Prepared in cooperation with the
Douglas Indian Association,
Alaska Department of Environmental Conservation, and the
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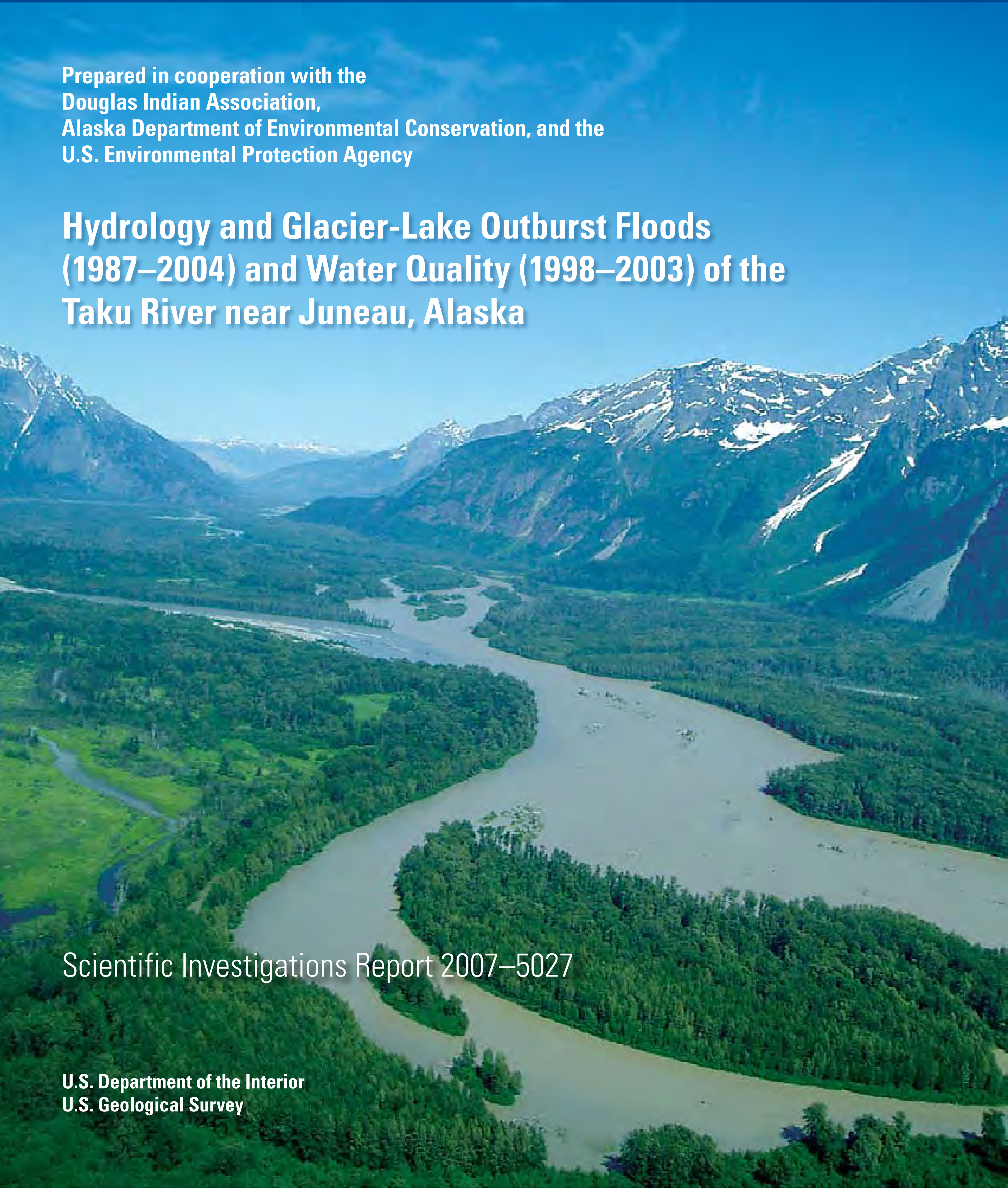
Hydrology and Glacier-Lake Outburst Floods (1987–2004) and Water Quality (1998–2003) of the Taku River near Juneau, Alaska



Scientific Investigations Report 2007–5027

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of the confluence of Taku and Tulsequah Rivers near Tulsequah, British Columbia. (Photograph taken by Jeff Goetz, U.S. Geological Survey, 2005.)

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Conversion Factors

Multiply	By	To Obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre-feet (ac-ft)	1230	cubic meters (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F= (1.8×°C) +32$$

Vertical Datum

Sea level: In this report, “sea level: refers to the National Geodetic Vertical Datum of 1929—A geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations and Acronyms

Abbreviations and Acronymns	Meaning
ADEC	Alaska Department of Environmental Conservation
DIA	Douglas Indian Association
DOC	dissolved organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Chemical Abbreviations:

Chemical Abbreviations	Meaning
mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemen per centimeter at 25°C

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Hydrology and Glacier-Lake Outburst Floods (1987–2004) and Water Quality (1998–2003) of the Taku River near Juneau, Alaska

By Edward G. Neal

Abstract

The Taku River Basin originates in British Columbia, Canada, and drains an area of 6,600 square miles at the U.S. Geological Survey's Taku River gaging station. Several mines operated within the basin prior to 1957, and mineral exploration has resumed signaling potential for future mining developments. The U.S. Geological Survey in cooperation with the Douglas Indian Association, Alaska Department of Environmental Conservation, and the U.S. Environmental Protection Agency conducted a water-quality and flood-hydrology study of the Taku River. Water-quality sampling of the Taku River from 1998 through 2003 established a baseline for assessing potential effects of future mining operations on water quality.

The annual mean discharge of the Taku River is 13,700 cubic feet per second. The monthly mean discharge ranges from a minimum of 1,940 cubic feet per second in February to a maximum of 34,400 cubic feet per second in June. Nearly 90 percent of the annual discharge is from May through November. The highest spring discharges are sourced primarily from snowmelt and moderate discharges are sustained throughout the summer by glacial meltwaters. An ice cover usually forms over the Taku River in December persisting through the winter into March and occasionally into April.

Glacier-lake-outburst floods originating from two glacier-dammed lakes along the margin of the Tulsequah Glacier in British Columbia, Canada, are the source of the greatest peak discharges on the Taku River. The largest flood during the period of record was 128,000 cubic feet per second on June 25, 2004, resulting from an outburst of Lake No Lake. Lake No Lake is the larger of the two lakes. The outburst-flood contribution to peak discharge was 80,000 cubic feet per second. The volume discharged from Lake No Lake is relatively consistent indicating drainage may be triggered when the lake reaches a critical stage. This suggests prediction of the timing of these outburst floods might be possible if lake-stage data were available. Further increases in the volume of Lake No Lake are unlikely as all tributary glaciers have retreated out of the lake basin. Decreasing outburst-flood volumes from Tulsequah Lake suggests a continued decline in the volume of this lake.

Physical and chemical parameters and concentrations of basic water-quality constituents indicate good water quality. Samples collected at the Taku River gaging station contained low concentrations of trace elements in the dissolved phase. Trace elements sampled were within acceptable limits when compared with the Alaska Department of Environmental Conservation aquatic-life criteria for fresh waters. The highest concentrations of total trace elements sampled were collected during glacial-outburst floods and likely are associated with suspended sediments. Total trace-element concentrations generally increase with increasing water discharge, although a high correlation for all constituents sampled does not always exist.

Introduction

The Taku River originates in Northwest British Columbia's Boundary Range and flows about 165 mi before emptying into the Taku Inlet just south of Juneau, Alaska (fig. 1). The Taku River drains one of the largest roadless watersheds remaining along the Pacific coast of North America and supports healthy runs of all five species of Pacific salmon. The diverse geography of the watershed provides habitat for various terrestrial and marine mammals, migratory waterfowl, shorebirds, and raptors. The Taku River Tlingit people have occupied the watershed for hundreds of years, and the salmon fishery and wildlife are vital to the traditional and subsistence-based lifestyles of these people. The Taku River Tlingit are represented by the Douglas Indian Association in Alaska and the Taku River Tlingit First Nation in Canada.

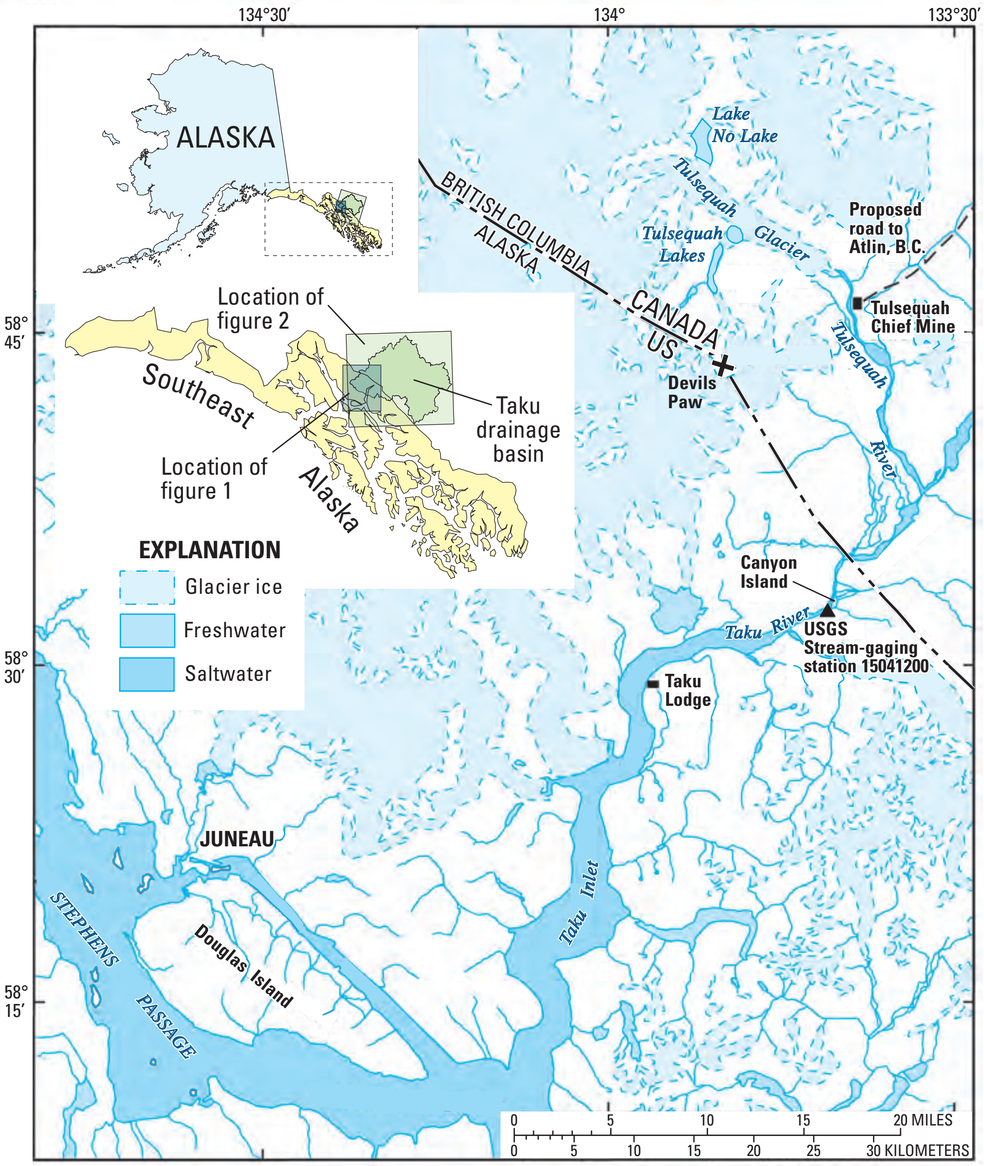


Figure 1. Location of study area.

In 1998, the U.S. Geological Survey (USGS), in cooperation with the Douglas Indian Association (DIA), the Alaska Department of Environmental Conservation (ADEC), and the U.S. Environmental Protection Agency (EPA), initiated a study to characterize the water quality and hydrology of the Taku River. The study stemmed from concerns about the potential reopening of the Tulsequah Chief Mine in British Columbia, Canada. The mine is about 18 mi upstream of the Taku River gaging station within the Tulsequah River valley. The Tulsequah River is a large glacial tributary subject to glacier-lake-outburst floods sourced from glacial lakes adjacent to the Tulsequah Glacier. The greatest peak flows on the Taku River are a result of these floods. The cooperating entities are concerned about the potential effects on water quality of the Taku River if development of the mine were to proceed.

Description of Study Area

The Taku River watershed encompasses diverse geography ranging from rocky slopes, icefields, and glaciers to coastal temperate rainforest. Some major tributaries to the Taku River include the Nakina, Nahlin, Inklin, Silver Salmon, Sloko, and Tulsequah Rivers (fig. 2). Due to the remote and rugged nature of the watershed, motorized access to the Taku River watershed is limited to boat or aircraft.

The large area and diversity of the watershed provides habitat for grizzly bear, black bear, wolves, mountain goat, Stone sheep, woodland caribou, moose, Sitka black-tailed deer, and harbor seals. The Taku River watershed also provides important habitat for various other wildlife including several species of migratory waterfowl, shorebirds, and raptors.

The Taku River supports all five species of Pacific salmon and is one of the largest producers of salmon in southeast Alaska. Estimates of the 10-year average total run size for chinook, coho, and sockeye salmon were 70,000, 165,000, and 250,000 fish, respectively (McPherson and others, 2000; Jones and others, 2006; and Pacific Salmon Commission, 2006). The Taku River watershed also supports healthy populations of rainbow/steelhead trout, cutthroat trout, Dolly Varden char, eulachon, and whitefish. A 2004 report (McDowell Group, written commun., 2004) estimated the U.S. commercial harvest and processing of Taku River salmon generates about 80 jobs and contributes $5.4 million annually to the regional economy. Sport fishing for Taku River salmon provides approximately 40 jobs and $2 million annually.

Native cultural and subsistence values attached to the Taku River transcend economics. In the past, the Taku River Tlingit depended on the Taku River for producing eulachon oil, dried salmon, game, medicines, plant foods, and a host of other cultural and human needs. The Taku River watershed is an area where the Tlingit culture is as intact as any place within their traditional territory. An active subsistence economy continues among Tlingit families with mixtures of commercial fishing incomes and other resources-based incomes.

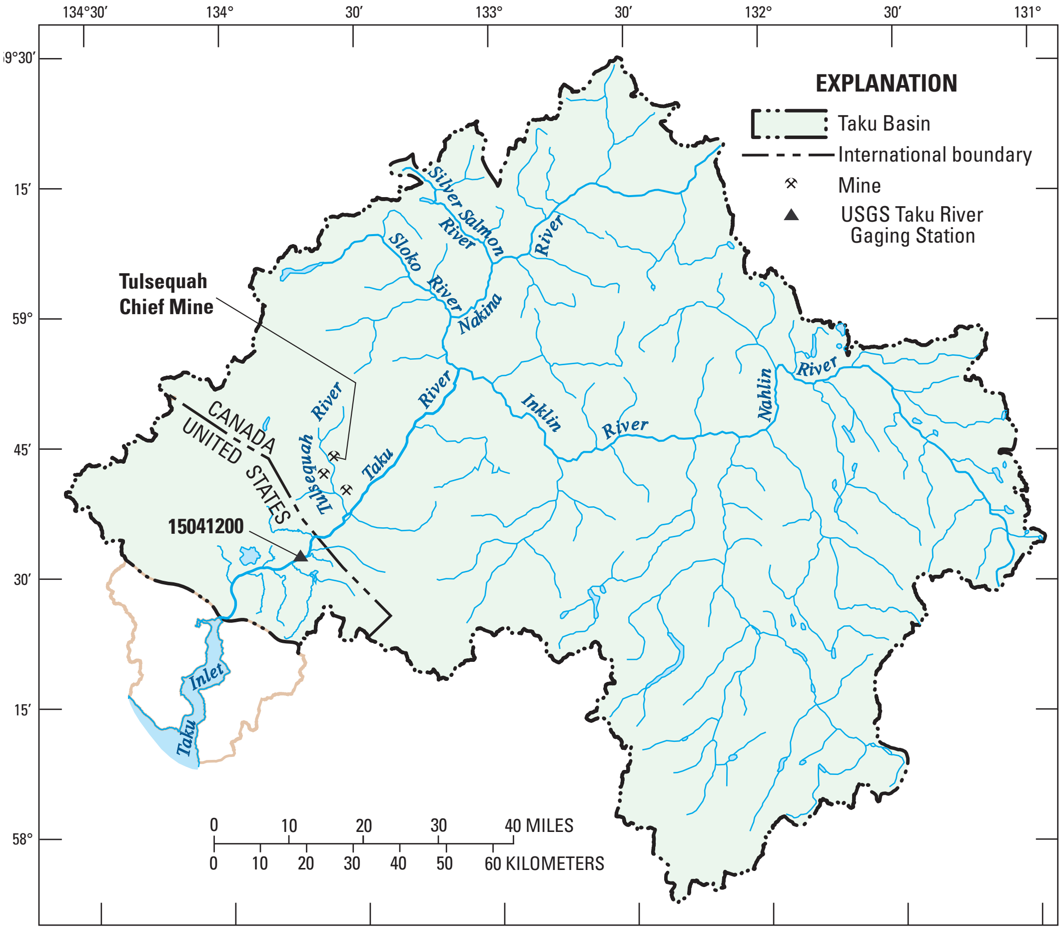


Figure 2. Taku River watershed.

Mining History of the Tulsequah Valley

The Taku and Tulsequah valleys have a history of mining exploration and operation dating back to the 1800s. The Taku valley was a route to the interior during the Klondike rush of 1897–98, and many prospectors detoured from their journey to prospect in the region. Large-scale mining operations began in the 1920s with the discovery of a large volcanogenic massive sulfide deposit just before the settlement of Tulsequah (Redfern Resources Ltd., URL accessed June 2006).

From the late 1920s to 1957, three different mines operated within the Tulsequah and Taku valleys (fig. 3). In 1937, the Polaris-Taku mine began production and operated until 1951, yielding 231,000 ounces of gold from 760,000 tons of ore. Just as the Polaris-Taku mine closed, the Tulsequah Chief and Big Bull mines began production. The ore from these mines was transported across the Tulsequah River and processed at the Polaris-Taku mill complex. These mines operated until 1957, when they were shut down because of low metals prices. The mine has not reopened, and the mill equipment was dismantled and sold in the late 1970s (Government of British Columbia, undated).

In 1987, Cominco Ltd., and Redfern Resources Ltd., resumed exploration of the Tulsequah area. Redfern Resources Ltd., purchased Cominco’s interest in the mine in 1992 and has proposed reactivating the former Tulsequah Chief Mine (Sebert and Barrett, 1996). Reopening the Tulsequah Chief mine on the Tulsequah River has been allowed by the Canadian government. If mining resumes, production of copper, lead, zinc, and gold concentrates from ore is projected to occur on site. Proposed access to the mine will be facilitated by constructing 73 mi of road connecting the project site with an existing road system servicing the community of Atlin, British Columbia. Because of uncertainties about the economic viability of reopening the mine, project development has been stalled.

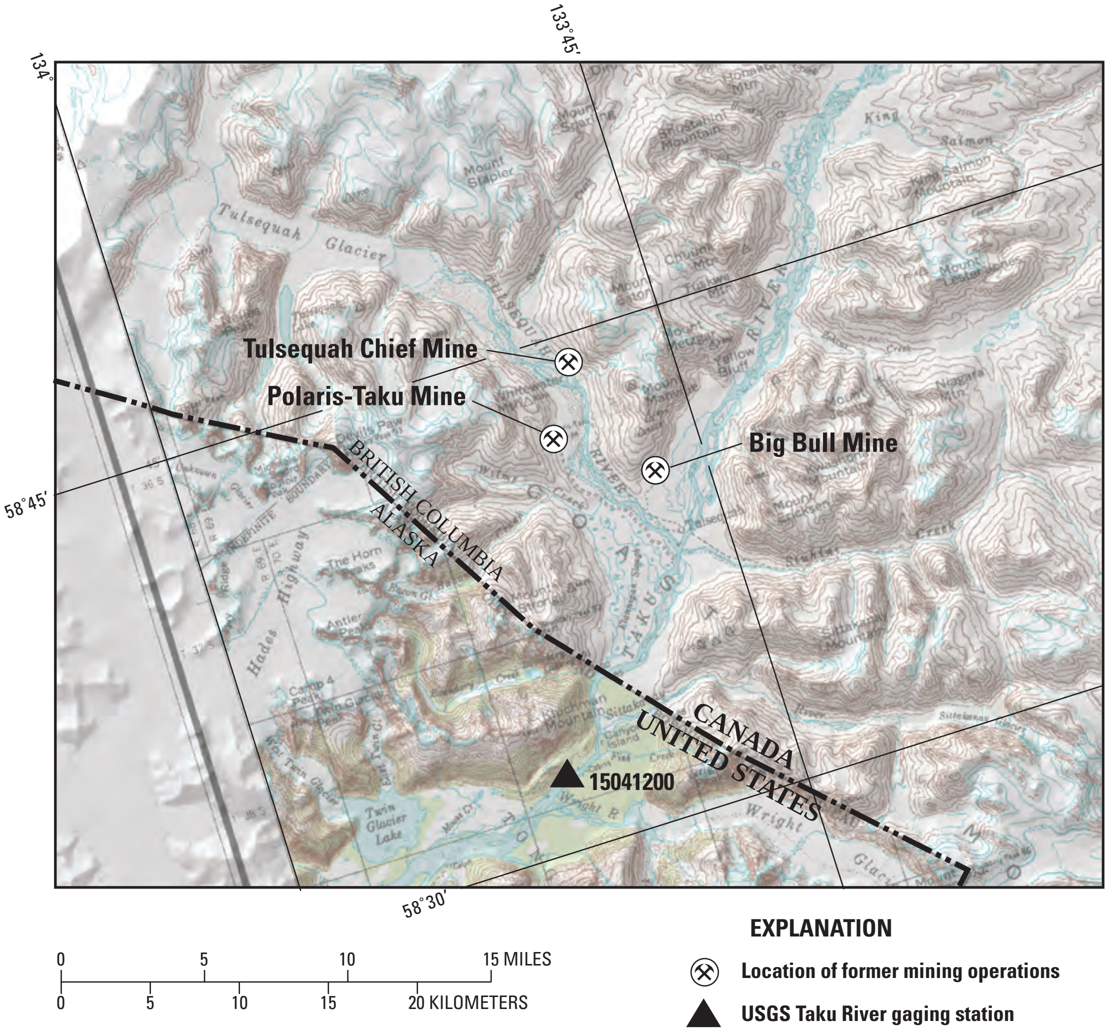


Figure 3. Location of prior mining activity in the Taku River watershed.

The water quality of the Tulsequah River below the Tulsequah Chief Mine has been measurably impacted from previous mining operations. Samples collected in February 2001 had concentrations of dissolved cadmium, copper, and zinc that exceeded ADEC (2003) aquatic-life criteria for fresh waters (Lough and Sharpe, 2003). Discharges from the Tulsequah Chief and Big Bull mines have been found to be in violation of the Canadian Fisheries Act (Office of the Auditor General of Canada, accessed online July 12, 2006).

Purpose and Scope

This report summarizes the results of a cooperative study by the DIA, EPA, ADEC, and USGS of the water quality and hydrology of the Taku River. The purpose of this study was threefold. First, the study presents an overview of streamflow and glacial-outburst flood characteristics of the Taku River. The study compares the surface-water-quality data to current freshwater aquatic-life water-quality criteria to determine if existing concentrations of trace elements could be adversely affecting aquatic life. Finally, the study establishes a baseline water-quality database for the Taku River that will aid in identification of future impacts of mining activities on the water quality of the Taku River.

Methods of Data Collection and Analysis

Streamflow

The USGS has gaged continuous streamflow on the Taku River near Juneau, Alaska (station No. 15041200) since July 1987. Measurements of stage and discharge were made using conventional methods outlined by Rantz and others (1982a) and acoustic Doppler current profilers (Simpson, 2001). Rantz and others (1982b) summarized methods for computation of continuous discharge.

Volume Computations for Glacial-Outburst Floods

The glacier-lake-outburst floods (outburst floods) of Tulsequah Lake and Lake No Lake were identified from hydrographs of the Taku River gaging station since data collection began in July 1987 (U.S. Geological Survey, 1988–2005). Most, but not all, of the larger outburst floods are easily distinguished by a characteristic hydrograph shape, which is recognizable by a 2- to 3-day exponential increase in discharge followed by an abrupt decrease lasting about 12–18 hours (fig. 4). Outburst floods were verified through hydrographic comparison with the Mendenhall River near Juneau (USGS station No. 15052500), Stikine River near Wrangell (USGS station No. 15024800), and Gold Creek at Juneau (USGS station No. 15050000). Without a witness to the event, it is difficult to determine with certainty the source of an individual outburst flood. Calculating the volume discharge for each outburst flood helped refine estimates of the probable source of each event. Various sources, including eyewitness accounts and previous publications, provided additional information about the origin of each flood.

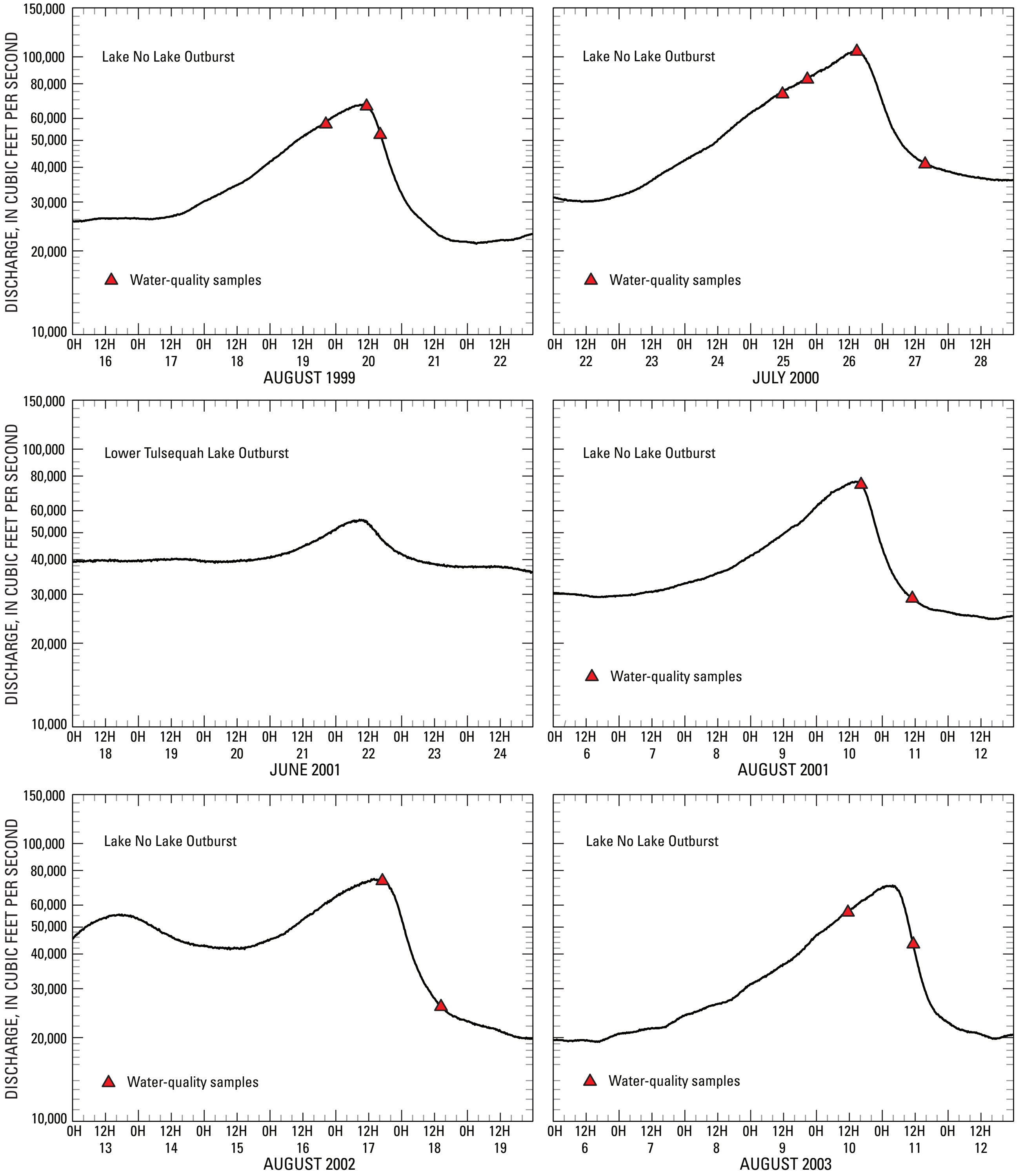
The volume of water released by each outburst flood was calculated by subtracting the base flow contribution of discharge from the outburst-flood hydrographs recorded at the Taku River gaging station. In some instances, precipitation or warming during or preceding the outburst complicated hydrograph separation of flood flow from base flow. Precipitation and warming can induce flow increases unrelated to the glacier-lake outbursts. Analysis of these hydrographs, with climatological data from the Juneau airport (National Oceanic and Atmospheric Administration, 1987–2004) and hydrographic comparison of nearby gaging stations, refined estimates of the base flow component of the flood hydrographs. Uncertainties involved with base flow estimations made 5 of the 41 outburst floods identified unsuitable for flood-volume computations. The outburst-flood component of peak discharge was calculated by subtracting the estimated base flow from instantaneous peak discharge. Outburst-flood data is used to provide a brief history and characterization of seasonal patterns of outburst flooding from July 1987 through September 30, 2004.

Water Quality

The objective of the sampling program was to determine the water quality of the Taku River over a wide range of flow conditions, including outburst floods, prior to reopening and operation of the Tulsequah Chief Mine. Water samples were analyzed for dissolved and total fractions of 13 trace elements, dissolved and total major inorganic constituents, selected nutrients, and dissolved and total organic carbon. Other chemical and physical parameters—including specific conductance, pH, water temperature, hardness, alkalinity, and dissolved-oxygen concentration—were measured during sampling.

Water-quality sample collection began in November 1998. Forty-four sample sets were collected at the Taku River gaging station (fig. 2). Monthly samples were collected during the open-water season from May to October when the greatest discharge and sediment transport occurs. Sample collection during the winter helped characterize water chemistry during low-flow periods. Samples collected during outburst floods provided data about water chemistry throughout the range of the hydrograph (fig. 4).

Figure 5 shows a flow-duration curve for the Taku River near Juneau, Alaska, for water years 1988 through 2003. Flow-duration curves show the average percentage of time that a specific daily mean discharge is equaled or exceeded at sites where continuous records of discharge are available. Using this approach, the flows sampled on the Taku River ranged from 0.1 percent exceedance to 93 percent exceedance.



H=Hour

Figure 4. Examples of outburst hydrographs from Lake No Lake and Tulsequah Lake recorded at the Taku River gaging station showing when water-quality samples were collected.

Methods of Sample Collection and Analysis

Sampling equipment was cleaned before use with a nonphosphate laboratory detergent, and then soaked in a 5-percent hydrochloric acid solution, and rinsed with deionized water. Equipment received a final rinsing with stream water just prior to sample collection. Wilde (2004) provides a comprehensive description of cleaning procedures for water-sampling equipment. Depth-integrated-water samples were collected across the stream using the equal-discharge-increment method (Edwards and Glysson, 1988) and processed within hours using methods and equipment described by Wilde and others (2004). Samples for organic carbon analysis were collected separately by dipping a baked glass bottle in the centroid of flow. Samples analyzed for dissolved constituents were filtered through 0.45-µm capsule filters. The USEPA Region Ten Manchester laboratory in Port Orchard, Washington, analyzed the water samples using standard USEPA analytical methods (U.S. Environmental Protection Agency, 1983, 1993, and 1994).

Prior to sample collection, a Yellow Springs Instrument multi-parameter meter was calibrated for field measurements of specific conductance, pH, water temperature, and dissolved-oxygen concentration. Field measurements were recorded as a cross-sectional average of the measurements at the sampling transect.

Hydrology of the Taku River

The Taku River, at the USGS gaging station, drains an area of about 6,600 mi^2 (fig. 2). The annual mean flow is 13,700 ft^3/s and ranges from a minimum monthly mean of 1,940 ft^3/s in February to a maximum monthly mean of 33,700 ft^3/s in June. The lowest daily mean discharge for the period of record was 710 ft^3/s on February 12, 1988. The instantaneous peak flow of 128,000 ft^3/s was on June 25, 2004, the result of a glacial-outburst flood originating within the tributary Tulsequah River drainage.

Streamflow of the Taku River shares similar characteristics with several of the larger drainages that flow out of Canada through the Alaska Coastal Range and discharge into the sea in southeast Alaska. These drainages are influenced by both the cooler, drier climates of interior Canada in their upper reaches and the maritime climate of coastal southeast Alaska in their distal reaches. Taku River discharge gradually increases in the spring and typically peaks in June when snowmelt is at a maximum. During the summer months, meltwaters from glaciers and ice fields along the perimeter of the basin maintain flow. As temperatures cool during late August through November, the contribution from glacial meltwater decreases, although increases in precipitation that are typical of coastal southeast Alaska during these months promote moderate flows. The Taku River is usually covered by ice from December through March, and often into April, with reduced flow during the period of ice cover. Figure 6 depicts the seasonal flow patterns of the Taku River as a percentage of annual mean discharge and shows that nearly 90 percent of the runoff for the Taku River is during the 6-month period from May to November.

Tulsequah Glacier Lakes

The Tulsequah Glacier (figs. 3 and 7) flows about 19 mi from its source in the Juneau Icefield to its terminus in the Tulsequah valley. Since the late 1800s, the Tulsequah Glacier and its tributaries have been receding. The Tulsequah Glacier has receded more slowly than many glaciers in the region due to the larger area and higher elevation of its accumulation zone (Marcus, 1960). Tulsequah lakes and Lake No Lake are located in valleys formerly occupied by tributary glaciers (fig. 7). These lakes formed through accelerated recession of tributary glaciers. Glacial meltwater and surface runoff behind what are now distributary arms of the Tulsequah Glacier fill these lakes. Mechanisms governing the release of flood waters from these lakes are poorly understood, however, multiple observers, including the author, have witnessed that drainage of the lakes is subglacial. The release of floods from similar glacier-dammed lakes may be triggered when waters rise to a critical elevation, followed by drainage through subglacial tunnels (Post and Mayo, 1971; Klingbjer, 2004). The tunnels grow in size as the flowing water melts the surrounding ice. When the outflow ceases, the tunnels close through plastic flow of the glacier, and the lakes can begin refilling (Nye, 1976). Lakes impounded by the Tulsequah Glacier have a history of outburst flood releases (Kerr, 1934; Marcus, 1960; Post and Mayo, 1971; Septer and Schwab, 1995; Geertsema and Clague, 2005).

Tulsequah Lake

Tulsequah Lake has a history of outburst flooding dating back to the early 1900s. The lake probably formed in the late 1800s when tributary glaciers receded from the trunk of the Tulsequah Glacier (Kerr, 1934; Marcus, 1960; Post and Mayo, 1971). Continued recession of tributary glaciers increased the lake's size, attaining its maximum volume between 1910 and 1920 (Marcus, 1960). After 1920, water levels in Tulsequah Lake began to fall, as continued downwasting of the Tulsequah Glacier reduced the ice-dam elevation. Vertical ablation of the ice barrier reduced the volume of outburst floods released by Tulsequah Lake from 737,000 acre-ft in 1910 to 186,000 acre-ft in 1958 (Marcus, 1960). The Tulsequah Lake valley was a single large lake in the early 1900s, but now consists of three smaller lakes (figs. 7 and 8). The volume of water released from Tulsequah Lake has continued to decline through the second half of the twentieth century. For at least the past decade, the greater outburst floods result from a glacier-dammed lake known as Lake No Lake (Geertsema and Clague, 2005).

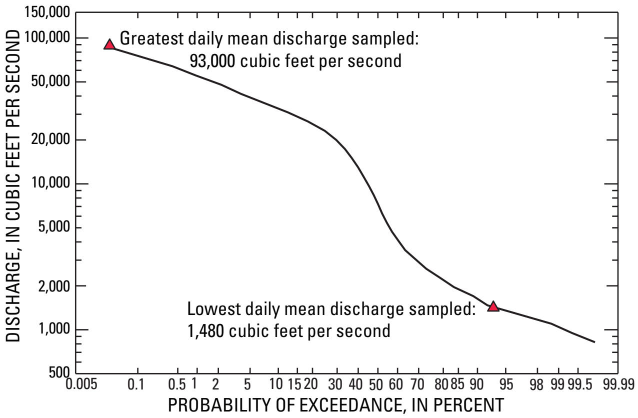


Figure 5. Flow-duration curve for Taku River near Juneau (1987–2003) showing range of flows sampled for water chemistry analysis.

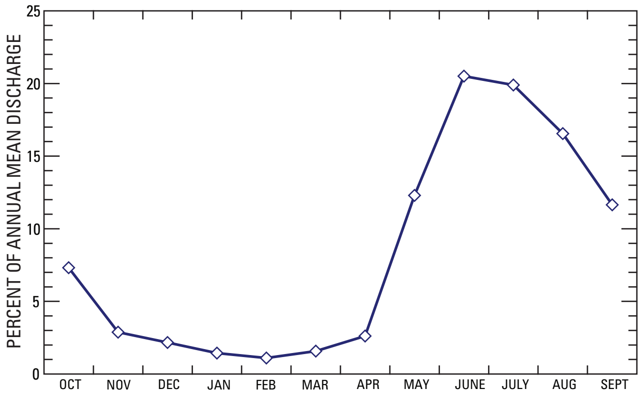


Figure 6. Monthly mean discharge of the Taku River expressed as a percentage of annual mean discharge.

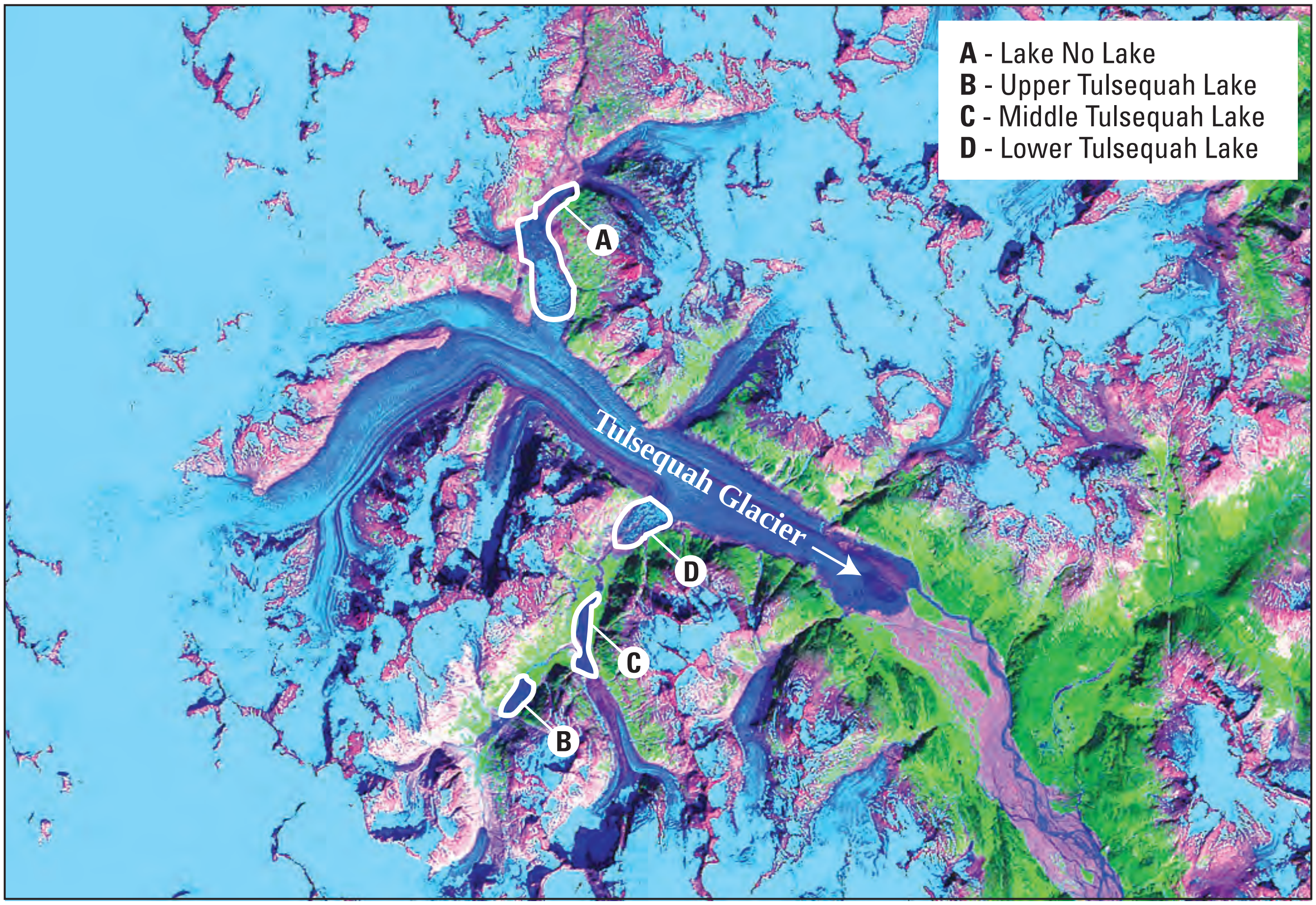


Figure 7. Tulsequah Glacier showing Tulsequah Lakes and Lake No Lake.

Lake No Lake

Lake No Lake is about 4 mi upstream and north of Tulsequah Lake (figs. 7 and 9) and formed as tributary glaciers to the Tulsequah Glacier receded during the mid-twentieth century. Lake No Lake has gradually increased in size from about 0.17 mi^2 in 1958 to 0.4 mi^2 in 1970. By 1999, it covered about 1.85 mi^2, with a total volume of approximately 584,000 acre-ft (Post and Mayo, 1971; Gertseema and Clague, 2005). In 1993, a large slab measuring 1,640 ft wide, 2,300 ft long, by 560 ft thick, calved off the distributary arm of the Tulsequah Glacier (Gertseema and Clague, 2005). Calving events of this extent increase lake volume and may account for some variability in outburst-flood duration and magnitude. Figure 7 shows Lake No Lake has likely reached a near maximum volume as tributary glaciers have retreated out of the valley in which it is impounded. Water-surface elevations are declining because of thinning of the Tulsequah Glacier (Gerseema and Clague, 2005). Further increases in lake volume, should they occur, will likely be the result of recession or calving of the distributary arm of the Tulsequah Glacier which impounds the lake.

Glacier-Lake-Outburst Floods

Glacial-outburst floods occur when water stored behind, under, or within glaciers is rapidly released. Floods of this type occur yearly and sometimes two or three times a year in the Tulsequah and Taku Rivers. During the larger outburst floods, the discharge of both rivers will typically increase rapidly over a 2- to 3-day period followed by a rapid recession from the peak discharge. The greatest flows on record for the Taku River are a result of glacial-outburst floods.

The larger outburst floods can temporarily disrupt commercial fishing in the Taku River and Taku Inlet as large pulses of debris are swept down river and into the inlet, fouling nets and creating hazardous boating conditions. Outburst floods also create difficulties in navigation of the Taku River delta. Shallow depths and high turbidity at the broad flat delta near the mouth of the river complicates boat access to the Taku River valley. Each year the Taku River typically establishes one or more large deep channels, which are navigable by shallow-draft vessels. Outburst floods alter these channels through redistribution of sediment and debris, making previously identified channels unsuitable for navigation.

There are approximately 82 parcels of private land in the Taku valley area, and many have dwellings ranging from small cabins to houses (McDowell Group, written commun., 2004). These parcels are frequented in the summer months mainly by Juneau residents. Although most structures are at elevations above typical outburst-flood stage, the larger floods create the potential for loss of property or structural damage.

Seasonal Patterns of Outburst Floods

A moderately persistent pattern in glacial-outburst flooding since 1987 is inferred from both the timing and volume released (table 1). The outburst-flood history shows a late spring or early summer outburst, likely sourced from lower Tulsequah Lake, has occurred in 14 of the last 17 years of record (1987–2004). The volumes of Tulsequah Lake outbursts ranged from 16,000 to 56,000 acre-ft, with the greater volumes released before 1995, suggesting a continued decrease in the volume of the lower Tulsequah Lake.

From 1987 through 2004, the largest annual outburst floods have been in July or August (16 out of 18 years). These floods ranged in volume from 95,000 to 220,000 acre-ft, although most of the annual-peak floods released between 141,000 to 155,000 acre-ft. The volumes of the annual-peak-outburst floods were within this range 10 of the last 18 years. The history of outburst floods (table 1) implies that in a typical year the lower Tulsequah Lake will release a comparatively small volume outburst in late spring or early summer. An annual-peak-outburst flood typically is released from Lake No Lake in July or August. During some years, a second and usually smaller outburst flood results from a second release from Lake No Lake later in the summer or autumn. An outburst-flood release in March 1999 suggests these events may not always be limited to the open-flow season.

The dynamic nature of these types of floods, coupled with the remote location of the glacier-dammed lakes, leaves some uncertainty about individual flood sources. It appears reasonable to surmise that smaller volume outbursts in late spring or early summer originate from the discharge of the lower Tulsequah Lake. This is consistent with eyewitness accounts stating that in recent years (lower) Tulsequah Lake has drained completely in late spring or early summer and did not refill through the summer months (Norm Graham, pilot, Discovery Helicopters, written commun., 2005). Eyewitness accounts in 1996, 1999, 2000, 2002, and 2005 (Geertsema and Clague, 2005; USGS Juneau Field Office personnel, oral commun., 2005) pointed out that Tulsequah Lake had emptied before the onset of the larger annual outburst floods. Furthermore, a distinct vegetation line is now visible around the perimeter of the Upper and Middle Tulsequah Lakes (fig. 7) suggesting these shorelines are no longer subjected to submergence, and implicating the lower Tulsequah Lake as the source of the smaller outburst floods.

Figure 8. Tulsequah Glacier (foreground) and Lower and Middle Tulsequah Lakes, June 30, 2005. Lower Tulsequah Lake drained on May 25–26, 2005. Stranded icebergs indicate the water-surface elevation before lake drainage. Photograph taken by Edward Neal.

Figure 9. Lake No Lake filled with meltwater and glacial ice calved from the Tulsequah Glacier. Photograph taken by Joe Smith.

Table 1. Summary of glacial-outburst floods recorded at the Taku River gaging station from July 1987 through September 2004.

[LNL, Lake No Lake; TL, Tulsequah Lake; acre-ft, acre-feet; ft^3/s, cubic feet per second; nd, not determined]

Year	Probable source	Dates of drainage	Volume (acre-ft)	Peak discharge (ft^3/s)	Outburst-flood component of peak discharge (ft^3/s)
1987	LNL	Aug. 25-28	151,000	62,300	38,400
1988	LNL	July 31–Aug. 2	95,000	68,200	43,300
	nd	Aug. 12-14	16,100	34,200	11,000
1989	TL	June 21-23	36,000	48,200	17,400
	[1]LNL	Aug. 15-18	[2]187,000	110,000	72,000
1990	TL	June 18-20	53,000	54,600	22,900
	[1]LNL	July 17-21	[2]160,000	79,800	47,000
		Aug. 19-21	nd	66,700	nd
1991	TL	July 4-6	56,000	57,400	24,400
	[3]LNL	Aug. 13-14	40,500	57,600	24,300
	LNL	Aug. 30–Sept. 2	129,000	61,900	39,600
1992	TL	July 7-9	54,000	71,600	20,700
	[3]LNL	Aug. 18-21	[2]170,000	84,500	[2]55,700
1993	TL	June 18-19	31,000	60,800	14,700
	LNL	July 25-29	[2]155,000	90,400	[2]51,000
	LNL	Sept. 2-5	nd	45,700	nd
1994	TL	June 19-21	55,000	57,400	20,400
	[3]LNL	July 28–Aug. 1	218,000	106,000	76,000
1995	TL	July 7-8	23,000	41,300	13,300
	LNL	July 24-27	142,000	95,500	60,000
	LNL	Oct. 23-28	106,000	31,000	25,800
1996	[3]LNL	Sept. 16-19	141,000	58,900	43,200
1997	TL	June 27-28	20,000	43,200	8,700
	LNL	July 24-28	[2]118,000	69,400	[2]36,900
	LNL	Sept. 23-26	nd	65,300	nd
1998	LNL	July 30–Aug. 3	154,000	69,000	46,000
1999	nd	March	nd	nd	nd
	TL	June 21-22	27,000	53,200	16,000
	LNL	Aug. 17-21	143,000	67,300	43,000
2000	TL	June 14-16	26,000	55,700	14,200
	LNL	July 23-27	148,000	104,000	54,000
	LNL	Oct. 6-8	nd	47,900	nd
2001	TL	June 21-22	[2]16,000	55,700	[2]12,500
	LNL	Aug. 7-11	148,000	76,600	50,000
	LNL	Oct. 7-10	48,000	28,800	nd
2002	TL	June 16-17	19,000	51,700	11,400
	[3]LNL	Aug. 13-18	[2]147,000	74,600	[2]48000
2003	TL	May 30–June 2	28,000	37,200	13,200
	LNL	Aug. 7-11	147,000	70,700	48,000
2004	LNL	June 23-26	220,000	128,000	80,000
	TL	July 13-15	27,000	55,400	15,900

[1] Septer and Schwab, 1995.

[2] Approximate.

[3] Geertsema and Clague, 2005.

The relative consistency in volume released during the largest annual outburst floods since 1995, combined with published accounts dating back to 1989 (Septer and Schwab, 1995; Geertsema and Clague, 2005) suggests that the larger floods since 1987 were sourced from Lake No Lake. Recent eyewitness accounts provide further support for this theory. The large proportion of flood volumes between 141,000 and 155,000 acre-ft indicates that outbursts from Lake No Lake might be triggered when the lake fills to a critical level. This has been documented in other glacier-dammed lakes (Mathews, 1965; Post and Mayo, 1971). This further suggests the timing of the outburst might be predictable within weeks or days if lake-stage data were available. The volume discharged since 1993 has been relatively consistent, except for 1994 and 2004 when the volume increased by 70,000 acre-ft. It is of interest to note the calving of the distributary arm in 1993 increased the lake volume about 48,500 acre-ft, implicating calving events as a potential source of variability in flood volume.

Outburst-Flood Prediction

Given sufficient long-term streamflow records, it becomes possible to estimate the largest flood expected, on average, once in every 50 years or once in every 100 years using standard statistical procedures. The magnitude and frequency of glacial-outburst floods cannot be estimated using standard statistical methods because glacial-outburst floods are not sourced from rainfall or snowmelt. Furthermore, hydrologic characteristics of basins containing glacier-dammed lakes may change suddenly and unsystematically (Post and Mayo, 1971). Glacier-outburst floods may develop abruptly in a river with no history of outburst flooding (Mathews and Clague, 1993). Conversely, a river with a history of outburst floods may suddenly stop flooding due to deterioration of the ice dam of the impounding glacier (Clague and Evans, 1994).

Taku River flood predictions are even more problematic since outburst floods originate from two lakes. The number of assumptions and uncertainties associated with flood prediction on the Taku River preclude estimates of recurrence intervals for floods of a specific magnitude. However, peak discharges from outburst floods given in table 1 allow for calculation of the magnitude of hypothetical large floods.

During most years since 1987, at least two outburst floods a year are detected in the Taku River discharge records. Given that two glacier-dammed lakes drain into the same river, large floods would be expected from a simultaneous release of both lakes. The flood magnitude resulting from a synchronous release of both lakes will be determined by the outburst contribution of peak discharge from each lake, and Taku River base flow at the time of the outbursts. Using the data provided in table 1 combined with daily streamflow data, various peak discharge scenarios can be estimated using the following equation:

$$\mathrm{Q}\mathit{Peak} = \mathrm{Q}\mathit{No\ Lake} + \mathrm{Q}\mathit{Tulsequah} + \mathrm{Q}\mathit{Base\ flow} \qquad (1)$$

where:

$\mathrm{Q}\mathit{Peak}$ is peak discharge from a synchronous release of both lakes,

$\mathrm{Q}\mathit{No\ Lake}$ is discharge contribution from Lake No Lake,

$\mathrm{Q}\mathit{Tulsequah}$ is discharge contribution from Tulsequah Lake, and

$\mathrm{Q}\mathit{Base\ flow}$ is discharge contribution from base flow.

For example, the June 25, 2004, outburst flood sourced from Lake No Lake produced a peak discharge of 128,000 ft^3/s. Taku River base flow was 48,000 ft^3/s and the outburst-flood contribution to peak discharge was 80,000 ft^3/s. If a Tulsequah Lake outburst flood similar to that of 1994 peaked at precisely the same time, the discharge would have increased by 20,400 ft^3/s, for a combined peak discharge of 148,000 ft^3/s. The release timing is a critical factor in these calculations due to the limited duration of the glacial-outburst peaks (fig. 4). For example, if the release from Tulsequah Lake were to peak 8–10 hours after a large peak released from Lake No Lake, the secondary peak would be of minor consequence.

Outburst Floods and Taku River Channel Morphology

Frequent floods of moderate magnitude have been shown to be determinants of channel and flood-plain morphology in many fluvial systems (Wolman and Miller, 1960). This is because a large portion of the total sediment transport of a stream typically occurs during peak discharges, with recurrence intervals from about 1 to 3 years, rather than large peak flows. Although large peaks flows also transport large amounts of sediments, moderate flood flows are more frequent than larger events. These moderate peak discharges often are responsible for creating or maintaining the characteristic size and shape of a river channel and are known as channel-forming discharges. The magnitude of channel-forming discharges can often be approximated by discharges that fill the stream channel from bank to bank up to the level of the flood plain (Leopold and others, 1964).

In the Taku River, the greatest annual-peak discharges from outburst floods have exceeded nearly all floods sourced from snowmelt or rainfall since 1987 (fig. 10). These data suggest outburst floods may be a critical component of existing Taku River channel and flood-plain morphology downstream from its confluence with the Tulsequah River. Other research has shown outburst floods can be important agents in shaping the morphology of alluvial channels (Desloges and Church, 1992; Cenderelli and Wohl, 2003).

The significance of outburst floods to Taku River channel morphology is of interest because of the inherent long-term instability of these types of floods. For example, the flood volume released by Tulsequah Lake has decreased from 700,000 acre-ft in 1910 (Marcus, 1960) to less than 30,000 acre-ft in recent years (table 1). Although the flood volumes released by Lake No Lake remain large, continued thinning of the Tulsequah Glacier could reduce the elevation of the ice dam impounding the lake, resulting in reduced flood magnitude and volume. Predicting changes in stream-channel morphology that might result from changes in magnitude or frequency of outburst floods is beyond the scope of this report.

Water Quality

In this study, several physical properties—such as specific conductance, pH, water temperature, and dissolved oxygen—and chemical constituents—including dissolved and total fractions of 13 trace elements, dissolved and total major inorganic constituents, selected nutrients, and dissolved and total organic carbon—were recorded periodically from November 1998 through September 2003. These data establish a water-quality baseline of the Taku River.

Water-Quality Criteria

The water-quality data for the Taku River were compared with Alaska Department of Environmental Conservation (2003) aquatic-life criteria for fresh waters (table 2). For trace elements, these criteria are adopted from the U.S. Environmental Protection Agency (1999) water-quality criteria for protecting aquatic organisms and their uses. Concentrations at or below these criteria should not result in unacceptable effects on aquatic organisms and their uses during a short-term exposure (U.S. Environmental Protection Agency, 1986). The freshwater chronic-toxicity guidelines estimate the highest chemical concentrations in surface water that aquatic organisms can tolerate for a defined time period without experiencing unacceptable effects. The time periods to which these chronic-toxicity guidelines apply vary with the chemical constituent being examined (Alaska Department of Environmental Conservation, 2003).

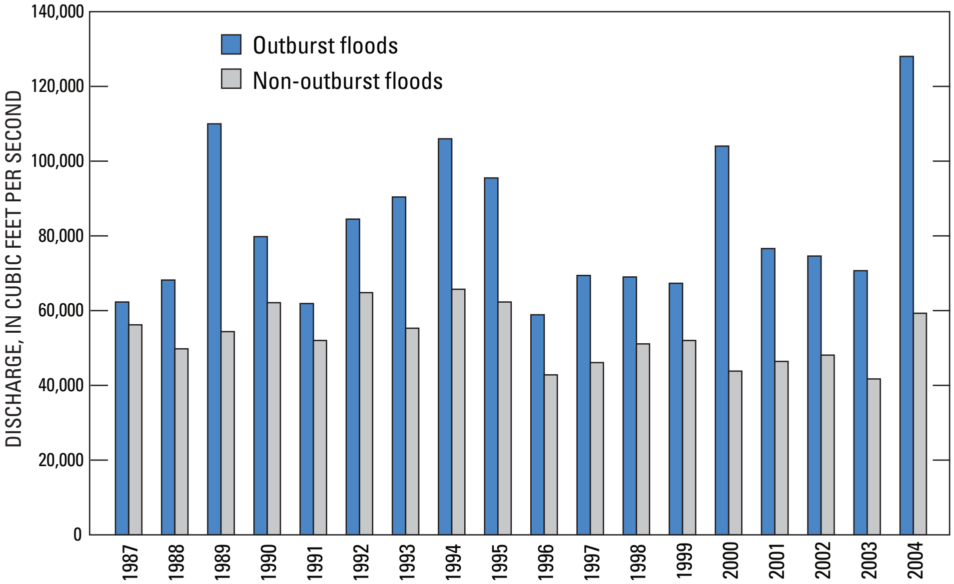


Figure 10. Greatest annual peak discharges generated by outburst floods compared with annual peak discharges generated by rainfall and/or snowmelt on the Taku River, July 1987 through September 2004.

Because elevated water hardness may reduce the toxicity of some metals (U.S. Environmental Protection Agency, 2001), the ADEC aquatic-life criterion for fresh waters for cadmium, chromium, copper, lead, nickel, silver, and zinc are expressed as a function of water hardness. Water hardness refers primarily to calcium and magnesium ions concentrations, although the ions of other polyvalent metals sometimes influence hardness. Because hardness cannot be attributed to a single constituent, it is usually reported as an equivalent concentration of calcium carbonate (Hem, 1985). The hardness dependent criteria shown in table 2 were calculated using the lowest observed hardness (31 mg/L as $CaCO_3$), yielding the strictest criteria limits for each constituent. Actual criteria are a function of water hardness for each discrete sample. Alaska Department of Environmental Conservation (2003) provides equations for calculation of hardness-dependent criteria.

Field Parameters

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electric current. The specific conductance of water is proportional to the ion concentration in solution; therefore, it can indicate the dissolved-solids or ion content of the water. A statistical relation often can be developed between specific conductance and the ionic components making up the dissolved solids in water. Values of specific conductance during the study period ranged from 67 to 247 µS/cm (table 3). Specific conductance was lowest during periods of glacial-outburst flooding, whereas greater values of specific conductance were measured during periods of winter low flow. In natural systems, periods of greater specific conductance often indicate a greater component of ground-water inflow. Ground water has increased potential to dissolve minerals having spent more time in contact with rocks and soil materials than rainwater, snow, or glacier meltwater. Periods of low specific conductance reflect runoff with a greater component of snow, glacial melt, or rainwater.

pH

The pH of water is a measure of its hydrogen-ion activity and can range from 0 (acidic) to 14 (alkaline) standard units. The pH of a system is often an important variable governing reactions and processes in aquatic systems and sometimes influences the bioavailability of metals. For example, the acidic pH range typically enhances bioavailability of cationic metals to aquatic organisms (Smith and Huyck, 1999). The pH of river water typically ranges between 6.5 and 8.5 standard units (Hem, 1985). During the study period, measured values of pH for the Taku River ranged from 6.9 to 8.7 (table 3).

Table 2. Trace-element and field-parameter summary statistics from samples collected on the Taku River, 1998–2003.

[ADEC, Alaska Department of Environmental Conservation; ºC, degrees Celsius; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; >, greater than; <, less than; --, not determined]

Constituent or property	ADEC aquatic-life water-quality criterion[1]	During glacial-outburst floods				During other flows			
		Number of detections/ samples	Minimum	Median	Maximum	Number of detections/ samples	Minimum	Median	Maximum
					Field Parameters				
Discharge (ft^3/s)	–	14/14	25,700	63,000	106,000	30/30	1,480	14,400	39,200
Water temperature (ºC)	<15	14/14	3.0	5.8	8.0	30/30	0	7	10.5
Specific conductance (µS/cm)	–	13/13	67.0	90.0	129.0	30/30	104	131	247
Oxygen, dissolved (mg/L)	>7	9/9	10.3	11.8	12.8	25/25	8	12	13
pH, field (standard units)	6.5-8.5	14/14	7.4	7.8	8.1	29/29	6.9	7.8	8.7
Alkalinity (mg/L as CaCO$_3$)	20,000	14/14	24.0	32.5	45.0	28/28	38	55	153
					Dissolved and Total Trace Elements				
Aluminum, dissolved (µg/L)	–	13/13	28	39	51	22/27	<20	31	63
Aluminum, total (µg/L)	[2]87	13/13	3,120	8,390	12,800	27/27	73	1,020	6,150
Arsenic, dissolved (µg/L)	150	13/13	.4	.5	1.1	27/27	.4	.6	1.2
Arsenic, total (µg/L)	–	13/13	3	7	9.7	27/27	.6	1.3	5
Barium, dissolved (µg/L)	–	13/13	18.8	24.7	29	27/27	23.1	29	45
Barium, total (µg/L)	–	13/13	86.5	189	280	27/27	39.9	51	130
Cadmium, dissolved (µg/L)	[3]0.11	0/13	<.04	–	–	5/27	<.04	–	.12
Cadmium, total (µg/L)	–	13/13	.13	.4	.5	14/27	<.04	–	.3
Chromium, dissolved (µg/L)	[3]28	4/13	<1	–	1.4	3/27	<1	–	2.1
Chromium, total (µg/L)	–	13/13	6	14	22	21/27	<1	3	12
Copper, dissolved (µg/L)	[3]3.3	0/13	<1	–	–	8/26	<1	–	2
Copper, total (µg/L)	–	13/13	8	24	36	25/26	<1	4	15
Iron, dissolved (µg/L)	[2]1,000	3/13	<10	–	12	14/27	<10	11	70
Iron, total (µg/L)	–	13/13	4,850	13,300	18,000	27/27	310	1,720	8,720
Lead, dissolved (µg/L)	[3]0.7	0/13	<.1	<.1	<.1	2/27	<.1	<.1	.29
Lead, total (µg/L)	–	13/13	3	9	12	27/27	0.2	1.5	7
Manganese, dissolved (µg/L)	–	13/13	6.7	9	12.7	27/27	4.4	8	42.2
Manganese, total (µg/L)	–	13/13	148	361	502	27/27	24	55	259
Nickel, dissolved (µg/L)	[3]19	13/13	.31	.54	.82	27/27	.41	.86	2
Nickel, total (µg/L)	–	13/13	9	21	31.7	27/27	1	4	21
Selenium, dissolved (µg/L)	5	0/6	<1	–	–	0/12	<1	–	–
Selenium, total (µg/L)	–	0/6	<1	–	–	1/11	<1	–	1
Silver, dissolved (µg/L)	[3,4]0.46	0/13	<.03	–	–	1/27	<.03	–	.04
Silver, total (µg/L)	–	10/13	<.1	.13	.25	5/25	<.03	<.1	.17
Zinc, dissolved	[3]44	2/13	<4	–	5	6/26	<4	–	7.7
Zinc, total	–	13/13	19	52	80	22/26	<4	10.5	32

[1] Alaska Department of Environmental Conservation (2003), all aquatic-life water-quality criterion values listed refer to the chronic criteria, unless otherwise noted. Criteria are upper limits of acceptable conditions, except as noted.

[2] Expressed in terms of total recoverable metal in the water column.

[3] Dissolved criteria were calculated using a hardness of 31 mg/L as CaCO$_3$ (for illustrative purposes only).

[4] Alaska Department of Environmental Conservation (2003), criterion values listed refer to acute criteria.

Table 3. Discharge and physical properties measured during sample collection from Taku River near Juneau, Alaska, November 1998 through September 2003.

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; –, no data; **bold**/shading indicates measurements taken during outburst floods]

Dates	Time	Discharge (ft^3/s)	Dissolved oxygen, (mg/L)	pH (standard units)	Specific conductance, (µS/cm)	Temperature, air, (degrees Celsius)	Temperature, water (degrees Celsius)	Alkalinity (mg/L as $CaCO_3$)
11-06-98	1430	6,230	13.0	7.8	187	1.5	1.5	80
03-31-99	1100	1,890	11.3	7.9	220	8.0	.0	86
04-13-99	1730	1,960	–	–	235	6.5	3.5	–
06-07-99	1300	22,000	10.7	7.8	138	22.0	8.0	63
06-28-99	1100	30,900	10.4	7.5	130	10.0	8.5	53
07-27-99	0930	21,700	–	7.9	104	–	8.5	42
08-19-99	**2050**	**62,100**	**–**	**7.6**	**75**	**–**	**4.0**	**28**
08-20-99	**1120**	**63,900**	**–**	**7.9**	**83**	**–**	**3.0**	**31**
	1750	**59,100**	**12.8**	**7.7**	**87**	**–**	**4.0**	**34**
09-13-99	1130	9,630	8.2	7.9	131	–	7.0	51
10-11-99	1200	6,220	–	8.1	163	3.5	4.5	44
04-05-00	0930	2,570	12.5	7.5	219	6.0	2.0	93
05-15-00	1500	14,600	11.6	7.6	167	–	6.5	38
06-16-00	1100	39,200	–	7.6	127	10.0	7.5	56
07-25-00	**1115**	**71,500**	**11.3**	**7.7**	**82**	**13.0**	**6.0**	**31**
	2015	**81,400**	**11.8**	**7.6**	**90**	**–**	**6.5**	**33**
07-26-00	**1500**	**106,000**	**11.5**	**7.4**	**95**	**–**	**6.5**	**34**
07-27-00	**1500**	**41,800**	**10.3**	**7.6**	**–**	**–**	**8.0**	**42**
08-29-00	1200	16,000	10.8	7.6	123	–	7.0	53
10-11-00	1145	13,900	–	7.7	128	6.5	4.5	56
04-11-01	1500	2,130	12.2	8.7	222	8.0	3.5	102
06-07-01	1400	33,900	11.4	7.8	137	–	9.0	58
06-28-01	1343	33,900	10.6	7.7	122	–	8.5	51
07-06-01	1232	31,100	11.1	6.9	118	11.0	8.0	45
08-10-01	**1610**	**73,900**	**10.6**	**8.0**	**90**	**20.5**	**7.0**	**32**
08-11-01	**1125**	**28,800**	**–**	**7.9**	**100**	**18.5**	**8.0**	**45**
09-20-01	1325	16,300	11.1	7.8	117	–	7.0	49
11-14-01	1240	3,390	13.4	8.1	210	3.0	0.5	92
03-29-02	1608	1,480	11.5	7.8	247	5.5	0.5	89
05-09-02	1025	4,380	11.9	7.9	124	11.0	6.5	84
06-12-02	1240	29,200	11.8	7.1	128	17.5	9.0	48
07-18-02	1600	29,100	11.8	7.8	110	–	10.5	–
08-16-02	**1957**	**58,200**	**–**	**7.9**	**111**	**14.0**	**4.5**	**28**
08-17-02	**1651**	**68,900**	**–**	**8.0**	**129**	**–**	**3.5**	**30**
08-18-02	**1432**	**25,700**	**12.4**	**7.7**	**108**	**–**	**7.0**	**42**
09-11-02	1600	14,300	12.5	7.8	130	–	7.5	53
11-05-02	1530	4,540	12.7	8.4	186	–	0.5	58
04-09-03	1645	1,950	11.5	8.0	238	6.5	2.5	153
05-20-03	1120	10,900	10.5	7.9	175	–	7.5	72
06-18-03	1200	26,500	10.5	7.8	124	–	9.0	52
07-11-03	950	36,600	10.7	7.7	111	–	10.5	46
08-10-03	**1115**	**65,200**	**12.5**	**8.1**	**67**	**17.5**	**4.0**	**24**
08-11-03	**1115**	**43,200**	**11.9**	**7.8**	**85**	**20.0**	**5.5**	**34**
09-29-03	0950	25,400	11.9	8.2	113	12.0	6.0	49

Water Temperature

Important biological processes such as metabolism and growth rates of aquatic organisms are influenced by water temperature, as are physiochemical processes such as oxygen solubility. Water temperature data for the Taku River was recorded using an electronic water-temperature probe beginning in June 1999. Figure 11 shows water temperature in the Taku River approximately mirrors the streamflow with temperatures at or near 0 °C through the winter low-flow periods, and gradually increases through the summer months as runoff increases.

Water temperatures recorded during outburst floods decreased by as much as 4.5 °C during the floods, due to the cooler temperature of the discharging lake water (fig. 11). During outburst floods, cross-sectional water temperature profiles measured at the gaging station decreased by as much as 3.5 °C when measured from the left (south) to right (north) bank. Similar cross-sectional profiles showed little or no variation during routine sampling. The Tulsequah River enters the Taku River on the right bank, approximately 8 mi upstream of the gaging station (fig. 2). The cross-sectional temperature differences demonstrate mixing of the cooler outburst water with the Taku River water is incomplete as far downstream as the USGS gaging station (Host and Dorava, 1999; U.S. Geological Survey, 1999–2003).

Dissolved Oxygen

In cold turbulent streams like the Taku River, the dissolved-oxygen concentration is primarily a function of water temperature and atmospheric pressure. Secondary factors influencing dissolved-oxygen concentration include air temperature, hydraulic characteristics of the stream, photosynthetic or respiratory activity of stream biota, and the quantity of organic matter present (Hem, 1985).

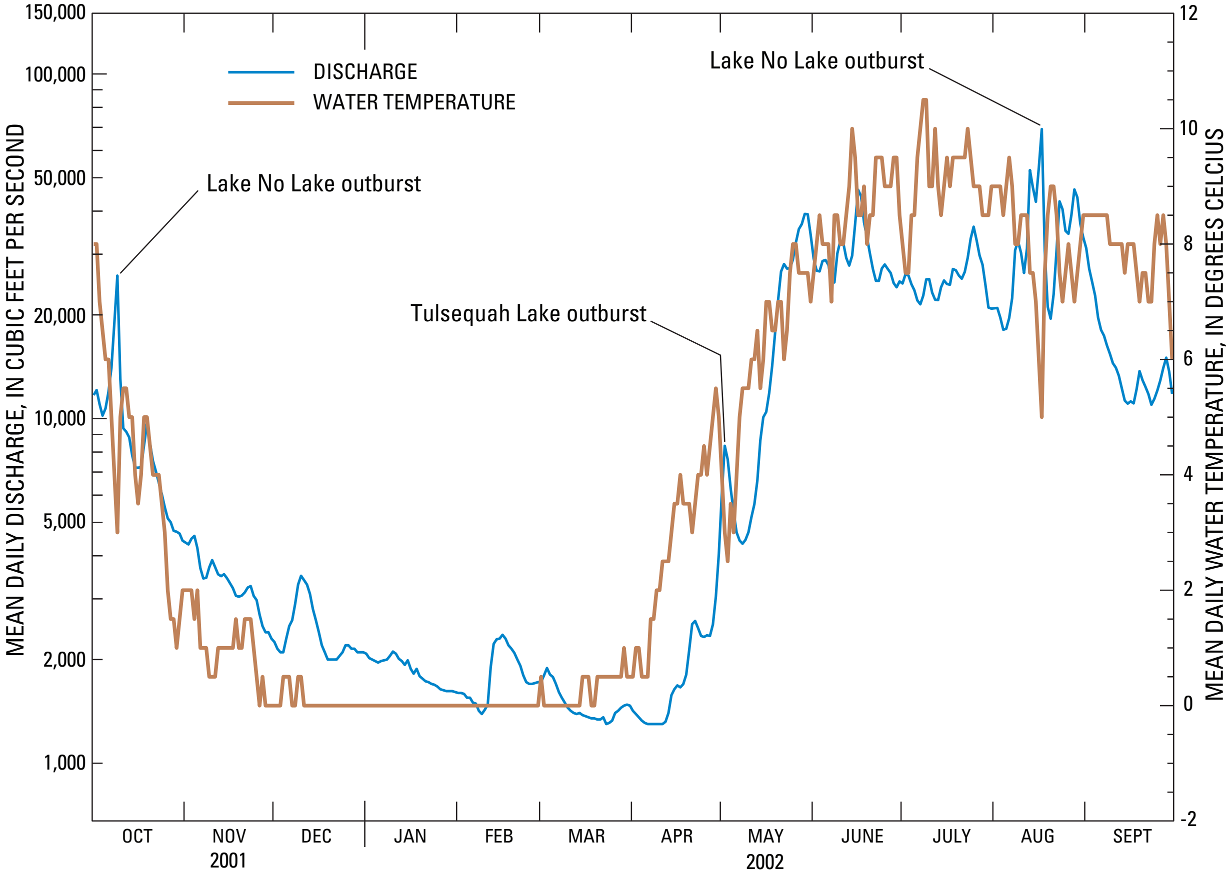


Figure 11. Mean daily discharge and water temperature for the Taku River near Juneau, October 2001 through September 2002.

Salmon and other species of fish indigenous to southeast Alaska streams need well-oxygenated water at every stage in their life, as do many forms of aquatic invertebrates. Measurements of dissolved-oxygen concentration on the Taku River taken during sample collection ranged from 8.2 to 13.4 mg/L (table 3). All measurements of dissolved-oxygen concentrations indicate acceptable concentrations to support salmonids.

Alkalinity

Alkalinity is a measure of the capacity of the substances dissolved in water to neutralize acid. In most natural waters, alkalinity results from bicarbonate and carbonate ions formed when carbon dioxide or carbonate rocks dissolve in water (Hem, 1985). Alkalinity for the Taku River—reported as equivalent concentration of calcium carbonate ($CaCO_3$)—ranged from 24 to 153 mg/L (table 3). Alkalinity concentrations were lowest during greater flows associated with outburst floods. The highest values for alkalinity were measured during periods of low flow in the winter and spring. The range of pH measured concurrently at this site indicates that most of the alkalinity results from dissolved bicarbonate ions.

Major Inorganic Constituents

Water samples collected from the Taku River were analyzed for major dissolved and total inorganic constituents. In rivers, these consist mainly of minerals from soil and rock weathering. Cations that make up most of the dissolved content in natural waters are calcium, magnesium, sodium, and potassium. The major anions typically are represented by sulfate, chloride, fluoride, nitrate, and those making up alkalinity (Hem, 1985).

Calcium and magnesium are both common alkaline-earth metals and essential elements in plant and animal nutrition, both are major components of positively charged ions in most natural waters (Hem, 1985). Dissolved concentrations ranged from about 9.8 to 37.5 mg/L for calcium and from 1.44 to 8.69 mg/L for magnesium (table 4). Sodium and potassium are present in most natural waters, but usually in low concentrations in rivers. Dissolved sodium concentration ranged from less than detection limits of 0.7 to 5.84 mg/L, and dissolved potassium concentrations ranged from values less than detection limits of 0.7 to 1.4 mg/L (table 4).

Bicarbonate was the dominant anion, with concentrations ranging from 29 to 187 mg/L. Other major dissolved anions were analyzed infrequently. Their relative abundance in the Taku River, in order, was: sulfate, silica, chloride, and fluoride (table 4).

Nutrients and Organic Carbon

Nitrogen is an important water-quality constituent because it is an essential nutrient in streams, rivers, and lakes. In aquatic environments, nitrogen commonly occurs in three ionic forms: nitrite (NO_2), nitrate (NO_3), and ammonium (NH_4). Nitrite and nitrate are oxidized forms of inorganic nitrogen and typically represent most dissolved nitrogen in well-oxygenated rivers such as the Taku River. Nitrate is usually more abundant than nitrite in oxygenated water because nitrite oxidizes to nitrate (Hem, 1985). Ammonium is analyzed as ammonia (NH_3) in the laboratory; thus, nitrogen concentrations are reported as total and dissolved ammonia and total and dissolved nitrite plus nitrate. Total ammonia concentrations represent the ammonium compounds in solution and are associated with colloidal material. The dissolved concentration represents the ammonium or nitrite plus nitrate in solution and is associated with material that can pass through a 0.45-µm-pore filter.

Concentrations of the various nitrogen forms were less than 1 mg/L, except for a single analysis for total ammonia that was 1.21 mg/L (table 5). Due to its toxicity to aquatic organisms, the Alaska Department of Environmental Conservation (2003) requires pH and temperature-dependent limits for un-ionized ammonia for waters to be suitable for fish propagation. Concentrations of un-ionized ammonia were all below recommended levels in the Taku River samples.

Phosphorus is vital to all forms of aquatic biota because it is involved in the capture and transfer of chemical energy, and it is an essential element in nucleic acids (Gaudy and Gaudy, 1988). Elevated concentrations of phosphorus in water are not considered toxic to human or aquatic life; however, elevated phosphorus concentrations can stimulate the growth of algae in lakes and streams. Total phosphorus analysis of Taku River samples included the phosphorus in solution, associated with colloidal material, and contained in or attached to biotic and inorganic particulate matter. Concentrations of total phosphorus ranged from 0.01 to 1.08 mg/L (table 5).

Dissolved organic carbon (DOC) is a major component of organic matter in aquatic ecosystems. By definition, DOC is organic carbon in the filtrate (dissolved and colloidal phases) that has passed through a 0.45-µm-pore filter. Generally, DOC is in greater abundance than particulate organic carbon, accounting for about 90 percent of the total organic carbon of most waters (Aiken and Cotsaris, 1995). Concentrations of DOC on the Taku River ranged from less than detection levels of 0.50 to 2.1 mg/L (table 5). Concentration of total organic carbon (TOC) includes the organic carbon in solution (DOC) and carbon associated with particulate matter in suspension. In the Taku River samples concentrations of TOC ranged from less than detection levels of 0.50 to 3.6 mg/L (table 5).

Table 4. Dissolved and total major inorganic constituents measured in water samples collected from the Taku River near Juneau, Alaska November 1998 through September 2003.

[All values in milligrams per liter; E, estimated; <, less than;–, not determined; **bold**/shading indicates measurements taken during outburst floods]

Dates	Times	Calcium, dissolved	Calcium, total	Magnesium, dissolved	Magnesium, total	Sodium, dissolved	Sodium, total	Potassium, dissolved	Potassium, total
11-06-98	1430	E29.3	–	E6.00	–	E2.70	–	E0.98	–
03-31-99	1100	31.6	–	–	–	4.80	–	1.40	–
06-07-99	1300	21.8	–	3.92	–	1.50	–	<.70	–
06-28-99	1100	20.2	–	3.35	–	1.30	–	<.70	–
07-27-99	0930	17.1	–	2.72	–	1.10	–	<.70	–
08-19-99	**2050**	**12.4**	**–**	**1.63**	**–**	**.60**	**–**	**<.70**	**–**
	1120	**13.7**	**–**	**2.04**	**–**	**–**	**–**	**<.70**	**–**
08-20-99	**1750**	**14.2**	**–**	**–**	**–**	**<.70**	**–**	**<.86**	**–**
09-13-99	1130	–	–	–	–	–	–	–	–
10-11-99	1200	26.3	–	5.20	–	2.40	–	.09	–
04-05-00	930	34.2	–	7.60	–	4.20	–	.09	–
05-15-00	1500	27.5	–	6.00	–	2.10	–	.70	–
06-16-00	1100	E21.1	–	3.90	–	1.50	–	<.70	–
07-25-00	**1115**	**13.7**	**–**	**1.80**	**–**	**.80**	**–**	**.80**	**–**
	2015	**17.5**	**–**	**2.70**	**–**	**1.00**	**–**	**.90**	**–**
07-26-00	**1500**	**–**	**–**	**2.40**	**–**	**0.70**	**–**	**1.20**	**–**
07-27-00	**1500**	**17.5**	**–**	**2.70**	**–**	**1.00**	**–**	**.90**	**–**
08-29-00	1200	19.8	–	3.90	–	1.50	–	.90	–
10-11-00	1145	20.6	–	4.03	–	1.70	–	<.70	–
04-11-01	1500	36.4	–	8.69	–	5.00	–	1.00	–
06-07-01	1400	20.6	–	4.16	–	1.50	–	<.70	–
06-28-01	1343	–	–	–	–	–	–	–	–
07-06-01	1232	17.8	–	3.25	–	1.50	–	<.70	–
08-10-01	**1610**	**15.0**	**–**	**2.42**	**–**	**0.73**	**–**	**<0.70**	**–**
08-11-01	**1125**	**16.9**	**–**	**2.87**	**–**	**1.10**	**–**	**1.20**	**–**
09-20-01	1325	18.3	–	3.28	–	1.40	–	<.70	–
11-14-01	1240	32.3	–	7.78	–	3.50	–	1.00	–
03-29-02	1608	37.5	–	8.32	–	5.84	–	1.00	–
05-09-02	1025	32.1	–	6.88	–	3.45	–	1.00	–
06-12-02	1240	17.5	–	3.51	–	1.43	–	<.70	–
07-18-02	1600	15.5	–	3.20	–	1.30	–	<.70	–
08-16-02	**1957**	**11.6**	**–**	**1.55**	**–**	**0.64**	**–**	**1.00**	**–**
08-17-02	**1651**	**13.2**	**–**	**2.11**	**–**	**0.62**	**–**	**1.00**	**–**
08-18-02	**1432**	**16.6**	**–**	**2.78**	**–**	**1.09**	**–**	**1.00**	**–**
09-11-02	1600	19.6	–	4.21	–	1.56	–	<.70	–
12-05-02	1530	26.0	–	5.10	–	2.60	–	.90	–
04-09-03	1645	32.0	33.2	8.10	8.5	4.60	4.7	.92	0.9
05-20-03	1120	25.1	27.0	5.70	6.1	2.54	2.5	.79	0.8
06-18-03	1200	17.8	19.1	3.53	5.0	1.57	1.7	.73	1.1
07-11-03	0950	15.8	19.7	2.91	7.1	1.30	1.9	.73	1.7
08-10-03	**1115**	**9.8**	**17.3**	**1.44**	**9.4**	**.65**	**1.9**	**.78**	**3.1**
08-11-03	**1115**	**12.9**	**16.0**	**2.17**	**6.2**	**.84**	**1.5**	**.86**	**2.1**
09-29-03	0950	19.1	21.7	3.22	6.8	1.52	2.3	.85	2.2

Table 4. Dissolved and total major inorganic constituents measured in water samples collected from the Taku River near Juneau, Alaska November 1998 through September 2003.—Continued

[All values in milligrams per liter; E, estimated; <, less than;–, not determined; **bold**/shading indicates measurements taken during outburst floods]

Date	Time	Bicarbonate, dissolved	Sulfate, dissolved	Sulfate, total	Chloride, dissolved	Chloride, total	Fluoride, dissolved	Fluoride, total	Silica, dissolved
11-06-98	1430	98	–	–	–	1.6	–	0.1	E5.90
03-31-99	1100	105	–	21.5	–	5.2	–	.1	E5.80
06-07-99	1300	77	11.0	11.0	0.4	.5	–	.07	–
06-28-99	1100	65	–	10.9	–	.4	–	<.1	–
07-27-99	0930	52	–	9.0	–	.4	–	<.1	–
08-19-99	**2050**	**34**	**–**	**8.8**	**–**	**.2**	**–**	**<.1**	**–**
08-20-99	**1120**	**38**	**–**	**10**	**–**	**–**	**–**	**<.1**	**–**
	1750	**50**	**–**	**9.4**	**–**	**.2**	**–**	**<.1**	**–**
09-13-99	1130	63	–	–	–	–	–	–	–
10-11-99	1200	53	–	15.4	–	1.4	–	.1	<5.90
04-05-00	930	113	–	18.0	–	3.7	–	.06	–
05-15-00	1500	46	–	12.0	–	.62	–	.07	–
06-16-00	1100	68	–	10.3	–	.47	–	.20	–
07-25-00	**1115**	**38**	**–**	**9.7**	**–**	**.59**	**–**	**.06**	**–**
	2015	**40**	**–**	**11.9**	**–**	**.21**	**–**	**.04**	**–**
07-26-00	**1500**	**42**	**–**	**12.4**	**–**	**.43**	**–**	**.04**	**–**
07-27-00	**1500**	**52**	**–**	**10.4**	**–**	**.39**	**–**	**.05**	**–**
08-29-00	1200	65	–	10.4	–	.57	–	.05	–
10-11-00	1145	68	–	11.8	–	.73	–	.06	–
04-11-01	1500	124	–	20.1	–	4.5	–	.07	–
06-07-01	1400	71	–	10.3	–	.78	–	.05	–
06-28-01	1343	55	–	–	–	–	–	–	–
07-06-01	1232	55	–	10.4	–	.36	–	.06	–
08-10-01	**1610**	**40**	**–**	**11.9**	**–**	**.17**	**–**	**.04**	**–**
08-11-01	**1125**	**55**	**–**	**9.8**	**–**	**.36**	**–**	**–**	**–**
09-20-01	1325	60	–	10.2	–	.62	–	.06	–
11-14-01	1240	122	–	18.5	–	2.1	–	.06	–
03-29-02	1608	109	–	20.9	–	5.4	–	.1	–
05-09-02	1025	103	–	17.7	–	1.9	–	.1	–
06-12-02	1240	59	–	17.7	–	.50	–	.05	–
07-18-02	1600	–	–	–	–	.30	–	.05	–
08-16-02	**1957**	**34**	**–**	**8.1**	**–**	**–**	**–**	**–**	**–**
08-17-02	**1651**	**36**	**–**	**10.3**	**–**	**.80**	**–**	**.04**	**–**
08-18-02	**1432**	**51**	**–**	**10.3**	**–**	**.50**	**–**	**.05**	**–**
09-11-02	1600	65	–	12.2	–	.50	–	.03	–
12-05-02	1530	71	–	16.8	–	1.71	–	.09	–
04-09-03	1645	187	19.5	19.8	4.0	4.20	<.10	<.1	–
05-20-03	1120	88	14.4	14.4	.7	.70	.10	.1	–
06-18-03	1200	64	–	11.2	–	.30	–	.1	–
07-11-03	0950	56	8.0	8.1	.2	.20	<.10	<.1	–
08-10-03	**1115**	**29**	**8.4**	**8.3**	**.4**	**.20**	**.05**	**.05**	**–**
08-11-03	**1115**	**41**	**9.6**	**9.6**	**.3**	**.30**	**.05**	**.05**	**–**
09-29-03	0950	59	–	10.3	–	.40	–	.1	–

Table 5. Nutrient and organic carbon concentrations measured in water samples collected from the Taku River (station 15041200).

[All values in milligrams per liter; NO_2+NO_3, nitrite plus nitrate; E, estimated; <, less than; –, not determined; **bold**/shading indicates samples collected during outburst floods]

Dates	Times	Nitrogen, ammonia, dissolved (as N)	Nitrogen, ammonia, total (as N)	Nitrogen, $NO_2 + NO_3$, dissolved (as N)	Nitrogen, NO_2 plus NO_3, total (as N)	Phosphorus, total (as P)	Dissolved organic carbon (as C)	Total organic carbon (as C)
11-06-98	1430	–	<0.04	–	–	–	–	0.9
03-31-99	1100	–	<.01	–	–	0.03	<0.5	<.5
06-07-99	1300	–	.01	–	–	.26	2.7	3.6
06-28-99	1100	–	<.02	–	–	.22	–	1.8
07-27-99	0930	–	<.25	–	–	.21	–	E1.0
08-19-99	**2050**	**–**	**<.20**	**–**	**–**	**1.08**	**<.5**	**E.9**
08-20-99	**1120**	**–**	**<.30**	**–**	**–**	**.70**	**<.5**	**E.6**
	1750	**–**	**<.35**	**–**	**–**	**.79**	**E.9**	**E.8**
10-11-99	1200	–	1.21	–	–	.03	–	.9
04-05-00	0930	–	<.20	–	.19	.03	–	1.2
05-15-00	1500	–	.03	–	.32	–	–	–
06-16-00	1100	–	.17	–	.06	.33	2.0	2.9
07-25-00	**1115**	**–**	**.04**	**–**	**.02**	**.61**	**<1.0**	**<1.0**
	2015	**–**	**.09**	**–**	**<.200**	**.76**	**<1.0**	**<1.0**
07-26-00	**1500**	**–**	**.04**	**–**	**<.200**	**.53**	**<1.0**	**<1.0**
07-27-00	**1500**	**–**	**.03**	**–**	**<.020**	**.23**	**<1.0**	**<1.0**
08-29-00	1200	–	.01	–	.08	.06	1.1	.9
10-11-00	1145	–	.03	–	.08	.05	1.2	1.5
04-11-01	1500	–	<.02	–	.15	.01	.9	1.4
06-07-01	1400	–	E.03	–	.03	.18	–	–
07-06-01	1232	–	E.01	–	<.020	.18	1.1	1.1
08-10-01	**1610**	**–**	**.09**	**–**	**<.020**	**.67**	**<.50**	**<.5**
08-11-01	**1125**	**–**	**.03**	**–**	**<.020**	**.26**	**<.50**	**<.5**
09-20-01	1325	–	<.02	–	<.020	.10	.53	.6
11-14-01	1240	–	.05	–	.07	.01	.9	.9
03-29-02	1608	–	.05	–	.19	.01	.5	<.7
05-09-02	1025	–	.04	–	.41	.02	2.1	1.9
06-12-02	1240	–	.06	–	.02	.07	1.2	1.2
07-18-02	1600	–	.07	–	.02	.19	1.0	1.2
08-16-02	**1957**	**–**	**–**	**–**	**–**	**–**	**.5**	**<.5**
08-17-02	**1651**	**–**	**.04**	**–**	**.04**	**.69**	**<.5**	**<.5**
08-18-02	**1432**	**–**	**.04**	**–**	**.05**	**.36**	**.5**	**.5**
09-11-02	1600	–	<.02	–	.02	.05	1.1	1.3
12-05-02	1530	–	.06	–	.27	.02	1.8	1.9
04-09-03	1645	<0.04	<.04	.15	.16	.02	.7	.8
05-20-03	1120	–	.07	–	.18	.03	2.0	2.2
06-18-03	1200	–	.03	–	.05	.10	–	<.5
07-11-03	0950	–	<.05	.03	.03	.44	.9	1.4
08-10-03	**1115**	**–**	**<.05**	**.02**	**.03**	**.72**	**.6**	**.9**
08-11-03	**1115**	**–**	**<.05**	**.03**	**.03**	**.43**	**.7**	**.7**
09-29-03	0950	–	<.10	–	.09	.32	<1.0	<1.0

Dissolved- and Total-Trace Elements

In this study, the term trace element refers to dissolved substances in natural water that nearly always occur in concentrations less than 1.0 mg/L (Hem, 1985). Although some trace elements such as zinc and selenium are essential in plant and animal metabolism, in aquatic systems elevated concentrations of these and other trace elements can be toxic to fish and other aquatic life (Hem, 1985; Smith and Huyck, 1999). Anthropogenic alterations of natural cycles of trace elements in the environment can lead to accumulation of potentially toxic metals in the food chain (Smith and Huyck, 1999). For instance, under natural conditions, chemical weathering of rocks and minerals typically proceeds at a slow rate. These same processes can be accelerated in chemically and physically altered mine tailings, elevating trace-element concentrations in receiving water bodies.

In the Taku River samples, concentrations of trace elements in the dissolved phase were low (tables 2 and 6). The ADEC aquatic-life criteria for fresh waters are for the dissolved form of most trace elements, except aluminum and iron. None of the dissolved-trace-element concentrations exceeded ADEC criteria.

Total-trace-element concentrations in the Taku River generally increase with increasing discharge (table 6 and fig. 12) because they are often associated with suspended-sediment particulates (Smith and Huyck, 1999). In glacial streams like the Taku River, the suspended-sediment load is usually strongly correlated with discharge. Although no suspended-sediment samples were collected for this study, studies of other glacial rivers in Alaska have shown that up to 95 percent of all suspended-sediment transport is during a 5-month period from May through September (Burrows and others, 1981; Brabets and others, 2000). This is similar to the seasonal distribution of runoff for the Taku River (fig. 6). The highest concentrations of total-trace elements were measured during outburst floods. During lower flows, concentrations of total-trace elements decreased as the energy available to transport suspended sediment and associated trace elements was reduced.

Figure 12 shows total-trace-element concentrations generally increased with increasing discharge. However, a high correlation did not exist across the range of discharges sampled or with all the trace elements analyzed. When a high correlation did exist, some of the scatter at the higher discharges can be explained as a sediment-depletion effect. Fine-grained sediments stored on the bed or banks of river channels during periods of low discharge become mobilized over the rising limb of the hydrograph. This source of sediment often becomes depleted before the river reaches its maximum discharge (Meade and others, 1990). For example, samples collected during outburst floods in August 1999 and July 2000 indicate the more common earth elements such as iron and aluminum reached maximum concentrations before peak discharges (table 6).

Although concentrations of total iron and aluminum appear to exceed ADEC aquatic-life criteria (table 2), the criteria were not designed to accommodate the high levels of particulate loading common in glacial streams. To allow for naturally high concentrations of total trace elements in rivers like the Taku River, ADEC also has site-specific criteria. In these instances, if the natural condition of a water body exceeds a water-quality criterion, the natural condition constitutes the applicable water-quality criterion (Alaska Department of Environmental Conservation, 2006).

Table 6. Dissolved- and trace-element concentrations measured in 40 water samples collected from the Taku River near Juneau, Alaska, November 1998 through September 2003.

[All values in micrograms per liter except hardness and discharge; ft^3/s, cubic feet per second; E, estimated; <, less than; --, no data; data shown in **bold**/shading indicate samples collected during outburst floods]

Date	Time	Discharge (ft^3/s)	Aluminum, dissolved	Aluminum, total	Arsenic, dissolved	Arsenic, total	Barium, dissolved	Barium, total	Cadmium, dissolved	Cadmium, total	Chromium, dissolved	Chromium, total	Copper, dissolved	Copper, total	Iron, dissolved	Iron, total
11-06-98	1430	6,230	E20	E290	E0.4	E0.8	E37.3	E41.8	<0.04	<0.04	<5	<5	E0.8	E10.7	E20	E540
03-31-99	1100	1,890	<20	380	.4	1	42.7	49.3	E.05	E.11	<5	<5	E1.5	E2.2	<10	730
06-07-99	1300	22,000	<20	3,000	.4	4	27.0	72.3	<.04	.17	<5	12	1.3	10.4	20	5,470
06-28-99	1100	30,900	25	4,030	.6	3	25.8	90.8	<.04	.18	<1	9	1.0	10.7	<10	6,140
07-27-99	0930	21,700	31	3,230	.6	2	23.7	79.2	.06	.15	<1	7	<.5	8.0	<10	4,780
08-19-99	**2050**	**62,100**	**45**	**12,100**	**.4**	**9**	**18.8**	**232**	**<.04**	**.47**	**<1**	**22**	**<.5**	**33.1**	**<10**	**18,000**
08-20-99	**1120**	**63,900**	**36**	**10,600**	**.4**	**9**	**21.5**	**218**	**<.04**	**.46**	**<1**	**21**	**<.5**	**32.1**	**<10**	**16,700**
08-20-99	**1750**	**59,100**	**28**	**8,700**	**.4**	**8**	**24.5**	**189**	**<.04**	**.32**	**<1**	**17**	**<.5**	**24**	**<10**	**13,900**
10-11-99	1200	6,220	23	622	E.5	1	34.3	44.6	.04	.09	<1	1	–	–	20	950
04-05-00	0930	2,570	24	340	.4	.9	41.3	45.6	<.1	.20	<1	2	<1	3.0	20	909
05-15-00	1500	14,600	35	1,000	.5	1	30.4	47.2	.1	.17	<1	3	2.0	5.5	30	1,920
06-16-00	1100	39,200	40	3,600	.6	3	25.7	85.9	<.1	.32	<1	8	1.0	12.6	10	6,290
07-25-00	**1115**	**71,500**	**51**	**8,640**	**.5**	**7**	**20.3**	**197**	**<.1**	**.40**	**1**	**14**	**<1**	**14**	**<10**	**13,400**
	2015	**81,400**	**39**	**8,390**	**.5**	**8**	**26.1**	**210**	**<.1**	**.13**	**1**	**14**	**<1**	**13.9**	**10**	**13,300**
07-26-00	**1500**	**106,000**	**37**	**7,250**	**.4**	**6**	**26.3**	**179**	**<.1**	**.36**	**<1**	**13**	**<1**	**26.2**	**10**	**12,000**
07-27-00	**1500**	**41,800**	**39**	**3,260**	**.5**	**3**	**26.1**	**86.5**	**<.1**	**.30**	**<1**	**6**	**<1**	**8.0**	**10**	**5,330**
08-29-00	1200	16,000	32	971	.5	1	27.1	44.6	<.1	.10	<1	2	<1	4.1	10	1,510
10-11-00	1145	13,900	25	1,020	.6	1	27.7	43.7	<.10	.15	<1	2	<1	3.7	20	1,420
04-11-01	1500	2,130	<20	169	.4	.7	43.7	45.4	<.10	<.10	<1	1	<1	1.6	20	570
06-07-01	1400	33,900	38	2,670	.5	2	24.5	69.7	<.10	.11	1.1	8	1.4	8.8	20	4,290
07-06-01	1232	31,100	34	2,530	.6	2	23.1	64.6	<.10	<.10	<1	5	<1	7.0	<10	3,770
08-10-01	**1610**	**73,900**	**34**	**7,630**	**.5**	**7**	**23.6**	**174**	**<.10**	**.31**	**1.2**	**16**	**<1**	**25.9**	**<10**	**11,800**
08-11-01	**1125**	**28,800**	**E29**	**E3,120**	**.5**	**3**	**25.3**	**87.9**	**<.10**	**.13**	**1.4**	**7**	**<1**	**10.3**	**<10**	**4,850**
09-20-01	1325	16,300	28	E1,880	.6	2	25.2	57.1	<.10	<.10	2.1	4	<1	4.4	<10	2,630
11-14-01	1240	3,390	27	144	.5	.6	38.5	41.0	<.10	<.10	–	<1	<1	1.1	30	310
03-29-02	1608	1,480	<20	73	.4	.7	44.8	47.0	<.10	<.10	<1	<1	<1	<1	<10	480
05-09-02	1025	4,380	<20	139	.6	1	40.5	45.0	<.10	<.10	<1	<1	1.3	1.7	70	420
06-12-02	1240	29,200	47	1,730	1.2	2	28.9	56.0	<.10	<.10	<1	<1	<1	4.4	<10	2,190
07-18-02	1600	29,100	63	2,890	1.2	3	27.6	74.0	<.10	<.12	1	5	<1	7.9	<10	3,960
08-17-02	**1651**	**68,900**	**43**	**12,800**	**.4**	**9**	**25.9**	**280**	**<.10**	**.39**	**<1**	**22**	**<1**	**35.0**	**<10**	**18,000**
08-18-02	**1432**	**25,700**	**45**	**5,950**	**.5**	**5**	**29.0**	**139**	**<.10**	**.18**	**<1**	**12**	**<1**	**17.5**	**<10**	**8,880**
09-11-02	1600	14,300	43	1,280	.6	1.3	30.0	51.0	.12	.17	<1	2	<1	3.7	<10	1,720
12-05-02	1530	4,540	40	773	.6	1	36.4	49.4	<.10	<.10	–	1	<1	2.3	20	970
04-09-03	1645	1,950	30	269	.4	1	44.0	51.2	<.10	<.10	<1	1	<1	1.8	<50	745
05-20-03	1120	10,900	43	546	1.2	1.4	33.0	39.9	<.10	<.10	<1	1	<1	2.1	20	740
06-18-03	1200	26,500	38	2,120	1.2	1.9	29.0	62.2	<.10	<.10	<1	4	<1	6.1	<10	3,140
07-11-03	0950	36,600	45	5,750	.73	4.7	24.5	122	<.10	.17	<1	12	<1	15.1	<10	8,720
08-10-03	**1115**	**65,200**	**48**	**12,000**	**1.1**	**9.7**	**21.1**	**267**	**<.10**	**.45**	**<1**	**22**	**<1**	**35.8**	**<10**	**17,500**
08-11-03	**1115**	**43,200**	**50**	**6,300**	**.5**	**6**	**24.7**	**157**	**<.10**	**.23**	**<1**	**11**	**<1**	**19.2**	**<10**	**9,610**
09-29-03	0950	25,400	51	6,150	1.2	5	28.8	130	<.10	.19	<1	9	<1	12.4	<10	8,370

Table 6. Dissolved- and trace-element concentrations measured in 40 water samples collected from the Taku River near Juneau, Alaska, November 1998 through September 2003.—Continued

[All values in micrograms per liter except hardness and discharge; ft³/s, cubic feet per second; E, estimated; <, less than; --, no data; data shown in red font indicate samples collected during outburst floods]

Date	Time	Discharge, (ft^3/s)	Lead, dissolved	Lead, total	Manganese, dissolved	Manganese, total	Nickel, dissolved	Nickel, total	Selenium, dissolved	Selenium, total	Silver, dissolved	Silver, total	Zinc, dissolved	Zinc, total	Hardness (mg/L as $CaCo_3$)
11-06-98	1430	6,230	<0.1	E0.4	E14	E26	E1.04	E2	<1	<1	<0.03	<0.03	<4	E10	98
03-31-99	1100	1,890	<.1	.6	25	40	1.08	2	<1		.04	<.03	5	7	–
06-07-99	1300	22,000	<.1	3	8.4	170	1.53	21	–	–	<.03	<.63	<4	22	36
06-28-99	1100	30,900	<.1	4	6.6	168	1.02	12	–	–	<.03	.05	<4	23	35
07-27-99	0930	21,700	<.1	3	6.0	132	.52	9	–	–	<.03	.04	<4	20	54
08-19-99	**2050**	**62,100**	**<.1**	**12**	**6.8**	**485**	**.43**	**27**	**–**	**–**	**<.03**	**.15**	**<4**	**72**	**38**
08-20-99	**1120**	**63,900**	**<.1**	**11**	**8.1**	**444**	**.48**	**27**	**–**	**–**	**<.03**	**.15**	**<4**	**71**	**42**
08-20-99	**1750**	**59,100**	**<.1**	**8**	**13**	**344**	**.57**	**20**	**–**	**–**	**<.03**	**.11**	**4**	**52**	**54**
10-11-99	1200	6,220	<.1	E.8	15	35	1.0	3	–	–	<.03	<.3	5	11	87
04-05-00	0930	2,570	<.1	E.9	41	55	1.2	3	<1.0	<1	<.1	–	8	–	120
05-15-00	1500	14,600	<.1	2	6.2	72	1.6	8	<1.0	1	<.1	–	4	12	93
06-16-00	1100	39,200	<.1	5	7.4	195	1.1	15	<1.0	<1	<.1	<.1	<4	23	69
07-25-00	**1115**	**71,500**	**<.1**	**12**	**9.4**	**415**	**.54**	**21**	**<1.0**	**<1**	**<1**	**.13**	**<4**	**62**	**49**
	2015	**81,400**	**<.1**	**12**	**7.7**	**420**	**.67**	**21**	**<1.0**	**<1**	**.1**	**.14**	**<4**	**61**	**47**
07-26-00	**1500**	**106,000**	**<.1**	**9**	**12**	**361**	**.72**	**21**	**<1.0**	**<1**	**<.100**	**.11**	**<4**	**51**	**49**
07-27-00	**1500**	**41,800**	**<.1**	**4**	**7.7**	**164**	**.67**	**9**	**<1.0**	**<1**	**<.100**	**<.100**	**<4**	**21**	**55**
08-29-00	1200	16,000	.11	1	9.2	54	.85	3	<1.0	<1	<.100	<.1	<4	7	65
10-11-00	1145	13,900	<.1	2	8.8	46	.83	4	<1.0	<1	<.1	<.1	<4	8	68
04-11-01	1500	2,130	<.1	0.3	42	50	1.29	2	<1.0	<1	<.1	<.1	6	8	130
06-07-01	1400	33,900	<.1	2	6.5	129	1.72	14	<1.0	<1	<.1	<.1	<4	17	69
07-06-01	1232	31,100	<.1	3	5.2	111	.84	8	<1.0	<1	<.1	<.1	4	22	58
08-10-01	**1610**	**73,900**	**<.1**	**8**	**8.3**	**348**	**.79**	**23**	**<1.0**	**<1**	**<.1**	**.11**	**5**	**52**	**47**
08-11-01	**1125**	**28,800**	**<.1**	**E3**	**6.9**	**148**	**.82**	**10**	**<1.0**	**<1**	**<.1**	**<.1**	**<4**	**19**	**54**
09-20-01	1325	16,300	<.1	E2	6.0	74	.87	4	<1.0	<1	<.1	<.1	<4	14	59
11-14-01	1240	3,390	<.1	.2	20	24	1.64	2	<1	<1	<.1	<.1	<4	<4	110
03-29-02	1608	1,480	<.1	.2	42	49	.56	1	–	–	<.1	<.1	<4	<4	130
05-09-02	1025	4,380	<.1	.2	20	29	E2	E2	–	–	<.1	<.1		<4	110
06-12-02	1240	29,200	<.1	1	5.5	63	.56	5	–	–	<.1	<.1	<4	9	58
17-18-02	1600	29,100	<.1	2.6	5.4	122	.5	8	–	–	<.1	<.1	<4	17	52
08-17-02	**1651**	**68,900**	**<.1**	**12**	**9.0**	**495**	**.46**	**28**	**–**	**–**	**<.1**	**.15**	**<4**	**80**	**42**
08-18-02	**1432**	**25,700**	**<.1**	**6**	**7.3**	**259**	**.42**	**17**	**–**	**–**	**<.1**	**<.1**	**<4**	**35**	**53**
09-11-02	1600	14,300	<.1	1.5	8.0	54	.55	4	–	–	<.1	<.1	<4	8	66
12-05-02	1530	4,540	<.1	.7	20	40	.77	3	–	–	<.1	<.1	<4	5	86
04-09-03	1645	1,950	<.1	.5	40	52	.62	2	–	–	<.1	<.1	<4	4	110
05-20-03	1120	10,900	<.1	.5	5.3	–	.86	3	–	–	<.1	<.1	<4	<4	86
06-18-03	1200	26,500	<.1	2	4.4	88	.48	7	–	–	<.1	.10	<4	11	59
07-11-03	0950	36,600	0.29	6	5.3	259	.41	15	–	–	<.1	.17	<4	26	51
08-10-03	**1115**	**65,200**	**<.1**	**12**	**6.7**	**502**	**.31**	**32**	**–**	**–**	**<.1**	**.25**	**<4**	**69**	**31**
08-11-03	**1115**	**43,200**	**<.1**	**6**	**9.1**	**257**	**.44**	**15**	**–**	**–**	**<.1**	**.16**	**<4**	**40**	**41**
09-29-03	0950	25,400	<.1	7	6.5	245	.5	12	–	–	<.1	.10	<4	32	61

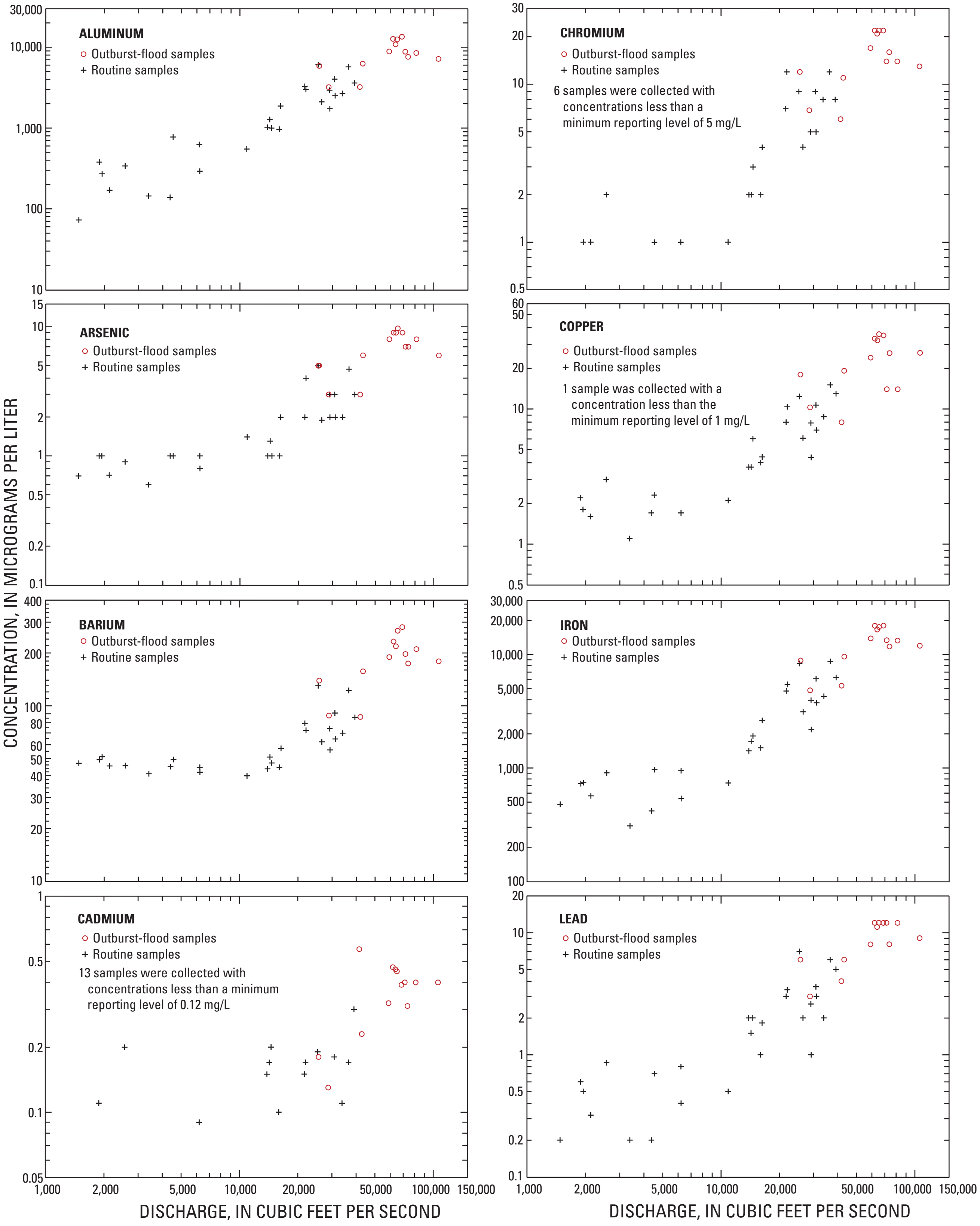


Figure 12. Water discharge and total-trace-element concentrations for the Taku River near Juneau, Alaska, November 1998 through September 2003.

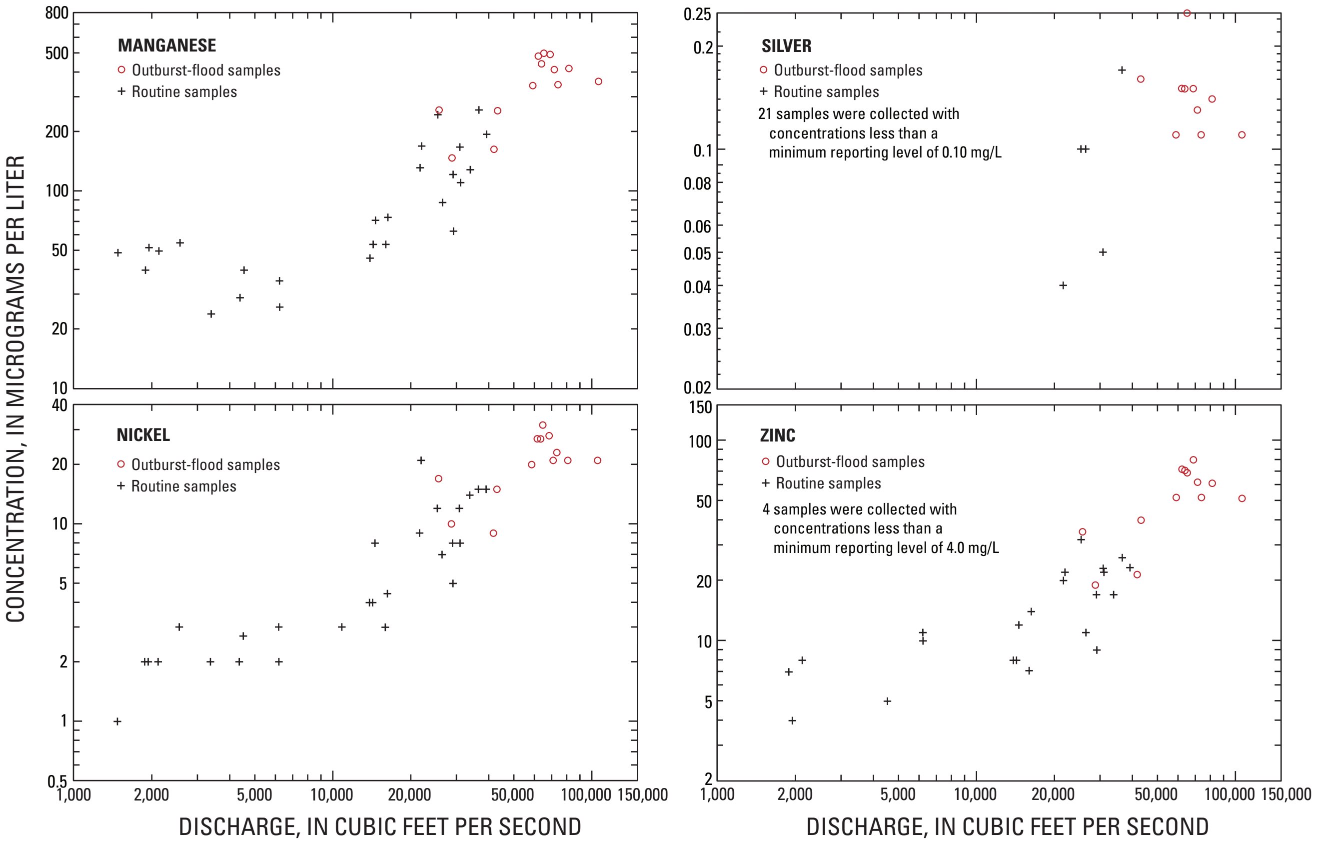


Figure 12.—Continued.

Summary and Conclusions

The possibility of reestablishing mining operations on one of its major tributaries prompted the water-quality (1998–2003) and flood-hydrology (1987–2004) study of the Taku River. The USGS study was part of a cooperative effort with the DIA, the ADEC, and the USEPA. The purpose of the study was to determine baseline levels for selected water-quality constituents and to provide an overview of the flood hydrology related to two self-draining, glacier-dammed lakes.

The average annual discharge of the Taku River is 13,700 ft^3/s and ranges from an average monthly discharge of 1,940 ft^3/s in February to 34,400 ft^3/s in June. Nearly 90 percent of the annual discharge occurs over the 6-month period from May through November. The greater flows during this period are sourced mainly from snowmelt in the spring and sustained throughout the summer by glacial meltwaters.

The greatest peak discharges on the Taku River since 1987, have originated from glacial-outburst floods from two self-draining, glacier-dammed lakes along the margin of the Tulsequah Glacier in British Columbia, Canada. The relatively consistent volume discharged from Lake No Lake, the larger of the two lakes, suggests the timing of these glacier-outburst floods might be predicted if lake-stage data were available. Additional analyses of flood volume and timing data suggests that Tulsequah Lake is continuing to decline in volume resulting in smaller outburst floods from this source. The largest flood during the period of record was on June 25, 2004, the result of an outburst from Lake No Lake, and had a peak discharge of 128,000 ft^3/s. The outburst-flood contribution of peak discharge was 80,000 ft^3/s.

Physical and chemical parameters and concentrations of basic water-quality constituents indicate good water quality. Samples collected at the Taku River gaging station contained low concentrations of trace elements in the dissolved phase. Trace elements sampled were compared with the ADEC aquatic-life criteria for fresh waters and found to be within acceptable limits. Total-trace-element concentrations generally increase with increasing water discharge, although a high correlation does not always exist. Concentrations of total trace elements were highest during glacial-outburst floods and are likely associated with suspended sediments.

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References Cited

Aiken, G.R., and Cotsaris, E., 1995, Soil and hydrology—Their effect on NOM: American Water Works Association, January, p. 26–45.

Alaska Department of Environmental Conservation, 2003, Alaska water quality criteria manual for toxic and other deleterious organic and inorganic substances, accessed April 2, 2005, at http://www.dec.state.ak.us/water/wqsar/wqs/pdfs/70wqsmanual.pdf.

Alaska Department of Environmental Conservation, 2006, Water Quality Standards, 18 AAC 70, accessed July 30, 2006, at http://www.dec.state.ak.us/water/wqsar/wqs/pdfs/18_AAC_70_revised_March2306.pdf.

Brabets, T.P., Wang, Browen, and Meade, Robert H., 2000, Environmental and hydrologic overview of the Yukon River Basin, Alaska and Canada: U.S. Geological Survey Water-Resources Investigations Report 99–4204, 106 p.

Burrows, R.L., Emmett, W.W., and Parks, Bruce, 1981, Sediment transport in the Tanana River near Fairbanks, Alaska, 1977–79: U.S. Geological Survey Water-Resources Investigations 81–20, 62 p.

Cenderelli, D.A., and Wohl, E.E., 2003, Flow hydraulics and geomorphic effects of Glacial-lake outburst floods in the Mount Everest region, Nepal: Earth Surface Processes and Landforms, v. 28, p. 385–407.

Clague, J.J., and Evans, S.G., 1994, Formation and failure of natural dams in the Canadian Cordillera: Geological Survey of Canada Bulletin 464, 35 p.

Desloges, J.R., and Church, M., 1992, Geomorphic implications of glacier outburst flooding: Noeick River valley, British Columbia: Canadian Journal of Earth Science, v. 29, p. 551–564.

Edwards, T.K., and Glysson, G.D., 1988, Field methods for measurement of fluvial sediment: U.S. Geological Survey Open-File Report 86–531, 118 p.

Gaudy, A.F., and Gaudy, E.T., 1988, Elements of bioenvironmental engineering: San Jose, Engineering Press, Inc. 592 p.

Geertsema, M., and Clague, J.J., 2005, Jökulhlaups at Tulsequah Glacier, northwestern British Columbia, Canada: The Holocene, v. 15, no. 2, p. 310–316.

Government of British Columbia Ministry of Energy, Mines and Petroleum Resources, undated, Minfile no. 104K 002: accessed June 2006, at URL http://www. empr.gov.bc.ca/Mining/GeolSurv/Minfile/App/Summary.aspx?minfilno=104K++002.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Host, R.H., and Dorava, J.M., 1999, Measurements of Taku River, Alaska during Tulsequah Lake outburst floods: U.S. Geological Survey Fact Sheet 131–99, 2 p.

Jones, E.L. III, McPherson, S.A., Bernard, D.R., and Boyce, I.M., 2006, Production of coho salmon from the Taku River, 1999–2003. Alaska Department of Fish and Game, Fishery Data Series No. 06–02, Anchorage.

Kerr, F.A., 1934, The ice dam and floods of the Talsekwe, British Columbia: Geographical Review, v. 24, p. 643–645.

Klingbjer, P., 2004, Recurring Jokulhlaups in Salka, Northern Sweden: Geografiska annaler, Series A, Physical geography, v. 86, issue 2, p. 169–179.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964, Fluvial Processes in geomorphology: San Francisco, W.H. Freeman and Company, 522 p.

Lough, J., and Sharpe, I., 2003, Tulsequah and Taku Rivers Mass Balance Water Quality Report: BC Ministry of Water Land and Air Protection Skeena Region Environmental Quality Section Data Report #2003–1.

Marcus, M.G., 1960, Periodic drainage of glacier-dammed Tulsequah Lake, British Columbia: Geographical Review 50, 89–106.

Mathews, W.H., 1965, Two self-dumping ice-dammed lakes in British Columbia: Geographical Review 55, p. 46–52.

Mathews, W.H., and Clague, J.J., 1993, The record of jokulhlaups from Summit Lake, northwestern British Columbia: Canadian Journal of Earth Science 30, p. 499–508.

McPherson, S.A., Bernard, D.R., and Clark, J.H., 2000, Optimal production of Chinook salmon from the Taku River: Alaska Department of Fish and Game, Fishery Manuscript No. 00–2, Anchorage.

Meade, R.H., Yuzyk, T.R., and Day, T.J., 1990, Movement and storage of sediment in rivers of the United States and Canada, in Wolmon, M.G., and Riggs, H.C., eds., Surface water hydrology: Geological Society of America, The geology of North America, v. O–1, p. 255–280.

National Oceanic and Atmospheric Administration, 1987–2004, Climatological data for Alaska: U.S. Department of Commerce, issued annually.

Nye, J.F., 1976, Water flow in glaciers: jökulhlaups, tunnels and veins: Journal of Glaciology, v. 15, no. 76, p. 181–207.

Office of the Auditor General of Canada, 2005, Environment Canada response to environmental petition no. 95B: accessed June 2006 at URL http://www.oag-bvg.gc.ca/domino/petitions.nsf/viewe1.0/7408CD2DB4DD1AC885257184005980B9.

Pacific Salmon Commission, 2006, Estimates of transboundary river salmon production, harvest, and escapement and a review of joint enhancement activities in 2003: Transboundary Technical Committee Report (05–1).

Post, Austin, and Mayo, L.R., 1971, Glacier Dammed Lakes and Outburst Floods in Alaska: U.S. Geological Survey Hydrologic Investigations Atlas HA–455, 10 p. and 1:1,000,000 scale map.

Rantz, S.E., and others, 1982a, Measurement and computation of streamflow: Volume 1, Measurement of discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Rantz, S.E., and others, 1982b, Measurement and computation of streamflow: Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Redfern Resources Ltd., 2006, accessed April 25, 2006, at http://www.redfern.bc.ca/projects/tulsequah/project_history.html.

Sebert, C., and Barrett, T.J., 1996, Stratigraphy, alteration, and mineralization at the Tulsequah Chief Massive Sulfide Deposit, Northwestern British Columbia: Exploring and mining geology, v. 5, no. 4, p. 282–308.

Septer, D., and Schwab, J.W., 1995, Rainstorm and flood damage: northwest British Columbia 1891–1991: BC Ministry of Forests Land Management Report 31, 196 p.

Simpson, Michael, 2001, Discharge Measurements Using a Broad-Band Acoustic Doppler Current Profiler: U.S. Geological Survey Open-File Report 01–01, 123 p.

Smith, K.S., and Huyck, L.O., 1999, An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals: Reviews in Economic Geology, 6a, p. 29–70.

U.S. Environmental Protection Agency, 1983, Methods of Chemical Analysis of Water and Wastes, NERL–Cincinnati, Cincinnati, Ohio (EPA–600/4–79–020).

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986 (Gold Book), Office of Water Regulation and Standards: EPA 440/5–86–001, [variously paged].

U.S. Environmental Protection Agency, 1993, Methods for the determination of inorganic substances in environmental samples, NERL–Cincinnati, Cincinnati, Ohio (EPA–600/R–93–100).

U.S. Environmental Protection Agency, 1994, Methods for the Determination of Metals in Environmental Samples, (EPA–600/R–94–111) Supplement I. [to EPA/600–4–91–010] May 1994: (NTIS/PB95–125472). Environmental Monitoring Systems Lab Office of Research and Development. EPA Cincinnati, Ohio 45268.

U.S. Environmental Protection Agency, 1999, National recommended water quality criteria—Correction: EPA 822–Z–99–001, 25 p.

U.S. Geological Survey, 1988–2005, Water resources data for Alaska water years 1987–04: U.S. Geological Survey Water-Data Reports AK–87–1 to AK–04–1 (published annually).

Watson, Samy, November 30, 2005, Response to petition number 95B, accessed July 12, 2006, at http://www. oag-bvg.gc.ca/domino/petitions.nsf/viewe1.0/7408CD2DB4DD1AC885257184005980B9.

Wilde, F.D., ed., April 2004, Cleaning of equipment for water sampling (version 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chap. A3, accessed April 25, 2006, at http://pubs.water.usgs.gov/twri9A3/.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., April 2004, Processing of water samples (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chap. A5, accessed April 25, 2006, at http://pubs.water.usgs.gov/twri9A5/.

Wolman, M.G., and Miller, J.P., 1960, Magnitude and frequency of forces in geomorphic processes: Journal of Geology, v. 68, p. 58–74.

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Bill Gibbs
Bob Crist
Debra Grillo
Christine Severtson
Sharon L. Wahlstrom

For more information concerning the research in this report, contact the
Alaska Science Center
U.S. Geological Survey
4230 University Drive, Suite 201
Anchorage, Alaska 99508-4664
http://alaska.usgs.gov

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Hydrology and Glacier-Lake Outburst Floods (1987–2004) and Water Quality (1998–2003) of the Taku River near Juneau, Alaska

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