for example, 1959 is from the minimum balance in 1958 to the minimum balance in 1959, and the 1959 $\bar{b}_m(s)$ occurred in the spring of 1959)

2 $\bar{b}_n$ for years 1959 through 1964 from Meier and Tangborn (1965)

3 Years 1965 through 1966 from Meier and others (1971)

4 Year 1967 from Tangborn and others (1977)

5 $\bar{b}_n$ for years 1968 through 1985 from Krimmel (1989)

☆U.S. GOVERNMENT PRINTING OFFICE: 1999-791-479/16016