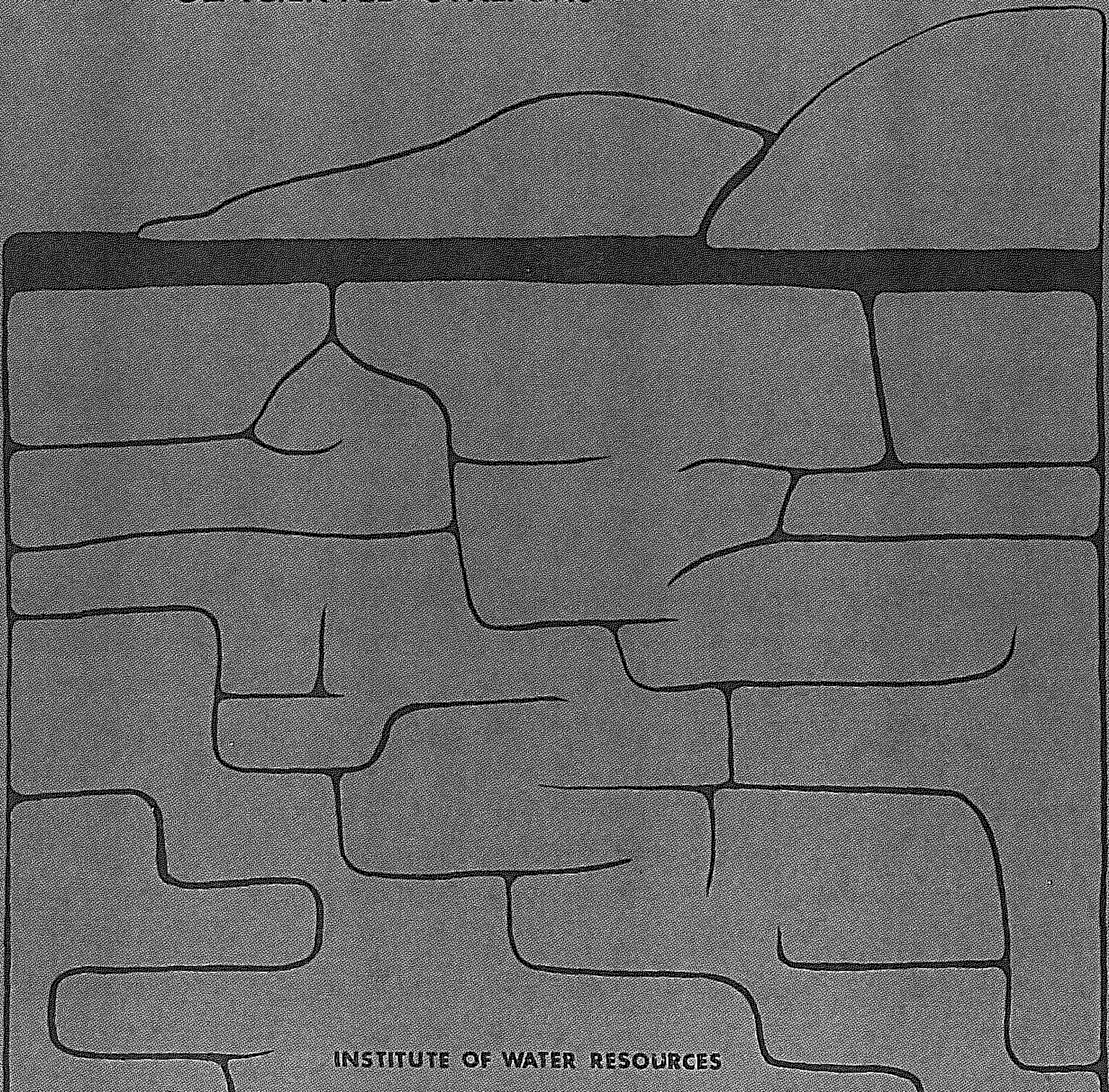
SEDIMENT RELATIONS OF SELECTED ALASKAN GLACIER-FED STREAMS



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SEDIMENT RELATIONS OF SELECTED ALASKAN GLACIER-FED STREAMS

COMPLETION REPORT

OWRR PROJECT NO. A-042-ALAS

Sediment relations of selected Alaskan glacier-fed streams
Completion report
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Report No. IWR-51 June, 1974

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INTRODUCTION

Streams originating from glaciers commonly carry large amounts of debris and sediment which are deposited as moraines or carried downstream as suspended-sediment load. Evidence of suspended sediment in glacial-fed streams is abundant in Alaska. Most of the suspended sediment is "glacial flour", a very fine grayish particulate material, unlike sediment in rivers in the southwestern United States and other parts of the more temperate regions. From just after breakup and throughout the short Alaskan summers, meltwaters from numerous glaciers add their sediment load to the streams. Only where streams are not tributary to glaciers are they relatively clear flowing during the summer. As freeze-up begins and glacial melt declines and eventually ceases, streams that were laden with sediment during the summer become less turbid.

Suspended sediment in Alaska's streams is probably the least understood quality characteristic of Alaska's water and one of the most significant quality parameters from the standpoint of the overall quality of Alaskan virgin fresh waters. It is this writer's judgment that a disproportionate share of the research dollar expended in cold regions is spent on glacier studies. The oft-repeated rationale for studying them is the need for knowledge related to water supply. Given the remote location of glaciers and icefields, it is doubtful that they will be used in the foreseeable future for large water supply projects requiring sophisticated analysis of water yield. Glacier-fed streams will no doubt someday be used for hydropower and water supply; however, the important problem will be water quality.

As development increases in Alaska and as misinformation and controversy continue over resources development, use, and conservation, the need increases to understand more fully sediment relations of Alaskan streams. Because this sediment is apparently related primarily to glacial meltwater outflow, it is a logical starting point for research on sediment relations in Alaskan waters.

The research reported here was conducted over a two-year period, beginning 1 July 1972 and ending 30 June 1974. A two-year period was required in order to permit one full melt season data collection during the summer of 1973. Data and assistance provided by the US Geological Survey, Anchorage and Fairbanks, greatly assisted in the success of this project. This completion report summarizes the results. The principal technical details are described in the literature.

OBJECTIVES

The objective of this research, in the broadest possible terms, was to extend scientific understanding of sediment yield relationships of glacial-fed streams in Alaska. The specific objectives of the research were to:

1) select a limited number of glaciers for an intensive data collection effort in order to understand the broad features of glacial sediment delivery rates and sediment transport relations;
2) determine the spatial distribution of glacial flour along the stream profile immediately below selected glaciers (e.g. sediment concentrations debouching directly from glacial melt, in the moraine, below known prior limits of the glacier);

3) establish the temporal character of sediment discharge for selected glaciers;

4) assemble the available sediment discharge data on selected glaciers that have been or are being studied in connection with other programs (such as IHD) and evaluate the use of this data for statistical estimation of sediment yield.

RESEARCH RESULTS

Objective number 1 was accomplished during the summer of 1972. Four glaciers, Eklutna, Maclaren, Wolverine and Gulkana, were selected for study based primarily upon ease of access and safe flow conditions for access to their meltwater outflow streams. Wolverine and Gulkana Glaciers had a good data base as the US Geological Survey maintains stream gauges and collects other data on these glaciers as part of the IHD program. Eklutna had no data base but was selected because it has significance as a power and water supply source for Anchorage, Alaska. Maclaren has a poor data base for determining conditions directly below the glacier; however, it was selected because it had recently been advancing. Because of a lack of data for Eklutna and Maclaren Glaciers, less emphasis on analysis was placed on them.

Objective number 2 was never fully realized due to lack of time and man-power. A limited amount of work was done on this subject; it is described in the thesis resulting from this project. In general, profile and cross-section conditions are not of paramount importance.

Objective number 3 is described in a journal article, "Strategy for Modeling Transport of Suspended Sediment in Glacier-Fed Streams," (1974) by this writer and B. L. Gaddis. The most significant concept to come out of this phase of work was that suspended-sediment concentration in the glaciers' melt water outflow could be modeled by relationships of the form

$$C_s = A \frac{Q_i^n}{Q_k^m}$$

where C_s is suspended-sediment concentration; Q_i is the prevailing instantaneous stream discharge; Q_k is a single previous discharge event, k days prior to measurement; and A, n, and m are coefficients determined by regression analysis using a limited amount of data. The parameter Q_i represents the melt streams prevailing supply of water energy for entraining and transporting sediment; the parameter Q_k represents memory of past hydraulic states in the glacier as these states relate to the availability of sediment for transport. Field data collected during the course of this phase of the project is included in Appendix A. This data consists primarily of suspended-sediment concentration (obtained by standard integrated depth samplers) and prevailing discharge at the time of measurement.

Objective 4 was reported in a published journal article by the writer, "Regional Sediment Yield Analysis of Alaska Streams." The main result of this work is that it was concluded that regional suspended sediment yield could be modeled by relationships of the form

$$Q_s = B\left(\frac{A_T}{A_G} L_G\right)^P$$

where Q_s is the suspended-sediment yield; A_T is the total drainage area; A_G is the glacier area; L_G is the stream length to the glacier terminus;

and B and P are coefficients to be determined by regression analysis using published data. The above relationship is adequate for the case of large A_T and L_G but is not adequate for stream reaches close to the glacier terminus.

The significance of this research can be summarized briefly as follows: it

- contributes to the general scientific study of sediment processes in Alaska;
- initiates much-needed further scientific study of sediment processes in Alaska;
- contributes to the establishment of baseline environmental conditions in Alaska;
- provides support studies related to other glaciology studies in Alaska;
- provides qualitative as well as quantitative knowledge of glacial runoff sediment processes;
- provides additional information for water supply studies.

TRAINING

One Master of Science student was trained under the direction of this writer. Work is completed for an M.S. in Geohydrology, a multi-disciplinary degree awarded by the University of Alaska, Fairbanks. An abstract of the thesis is included below.

DISSEMINATION OF RESEARCH

Four publications (two technical publications, one translation, and one thesis) were developed during this project, as follows:

Sediment Yield of Alaska Streams

Abstract: Sparse suspended sediment data for Alaska were evaluated to verify previous work on regional sediment yield relationships and to test alternative regression correlations using readily obtained watershed parameters. Glacier-fed streams in the south central region of Alaska were emphasized, although one nonglacial stream in the interior region of Alaska was included for comparison. Results indicate that plausible, simple relationships can be developed for stream reaches well downstream from the glacier which deliver a high fraction of the total suspended sediment load. A great deal of uncertainty is associated with correlation attempts for short stream reaches near the glacier delivery source. [Guymon, Gary L., 1974, "Regional Sediment Yield Analysis of Alaska Streams: Journal of the Hydraulics Division, ASCE, Vol. 100, No. HY1, Proc. Paper 10255, pp. 41-51.]

A Study of Sediment Transport in Norwegian Glacial Rivers, 1969

This report was translated during this project in order to make Norwegian research available to US researchers. This report concerns a discussion of data collected on several Norwegian glaciers during 1969. Daily variations in discharge and sediment transport are presented. Suspended sediment data was collected by the bottle-dip method. Bed load was determined by constructing a large fence trap. [Østrem, G., T. Ziegler, and S. R. Ekman, 1970, "A Study of Sediment Transport in Norwegian Glacier Rivers, 1969," (translated by H. Carsten), Publication No. IWR-35, Institute of Water Resources, University of Alaska, Fairbanks, Alaska, 1973.]

Suspended Sediment Transport Relationships for Four Alaskan Glacier Streams

Abstract: Estimates of suspended sediment transport for four Alaskan glacier streams are made for the 1973 summer melt season. Two types of field data were requisite for establishing linear models relating discharge and suspended sediment concentrations: (1) suspended sediment concentration and corresponding discharge measurements, and (2) a seasonal discharge record.

Comparison of monthly percentages of season total discharge and suspended sediment transport suggest that variations between discharge and suspended sediment transport magnitudes depend primarily on sediment availability. Changes in sediment availability are qualitatively discussed in relation to the glacier drainage system.

Sediment availability differences between glaciers are attributed to meteorological changes affecting the discharge, variation in the mechanics of sediment entrainment, and the difference in the amount of sediment for transport.

The procedures presented for estimating suspended sediment transport for a melt season remain similar for glaciers that have a defined glacier stream(s), issuing from the terminus, regardless of climatic or regional setting. [Gaddis, B.L., 1974, "Suspended-Sediment Transport Relationships for Four Alaskan Glacier Streams," a thesis submitted to the University of Alaska, Fairbanks, in partial fulfillment of the requirements for a Master of Science degree.]

Strategy For Modeling Transport of Suspended Sediment in Glacier-Fed Streams

Abstract: Suspended-sediment and discharge data were collected from the meltwater stream from Gulkana and Wolverine Glaciers in Alaska during the summer 1973 melt season. Analysis of this data for Wolverine Glacier suggests a simple log-linear model relating suspended-sediment concentration to the prevailing instantaneous discharge. In the case of Gulkana Glacier, a multi-log-linear model is proposed which relates suspended-sediment concentration to the prevailing instantaneous discharge and a single previous discharge event. The prevailing discharge characterizes the available unit water power in the glacier and meltwater outflow stream for entraining and transporting sediment. The incorporation of a single previous discharge event characterizes antecedent (memory) conditions, and this model variable is assumed to be an index describing sediment availability. Suspended-sediment delivery is considered in terms of prevailing water energy supply and sediment availability and it is suggested that general suspended-sediment models for glacier-fed streams can be developed using only knowledge of outflow events. [Guymon, G. L., and B. L. Gaddis, 1974, "Strategy for Modeling Transport of Suspended Sediment in Glacier-Fed Streams," submitted to J. of Hydrology for possible publication.]

APPENDIX A

APPENDIX A

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

Gulkana Glacier Data Summary, June 12 - Sept. 15, 1973

DATE/TIME day/hour	Q, discharge[a] ft^3/sec., (m^3/sec.)		C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
June 12/1700			216	
June 12/1800			200	
June 12/2000			234	
June 12/2200			136	
June 12/2400			123	
June 13/0200			110	
June 13/0400			97	
June 13/0600			113	
June 13/0800			122	
June 13/1000			211	
June 13/1200			238	
June 13/1400			196	
June 13/1600	129	(3.68)	210	Water temp.=0.15°C
June 30/1035	150	(4.25)	1066	
June 30/1130	150	(4.25)	1312	
June 30/1205	161	(4.56)	(1)1019,(2)1162	
July 10/1630	293	(8.30)	(1)1144,(2)1731	
July 11/0900	238	(6.74)	(1)774, (2)457	
July 11/1615	271	(7.68)	(1)672, (2)611	
July 12/1000	216	(6.12)	(1)697, (2)515	

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

DATE/TIME day/hour	Q, discharge[a] ft^3/sec., (m^3/sec.)		C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
July 12/1600	238	(6.74)	(1)492, (2)805	
July 13/0905	194	(5.50)	(1)270, (2)320, (3)269	
July 13/1500	249	(7.05)	(1)1073,(2)665	
August 13/1305	60	(1.70)	(1)226, (2)198	
August 13/1400	60	(1.70)	(1)248, (2)206	
August 13/1535	70	(1.98)	(1)328, (2)303	pH=8.5, water temp.=2°C
August 13/1615	73	(2.07)	(1)335, (2)246	Alkalinity=27 mg/l $CaCO_3$
September 15/1215	17	(0.48)	(1)979, (2)1011	
September 15/1315[b]	18	(0.51)	(1)1526,(2)1556,(3)1556,(4)1509	
September 15/1415[b]	19	(0.54)	(1)1158,(2)1248,(3)2657,(4)1749	
September 15/1505[b]	20	(0.57)	(1)1188,(2)1102,(3)1303,(4)1363	
Maclaren* Glacier Data Summary, June 14 - Sept. 15, 1973				
June 14/1545	3724	(105.50)	(1)744, (2)417	Water temp.=9.3°C
June 29/1910	2806	(79.49)	(1)300, (2)422, (3)697	
July 13/1215	2456	(69.58)	301[d]	
August 13/1930	1571	(44.50)	(1)176, (2)2524	
August 14/1100	1350	(38.24)	(1)520, (2)533, (3)878	pH=7.3, water temp.=8°C
September 15/1750	777	(22.01)	419[d]	Alkalinity = 25 mg/l $CaCO_3$

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

Maclaren
1964 - 1968 U.S.G.S. Data

DATE/TIME day/hour	Q, discharge[a] ft^3/sec.,	(m^3/sec.)	C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
June/1964	5070	(144)	760	
July/1964	2720	(77)	350	
July/1965	2640	(75)	550	
Sept./1965	2810[e]	(80)	740	
Oct./1965	724	(21)	100	
July/1966	2160	(61)	550	
August/1966	239	(7)	450	
Sept./1966	624	(18)	20	
June/1967	3620	(103)	649	
July/1967	4030	(114)	677	
August/1967	5320	(151)	1040	
Sept./1967	936	(27)	52	
March/1968	94	(3)	6	

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND
SUSPENDED-SEDIMENT CONCENTRATION

Eklutna Glacier Data Summary, June 3 - Sept. 21, 1973

DATE/TIME day/hour	Q, discharge[a] ft^3/sec., (m^3/sec.)		C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
June 3/2230	16	(0.45)	31[d]	
June 3/2300	18	(0.51)	34	
June 3/0000	17	(0.48)	33	
June 4/0100	17	(0.48)	32	
June 4/0200	17	(0.48)	21	
June 4/0300	16	(0.45)	22	
June 4/0400	16	(0.45)	24	
June 4/0500	16	(0.45)	160	
June 4/0600	16	(0.45)	30	
June 4/0700	16	(0.45)	20	
June 4/0800	16	(0.45)	23	
June 4/0900	16	(0.45)	22	
June 4/1000	16	(0.45)	20	
June 4/1100	17	(0.48)	21	
June 4/1200	18	(0.51)	22	
June 4/1300	20	(0.57)	35	
June 4/1400	22	(0.62)	26	
June 4/1500	22	(0.62)	28	
June 4/1600	22	(0.62)	24	
June 4/1700	22	(0.62)	35	

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

DATE/TIME day/hour	Q, discharge[a] ft^3/sec., (m^3/sec.)		C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
June 4/1800	22	(0.62)	20	
June 4/1900	21	(0.59)	25	
June 4/2000	21	(0.59)	23	
June 4/2100	21	(0.59)	19	
June 4/2200	20	(0.57)	22	
June 23/1310	200	(5.67)	1085	
June 23/1910	138	(3.91)	(1)935, (2)1006	
June 24/1020[b]	140	(3.97)	(1)683, (2)659, (3)657, (4)685	Water temp.=0.7°C
June 24/1530	145	(4.11)	(1)661, (2)675	Water temp.=0.6°C
June 24/2000[b]	138	(3.91)	(1)595, (2)594, (3)621, (4)599	
July 20/1845	450	(12.75)	(1)336, (2)315	
July 21/0945	275	(7.79)	(1)311, (2)329	
July 21/1445	550	(15.58)	(1)503, (2)515, (3)526[c], (4)538	
July 21/1845	550	(15.58)	(1)430, (2)500	
July 22/0755	475	(13.46)	(1)319, (2)352	
July 22/1210	525	(14.87)	(1)360, (2)410	
July 22/1610	925	(26.20)	(1)599, (2)545	
July 22/2000	925	(26.20)	(1)516, (2)458[c], (3)425	
July 23/0820	525	(14.87)	(1)394, (2)439	
August 20/1830	275	(7.79)	(1)592, (2)697	
August 20/2030	275	(7.79)	(1)535, (2)521	

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

DATE/TIME	Q, discharge ft^3/sec.,	(m^3/sec.)	C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
August 21/1050	870	(24.65)	(1)3053,(2)2763	
August 21/1300	1010	(28.61)	(1)2715,(2)2692	
August 21/1400	1015	(28.75)	(1)2827,(2)2711	
August 21/1500	1040	(29.46)	(1)2337,(2)2653	
August 21/1700	1035	(29.32)	(1)2357,(2)2359	pH=9.5, water temp=5.1°C Alkalinity=26 mg/l $CaCO_3$
September 21/1050	37	(1.05)	38(average)[d]	

Wolverine Glacier Data Summary, May 31 - Sept. 21, 1973

DATE/TIME	Q, discharge ft^3/sec.,	(m^3/sec.)	C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
May 31/0830	20	(0.57)	40	
May 31/0930	20	(0.57)	43	
May 31/1030	21	(0.59)	32	
May 31/1130	21	(0.59)	51	
May 31/1230	21	(0.59)	66	
May 31/1330	21	(0.59)	56	
May 31/1430	21	(0.59)	56	
May 31/1530	23	(0.65)	63	
May 31/1630	25	(0.71)	67	
May 31/1730	25	(0.71)	77	
May 31/1830	25	(0.71)	75	
May 31/1930	25	(0.71)	72	

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND
SUSPENDED-SEDIMENT CONCENTRATION

DATE/TIME day/hour	Q, discharge $ft^3/sec.$,	$(m^3/sec.)$	C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
May 31/2030	25	(0.71)	65	
May 31/2130	25	(0.71)	62	
May 31/2230	23	(0.65)	64	
May 31/2330	23	(0.65)	69	
June 1/0030	23	(0.65)	57	
June 1/0130	22	(0.62)	75	
June 1/0230	22	(0.62)	55	
June 1/0330	24	(0.68)	61	
June 1/0430	23	(0.65)	47	
June 1/0530	23	(0.65)	57	
June 1/0630	22	(0.62)	61	
June 1/0730	21	(0.59)	58	
June 1/0830	22	(0.62)	62	
June 1/0930	22	(0.62)	70	
June 1/1830	25	(0.71)	64	
June 21/2130	174	(4.93)	(1) 89, (2) 29	
July 7/unk.	309	(8.75)	478[c]	
July 8/unk.	171	(4.84)	175[c]	
July 24/1700	438	(12.41)	319	
July 24/1900	391	(11.08)	193	
July 24/2100	362	(10.25)	185	

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

DATE/TIME day/hour	Q, discharge ft^3/sec.,	(m^3/sec.)	C_s, Suspended-Sediment Concentration, mg/l	Miscellaneous Data
July 25/0945	270	(7.65)	158	
July 25/1145	270	(7.65)	178	
July 25/1345	309	(8.75)	160	
July 25/1545	340	(9.63)	194	
July 25/1745	396	(11.22)	174	
July 25/1945	362	(10.25)	182	
July 26/0830	258	(7.31)	149	
July 26/1030	295	(8.36)	144	
July 26/1230	276	(7.82)	146	
August 22/1700	522	(14.79)	634	
August 22/1900	494	(14.00)	(1)568, (2)461	
August 22/2100	472	(13.37)	350	
August 23/0815	416	(11.78)	(1)459, (2)421	
August 23/1000	444	(12.58)	(1)491, (2)496	Water temp.=2°C, pH-7.1, Alkalinity=7.92 mg/l $CaCO_3$
August 23/1200	514	(14.56)	(1)1015,(2)1037	
August 23/1400	569	(16.12)	(1)791, (2)978	
September 21/1000	80	(2.27)	(1) 29, (2) 58	

APPENDIX A - Continued

GLACIER DATA SUMMARIES OF DISCHARGE AND SUSPENDED-SEDIMENT CONCENTRATION

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[a] Q determined from stage-discharge relationship
[b] samples (1) and (2) and (3) and (4) taken at two different points across stream
[c] sample taken by hand-dipping bottle
[d] cross-section profile average
[e] mean daily discharge