Hydrologic and Mass-Movement Hazards near McCarthy, Wrangell-St. Elias National Park and Preserve, Alaska

By Stanley H. Jones *and* Roy L. Glass

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
ton	0.9072	megagram
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929):

A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Notes:

In this report, "Kennecott" pertains to the mines, mining company, ore deposits, and related topics, and "Kennicott" to geographic and geologic features. The rationale for the dual spelling and usage is as follows: the mining company was named for the Kennicott Glacier, which was named for Robert Kennicott, a pioneer surveyor; somehow, probably inadvertently, an "e" was substituted for the "i" in company name.

A "Glossary" of technical terms used in this report starts on page 48. A term defined in the glossary appears in **bold** type at its primary reference in the text or on a table.

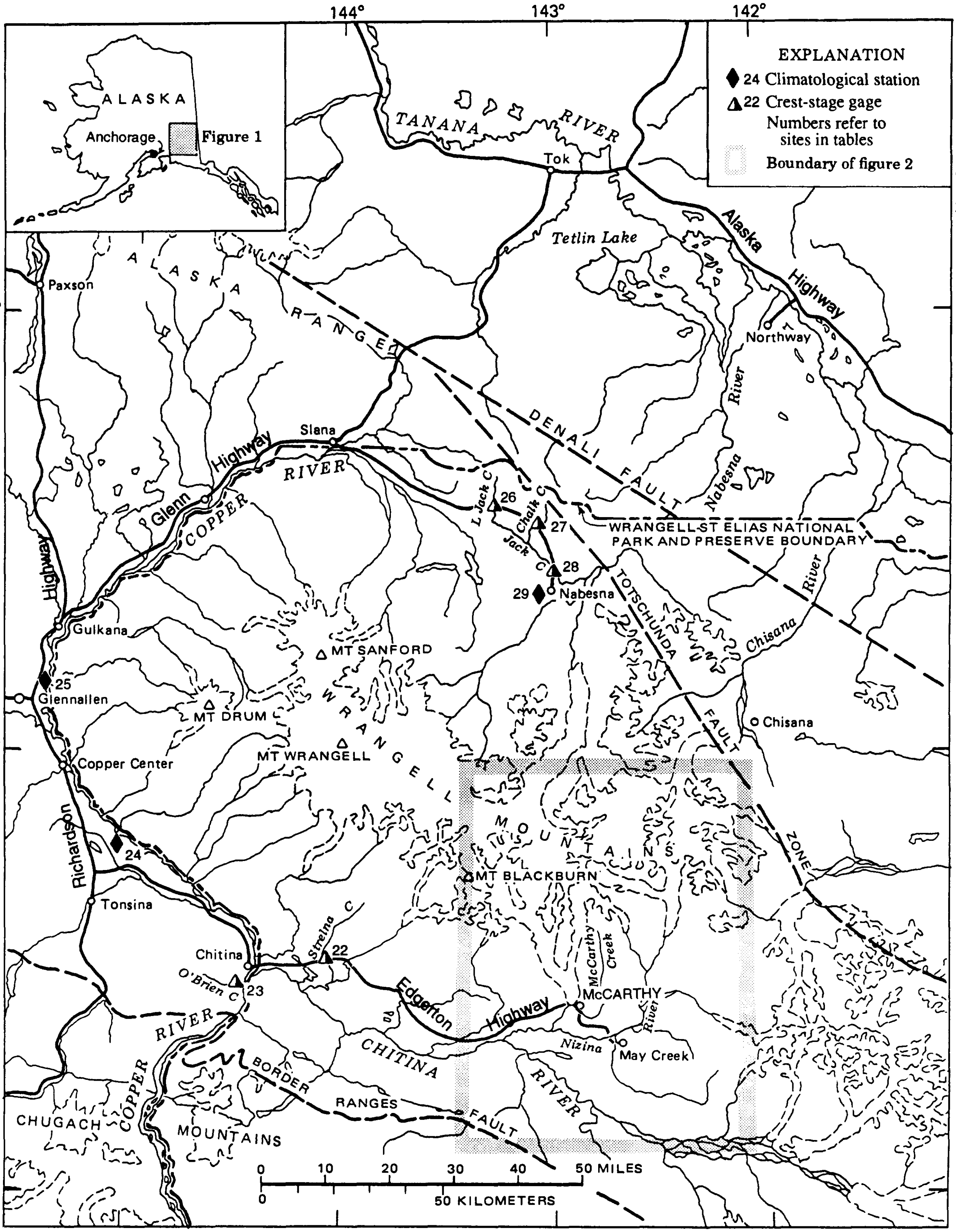

Figure 1. Location of part of the Wrangell-St. Elias National Park and Preserve showing selected data-collection sites and the McCarthy study area.

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Abstract

McCarthy, Alaska, is at the confluence of McCarthy Creek and the Kennicott River, about 1 mile from the terminus of Kennicott Glacier in the Wrangell-St. Elias National Park and Preserve. McCarthy Creek and Kennicott River basins are prone to several natural hazards including floods; formation and failure of natural dams; stream erosion and sediment deposition; snow avalanches; aufeis; and the mass wasting of rock, soil, and debris. Low-lying areas along the Kennicott River flood annually, commonly during late July or early August, as a result of outbursts from glacier-dammed lakes, but floods can occur during any month of the year. Flood plains along McCarthy Creek and its tributaries are frequently flooded and are prone to rapid erosion and deposition during intense rainfall and periods of rapid snowmelt. Sediments from continual mass wasting accumulate in stream channels and are mobilized during floods. Severe lateral erosion, scour, and deposition resulting from floods in September 1980 and August 1985 destroyed bridges near McCarthy. Several historical structures at McCarthy were jeopardized by the rapidly eroding northern stream-bank of McCarthy Creek. Flood discharges were determined using the slope-area method at two high-gradient reaches on the Kennicott River, four on McCarthy Creek, and one on Nikolai Creek. During the flood of September 13, 1980, peak discharge for McCarthy Creek at McCarthy was 4,500 cubic feet per second.

INTRODUCTION

The small town of McCarthy (fig. 1) is in the eastern part of southcentral Alaska and is in the largest national park in the United States, Wrangell-St. Elias National Park and Preserve. The park contains areas of extremely rugged high mountain terrain (including some of the highest peaks in the United States), an extensive array of glaciers and icefields, and significant mineral deposits. More than 591,000 tons of copper ore was mined and processed in the McCarthy area from 1908 through 1938. Most of the copper was from mines on Bonanza Ridge (4 mi north of McCarthy), but mines on Green Butte (6.5 mi northeast of McCarthy) and in the upper reach of Nikolai Creek (8 mi east-northeast of McCarthy) also yielded large amounts of copper. Several buildings in McCarthy, including some having significant historical value, are in flood plains of McCarthy Creek and Kennicott River. Many of the roads and trails leading to mines are located in flood plains and cross landslides and rock glaciers. A trail along McCarthy Creek crosses the stream in several locations and passes through two tunnels.

The National Park Service is responsible for preparing and reviewing environmental assessments of any proposed mining plans of operation within a park. An essential part of an environmental assessment is an appraisal of hydrologic resources. The U.S. Geological Survey (USGS), in cooperation with the National Park Service, evaluated hydrologic conditions and natural hazards in the McCarthy Creek and Kennicott River basins.

Purpose and Scope

This report describes results of the study in the McCarthy Creek and Kennicott River basins. The work included: (1) identifying and mapping landslides, glacier-dammed lakes, perennial snowfields, snow **avalanches**[1], glaciers, and rock glaciers, using field surveys and aerial photographs; (2) conducting flood surveys at two sites on the Kennicott River, four sites on McCarthy Creek, and one site on Nikolai Creek to determine water-surface elevation and flood peak discharge; (3) determining regional flood frequencies for streams near McCarthy and flood magnitude and frequency for sites in McCarthy Creek basin; (4) delineating past flood boundaries; and (5) delineating areas susceptible to mass-movement and flood-related hazards. Other natural hazards known in this area, such as intense storms and earthquakes, are not analyzed here.

Vertical aerial photographs studied were taken on July 29, 1957; August 1978; August 19, 1983; August 10, 1988; August 10, 1989; and August 22, 1990 (table 1). Low altitude oblique aerial photographs were taken on July 11, 1988, and July 16 and 25, 1990. Terrestrial photographs were taken on July 6-12, 1988, and June 20-21 and August 5-6, 1989. Field surveys were made during July and September 1990, and May, June, and September 1991.

Table 1. Vertical aerial photography for McCarthy study area

Date	Scale	Source	Type
7-29-57	1:48,600	U.S. Geological Survey	Black and white
8-78	1:71,300	U.S. Geological Survey	Infrared color
8-19-83	1:12,000	Aeromap, Inc.	Natural color
8-10-88	Variable	National Park Service	Natural color
8-10-89	1:40,000	Aeromap, Inc.	Natural color
8-22-90	Variable	National Park Service	Natural color

Acknowledgments

The assistance, cooperation, and information provided by personnel of the Wrangell-St. Elias National Park and Preserve and by local residents of McCarthy are gratefully acknowledged. Loy Green and Edward LaChapelle, residents of McCarthy, provided valuable historical and technical information regarding past floods, flood damage, snow avalanches, and glaciers.

[1]Bold terms are defined in "Glossary."

HYDROLOGY AND CLIMATE

The town of McCarthy is on an alluvial terrace near the confluence of McCarthy Creek and the Kennicott River, and about 1 mi from the terminus of Kennicott Glacier in the southern part of the Wrangell Mountains and in the Copper River basin (figs. 1, 2, and plate 1). The volumes of precipitation and surface-water runoff of the basin are highly variable because of the large elevation span and presence of glaciers (Emery and others, 1985). The town is at an elevation of about 1,400 ft (NGVD of 1929); ridges enclosing the McCarthy Creek basin are from 6,000 to 9,000 ft high; and several peaks in the Kennicott River basin are higher than 13,000 ft. Nearby Mount Blackburn, the highest summit in the Wrangell Mountains, has an elevation of 16,390 ft. The drainage area of McCarthy Creek above its confluence with Kennicott River is 76.8 mi^2 and the drainage area of Kennicott River above McCarthy Creek is 352 mi^2. Glaciers and perennial snowfields presently cover about 4 percent of the McCarthy Creek basin; in 1957, they covered about 46 percent of the Kennicott River basin. Many glaciers within the Wrangell Mountains block tributary valleys and cause lakes to form behind the ice masses. Repeated failure of the glacier-ice dams cause periodic flooding downstream.

The McCarthy area is in a transitional climate zone between the wet, temperate climate of the coast and the drier climate with higher and lower temperature extremes of the interior. Climate data have been collected intermittently near the town of McCarthy at four climatological stations (Kennicott, McCarthy, McCarthy 1 NE, and McCarthy 3 SW; plate 2 and table 2). Currently, climatological data collected at McCarthy 3 SW (site 21), about 3 mi southwest of McCarthy, are published monthly by National Oceanic and Atmospheric Administration (1922-91) and are summarized intermittently by the Arctic Environmental Information and Data Center (Leslie, 1989).

Table 2. Precipitation at selected climatological stations in the Copper River Basin above Chitina
[Data from National Weather Service (National Oceanic and Atmospheric Administration, 1922-89); see figs. 1, 2 and plate 2 for site locations]

Site No.	Station name	Latitude	Longitude	Elevation (feet) (NGVD of 1929)	Period of record	Mean annual precipitation (inches)	Maximum daily rainfall[1] (inches)
3	May Creek	61°21'	142°41'	1,500	1/63-12/66	15.63	0.94
4	May Creek	61°20'	142°42'	1,500	1990	(2)	(2)
5	Kennicott	61°29'	142°53'	2,210	1/22-8/47	23.26	1.97
8	McCarthy 1 NE	61°26'	142°54'	1,540	10/76-2/83	20.82	2.00
9	McCarthy	61°26'	142°55'	1,380	7/68-9/76	17.23	1.13
21	McCarthy 3 SW	61°25'	143°00'	1,250	1/84-10/90	21.47	2.33
24	Old Edgerton	61°48'	144°59'	1,320	4/70-10/90	11.22	1.48
25	Gulkana	62°09'	145°27'	1,570	6/49-10/90	10.97	2.06
29	Nabesna	62°24'	143°00'	2,900	10/66-4/68 and 8/80-10/90	13.23	1.15

[1]For months May through September.
[2]Unpublished data available from Bureau of Land Management.

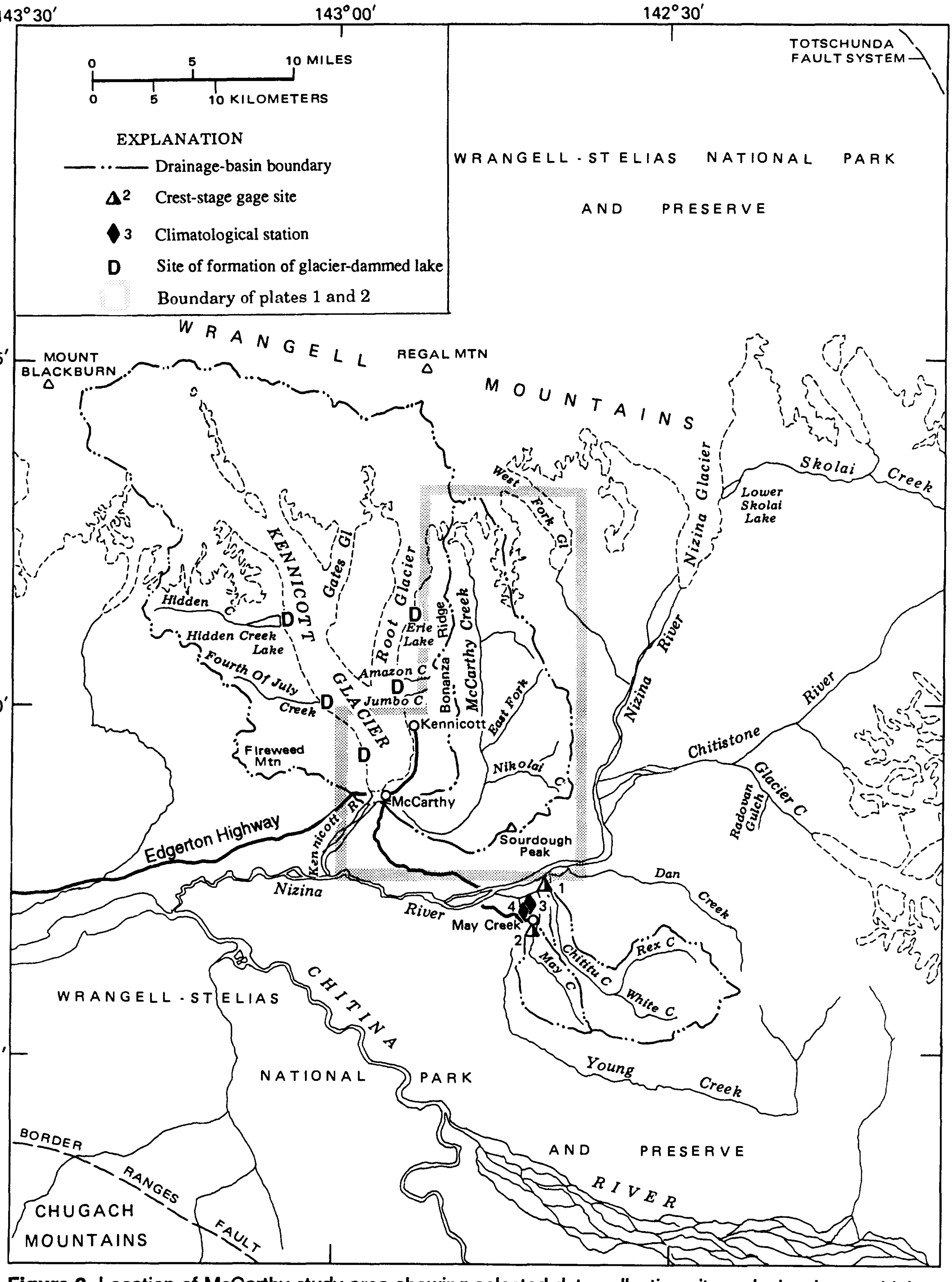


Figure 2. Location of McCarthy study area showing selected data-collection sites, glacier-dammed lakes, and the area of plates 1 and 2.

Recorded values of annual precipitation range from 10.11 in. (during 1969 at McCarthy) to 30.68 in. (during 1944 at Kennicott). Mean annual precipitation for McCarthy 3 SW is 21.47 in. (table 2). Although low-lying areas may receive less than 20 in. annually, mountainous areas above McCarthy receive from 40 to more than 80 in. (fig. 3). The generalized mean annual precipitation map of the Copper River basin (fig. 3) was developed by Charles B. Fahl, Alaska Pacific University, Anchorage, Alaska. Lines of equal mean annual precipitation are based on data from 304 climatological stations, 102 snow survey stations, and 223 streamflow stations in Alaska west of longitude 141°.

Winter low temperatures in McCarthy range from -20 to -40 °F, and summer high temperatures range from 70 to 80 °F. The average annual temperature is slightly below freezing, which causes discontinuous permafrost to occur in the region (Péwé, 1975).

GEOLOGY AND GEOLOGIC HAZARDS

Geologic maps of the McCarthy area have been published by MacKevett (1970, 1971, 1972a, 1972b, 1974, 1976, and 1978). Descriptions of the geology of the Copper River basin are published by Mendenhall (1905), Moffit and Capps (1911), Moffit (1938), and Ferrians and others (1983). The tectonic features of the area are described by MacKevett and Plafker (1974), Berg and others (1972), and Richter and Matson (1971). Geologic information in this report is summarized from these authors.

The Wrangell Mountains are large shield and composite volcanoes. One of these, Mount Wrangell, is still active. Although this volcano has not erupted during historic time, it occasionally emits small amounts of steam and ash. The volcanoes are composed of volcanics of Cenozoic age resting on sedimentary and volcanic rocks of Paleozoic and Mesozoic ages.

The McCarthy area is within an extensive fault-bounded belt of Mesozoic rocks. About 23 mi southwest of McCarthy lies the Border Ranges fault and about 42 mi northeast of McCarthy lies the Totschunda fault system (figs. 1 and 2) (MacKevett, 1978; Richter, 1975). A series of thrust faults (not shown) along the southern flank of the Wrangell Mountains near McCarthy is thought to be due to compression during early stages of the Border Ranges activity in Late Jurassic and Early Cretaceous periods. Activity on the Border Ranges fault apparently waned after the early Tertiary period (MacKevett and Plafker, 1974, p. 329). Movement as recent as post-Wisconsin is well defined along the Totschunda fault system by small scarps and offset glacial deposits and streams, but evidence of very recent activity is lacking (Richter and Matson, 1971, p. 1534-1535). However, the earthquake in 1964 caused extensive ground cracks in alluvial flats of the large rivers in the McCarthy Creek area (Hansen and others, 1966, p. 11-12).

Bedrock

The generalized areal distributions of geologic units in the McCarthy area (plate 1) are based on 1:63,360 scale maps from MacKevett (1970, 1974) and MacKevett and Smith (1972). In general, from the southwest to northeast, bedrock within the study area is composed of sedimentary rocks of Cretaceous age (outcrop areas outlined on plate 1 using the symbol "K"); intrusive rocks of Tertiary age (Ti); Triassic greenstone and limestones (Tr); sedimentary rocks of Jurassic and Triassic age (JTr) consisting of impure limestone, shales, and chert; Tertiary sedimentary rocks (T); and lavas of Quaternary and Tertiary age (Q). The copper mineralization exploited by the Kennecott mines on Bonanza Ridge occurred in the lower few hundred feet of Chitistone Limestone.

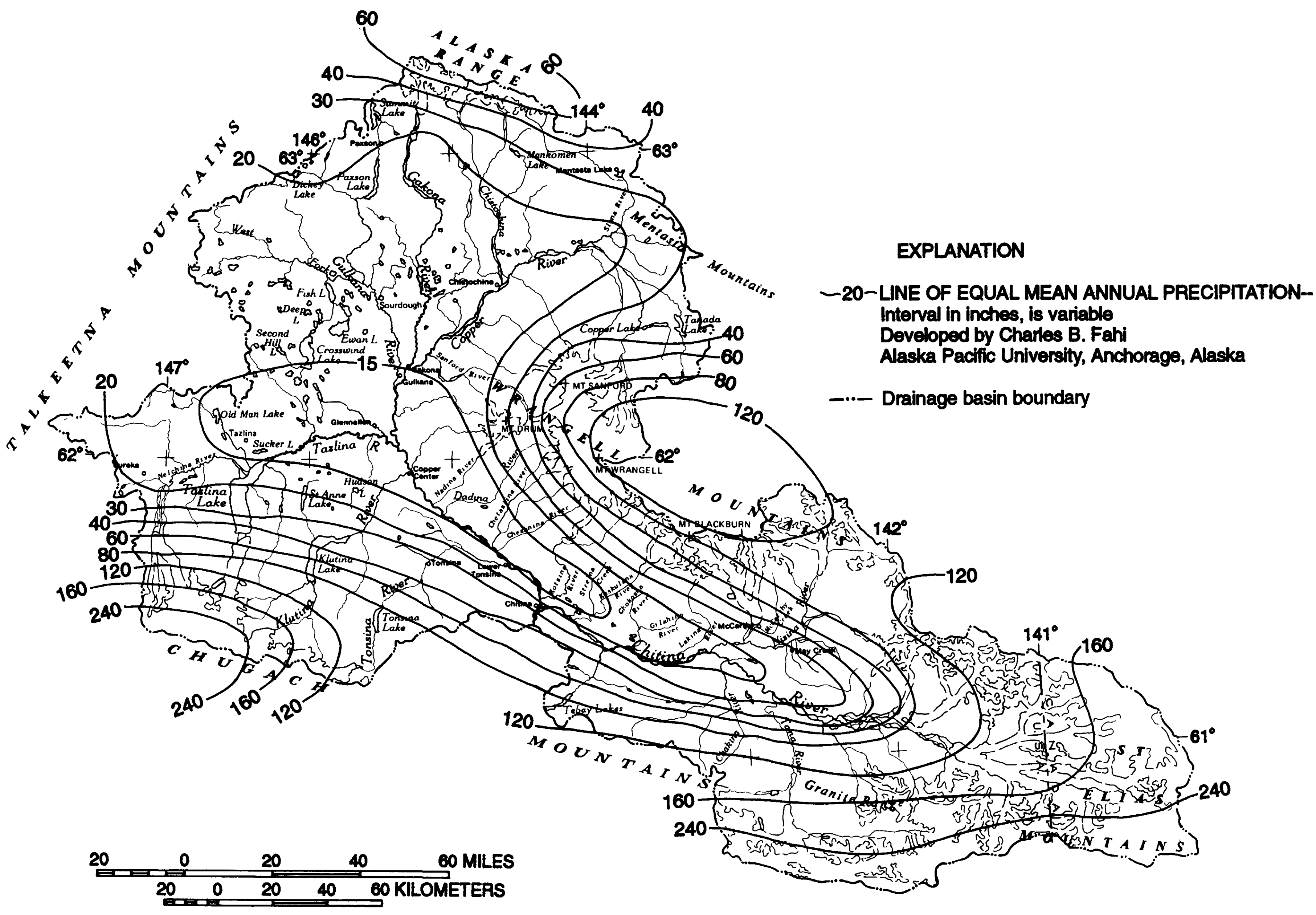


Figure 3. Generalized mean annual precipitation, 1951-80, for the Copper River Basin above Chitina.

Unconsolidated Materials

Unconsolidated surficial deposits are widespread and include alluvium, fluvial and glaciolacustrine deposits, moraines, landslides, talus, and rock glaciers. The area was glaciated repeatedly during the Pleistocene Epoch.

Alluvial and Glacial Deposits

Alluvium (Qal) occupies active flood plains and lower terraces along McCarthy Creek and Kennicott River. The alluvial deposits consist of poorly sorted silt, sand, gravel, and cobble outwash from sediment-laden glacial streams. Boulders larger than 10 ft in diameter are common in the alluvium and may be remnants from erosion of landslide or glacier deposits. The active channels in the alluvium are braided, and their courses shift continually. Alluvial fans are the result of sediment deposition as streams leave steep mountain fronts and discharge onto lower gradient valley floors.

Older alluvium (Qoa) and fluvial and glaciolacustrine deposits (Qfg) form terraces that support vegetation above active flood plains. Terraces in the upper reach of McCarthy Creek are as much as 200 ft higher than the present level of the stream and may represent outwash from previous glaciations. Maximum thicknesses of these deposits are not known. They consist of poorly consolidated sand and silt with some clay, granules, pebbles, and boulders. Some of these deposits were formed in a large periglacial lake in the Copper River basin during the Pleistocene Epoch. As the glaciers retreated, these deposits were reworked by lake currents or buried by lake sediments. The complicated interfingering of lake and glacial deposits and numerous shoreline features at elevations below 2,650 ft (NGVD of 1929) indicate that the lake level fluctuated widely. Where these deposits are saturated and have steep slopes, such as along the lower reach of McCarthy Creek, they are susceptible to erosion and **mass wasting**.

Moraines

Glacial moraines are accumulations of poorly sorted and poorly stratified materials deposited chiefly by direct action of glacial ice. Many are relicts of older, more extensive glaciation (Qm), whereas others are associated with or overlie modern glaciers (Qmi). The moraines consist mainly of angular and subangular rocks that have a great range in size. Lateral moraines along McCarthy Creek Glacier are about 250 ft across at their base and as much as 100 ft high (fig. 4).

Landslides

Landslides (Ql), as used in this report, include all slope-movement processes and classifications defined by Varnes (1978). The type of movement includes falls, topples, slides, spreads, flows, and complex slope movements of both rock and soil. The movement of materials down a slope is influenced by types and strengths of both rocks and soils present on the slope, slope angle, moisture content within the materials, and physical weathering. A landslide scar is a bare surface on the side of a steep slope that is left by the removal of rock, soil, and vegetation from the landslide source area. Landslides and boundaries of landslide scars were delineated on plates 1 and 2 by using geologic mapping published by MacKevett (1970, 1971, 1972a, 1972b, 1974, 1976, and 1978), interpretation of vertical aerial photographs (table 1), and field investigations during July and September 1990 and May, June, and September 1991.

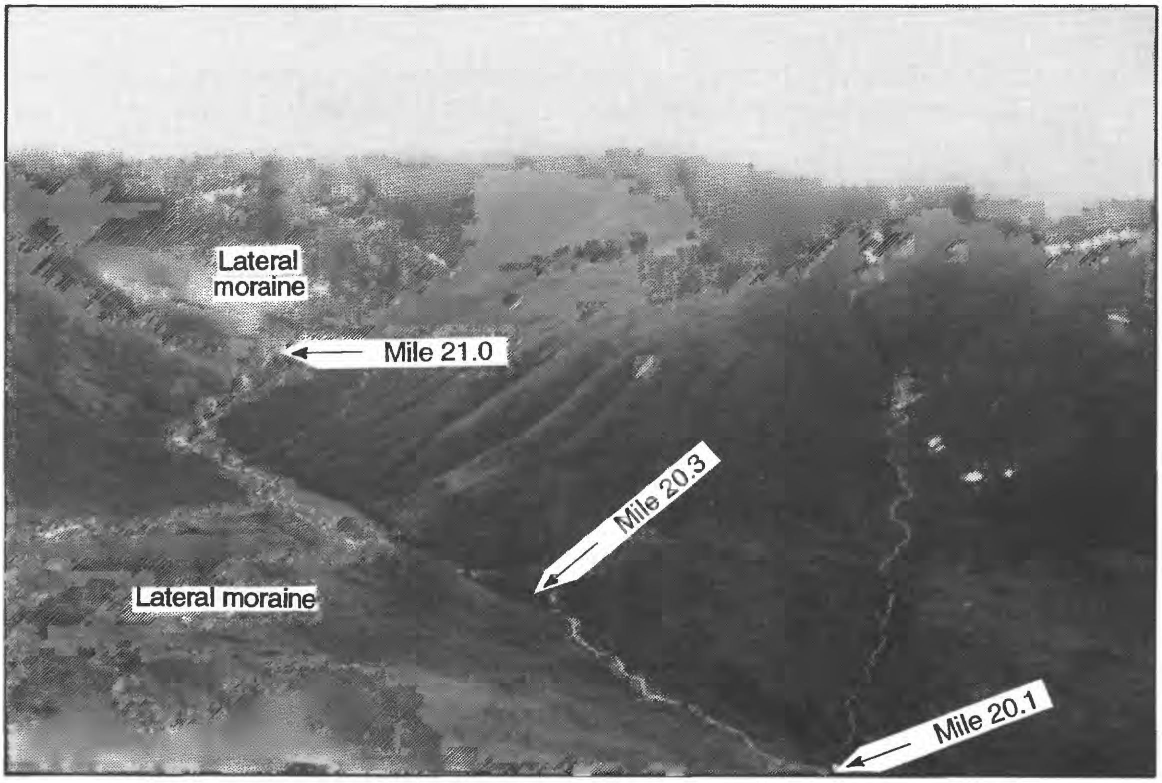


Figure 4. Aerial photograph of McCarthy Creek Glacier lateral moraine (stream mile 20.3) and tributary glacier stream (stream mile 20.3 to 21.0), July 12, 1990.

In the upper reach of McCarthy Creek where valley walls are steep, landslides have deposited large quantities of materials ranging in size from clay to boulders. Landslides along a bluff near the southernmost bend in McCarthy Creek (fig. 5) consist mainly of wet clays, silts, and sands. These landslides were saturated and actively sliding and **slumping** during July 1988 and June 1989 (Laurie Daniel, National Park Service, written commun., 1989) and in July and September 1990.

Talus

Deposits of **talus** (Qt) consisting of loose rock fragments and slabs are numerous, particularly along the valley walls above McCarthy Creek, along both sides of Bonanza Ridge, at the base of cliffs below Green Butte, and near the bases of cirque headwalls. Deposits of talus are included in the classification of landslides on plate 2, but have been delineated separately on the generalized geology map (plate 1). A comparison of a photograph published by Moffit and Capps (1911, plate IVA) and vertical aerial photographs taken on August 10, 1988, shows insignificant change of talus cones on the east side of McCarthy Creek at the base of the cliffs below Green Butte. Cuts into talus deposits, such as for roads, may initiate mass movement of these materials.

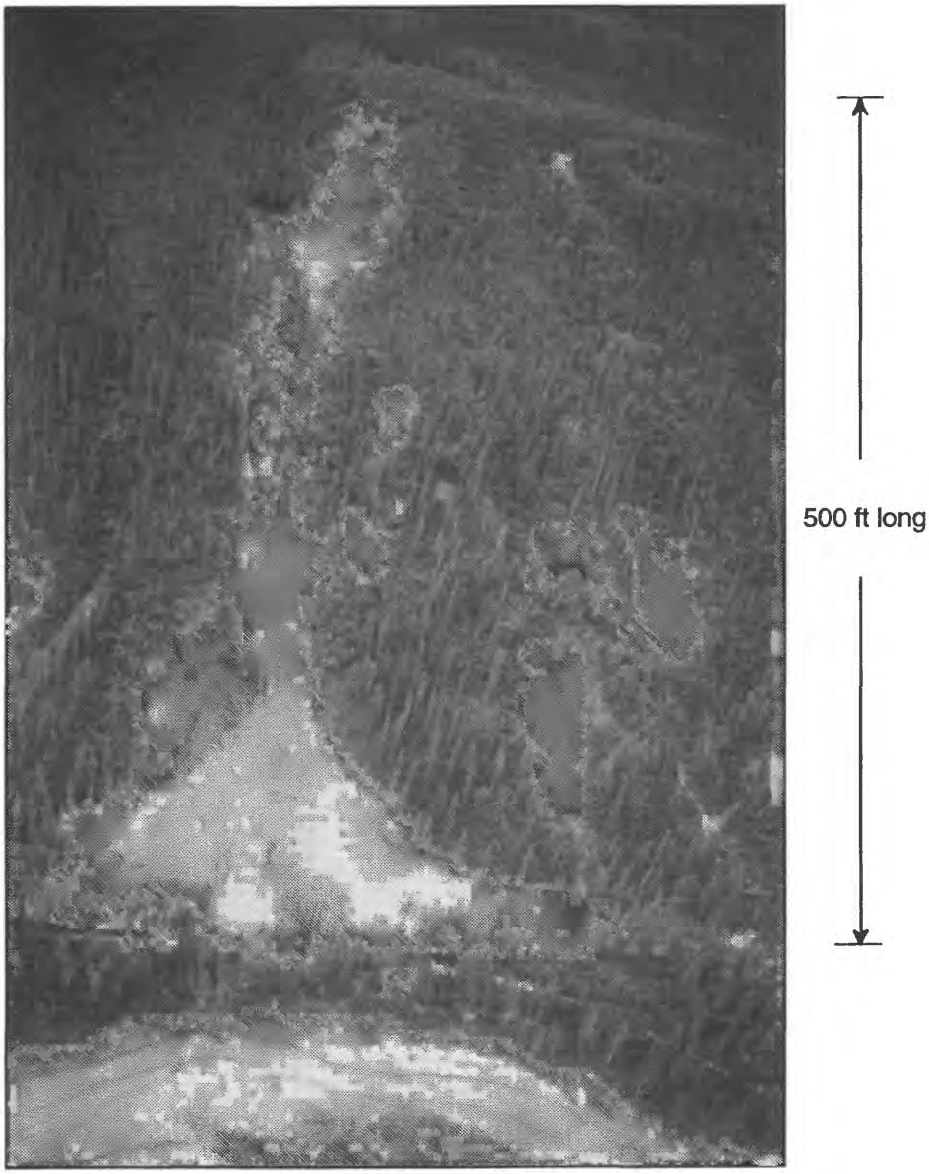


Figure 5. Debris-avalanche scar (approximately 500 feet long) along the south terrace of lacustrine sediments, McCarthy Creek (stream mile 4) , July 12, 1990.

Rock Glaciers

Rock glaciers (Qrg) superficially resemble glaciers or viscous lava flows, but consist of ice-bonded angular boulders, rubble, and cobbles derived from cirque walls or steep cliffs (Wahrhaftig and Cox, 1959). They are a few hundred feet to more than 2 mi long in the direction of flow, and a few hundred feet to more than 1 mi wide. In their upper parts, rock glaciers may have longitudinal ridges, whereas lower down, they have concentric ridges paralleling a steep-faced front (figs. 6 and 7). The rock glaciers in the McCarthy area are described by Capps (1910), Moffit and Capps (1911), and Moffit (1938). The types and processes of rock glaciers are discussed by Wahrhaftig and Cox (1959) and Giardino and others (1987). Wahrhaftig and Cox found that rock glaciers in the Alaska Range appeared to consist of a thin layer of coarse blocks at their heads and much

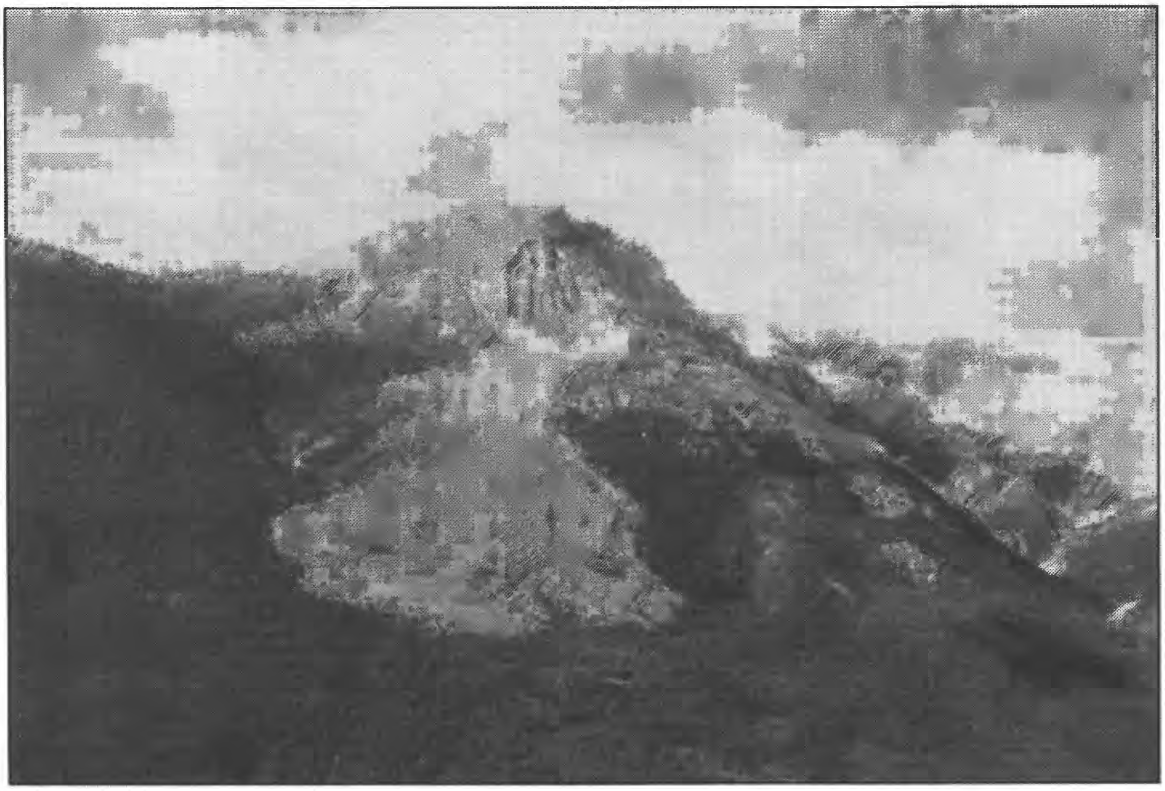


Figure 6. Sourdough Peak rock glacier, July 12, 1990.

thicker lower layers in which similar coarse blocks are mixed with sand, silt, and interstitial ice. At the present time, rock glaciers in the McCarthy Creek basin appear to have lost much of their interstitial ice and are now stagnant (Field, 1975). The fronts of the rock glaciers are covered with lichens and vegetation.

Although the potential for hazard at rock glaciers is low, an earthquake could cause a landslide at the steep-faced front of the rock glacier at the lower end of Porphyry Mountain (stream mile 10.3 of McCarthy Creek, fig. 7); the landslide could form a dam across the stream channel. Capps (1910) stated that, "McCarthy Creek is now actively cutting into the lower end of the rock glacier originating in the cirque headwall of Porphyry Mountain, which has been in existence long enough for large spruce trees to grow upon its surface. * * * McCarthy Creek has so far been unable to do more than keep a narrow channel open along the foot of the rock glacier [fig. 7, p. 369]. * * * There is no evidence that the rock glacier ever extended the 75 feet farther east which would have carried it to the rock bluff on the east side of the valley."

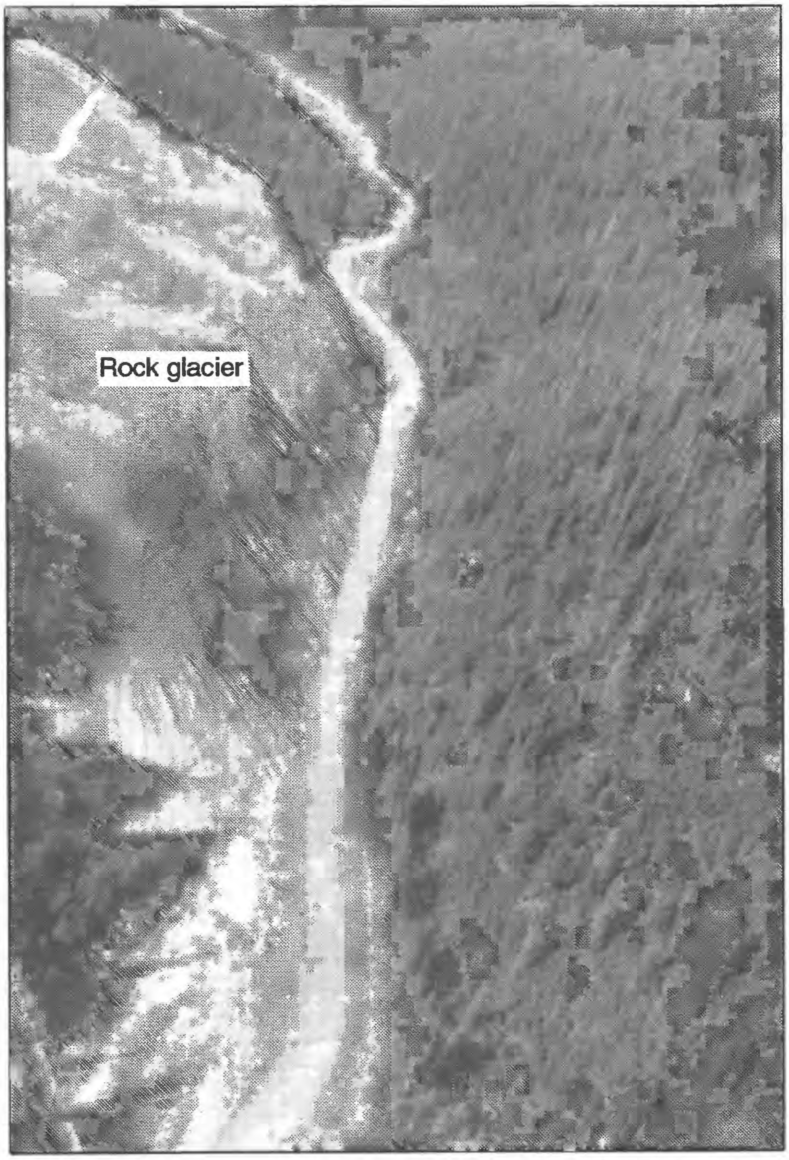


Figure 7. Lower end of Porphyry Mountain rock glacier on McCarthy Creek (stream mile 10.3), July 12, 1990. Vertical height at terminus is 100 to 150 feet.

DESCRIPTION OF DRAINAGE BASINS

Physical and climatic descriptions of drainage basins are necessary to estimate streamflow characteristics for gaged and ungaged streams. The magnitude of mean and peak streamflows in a basin is influenced by the basin's area, slope, type and distribution of rocks, land cover (glaciers, forests, lakes, ponds), precipitation, and temperature. The boundaries of the McCarthy Creek and Kennicott River drainage basins above McCarthy are shown in figure 2.

McCarthy Creek Basin

Physical Characteristics

McCarthy Creek originates from glaciers along the south slope of the Wrangell Mountains (plate 2 and fig. 8). Below its origin along the base of the ice-cored moraine of McCarthy Creek Glacier (stream mile 19.8 on plate 2), the braided stream flows southward over a 300- to 600-foot wide alluvial flood plain and has an average stream slope of 0.023 (fig. 9). Between stream miles 12.3 and 5, the stream flows through a series of bedrock canyons before turning west over an alluvial flood plain. Stream slope averages 0.019 between stream miles 5 and its mouth. Above its confluence with the Kennicott River, McCarthy Creek has a basin area of 76.8 mi^2.

An ice divide separates the accumulation area of McCarthy Creek Glacier from that of West Fork Glacier. McCarthy Creek Glacier is unusual because it flows from an elevation of 8,400 ft to 6,800 ft (NGVD of 1929), where individual ice blocks can fall or snow can avalanche approximately 1,000 ft down a cirque headwall, re-forming the glacier in the valley below (plate 2). The 0.59-square-mile lower glacier is fed by the icefalls and snow avalanches from the 0.81-square-mile upper icefield. The 1.40-square-mile McCarthy Creek Glacier and a 0.68-square-mile glacier east of the upper McCarthy Creek Glacier are covered in their lower parts by a thick mantle of moraine, which provides insulation and inhibits melting.

Recent Glacier Activity

Lateral moraines approximately 100 ft above surrounding terrain have formed along the lower part of McCarthy Creek Glacier (fig. 10). A comparison of a photograph taken by Moffit (1938, plate 12B) and vertical aerial photographs taken on July 29, 1957, shows that the glacier and its lateral moraine along the western margin have remained unchanged. One of the 1957 photographs shows that the moraine-covered part of the glacier was in contact with the eastern streambank of McCarthy Creek at stream mile 20 and that the stream was draining subglacially. By August 1978, the ice-cored moraine had receded and thinned, exposing till deposits. Aerial photographs taken on August 22, 1990 show that since July 29, 1957, the lower glacier has thinned and receded more than 800 ft along its eastern margin and receded 1,500 ft at its terminus. These photographs also indicate that other glaciers within the McCarthy Creek basin have thinned and receded more rapidly during the past 10 to 15 years than during the years 1938 to 1957.

The maximum extents of lateral and terminal moraines along the eastern margins of the lower glacier indicate that a tributary stream to the east has been blocked by the glacier or its lateral moraine. Although no sedimentological evidence of outburst flooding (as defined by Costa, 1987) was found below the damming site (site 10 on plate 2 and fig. 10), older vegetated terraces composed of alluvial deposits found upstream indicate that damming could have occurred. Erosion of the cirque headwall of McCarthy Creek Glacier by freeze-thaw action and by joint-block removal

Figure 8. View from Porphyry Mountain rock glacier showing McCarthy Creek drainage and Green Butte Mine, July 12, 1990.

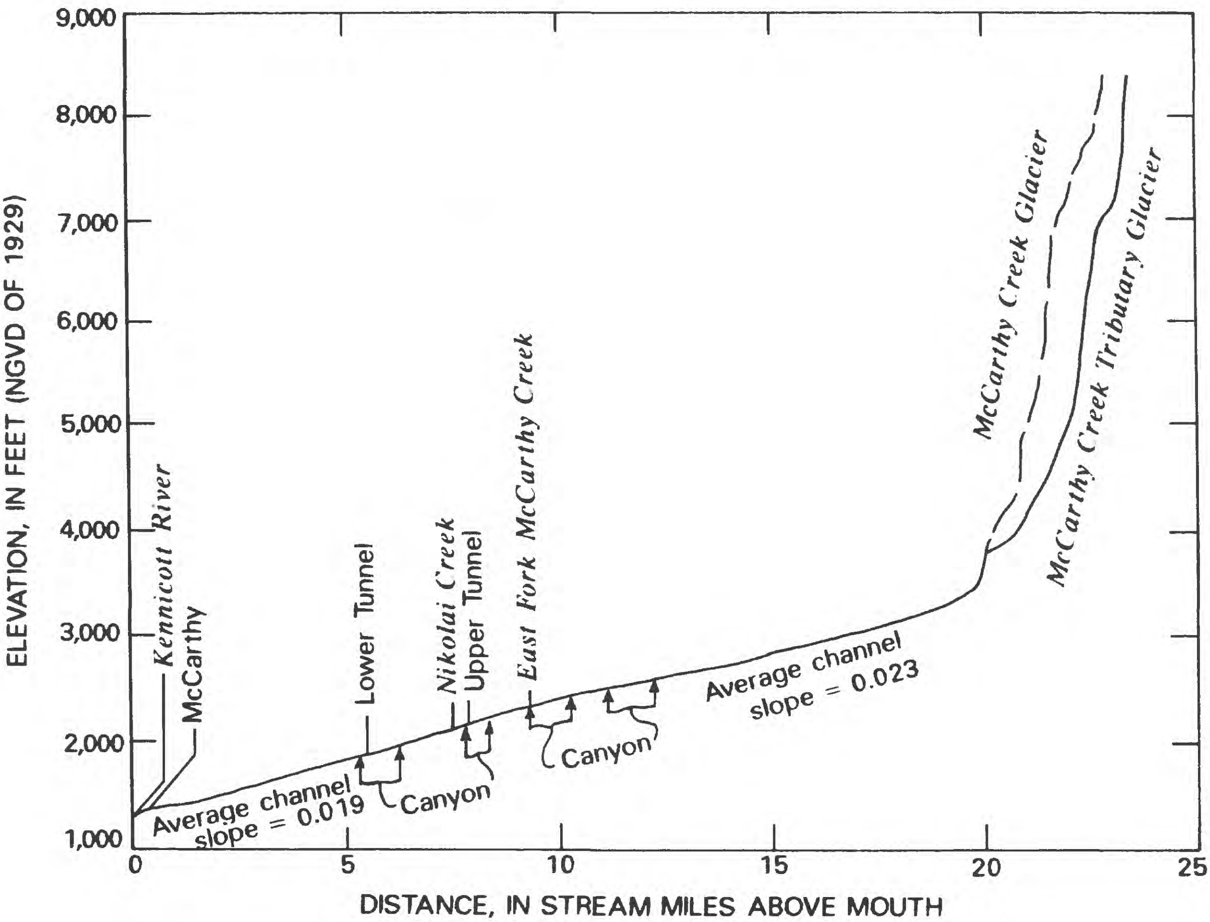


Figure 9. Longitudinal profile of McCarthy Creek.

has deposited large boulders on the ice surface. These massive rocks are transported by ice and deposited in the lateral and terminal moraines along the eastern margin of the glacier. Subsequent slumping, sliding, and erosion of the lateral moraines have deposited numerous large angular boulders (diameters larger than 10 ft) in the stream channel at the damming site (fig. 10). The reach of the stream channel near the damming site has a high potential for a landslide dam to form from steep morainal deposits during a prolonged or intense rainfall, rapid snowmelt, or earthquake.

The horizontally projected area shown as ice and perennial snow on the July 29, 1957 aerial photographs has decreased 49 percent over the entire McCarthy Creek basin above its mouth (site 20 on plate 2 and table 3) when compared with the August 22, 1990 aerial photographs. Comparison of the July 29, 1957 and August 27, 1990 aerial photographs of the 3.55-square-mile basin (site 10 on plate 2 and table 3) draining the 0.68-square-mile glacier to the east shows a similar decrease of 54 percent in the horizontally projected area shown as ice and perennial snow. During the same period, exposed areas of glacial moraines have increased along their lateral and terminal margins. The surface area of rock glaciers has remained nearly constant in all areas except in some accumulation zones where areas covered by rock and debris have increased because of the melting of perennial snow and ice.

Figure 10. McCarthy Creek tributary at McCarthy Creek Glacier (site 10), July 24, 1990. View downstream at McCarthy Creek Glacier lateral moraine. Boulders range from 6 feet to18 feet long.

Table 3. Basin characteristics of selected streams in the Copper River Basin above Chitina

[Methods from Thomas and Benson (1970); mi^2, square mile; ft, foot; mi, mile; inch; °F, degree Fahrenheit; see figs. 1, 2 and plate 2 for site locations]

Site No.	Station number	Stream name	Location		Drainage area (mi^2)	Main channel slope (ft/mi)	Stream length (mi)	Mean basin elevation (ft, NGVD of 1929)	Area, in percent							Mean annual precip-itation[4] (in.)	Mean minimum January tempera-ture[5] (°F)
			Latitude	Longitude					Lakes and ponds[1]	Ice dam lakes[2]	Forest	Glacier[3] 1957	Glacier[3] 1990	Rock glacier 1957	Rock glacier 1990		
1	15209000	Chititu Creek near May Creek	61° 22'12"	142°40'50"	30.9	305	13.0	4,150	0	0	26	3	--	--	--	30	0
2	15209100	May Creek near May Creek	61° 20'42"	142° 41'49"	10.4	429	7.00	2,450	0	0	92	0	0	0	0	20	0
6	----	Kennicott River main channel at McCarthy	61° 26'03"	142° 56'26"	[6]352	164	[7]32.5	5,580	0.1	0.3	4	46	--	1.4	--	80	-12
7	----	Kennicott River overflow channel at McCarthy	61° 26'04"	142° 55'49"	(Same values as site 6)												
10	----	McCarthy Creek tributary at McCar-thy Creek Glacier	61° 36'56"	142° 47'47"	3.55	948	3.09	5,640	0	0	3	41	19	0	0	100	-12
11	----	McCarthy Creek below Lubbe Creek	61° 32'42"	142° 47'07"	21.7	486	7.72	4,800	0	0	--	20	9.7	0	0	90	-12
12	----	McCarthy Creek at Green Butte Mine above landslide	61° 30'09"	142° 46'55"	32.1	276	11.1	4,780	0	0	20	16	8.6	0.9	1.2	80	-12
13	----	McCarthy Creek above East Fork McCarthy Creek	61° 28'02"	142° 46'48"	36.6	193	13.8	4,460	0	0	22	14	7.5	1.6	1.7	80	-10
14	----	East Fork McCar-thy Creek at mouth	61° 28'01"	142° 46'45"	10.9	705	5.27	4,870	0	0	9	1.2	0	3.3	3.3	60	-10
15	----	McCarthy Creek above Nikolai Creek near McCarthy	61° 26'43"	142° 46'30"	52.2	162	15.6	4,610	0	0	22	11	5.8	2.2	2.4	60	-8
16	----	Nikolai Creek trib-utary at mouth near McCarthy	61° 26'43"	142° 45'43"	2.47	1,040	3.60	4,430	0	0	9	0	0	8.1	8.1	50	-8

Table 3. Basin characteristics of selected streams in the Copper River Basin above Chitina--Continued

Site No.	Station number	Stream name	Location		Drainage area (mi^2)	Main channel slope (ft/mi)	Stream length (mi)	Mean basin elevation (ft, NGVD of 1929)	Area, in percent								Mean annual precip-itation[4] (in.)	Mean minimum January tempera-ture[5] (°F)
			Latitude	Longitude					Lakes and ponds[1]	Ice dam lakes[2]	Forest	Glacier[3] 1957	Glacier[3] 1990	Rock glacier 1957	Rock glacier 1990			
17	----	Nikolai Creek at mouth near McCar-thy	61° 26'43"	142° 46'26"	10.8	630	5.26	4,440	0	0	12	0	0	1.8	1.8	50	-8
18	----	McCarthy Creek near McCarthy	61° 25'21"	142° 53'23"	74.0	134	21.5	4,320	0	0	28	7.6	3.9	2.5	2.5	50	-6
19	15210000	McCarthy Creek near McCarthy	61° 25'42"	142° 54'18"	76.4	132	22.2	4,260	0	0	30	7.4	3.8	2.4	2.4	50	-6
20	----	McCarthy Creek at McCarthy	61° 25'55"	142° 55'27"	76.8	126	22.9	4,240	0	0	30	7.4	3.8	2.4	2.4	50	-6
22	15211700	Strelna Creek near Chitina	61° 30'40"	144°04'00"	23.8	264	11.4	3,350	0	0	31	0	0	0	0	25	-3
23	15211900	O'Brien Creek near Chitina	61° 28'59"	144° 27'23"	44.8	282	14.2	4,120	0	0	18	0	0	0	0	30	-6
26	15470300	Little Jack Creek near Nabesna	62°32 47"	143° 19'30"	6.73	344	6.60	4,680	1	0	30	0	0	0	0	30	-20
27	15470330	Chalk Creek near Nabesna	62° 30'19"	143° 09'24"	14.8	198	5.90	3,960	3	0	73	0	0	0	0	30	-20
28	15470340	Jack Creek near Nabesna	62° 27'52"	143° 05'18"	115	91.0	23.1	4,340	1	0	41	1	0	0	0	30	-20

[1]Percent without ice-dammed lakes or morainal lakes.
[2]Percent with only ice-dammed lakes and morainal lakes subject to release of stored water.
[3]Glacier includes ice and perennial snow.
[4]See figure 3.
[5]Mean minimum January temperature from Hartman and Johnson (1984, p. 71).
[6]Combined drainage area of main channel and overflow channel.
[7]Includes 0.5 mi of river channel and 32.0 mi of glacier.

Comparison of aerial photographs of McCarthy Creek Glacier taken on July 27, 1957 and August 22, 1990 shows that perennial snow and ice in its accumulation zone have receded beyond a cirque headwall, separating the glacier into two parts. Separation of the lower part of McCarthy Creek Glacier from the upper icefield may reduce the volume of snow and ice being supplied to the lower part of the glacier and cause the lower glacier to thin and recede more rapidly than other nearby glaciers.

Along the south slopes of the Wrangell Mountains, not all glaciers originating in cirque headwalls and being fed by snow and ice avalanches are thinning and receding. A glacier in Radovan Gulch (fig. 2), 19 mi east of McCarthy, is fed by snow avalanches from adjacent steep headwalls; the glacier surged about 1 mi towards Glacier Creek between the fall of 1988 and spring of 1989 (Monte Wilson, National Park Service volunteer, written commun., 1989, and Edward LaChapelle, oral commun., 1990).

Streamflow Characteristics

The size distribution of rocks that make up the streambed of McCarthy Creek and the quantity and size distribution of sediments being transported along the bottom of the stream (**bedload**) on August 15, 1986 at site 11 (about 4 mi below McCarthy Creek Glacier) were analyzed by W.W. Emmett (appendix table A1). However, bedload discharge is subject to wide temporal and spatial variation.

Intermittent measurements of stream discharge have been made in the McCarthy Creek basin. A gaging station was operated for a few months during 1913 about 0.75 mi above the mouth of McCarthy Creek (site 19) (Ellsworth and Davenport, 1915). Values of daily discharge for 1913 are listed in appendix table A2. Miscellaneous measurements of discharge in McCarthy Creek and its tributaries are listed in appendix table A3. Flood discharges (table 4) were determined using the **slope-area method** (Barnes and Davidian, 1978) at two reaches on the Kennicott River (sites 6 and 7), four reaches on McCarthy Creek (sites 13, 18, 19, and 20), and at one on Nikolai Creek (site 17). Average velocity in the active channel is higher than or equal to the average velocity in the bankfull channel (table 4) because of the roughness of the vegetated overflow flood plain.

A multiple regression analysis of mean annual runoff (Q_A) was made for five glacial streams in the Copper River basin and for Phelan Creek near Paxson in the Alaska Range. Drainage basins having glaciers covering from 8 to 69 percent of their areas were used to develop the following equation that applies only to glaciated basins within the Copper River basin:

$$Q_A = 1.242A^{0.926}P^{-0.154}GL^{0.573}, \qquad (1)$$

where A is drainage area in square miles;
P is mean annual precipitation, in inches (fig. 3); and
GL is percentage of the total drainage area shown as perennial snow or ice on the topographic maps, and represents the conditions at the time the aerial photographs were taken to make the maps.

The average standard error of estimate of equation 1 for estimating mean annual runoff for glaciated drainage basins within the Copper River basins is 12 percent. Using equation 1, mean annual runoff of McCarthy Creek at McCarthy (site 20) is estimated to be about 120 ft^3/s. The equation is not valid for estimating mean annual runoff from glaciated drainage basins outside the Copper River basin.

Table 4. Hydraulic properties for slope-area discharge determinations for selected streams in the McCarthy area

[ft, foot; ft^3/s, cubic foot per second; ft/s foot per second]

Site No. (plate 2)	Stream name	Date of flood	Peak discharge (ft^3/s)	Accuracy of peak discharge	Average active channel		Average bankfull channel						Maximum velocity head (ft)	Maximum Froude number[1]
					Manning roughness coefficient	Velocity (ft/s)	Cross-sectional area (ft^2)	Width (ft)	Depth (ft)	Velocity (ft/s)	Hydraulic radius[1]	Friction slope[1]		
6	Kennicott River main channel at McCarthy	8-4-91	17,800	Poor	0.052	10.2	2,170	333	6.52	10.7	6.37	0.0110	2.97	1.01
7	Kennicott River overflow channel at McCarthy	8-4-91	4,560	Poor	.052	5.28	2,040	270	7.56	2.24	7.86	.0114	2.08	.90
13	McCarthy Creek above East Fork McCarthy Creek	9-13-80	2,730	Fair	.045	11.8	268	88.3	3.04	10.2	2.95	.0127	2.43	1.12
17	Nikolai Creek at mouth near McCarthy	--	830	Poor	.060	12.3	67.7	25.0	2.71	12.3	2.46	.0728	2.36	1.38
18	McCarthy Creek near McCarthy	8-13-85	2,800	Fair	.045	8.72	321	123	2.61	8.72	2.67	.0158	1.53	.98
19	McCarthy Creek near McCarthy	7-1-75	2,080	Fair	.046	7.15	291	115	2.53	7.15	2.80	.0150	.92	.85
20	McCarthy Creek at McCarthy	9-13-80	4,500	Poor	.045	9.72	608	224	2.72	7.40	2.42	.0167	1.72	1.06

[1]See "Glossary" for definition.

Kennicott River Basin

The Kennicott River basin covers 352 mi^2, of which 46 percent was perennial snow and ice in 1957. The largest glacier within the basin is Kennicott Glacier, which is 27.8 mi long and drains the southeastern slopes of Mount Blackburn and southern slopes of Regal Mountain. Kennicott River flows from the terminus of the Kennicott Glacier to the Nizina River, a distance of 4.7 mi. Two channels flow from the terminus of the glacier: the main channel is on the western side of an alluvial fan (site 6, plate 2) and the overflow channel is on the eastern side (site 7, plate 2). To reach McCarthy, residents and visitors must cross the Kennicott River in hand-pulled trams suspended from cables across these two channels, because bridges across the river were destroyed by floods. However, during November and December, flows are commonly low enough to allow heavy vehicles to drive across the channels.

Kennicott Glacier has been described by Bateman (1922), Field (1975), and Denton (1975). Aerial photographs taken during the last decade indicate that the lower part of Kennicott Glacier has thinned and retreated. Since 1988, an ice-cored moraine at the terminus of the glacier has thawed. Flows in the eastern channel have decreased, while flows in the western channel have increased.

A comparison of aerial photographs taken by Bradford Washburn in 1937 and 1938, by the USGS on July 29, 1957, and by Austin Post during 1964, shows that the glacier changed little from 1937 to 1964 (Denton, 1975). The 1937 and 1938 aerial photographs taken by Washburn show that the ice had withdrawn from its terminal moraine "a few hundred meters" (Denton, 1975). Botanical observations of the terminal moraine indicate that the maximum extent of the moraine occurred in about 1860; a 360-year-old group of trees, partly buried by alluvial deposits, indicates that the glacier has not extended beyond its 1860 maximum since at least 1600 (Viereck, 1967).

Mean annual runoff of Kennicott River at McCarthy (sites 6 and 7) is estimated to be about 1,300 ft^3/s using equation 1. Flood discharges (table 4) were determined using the slope-area method at Kennicott River main channel (site 6) and Kennicott River overflow channel (site 7).

HYDROLOGIC AND MASS-MOVEMENT HAZARDS

McCarthy Creek and Kennicott River basins are prone to several natural hazards: floods, glacier-dammed lakes and outburst floods, stream erosion and sediment deposition, snow avalanches, **aufeis**, and landslides.

Hazard Potentials

Many areas susceptible to hydrologic and mass-movement hazards are delineated on plate 2, and their potentials for hazard are rated on the basis of their physical conditions (table 5). The hazard potentials were based on hydrologic and geologic interpretation of vertical aerial photographs, oblique aerial photographs, terrestrial photographs, and field-observed data. Detailed hazard mapping (plate 2) was based on superpositioning historic vertical aerial photographs (table 1) using a stereo zoom transfer scope.

A hazard potential is designated as high ("H" on plate 2) on the basis of relatively high-frequency and (or) recent (1990) occurrences and conditions that make streams or basins highly susceptible to mass-movement or flood phenomena. These include steep slopes, unconsolidated material on steep slopes and fans, and the formation of snow avalanche dams, landslide dams, and moraine lakes and dams. Areas designated as high potential have been documented in reports and photographs dating back to Capps in 1910. In table 5, an "annual" event can occur each year.

A hazard potential is designated as low ("L" on plate 2) on the basis of relatively low-frequency occurrences of an extreme or extraordinary seismic or hydrologic event. These include intense rainfall, rapid snowmelt, rapid thaw of frozen soils, or earthquakes. In table 5, an "extreme" event has a return period in excess of about 100 years.

The sites where natural dams are formed from landslides, snow avalanches, glaciers, or moraines are designated as "D" on plate 2; the sites designated "D" on figure 2 are sites where only glacier-dammed lakes are formed. The natural dams formed by glaciers have been documented in reports by Ellsworth and Davenport (1915), Moffit (1938), Post and Mayo (1971), and Friend (1988). The natural dams formed by landslides, snow avalanches, or moraines were identified on vertical aerial photographs (table 1) and during field investigations done in July and September 1990 and May, June, and September 1991. It is difficult to predict the magnitude or frequency of these events because of insufficient information on the frequency of landslides caused by rainfall, snowmelt, soil saturation, thawing of frozen soils, and earthquakes.

History of Floods

Low-lying areas along McCarthy Creek and the Kennicott River have a history of flooding and flood damage. Floods in the McCarthy Creek basin are commonly caused by intense and prolonged rainfall. During a storm from June 30 through July 1, 1975, a total of 1.56 in. of rain was recorded at McCarthy. Rainfall in the basin resulted in a peak discharge on July 1 of 2,080 ft^3/s [unit runoff, 27.2 $(ft^3/s)/mi^2$] at site 19 (plate 2 and table 6) near the town of McCarthy. In table 6, the term "maximum known flood" is used when the approximate time and cause (such as snowmelt, rain, glacial outburst) are known. In contrast, a "maximum evident flood" is based on flood evidence whose timing and cause are uncertain. It is determined from the highest flood debris, washlines on steep banks, and channels swept clear of vegetation (Childers, 1974).

During a storm of September 13-16, 1980, a total of 4.92 in. of rain fell at climatological station McCarthy 1 NE (site 8, plate 2). The maximum-daily rainfall during this period was 2.00 in. (table 2) on September 13. The peak discharge associated with this storm was 4,500 ft^3/s [unit runoff, 58.6 $(ft^3/s)/mi^2$] at site 20 (plate 2 and table 6). A bridge over McCarthy Creek near site 20 and all bridges within the McCarthy Creek basin that had been rebuilt in 1970 were destroyed by this flood (Loy Green, McCarthy resident, oral commun., 1990).

During August 12-18, 1985, a total of 4.72 in. of rain was recorded at climatological station McCarthy 3 SW (site 21, plate 2). Maximum daily rainfall during the period was 2.33 in. (table 2) on August 13. Floodwaters from McCarthy Creek eroded at least 30 ft of the northern bank about 800 ft upstream from a historical powerhouse (now used as a hotel) and deposited a layer of sediment 3 to 4 ft thick near the powerhouse (Jones, 1988, p. 1). Water reached the doorsill of the powerhouse during this flood.

According to Loy Green, McCarthy resident since 1965, the 1980 flood peak discharge was the highest and the 1985 flood peak discharge was the second highest on McCarthy Creek during the period of his residency.

Table 5. Hydrologic and mass-movement hazards in the McCarthy area

[H, high-frequency and (or) recent (1990) occurrences and conditions make streams or basins highly susceptible to mass-movement or flood phenomena: steep slopes, unconsolidated material on steep slopes and fans, snow avalanche dams, landslide dams, ice dams, and morainal lakes and dams subject to storage and release. An "annual" event can occur each year.
L, low-frequency occurrences of one or more extraordinary seismic or hydrologic events: intense prolonged rainfall, rapid snowmelt, rapid thaw of frozen soils, or earthquakes. An "extreme" event has a return period in excess of about 100 years.
D, site of formation of natural dam from landslide, snow avalanche, glacier, or moraine.]

Type of hazard	McCarthy Creek			Kennicott River			Effect
	Location (stream miles above mouth)	Hazard potential (plate 2)	Type of event	Location (stream miles above mouth)	Hazard potential (plate 2)	Type of event	
Landslides							
Rockfalls, topples, and slides	5.2 - 6.0	H	Annual	--	--	--	Direct damage to personal property, roads, and structures. Formation and failure of dams, sedimentation of stream channels
	7.6 - 8.3	H	Annual				
	9.3 - 10.2	H	Annual				
	10.2 - 10.4	LD	Earthquake	--	--	--	
	11.6 - 12.3	HD	Annual				
Debris slides and debris flows	2.3 - 10.2	H	Annual				
	13.2 - 20.4	H	Annual				
Natural dams							Formation and failure of dams cause floods and tremendous quantities of sediment and debris to be eroded, transported, and deposited downstream
Glaciers	--	--	--	See figure 2	HD	Annual	
Morainal	--	--	--	5.0 - 7.0	LD	Extreme	
Landslide	11.6 - 12.3	HD	Annual	--	--	--	
	20.0 - 20.4	LD	Extreme	--	--	--	
Snow avalanches	2.3 - 20.8	H	Annual	--	--	--	Direct damage to personal property, roads, and structures; formation and failure of dams

Table 5. Hydrologic and mass-movement hazards in the McCarthy area--Continued

Type of hazard	McCarthy Creek			Kennicott River			Effect
	Location (stream miles above mouth)	Hazard potential (plate 2)	Type of event	Location (stream miles above mouth)	Hazard potential (plate 2)	Type of event	
<u>Floods</u>							
Snowmelt	0 - 20.8	H	See "Flood	0 - 7.5	H	See "Flood	Inundation, streambed
Glacier icemelt	0 - 20.8	H	Magnitudes" and	0 - 7.5	H	Magnitudes" and	scour, erosion, and
Rainstorms	0 - 20.8	H	"Flood Fre-	0 - 7.5	H	"Flood Frequency"	deposition; direct dam-
Rain on snow	0 - 20.8	H	quency"	0 - 7.5	H	sections	age to personal prop-
Snow and ice jams	0 - 20.8	H	sections Annual	0 - 7.5	H	Annual	erty, roads, and structures
<u>Aufeis</u>	0 - 20.8	H	Annual	0 - 7.5	H	Annual	Flooding and direct damage to structures
<u>Seismic activity</u>	0 - 20.8	L	Extreme	--	--	--	Induces landslides and snow avalanches

Table 6. Flood stages and discharges of selected streams in the Copper River Basin above Chitina

[mi^2, square mile; ft, foot; ft^3/s, cubic foot per second; $(ft^3/s)/mi^2$, cubic foot per second per square mile; see figs. 1, 2 and plate 2 for site locations]

Site No.	Station number	Stream name	Location		Drainage area (mi^2)	Period of record	Maximum known flood				Maximum evident flood	
			Latitude	Longitude			Date	Stage (ft)	Discharge (ft^3/s)	Unit runoff [$(ft^3/s)/mi^2$]	Discharge (ft^3/s)	Unit runoff [$(ft^3/s)/mi^2$]
1	15209000	Chititu Creek near May Creek	61° 22'12"	142° 40'50"	30.9	1973-83 1985, 90	8-7-81	6.22	970	31.4	--	--
2	15209100	May Creek near May Creek	61° 20'42	142° 41'49"	10.4	1973-83 1985, 90	8-7-81	6.87	168	16.2	--	--
6	----	Kennicott River main channel at McCarthy	61° 26'03"	142° 56'26"	[a]352	1991	8-4-91	[b]1,343.40	17,800	[c]63.5	--	--
7	----	Kennicott River overflow channel at McCarthy	61° 26'04"	142° 55'49"	(a)	1991	8-4-91	[b]1,355.00	4,560	--	--	--
12	---	McCarthy Creek at Green Butte Mine above landslide	61° 30'09"	142° 46'55"	32.1	1990	--	--	--	--	2,810	87.5
13	----	McCarthy Creek above East Fork McCarthy Creek	61° 28'02"	142° 46'48"	36.6	1980, 90	9-13-80	--	2,730	75.0	--	--
17	----	Nikolai Creek at mouth near McCarthy	61° 26'43"	142° 46'26"	10.8	1990	--	--	--	--	830	76.8
18	----	McCarthy Creek near McCarthy	61° 25'21"	142° 53'23"	74.0	1985, 90	8-13-85	(d)	2,800	37.8	--	--
19	15210000	McCarthy Creek near McCarthy	61° 25'42"	142° 54'18"	76.4	1975	7-1-75	--	2,080	27.2	--	--
20	----	McCarthy Creek at McCarthy	61° 25'55"	142° 55'27"	76.8	1990	9-13-80	[e]63.70	4,500	58.6	--	--

Table 6. Flood stages and discharges of selected streams in the Copper River Basin above Chitina--Continued

Site No.	Station number	Stream name	Location		Drainage area (mi^2)	Period of record	Maximum known flood				Maximum evident flood	
			Latitude	Longitude			Date	Stage (ft)	Discharge (ft^3/s)	Unit runoff [(ft^3/s)/mi^2]	Discharge (ft^3/s)	Unit runoff [(ft^3/s)/mi^2]
22	15211700	Strelna Creek near Chitina	61° 30'40"	144° 04'00"	23.8	1971-90	8-12-85	26.57	670	28.2	--	--
23	15211900	O'Brien Creek near Chitina	61° 28'59"	144° 27'23"	44.8	1970-90	8-7-81	3.40	1,940	43.3	--	--
26	15470300	Little Jack Creek near Nabesna	62° 32'47"	143°19'30"	6.73	1975-90	9-11-75	16.92	171	25.4	--	--
27	15470330	Chalk Creek near Nabesna	62° 30'19"	143° 09'24"	14.8	1975-90	8-10-78	18.00	360	24.3	--	--
28	15470340	Jack Creek near Nabesna	62° 27'52"	143° 06'18"	115	1975-83	6-11-75	21.60	2,440	21.2	--	--

[a]Combined drainage area of main channel and overflow channel.
[b]Arbitrary datum.
[c]Combined discharge of main channel and overflow channel.
[d]Below the 1980 flood.
[e]See figure 13.

Glacier-Dammed Lakes and Outburst Floods

The major hazard posed by glacier-dammed lakes is catastrophic flooding that occurs when an ice dam fails. Detailed descriptions of glacier-dammed lakes and outburst floods in Alaska can be found in reports by Post and Mayo (1971), Costa (1987), Sturm and others (1987), Friend (1988), and Mayo (1988). Ellsworth and Davenport (1915) describe extreme floods caused by sudden release of water from subglacial channels beneath Kennicott Glacier. Bateman (1922) reported the subglacial draining of Hidden Creek Lake causing the sudden rise of "Pothole," a glacial moraine lake located at the terminus of Kennicott Glacier. Subglacial release of Hidden Creek Lake also was reported by Moffit (1938, p. 13, plate 5A). Much of the following section summarizes portions of the Post and Mayo (1971) report that relate to conditions in the McCarthy area. Five sites where glaciers have flowed across the mouths of adjoining valleys and caused lakes to form are shown as "D" on figure 2.

Glacier-dammed releases during the winter may cause ice-jam flooding and river stages much higher than they would be during open-water releases. The formation of ice jams causes flooding upstream from the jam; the sudden failure of ice jams causes the surge of water downstream. During an unusually cold period in 1909, the outlet of the subglacial lake known as "Pothole" was closed and water ponded upstream; the water later released from the lake flooded the Kennicott River (Moffit and Capps, 1911). Post and Mayo (1971) describe winter releases of Hidden Creek Lake near McCarthy that cause icings and flooding over river ice downstream. Ice-jam floods have been documented more frequently for the more populated Kenai Peninsula than for the remote McCarthy area. On the Kenai River, flooding during winter is the result of the sudden release of water from Skilak Glacier (250 mi southwest of McCarthy) and from Snow River Glacier (210 mi southwest of McCarthy). Ice-jam flood damage occurred on the Kenai River in January 1969 and on the Snow River in December 1985 and November 1990.

Sturm and others (1987, p. 88) observed that the filling and draining of ice-dammed lakes can be irregular in periodicity and style of draining, and that the magnitude of outburst floods can vary markedly from year to year. Strandline Lake, about 70 mi west northwest of Anchorage, drained at intervals of 2 years between 1980 and 1986, but from 1974 to 1979, no flood occurred. Costa (1987, p. 451) found that the phenomena of outbursts are more complex than can easily be analyzed, and therefore models to predict flood magnitude are not reliable. More documentation of the time, magnitude, and extent of outburst floods would be required to predict magnitude and frequency of floods near McCarthy.

Large floods can occur from the sudden release of water stored along, within, or on the surface of a glacier or in depressions in ice-cored moraines. Numerous small moraine lakes are present in the ice-cored terminal or recessional moraine of Kennicott Glacier. Terminal or recessional moraines in glaciated areas may be so well preserved that they impound water from the melting glacier. These dams subsequently may fail by overtopping and rapid erosion (Costa, 1987).

Kennicott River Floods

The Kennicott River is subject to floods, usually one or more each year, that are caused by outbursts from glacier-dammed lakes (designated as "D" on fig. 2) or from temporarily clogged subglacial channels. These releases of water inundate low-lying areas of the Kennicott River alluvial flood plain. In some places, flooding occurs annually, but many exceptions occur and the situations can change rapidly from one year to the next. Glacier-dammed lakes most commonly break out during late July or early August. Aerial photographs show that most glacier-dammed lakes in the McCarthy area have drained by late August. The time of glacier lake release is not related to weather patterns in any simple way. Regardless of the time of year, glacier-dammed lakes release whenever they become filled to critical levels. An abrupt release of water, even from very small lakes, can present local flood hazards. Wide flood plains can be inundated, and high discharge rates can cause rapid erosion, deposition, and channel changes. Damage may occur in spring, summer, or fall, especially when the outburst flood is superimposed on already high discharge from melting snow or rainstorms.

Since 1988, outburst flood flows discharging from the eastern terminus of the Kennicott Glacier have eroded a larger channel in the terminal moraine at the head of the island separating the two channels (fig. 11). High flows from the east channel have been captured by the main channel to the west as the Kennicott River incises through the thawing moraine. As this trend continues, the overflow channel to the east may eventually become perched and carry no flow. Several abandoned channels remain perched along the terminal moraine above the present active stream channel.

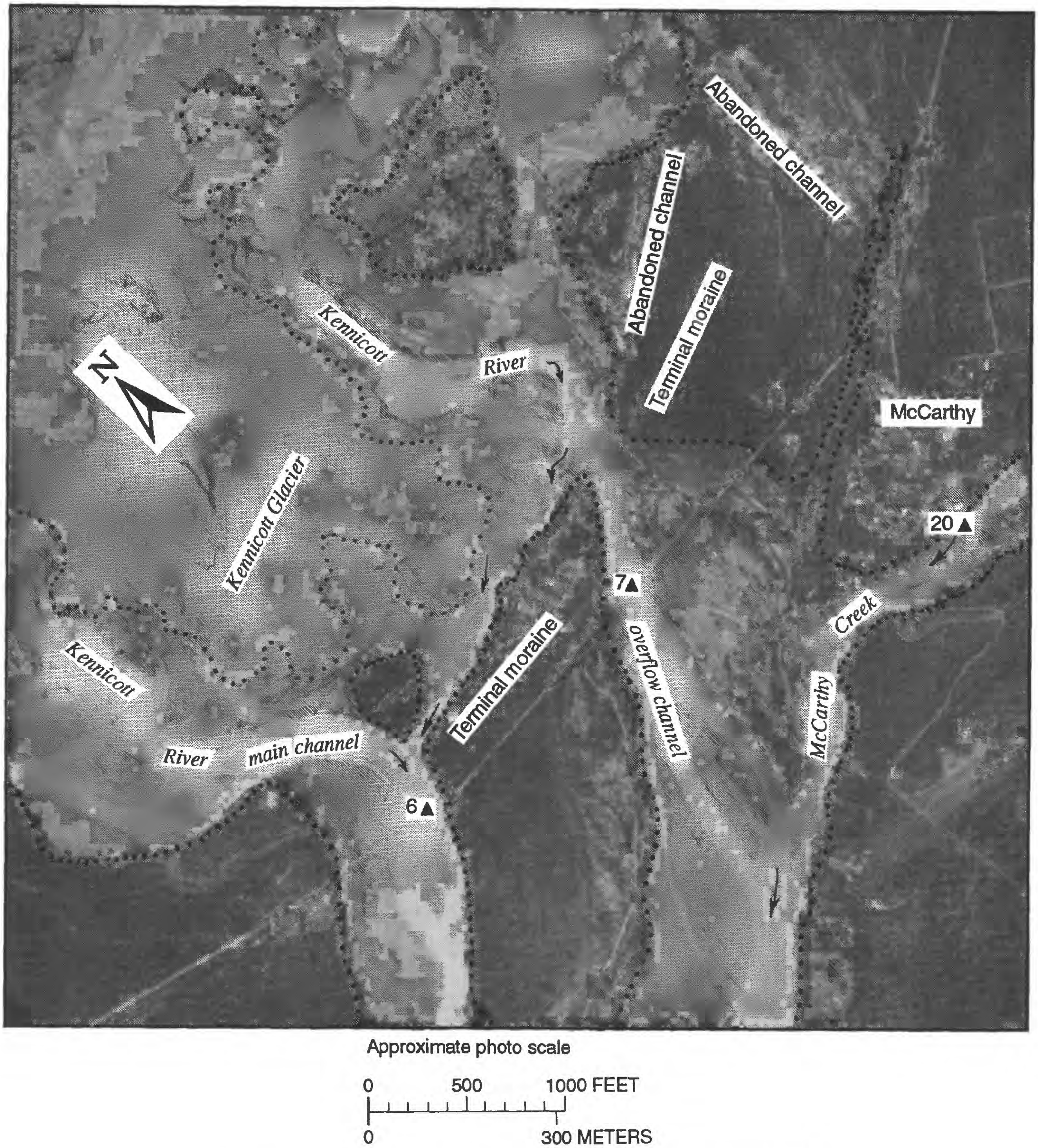
Hidden Creek Lake

The largest known flows on the Kennicott River have been from sudden releases of ice-dammed Hidden Creek Lake (fig. 2), about 10.5 mi northwest of McCarthy. The water from Hidden Creek Lake flows beneath or through the Kennicott Glacier and water backs up along the opposite (eastern) side. All sparsely vegetated low-lying areas near the river, including a parking area on the western bank, are commonly inundated (fig. 11 and plate 2). During field surveys in 1991, the maximum evident outburst flood boundary was defined (fig. 11) according to guidelines from Childers (1974). The maximum evident outburst flood boundary represents the historic maximum outburst flood evidence deposited when the Kennicott Glacier terminus was closer to the terminal moraine and larger outburst flood flows were carried by the overflow channel. The abandoned channels shown on figure 11 were actively carrying flow during 1911 (Moffit and Capps, 1911, plate II).

During the summer of 1986, Friend (1988) determined that Hidden Creek Lake had an area of approximately 1 mi^2, a depth of nearly 400 ft near the glacier, and a volume between 2.5×10^9 and 3.2×10^9 ft^3, of which at least 25 percent was ice. In 1986, some ice blocks remaining on the drained lakebed were more than 400 ft high (Friend, 1988). Release of water from Hidden Creek Lake usually occurs between July 20 and August 15, and occasionally in winter or fall (Friend, 1988, p. 11 and 31). However, in 1990 it occurred on July 4 (Edward LaChapelle, McCarthy resident, oral commun., 1990).

During 1986, Hidden Creek Lake started to release on August 2. Instantaneous peak discharge occurred at McCarthy on August 6 and was calculated to be 13,500 ft^3/s (Friend, 1988, p. 49), of which base flow was estimated to be 4,200 ft^3/s. Friend (1988, p. 33) had observed peak flows in years prior to 1986 and estimated that those discharges were three times greater than the 1986 peak discharge.

During 1991, Hidden Creek Lake started to drain subglacially on August 3. By the next day, subglacial flow filled Jumbo Lake on the opposite (east) side of the glacier and subsequently flowed from the glacier's terminus in the eastern channel (site 7). The highest discharge was on August 4 (Edward LaChapelle, written commun., 1991) and Hidden Creek Lake was observed to be drained by August 5 (Cynthia Aldrich, local resident, oral commun., 1991). Instantaneous peak discharges at sites 6 and 7 were 17,800 and 4,560 ft^3/s respectively (table 4), determined on the basis of slope-area methods.



EXPLANATION

7▲	Site location and number listed in tables	...	Boundary of maximum evident outburst flood

Figure 11. Kennicott Glacier and River at McCarthy, August 10, 1988. (Aerial photograph from National Park Service.)

Other Glacier-Dammed Lakes near McCarthy

Jumbo and Amazon Creeks (fig. 2) are short, steep-gradient streams on the west side of Bonanza Ridge about 5 mi north of McCarthy. Early summer flows from these creeks are temporarily restricted by a glacier, and the narrow lake that forms can be greater than 1 mi long. Like Hidden Creek Lake, this lake usually breaks out in late July or early August. During 1990, this lake filled in about 19 days and emptied in one day, flooding the lower parking area on the western bank of the Kennicott River (Roger Elconin, graduate student, Humboldt State College, oral commun., 1990).

A third glacier-dammed lake forms about 9 mi north of McCarthy, adjacent to Root Glacier (fig. 2) and Bonanza Ridge at an elevation of 3,000 ft (NGVD of 1929). Locally this lake is known as "Erie Lake" and it also drains every year. Large blocks of ice calve into this lake from the glacier. It has been reported that when the lake drains, blocks of ice have frozen to the lakebed. Subsequent refilling of the lake submerges these ice blocks, which later suddenly release their hold on the lakebed and refloat (Roger Elconin, oral commun., 1990).

Smaller glacier-dammed lakes also form on Fourth of July Creek (fig. 2) and on an unnamed stream on the northeast side of Fireweed Mountain. Lakes near the confluence of Kennicott and Root Glaciers are in depressions in moraines or bedrock, and these lakes do not appear to release.

Erosion and Deposition

Areas delineated as "flood and erosion prone" (plate 2) are valley alluvium and alluvial fans that are subject to stream and overbank flooding, rapid scour and fill, and unpredictable lateral erosion during floods. Delineation of flood and erosion prone boundaries were based on geologic mapping by MacKevett (1970, 1971, 1972a, 1972b, 1974, 1976, 1978), interpretation of vertical aerial photographs (table 1), and field surveys of high-water profiles at slope-area reaches (sites 13, 18, 19, and 20; table 4). Areas prone to erosion were delineated by superpositioning of historical aerial photographs (table 1) using a stereo zoom transfer scope.

Alluvial fans below the mouths of mountain canyons are prone to flooding and transport of sediment from landslide accumulations in tributary streams. Debris from active landslides accumulates in the canyon stream channels and is subsequently mobilized during rapid snowmelt or intense rainfall floods. Many of these landslides form dams within the canyons and may fail catastrophically or become mobilized as **debris flows**. Transportation routes or structures located on alluvial fans are subject to damage depending on factors such as depth, velocity, and duration of flow; sediment content; and size of material transported. Dawdy (1979) and the Federal Emergency Management Agency (1985) describe methods for evaluating floods on alluvial fans.

The streambank of McCarthy Creek at McCarthy townsite (fig. 12) is eroding and erosion will eventually destroy historical buildings if the streambank remains unprotected. A few hundred feet upstream from the town, McCarthy Creek is eroding its northern bank, whereas near the town the channel is aggrading and shifting its course closer to buildings on the northern bank (Jones, 1988, p. 5). The locations of the main channel in 1983 and in 1990 are shown in figure 12; a cross section of McCarthy Creek surveyed during September 1990 is shown in figure 13. Several structures, including the historical powerhouse, are on lowlands bordering the stream. After a flood in 1980, town residents began building retaining walls and gabion dikes to help prevent or lessen damages from future floods. However, a flood in 1985 covered these structures with sediment and

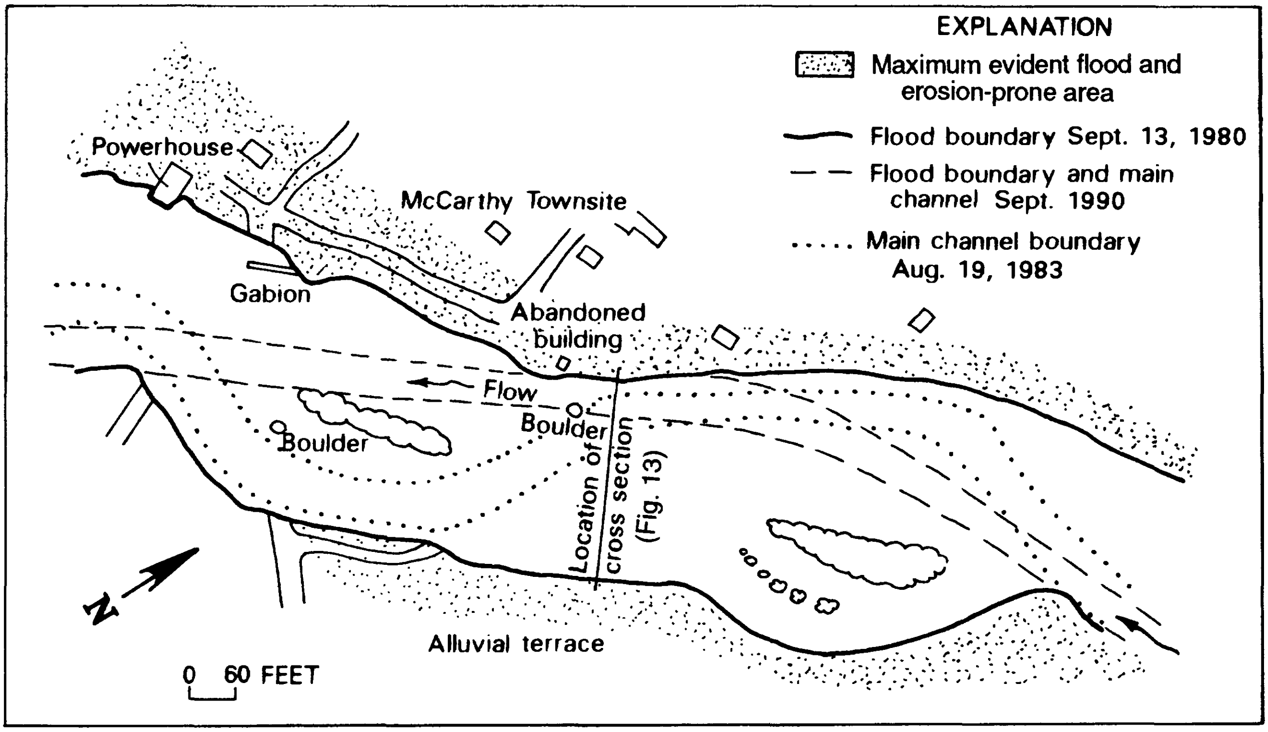


Figure 12. Active flood channel, McCarthy Creek at McCarthy (site 20).

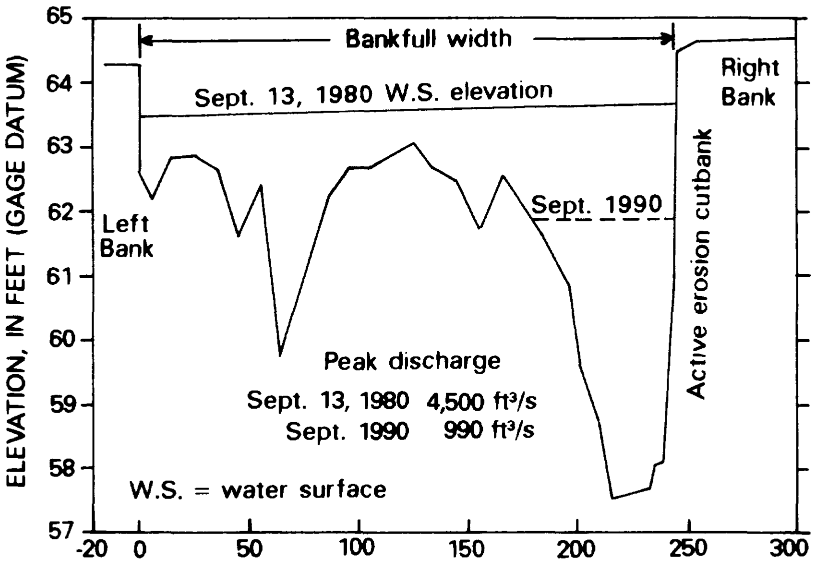


Figure 13. Channel cross section, McCarthy Creek at McCarthy (site 20), September 1990. (See figure 12 for location.)

the active stream channel moved closer to the buildings. Farther upstream, at stream mile 11.2, lateral erosion of the eastern streambank of McCarthy Creek will eventually breach a series of interconnected beaver dams and may suddenly release the impounded water. Methods to protect streambanks are described by Charlton (1982).

Snow Avalanches

Snow avalanching occurs during winter and spring on all slopes delineated as landslide-prone areas on plate 2, within all steep-walled canyons, and along the cirque headwalls of tributary streams, rock glaciers, and glaciers. Snow avalanches can bury roads and trails, and can destroy structures located in downslope impact zones. An air-blast zone may extend beyond the farthest deposition of snow (Trabant and others, 1990). Runout zones may be long, such as over an alluvial fan, or may end abruptly, such as at the bottom of a gorge.

Avalanche deposits may temporarily block river channels and cause flooding above the dam and subsequent flooding below the dam when it is breached (Trabant and others, 1990). Dam stability and flood hazard increase as the amount of rock in the avalanche increases (Martinec, 1989). Because of their weight and density, wet snow avalanches (as defined by LaChapelle, 1985) possess enough strength to temporarily dam creeks and rivers and create short-term natural reservoirs (Butler, 1989). On July 12, 1990, many snow avalanche deposits were observed crossing steep canyon tributaries to McCarthy Creek, but no evidence of flooding was detected.

Rock, debris, and snow avalanches frequently dam McCarthy Creek at stream mile 12.2 (fig. 14). A photograph taken by Moffit (1938, plate 7) shows an active landslide at stream mile 12.2. Rock and remaining snow avalanche deposits found on July 12, 1990 at this site indicate that the 50-foot-wide stream channel had been blocked earlier that year and had a maximum snow depth of about 25 ft. Streamflow may have been sufficiently low to percolate through coarse streambed materials, snow, and rock debris and prevent the formation of a lake. Sediment deposits upstream from the damming site indicate a frequent recurrence of avalanching, but there is no evidence of catastrophic water release downstream. Although no evidence of the formation and failure of a short-term natural reservoir was found, the potential is high, nevertheless, for the formation of a large dam and a subsequent catastrophic failure at this site during excessive rainfall, rapid snowmelt, or an earthquake.

Aufeis

Aufeis is a mass of ice that forms by the overflow and subsequent freezing of sheets of surface water or emerging ground water. Persistent water seepages during winter from a river or from a spring can lead to extensive icing deposits. Aufeis can cause a problem for roadways, culverts, and structures built in areas susceptible to ice accumulation or whose construction inadvertently causes icings (Sloan and others, 1976; Slaughter, 1990). Even very low flows of water over ice in stream channels during winter can produce an accumulation of ice sufficient to block culverts and bridges. Flows of water over roads in winter and subsequent freezing can impede traffic flow. In sidehill locations, the final ice surface slope may be steep and slippery so that it may not be traversable by wheeled vehicles. The presence of aufeis in streams can increase channel and bank erosion, and can induce or accelerate scour around piers and abutments of bridges and other instream structures (Slaughter, 1990, p. 449). Extensive aufeis accumulations occur in McCarthy Creek basin during winter (Loy Green, McCarthy resident, oral commun., 1990).

Figure 14. Aerial photograph of McCarthy Creek landslide and snow avalanche dam site, (stream mile 12.2) , July 12, 1990.

Landslides

Landslide-prone areas delineated on plate 2 include all slope-movement processes and classifications defined by Varnes (1978). The type of movement includes falls, topples, slides, spreads, flows, and complex slope movements of both rock and soil. Delineation of landslide-prone areas was based on geologic mapping published by MacKevett (1970, 1971, 1972a, 1972b, 1974, 1976, and 1978), interpretation of vertical aerial photographs (table 1), and field investigations during July and September 1990 and May, June, and September 1991. Detailed landslide mapping on plate 2 was based on superpositioning of historical vertical aerial photographs (table 1) using a stereo zoom transfer scope. Historical terrestrial photographs published by Moffit and Capps (1911, plates IVA and XA), Ellsworth and Davenport (1915, plate VIIB), and Moffit (1938, plate 7) were compared with vertical aerial photographs taken on August 10, 1988, to identify landslide-prone areas where landslides have occurred in the past.

Intense, prolonged rainfall, rapid snowmelt, saturated soils, thaw of frozen soils, and earthquakes are major factors contributing to failures of unconsolidated deposits on steep slopes. A slope failure may be gradual or rapid. A failure may start as a sliding failure (debris slide). As it moves downslope, it may accelerate to become a **debris avalanche**, or, with increasing liquefaction, it may develop into a debris flow (Sidle and others, 1985). A debris flow may also be produced when a large volume of soil and rock reaches a stream channel and the materials become mixed with water in the stream.

The most common types of mass movements that form landslide dams are rock and debris avalanches; rock and soil slumps and slides; and mud, debris, and earth flows (Costa and Schuster, 1988). Landslide dams form most frequently where narrow steep valleys of glacially oversteepened slopes are bordered by high rugged mountains.

If landslides are large relative to streamflow, they can block the flow and cause impoundment and flooding above the dam site. If the dam fails catastrophically, large volumes of water and sediment are suddenly released. A landslide and snow avalanche dam (fig. 14) commonly forms at McCarthy Creek stream mile 12.2 below site 12 (plate 2). The potential is high for a landslide dam to form near the terminus of McCarthy Creek Glacier (site 10, stream mile 20.4) during prolonged or intense rainfall. The steep lateral moraine deposits (fig. 10) are about 100 ft high along the streambed and are prone to mobilization during floods.

Where rock glaciers and creeping landslides enter McCarthy Creek, the streamflow is able to remove materials at the same rate as they are deposited into the stream channel. The steep-faced front of Porphyry Mountain rock glacier (fig. 7) presents a low hazard of damming between stream miles 10.2 and 10.4. Aerial photographs taken between 1957 and 1990 show no change in the location of the lower end of Porphyry Mountain rock glacier on McCarthy Creek. However, an earthquake could cause a large volume of rocks to fall or slide into McCarthy Creek and form a dam. If rock and snow avalanching increased loading in the upper accumulation zone of the rock glacier, the downslope movement of the rock glacier could increase. Several rock glaciers are traversed by foot trails, and travel over their angular rocks is not difficult. The trail traversing Porphyry Mountain rock glacier appears to be stable and has not changed significantly since it was built, probably about 20 years ago.

Landslide-prone areas are steep and unstable; they are also major contributors of sediment to the streams. Large concentrations of landslides within the headwaters of Nikolai Creek tributary (fig. 15) contribute to high sediment loads of this stream. Landslides along McCarthy Creek from stream mile 2 to 7.5 consist mainly of wet soils, silts, and sands. Landslides above mile 7.5 consist of a wide variety of materials ranging from silts to boulders. Construction or enlargement of trails and roads in landslide-prone areas, and especially the excavation of landslide toes, may increase the rate of mass wasting, increase stream sediment loads, and increase channel aggradation near the town of McCarthy. The trail along McCarthy Creek passes through two tunnels (fig. 9 and plate 2): the lower tunnel is approximately 70 ft long and 14 ft wide, and the upper tunnel is 90 ft long and from 10 to 13 ft wide (Laurie Daniel, National Park Service, written commun., 1989). Tunnel entrances are prone to rockfalls and slides, and landslides.

To assist planners and designers in the mitigation of landslide and debris-flow hazards, susceptible areas have been identified on plate 2. Methods for predicting, analyzing, and controlling soil mass movement are described by Schuster and Krizek (1978) and Sidle and others (1985, p. 79-83, p. 89-108).

Figure 15. Landslide scars in Nikolai Creek tributary, July 12, 1990.

HYDRAULIC AND STATISTICAL ANALYSES

The magnitude and frequency of floods were determined using regional flood-frequency area equations and at-site station frequency analyses. Historical floods were determined using at-site high-water marks and stream channel hydraulic properties. The magnitude and frequency of rainfall were analyzed using climate date from McCarthy.

Accuracy of Flood Surveys

The slope-area method (Dalrymple and Benson, 1967) using flood-water surface profiles was applied to compute peak discharges of floods on streams in the McCarthy area (table 6). The hydraulic properties used in the computation of peak discharges are listed in table 4. The uncertainty of these indirect measurements of peak discharge using the slope-area method ranges is high; errors could be 25 percent or greater because of changes in channel shape since the time of the peak discharge, interpretation of high-water marks, and estimation of hydraulic properties.

Flood Magnitudes

Peak stages and discharges (table 6) were determined at five slope-area sites within the McCarthy Creek basin (sites 12, 13, 17, 18 and 20), at two sites on the Kennicott River (main and overflow channels, sites 6 and 7), and at four crest-stage gage stations within the Copper River basin (sites 1, 2, 22, and 23). For comparison, peak stage and discharge data from previous studies are also included in table 6 for other sites in the Wrangell-St. Elias National Park and Preserve (sites 26, 27, and 28; fig. 1).

The relation between peak discharge and drainage area is shown in figure 16 for sites within the area shaded on the inset map. This area includes sites within the Copper, Yukon, and Kuskokwim River basins and river basins in northern Alaska. Peak-discharge data for sites listed in table 6 are identified. The envelope curve (fig. 16), which is based on 261 maximum known floods through 1990 for sites in the shaded area, provides a guide for estimating the magnitude of potential floods. Values of unit runoff, which is the peak discharge of a site divided by the drainage area above the site, can be used to compare flood magnitudes among sites. Unit-runoff values from the September 1980 flood at sites 13 and 20 [75.0 and 58.6 $(ft^3/s)/mi^2$, respectively], in the middle and lower reaches of McCarthy Creek, were much higher than runoff values for other known floods at about the same time at nearby sites. Although runoff values from the 1980 storm were relatively high, the discharges were substantially less than discharges defined by the envelope curve and corresponding drainage areas.

Bankfull discharge for mountain streams in Alaska is about a 50-year flood (Riggs, 1978). The magnitude of bankfull discharge at selected sites (table 7) was calculated by: (1) the slope-area method using **bankfull stages**, (2) equations developed by Riggs (1978), and (3) equations developed by Parks and Lamke (1984). Bankfull discharges determined by the slope-area method from channels formed on alluvial fan streams, such as Chititu, May, and Strelna Creeks, are much lower than bankfull discharges computed using the Riggs and Parks/Lamke equations. Channel and flood characteristics at bankfull stage for the Kennicott River eastern overflow channel (site 7, table 7) were formed by larger flood discharges prior to the 1988 capture of the eastern channel by the western main channel and do not represent flood potential.

Flood Frequency

Floods in the McCarthy Creek basin are caused by rainfall, snowmelt, formation and subsequent failure of landslide dams, failure of snow avalanche dams, and sudden releases of channel blockage by snow and ice. However, because data are insufficient to define the magnitude and frequency of the formation and failure of natural dams, the frequency analysis presented in this report applies only to instantaneous peak discharges that result from rainfall, snowmelt, and rain on snow.

The recurrence interval is the average number of years within which a flood of a given magnitude will be equaled or exceeded. The frequency of a flood may also be stated in terms of probability of occurrence, which for large floods is the reciprocal of the recurrence interval. For example, a flood with a 100-year recurrence interval would have a probability of 0.01, or a 1 percent chance of being exceeded in any given year. Station frequencies, or recurrence intervals, were estimated from station data using log-Pearson Type III frequency analysis procedures described in Bulletin 17B of the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (1982).

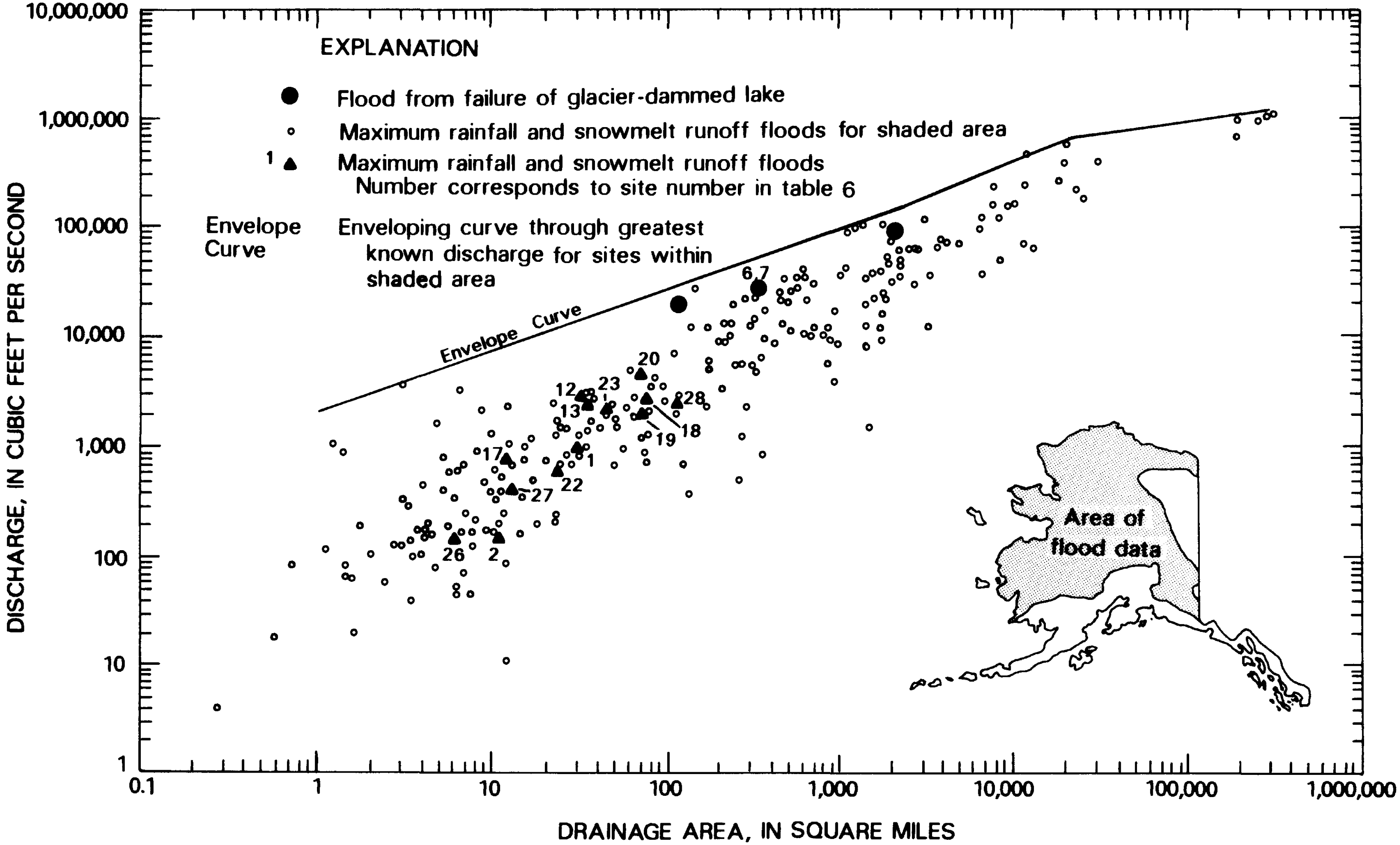


Figure 16. Peak discharge as a function of drainage area.

Table 7. Channel and flood characteristics at selected sites in the Copper River Basin above Chitina

[ft, foot; ft^2, square foot; ft/s, foot per second; ft^3/s, cubic foot per second; --, not determined; see figures 1, 2 and plate 2 for site locations]

Site No.	Stream name	Channel and flood characteristics at bankfull					Bankfull discharge (ft^3/s)		Reccurrence interval Year Q_{50} Discharge (ft^3/s)		
		Width (ft)	Depth (ft)	Area (ft^2)	Average velocity (ft/s)	Slope	Slope-area method[1]	Riggs method[2]	Parks method[3]	Station frequency through 1990 Weighted skew[4]	Flood-frequency area equation[5]
1	Chititu Creek near May Creek	50	2.30	115	4.43	0.0067	510	1,800	1,970	999	1,500
2	May Creek near May Creek	16	2.00	32	2.19	.0057	70	--	330	197	591
6	Kennicott River main channel at McCarthy	277	7.57	2,100	11.9	.0104	25,000	--	28,400	--	[6]15,400
7	Kennicott River overflow channel at McCarthy	216	9.07	1,960	10.3	.0124	20,200	--	19,300	--	(see site 6)
12	McCarthy Creek at Green Butte Mine above landslide	38	4.82	183	11.4	.0182	2,080	--	1,280	--	2,530
13	McCarthy Creek above East Fork McCarthy Creek	76	3.18	242	9.17	.0127	2,220	2,800	3,780	--	2,850
17	Nikolai Creek at mouth near McCarthy	25	2.71	68	12.3	.0728	830	--	670	--	856
18	McCarthy Creek near McCarthy	90	3.02	272	8.42	.0158	2,290	5,200	4,920	--	3,860
22	Strelna Creek near Chitina	27	1.80	49	5.35	.0150	260	--	752	618	1,170

[1]Slope-area method at bankfull.
[2]Riggs (1978, p. 90, fig. 3).
[3]Parks and Lamke (1984).
[4]Hydrology Subcommittee (1982), using a generalized-mean unbiased skew coefficient $\overline{G}$=0.13 and standard error of generalized-mean unbiased skew coefficient $SE_{\overline{G}} = 1.15$ determined by author.
[5]Determined by author.
[6]Combined drainage of sites 6 and 7.

An analysis of flood magnitude and frequency was made for streams in the McCarthy area using two methods (table 8). The first method uses flood-frequency area equations developed by the senior author using a regional multiple regression analysis of 109 peak-flow stations located in the shaded area of figure 16:

$$Q_{50} = 147A^{0.778}P^{0.544}(ST+1)^{-0.187}E^{-0.264}$$

$$Q_{100} = 185A^{0.765}P^{0.509}(ST+1)^{-0.179}E^{-0.257}$$

where A is drainage area in square miles;
P is mean annual precipitation, in inches (fig. 3);
ST is area of lakes and ponds, in percent; and
E is the mean basin elevation in feet (NGVD of 1929).

The range of standard error of prediction is -42 to 70 percent for the Q_{50} and -44 to 80 percent for the Q_{100}. The flood-frequency estimating equations apply only to the shaded area shown in figure 16; they are not valid for estimating flood magnitude and frequency outside the shaded area. Climate and physiographic characteristics of the basins (Thomas and Benson, 1970) (table 3) were used in the flood-frequency area equations to compute the magnitude and frequency of floods.

In the second method, flood magnitude and frequency at seven sites were also determined through 1990 using a station frequency method described by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (1982). In this method, a **generalized-mean unbiased skew coefficient** of 0.13 and a **standard error of generalized-mean unbiased skew coefficient** of 1.15 were used.

Discharges that were determined (table 8) using station frequency and station skew at six crest-stage gage stations (sites 1, 2, 22, 26, 27, 28; figs. 1 and 2) averaged 35 percent lower than discharge values computed using the flood-frequency area equations. An exception was at site 23, which was 38 percent higher using the flood-frequency area equations. The flood-frequency area equations overestimate flood discharge for streams that flow over large alluvial fans, such as May and Strelna Creeks. Flood-frequency area equations do not account for flood peak discharge attenuation or channel losses along streams traversing alluvial fans.

Peak discharges determined for the 1980 flood at site 20 and the peak discharge for the maximum-evident flood at site 12 were greater than the values associated with a recurrence interval of 100 years using the flood-frequency area equations.

The flood-frequency area flood-discharge values (table 8) can be used for eight sites on McCarthy Creek to help estimate the magnitude and frequency of rainfall and snowmelt floods at any site along the stream. The relation between discharges at 50-year and 100-year recurrence intervals and distance upstream from the mouth of McCarthy Creek is shown in figure 17.

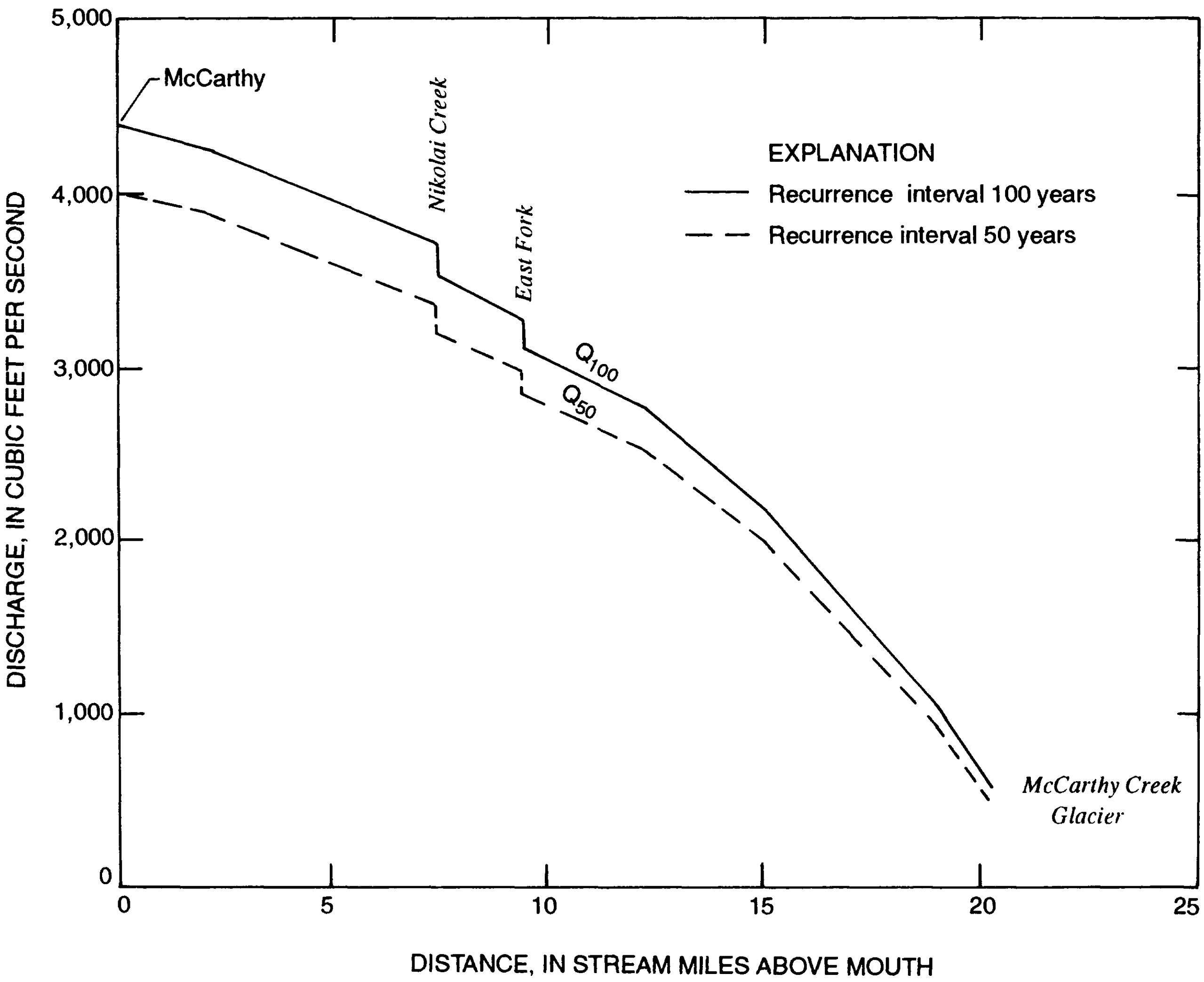


Figure 17. Estimates of 50-year and 100-year recurrence interval floods for McCarthy Creek.

Table 8. Flood magnitudes and frequency determinations for mountain drainages in the Copper River Basin above Chitina,using selected methods

Site No.	Station number	Stream name	Period of record	Maximum peak discharge	Flood discharge: Flood frequency area equation[1] Recurrence interval Year		Flood discharge: Station frequency through 1990 Weighted skew[2] Recurrence interval Year	
					Q_{50}	Q_{100}	Q_{50}	Q_{100}
1	15209000	Chititu Creek near May Creek	1973-83 1985-90	970	1,500	1,690	999	1,200
2	15209100	May Creek near May Creek	1973-83 1985, 90	168	591	686	197	232
6,7	----	Kennicott River at McCarthy	1991	[3]22,400	15,400	16,400	---	---
10	----	McCarthy Creek tributary at McCarthy Creek Glacier	---	---	493	552	---	---
11	----	McCarthy Creek below Lubbe Creek	---	---	1,990	2,180	---	---
12	----	McCarthy Creek at Green Butte Mine above landslide	1990	[4]2,810	2,530	2,770	---	---
13	----	McCarthy Creek above East Fork McCarthy Creek	1990	2,730	2,850	3,120	---	---
14	----	East Fork McCarthy Creek at mouth	---	--	930	1,040	---	---
15	----	McCarthy Creek above Nikolai Creek near McCarthy	---	---	3,190	3,510	---	---
16	----	Nikolai Creek tributary at mouth near McCarthy	---	---	272	313	---	---
17	----	Nikolai Creek at mouth near McCarthy	1990	[4]830	856	966	---	---

Table 8. Flood magnitudes and frequency determinations for mountain drainages in the Copper River Basin above Chitina, using selected methods--Continued

Site No.	Station number	Stream name	Period of record	Maximum peak discharge	Flood discharge: Flood frequency area equation[1] Recurrence interval Year Q_{50}	Flood discharge: Flood frequency area equation[1] Recurrence interval Year Q_{100}	Flood discharge: Station frequency through 1990 Weighted skew[2] Recurrence interval Year Q_{50}	Flood discharge: Station frequency through 1990 Weighted skew[2] Recurrence interval Year Q_{100}
18	----	McCarthy Creek near McCarthy	---	---	3,860	4,240	---	---
19	15210000	McCarthy Creek near McCarthy	1975	2,080	3,970	4,360	---	---
20	----	McCarthy Creek at McCarthy	1990	4,500	3,990	4,380	---	---
22	15211700	Strelna Creek near Chitina	1971-90	670	1,170	1,340	618	707
23	15211900	O'Brien Creek near Chitina	1970-90	1,940	2,000	2,260	2,700	3,200
26	15470300	Little Jack Creek near Nabesna	1975-90	171	389	452	275	317
27	15470330	Chalk Creek near Nabesna	1975-90	360	659	762	452	545
28	15470340	Jack Creek near Nabesna	1975-83	2,400	3,610	4,040	3,310	3,850

[1]Determined by author.

[2]Hydrology Subcommittee (1982) using a generalized-mean unbiased skew coefficient $\overline{G} = 0.13$ and standard error of generalized-mean skew coefficient $SE_{\overline{G}} = 1.15$ determined by author.

[3]Combined peak discharge of main channel and overflow channel.

[4]Maximum evident flood.

To predict the stage of floods at different recurrence intervals at any location in the McCarthy Creek basin the following methods are applicable:

1. McCarthy Creek:
   a. Estimate the flood discharge at the desired distance above the mouth using the 50- and 100-year recurrence intervals as guides (fig. 17).
   b. Determine the channel geometry and Manning roughness coefficient at the site of interest.
   c. Compute water-surface profiles on the basis of discharge, channel geometry, and Manning roughness coefficient using methods recommended by the Federal Emergency Management Agency (1985).

2. Tributary streams to McCarthy Creek at the highest point on an alluvial fan (apex) where the stream emerges from the mountain or confining canyon walls:
   a. Determine drainage area, mean annual precipitation, percentage lakes and ponds, percentage forest, and mean basin elevation for the basin above the site of interest.
   b. Estimate magnitude and frequency of floods on the basis of the flood-frequency area equation.
   c. Compute water-surface profiles on the basis of flood discharge, channel geometry, and Manning roughness coefficient using methods recommended by the Federal Emergency Management Agency (1985).

3. Tributary streams to McCarthy Creek on an alluvial fan:
   a. Determine magnitude and frequency of floods at the apex.
   b. Estimate flood-flow characteristics using methods developed by Dawdy (1979) and Federal Emergency Management Agency (1985).

The frequency analysis for the Kennicott River at McCarthy (sites 6 and 7) shown in table 8 applies to rainfall and snowmelt floods in which runoff was not affected by glacier-dammed outburst floods. Data are insufficient to define the magnitude and frequency of outburst floods in the Kennicott River basin.

The flood boundary of the area covered by the 1980 flood (plate 2) was delineated using field surveys of high-water profiles at slope-area reaches (sites 13, 18, and 20), interpretation of vertical aerial photographs (table 1), and field investigations during July and September 1990 and May, June, and September 1991. Flood- and erosion-prone areas (plate 2) were delineated using approximate study methods as defined by the Federal Emergency Management Agency (1985). Flood- and erosion-prone areas only indicate potential areas of flood and erosion, and may need a more detailed hydraulic analysis as described in the "Erosion and Deposition" section of this report and by the methods to predict flood magnitude, recurrence interval, and stage described in this section of the report.

Rainfall Frequency

Since 1968, precipitation for McCarthy has been measured at three different sites (table 2). Using a technique described by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (1982), 19 sets of maximum-daily rainfall data (1969-87) for months May through September were combined and analyzed using a Pearson Type III distribution, log-transformations, and a 1.31 skew coefficient. No adjustments were made for areal variations or differences in elevation between the three stations or for periods of missing record. Recurrence intervals were calculated for the three largest recent storms on the basis of maximum daily rainfall during each storm, with the following results:

Climatological station (plate 2)		Storm date	Total storm rainfall (inches)	Maximum daily rainfall (inches)	Recurrence interval (years)
Site No	Name				
8	McCarthy 1 NE	9-13 to 9-16-80	4.92	2.00	20
9	McCarthy	6-30 to 7-1-75	1.56	1.13	10
21	McCarthy 3 SW	8-12 to 8-18-85	4.72	2.33	25-50

Although total storm rainfall and maximum daily rainfall measured at McCarthy for the 1980 and 1985 storms are low, more rain falls in the mountains. Mean annual precipitation and frequency of precipitation generally increase with elevation (fig. 3).

SUGGESTIONS FOR FUTURE STUDY

This report provides an overview of hydrologic hazards near McCarthy, especially in the McCarthy Creek basin. Evaluation of site-specific mass-movement and flood-related hazards associated with any mining activity, road, or building construction in the basin would improve understanding of the hazards. Site-specific studies that may be useful include:

1. Landslide and debris avalanches:
   - Assess probability of triggering events by developing relations between rainfall, snowmelt, soil saturation, thawing of frozen soils, and landslide movement.
   - Monitor landslide damming sites by using aerial observations and photography following a significant flood or earthquake-related event.
   - Investigate geologic evidence for earlier events.
2. Snow avalanches:
   - Identify snow avalanche hazard areas using annual aerial observations and site observations of vegetation damage.
3. Aufeis:
   - Identify aufeis formations using annual observations.
   - Determine the source of water for these aufeis formations and the reasons for overflow.
4. Glacier-dammed lakes and outburst floods:
   - Determine the magnitude and frequency of the occurrence of outburst floods from Hidden Creek Lake.
   - Document significant changes in the occurrence of lakes from year to year.

SUMMARY

Knowledge of geologic and hydrologic hazards and conditions is important in evaluating proposed activities in a drainage basin. Site-specific studies may be necessary to fully assess the numerous dynamic conditions in the McCarthy area . The basins of McCarthy Creek and Kennicott River are prone to several natural hazards including floods, glacier-dammed lakes and outburst floods, stream erosion and sediment deposition, snow avalanches, aufeis, and landslides.

Most floods in the McCarthy Creek basin are caused by snowmelt and rainfall, but floods caused by sudden releases of landslide dams are possible. Analysis of a maximum-evident flood survey indicated that the peak discharge near the mouth of McCarthy Creek was 4,500 ft^3/s and was caused by a rainstorm during September 1980. Using the flood-frequency area equation, the magnitude of this flood was determined to have a recurrence interval greater than 100 years. Methods are presented to estimate discharge and stage for sites along McCarthy Creek for floods of various frequencies.

Outbursts are large floods that can occur each year when glacier-dammed lakes in the Kennicott River basin suddenly release impounded waters. Five such lakes were identified in this basin. The largest flows are caused by outbursts from Hidden Creek Lake, usually in late July or early August. When full, this lake covers about 1 mi^2 and is almost 400 ft deep.

Even under typical streamflow conditions, the erosion of unconsolidated sediments and rocks that have been carried downslope by landslides results in large quantities of materials suspended in the flowing waters. During floods, overbank flooding and greater streamflow velocities increase erosion and sediment-transport rates. Continued erosion of the northern bank of McCarthy Creek near McCarthy will eventually cause damage to historical structures. A short distance downstream, however, sediments accumulating in the channel are changing the course and raising the level of the stream. Structures in this area may be subject to flooding during future high-water events.

Snow avalanches can destroy structures and block roads and streams. In the McCarthy area, avalanches occur in all areas delineated as "landslide-prone," in all steep-walled canyons, and along cirque headwalls.

Aufeis consists of sheets of ice formed during winter by the overflow and subsequent freezing of surface or emerging ground water. These ice accumulations may block culverts and bridges and impede traffic flow over roads and trails near McCarthy Creek.

Landslides deposits are hazardous because they are unstable, contribute sediment to streams, and can dam streams. If the dam fails catastrophically, large volumes of water and sediment can be suddenly released. Earthquakes and rainstorms can induce landslides to occur. Landslide scars are evident and areas prone to landslides are known in the McCarthy area. Landslides along McCarthy Creek from stream mile 2 to 7.5 consist mainly of wet soils, silts, and sands. Landslides above mile 7.5 consist of materials ranging from silts to boulders. Talus deposits along steep valley walls and near bases of cirque headwalls consist of loose rock fragments and slabs.

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GLOSSARY

Aufeis. A mass of ice that forms by the overflow and subsequent freezing of sheets of surface water or emerging ground water.

Avalanche. A large mass of snow, ice, soil, or rock, or mixtures of these materials, falling, sliding, or flowing very rapidly under the force of gravity.

Bankfull stage. The stage at which the channel just begins to overflow the flood plain (Hedman and Osterkamp, 1982, p. 4). The reference level for this section (bankfull stage) is variously defined by breaks in bank slope, by the edges of the flood plain, or by the lower limits of permanent vegetation.

Bedload. The part of the total sediment load that is moved on or immediately above the streambed, such as the larger or heavier particles (boulders, pebbles, gravel) transported by traction or bouncing along the bottom.

Debris avalanche. The very rapid and usually sudden sliding and flowage of incoherent, unsorted mixtures of soil and weathered bedrock.

Debris flow. A moving mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size.

Friction slope. The friction head, or loss per unit length of conduit. The friction slope coincides with the energy gradient, but where a distinction is made between energy losses due to bends and expansions, a distinction must be made between the friction slope and energy gradient.

Froude number. A dimensionless numerical quantity used as an index to characterize the type of flow in a hydraulic structure that has the force of gravity (as the only force producing motion) in conjunction with the resisting force of inertia.

Generalized-mean unbiased skew coefficient, $\overline{G}$. Skew coefficients derived by a procedure that integrates skew coefficients obtained at many locations within a given area.

Hydraulic radius. In a stream, the ratio of the area of its cross section to its wetted perimeter.

Mass wasting. The dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses.

Slope-area method. Method of computing water discharge by using the Manning equation for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the streambed, and the area, hydraulic radius, and depth remain constant throughout the reach.

Slump. A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface and about an axis parallel to the slope from which it descends, and by backward tilting of the mass, so that the slump surface often exhibits a reversed slope facing uphill.

Standard error of generalized-mean unbiased skew coefficient, $SE_{\overline{G}}$. Standard error of sample skew coefficient is an estimate of the standard deviation of station skews. The standard error expresses the reliability of the generalized skew estimate and determines the relative weights to be put on the generalized and station skews in computing the weighted skew estimate recommended by the Hydrology Subcommittee.

Talus. Rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope.

APPENDIX

Table A1. Hydraulic, bedload, and bed-material characteristics for site 11 on McCarthy Creek, Alaska

Table A2. Daily discharge for McCarthy Creek near McCarthy, Alaska in 1913

Table A3. Water discharge at selected sites in the Copper River Basin above Chitina

Table A1. Hydraulic, bedload, and bed-material characteristics for site 11 on McCarthy Creek, Alaska

[Data from W.W. Emmett, U.S. Geological Survey, written commun., 1986]

Basin characteristics	
Location	Latitude 61°32'42" Longitude 142°47'07"
Elevation at site (NGVD of 1929)	2,820 feet
Drainage area above site	21.7 square miles
Slope of stream channel at site, surveyed value	0.016

Streamflow -- August 15, 1986	
Discharge	74.3 cubic feet per second
Area	28.2 square feet
Width	45.5 feet
Mean depth	0.62 feet
Mean velocity	2.64 feet per second

Bedload -- August 15, 1986	
Sampler type	Helley-Smith
Sample time interval	30 seconds at each sample location
Effective width	38 feet
Number of verticals (sample locations)	34
Water temperature	4 degrees Celsius
Dry weight of sample	44.15 grams
Dry bedload	0.000381 pounds of bedload per second per foot of stream width
Total	0.626 ton per day

Table A1.--Hydraulic, bedload, and bed-material characteristics for site 11 on McCarthy Creek, Alaska--Continued

Particle size distribution of bedload

Sieve size (mm)	Percent retained on sieve, by weight	Percentage by weight finer than size (mm) indicated
<0.062	Trace	0
0.062	Trace	0
0.125	0.5	0
0.25	3.5	4
0.50	10.9	14
1.0	33.5	48
2.0	32.1	80
4.0	15.2	95
8.0	4.4	100

Pebble count of bed material (on left bank, looking downstream)

Size (mm)	Percent in size class, by size
<2	14
2-4	5
4-8	7
8-16	7
16-32	16
32-64	29
64-128	13
128-256	8
256-512	1
>512	--

Table A2. Daily discharge for McCarthy Creek near McCarthy, Alaska (site 19) in 1913

[Data in cubic feet per second]

Day	June	July	August	September	October	November
1	--	427	170	91	170	--
2	--	485	174	90	154	--
3	--	495	210	91	139	37
4	--	544	210	84	93	--
5	--	544	226	83	76	24
6	--	465	437	--	91	--
7	--	437	362	--	76	--
8	539	344	418	--	44	--
9	519	326	451	--	76	--
10	389	282	380	--	37	--
11	353	250	226	--	37	--
12	418	218	218	--	37	--
13	654	242	210	--	--	--
14	700	266	154	--	--	--
15	684	254	145	--	--	--
16	654	230	151	--	--	--
17	564	238	151	--	--	--
18	664	202	170	--	--	--
19	798	151	174	--	--	--
20	504	134	158	--	--	--
21	634	145	186	61	--	--
22	669	206	186	63	--	--
23	777	206	202	480	--	--
24	876	250	170	624	--	--
25	644	226	167	485	--	--
26	609	258	158	451	--	--
27	574	437	161	290	--	--
28	504	242	158	--	--	--
29	519	246	151	574	--	--
30	446	226	97	--	--	--
31	--	186	97	--	--	--
Mean	595	296	211	--	85.8	--
Maximum	876	544	451	--	170	--
Minimum	353	134	97	--	37	--

Table A3. Water discharge at selected sites in the Copper River Basin above Chitina

[mi^2, square miles; ft^3/s, cubic feet per second; *p*, peak flow]

Site information		Date	Discharge (ft^3/s)
Site No.:	1	06-14-73	106
Station No.:	15209000	07-13-73	111
Site name:	Chititu Creek near May Creek	07-73	*p*430
Latitude:	61°22'12"	08-26-73	70
Longitude:	142°40'50"	10-05-73	9.1
Drainage area:	30.9 mi^2	06-19-74	62
		06-74	*p*290
		07-27-74	88
		05-21-75	35
		06-25-75	190
		09-75	*p*380
		06-76	*p*220
		07-13-76	76
		05-24-77	44
		07-07-77	135
		07-77	*p*250
		07-06-78	114
		08-10-78	*p*360
		09-01-78	33
		06-27-79	88
		07-79	*p*250
		09-28-79	16
		06-27-80	84
		06-80	*p*360
		09-11-80	35
		05-21-81	69
		08-07-81	*p*970
		09-09-81	45
		07-29-82	101
		09-21-82	54
		09-82	*p*380
		05-24-83	29
		05-83	*p*460
		08-16-83	166
		10-04-83	66
		1985	*p*600

Table A3. Water discharge at selected sites in the Copper River Basin above Chitina--Continued

Site information		Date	Discharge (ft^3/s)
Site No.:	2	1973	No flow
Station No.:	15209100	06-14-73	8.6
Site name:	May Creek near May Creek	07-13-73	5.8
Latitude:	61°20'42"	10-05-73	1.0
Longitude:	142°41'49"	06-19-74	1.0
Drainage area:	10.4 mi^2	06-74	*p*43
		07-27-74	No flow
		05-20-75	24
		06-25-75	19
		07-01-75	*p*81
		10-02-75	17
		05-29-76	15
		06-76	*p*37
		07-13-76	1.1
		05-24-77	6.6
		05-77	*p*80
		07-07-77	13
		05-78	*p*12
		07-07-78	1.4
		09-01-78	0.53
		06-27-79	1.1
		06-79	*p*90
		09-28-79	2.5
		06-27-80	3.7
		06-80	*p*35
		09-11-80	7.9
		05-21-81	9.7
		08-07-81	*p*168
		09-08-81	8.2
		05-27-82	11
		05-82	*p*68
		07-29-82	1.9
		09-21-82	1.6
		05-24-83	4.7
		05-83	p66
		08-16-83	21
		10-04-83	9.0
		1985	*p*90
		07-90	No flow

Table A3. Water discharge at selected sites in the Copper River Basin above Chitina--Continued

Site information		Date	Discharge (ft^3/s)
Site No.:	19	05-29-13	191
Station No.:	15210000	06-08-13	540
Site name:	McCarthy Creek near McCarthy	09-21-13	61
Latitude:	61°25'42"	11-03-13	37
Longitude:	142°54'18"	11-05-13	24
Drainage area:	76.4 mi^2	07-01-75	*p*2,080
Site No.:	20	09-13-80	*p*4,500
Site name:	McCarthy Creek at McCarthy	07-25-90	346
Latitude:	61°25'55"	09-90	*p*990
Longitude:	142°55'27"		
Drainage area:	76.8 mi^2		

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