GLACIAL PROCESSES AND THEIR

RELATIONSHIP TO STREAMFLOW

FLUTE GLACIER, ALASKA

Glacial processes and their relationship to streamflow, Flute Glacier, Alaska
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INTRODUCTION

Flute Glacier is located at the head of the South Fork of Eagle River, Alaska, about twenty air-miles east northeast of Anchorage. It is a small north-facing glacier, approximately two miles long and half a mile wide, situated in a deep glacial valley (see Figure 1). Elevations on the glacier range from 3,500 feet at the terminous to 5,800 feet at the top of the accumulation area.

Water from Flute Glacier becomes the South Fork of Eagle River, draining about 32 square miles of area compared to a 192 square mile drainage basin for Eagle River. Limited discharge measurements made during October 1968 suggest that the South Fork contributes about 20% of the water flowing down Eagle River. Glacial meltwater forms an important percentage of the waters of the Eagle River system.

Glaciers feeding the main Eagle River are large, complex and difficult to study. Flute Glacier, relatively small and of simple plan, was selected for study because of its small size and proximity to the metropolitan area of Anchorage. Water from the Eagle River system is presently included in the plans for future water supply for Anchorage. The Eagle River valley up to the 500 ft contour is a federal power reserve.

The climate of the area surrounding Flute Glacier is alpine with cool temperatures and higher than average precipitation for the area. All the glacier is above tree line so no plant life is obvious. Mountain sheep inhabit the sharp alpine peaks surrounding the glacier.

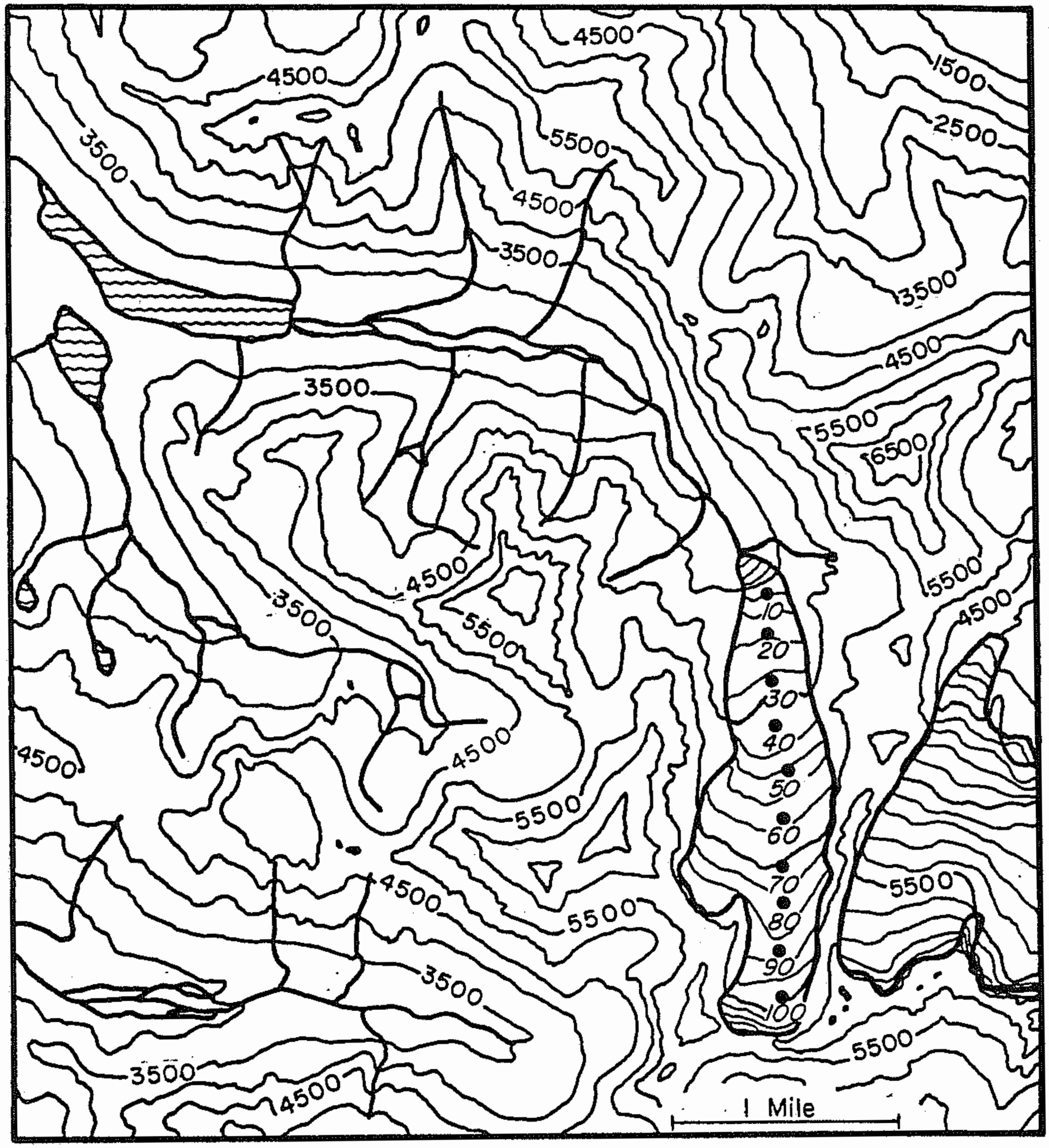

Figure 1

FLUTE GLACIER AND VICINITY

DISCHARGE

Streams flowing from the glacial terminous are assumed to represent the amount of glacial melt since in temperate valley glaciers, melting is the dominant form of ablation. Therefore, the discharge measured very near the glacial terminous indicates the volume of water lost from the glacier for a given season.

Three stations were established on the stream below Flute Glacier: Station III within a few hundred yards of the terminous; a second, Station II, about one mile downstream; and Station I about 1 1/2 miles down from the terminous near a campsite used for glacier workers. Station II 1969 data have not been used because of infrequent readings and loss of the staff gage over a waterfall. Stations I and III provide equivalent discharge curves so that readings from either station are used for discharge figures and calculations.

Discharge measurements were made only once during any given day at only one or two stations, and the time of measurement was commonly during mid-day hours when the stream levels were high. Arithmetic means calculated from these data are probably too high. Staff gages were placed at each station and readings were taken whenever possible during the summer.

Curves of staff gage height vs. discharge were drawn to evaluate discharge from staff gage readings. These curves are controlled by a limited number of measurements but follow a definite pattern, (Figure 2). In order to estimate discharge for days when no measurements were made, curves were drawn patterning South Fork data after mainstream Eagle River discharge curves obtained from a U.S.G.S. gaging station located at the Eagle River highway bridge.

Errors in discharge measurements come from lack of diurnal variation data, staff gage reading inaccuracies (inadequate installation as well as resulting curve analysis), and from estimates for days when no data were collected.

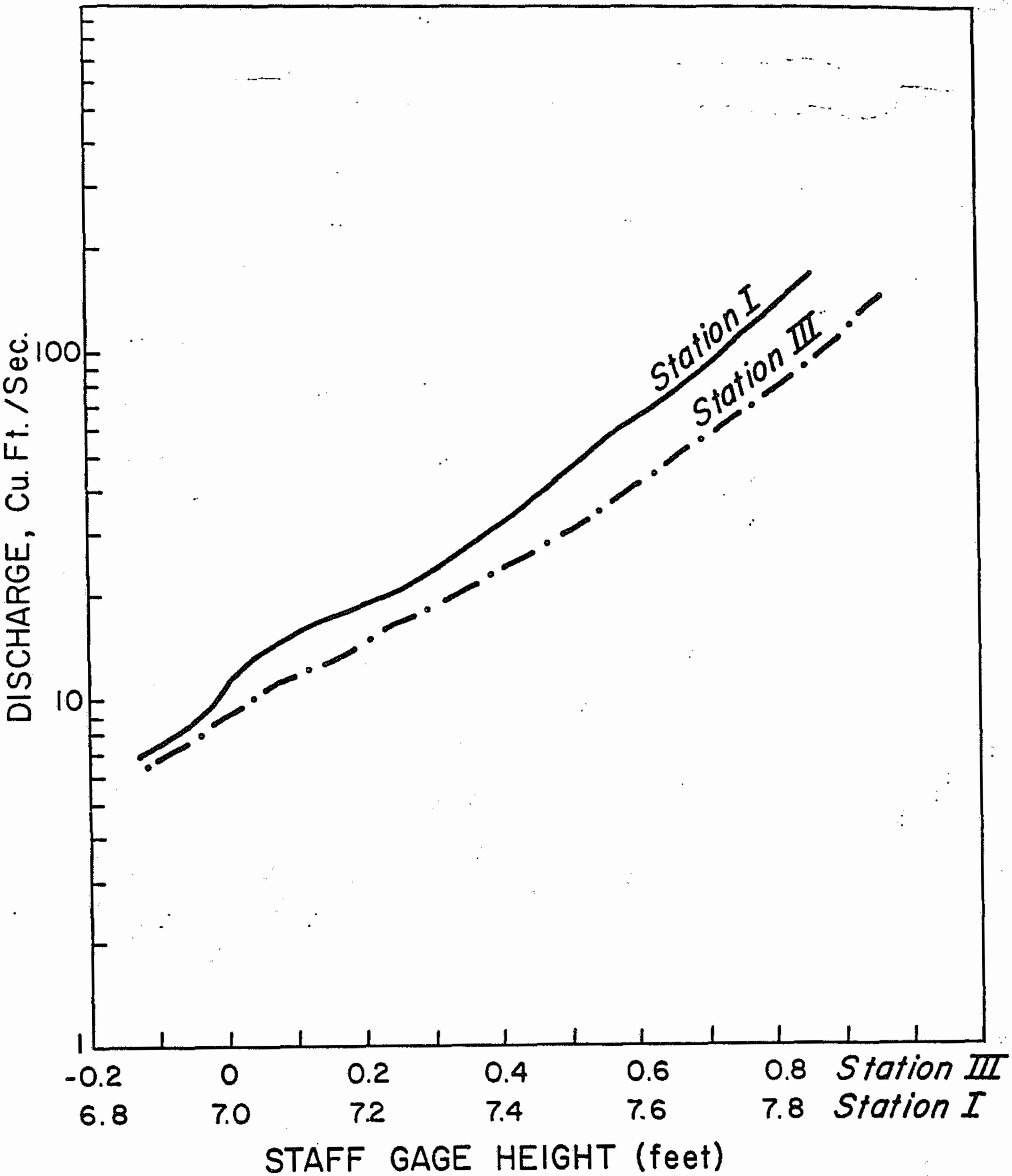
DISCHARGE, Cu. Ft. /Sec.
100
10
1
Station I
Station III
-0.2
0
0.2
0.4
0.6
0.8
Station III
6.8
7.0
7.2
7.4
7.6
7.8
Station I
STAFF GAGE HEIGHT (feet)

Figure 2

Results of discharge measurements are shown in Figure 3. The pattern of the daily discharge graph looks very similar to the pattern for the Eagle River (Figure 3). Fluctuations of the South Fork are larger than those of the mainstream.

Maximum discharge for the South Fork was 110 cfs in 1969 and low was zero during most of the winter season.

Measurements made on 12 October 1968 at site II show discharge of 0.77 and 1.06 cfs. Visual observations of the stream suggest that the meltseason ends about the first of September at Flute Glacier. Even in late August the streams were very low and the water no longer was milky-colored from glacial silt. Water begins to fill the channel again in late May or early June for the following melt-season.

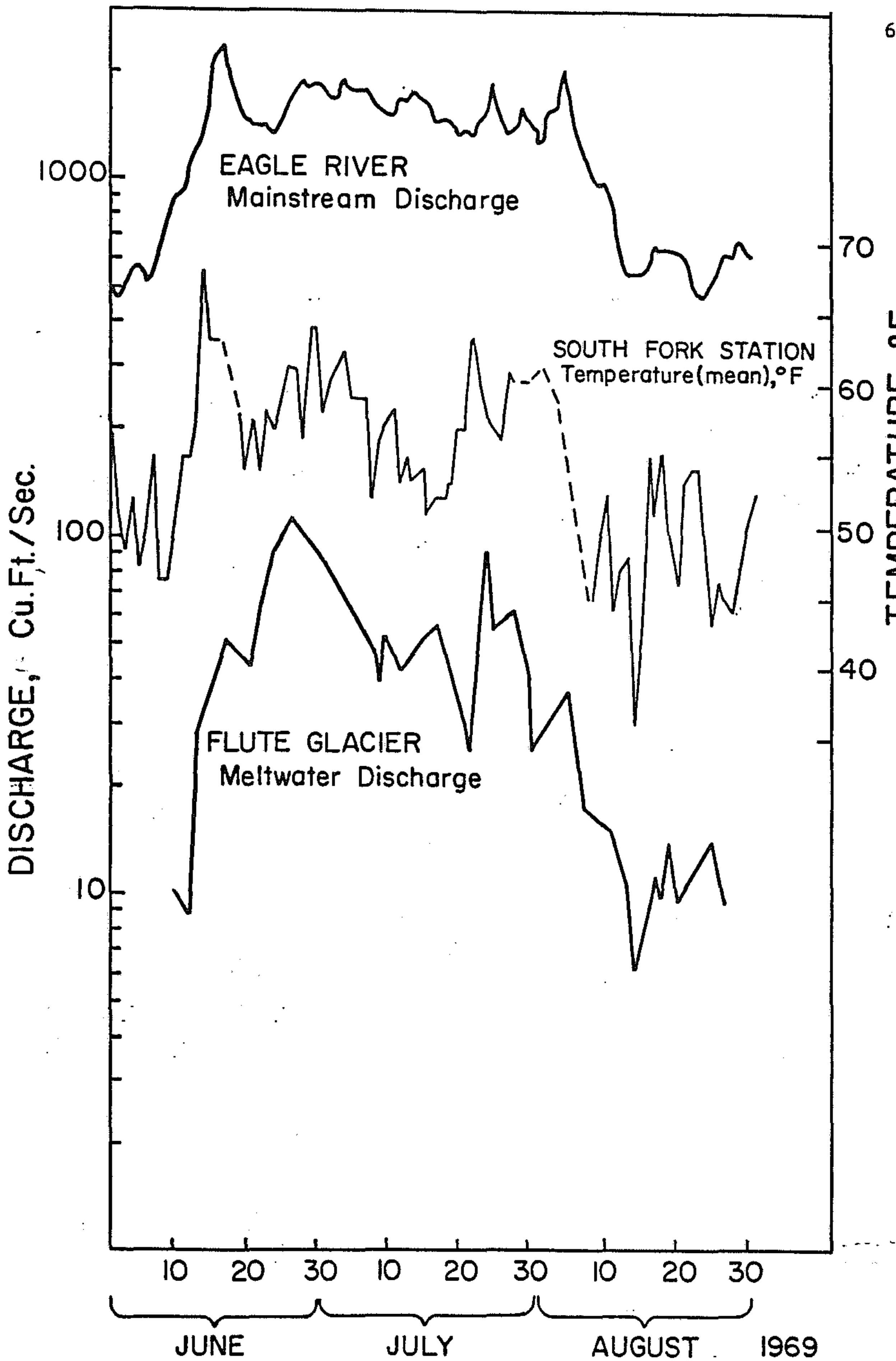
EAGLE RIVER
Mainstream Discharge
SOUTH FORK STATION
Temperature(mean),°F
FLUTE GLACIER
Meltwater Discharge
DISCHARGE, Cu.Ft./Sec.
TEMPERATURE, °F
1000
100
10
70
60
50
40
10
20
30
10
20
30
10
20
30
JUNE
JULY
AUGUST
1969

Figure 3

ACCUMULATION AND ABLATION

In order to evaluate the accumulation and ablation of the Flute Glacier a pattern of poles was established on the glacier surface. Eleven poles were placed along the approximate center of the glacier and numbered 10, 20 ... 110, following the numbering suggested by Ostrem and Stanley (1966). Pole locations are shown on map, (Figure 1). Five more poles were added by making offsets from poles 80, 100 and 110.

Thin-wall metallic conduit was used for poles, 10 feet long and 2 inches in diameter, with standard conduit couplers used to add lengths as sections were needed in the accumulation area or during the winter season. Poles were placed in holes drilled by a gasoline-powered, revolving hand auger.

The poles were planted to a depth of about 9.5 ft. so that melting ice could expose them. In the ablation zone poles were reset at least once per summer.

Ablation rates were established by periodic measurements from the top of the pole to the snow surface, generally following procedures suggested by Ostrem and Stanley (1966). Errors result from poles leaning or falling over as they melt out of the glacier, from irregularities of snow surface, and from snowfall during the melt season. These errors should not be large.

Results of ablation measurements are shown in Table 1. The rate was highest during July, the warmest month, and high melting and runoff were coincident with clear sunny weather. The mean ablation for summer 1969 was 89.0 inches with a maximum ablation of 100.8 inches at pole #10.

The ablation zone of the Flute Glacier is about 0.69 square miles which should produce 128,458,649 cubic feet of water for the three summer months of 1969 (assuming an ice density of 0.9).

TABLE 1

	Pole No.	TOTAL MEASURED ABLATION 27 June - 26 Aug., 1969 Inches of Ablation	ASSUMED TOTAL SUMMER ABLATION 27 June - 23 July + 2(23 July - 26 Aug.) Inches of Ablation
Inches of Glacier Ice Density, 0.9			
	10	28.8	100.8
	20	27.5	96.2
	30	26.5	92.7
	40	67.0	92.3
	50	62.5	85.5
	60	72.6	93.5
	70	60.0	74.7
	80	64.8	76.3
Inches of Firn Density, Ca.0.5			
	90	15.8	--
	100	48.2	51.4
	110	38.6	--

Mean total ablation: 89.0 inches

Accumulation occurs in a zone which is 0.23 square miles making up only 25% of the total glacier surface of 0.92 square miles. Measurement of accumulation is based on a single pit located at an elevation of about 5,600 feet. The pit was dug at the end of the 1969 melt season and depth-density data are given in Table 2.

TABLE 2

FIRN DENSITY
For 1968-69 Accumulation

Pole Number 112

Depth In.	Density
0-12	0.532
12-24	0.458
24-36	0.532
36-48	0.502
48-55 7/8	0.462

Mean firn density = 0.497

Generally, large amounts of snow accumulate during winter because of the wind protection afforded by the deep glacial canyon. Snowfall in winter 1968-69 buried 15 ft. long poles erected in the fall of the year 1968.

The pit wall showed 4.67 feet of firn with a mean density of 0.497. By the end of the melt season the assumed cross-section of firn was a wedge ranging in thickness from zero to 4.67 feet.

This same thickness is assumed to have covered the entire glacier, contributing to early runoff down the stream. Thus 0.92 mi^2 x 4.67 feet of firn at a density of 0.5 would produce 59,888,379 cubic feet from snowmelt. 7,486,047 cubic feet of water remain in the accumulation zone, so 52,402,331 cubic feet of water are formed from snowmelt.

Poles placed in the accumulation zone sank gradually into the firn and also were buried by winter snow. Therefore measurements made on the poles in the zone of accumulation are not reliable and these data have not been used for calculation of accumulation.

Errors in accumulation measurements include firn-depth miscalculations, variable firn-depth, inadequacy of the simple-wedge accumulation zone model, and inadequacy of the snowmelt model. Accumulation data are probably more likely prone to error than other measurements discussed.

CLIMATOLOGICAL DATA

A weather shelter was erected at a camp located 1 1/2 miles downstream from the glacial terminous and at an elevation of about 2,700 feet. Records were sucessfully obtained during the 1968 summer season but not during summer 1969.

The nearest weather station to the glacier is South Fork Station, privately maintained by the Janke family at their homestead located about 12 miles downstream at an elevation of 1,300 feet. Temperatures for 1969 were taken from this station.

Precipitation for the 1969 meltseason is based on data taken at a station on Moose Run Golf Course located at the base of the mountains along Ship Creek, about 14 air-miles from the glacier. During the months of June, July and August, 4.6 inches of precipitation were recorded at Moose Run Golf Course.

The drainage basin above Station I below Flute Glacier is 3.87 square miles in area. Precipitation of 4.6 inches over that area should produce a runoff of 41,357,606 cubic feet of water. Probably the precipitation at the location of Flute Glacier is greater than 4.6 inches.

Temperature curves when plotted adjacent to discharge curves show related patterns (see Figure 3). High temperatures melt glacier ice more rapidly with consequent stream discharge increase.

GLACIAL MOVEMENT

Two instrument stations were established during summer 1969 in order to triangulate accumulation-ablation poles. Surveying was done at the close of 1969 season and during the summer of 1970. These angles were not of adequate accuracy and survey data must wait establishing of a base line. Until a base line is established, the angles cannot be fixed. Therefore, movement surveys have not yet produced useable information, but with a base line and one more good surveying effort, rates of movement of poles could be established.

SUMMARY

The mass balance of Flute Glacier when compared to the discharge shows discrepancies. The 1969 summer discharge from the total drainage basin above Station I is calculated to be 275,261,760 cubic feet. The model proposed is that such water should come from: (1) snowmelt of previous winter's snow, (2) precipitation during the melt season, and (3) ablation of glacier ice. These volumes of water have been calculated based on very limited data from Flute Glacier observations as follows for summer 1969.

Snowmelt:	52,402,000 cu. ft.
Precipitation:	41,358,000 cu. ft.
Ablation:	128,459,000 cu. ft.
	222,219,000 cu. ft.

Discharge measurements for the same period total 275,262,000 cubic feet. The discrepancy of 53,043,000 cubic feet is at least partly due to inadequate measurement of all parameters. Also, nearly all discharge measurements were made during the time of highest flow in a given day thus giving an anomalously high total. Another probable error source would be inadequate data for snow accumulation in the drainage basin during winter (i.e. accumulation could be greater than that assumed). Also more of the basin than just the glacier collects winter snow, which would runoff during summer melt-season. Finally, precipitation is probably greater than that indicated.

The above figures also indicate that the dominant source of water for the uppermost part of the South Fork of Eagle River is Flute Glacier, providing about 58% of the summer discharge.

Mass balance studies show 7,486,000 cubic feet of water being added to the glacier during 1968-69 season while 128,459,000 cubic feet wasted away. Therefore, 120,973,000 cubic feet of water were lost by the glacier during the 1968-69 season.

Assuming mean glacial depth of 400 feet, the volume of ice in the Flute Glacier is 10,259,200,000 cubic feet. At the rate of 1968-69 ice loss, the glacier should last for another 85 years. Realizing each year's climatic conditions vary, such a figure as 85 years of life for Flute Glacier results from an inadequate duration of observation. Nevertheless, all indications are that the glacier is receding rapidly with the terminous retreating about 50 feet each year and probably the surface lowering. Another indication of poor glacial health is the small percentage of glacial surface accumulating firn; only 25% of the glacier's surface is accumulation zone.

Suggested future work for Flute Glacier and the South Fork of Eagle River includes further surveying of movement of accumulation ablation poles and stream gaging to establish discharge of the whole South Fork drainage basin to evaluate the glacial melt contribution to the basin. Sediment studies in the stream and in Eagle Lake, located 2 miles downstream from the Flute Glacier, would be useful for sediment-fill rates and erosion-rate information. A seismic study of ice thickness would provide important information as to the total amount of ice in Flute Glacier.

A more complete understanding of the South Fork of Eagle River and mainstream Eagle River should have immediate value because the river is already part of the water supply plan for the Anchorage area and a federal power reserve. In 85 years, for instance, a major source of water for the South Fork might cease to exist, and a similar fate could occur to the glacial source for the much larger glacier-system which provides water for the main Eagle River.

REFERENCES

Ostrem G. and Stanley A., 1966, Glacier mass balance measurements, a manual for field work; Department of Energy, Mines and Resources, Glaciology section, Ottawa, Canada, 81 p.

U. S. Geological Survey, 1969, Water Resources data for Alaska, part 1, Surface water records, U. S. Department of Interior, Geological Survey.

APPENDICES

DISCHARGE, SOUTH FORK
Summer 1968

Date	Time	Station I Cu.ft/sec.	Station I Guage	Station II Cu.ft/sec.	Station II Guage	Station III Cu.ft/sec.	Station III Guage
June 19	(13:00)	12.27				12.75	
20	(11:30)			18.55		19.58	
26				20.53		15.45	
27				23 .37		15.53	
July 11	(11:30-16:20)			38.17	4.31	31.42	7.54
12		38.44					
15		43.80					
16				37.65	4.30		7.55
17	(12:30-14:40)				4.28-4.36	37.77	7.55
18	(12:30)			38.27	4.28		7.56
19		35.14					
23	(11:15-17:00)				4.32		7.60-7.66
24	(11:45-17:30)				4.30-4.46		7.60-7.70
25	(10:30-19:30)				4.36-4.60		7.62-7.70
30	(12:30-14:45)				4.36		7.58-7.60
31	(11:00-18:00)				4.28-4.36		7.59-7.62
Aug. 1	(11:30-13:30)				4.16-4.20	28.34	7.42-7.46*
2		35.36					(7.58)
3	(8:30)				4.21		7.52
4	(18:30)				4.38		7.76
6	(11:00-17:00)	54.80			4.46-4.92*		7.84
7	(12:00-14:00)		1.28		4.80-4.94	64.55	7.92-7.98*
8	(10:30-13:00)		1.05-1.14	75.85	4.18-4.20		7.90
9	(10:00)	57.51	1.00				
13	(11:00-17:00)	37.97	0.88-0.86		4.12-4.10		7.86
14	(11:00-13:00)		0.70-0.80		4.06	36.32	7.78
15	(10:30-12:00)		0.70-0.74	34.87	4.02-4.04		7.75-7.75
	(17:35)		0.78				
16	(07:45)	16.30	0.60				
20	(17:00	55.17	0.90				
21	(12:00-15:00)		0.74-0.78		4.10-4.11	44.45	7.84
22	(10:00-17:00)		0.60-0.70	34.80	4.01-4.08		7.64-7.78
27	(11:00-13:00)	15.89	0.47-0.52		3.90-3.92		7.48-7.48
28	(10:15-17:00)		0.40-0.48		3.84-3.90	[illegible]	7.30
	(16:15-16:45)					16.43	7.38-7.42
29	(10:00-15:00)		0.40-0.56	20.15	3.82-3.96		7.32-7.58
30	(09:30)	13.20	0.44				

* Guage readjusted

APPENDIX II

DISCHARGE, SOUTH FORK
Summer, 1969

Date	Station I cfs	Station I Gage	Station II cfs	Station II Gage	Station III cfs	Station III Gage
June 7	45.68 (South Fork Bridge)					
10	--	--	19.95	--	9.99	--
11	--	--	21.48	--	9.75	--
12	--	--	34.27	--	8.74	--
13	27.62	--	--	--	--	--
17	51.42	0.70	--	--	--	--
18	--	--	61.60	--	--	--
23	--	--	--	--	77.0*	7.85
27	100.00*	0.73	--	--	110.0*	7.95
	103.0*	0.74	--	--	--	--
July 9	39.81	0.60	56.99	--	--	--
10	49.82	0.50	--	--	50.23	--
11	37.89	0.48	--	--	--	--
15	49.58	--	--	--	--	--
16	--	--	--	--	55.89	7.74
17	--	--	53.84	--	--	--
18	53.10	--	--	--	--	--
22	24.10	0.40	--	--	--	--
23	45.00*	0.4-0.6	--	--	52.96	7.74
	90.00*	0.70	--	--	--	--
24	90.00	0.56-0.6	--	--	--	--
25	--	0.50	--	--	--	--
	57.40	0.57	--	--	--	--
28	63.90	0.60	--	--	--	--
29	56.00*	0.56	64.49	--	50.56	7.68
30	56.00*	0.56	--	3.80	41.0*	7.60
	52.00*	0.54	--	3.74	43.25	--
31	27.00*	0.36	--	3.68	25.0*	7.44
	56.00*	0.57	--	3.82	50.11	7.66
Aug. 1	28.38	0.34	--	--	--	--
6	38.0*	0.46	--	3.74	36.0*	7.56
7	23.0*	0.30	--	3.59	26.73	7.46
8	17.24	0.18	--	--	--	--
12	15.33	0.10	--	--	--	--
13	12.5*	0.04	--	(—)	6.70	6.90
14	10.5*	0.00	--	(—)	6.7*	6.90
15	6.23	-0.04	--	--	--	--
18	11.40	0.08	--	--	--	--
19	8.8*	-0.04	--	--	10.34	7.04
20	12.5*	0.04	--	3.48	14.02	7.20
21	--	--	--	--	9.55	7.02
22	9.19	-0.02	--	--	--	--
25	12.48	0.02	--	--	--	--
26	9.68	-0.07	--	(—)	14.0*	7.18
27	12.0*	0.03	--	3.39	12.54	7.14
28	12.5*	0.04	--	3.35	9.24	6.99

* Derived from staff gage vs. discharge curve.

APPENDIX III

ACCUMULATION RECORD

Winter, 1968-69

Pole No.	28 Aug. 1968 Joint Height	12 Oct. 1968 Pole	12 Oct. 1968 Measured Snow Depth
10	56.3	54.3	4.5
20	61.4	50.0	5.3
30	68.9	60.7	9.5
40	49.5	47.5	11.0
50	60.3	51.5	13.0
60	57.1	57.9	8.5
70	55.3	48.0	14.3
80	53.6		
90			
100			
110			

ABLATION RECORD

Summer, 1969

Pole No.	27 June Height	23 July Old Ht.	23 July New Ht.	31 July Height	7 Aug. Height	13 Aug. Height	20 Aug. Height	26 Aug. Height	27 Aug. Height	April 1970
10	86.0	--	14.7	24.5	36.8	38.0	42.3	43.5	44.8	48.0
20	80.0	--	10.5	17.5	29.9	32.0	35.0	37.0	35.9	28.2
30	71.0	--	9.5	17.2	30.3	32.5	33.5	36.0	33.5	9.0
40	61.3	103.0	10.7	18.0	31.0	33.3	34.0	36.0	35.7	7.8
50	70.0	109.5	12.5	20.5	30.3	32.3	33.7	35.5	35.0	16.3
60	45.8	87.5	11.3	17.1	26.7	28.7	30.4	32.2	31.0	--
70	39.2	84.5	--	90.2	98.9	102.3	98.5	99.2	98.7	--
80	16.7	70.0	--	70.5	79.3	82.3	80.7	81.5	--	76.0
90	95.0	25.5	--	23.9	35.0	37.5	40.3	41.3	--	---
100	33.3	78.3	--	71.0	80.9	83.3	83.4	81.5	--	--
110	28.0	69.2	--	65.5	69.5	72.0	67.1	66.6	--	--
81	47.2	81.0	--	81.4	91.7	92.0	94.5	95.3	--	--
82	13.5	64.5	[illegible]	59.4	74.7	76.0	73.2	74.6	73.5	--
101	--	77.0	--	71.0	80.3	83.0	84.6	115.5	--	33.7
102	53.4	105.0	--	92.8	104-107	111.7	113.3	84.5	94.0	--
112	37.0	76.5	--	--	75.6	75.5	74.1	--	69.4	--

APPENDIX V

MEASURED ABLATION

Summer, 1969

Pole No.	Inches of Ablation 27 June - 23 July	Inches of Ablation 23 July - 26 Aug.
10	--	28.8
20	--	27.5
30	--	26.5
40	41.7	25.3
50	39.5	23.0
60	41.7	20.9
70	45.3	14.7
80	53.3	11.5
90	--	15.8
100	45.0	3.2
110	41.2	--
81	33.8	14.3
82	51.0	10.1
101	--	7.5
102	51.6	10.5
112	39.5	--

APPENDIX VI

ABLATION RECORD

Summer, 1968

Pole No.	23 July	24 July	25 July	31 July	6 Aug.	13 Aug.	22 Aug.	28 Aug.
10	13.7	16.7	20.0	32.0	42	51.4	58.7	58.3
20	18.7	21.0	24.3	35.5	45.7	57.5	62.8	61.1
30	21.7	24.7	28.3	29.0	49.3	62.4	70.7	70.4
40	--	12.3	14.7	25.0	34.4	48.0	50.5	51.7
50	--	12.3	14.7	26.3	34.1	50.3	61.7	63.1
60	--	11.3	13.7	27.0	36.5	47.7	58.3	61.1
70	--	--	12.3	26.5	35.5	49.5	57.4	58.4
80	--	--	11.3	23.5	30.3	45.9	54.5	56.5
90	--	--	--	62.5	68.5	68.5	62.7	56.1
100	--	--	--	45.5	42.3	38.3	27.3	18.5
110	--	--	6.3	88.0	90.5	86.5	70.6	56.6
81	--	--	--	--	--	47.0	44.0	35.0
82	--	--	--	--	--	--	--	--
101	--	--	--	--	46.0	40.7	32.3	26.5
102	--	--	--	--	75.4	82.9	89.9	90 + 10
111	--	--	--	--	--	--	--	69.3