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Water Quality of the Tlikakila River and Five Major Tributaries to Lake Clark, Lake Clark National Park and Preserve, Alaska, 1999–2001

By TIMOTHY P. BRABETS

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CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY INFORMATION

Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons (Mgal)	3,785	cubic meter
ton	0.9072	megagram
acre-feet	1,233	cubic meter

In this report, temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\ (°C) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C.

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.

Water Quality of the Tlikakila River and Five Major Tributaries to Lake Clark, Lake Clark National Park and Preserve, Alaska, 1999-2001

By Timothy P. Brabets

ABSTRACT

The Tlikakila River Basin, located in Lake Clark National Park and Preserve, drains an area of 622 square miles. This watershed comprises about 21 percent of the Lake Clark Basin, making it one of the major tributaries to Lake Clark. Due to a sharp decline in sockeye salmon population and the lack of hydrologic data, the Tlikakila River and five other major tributaries to Lake Clark were studied during the summer runoff months (May through September) from 1999 through 2001 as part of a cooperative study with the National Park Service.

Measurements of pH and dissolved oxygen concentrations of the Tlikakila River are within acceptable limits for fish survival. Water temperatures at the measurement site reach 0 ^{o}C during the winter and this part of the Tlikakila River may not be suitable for fish. Water temperatures are within acceptable limits for fish during the summer months. The Tlikakila River is a calcium bicarbonate type water with a low buffering capacity. Concentrations of un-ionized ammonia are well below the recommended value of 0.02 mg/L for fish propagation. Annual transport of suspended sediment by the Tlikakila River into Lake Clark ranged from 0.4 to 1.5 million tons during 1999–2001. The fine sediment from the Tlikakila River disperses through the lake over the summer, affecting light transmissivity.

Most runoff from the Tlikakila River occurs from mid-to-late May through September. Average discharge for these months during 1999–2001 was 6,600 ft^3/s. Total annual inflow to Lake Clark from the Tlikakila River ranged from 32 to 45 percent of the total inflow. The relatively high proportion of inflow is due to the presence of glaciers, which comprise 36 percent of the watershed.

Monthly measurements of flow, field water-quality parameters, alkalinity, and suspended sediment were collected on the remaining five tributaries to Lake Clark: the Chokotonk River, Currant Creek, the Kijik River, the Tanalian River and the Chulitna River. Similar to the Tlikakila River, pH and dissolved oxygen concentrations of these rivers are within acceptable limits for fish survival and the rivers have a low buffering capacity. Small amounts of suspended sediment are transported by the Kijik and Tanalian Rivers due to lakes acting as settling basins in their watersheds. The Chulitna River also transports small amounts of suspended sediment due to its flat topography and the presence of many lakes in the basin. Some suspended sediment is transported by the Chokotonk River and Currant Creek during the runoff season due to the presence of glaciers within their basins, but not as much as the Tlikakila River. The Chulitna River provides the most discharge into Lake Clark after the Tlikakila River and has the warmest water temperature of the major tributaries to Lake Clark. Water temperatures of Currant Creek and the Chokotonk River are similar to the Tlikakila River. The Kijik River and Tanalian River have similar temperatures that may be due to the presence of lakes in their basins and are characterize by slowly declining and rising temperatures. At all sites water temperature approaches 0 ^{o}C during winter months which may not be suitable for fish survival.

INTRODUCTION

Lake Clark National Park and Preserve is located in south-central/southwest Alaska (fig. 1). The park is approximately 6,300 mi^2 in area and straddles several river basins. Approximately one-third of the park is located in the Cook Inlet Basin of south central Alaska. Streams and rivers in this section of the park flow east into Cook Inlet. The remaining two-thirds of the park is located in the Kvichak, the Kuskokwim, and the Nushagak River Basins of southwest Alaska. Streams and rivers in the Kvichak and Nushagak River Basins flow southwest, eventually entering Bristol Bay. In terms of sockeye salmon (Oncorhynchus nerka), the Kvichak River Basin is one of the most productive basins in Alaska. Each year, millions of fish make their way up from Bristol Bay to spawn in the many streams and rivers located in the park.

Lake Clark National Park and Preserve was established in 1980 as part of the Alaska National Interest Lands Conservation Act (ANILCA). The primary purposes stated in the park's enabling legislation include "...protect the watershed necessary for perpetuation of the red salmon fishery in Bristol Bay;...maintain unimpaired the scenic beauty and quality, including...glaciers, wild rivers, lakes, waterfalls...in their natural state" (Alaska National Interest Lands Conservation Act, 1980). The Tlikakila River, a federally designated Wild and Scenic River, is entirely located in Lake Clark National Park and Preserve. The second largest watershed of the Lake Clark Basin (fig. 2), the Tlikak-

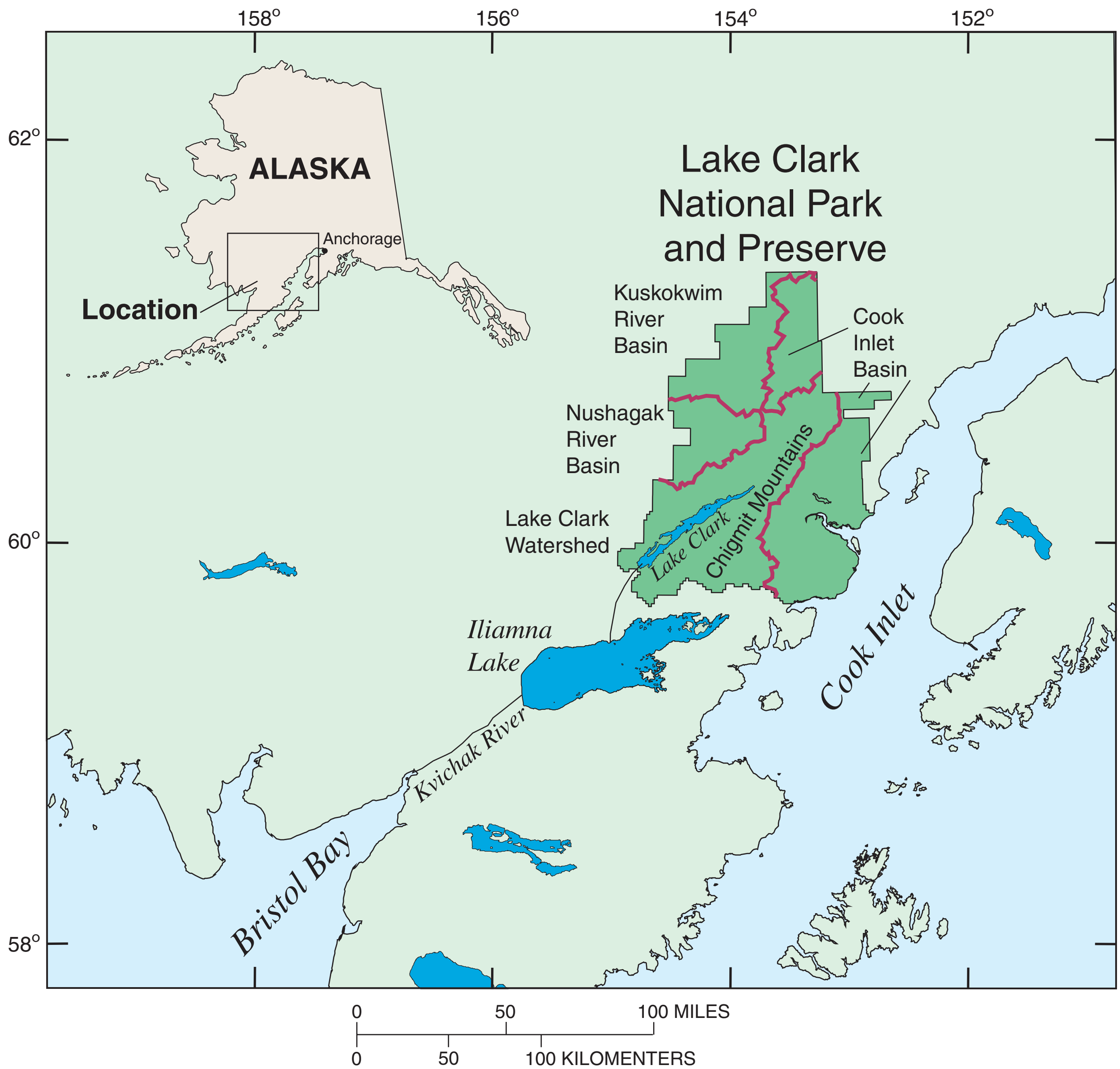

Figure 1. Location of Lake Clark National Park and Preserve.

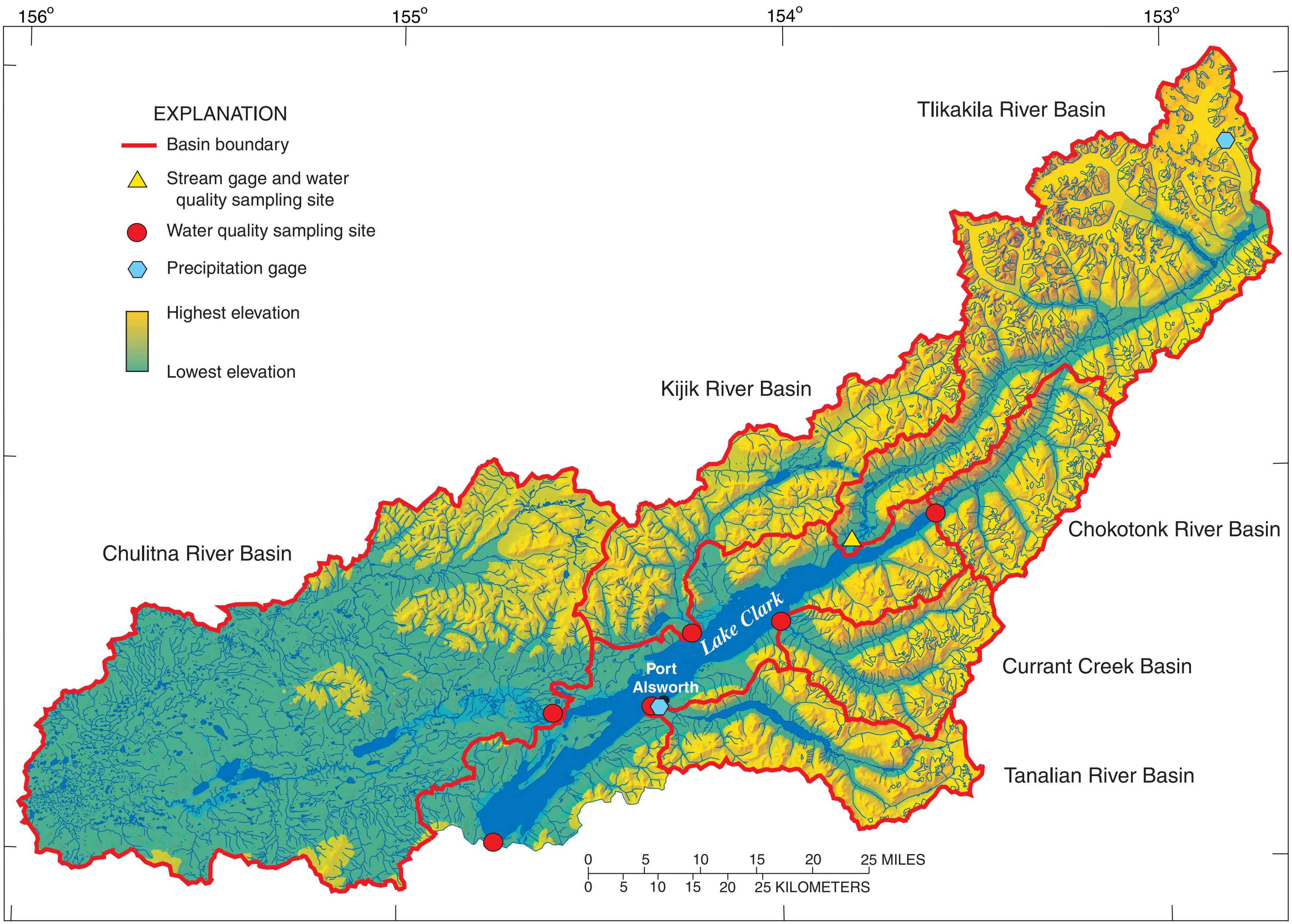

Figure 2. Shaded relief of the Lake Clark watershed, sampling sites, and precipitation sites.

ila, embodies all of the resource qualities: glaciers, rivers, waterfalls, mountain scenery, and salmon habitat, for which the park was established.

Sockeye salmon, a keystone species of Lake Clark National Park and Preserve, are declining for unknown reasons. In 1996, the number of adult salmon returning to the Lake Clark watershed was only 2.3 percent of the previouseight-year average (National Park Service, oral commun., 1998). This low percentage of return has continued to the present. Changes in the water quality of Lake Clark or its tributaries could be a contributing factor to the decline. However, no water-quality or water-quantity data exist for the Tlikakila River. A basic understanding of the Lake Clark watershed is necessary for park managers to preserve the high quality of water resources. This includes not only Lake Clark, but the inflows to the lake as well. Obtaining knowledge of the entire watershed could lead to a better understanding of the spawning habitat of sockeye salmon.

Purpose and Scope

This report summarizes the results of a cooperative study by the National Park Service (NPS)and the U.S. Geological Survey (USGS) to measure the water quality and quantity of the Tlikakila River, one of the major tributaries to Lake Clark. The purpose of the study was threefold: (1) determine if the present water-quality of the Tlikakila River is detrimental to sockeye salmon, (2) establish a baseline water quality and water quantity data base for the Tlikakila River, and (3) collect some flow and water-quality data from the other major tributaries to Lake Clark to compare with the data collected from the Tlikakila River. The Tlikakila River Basin was chosen as the main focus of the study because it is the largest river basin of the Lake Clark watershed that is located entirely within the park and it was felt that it is the most dominant of the six tributaries to Lake Clark due to the amount of glaciers present in the basin.

Methods of Data Collection and Analysis

Water-quality and flow variables in the Tlikakila River that can affect salmon include dissolved oxygen concentration, water temperature, and sediment. Other variables such as specific conductance or flow may not directly affect salmon, but are important in establishing a hydrologic baseline. In balancing the three objectives of the study, the following approach was taken for data collection.

Most runoff from southwest Alaska rivers, such as the Tlikakila, occurs from about mid-May to early October. Thus, most data collection was done during this period. Water-quality samples were collected on a monthly basis during this time in 1999 and 2000 to sample a range of discharges. A streamflow gaging station was established near the mouth of the Tlikakila River to monitor flow during the summer months (mid-May through September). Instruments were also installed at this site during 1999 and 2000 to collect some or all of the following water quality constituents on a continuous basis: water temperature, pH, specific conductance, and dissolved oxygen concentration. Daily lake elevations of Lake Clark were taken by NPS personnel at Port Alsworth to determine if there was some correlation between lake elevation and flow of the Tlikakila River.

Water samples collected from the Tlikakila River were analyzed for nutrients, organic carbon, major ions, dissolved solids, and suspended sediment. The field-collection and processing equipment used was made from Teflon, glass, or stainless steel to prevent sample contamination and to minimize analyte losses through adsorption. All sampling equipment was cleaned prior to use with a non phosphate laboratory detergent and then rinsed with distilled water and finally by stream water just prior to sample collection. Depth integrated water samples were collected across the river by using the equal-width-increment method (Edwards and Glysson, 1988) and processed onsite using methods and equipment described by Shelton (1994). Samples for organic-carbon analysis were collected separately by dipping a baked glass bottle in the centroid of flow. Samples to be analyzed for dissolved constituents were filtered either onsite or at park headquarters in Port Alsworth through 0.45-μm capsule filters. Water samples were sent to the USGS National Water Quality Laboratory in Lakewood, Colorado, for analysis using standard USGS analytical methods (Fishman and Friedman, 1989; Patton and Truitt, 1992; Fishman, 1993). Suspended-sediment samples were sent to the USGS Sediment Analysis Laboratory in Vancouver, Washington, for concentration and particle-size analysis.

A Hydrolab or Yellow Springs Instrument (YSI) meter was used to measure water temperature, dissolved-oxygen concentration, specific conductance, and hydrogen-ion activity (pH) at the time of sampling.

Onsite water-quality probes would be cleaned at the time of sampling and the field measurements would be compared with the water-quality probe reading to insure accurate readings. Adjustments to the continuous water-quality data were made if necessary to reflect the Hydrolab or YSI reading using methods outlined by Wagner and others (2000). Discharge measurements were made at the time of sampling using methods outlined by Rantz and others (1982) or by using an acoustic doppler current profiler (ADCP) manufactured by RD Instruments and following the guidelines outlined by Lipscomb (1995).

It was beyond the scope of this study to monitor the other 5 major tributaries to Lake Clark at the same scale as the Tlikakila River. However, at the time of the Tlikakila River sampling, efforts were made to visit the other major tributaries and the outlet of Lake Clark. At these sites, field water quality parameters and flow were measured and samples for suspended sediment and alkalinity were collected. Hourly water temperature data were collected at these sites at various times during the study. Thus, at the completion of the data collection phase of the study, each of these sites had some data that could be compared to the Tlikakila River data as well as each other.

After the data were collected, checked, and compiled, data analysis was undertaken. The concentrations of various water-quality constituents in the Tlikakila River were compared to known or published concentrations that are recommended for fish survival. A water budget of Lake Clark was developed to determine the contribution of the Tlikakila River. Loads of selected water-quality constituents transported by the Tlikakila River were computed to determine how much of a particular constituent enters Lake Clark. These techniques are explained in more detail in the following sections. Finally, the data collected from the other major tributaries were compared to the Tlikakila River data to determine similarities and differences in water quality among the major tributaries to Lake Clark.

Acknowledgments

The author gratefully appreciates the help of Judy Putera, Dan Young, and Alex Wilkens of the National Park Service at Port Alsworth for recording lake levels and assisting in field work. Special thanks to Jack Ross of Port Alsworth for assistance in field work and for sharing his knowledge of Lake Clark with the author.

DESCRIPTION OF STUDY AREA

Lake Clark occupies an elongated, glacially steepened depression. This glacial lake is fed primarily by inflow from six rivers (fig. 2): the Chokotonk, Tlikakila, Currant, Kijik, Tanalian, and Chulitna. Two hydrologic seasons characterize Lake Clark: (1) summer when the lake is ice-free and when most of the annual inflow enters the lake, and (2) winter, when the lake and most of the inflow streams are frozen, and there is minimum inflow into the lake. The length of the winter season may equal or exceed that of the summer season.

In terms of thermal classification, Lake Clark is similar to a polymictic lake (Alex Wilkens, National Park Service, oral commun., 2002). Polymictic lakes such as Lake Clark undergo frequent circulation due to winds that are present in this region throughout the entire year. The morphometry of Lake Clark (table 1) indicates that the lake is long (41 mi), narrow (3.1 mi), and deep (mean depth, 330 ft). The combined flow of the six rivers is highly seasonal and thus the corresponding lake level altitude has a large annual variation (fig. 3).

The Lake Clark watershed (fig. 2) drains 2,942 mi^2. In addition to the six major rivers that flow into Lake Clark, there are numerous small glacier-fed streams originating in the mountains and clearwater streams originating in the foothills and lowlands that flow into Lake Clark. The topography of the Lake Clark watershed ranges from relatively flat in the Chulitna River Basin to relatively steep in the other basins (fig. 2). For example, the mean basin slope for the Chulitna River Basin is 7 percent while the remaining basins have average slopes between 21 and 25 percent (table 2). Precipitation also is variable (fig. 4): the mean annual precipitation for the Chulitna River Basin is 26 inches, but increases to 80 inches for the Chokotonk River Basin (Jones and Fahl, 1994).

Table 1. Morphometry of Lake Clark at 295.00 feet water-surface altitude (calculations based on methods by Hakanson, 1981)

Lake characteristic	Value	Unit
Area	128	square miles
Volume	2.7×10^7	acre-feet
Length	41	miles
Mean depth	330	feet
Maximum depth	1,000	feet
Mean width	3.1	miles
Maximum width	4.5	miles
Shoreline	158	miles

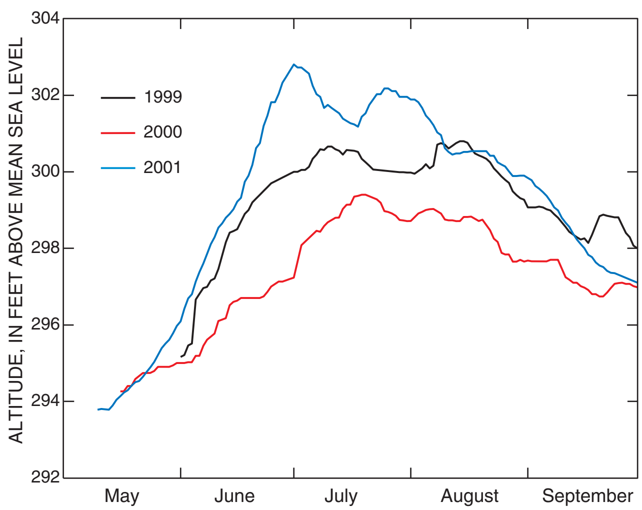

Figure 3. Altitude of Lake clark from May through September 1999-2000.

Bedrock geology of the Lake Clark Basin varies from predominantly Mesozoic sedimentary rocks (youngest age) in the Kijik, Tanalian, and Chulitna River Basins to predominantly cenozoic intrusive rocks in the Chokotonk River, Currant Creek, and Tlikakila River Basins (oldest age) (Nelson and others, 1983). The Chulitna River Basin consists primarily of sedimentary deposits and volcanic rocks (Quaternary). The Kijik and Tanalian River Basins consist primarily of volcanic rocks of tertiary age. Proceeding up the basin to the more rugged lands, the Currant Creek and Chokotonk River Basins consist of tertiary and cretaceous rocks made up of granodiorite. The Tlikakila River Basin contains many areas of metamorphosed igneous and sedimentary rocks. The predominant rock feature in this basin is Cretaceous and Jurassic rocks.

Most of the Lake Clark Basin is composed of rough mountainous lands with no soil. Soils are found in the Chulitna River Basin and consist of andisols, histosols, and spodosols (U.S. Department of Agriculture, 1975). Vegetation in the Lake Clark Basin consists primarily of alpine tundra and tall shrub with the exception of the Chulitna River Basin (Alaska Geospatial Data Clearinghouse, 1998). The Chulitna River Basin consists primarily of low shrub and tall shrub.

The Tlikakila River, a designated wild and scenic river, begins at Summit Lake in Lake Clark Pass and travels through a deep narrow valley into Lake Clark (fig. 5). This river basin, which is the second largest basin of the Lake Clark watershed (table 2), drains about 21 percent of the Lake Clark watershed. Two distinct features of this basin are (1) the presence of glaciers in about 36 percent of the basin (figs. 5 and 6) and (2) the relatively high mean annual precipitation (79 inches) compared to the other five basins in the watershed.

WATER QUALITY OF THE TLIKAKILA RIVER

In this study a number of physical properties such as pH, specific conductance, water temperature, and dissolved oxygen; and chemical constituents such as major ions, nutrients, organic carbon, and suspended sediment were measured several times in the Tlikakila River during the 1999-2000 water years (appendix 1, at the back of the reprort). These data establish the first hydrologic database of the Tlikakila River and also provide insights as to whether the concentrations or

Table 2. Basin characteristics of six major tributaries to Lake Clark

[mi^2, square miles; in., inches; ft, feet;]

Tributary	Area (mi^2)	Mean basin slope (percent)	Mean annual precipitation (in.)	Average elevation (ft)	Glaciers (mi^2)	Lakes (mi^2)	Major rock type	Major soil type	Major vegetation type
Chokotonk River	168	25	80	2,940	29.5	0.1	Cenozoic intrusive	rough mountainous land	alpine tundra/tall shrub
Tlikakila River	622	22	79	3,640	227.3	1.8	Cenozoic intrusive	rough mountainous lands	alpine tundra/tall shrub
Currant Creek	165	25	66	2,930	25.9	0.1	Cenozoic intrusive	rough mountainous lands	alpine tundra/tall shrub
Kijik River	298	21	50	2,650	7.4	4	Mesozoic sedimantary	rough mountainous land	alpine tundra/tall shrub
Tanalian River	205	23	52	2,670	14.6	8.8	Mesozoic sedimentary	rough mountainous land	alpine tundra/tall shrub
Chulitna River	1,157	7	26	1,080	0	35.5	Mesozoic sedimen tary	spodosols/histosols/andisols	low shrub/tall shrub

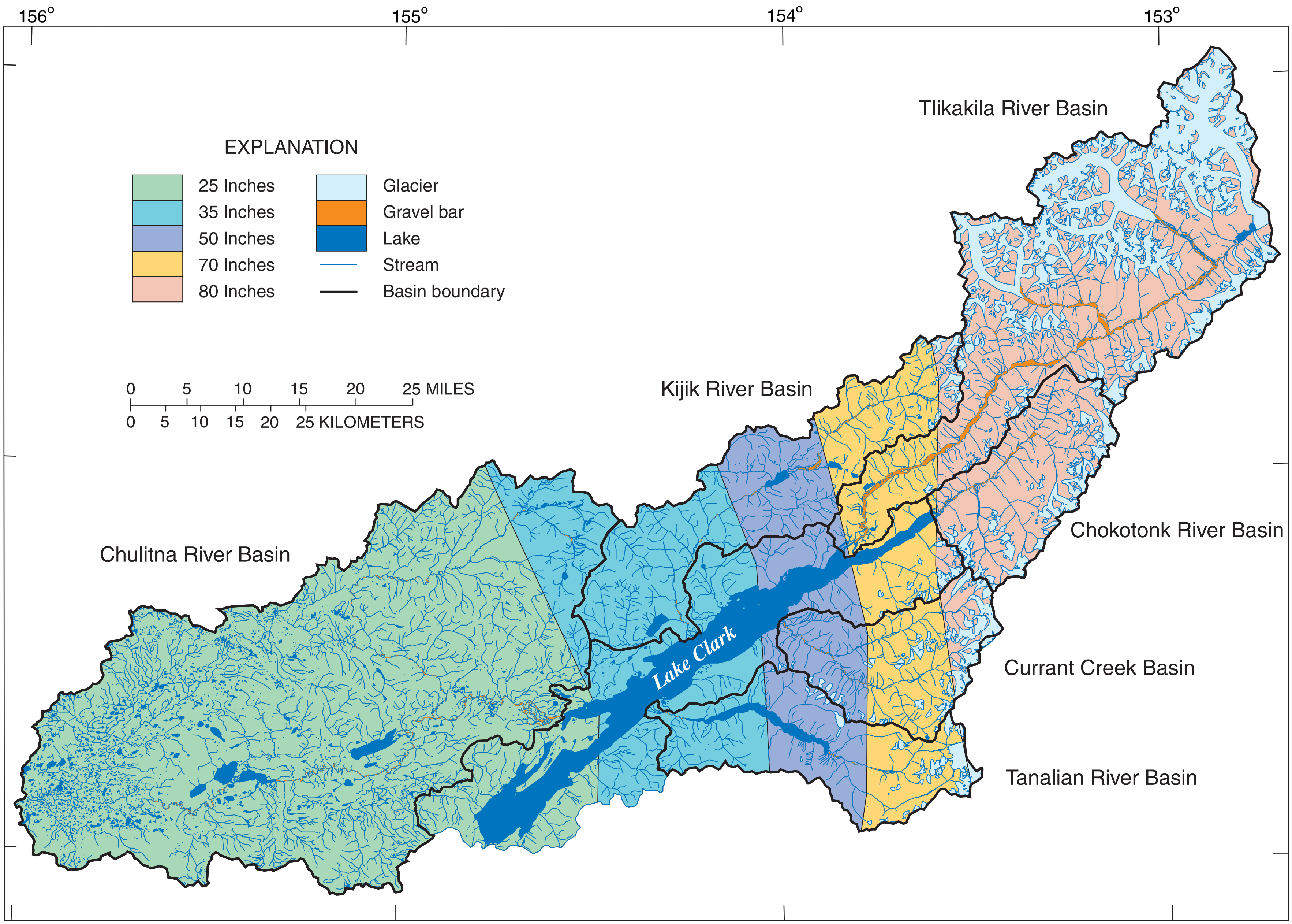

Figure 4. Man annual precipitation regions of the Lake Clark watershed (from Jones and Fahl, 1994).

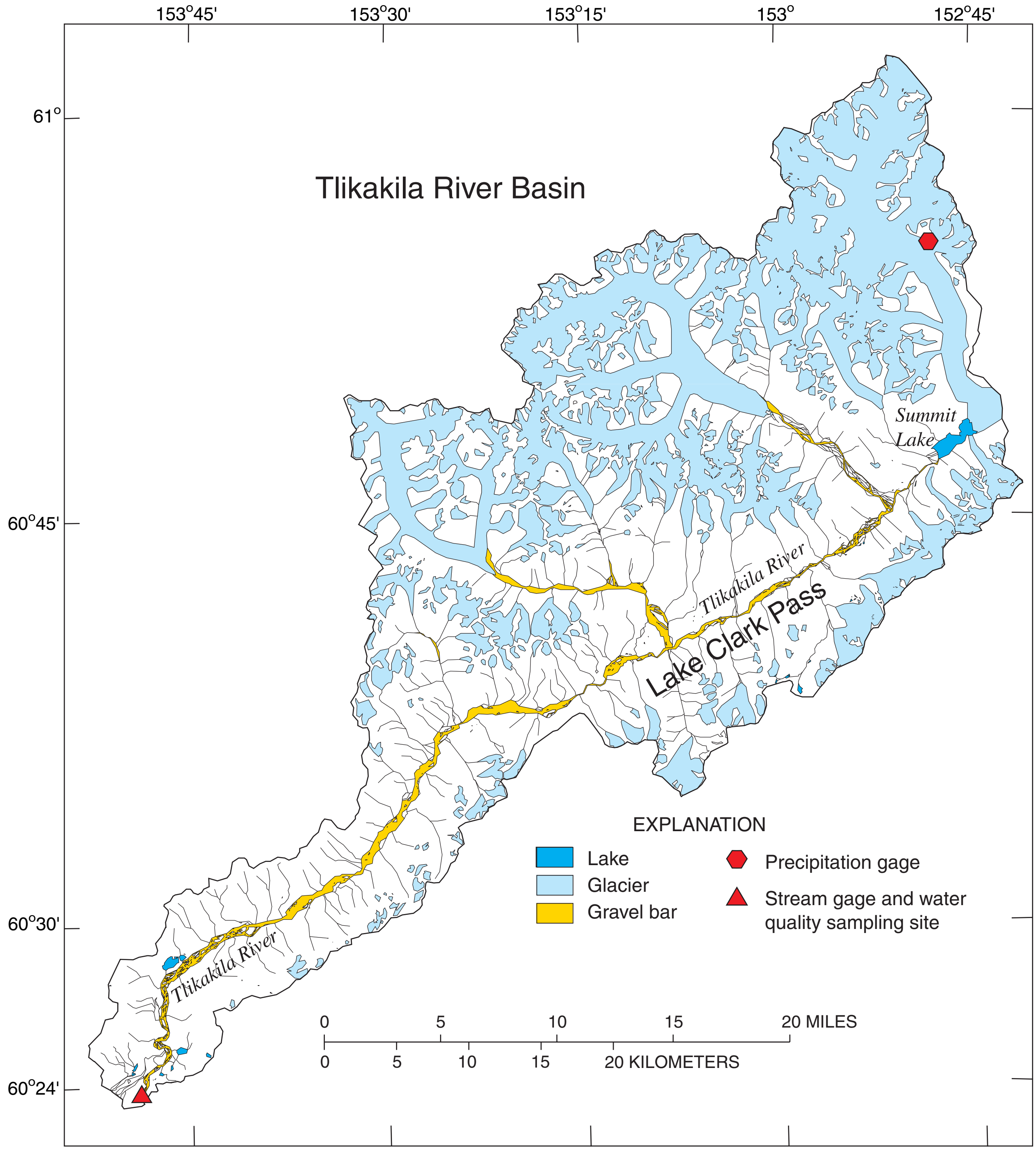

Figure 5. Tlikakila River Basin, location of precipitation gage and streamgage, and water-quality sampling site.

values of certain constituents are harmful to sockeye salmon.

Physical Properties

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electric current and is determined by the type and concentration of ions in solution. It is a readily measured property that can be used to indicate the dissolved-solids or ion content in water, provided a statistical relation can be developed between specific conductance and a particular ion. During the low flow periods of May and late September 2000, the daily specific conductance of the Tlikakila River was greater than the specific conductance recorded from June to

Figure 6. Unnamed glacier in the upper Tlikakila River Basin (photograph by T.P. Brabets, U.S. Geological Survey)

early September (fig. 7). Surface runoff is at a minimum during this time and conductance values are indicative of ground-water inflow. From June through early September, the primary runoff season, the lowest values of specific conductance occurred. This period reflects runoff from snowmelt, ice melt, and rainfall events that probably do not contain the same amount of dissolved ions as ground water and thus these components of runoff create a dilution effect. Values of specific conductance for the water samples collected in 1999 through 2000 ranged from 31 to 117 μS/cm (table 3, app. 1). The highest values occurred in March, May, September, and October, the time of low flow and the lowest values occurred in June, July or August, the period of high flow.

pH

The pH of water is a measure of its hydrogen-ion activity and can range from 0 (very acidic) to 14 (very alkaline) standard units. The pH of river water not affected by contamination is typically between 6.5 and 8.0 standard units (Hem, 1985) and for fish growth and survival, the pH should remain in the 6.5 - 9.0 standard unit range. During 1999 and 2000, the pH of the Tlikakila River ranged from 7.2 to 8.1 standard units (table 3, app. 1), within the typical range for fish growth and survival.

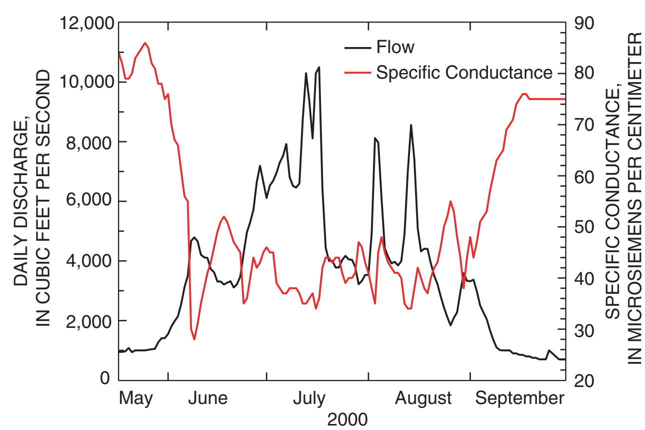

Figure 7. Daily specific conductance and discharge of the Tlikakila River, May-September 2000.

Water Temperature

Water temperature determines the amount of oxygen water can contain when at equilibrium with the atmosphere and it also controls the metabolic rates of fish and their rates of growth. Sockeye salmon have adapted to specific spawning times and water temperatures in order that incubation and emergence occur at the most favorable time of the year (Kyle and Brabets, 2001). At the streamgage site (fig. 5), water temperature remains at 0 ^oC from late October to mid-April (fig. 8). For incubation of sockeye salmon, water temperature should be at least 2.0 ^oC; thus sockeye salmon would probably not survive in this area of the Tlikakila River during this period. In April, after the river ice is gone, the water temperature rises quickly to between 5 and 6 ^oC. As air temperature and runoff increase, water temperature increases to approximately 10 ^oC in mid-May. In June, as runoff from snowmelt and glacier ice enter the Tlikakila River, a general cooling trend begins and continues as the water temperature reaches near freezing temperatures for the following winter.

Dissolved Oxygen

The dissolved-oxygen concentration in a stream is controlled by water temperature, air temperature and pressure, hydraulic characteristics of the stream, photosynthetic or respiratory activity of stream biota, and the quantity of organic matter present. Sockeye salmon and other fish require well-oxygenated water at every stage in their life, but young fish are more susceptible to oxygen deficiencies than adult fish. Dissolved-oxygen concentrations in water samples collected from the Tlikakila River during the study period ranged from 11.0 to 14.0 mg/L (table 3, app. 1). Dissolved oxygen concentrations were recorded continuously from July 26, 1999 to September 30, 1999 (fig. 9). During this period dissolved oxygen concentrations varied between 11.5 and 16.5 mg/L, but all concentrations were sufficient to support fish.

Alkalinity

Alkalinity is a measure of the capacity of the substances dissolved in water to neutralize acid. In most natural waters, alkalinity is produced mainly by bicarbonate and carbonate ions (Hem, 1985), which are formed when carbon dioxide or carbonate rocks dissolve in water. Alkalinity concentrations (reported as equivalent concentrations of calcium carbonate ($CaCO_3$)) for the Tlikakila River ranged from 13 to 37 mg/L (table 3, app. 1) with a median concentration of 18 mg/L. These alkalinity concentrations indi-

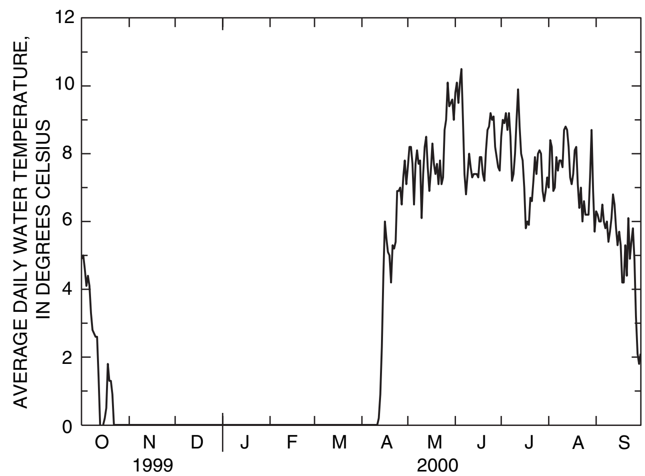

Figure 8. Water temperature of the Tlikakila River, October 1999 through September 2000.

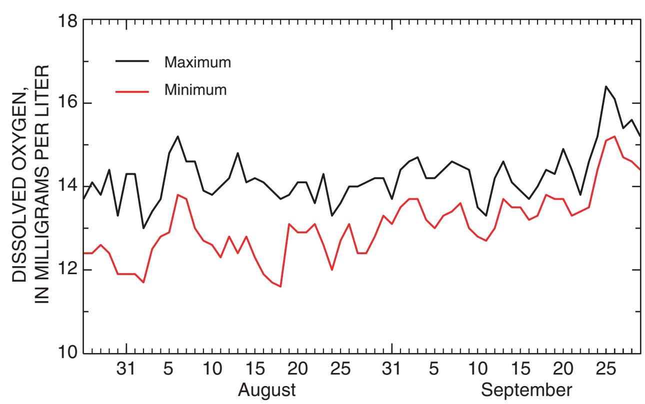

Figure 9. Dissolved oxygen concentration of the Tlikakila River, July 27 through September 30, 1999.

Table 3. Physical properties measured in 12 water samples collected from the Tlikakila River, March 1999 through September 2000 (station 15297970)

Constituent	Minimum	Maximum	Mean	Median
Specific Conductance (microsiemens/centimeter)	31	117	61	51
pH (standard units)	7.2	8.1	7.5	7.6
Water Temperature (^oC)	0.0	9.4	5.8	6.8
Dissolved Oxygen (mg/L)	11.0	14.0	12.2	12.0
Alkainity (mg/L as $CaCO_3$)	13	37	21	18

cate that water in the Tlikakila River has a low buffering capacity and limited availability of inorganic carbon. Also, given the range of pH values of the Tlikakila River, most of the alkalinity can be assigned entirely to dissolved bicarbonate (Hem, 1985).

Major ions and Dissolved Solids

During 1999-2000, 11 water samples collected from the Tlikakila River were analyzed for major and dissolved ions (appendix 1), which are primarily derived from soil and rock weathering. Concentrations generally are greatest in streams draining basins with rocks and soils that contain easily dissolved minerals. The Tlikakila River Basin is composed primarily of Cenozoic intrusive rocks that are not easily dissolved; thus dissolved solids concentrations are generally low, ranging from 11 to 76 mg/L, with a median concentration of 34 mg/L (table 4, appendix 1).

Calcium and magnesium are both essential elements for plants and animals. Calcium is usually the dominant positively charged ion in most natural waters, followed by magnesium (Hem, 1985). Concentrations ranged from 4.7 to 15 mg/L for calcium and from 0.4 to 1.8 mg/L for magnesium with median concentrations of 7.2 and 0.6, respectively (table 4, appendix 1).

Sodium is present in all natural waters, but usually in low concentrations in rivers. Median concentration for this constituent was 0.7 mg/L (table 4). Potassium, an essential element for both plants and animals, is abundant in nature, but seldom occurs in high concentrations in natural waters (Hem, 1985). Median concentration for this element was 1.1 mg/L (table 4). Bicarbonate, which originates from dissolution of sedimentary rocks, was the dominant anion and ranged from 16 to 45 mg/L, with a median of 22 mg/L (table 4, app. 1).

Sulfate in rivers is mostly from the weathering of sedimentary and igneous rocks and biochemical processes. Median concentration of this constituent in the Tlikakila River was 4.5 mg/L (table 4). Chloride is present in the Tlikakila River but median concentration was only 0.3 mg/L. Silica is dissolved from rocks and soils, and concentrations most commonly determined in natural water are between 1 and 30 mg/L as SiO_2 (Hem, 1985). Median concentration of this element in the Tlikakila River was 3.8 mg/L (table 4).

Concentrations of the major ions in milliequivalents per liter, (Drever, 1997) were plotted on a trilinear diagram (fig. 10). The trilinear diagram helps display water-chemistry data in a manner to classify the chemical composition of the water. Based on the 11 samples collected during this study, the water of the Tlikakila River would be classified as calcium bicarbonate water.

Most of the major ions measured at the Tlikakila River indicate a good statistical relation to specific conductance (fig. 11; table 5). With the exception of sodium and potassium, the coefficients of determination (R^2) were 0.77 or greater and the regression equations were statistically valid at a significance level of better than 99 percent. Thus, valid estimates of concentrations of these dissolved constituents can be calculated from the equations and measured values for specific conductance.

Nutrients and Organic Carbon

Nitrogen is an important water-quality constituent, in part because it is an important component of the protoplasm of aquatic biota. In aquatic ecosystems, nitrogen commonly occurs in three ionic forms: ammonium

Table 4. Major dissolved inorganic constituents measured in 11 water samples collected from the Tlikakila River, March 1999 through September 2000 (station 15297970)

[all values in milligarms per liter].

Constituent	Minimum	Maximum	Mean	Median
Calcium	4.7	15	8.2	7.2
Magnesium	0.4	1.8	0.7	0.6
Sodium	0.5	2.3	--	0.7
Potassium	0.8	1.9	1.3	1.1
Bicarbonate	16	45	28	22
Sulfate	1.9	10.5	4.8	4.5
Chloride	<0.1	1.8	0.6	0.3
Flouride	<0.1	<0.1	--	<0.1
Silica	2.5	8.6	4.8	3.8
Dissolved Solids	11	76	38	34

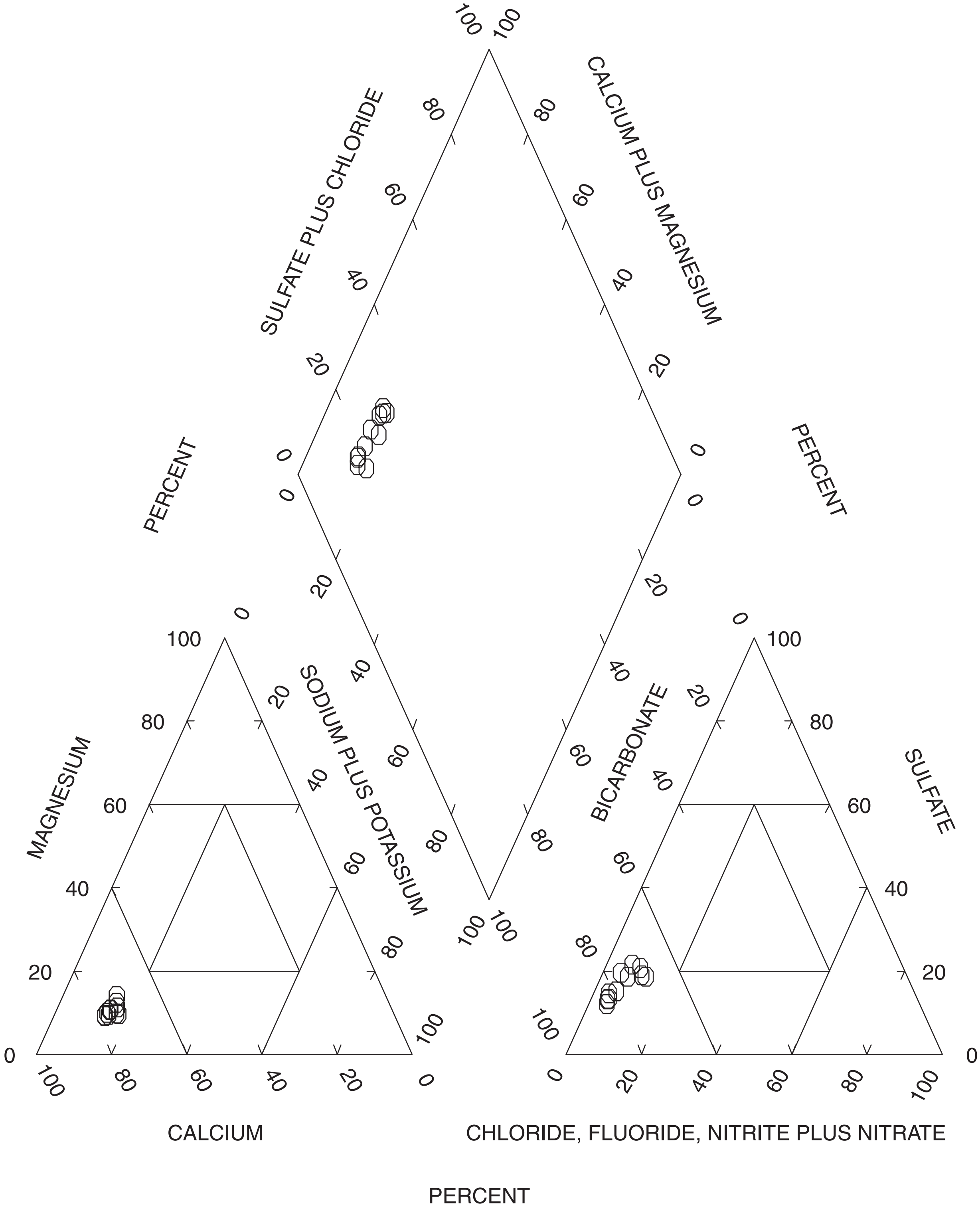

Figure 10. Trilinear diagram Eleven water samples of the Tlikakila River Collected from March 1999 through September 2000.

(NH_4), nitrite (NO_2), and nitrate (NO_3). In the laboratory, ammonium is analyzed as ammonia (NH_3); thus nitrogen concentrations are reported as total and dissolved ammonia plus organic nitrogen (often called Kjeldahl nitrogen), dissolved ammonia, dissolved nitrite plus nitrate, and dissolved nitrite. Nitrite readily oxidizes to nitrate in oxygenated water; therefore nitrate is generally more abundant than nitrite in water bodies.

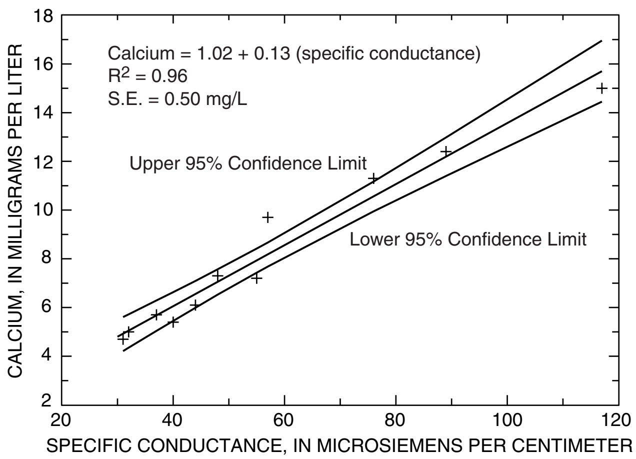

Figure 11. Relation between specific conductance and calcium concentration in 11 streamflow samples from the Tlikakila River, 1999-2000.

Total ammonia plus organic nitrogen concentrations represent the ammonium and organic nitrogen compounds in solution and associated with colloidal material. Nitrite and nitrate are oxidized forms of inorganic nitrogen that together make up most of the dissolved nitrogen in well-aerated streams. The dissolved concentrations represent the ammonium or nitrite plus nitrate in solution and associated with colloidal material capable of passing through a 0.45-um pore.

All concentrations of the various nitrogen forms were less than 1.0 mg/L (table 6; app. 1). Total nitrogen (sum of Kjeldahl nitrogen and the nitrate-plus-nitrite nitrogen) ranged from 0.17 mg/L to 0.92 mg/L (appendix 1). Due to its toxicity to freshwater aquatic life, the U.S. Environmental Protection Agency (USEPA) (U.S. Environmental Protection Agency, 1976) suggests a limitation of 0.02 mg/L of ammonia (as un-ionized ammonia, NH_3) for waters to be suitable for fish propagation. Based on the values of ammonia, pH, and water temperature in the Tlikakila River the un-ionized ammonia, was calculated as 0.19 percent of dissolved ammonia (interpolated from table 3, USEPA, 1976, p. 11). Thus, even at the maximum concentration of dissolved ammonia (0.028 mg/L), the concentration of un-ionized ammonia is well below the recommended criteria for fish propagation.

Phosphorus is an essential element in the growth of plants and animals. It occurs as organically bound phosphorus or as phosphate. High concentrations of phosphorus in water are not considered to be toxic to human or aquatic life. However, its presence can stimulate the growth of algae in lakes and streams. It was first noted by Sawyer (1947) that nuisance algal conditions could be expected in lakes when concentrations of inorganic nitrogen ($NH_3 + NO_2 + NO_3$ as N) as low as 0.3 mg/L are present in conjunction with as much as 0.01 mg/L of phosphorus.

Phosphorus concentrations are reported as total phosphorus and dissolved orthophosphate. Total-phosphate concentrations represent the phosphorus in solution, associated with colloidal material, and contained in or attached to biotic and abiotic particulate material. The dissolved concentrations are determined from the filtrate that passes through a filter with a nominal pore size of 0.45 µm. The orthophosphate ion, PO_4, is the most important form of phosphorus because it is directly available for metabolic use by aquatic plants. Concentrations of total phosphorus and dissolved phosphorus were less than 1.0 mg/L for all samples collected on the Tlikakila River.

The nitrogen and phosphorus concentrations were used to compute the nitrogen-phosphorus ratio. This ratio varies with the water, season, temperature, and

Table 5. Results of regression analysis relating concentrations of dissolved solids and major ions to specific conductance in 11 streamflow samples collected from the Tlikakila River, March 1999 through September 2000 (station 15297970).

[SC, specific conductance; all equations significant at the 99 percent level]

Constituent	Regression	Coefficient of determination	Standard Error (mg/L)
Calcium	1.02 + 0.12 (SC)	0.92	0.72
Magnesium	-0.21 + 0.02 (SC)	0.96	0.07
Sodium	-0.34 + 0.02 (SC)	0.67	0.31
Potassium	0.56 + 0.01 (SC)	0.54	0.22
Bicarbonate	7.1 + 0.32 (SC)	0.98	1.4
Sulfate	-0.69 + 0.10 (SC)	0.81	0.89
Chloride	-0.53 + 0.02 (SC)	0.92	0.12
Silica	0.09 + 0.08 (SC)	0.77	0.84
Dissolved Solids	0.84 + 0.66 (SC)	0.83	5.7

Table 6. Nutrient and organic carbon concentrations measured in 12 water samples collected from the Tlikakila River, March 1999 through September 2000 (station 15297970)
[all values in mg/L; $NO_2 + NO_3$, nitrate plus nitrite, E, estimated, <, less than].

Constituent	Minimum	Maximum	Mean	Median
Nitrogen, Nitrite Dissolved	<0.001	.001	--	.001
Nitrogen, NO_2+NO_3 Dissolved	.065	.818	.274	.163
Nitrogen, Ammonia Dissolved	<0.002	.028	--	.004
Nitrogen, Ammonia + Organic, Total	<0.10	.27	--	<.10
Nitrogen, Ammonia + Organic, Dissolved	<0.10	0.10	--	0.10
Phosphorus,Total	.029	.902	.249	.203
Phosphorus, Dissolved	E.003	<.005	--	.004
Phosphorus, Ortho, Dissolved	<0.001	.005	--	.001
Dissolved Organic Carbon	E.17	.70	.42	.40
Particulate Organic Carbon	<.2	.9	--	.2

geological formation, and may range from 1 or 2:1 to 100:1. In natural waters, the ratio is often near 10:1, and this appears to be a good guideline for indicating normal conditions. The ratio of nitrogen to phosphorus is an indication of the potential for excess growth of algae. If phosphorus is considered the limiting nutrient, a low ratio suggests that there is sufficient phosphorus for algae to utilize all the available nitrogen for growth, and a high ratio indicates that there is not enough phosphorus for algae to use all the available nitrogen. For the Tlikakila River, the ratio of total nitrogen to phosphorus ranged from less than 1.0 to about 26. High ratios occur during low flow periods in March, May, and September (indicating insufficient phosphorus) and low ratios occur during the high runoff periods (indicating sufficient phosphorus).

Dissolved organic carbon (DOC) is commonly a major pool of organic matter in ecosystems. DOC is defined as organic carbon in the filtrate (dissolved and colloidal phases) that has passed through a 0.45 -µm pore-size filter. Generally, DOC is in greater abundance than particulate organic carbon (POC), accounting for approximately 90 percent of the total organic carbon of most waters (Aiken and Cotsaris, 1995). In the aquatic system, the sources of DOC can be categorized as (1) allochthonous—entering the system from a terrestrial watershed, and (2) autochthonous—being derived from biota (ie algae, bacteria, macrophytes) growing in the water body.

For the Tlikakila River, all concentrations of DOC and POC were less than 1.0 mg/L (table 6, App. 1). During high discharges in summer, concentrations of POC were greater than DOC. These low concentrations of POC and DOC reflect the fact that most of the Tlikakila River Basin consists of rough mountainous lands with a thin soil cover. Thus, only a small amount of organic matter is present that can be degraded.

Suspended Sediment

Sediment in the Tlikakila River is transported in suspension and as bedload. Suspended sediment consists of fine particles, usually clay or silt, that are transported in a stream while being held in suspension by the turbulence of flowing water. Bedload consists of coarse sediment, usually sands, gravels, and larger particles, that are transported on or near the streambed.

In late May, as air temperatures begin to rise above freezing at higher altitudes, glacial meltwater begins to contribute to the streamflow, and a corresponding increase in silt-clay concentration occurs. This causes the Tlikakila River to take on the turbid, milky appearance that is characteristic of glacier-fed rivers. As the runoff season progresses, some sediment is deposited at the mouth of the Tlikakila River (fig. 12), forming a delta that almost blocks Lake Clark from Little Lake Clark (fig. 13). The suspended sediment that remains in suspension from the Tlikakila River travels downlake (fig. 13) and by the end of the runoff season the plume has traveled almost the entire length of Lake Clark. The significance of this sediment plume is that it reduces the light transmissivity of the water column. A reduction in light transmissivity combined with other limnology factors can affect the productivity of Lake Clark.

Of the 11 samples collected for suspended sediment, 6 were analyzed for percentage of silt and clay (<0.063 mm) (table 7). The samples averaged 66 percent finer than 0.063 mm and thus most of the suspended load consists of silt-clay particles with some fine sand. A stream discharge and suspended sediment load relation was developed to provide information on

Figure 12. Mouth of the Tlikakila River showing a large deposition area (photograph by T.P. Brabets, U.S. Geological Survey.

the amount of suspended sediment transported for a particular discharge (fig. 14). Although the correlation between discharge and load is considered good ($R^2 = 0.92$), the standard error is consider to be somewhat high. This relation was utilized to compute sediment loads for periods when only daily flow data were available.

FLOW CHARACTERISTICS OF THE TLIKAKILA RIVER

Glaciers store an enormous amount of water in the form of ice. This feature alone makes any drainage basin containing glaciers both unique and complex. The release of this water is highly dependent on the energy supplied by solar radiation and air temperature (Meier, 1969). A hot summer will cause substantial melting and runoff, whereas a cool summer will produce much less melting and runoff.

Runoff from glacier-fed rivers is strongly influenced by the glacier behavior. For example, during a single year, the mass of a glacier may increase, decrease, or remain the same. When glacier mass decreases (negative mass balance), the basin will yield more water than a similar basin without glaciers. A growing glacier stores and thus withholds some water from the normal runoff in the stream. Even if a glacier is in equilibrium, most of the meltwater will be released during a fairly short summer season. The peak runoff in rivers receiving glacier meltwater occurs later in the year than in rivers not affected by glaciers (Meier and Tangborn, 1961).

The hydrograph of the Tlikakila River (USGS station number 15297970) (July 1-15, 2000) provides a good picture of its characteristics (fig. 15). Distinct diurnal fluctuations occurs as follows: the low flow of the day usually occurs in the early morning and the high flow occurs at about midday, reflecting a time lag between melting of snow and ice and the arrival of the resulting meltwater at the streamflow gaging site.

Most of the annual flow of the Tlikakila River occurs during June to September (fig. 16). Flow in June is dominated by snowmelt, and in July through August, by glacier ice melt and rainfall. The runoff from the Tlikakila River indicates some trend with the lake elevation (fig. 3); the lowest lake elevation and the lowest

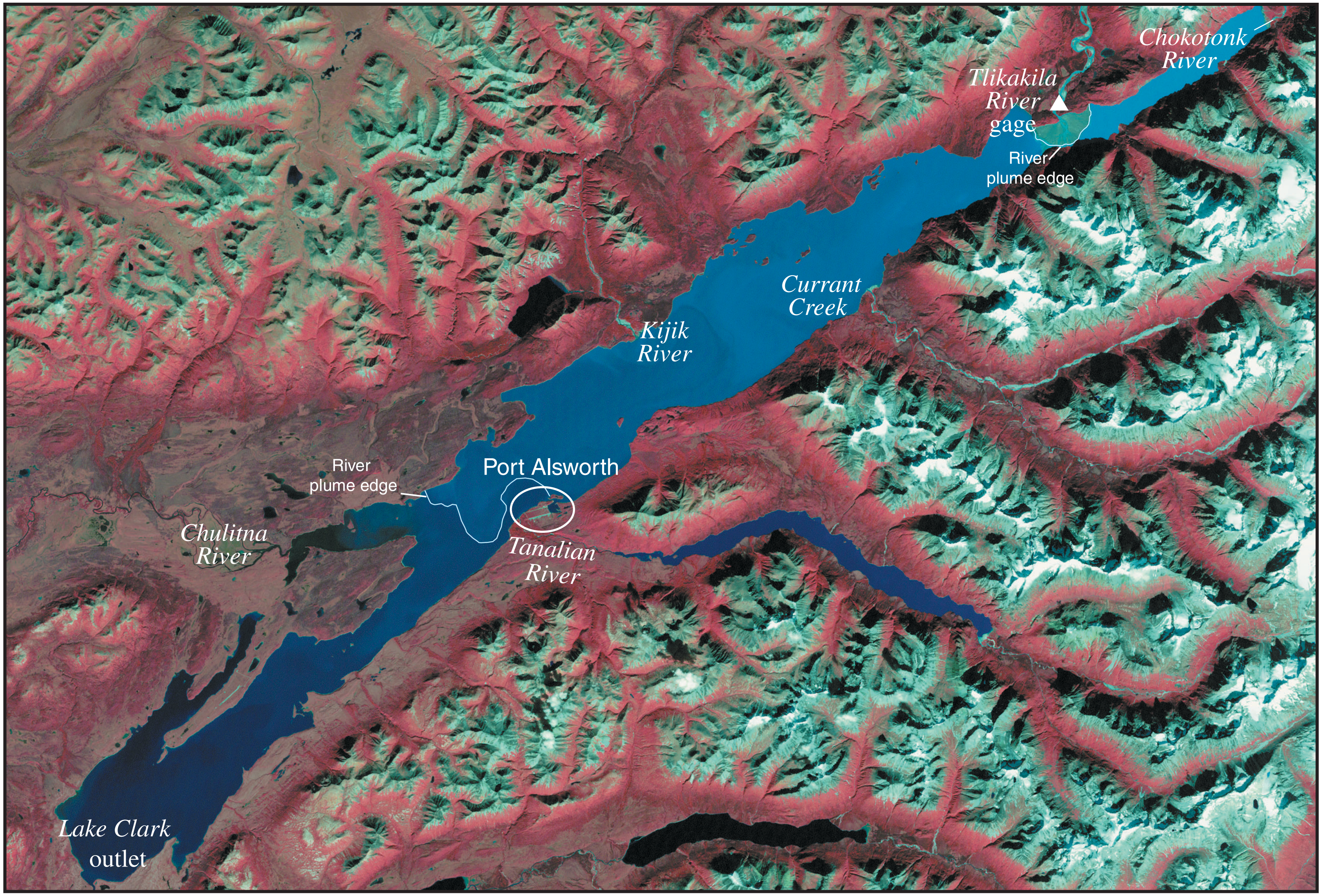

Figure 13. Landsat image of Lake Clark taken September 6, 1999, showing sediment plumes from the Tlikakila River.

Table 7. Suspended-sediment concentrations measured in 12 water samples collected from the Tlikakila River, March 1999 through September 2000 (station 15297970).

[mg/L, milligrams per liter; mm, millimeter; ft^3/s, cubic feet per second]

Date	Suspended sediment concentration (mg/L)	Percent finer than .063 mm	Discharge (ft^3/s)	Suspended sediment discharge[a] (tons/day)
3-16-99	5	--	25	0.3
5-13-99	25	--	510	34.4
6-16-99	710	63	7,500	14,400
7-26-99	227	68	12,000	7,350
8-18-99	397	62	6,160	6,600
9-16-99	71	--	3,070	588
10-14-99	9	--	871	21.2
5-16-00	29	--	950	74.4
6-20-00	676	69	3,320	6,060
7-18-00	528	70	6,440	9,180
8-31-00	318	64	3,330	2,860
9-21-00	118	--	750	239

[a]Suspended sediment discharge calculated as (0.0027)*(suspended-sediment concentration)*(discharge).

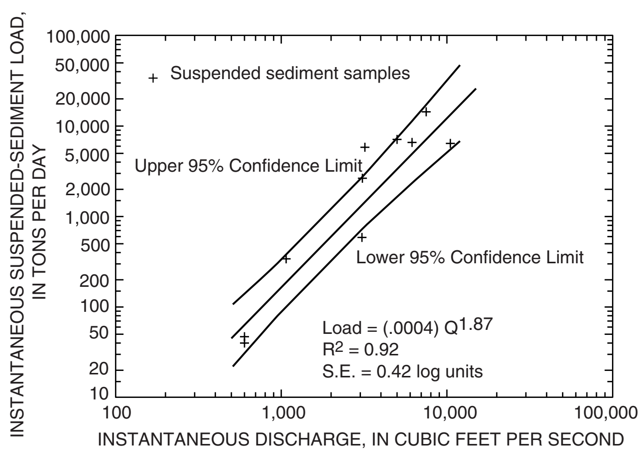

Figure 14. Relation between instantaneous discharge and instantaneous suspended-sediment load for the Tlikakila River, 1999-2000.

amount of flow from the Tlikakila both occurred in 2000. Peak discharges noted in 1999 and 2000 were the result of relatively intense rainstorms that occurred in the region. In 2001, there were no intense rainstorms, but there was more sustained flow due to warm air temperatures.

Runoff from June 1 to September 30 during 1999-2001 totaled 52.4 in., 28.7 in., and 65.4 in., respectively. Average discharge was 7,200 ft^3/s, 3,900 ft^3/s, and 8,600 ft^3/s respectively (or 6,600 ft^3/s averaged for the three year period). The large difference in runoff between the 2000 runoff season and the 1999 and 2001 runoff seasons probably is due to the snowpack in the basin at the time of spring snowmelt and the amount of rainfall that occurred during the summer months. Based on snowpack data from the National Resource Conservation Service (U.S. Department of Agriculture, 1999, 2000, 2001), snowpacks near the Tlikakila River Basin were 29 percent below average in 1999, 43 percent below average in 2000, and 3 percent above average in 2001. Based on rainfall data from the National Weather Service (1999, 2000, 2001)

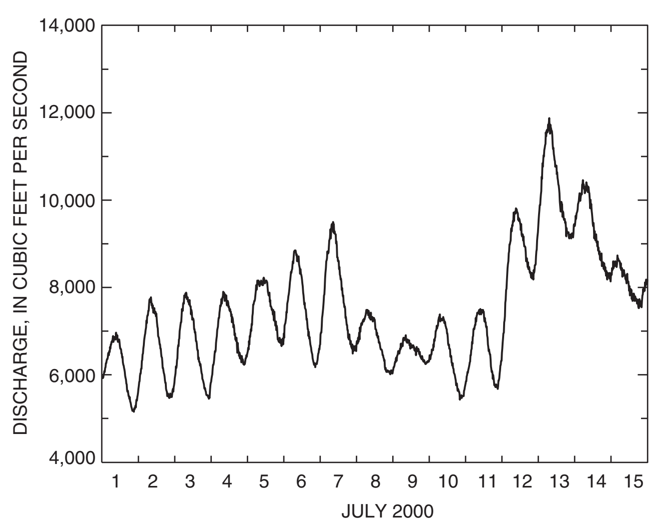

Figure 15. Discharge hydrograph for the Tlikakila River, July 1-15, 2000.

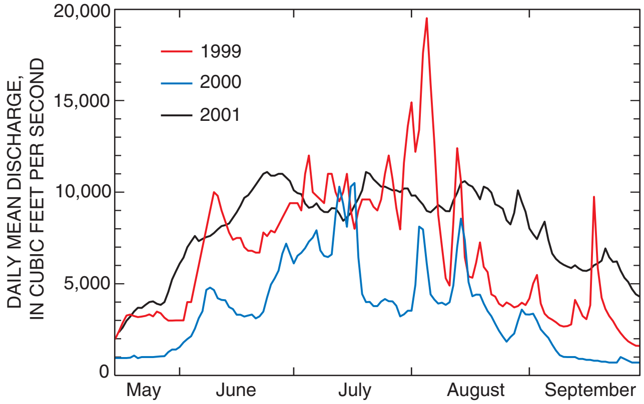

Figure 16. discharge hydrograph for the Tlikakila River, May through September 1999.

from a station at Port Alsworth and from stations adjacent to the Tlikakila River Basin, rainfall was below average during 2000. Rainfall records from a gage placed in the upper part of the Tlikakila River Basin during 2001 (fig. 2), indicated that more rainfall occurs in the upper part of the basin (fig. 4, 17).

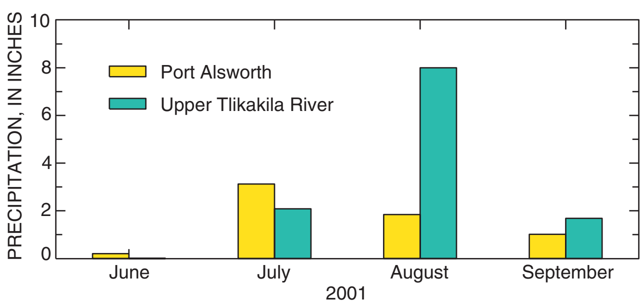

Figure 17. Precipitation at Port Alsworth and upper Tlikakila River, June through September, 2001

WATER BUDGET OF LAKE CLARK

The water budget of a lake, in its simplest terms, is the amount of water into and out of the lake. Mathematically, the relation is:

I - O = S

where:

I = Inflow

O = Outflow

S = change in storage

In different regions, the water budget equation will also account for other variables such as ground water inflow and evaporation. For Lake Clark, these variables were not considered to be significant and were not part of the water-budget equation.

The water budget of a lake can provide not only the total amount of water that enters and exits the lake in a given time period, but also can provide information such as the relative contribution from the various input components. For Lake Clark, sufficient information was available to assess the relative contribution of the Tlikakila River to the Lake Clark water budget.

During 1999-2001, discharge measurements made at the outlet of Lake Clark indicated a good statistical relation ($r^2 = 0.99$) with the lake elevation (fig. 18). Having daily lake elevation readings and using this statistical relation allowed the calculation of daily outflow from Lake Clark. The change in storage could be calculated by using the lake elevation data and the area of the lake surface (128 mi^2). This assumed that the lake area does not change significantly with lake elevation.

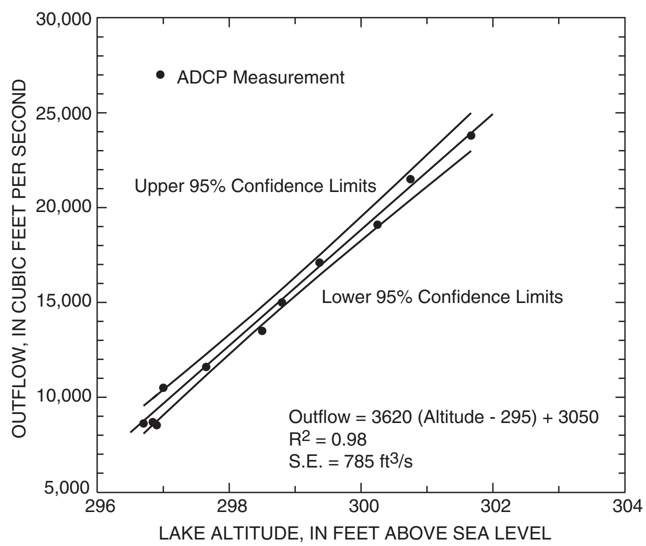

Figure 18. Relation between lake altitude and out-flow of Lake Clark.

Knowing the outflow and change in storage, the total inflow was calculated. Comparing the discharge of the Tlikakila River with the total amount of inflow indicated the relative contribution of the Tlikakila River to the water budget of Lake Clark. Results of the water-balance analysis (table 8) indicated that for the runoff period June to September 1999 there was a total of 4.24 million acre feet of inflow to Lake Clark with the Tlikakila River accounting for 1.74 million acre feet or 41 percent. In 2000, there was a total inflow into Lake Clark of 3.01 million acre feet with the Tlikakila River accounting for 0.95 million acre feet or 32 percent. In 2001, total inflow to Lake Clark was 4.65 million acre-feet with the Tlikakila accounting for 2.09 million acre feet or 45 percent. Thus, although the Tlikakila River Basin comprises only 21 percent of the Lake Clark watershed, it provides a substantially larger fraction of the total inflow to Lake Clark.

LOADS OF SELECTED WATER-QUALITY CONSTITUENTS

Analysis of the water-quality samples collected on the Tlikakila River for dissolved constituents indicated good correlation between specific conductance and the major dissolved ions (table 5). Using the regression equation developed for each constituent together with the continuous specific conductance collected on the Tlikakila River in 2000, loads of these constituents were computed as follows:

1) Using the average specific conductance for the day, the average concentration of each dissolved element was determined using the regression equation for the respective constituent (table 5).

2) Using the daily discharge and average concentration of the specific dissolved constituent, the daily load was computed using the equation:

$L = (Q)(C)(.0027)$

where:

L = daily load in tons

Q = daily mean discharge in ft^3/s

C = daily mean concentration in mg/L

.0027 = unit conversion factor

Loads of the dissolved major ions from June through September 2000 ranged from 419 tons for chloride to about 27,000 tons for bicarbonate (table 9). Bicarbonate loads constitute the greatest loads every month, followed by calcium, silica, and sulfate. The greatest loads of these constituents were transported in July, the month of maximum discharge.

Daily suspended-sediment loads for the Tlikakila River were calculated using the minimum variance unbiased estimator (MVUE) or Bradu-Mundlak estimator as outlined by Cohn and others (1989). This technique uses the relation between the instantaneous discharge and instantaneous suspended load (fig. 14) and the continuous daily discharge and corrects the relation between the instantaneous values for the daily values. Also, because the equation relating suspended sediment load and discharge was based on the logarithm of discharge, a bias correction factor is applied.

Using the MVUE technique, monthly suspended-sediment loads from June through September 1999-2001 were determined for the Tlikakila River

Table 8. Water budget of Lake Clark and contribution of the Tlikakila River

[values in acre-feet, values are rounded]

Month	Inflow to Lake Clark	Outflow from Lake Clark	Change in storage of Lake Clark	Tlikakila contribution	Percent of inflow from Tlikakila River
1999					
June	1,170,000	778,000	392,000	430,000	37
July	1,190,000	1,190,000	0	616,000	55
August	1,120,000	1,180,000	-60,000	486,000	43
September	761,000	865,000	-104,000	205,000	27
Total	4,240,000			1,740,000	41
2000					
June	624,000	444,000	180,000	233,000	37
July	1,040,000	918,000	122,000	376,000	36
August	791,000	878,000	-87,000	268,000	34
September	558,000	613,000	-55,000	75,700	14
Total	3,010,000			953,000	32
2001					
June	1,530,000	997,000	533,000	535,000	35
July	1,430,000	1,490,000	-60,000	596,000	42
August	1,090,000	1,260,000	-170,000	585,000	54
September	595,000	798,000	-203,000	370,000	62
Total	4,650,000			2,090,000	45

Table 9. Monthly loads of selected water-quality constituents for the Tlikakila River, June through September 2000 (station 15297970)

[values in tons, total values rounded]

Constituent	June	July	August	September	Total
Dissolved Solids	9,600	13,700	10,200	4,200	37,700
Calcium	1,900	2,900	2,200	857	7,860
Magnesium	215	294	222	104	835
Potassium	361	547	398	139	1,400
Bicarbonate	6,800	10,100	7,400	2,700	27,000
Sodium	230	308	234	116	888
Chloride	113	130	105	71	419
Silica	1,300	1,800	1,400	574	5,100
Sulfate	1,200	1,700	1,200	557	4,700

(table 10). Due to the relatively large confidence limits of the relation between discharge and suspended sediment (fig. 14), the estimates of the monthly suspended-sediment loads have a large variation. Because suspended-sediment load is highly dependent on the amount of flow, more than twice as much suspended sediment was transported during the 1999 and 2001 runoff seasons (1.1 and 1.4 million tons respectively) than during the 2000 runoff season (0.4 million tons). Most suspended-sediment load is transported during July and August (the time of maximum flow) for all three years.

OTHER MAJOR TRIBUTARIES TO LAKE CLARK

Some flow and water-quality data were collected during the study from the remaining five tributaries and at the outlet of Lake Clark (appendix 2-7). Flow data consisted of monthly miscellaneous measurements during the open-water season from June through September. Water-quality data consisted of field determinations (specific conductance, pH, water temperature, and dissolved oxygen), alkalinity, and suspended sediment. At all locations, continuous water-temperature data were collected periodically.

Monthly discharge measurements (fig. 19, table 11) help define the relative contribution of inflow from each tributary. Each monthly set of measurements usually took 2-3 days to complete and represent only that one short period of the month. Since there are daily fluctuations in discharge at all the major tributaries during a particular month, the relative contribution of discharge from each tributary could change within the month.

During the study period, the monthly discharge measurements indicated that the Chulitna River generally contributed the second highest flow (after the Tlikakila) to Lake Clark, with the exception of two times when it provided the greatest discharge to Lake Clark or once when the Tanalian River provided the second highest inflow. Several times, discharges for the Chokotonk River and Currant Creek, two basins about the same size and with about the same amount of glacier cover (table 2) were almost equal.

In terms of water quality, the range of specific conductance, pH, dissolved oxygen, and alkalinity among the other tributaries was similar (table 11) and would not be detrimental to fish. Concentrations of alkalinity indicate that the other tributaries have a low buffering capacity similar to the Tlikakila River. Suspended-sediment concentrations were greatest from the Tlikakila and the other two glacier dominated streams—the Chokotonk River and Currant Creek (fig. 20). The

Table 10. Monthly loads of suspended sediment for the Tlikakila River, June through September 1999-2001 (station 15297970)

[values in tons]

Water Year	June	July	August	September	Total (rounded)
1999	248,000	453,000	363,000	69,000	1,100,000
2000	83,000	197,000	108,000	12,000	400,000
2001	376,000	424,000	414,000	240,000	1,500,000
Average					1,000,000

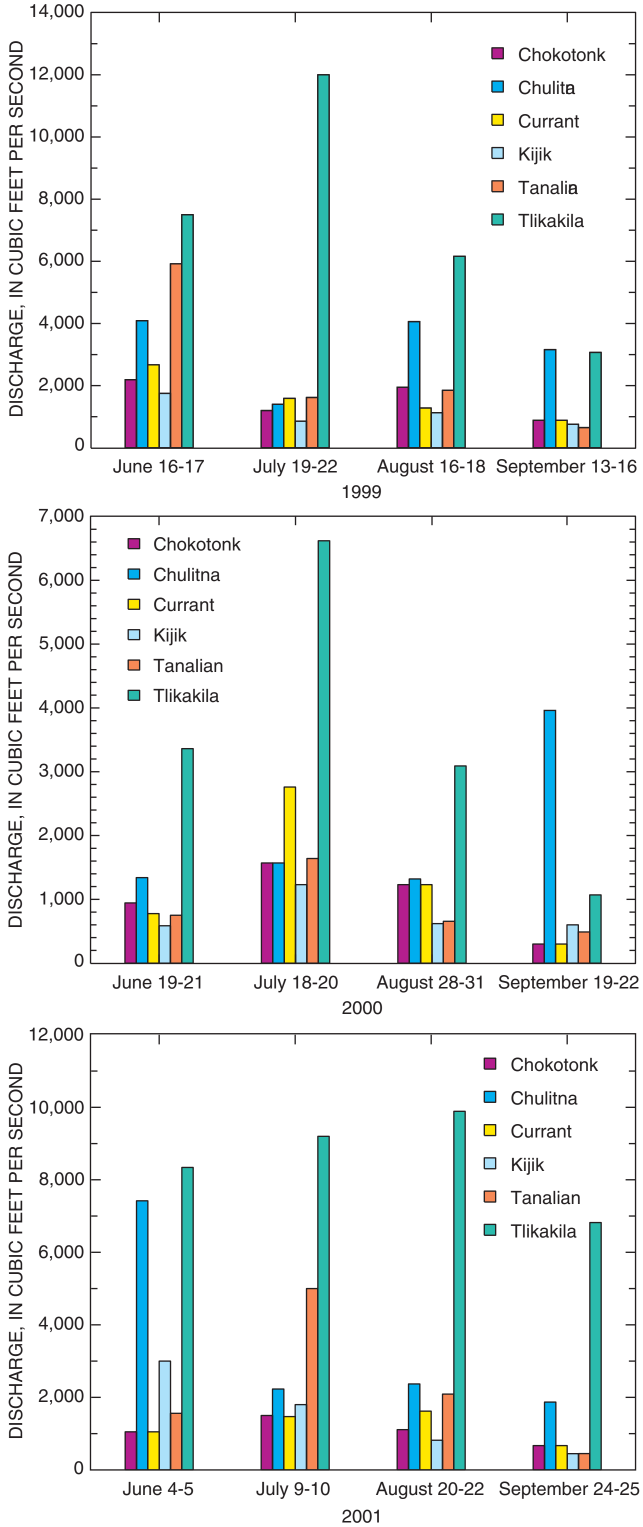

Figure 19. Discharge measurments made at major tributaries to Lake Clark, June through September 1999-2001.

other tributaries contribute relatively small amounts of sediment, probably because lakes in their basins trap sediments (Tanalian and Kijik River Basins), or rela

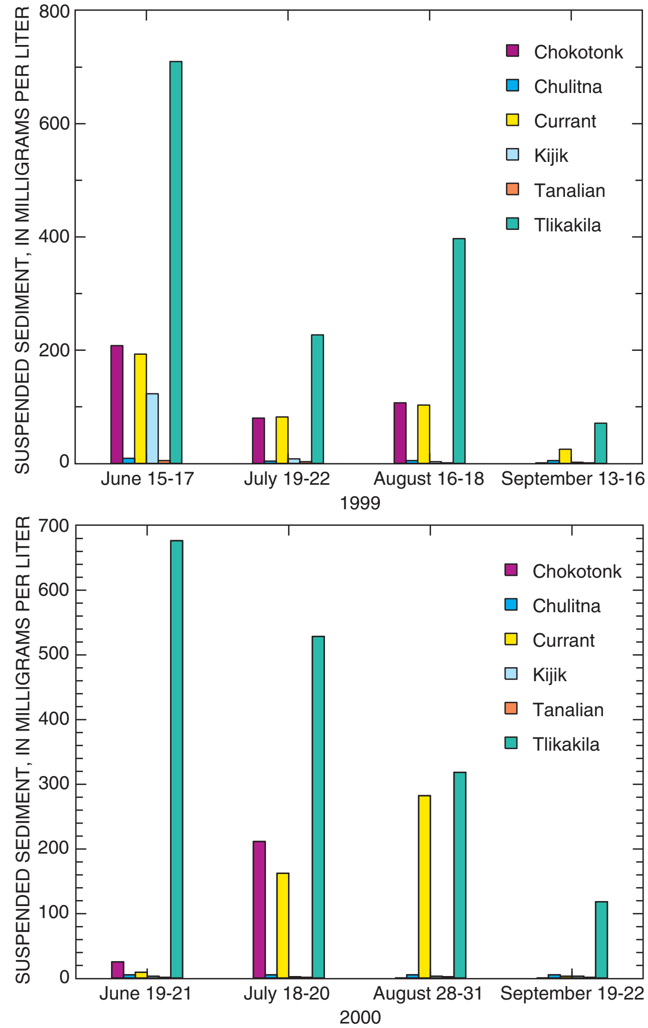

Figure 20. Suspended-sediment concentrations of major tributaries to Lake Clark, June through September 1999-2000.

tively flat basin topography, and the presence of many lakes within the basin that act as settling basins (Chulitna River Basin).

Continuous water-temperature data from the major tributaries provide insights into the characteristics of each river (fig. 21). The Chulitna River provides the warmest water to Lake Clark. From late-June to mid-August, water temperatures are near or above 14^{o}C. In late August, temperatures decline rapidly. For the outlet of Lake Clark and the two rivers that have large lakes located in their watersheds, the Kijik River and the Tanalian River, the warmest temperatures can exceed 13^{o}C (fig. 21). However, there is a gradual warming and cooling of these rivers due to the lake affect. During the winter, temperatures may reach 0^{o}C (unsuitable for fish), but for only relatively short peri

Table 11. Ranges in discharges and selected water-quality constituents for six major tributaries to Lake Clark, 1999-2001

[ft^3/s, cubic feet per second, mg/L, milligrams per liter, us/cm, microsiemens per centimeter, ^oC, degrees Celsius]

Tributary	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (us/cm)	Water temperature (^oC)	Alkalinity (mg/L as $CaCo_3$)	Suspended sediment (mg/L)
Chokotonk River	258-2,190	11.3-14.3	7.0-8.2	28-74	0.0-10.0	11-24	9-211
Tlikakila River	25-12,000	11-14	7.2-8.1	31-117	0-9.4	13-37	5-710
Currant Creek	279-2,760	11.1-14.9	6.9-7.6	36-74	1.7-7.5	11-20	3-282
Kijik River	432-3,000	9.4-13.7	7.0-7.8	70-88	3.5-12.5	24-28	2-123
Tanalian River	179-5,920	10.1-13.8	7.0-7.8	44-54	5.5-13.5	10-13	1-5
Chulitna River	1,320-7,420	10.0-13.2	7.0-7.8	53-85	1.0-14.5	21-36	4-9
Lake Clark outlet	8,530-23,800	10.3-14.1	7.0-7.9	55-62	4.5-11.5	20-21	1-5

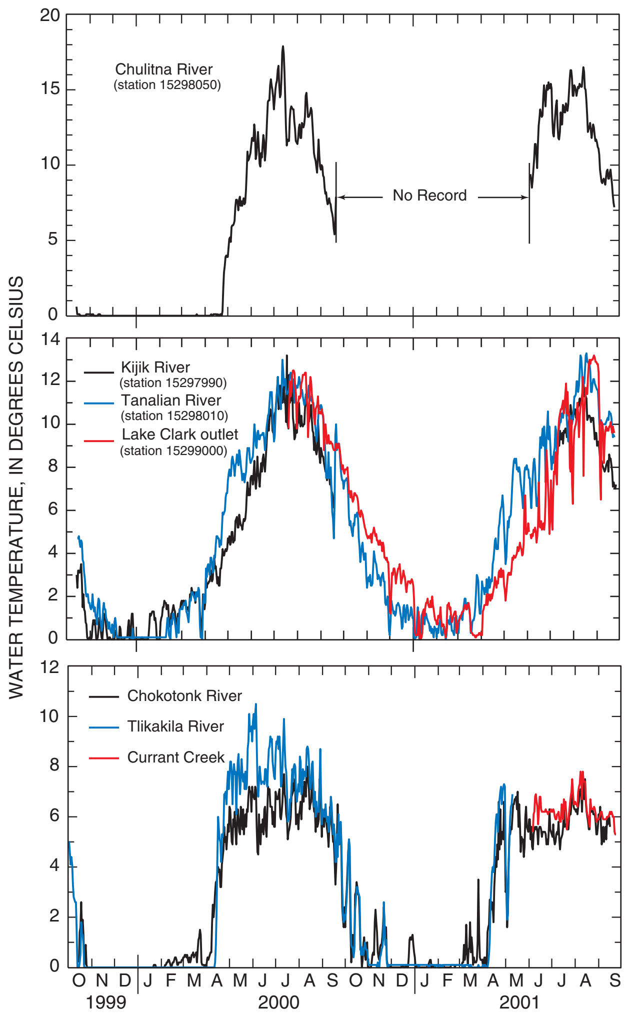

Figure 21. Water temperature of major tributaries to Lake Clark, October 1999 through September 2001.

ods. The three glacier streams, the Chokotonk River, Currant Creek, and the Tlikakila River, have the coldest water temperatures. Temperatures at these streams reflect glacier melt and the warmest temperatures reach about 10^oC. Temperatures rapidly rise in April and rapidly fall in September and October.

SUMMARY AND CONCLUSIONS

The Tlikakila River Basin, located in Lake Clark National Park and Preserve, drains an area of 622 mi^2. This watershed comprises about 21 percent of the Lake Clark Basin, making it one of the major tributaries to Lake Clark. Due to a sharp decline in sockeye salmon population and the lack of hydrologic data, the Tlikakila River and five other major tributaries to Lake Clark were studied during the summer runoff months (may through September) from 1999 through 2001 as part of a cooperative study with the National Park Service. Major findings are:

• Field measurements of dissolved oxygen and pH of the Tlikakila River were within acceptable levels for fish survival. The highest measurements of specific conductance occur during low-flow periods and field alkalinity concentrations indicate a low buffering capacity of the river.

• Water temperature of the Tlikakila River is 0^oC from late October to mid-April, which is not suitable for fish at this location. After the river ice is gone, water temperature rises quickly to between 5 and 6^oC. As air temperature and runoff increases, water temperature increases to approximately 10^oC in mid-May. As runoff from snowmelt and glacier ice melt enter the Tlikakila, a general cooling trend takes place to the end of September.

• The ionic composition of water of the Tlikakila River is a calcium bicarbonate water type. Values of un-ionized ammonia are well below the value of 0.02 mg/L recommended by the USEPA for fish propagation. The nitrogen to phosphorus ratio varies from less than 1 during high flow periods to about 25 during low flow periods. Concentrations of dissolved organic carbon and particulate organic carbon were less than 1.0

mg/L, reflecting the fact that most of the Tlikakila River Basin consists of rough mountainous lands with a thin soil cover.

• The Tlikakila River is the major contributor of suspended sediment to Lake Clark. During the three years of study, the Tlikakila River transported 1.1, 0.4, and 1.5 million tons respectively of suspended sediment to Lake Clark. Most of the suspended sediment consists of silt and clay particles that are dispersed throughout the entire lake, affecting light transmissivity.

• Most of the runoff from the Tlikakila River occurs from mid-May through September. Average flow during 1999 - 2001 was 6,600 ft^3/s. Total annual inflow to Lake Clark from the Tlikakila River ranged from 32 to 45 percent of the total inflow. The relatively high proportion of inflow is due to the presence of glaciers, which comprise 36 percent of the watershed.

• In addition to the Tlikakila River, there are five other major tributaries to Lake Clark - the Chokotonk, Chulitna, Kijik, and Tanalian Rivers, and Currant Creek. The Chulitna River, which drains the largest basin in the Lake Clark watershed, generally had the second highest discharges during the study period, although the Tanalian River had higher measured discharges on two occasions. Currant Creek and the Chokotonk River, which have glaciers in a portion of their basins, transport some suspended sediment, although considerably less than the amounts transported by the Tlikakila River. The Chulitna River, which has a relatively flat slope, and the Kijik and Tanalian Rivers, which have large lakes located in their basins, generally transport only small amounts of suspended sediment. The Chulitna River has the warmest water temperature of the major tributaries to Lake Clark. The Kijik River and Tanalian River have similar temperature ranges that may be due to the presence of lakes in their basins and are characterized by relatively, slowly declining and rising temperatures. Water temperatures of Currant Creek and the Chokotonk River are similar to the Tlikakila River and have the coldest temperatures due to glacier ice melt. These rivers are characterized by rapidly rising and falling temperatures.

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Appendix 1. Physical properties and water-quality constituents of streamflow samples collected from the Tlikakila River, March through September 2000 (USGS station number 15297970)

[ft^3/s, cubic feet per second; μs/cm, microsiemens per centimeter; ^oC, degrees Celsius; mg/L, milligrams per liter; --, no data; E, estimated]

Date (mm-dd-yy)	Time	Discharge (ft^3/s)	Specific conductance (μs/cm)	pH	Water temperature (^oC)	Dissolved oxygen (mg/L)	Calcium (mg/L)	Magnesium (mg/L)
3-16-99	1700	25	117	7.5	0.0	11.8	15.0	1.76
5-13-99	1417	510	89	7.6	9.0	11.7	12.4	1.29
6-16-99	1130	7,500	40	8.1	6.0	12.2	5.44	0.46
7-26-99	1730	12,000	31	7.6	7.0	11.3	4.66	0.37
8-18-99	1610	6,160	32	7.4	7.0	11.7	5.05	0.38
9-16-99	1430	3,070	55	7.2	6.0	13.3	7.15	0.57
10-14-99	1115	871	91	7.3	0.0	11.6	--	--
5-16-00	1815	950	76	7.6	9.4	13.6	11.3	1.06
6-20-00	1645	3,320	48	7.5	7.5	11.0	7.30	0.59
7-18-00	1315	6,440	37	7.6	5.0	14.0	5.67	0.41
8-31-00	1345	3,330	44	7.5	5.0	13.0	6.06	0.44
9-21-00	1620	750	71	7.5	8.0	11.0	9.67	0.84

Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L as HCO_3)	Alkalinity (mg/L as $CaCO_3$)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)
3-16-99	1700	2.3	1.9	45	37	10.5	1.8	<.1	8.6
5-13-99	1417	1.9	1.8	35	29	7.4	1.4	<.1	7.9
6-16-99	1130	0.7	0.8	22	17	3.3	0.3	<.1	3.5
7-26-99	1730	0.6	1.1	16	13	2.3	<.1	<.1	2.5
8-18-99	1610	0.5	0.9	17	14	1.9	0.2	<.1	2.5
9-16-99	1430	0.8	1.1	22	18	4.5	<.3	<.1	3.8
10-14-99	1115	--	--	36	30	--	--	--	--
5-16-00	1815	1.7	1.9	34	26	7.2	1.1	<.1	7.9
6-20-00	1645	1.0	1.5	23	18	4.5	0.4	<.1	4.8
7-18-00	1315	0.6	1.0	20	15	2.6	0.3	<.1	2.8
8-31-00	1345	0.6	1.0	21	16	2.6	0.3	<.1	2.8
9-21-00	1620	1.3	1.5	30	23	7.1	0.7	0.2	5.3

Date	Time	Solids residue at 180 ^oC dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L)	Nitrogen, ammonia dissolved (mg/L)	Nitrogen, ammonia + organic Total (mg/L)	Nitrogen, ammonia + organic dissolved (mg/L)	Nitrogen, total (mg/L)	Phosphorus, total (mg/L as P)
3-16-99	1700	76	0.001	0.576	0.013	0.10	E.10	0.68	0.029
5-13-99	1417	56	0.001	0.568	0.005	E.10	E.10	0.67	0.034
6-16-99	1130	34	0.001	0.163	0.003	0.27	0.10	0.43	0.902
7-26-99	1730	11	<.001	0.065	.002	<.10	E.10	0.17	0.356
8-18-99	1610	21	<.001	0.069	0.004	0.25	<.10	0.32	0.352
9-16-99	1430	33	0.001	0.129	0.028	<.10	<.10	0.23	0.085
10-14-99	1115	--	--	--	--	--	--		--
5-16-00	1815	53	0.001	0.818	0.002	E.10	E.10	0.92	0.036
6-20-00	1645	36	<.001	0.252	0.002	<.10	<.10	0.35	0.203
7-18-00	1315	25	0.001	0.077	<.002	<.10	<.10	0.18	0.424
8-31-00	1345	28	0.001	0.080	<.002	<.10	<.10	0.18	0.244
9-21-00	1620	48	<.001	0.220	0.004	<.10	<.10	0.32	0.077

Appendix 1. Continued

Date	Time	Phophorus dissolved (mg/L as P)	Phosphorus ortho dissolved (mg/L as P)	Iron dissolved (ug/L as Fe)	Manganese dissolved (ug/L as Mn)	Dissolved organic carbon (mg/L as C)	Particulate organic carbon total (mg/L as C)	Suspended sediment concentration (mg/L)
3-16-99	1700	<.004	.002	26	15	0.60	<.2	5
5-13-99	1417	<.004	0.001	80	8	0.70	<.2	25
6-16-99	1130	0.004	0.004	80	6	0.70	0.9	710
7-26-99	1730	0.005	0.005	20	6	0.40	0.5	227
8-18-99	1610	<.004	<.001	10	5	0.20	0.2	397
9-16-99	1430	<.004	<.001	10	3	0.30	0.2	71
10-14-99	1115	--	--	--	--	--	--	9
5-16-00	1815	E.003	0.003	60	6	0.60	0.2	29
6-20-00	1645	<.006	<.001	40	3	0.41	<.2	676
7-18-00	1315	<.006	0.003	30	5	E.24	0.2	528
8-31-00	1345	<.006	0.001	30	5	E.17	0.3	318
9-21-00	1620	<.006	0.001	<10	3	0.35	<.2	118

Appendix 2. Physical properties and water-quality constituents of streamflow samples collected from the Chokotonk River, June through September 1999-2001(USGS Station number 15297930)

[ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter; ^oC), degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (µs/cm)	Water temperature (^oC)	Alkalinity (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Suspended sediment concentration (mg/L)
6-16-99	1416	2,190	12.5	8.2	28	6.0	11		208
7-22-99	1515	1,200	--	7.6	33	10.0	11		80
8-17-99	1145	1,950	11.3	7.3	31	5.5	12		107
10-14-99	1330	258	11.6	7.1	74	0.0	24		9
6-20-00	1300	944	12.5	7.2	40	6.0	16		25
7-18-00	1120	1,500	14.3	7.4	30	4.5	11		211
7-10-01	1200	--	12.8	7.6	35	4.5	--	--	--
8-22-01	1130	--	12.1	7.0	30	4.5	--	--	--
9-17-01	1450	--	12.2	7.2	45	6.5	--	--	--

Appendix 3. Physical properties and water-quality constituents of streamflow samples collected from the Chulitna River, June through September 1999-2001 (USGS station number 15298050)

[ft^3/s, cubic feet per second; µs/cm, microsiements per centimeter; ^oC, degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (µs/cm)	Water temperature (^oC)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment concentration (mg/L)
6-17-99	1430	4,090	10.6	7.1	58	11.5	21	9
7-20-99	1710	1,400	10.8	7.7	77	12.4	31	4
8-16-99	1515	4,060	10.5	7.4	70	11.2	28	5
9-13-99	1615	3,160	11.2	7.5	76	9.0	29	5
10-13-99	1245	2,570	13.2	7.4	76	1.0	28	5
6-19-00	1700	1,340	11.2	7.4	69	10.0	28	5
7-19-00	1325	1,570	10.3	7.8	78	11.0	32	5
8-28-00	1900	1,320	10.0	7.8	85	11.0	36	5
9-22-00	1300	3,960	12.2	7.0	66	8.0	24	5
6-4-01	1800	7,420	12.9	7.1	53	9.5	--	--
7-9-01	1830	2,230	10.1	7.8	71	14.5	--	--
8-20-01	1445	2,370	10.0	7.6	81	12.0	--	--
9-25-01	1345	1,870	11.4	7.0	82	7.5	--	--

Appendix 4. Physical properties and water-quality constituents of streamflow samples collected from Currant Creek, June through September 1999-2001 (USGS station number 15297980)

[ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (µs/cm)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment concentration (mg/L)
6-16-99	1655	2,670	12.1	7.4	45	7.5	12	193
7-21-99	1415	1,590	--	7.5	36	7.0	11	82
8-17-99	1425	1,280	11.1	7.4	40	7.5	13	103
9-15-99	1515	885	12.6	7.0	51	6.0	15	25
10-17-99	1720	279	11.6	7.3	74	2.0	20	7
6-21-00	1100	776	14.0	7.6	37	5.4	12	9
7-18-00	1510	2,760	13.8	7.5	37	5.5	12	162
8-29-00	1215	1,230	12.0	7.4	36	6.5	11	282
9-19-00	1725	297	14.9	7.4	71	6.5	19	3
6-5-01	1200	1,050	14.3	7.6	54	6.0	--	--
7-10-01	1430	1,470	12.4	7.4	43	6.0	--	--
8-22-01	1500	1,620	11.4	6.9	38	7.5	--	--
9-25-01	1645	671	13.7	7.0	55	5.5	--	--

Appendix 5. Physical properties and water-quality constituents of streamflow samples collected from the Kijik River, June through September 1999-2001 (USGS station number 15297990)

[ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductanc e (*u*s/cm)	Water temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment concentration (mg/L)
6-17-99	1600	1,750	12.7	7.6	76	7.5	25	123
7-20-99	1415	857	11.1	7.6	80	10.5	24	8
8-17-99	1730	1,130	9.4	7.7	78	12.5	24	3
9-14-99	0915	758	12.3	7.1	88	7.5	25	2
10-13-99	1445	432	11.2	7.3	88	3.5	28	6
6-21-00	1630	586	11.6	7.6	84	12.0	25	3
7-20-00	0930	1,230	11.6	7.8	78	9.0	26	2
8-29-00	1410	620	10.6	7.7	80	9.5	25	3
9-19-00	1550	600	13.5	7.6	85	7.5	27	3
6-5-01	1300	3,000	13.7	7.7	70	6.5	--	--
8-20-01	1630	817	10.2	7.6	73	12.0	--	--
9-25-01	1530	447	11.7	7.0	86	8.5	--	--

Appendix 6. Physical properties and water-quality constituents of streamflow samples collected from the Tanalian River, March through September 1999-2001 (USGS station number 15298010)

[ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter; ^oC, degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (*u*s/cm)	Water temperature (^oC)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment concnetration (mg/L)
6-17-99	1800	5,920	13.0	7.4	54	7.0	13	5
7-19-99	1845	1,620	11.4	7.5	44	11.3	10	3
8-16-99	1640	1,850	11.3	7.2	44	11.5	11	1
9-13-99	1801	650	10.4	7.1	50	10.5	11	1
10-14-99	1650	543	10.3	7.0	52	5.5	12	3
5-15-00	1500	179	11.5	7.4	54	8.5	13	2
6-21-00	1820	750	11.4	7.7	47	10.5	12	1
7-19-00	1530	1,640	10.1	7.8	46	11.5	11	1
8-30-00	1315	656	10.5	7.3	45	11.0	11	2
9-20-00	1100	489	12.0	7.2	50	8.5	12	1
6-5-01	1545	1,560	13.8	7.5	54	7.0	--	--
8-20-01	1730	2,090	13.4	7.5	45	13.5	--	--
9-24-01	1700	450	11.4	7.0	44	10.0	--	--

Appendix 7. Physical properties and water-quality constituents of streamflow samples collected from Lake Clark outlet, June through September 1999-2001 (USGS station number 15299000)

[ft^3/s, cubic feet per second; µs/cm, microsiemens per centimeter; ^oC, degrees Celsius; mg/L, milligrams per liter]

Date	Time	Discharge (ft^3/s)	Dissolved oxygen (mg/L)	pH	Specific conductance (*u*s/cm)	Water temperature (^oC)	Alkalinity (mg/L as $CaCO_3$)	Suspended sediment concentration (mg/L)
6-17-99	1030	13,500	12.5	7.9	62	4.5	20	1
7-19-99	1705	19,100	13.6	7.8	56	6.0	20	2
8-16-99	1300	21,400	10.3	7.6	57	10.5	20	1
9-14-99	1400	15,300	11.8	7.3	58	11.0	21	1
10-12-99	1620	10,800	11.2	7.3	62	6.5	20	1
6-19-00	1230	8,620	11.8	7.3	55	5.0	20	1
7-19-00	1115	17,100	11.4	7.6	58	9.5	21	1
8-28-00	1645	11,600	11.0	7.8	58	11.5	21	3
9-22-00	1100	8,690	12.4	7.0	58	8.5	20	5
6-4-01	1600	8,530	14.1	7.9	59	6.0	--	--
7-9-01	1630	23,800	11.6	7.8	60	7.5	--	--
8-20-01	1230	21,600	10.4	7.6	58	7.6	--	--
9-25-01	1100	10,600	10.8	7.2	57	10.0	--	--