UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYDROLOGIC RECONNAISSANCE OF THE CHILKAT RIVER BASIN, SOUTHEAST ALASKA

With Special Reference to the Bald Eagle Critical Habitat at the Tsirku River Alluvial Fan

By Edward F. Bugliosi

U.S. GEOLOGICAL SURVEY

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Multiply	by	to obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
ton, short, per day (ton/d)	0.9072	megagram per day (Mg/d)
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius (°C)
micromho per centimeter at 25°C (µmho/cm at 25° C)	1.0000	microsiemens per centimeter at 25°C (µS/cm at 25° C)

Other abbreviations in this report are:

mg/L, milligram per liter
µg/L, microgram per liter
NTU, nephelometric turbidity unit

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ABSTRACT

The Chilkat River basin in southeast Alaska is characterized by rugged, highly dissected mountains with steep-gradient streams, braided rivers in broad alluvium-filled valleys, and numerous glaciers. A wide seasonal range in temperature and strong orographic effects cause variations in the amount and distribution of precipitation, and thus in the resulting runoff and streamflow. Streamflow is lowest in winter, when precipitation at higher altitudes is stored as snow, and greatest in summer, when melting snow and glacier ice augment flow. Ground-water seeps and springs flowing from alluvial fans contribute to streamflow year round.

A ground-water discharge zone of particular interest is that along the toe of the Tsirku River alluvial fan, 20 miles north of Haines. During winter, the relatively warm (4 to 6 degrees Celsius) ground water maintains open leads in a reach of the Chilkat River downstream from the fan. This ice-free reach provides favorable spawning habitat for a late run of chum and coho (silver) salmon, which in turn attracts the world's largest concentration of bald eagles (more than 3,000 birds). The principal source of recharge to the ground-water system in the fan is loss of water through the beds of the many distributary channels across the fan surface.

Calculation of a water budget for the system for the period October 1982 through May 1983 indicates that ground-water discharge at the toe of the fan averages 640 cubic feet per second.

Surface and ground waters are chemically similar, calcium bicarbonate types. All stream samples had dissolved-solids concentrations of less than 115 milligrams per liter; values for ground water were slightly greater. During high summer flows, the suspended-sediment concentrations of the glacially fed Chilkat, Tsirku, and Klehini Rivers ranged from 361 to 1,530 milligrams per liter (6,360 to 22,300 tons per day).

INTRODUCTION

The Chilkat River basin, at the head of Lynn Canal about 80 mi northwest of Juneau in southeast Alaska (fig. 1), is bordered by the Takhinsha Mountains and Glacier Bay National Park and Preserve to the south and by the Takshanuk Mountains to the east (fig. 2). The northern and western parts of the basin lie within British Columbia, Canada.

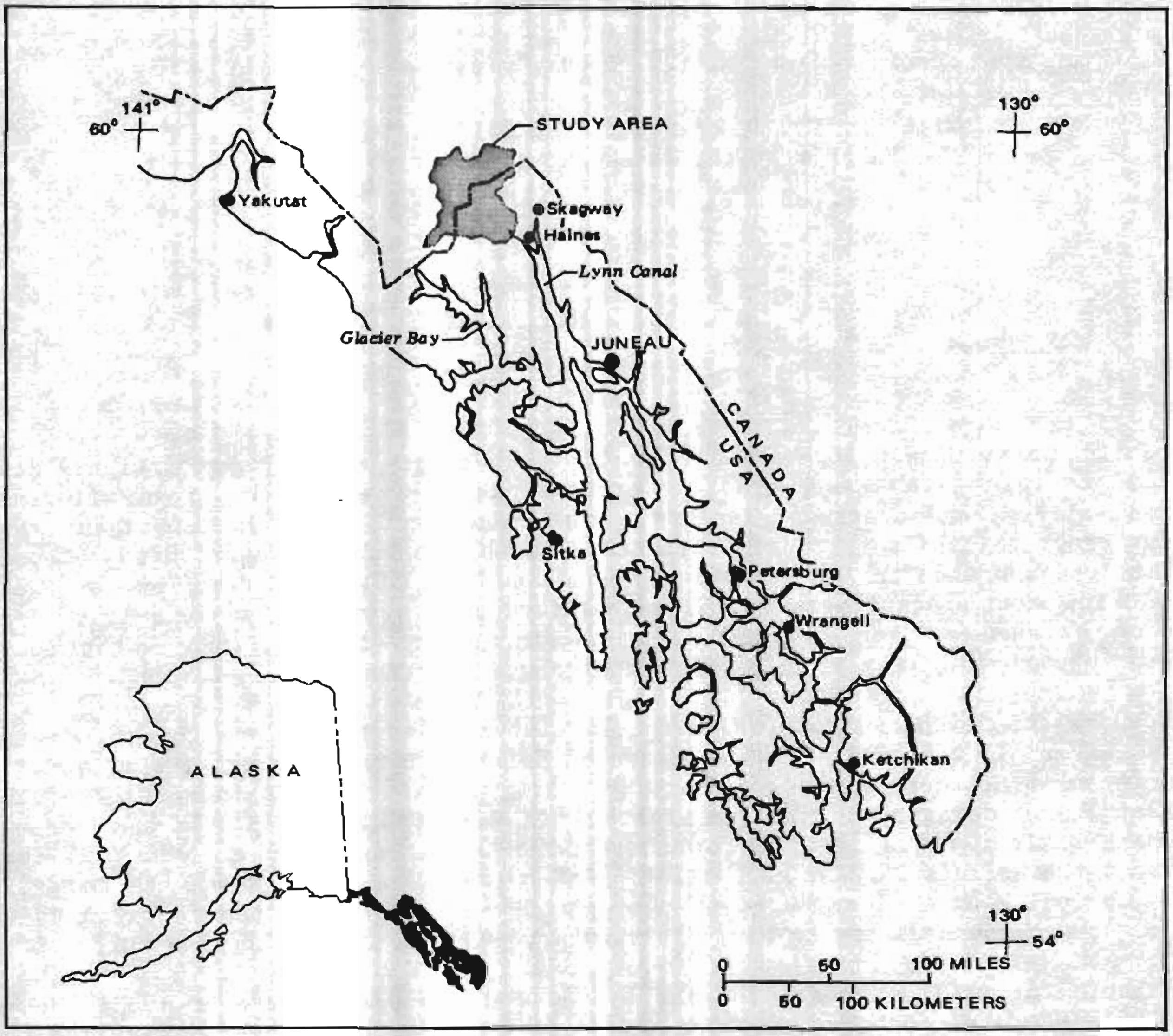

Figure 1. - Location of study area.

During the period May 1982 to June 1983, the temperature at Haines ranged from -12 to 92° F. It is not uncommon for simultaneous temperatures to differ by as much as 10° F between Haines and Klukwan, 20 mi from each other. Precipitation also differs significantly between the two areas (fig. 3). Generally, during winter, the Tsirku alluvial fan area near Klukwan is colder and receives less precipitation than Haines.

GEOLOGY

The Chilkat River basin is divided into two distinct geologic provinces by the Chilkat River fault (which roughly parallels the Chilkat River), an extension of the Chatham Strait fault system to the south (Brew and others, 1966; Ovenshine and Brew, 1972). The geology of two 1:63,360 quadrangles (Skagway B-3 and B-4) has been mapped by MacKevett and others (1974). East of the fault and Chilkat River, structural trends are predominantly northwest, as in much of southeast Alaska; west of the fault and river the structural trends are complex and include west-trending faults and lineaments.

The rocks east of the Chilkat River consist of intrusives and metavolcanics that range in age from Cretaceous to early Tertiary, from about 100 to 50 million years old (figs. 4 and 5). West of the river, the basin is underlain by lithologically diverse, metamorphosed Paleozoic, Cretaceous, and Tertiary rocks, from 500 to 50 million years old.

GEOMORPHIC AND GLACIAL HISTORY

The geologic history of the Chilkat River basin includes periods of mountain building which began as late as Cenozoic time (60 million years ago) and presently continues (Ovenshine and Brew, 1972). This movement produced the rugged, highly dissected mountains characteristic of the area. The principal land-shaping process in recent (Quaternary) geologic time has been glaciation, which is still dominant in the upper parts of the basin. Most types of glacial features can be found in the Chilkat River basin, including ground moraine which covers much of the bedrock at lower altitudes, especially in the area of the Tsirku River alluvial fan.

The complex glacial history includes multiple, basin-wide glaciations and local fluctuations of individual glaciers. The last advance of ice into the lower altitudes of the valleys (at least as far downvalley as the Tsirku alluvial fan) may have been as recent as about 1,700 years or as early as about 11,000 years before present (McKenzie and Goldthwait, 1971). Multiple Wisconsin glacial fluctuations in the study area have not been defined, but the fluctuations probably paralleled those in Adams Inlet of Glacier Bay National Monument (McKenzie and Goldthwait, 1971).

Topographic maps compiled from aerial photographs taken in 1962 show about 25 percent of the Chilkat River basin covered by glaciers. Ice cover within the major subbasins ranges from 5 to 37 percent (table 1). More recent observations and aerial photographs indicate the glaciers have been retreating during the past 30 years (L. R. Mayo, U.S. Geological Survey, oral commun., 1982), so that present-day ice cover in the basin is probably less than that shown on the maps.

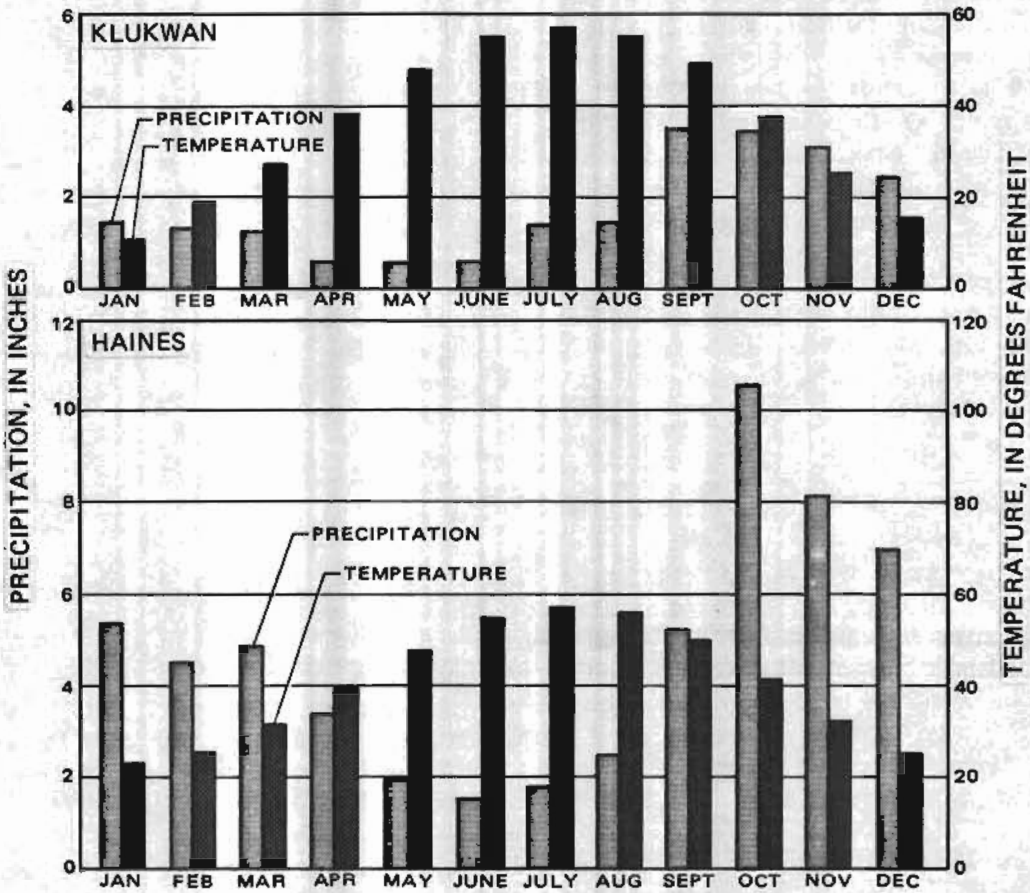

Figure 3. -- Comparison of mean monthly values of precipitation and temperature for Haines and Klukwan 1927-1943 (from Johnson and Twenhofel, 1953).

Table 1.--Percentage ice cover in the major subbasins within the Chilkat River basin

Subbasin	Ice cover
Chilkat Lake	5
Kelsall River	5
Klehini River	22
Tahini River	10
Takhin River	37
Tsirku River	35

SURFACE WATER

Chilkat Lake

There are many glacial lakes in the Chilkat River basin, but only three—Duff, Kelsall, and Chilkat--have areas equal to or greater than 0.5 mi^2. Chilkat Lake, the only one of these three that lies within Alaska, occupies a glacially scoured, fault valley about 3 mi southwest of Klukwan (fig. 2). The lake was formed by blockage at its northwest end either as the glacier that occupied the valley retreated toward the northwest, or as outwash debris from the glacier accumulated to its present altitude of about 200 ft. A former outlet at an altitude of 300 to 400 ft (sec. 17 and 19, T. 29 S., R. 57 E.; fig. 6) suggests that the present outlet was once dammed by a glacier. The older outlet has since been abandoned for the present, lower one located between the lake and the Tsirku River (fig. 6). The lake is now about 6 mi long, 1.5 mi at the widest spot, and has an area of about 4 mi^2. The greatest measured depth was more than 200 ft.

Inflow to Chilkat Lake is derived from perennial and intermittent streams that drain an area of 43 mi^2, about 5 percent of which is ice covered. Some ground water flows to the lake from the highly fractured bedrock and numerous faults in the area. No direct measurements of such inflow have been made. Outflow is primarily via a stream to the Tsirku River. Discharge at the lake outlet, measured at both high- and low-flow conditions, was 304 ft^3/s on August 18, 1981 and 27 ft^3/s on April 6, 1982.

Vertical profiles of temperature, specific conductance, pH, and dissolved-oxygen concentration were measured at a site (fig. 6) on Chilkat Lake on August 18, 1981 and March 15, 1983 (fig. 7). Two samples were collected on each date, one at mid-epilimnion (20 to 25 ft) and one at mid-hypolimnion (100 to 125 ft). Samples were analyzed for major inorganic constituents, nutrients, selected trace metals, and total organic carbon (table 2).

The calcium bicarbonate water of Chilkat Lake differs only slightly in chemical makeup between the epilimnion and hypolimnion (fig. 8). The waters of the lake and of a major stream entering the southern end of the lake are chemically similar

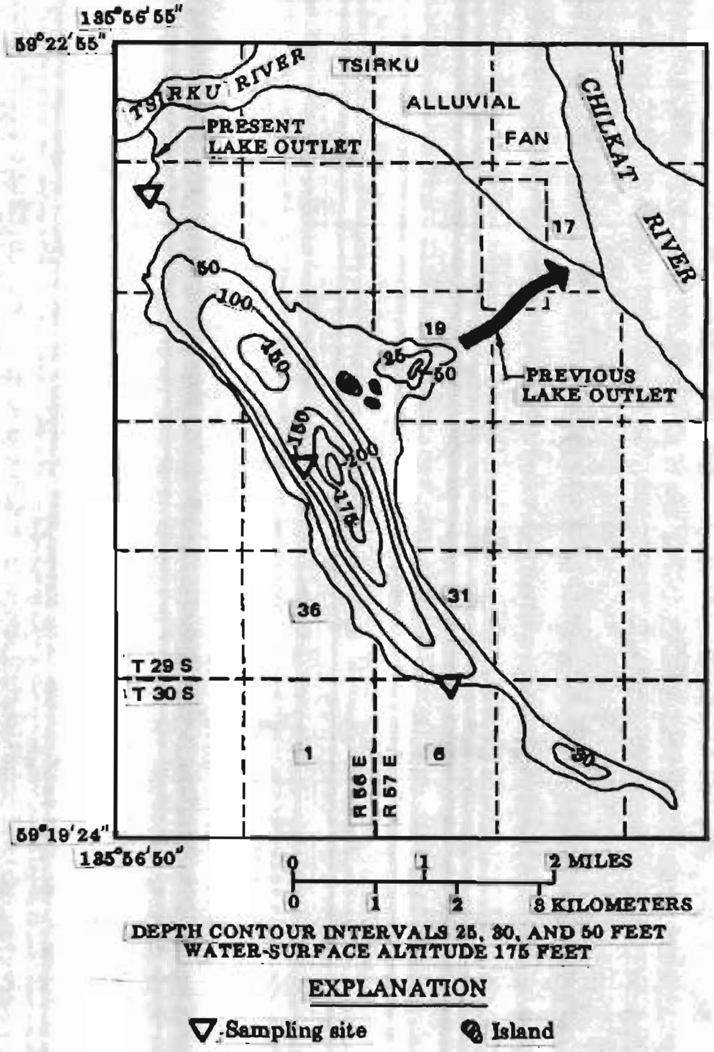

Figure 6. – Bathymetric map and water-quality sampling sites at Chilkat Lake near Klukwan.

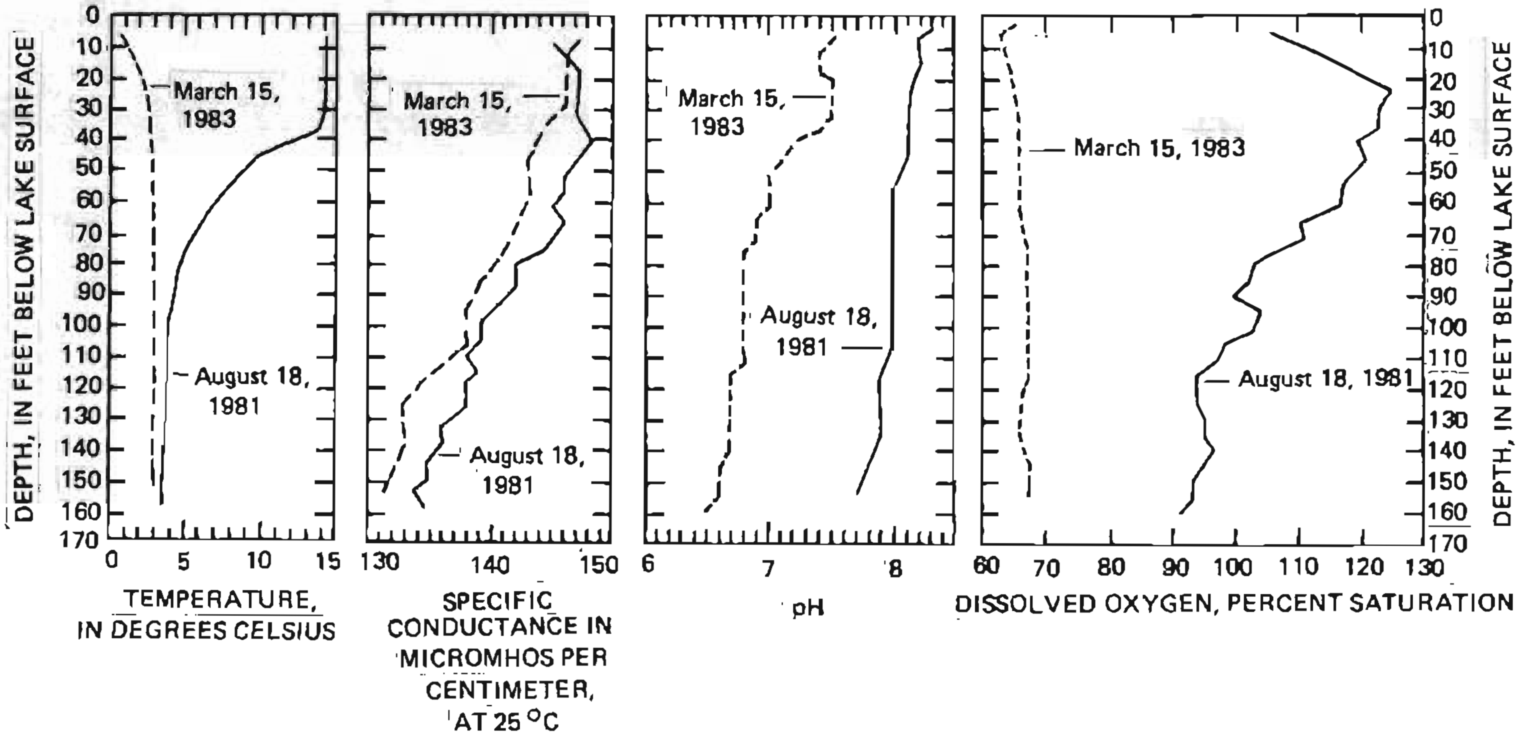

Figure 7.–Temperature, specific conductance, pH, and dissolved-oxygen profiles of Chilkat Lake.

Table 2. -- Surface-water quality data for selected sites in the Chilkat River basin

Parameters and constituents	C-1 Chilkat River near Klukwan		C-2 Klehini River near Klukwan		C-3 Tsirku River above fan		C-4 Takhin River at mouth	C-5 Chilkat Lake tributary	L-1 Chilkat Lake southwest of islands near Klukwan			
Map number (fig. 13)------- / Station name---- / Date of sample--	8-15-81	4-6-82	8-16-81	4-7-82	8-19-81	4-6-82	8-22-81	8-18-81	8-18-81	8-18-81	3-15-83	3-15-83
									Parameter			
Depth, sample (ft) - - - - - - - - - -	--	--	--	--	--	--	--	--	20	100	125	25
Discharge (ft³/s)- - - - - - - - - -	7,100	300	3,510	190	5,390	140	730	--	--	--	--	--
Specific conductance - - - - - - - - (µmho/cm at 25°C)	47	--	151	--	169	140	88	160	147	139	143	145
Temperature (°C) - - - - - - - - - -	7.0	--	8.0	5.5	6.0	6.0	4.0	6.5	14.0	4.0	3.0	2.3
pH - - - - - - - - - - - - - - -	6.8	5.7	7.7	--	7.6	7.5	7.7	7.3	7.5	6.8	7.9	8.1
Turbidity (NTU)- - - - - - - - - - -	42	2.0	160	.90	430	1.2	130	.90	.90	.70	.40	.70
Constituent concentration, in milligrams per liter												
Suspended sediment - - - - - - - - -	361	16	716	1.0	1,530	1.0	--	--	--	--	--	--
Dissolved oxygen - - - - - - - - - -	12.4	--	12.0	--	10.8	12.6	12.4	12.3	12.4	13.4	8.9	9.0
Hardness - - - - - - - - - - - - -	16	109	76	131	77	127	53	74	73	75	75	82
Calcium, dissolved - - - - - - - - -	5	33	25	39	26	41	19	27	26	27	27	29
Magnesium, dissolved - - - - - - - -	.8	6.4	3.2	8.2	3.0	6.0	1.4	1.7	1.9	1.9	1.9	2.3
Sodium, dissolved- - - - - - - - - -	.6	8.3	.9	2.5	.9	1.6	.6	1.3	1.3	1.7	1.9	1.9
Potassium, dissolved - - - - - - - -	1.0	2.6	1.6	2.1	1.2	1.7	1.2	1.3	1.1	1.1	1.0	1.0
Alkalinity - - - - - - - - - - - - -	16.0	95	48	93	59	86	47	35	57	55	59	47
Sulfate, dissolved - - - - - - - - -	5.0	26	23	41	25	42	< 5.0	34	17	16	18	19
Chloride, dissolved- - - - - - - - -	1.2	8.3	1.2	.6	.4	1.2	2.6	.5	3.2	1.8	4.1	18
Fluoride, dissolved- - - - - - - - -	.0	.1	.0	<.1	.0	<.1	.0	.0	.0	.0	<.1	<.1
Nitrogen, ammonia- - - - - - - - - -	.14	.18	.09	.06	.1	.08	.09	--	.110	.080	--	--
Nitrogen, nitrite- - - - - - - - - -	.19	.23	.05	.22	.08	.24	.09	--	.000	.000	--	--
Nitrogen, ammonia- - - - - - - - - - plus organic	.82	.56	<.20	.10	<.20	.30	.41	--	--	--	--	--
Phosphorus, dissolved- - - - - - - -	.03	.010	.020	.010	.020	.010	.030	.020	--	--	.010	.010
Carbon, organic- - - - - - - - - - - dissolved	4.0	1.2	.7	1.0	2.1	1.4	.8	1.3	--	--	--	1.8
Carbon, organic- - - - - - - - - - - suspended	2.1	.1	1.1	.1	>4.0	<.1	2.5	.4	--	--	--	1.9
Total recoverable constituent concentration, in micrograms per liter												
Arsenic- - - - - - - - - - - - - - -	0.0	1	2	<1	3	1	4	1	0	0	<1	<1
Barium - - - - - - - - - - - - - - -	100.0	<100	200	100	400	100	200	0	0	0	100	100
Copper - - - - - - - - - - - - - - -	50.0	4	60	3	60	3	17	5	4	4	4	2
Iron - - - - - - - - - - - - - - - -	4,900	1,600	20,000	170	53,000	120	12,000	320	70	60	90	70
Lead - - - - - - - - - - - - - - - -	48	<1	68	2	29	2	8	6	21	9	9	2
Manganese- - - - - - - - - - - - - -	100.0	150	420	10	1,000	20	240	10	10	10	<10	<10
Mercury- - - - - - - - - - - - - - -	.3	.1	1.0	<.1	1.3	<.1	.4	.1	.1	.3	.2	.1
Selenium - - - - - - - - - - - - - -	.0	<.1	1	1	2	1	0	1	0	0	1	1
Silver - - - - - - - - - - - - - - -	.0	<.1	0	<1	0	1	0	0	0	<1	<1	<1
Zinc - - - - - - - - - - - - - - - -	60	10	120	10	180	10	40	20	10	10	10	20

Table 2. – Continued

Parameters and constituents	Map number (fig. 13) / Station name / Date of sample	C-6 Chilkat Lake outlet near Klukwan 8-18-81	C-7 Chilkat River below Klukwan 2-10-83	C-8 Unnamed Creek on Klukwan Fan 8-23-81	C-8 Unnamed Creek on Klukwan Fan 5-26-82	C-9 Glacier Creek 8-25-81	C-10 Little Boulder Creek 4-9-82	C-11 Klehini River above Canadian Border 8-21-81
Depth, sample (ft)		—	—	—	—	—	—	—
Discharge (ft³/s)		300	—	7.2	—	—	21	—
Specific conductance (µmho/cm at 25°C)		—	278	322	330	144	120	59
Temperature (°C)		—	.4	6.5	6.0	4.5	3.0	5.5
pH		—	8.0	7.1	7.5	7.5	8.3	7.7
Turbidity (NTU)		2.0	1.5	6.8	—	25	.20	200
	Constituent concentration, in milligrams per liter							
Suspended sediment		—	—	—	—	—	—	—
Dissolved oxygen		—	10.5	12.0	11.5	12.9	—	12.4
Hardness		73	127	144	—	72	133	44
Calcium, dissolved		26	40	52	—	26	42	16
Magnesium, dissolved		1.9	6.6	3.5	—	1.8	6.8	1.1
Sodium, dissolved		1.3	7.3	1.7	—	.6	1.9	.9
Potassium, dissolved		1.0	5.6	.8	—	1.6	2.8	.7
Alkalinity		50	104	35	—	45	99	38
Sulfate, dissolved		17	34	100	—	29	39	<5.0
Chloride, dissolved		1.0	5.5	2.7	—	.2	.8	<.1
Fluoride, dissolved		.0	<.1	.0	—	0	<.1	.1
Nitrogen, ammonia		—	—	.09	—	.07	.08	.13
Nitrogen, nitrite		—	—	1.0	—	.07	.51	1.7
Nitrogen, ammonia plus organic		—	—	.36	—	.45	.65	.69
Phosphorus, dissolved		—	.020	.020	—	<.010	.050	.020
Carbon, organic dissolved		—	1.9	.5	—	.7	.5	1.5
Carbon, organic suspended		—	.1	.7	—	.7	.1	3.6
	Total recoverable constituent concentration, in micrograms per liter							
Arsenic		1	1	2	—	0	<1	3
Barium		0	<100	0	—	100	<100	0
Copper		7	2	23	—	14	2	54
Iron		250	230	2,900	—	6,200	20	32,000
Lead		920	4	15	—	6	<1	11
Manganese		10	80	50	—	130	<10	730
Mercury		.1	.6	.1	—	.5	<.1	.7
Selenium		0	1	1	—	1	1	0
Silver		0	<1	0	—	1	<1	0
Zinc		10	10	20	—	40	10	120

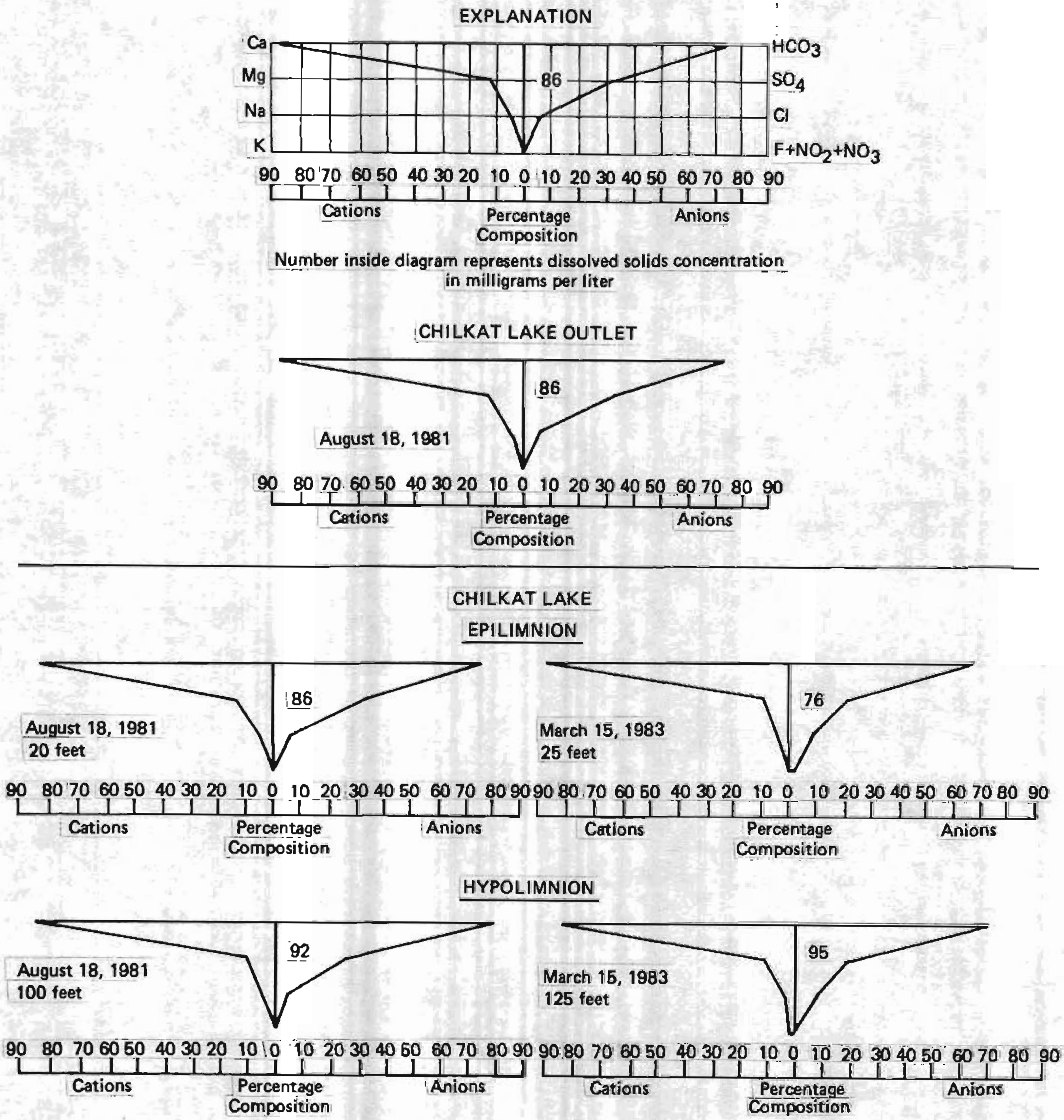

Figure 8.–Percentage composition of major cations and anions, and dissolved-solids concentration for Chilkat Lake and its outlet stream.

Table 3.--Drainage area, period of record, and maximum and minimum discharge for selected streams measured in the Chilkat River basin

Map No. (fig. 9)	Station No.	Stream	Drainage area (mi^2)	Period of record	Discharge (ft^3/s) Maximum	Discharge (ft^3/s) Minimum
C-1	15056500	Chilkat River near Klukwan.	760	[1]1959-1961 [2]1981-1982	[3] 20,400 7,100	80 300
C-2	15056560	Klehini River near Klukwan.	245	[2]1981 [1]1982-1983	9,000	116
C-3	15056580	Tsirku River near Klukwan.	230	[2]1981-1983	5,390	142
C-4	591630135410200	Takhin River at mouth.	100	[2]1981-1982	722	--
C-8	592436135545000	Unnamed creek south of Wells near Klukwan.	[4]2	[2]1981-1982	4	0
C-10	592546136074700	Little Boulder Creek.	25	[2]1981-1982	92	21

[1] Continuous streamflow record.
[2] Miscellaneous measurements only.
[3] Mean flow for periods of record is 3,261 ft^3/s.
[4] Approximate.

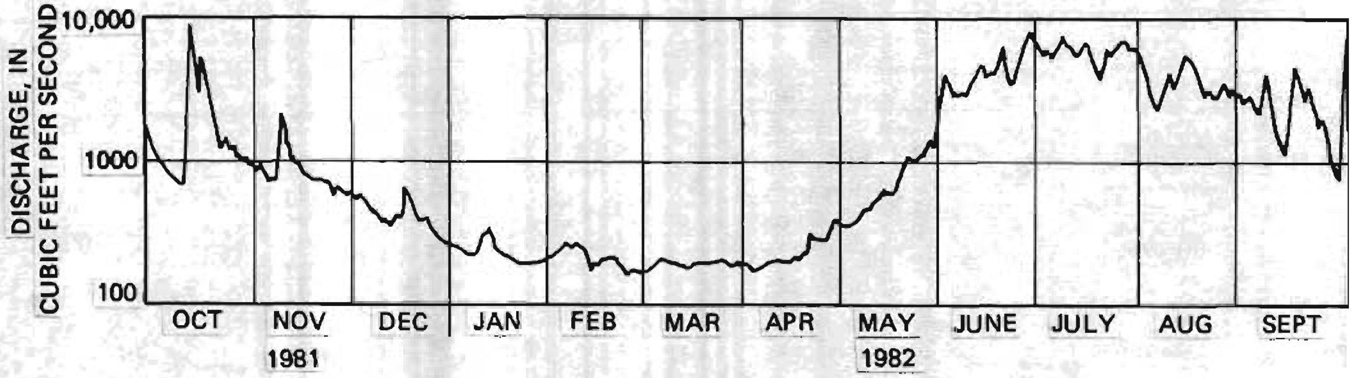

Figure 10.--Hydrograph for Klehini River (15056560), October 1981 to September 1982.

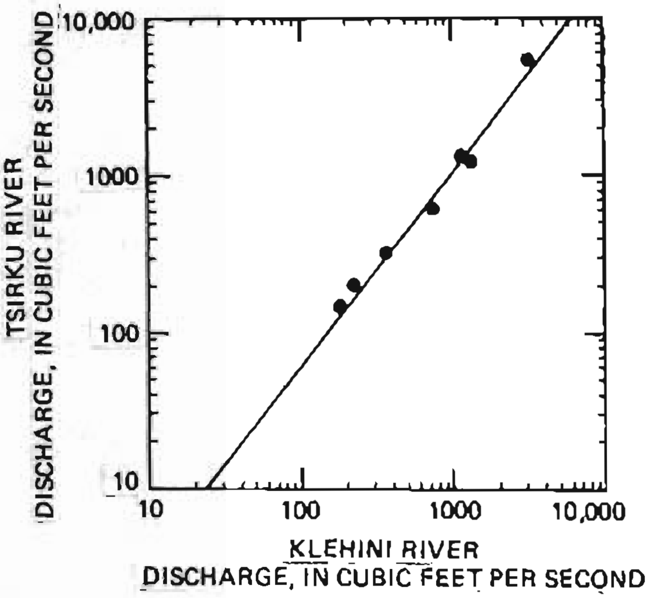

Figure 11.--Discharge relationship between Klehini and Tsirku Rivers.

monthly and annual mean flow of the Tsirku River can be estimated from the continuous record on the Klehini River using techniques described by Riggs (1969). The Tsirku River also exhibits the same seasonal streamflow fluctuations as the Klehini River (table 4).

A seepage run, a series of stream discharge measurements along a stream reach, was made in the Tsirku alluvial fan area on April 6, 1982, during an early spring low-flow period (fig. 12). Comparison of discharge measurements indicates that of a total flow of 142 ft^3/s at the head of the fan, 100 ft^3/s, or 70 percent of that flow, was from ground-water discharge in the Little Salmon River and Clear Creek areas. Nineteen percent, or 27 ft^3/s, was from outflow from Chilkat Lake. The remaining 11 percent, or 15 ft^3/s was probably contributed primarily by melt at the base of the glacier (L. R. Mayo, U.S. Geological Survey, oral commun., 1983).

Chemical Quality

Throughout the basin, surface water is generally a calcium bicarbonate type (fig. 13 and table 2), except in an unnamed stream (site C-8) on the Klukwan alluvial fan east of the community of Klukwan. This stream had a greater concentration of dissolved sulfate and a greater specific conductance than other sites sampled. Iron concentration may be very high (up to 53,000 µg/L in the Tsirku River on August 19, 1981), especially during summer high-flow periods on all streams sampled within the basin (table 2). Anomalously high concentrations of barium in the Klehini, Tsirku, and Takhin Rivers and Glacier Creek, probably reflect the presence of barite deposits in these basins (MacKevett and others, 1974). Water temperatures in glacial streams ranged from near freezing in winter to 6° C during the summer months. Small nonglacial streams can be expected to be somewhat warmer than glacier-fed streams in summer months.

Suspended Sediment

Suspended-sediment samples were collected during high- and low-flow periods in August 1981 and April 1982, respectively, on the Chilkat River, the Tsirku River above Tsirku alluvial fan, and the Klehini River. Although there are not enough data to compute statistically valid sediment concentrations on a monthly or yearly basis, some general conclusions can be drawn from the information available.

At low-flow conditions, all three rivers carried relatively low concentrations of suspended sediment (1-16 mg/L or 0.38-13 ton/d) in comparison to the concentration at higher flow periods (361-1,530 mg/L or 6,360-22,300 ton/d)(table 2). During the low-flow sampling, the Chilkat River carried almost 20 times more suspended sediment than the Tsirku or Klehini Rivers (fig. 14). This is most likely a function of stream gradients and available material, which consists mostly of fine-grained sediment in the Chilkat River near Klukwan but coarse material in the Tsirku and Klehini Rivers. At high flow, the suspended-sediment load increases by three to four orders of magnitude in each stream (fig. 14). At high flows, however, the Tsirku River carries a slightly greater sediment load than the Klehini and Chilkat Rivers. This higher sediment load is probably due in part to a greater abundance of glaciers (and their included debris) in the Tsirku basin.

Table 4.--Monthly mean flow for Klehini and Tsirku Rivers, 1982 water year (Oct. 1, 1981 - Sept. 30, 1982)

Stream	Monthly mean flow, in cubic feet per second												Annual mean
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Klehini River	2,012	905	446	244	217	199	238	789	4,266	5,424	3,293	2,329	1,706
Tsirku River	2,500	900	345	185	155	143	177	780	6,200	8,600	4,600	2,950	2,000

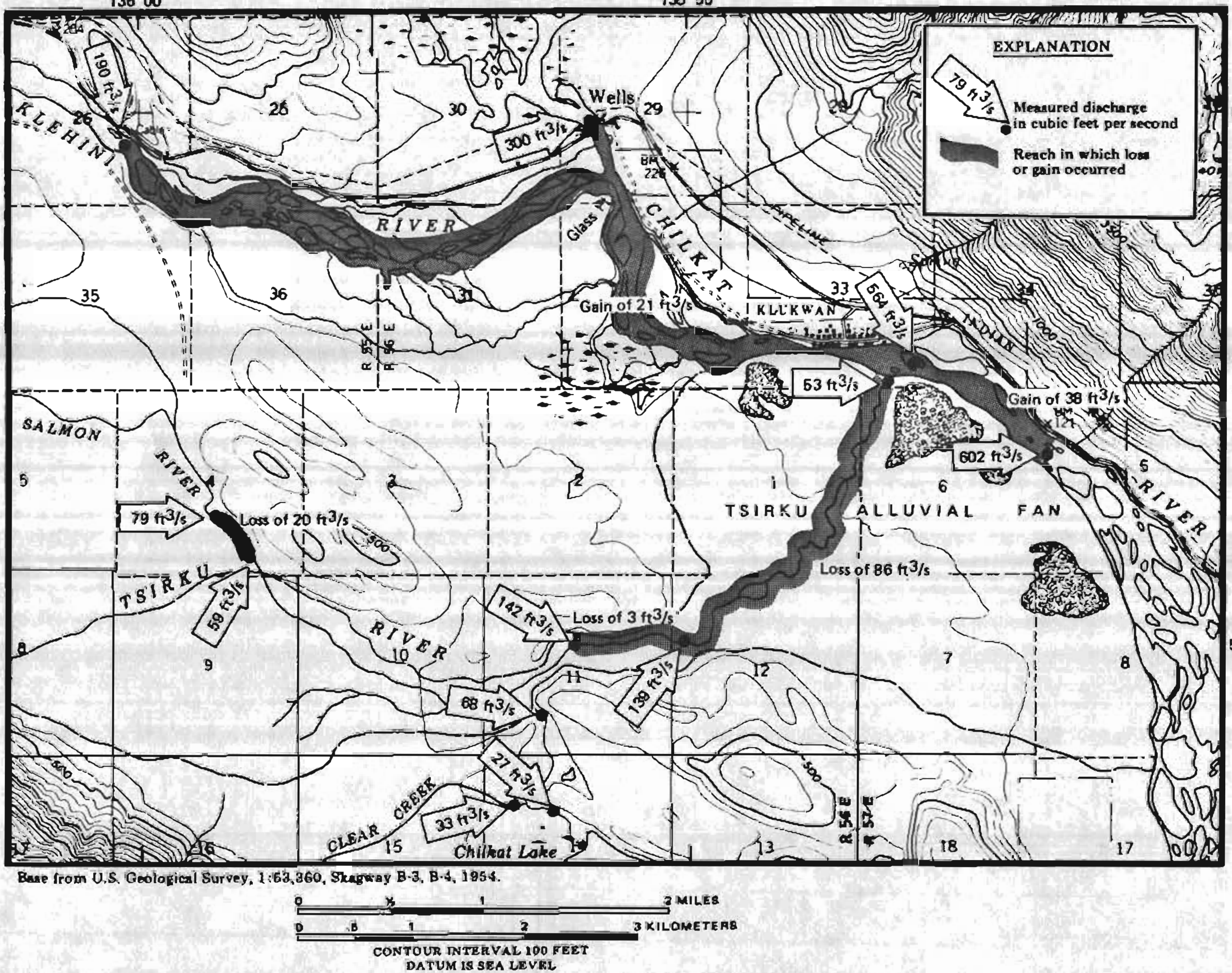

Figure 12. -- Losses and gains in streamflow in the Tsirku River alluvial fan area, April 6, 1982.

GROUND WATER

Ground water in the Chilkat River basin occurs under unconfined and confined conditions in bedrock and alluvium. Unconfined ground water is usually found in alluvium in valleys, but confined conditions may occur in alluvium overlain by clay and silt at depth or at the base of steep alluvial fans on the sides of mountains, and in fractured bedrock beneath valleys.

Bedrock aquifers in the Chilkat basin transmit water through secondary structures such as fractures and joints. Primary porosity (created during formation of the rocks) is probably negligible. Permeability of the rocks may be greater near faults where rock movement has caused more intensive fracturing. However, no data are available to quantify bedrock permeability.

Alluvial/colluvial fans along the east side of the Chilkat River valley have been formed primarily by debris flows off the steep flanks of the Takshanuk Mountains. The fans are aquifers, but probably have lesser capacities to transmit water than do alluvial aquifers deposited by the large rivers because poor grading tends to reduce permeability. Perennial seeps and springs flowing from these fans into the Chilkat River sustain the flow in small tributary channels that, in many cases, salmon favor for spawning. The Klukwan alluvial fan, a large fan aquifer, supplies water to a spring that is used as a year-round source of water for the village of Klukwan.

Alluvial aquifers that underlie major river valleys are commonly very thick. Data from seismic traverses across the Chilkat River valley near Klukwan indicate that depth to bedrock is greater than 850 ft below land surface (fig. 15). A seismic traverse in the Klehini River valley at mile 27 Haines Highway, indicates depth to bedrock of at least 250 ft. A traverse across the flat outwash plain between the Klehini and Tsirku River valleys in the area of the Little Salmon River indicates a depth to bedrock of at least 200 ft. All seismic data were analyzed by the methods of Scott and others (1972).

Interpretation of seismic traverses in the Little Salmon Creek area indicates that unconsolidated gravels are continuous between the Klehini, Tsirku, and Chilkat valleys near the mouth of the Klehini River. Aquifers in these interconnected gravels are probably hydraulically continuous. The water table in those aquifers has not been mapped in the Klehini Valley nor in much of the Chilkat Valley. However, as in most alluvial-valley aquifers, the water table probably slopes downvalley at approximately the gradient of the valley axis.

Analyses of samples from four of the observation wells indicate that the ground water has a slightly greater dissolved-solids content, but is otherwise chemically similar to the streams. Results of the analyses are on table 5 and shown graphically in figure 16.

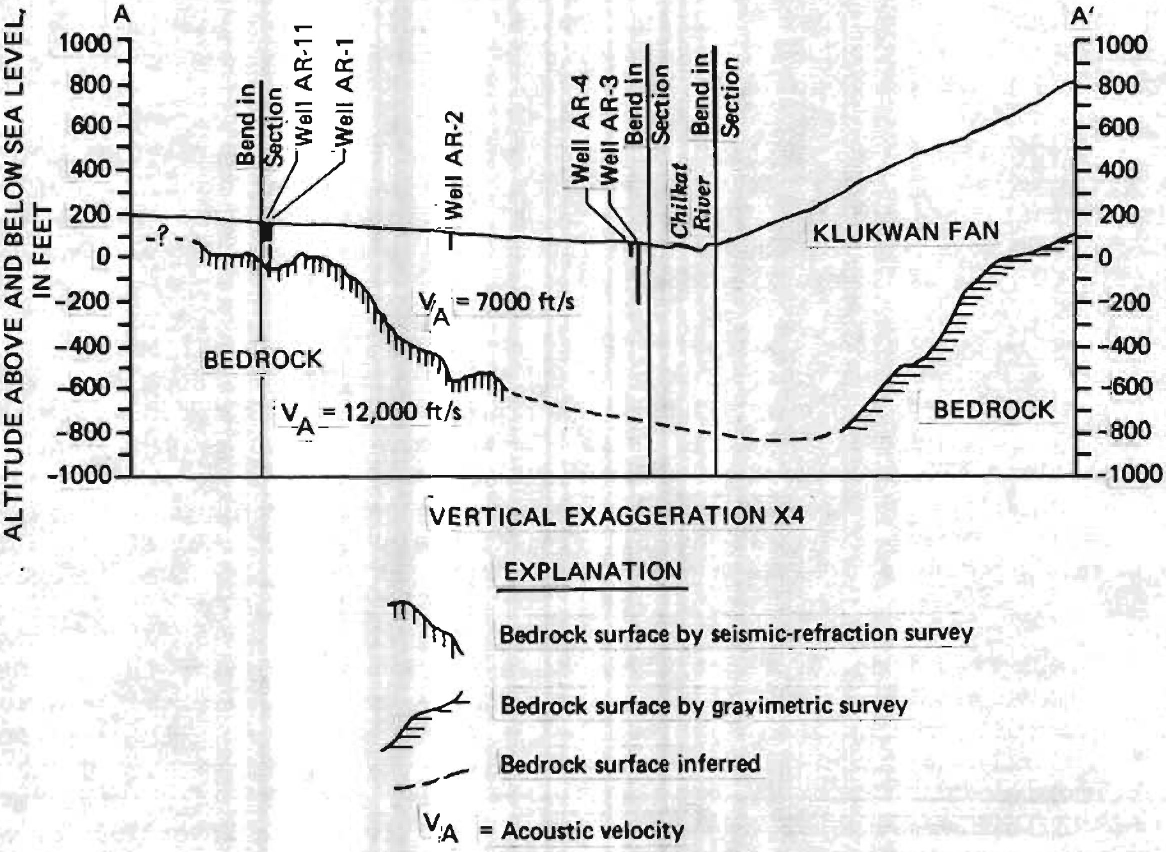

Figure 15.–Cross section across Chilkat Valley and Tsirku alluvial fan showing bedrock depth from seismic refraction and gravimetric data. See figure 17 for location of line A-A'. (Gravimetric data, 1972, from M.M. Holmes, Klukwan Iron Ore Co., written communication.)

Table 5.--Ground-water quality data for four observation wells in the Chilkat River basin

Parameters and constituents	Well No. (fig. 16) Date of sample	AR-10 3-16-83	AR-3 12-13-82	AR-4 12-13-82	VC-1 2-10-83
	Parameter				
Well depth (ft)		40	260	40	30
Specific conductance (µmho/cm at 25°C)		360	200	205	250
Temperature (°C)		6.2	4.5	4.2	4.5
pH		7.6	8.2	9.2	8.4
Turbidity (NTU)		--	24	32	1.6
	Constituent concentration, in milligrams per liter				
Dissolved oxygen		--	4.6	4.3	--
Hardness		169	88	90	119
Calcium, dissolved		56	26	28	34
Magnesium, dissolved		7.0	5.7	4.8	8.2
Sodium, dissolved		1.5	1.8	1.3	5.8
Potassium, dissolved		1.6	1.6	1.5	1.6
Alkalinity		125	28	59	93
Sulfate, dissolved		46	39	36	36
Chloride, dissolved		.8	20	.8	6.3
Fluoride, dissolved		.1	.1	.1	.1
Nitrogen, $NO_2 + NO_3$		.20	.20	.10	.20
Nitrogen, nitrate		--	--	.08	--
Nitrogen, nitrite		<.020	<.020	.020	<.070
Nitrogen, ammonia		<.060	.130	.060	<.060
Phosphorus, as P		.020	.030	.050	.030
Phosphorus, as PO_4		.06	.09	.15	.09
Phosphorus, ortho-		.020	<.010	.020	.010
Carbon, organic		1.0	2.3	2.6	.7
	Total recoverable constituent concentration, in micrograms per liter				
Arsenic		1	1	1	1
Barium		<100	<100	<100	<100
Copper		4	9	13	5
Iron		580	14,000	14,000	300
Lead		7	52	30	1
Manganese		30	530	200	10
Mercury		.1	.4	.3	.7
Selenium		2	<1	<1	1
Silver		<1	<5	<5	<1
Zinc		20	220	70	30

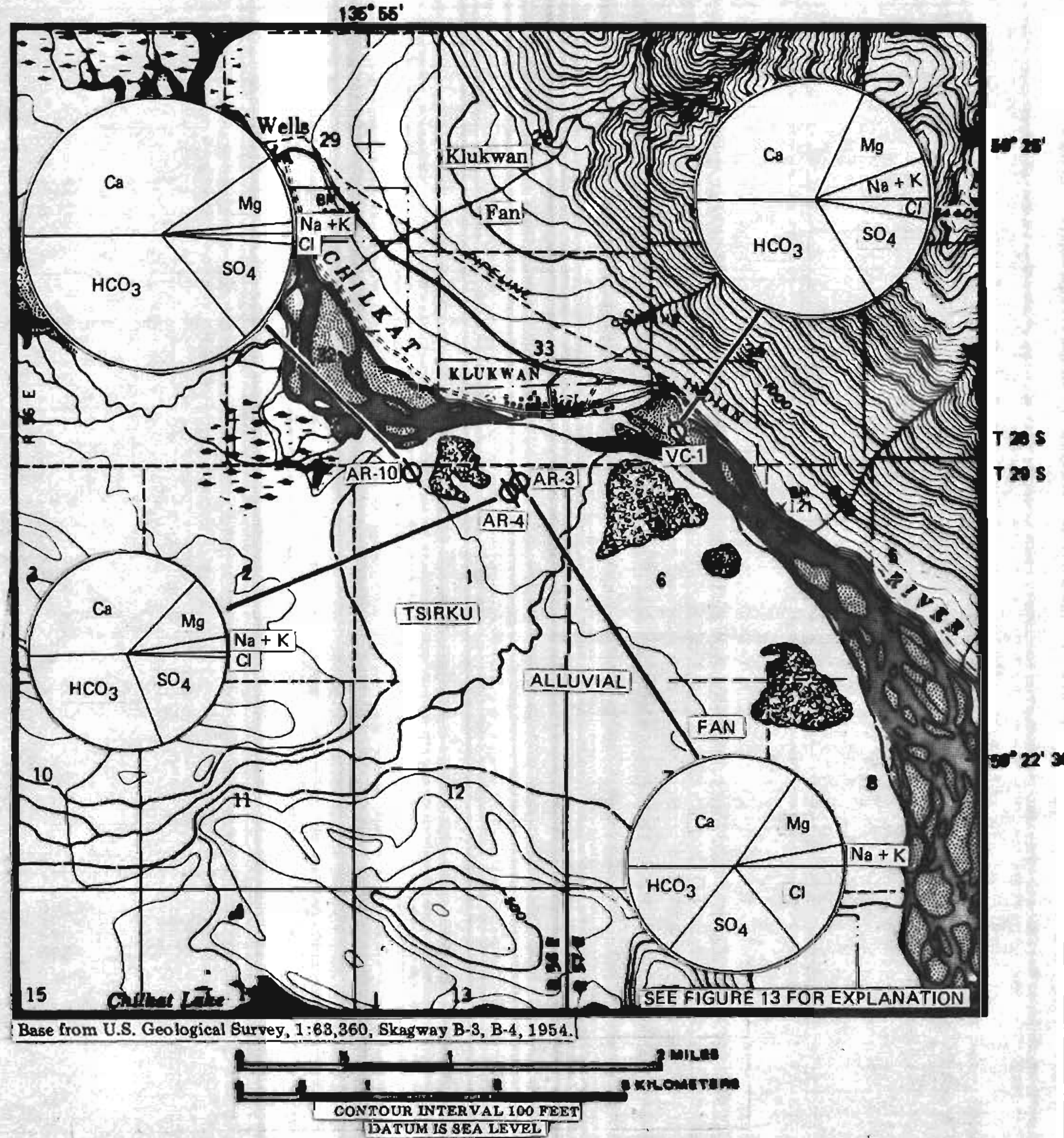

Figure 16. – Ground-water-quality sites on and near the Tsirku alluvial fan, percentage of major cations and anions, and total hardness.

TSIRKU RIVER ALLUVIAL FAN

The 5-mi² Tsirku River alluvial fan is a low-gradient alluvial fan deposited by the Tsirku River as it leaves the confines of its bedrock valley and flows into the Chilkat River valley (fig. 17). The Chilkat River borders the toe of the fan along the toe's entire 4.9-mi perimeter. During low-flow periods in 1982 and 1983, the main channel on the fan was about 2 mi long. The surface of the fan descends from an altitude of about 160 ft near the head to about 95 ft near the toe. This vertical drop of 65 ft in a distance of about 1.8 mi is equivalent to a gradient of 36 ft/mi, in contrast to a gradient of 48 ft/mi for the Tsirku River directly above the fan.

The fan is composed of material that ranges in size from boulders greater than 1 ft in diameter to silt- and clay-sized particles (fig. 18). Most of the perimeter of the fan is covered by low-lying bushes and grasses growing on inactive channels and on overbank deposits. Stands of cottonwood trees grow along the toe and on the sides of the fan. However, most of the upper and middle parts of the fan are unvegetated or very sparsely vegetated.

Glacial History

The Tsirku alluvial fan area presumably underwent multiple glacial episodes as did most of this part of southeast Alaska. The Chilkat River valley and the area of the fan appear to have been ice free earlier than the surrounding areas such as Glacier Bay National Monument (H. J. Kaiser Co., written commun., 1972). During the last major glacial period (about 10,000 years ago), sea level was considerably lower than at present, perhaps by as much as 300 ft.

As glaciers in the Chilkat River valley retreated, large amounts of sediment were deposited as outwash, valley train, and deltaic deposits. An average rate of deposition would have been about 0.1 ft/yr assuming the area became ice free 10,000 years ago and the glacier had scoured to bedrock. This compares with an accretion rate for Klukwan alluvial fan of 0.4 ft/yr calculated from a carbon-14 dated piece of wood (H. J. Kaiser Co., written commun., 1972). The types of sediment filling the valley vary from till (ice-contact materials) to alluvium (outwash materials) to deltaic and marine deposits. The alluvial deposits are better sorted (lesser percentage of silt and clay) than the till.

The relationship of the altitude of the bedrock valley floor in the Tsirku alluvial fan area, at an estimated 850 ft below sea level (fig. 15), to present-day sea level indicates that sea water could have intruded into the valley. Test drilling at the mouth of the Chilkat River, 20 mi downstream, penetrated a marine deposit more than 100 ft thick whose upper surface is 20 ft below present sea level (Alaska Dept. of Highways, 1968). However, no marine deposits were identified in observation well AR-3, which was drilled to a depth of 260 ft below land surface, about 146 ft below present sea level. If the sea once did extend up the Chilkat Valley as far as the Tsirku alluvial fan area, marine deposits may be present at a depth greater than 260 ft.

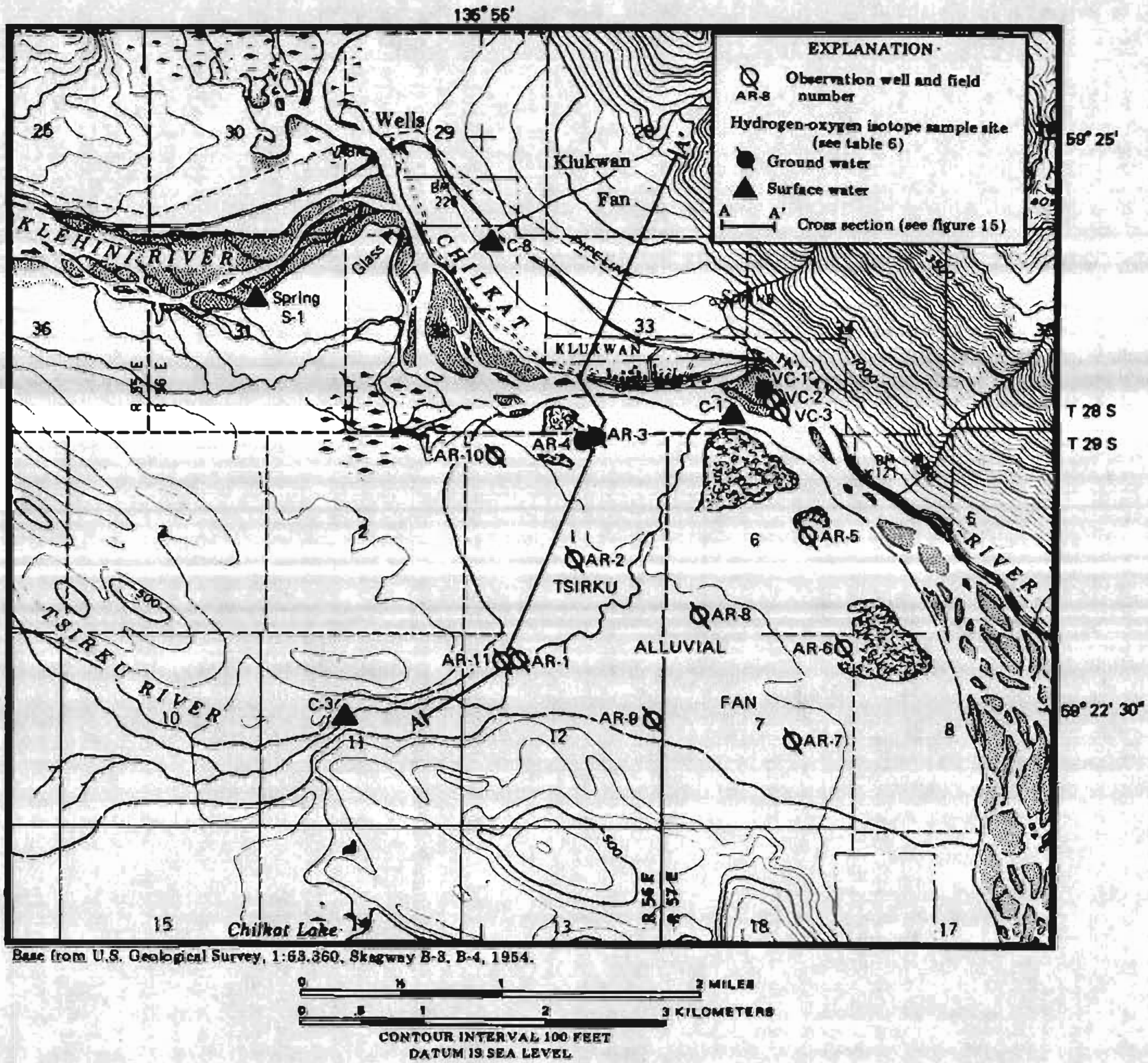

Figure 17. – Tsirku alluvial fan and vicinity, locations of observation wells (drilled November-January 1982-83), and hydrogen-oxygen isotope sampling sites.

Figure 18. – Tsirku alluvial fan, October 5, 1981. View is northwest toward head of fan (low dark hills in upper part of photograph). Note variance in size of sediment on fan surface. Also note inactive channel in the middle of photograph with finer sediment and typical vegetation growing on fan surface (vegetation is approximately 2.5 feet high).

Fan Sedimentology and Morphology

The composition of sediment and the channel morphology of the Tsirku alluvial fan reflect its depositional history. An alluvial fan is built by both lateral and vertical migration of channels. As sediment is deposited, the channel eventually becomes clogged, resulting in a diversion of water from that channel toward an area that is lower (Fahnestock, 1967). A new channel is then formed, in which the process begins again in the area of the new channel.

The vertical sedimentary structure of the fan is also the result of a repetitive building process. Coarse sediment is selectively deposited by different quantities and velocities of water in the channel. A decrease in velocity results in a decrease in the size of sediment that can be transported until, with a decrease in flow of water, the velocity slows sufficiently so that only silt- and clay-sized material can be transported. Eventually even these fine-grained materials are deposited upon the coarser sediments as flow ceases.

TSIRKU ALLUVIAL FAN AQUIFER

The alluvium of the Tsirku alluvial fan comprises an unconfined aquifer bounded on the northeast and southwest by the bedrock walls of the valley. At the northwest and southeast boundaries the aquifer grades into and is hydraulically continuous with alluvial aquifers of the Klehini and Chilkat Valleys. The base of the aquifer in the eastern part of the Chilkat Valley has not been defined, but is likely to be the contact between alluvial material and low-permeability marine or deltaic deposits at a depth greater than 260 ft below land surface. On the north, the Tsirku alluvial fan sediments interfinger with sediments of the Klukwan alluvial fan (H.J. Kaiser, written commun., 1972). Klukwan alluvial fan sediments are poorly sorted debris-flow deposits of lower permeability than Tsirku alluvial fan sediments.

In the Tsirku alluvial fan aquifer, seasonal fluctuations of the water table are observed in both deep and shallow wells (figs. 19 and 20). In observation well AR-3 (depth, 260 ft), water levels decreased slowly from December 1982 until about mid-April 1983, then rose rapidly at an average of 0.2 ft/d until mid-May 1983. Observation well AR-1 (depth, 220 ft), which is drilled 20 ft into bedrock, shows a similar response, but with a more rapid rise in water level, about 0.6 ft/d from mid-April to mid-May. Shallow wells AR-4 and AR-7 (both 40 ft deep) react similarly. Synchronous fluctuations of water levels in both deep and shallow wells indicate hydraulic continuity between deep and shallow parts of the aquifer.

Flow lines drawn perpendicular to potentiometric-surface contours (fig. 21a and b) indicate that as shallow ground water moves through the head of the fan it spreads out in a deltaic pattern. After the water has moved about one-third of the distance from head to toe of the fan, its direction becomes skewed downvalley. This downvalley trend is most pronounced in late winter (March) data, when the potentiometric surface is lowest.

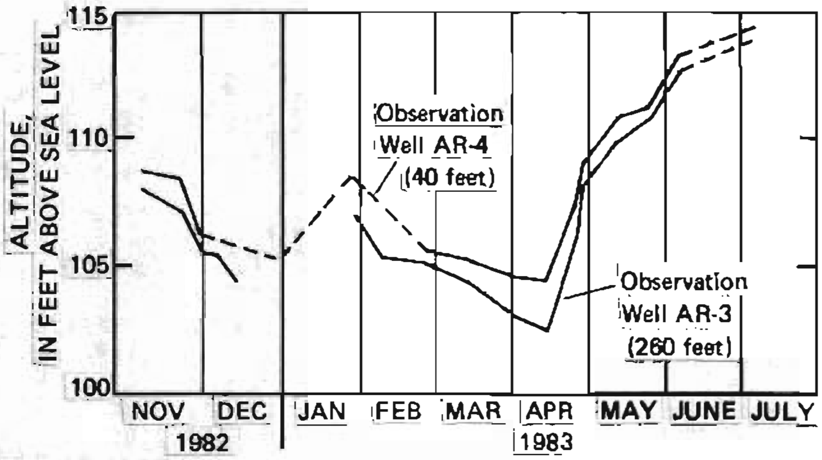

Figure 19.–Hydrograph of observation wells AR-3 and AR-4 at the toe of the Tsirku alluvial fan showing relation between potentiometric surface in deep and shallow ground-water systems.

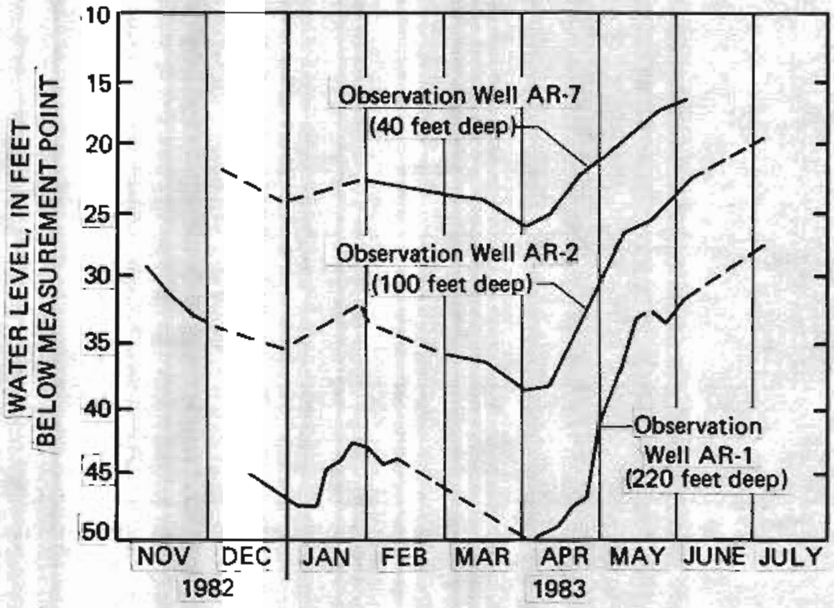

Figure 20. – Hydrograph of observation wells AR-1, AR-2, and AR-7 on Tsirku alluvial fan showing the relationship between wells at the head, middle, and toe of fan.

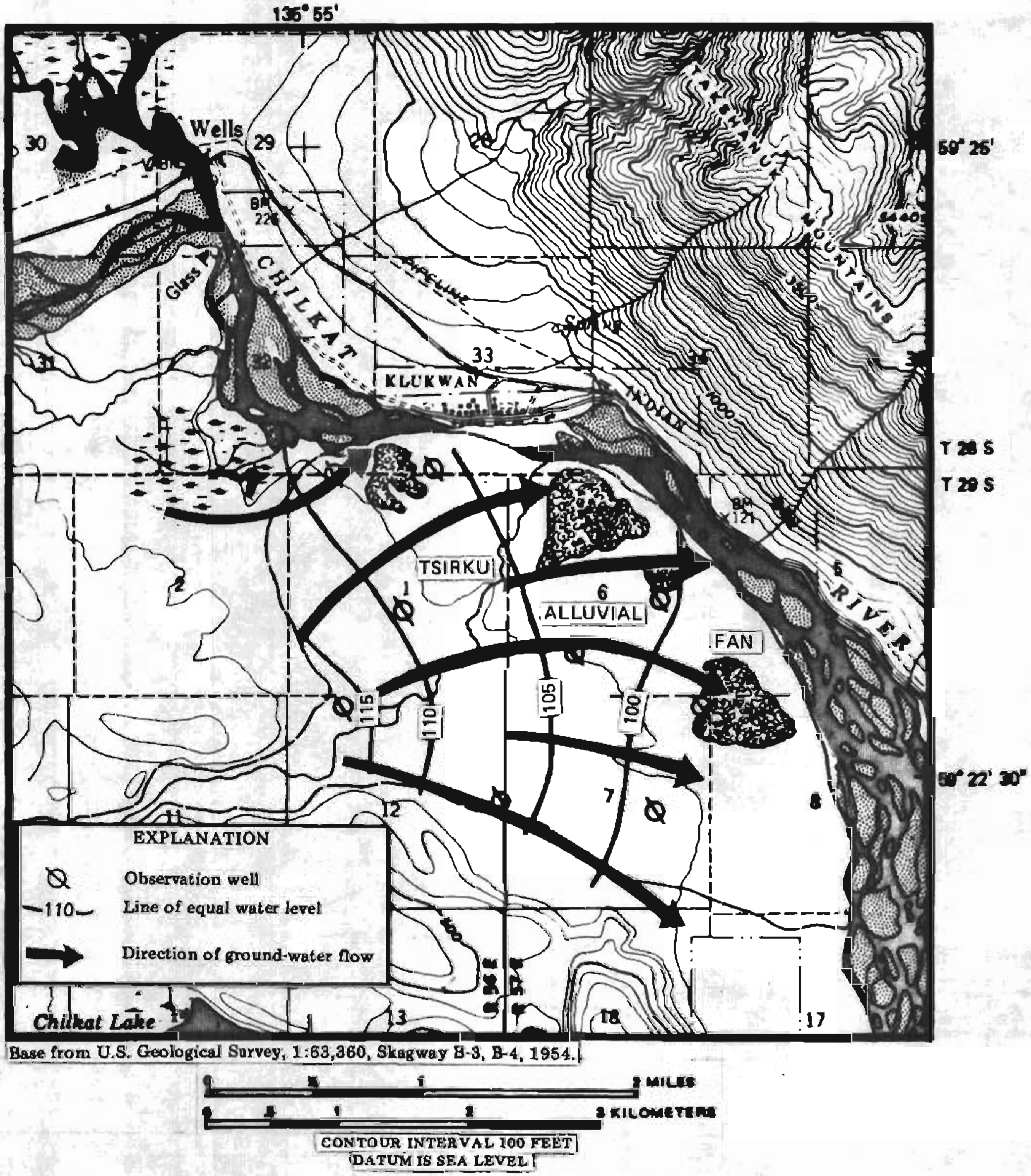

Figure 21a. – Potentiometric surface map of shallow ground-water system and direction of ground-water movement, Tsirku alluvial fan, March 11-16, 1983.

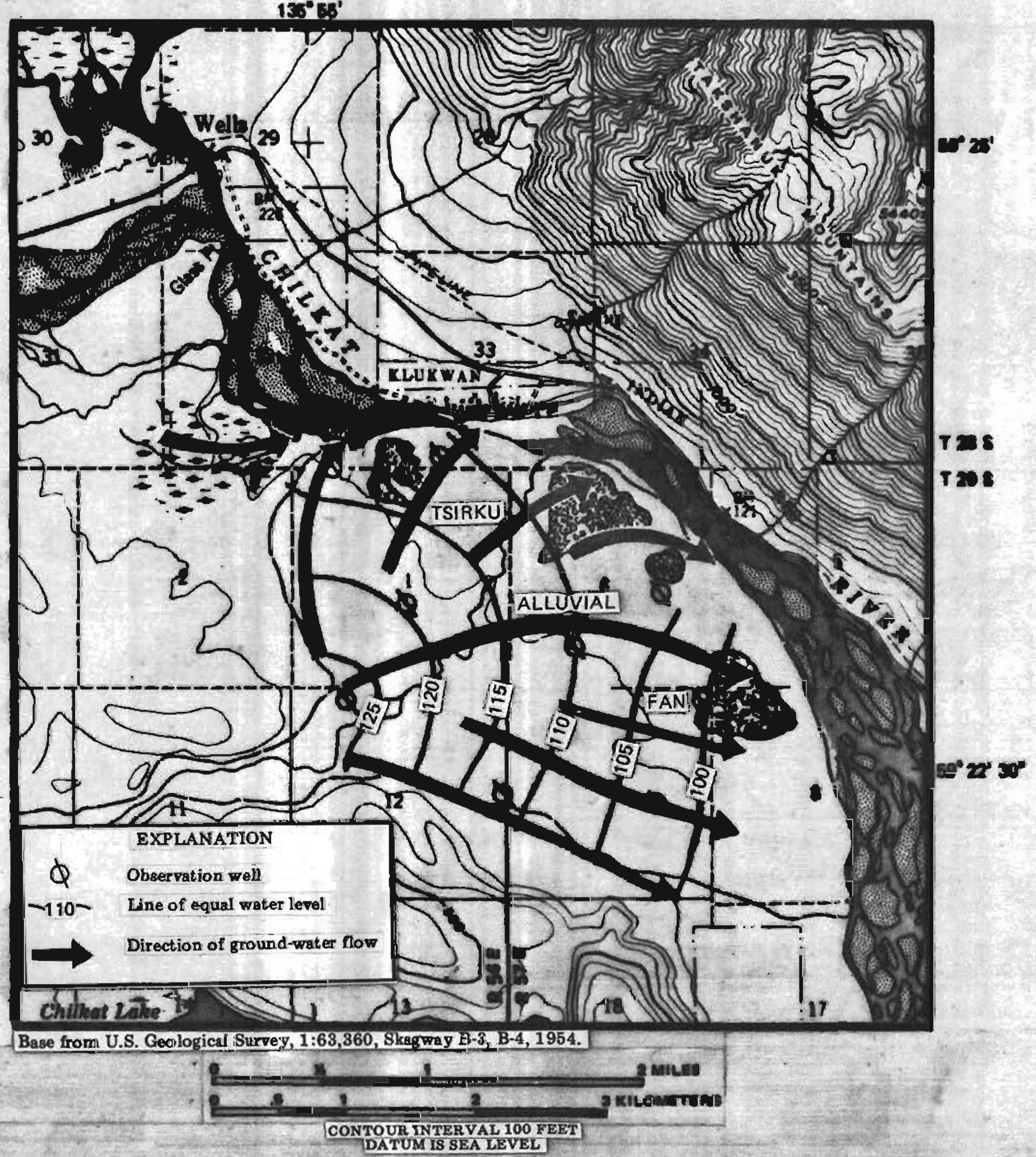

Figure 21b. -- Potentiometric surface map of shallow ground-water system and direction of ground-water movement, Tsirku alluvial fan, May 11, 1983.

Rates of ground-water flow can be estimated from Darcy's law:

$$V = \frac{K}{\theta} i$$

where V is average linear velocity, in feet per day;
K is hydraulic conductivity, in feet per day;
i is hydraulic gradient, a dimensionless variable; and
θ is porosity of aquifer, expressed as a decimal.

The hydraulic conductivity and porosity have not been determined for the Tsirku alluvial fan sediments. However, hydraulic conductivity of coarse sandy gravel is typically in the range of 200 to 2,000 ft/d. The porosity is about 0.25, and the gradient is 0.0052. Ground water accordingly is calculated to move at rates from 4 to 40 ft/d and travel time of the water from the apex to toe of the fan ranges from 0.5 to 5 years.

Stable isotopes of oxygen and hydrogen can indicate the source of precipitation that recharged the aquifer (Muir and Coplen, 1981). Precipitation at higher altitudes in inland areas is more depleted in oxygen-18 and hydrogen-2 than precipitation near the coast. Oxygen and hydrogen isotopes can also be used as tracers of ground-water movements.

The oxygen 0-18/16 and hydrogen H-2/1 isotopic "signatures" of water samples from the Chilkat and Tsirku Rivers near the Tsirku alluvial fan and from shallow observation wells (AR-4, VC-1) near the Chilkat River (table 6) indicate a relatively recent water, probably from a low-altitude, near-coast source (Ivan Barnes, U.S. Geological Survey, oral commun., 1983). However, isotopic data from observation well AR-3 (260 ft) indicate a relatively older water, probably from a higher altitude, continental source (Tyler Coplen, U.S. Geological Survey, oral commun., 1983). Water from the deeper well perhaps originates in recharge areas at the headwaters of the Chilkat basin (in interior British Columbia).

Table 6.--Oxygen and hydrogen isotope data from samples collected at selected surface-water sites and observation wells

Map No. (fig. 17)	Date sampled	Well depth (ft)	Hydrogen^2/hydrogen^1 (per mil)	Oxygen^{18}/oxygen^{16} (per mil)
Surface-water site				
C-1	02-10-83	--	-136.0	-18.1
C-3	12-15-82	--	-133.0	-17.4
C-8	04-08-83	--	-142.0	-18.9
S-1	04-08-83	--	-133.0	-17.8
Observation well				
AR-3	12-13-82	260	-80.0	-10.4
AR-4	12-13-82	40	-130.0	-17.2
VC-1	02-10-83	30	-131.0	-17.6

Discharge Areas

Ground-water discharge areas on gravel bars in the Chilkat River along the toe of the Tsirku alluvial fan can be easily identified by ice-free channels during the winter period (fig. 22). The relatively warm (4 to 6° C) water keeps the channels open in the discharge areas and in a 10-mi reach below the fan. During winter, water levels in observation wells VC-1, -2, and -3 (drilled to depths of 30, 15, and 25 ft, respectively) in the gravel bars were higher than in the adjacent stream and ground-water flow into the channel was evident. During summer high flow in the Chilkat River, these gravel bars are completely inundated and the ground-water discharge zones are concealed.

Ground-water discharge in the Chilkat River at the toe of the Tsirku alluvial fan is probably caused by a downstream decrease in hydraulic conductivity and thickness of fluvial sediments, and a narrowing of the Chilkat River valley. A down-valley decrease in thickness and hydraulic conductivity of the sediments would induce a damming effect, cause the potentiometric surface at the toe of the Tsirku alluvial fan to rise above the altitude of the land surface, and result in ground-water discharge. No geochemical, isotopic, or physical evidence was found to indicate that the Chilkat River fault has any influence on ground-water flow paths or discharge at the toe of the Tsirku alluvial fan.

Other areas of ground-water discharge are present in the channels of the Chilkat River both upstream and downstream from the toe of the Tsirku alluvial fan, and at several locations in the Takhin, Klehini, and Kelsall River valleys. Most of the

Figure 22. – Part of toe of Tsirku alluvial fan, and Chilkat River on March 23, 1982. View northwest up Chilkat River valley, Taksanuk Mountains at right of photograph. Note dendritic pattern of open channels in Chilkat River where ground-water discharge at the surface keeps channels open. Klukwan is at upper left corner of photograph.

discharge zones up- and downvalley from the Tsirku alluvial fan are seeps and springs at the bases of the alluvial and colluvial fans on the western slopes of the Takshanuk Mountains (fig. 2). This relatively warm ground water keeps the adjacent and near-downstream reaches of the Chilkat River open (ice free) during winter.

Recharge Areas

Ground water in the Tsirku alluvial fan is recharged by direct precipitation and infiltration, loss of flow from streams on the fan, and inflow along the hydrologic boundaries. During high-flow periods most of the recharge is from stream loss to the fan. During low-flow periods, however, inflow of ground water through the hydrologic boundaries becomes a more important factor because water loss from the few channels on the fan contributes less recharge to the aquifer.

Tsirku Fan Water Budget

The development of a water budget is a technique commonly used to estimate the sources and quantities of water being recharged to, stored in, and discharged from a ground-water system.

Ground-water inflow through the alluvium at the head of the fan can be calculated from Darcy's law:

$$Q = KAi$$

where Q is flux, in cubic feet per day;
K is hydraulic conductivity, in feet per day;
A is cross-sectional area of saturated materials, in square feet; and
i is hydraulic gradient.

A seismic profile across the head of the fan indicated that the cross-sectional area of saturated alluvium was 60,000 ft^2 during the summer, when the potentiometric surface was high, and 10,000 ft^2 during winter low water-table conditions. The hydraulic gradient was .00520 when the water table is high and .00158 when the water table is low. If the hydraulic conductivity is assumed to range from 200 to 2,000 ft/d, then the ground-water flow is 62,000 to 620,000 ft^3/d during the summer and 3,160 to 31,600 ft^3/d during the winter. Using the upper limits of the ranges, total ground-water inflow at the head of the fan is less than 1 percent of the total recharge to the fan.

Precipitation on the fan is 21 in/yr. If all the precipitation infiltrates to the aquifer, total recharge would be only about 5,000 acre-ft/yr, most of which occurs during the summer. Precipitation then would be less than 2 percent of the annual budget and an insignificant part of the winter budget.

Loss of streamflow from the Tsirku River as it crosses the fan is the major source of recharge to the fan. During low-flow months, usually from December to April, there is commonly only one main channel across the fan (fig. 23), which results in less recharge to the ground-water system than during summer months. The seepage

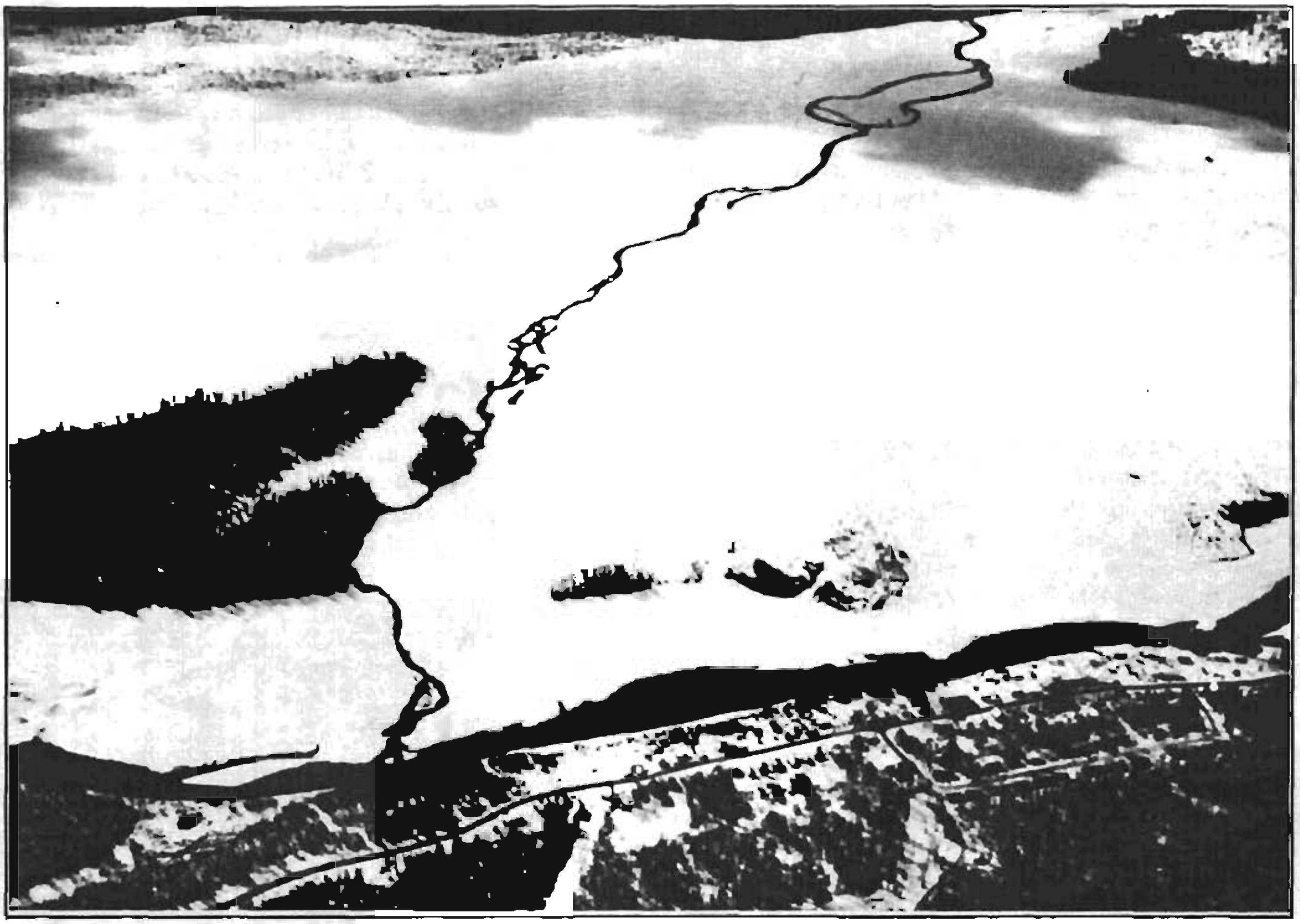

Figure 23. – Tsirku alluvial fan, March 22, 1982. View southwest toward head of fan, shows single open channel extending across fan and the open channel of Chilkat River along toe of fan. Village of Klukwan is at lower right.

run conducted on April 6, 1982 (fig. 12) indicated that 63 percent of streamflow entering the head of the fan was lost to the aquifer. From about late May to early September, up to one-third of the Tsirku alluvial fan's surface area is covered by numerous distributary channels (fig. 24). A greater quantity of water is lost to the ground-water system by these channels than in the winter period.

A water budget was calculated for the period October 1, 1982 to May 30, 1983. The magnitude of and relation between the elements of the water budget -- additions to and losses from the aquifer -- are shown in figure 25. Infiltration during this time was 2.8×10^5 acre-ft. Water released from storage as the water table declined was 2.4×10^4 acre-ft. Virtually all this water, 3.04×10^5 acre-ft, is estimated to have been discharged to the Chilkat River at the toe of the Tsirku alluvial fan at an average rate of about 640 ft^3/s.

HEAT-FLOW CALCULATIONS

Heat contained in the relatively warm (average 5° C) ground water that discharges at the toe of the alluvial fan maintains open-water leads in the winter ice cover of the Chilkat River adjacent to and downstream from the fan. If there is no significant change in the ice cover for a period of several days, then heat-flow calculations (Jobson, 1979 and 1980) can be simplified and used to calculate the amount of ground water that must flow into the river to maintain an observed amount of open water.

In order to check the validity of the simplified equations, J.D. Bredehoeft (U.S. Geological Survey, written commun., 1983) calculated the amount of ground water at 5° C that would be required to maintain the 2-mi-long, 130-ft-wide lead between Wells, near the bridge spanning the Chilkat River, and site C-7 near Klukwan. The calculations indicate that, on a cold cloudless winter night, 86 ft^3/s of ground water would balance the heat loss to the atmosphere. This value does not differ greatly from the 59 ft^3/s of streamflow gain measured in this reach on April 6, 1982.

The amount of ground water flowing into the stream is directly proportional to the open area of the stream. The total open area adjacent to and downstream from the Tsirku alluvial fan is 1.3×10^7 ft^2, or nine times as much as the open area between Wells and site C-7. The total ground-water inflow to the stream below the fan would therefore be nine times as much as between Wells and C-7, or about 770 ft^3/s. This flow rate agrees reasonably well with that derived from water-budget calculations.

SUMMARY AND CONCLUSIONS

Flow patterns of the Chilkat, Klehini, Tsirku, and Takhin Rivers, and selected smaller streams in the Chilkat Basin are typical of streams in the northern part of southeast Alaska. Peak flows occur during the summer, glacier-melt periods, and also during high precipitation events that are common in early fall. Lowest flows occur during winter and early spring. Water is of calcium bicarbonate composition

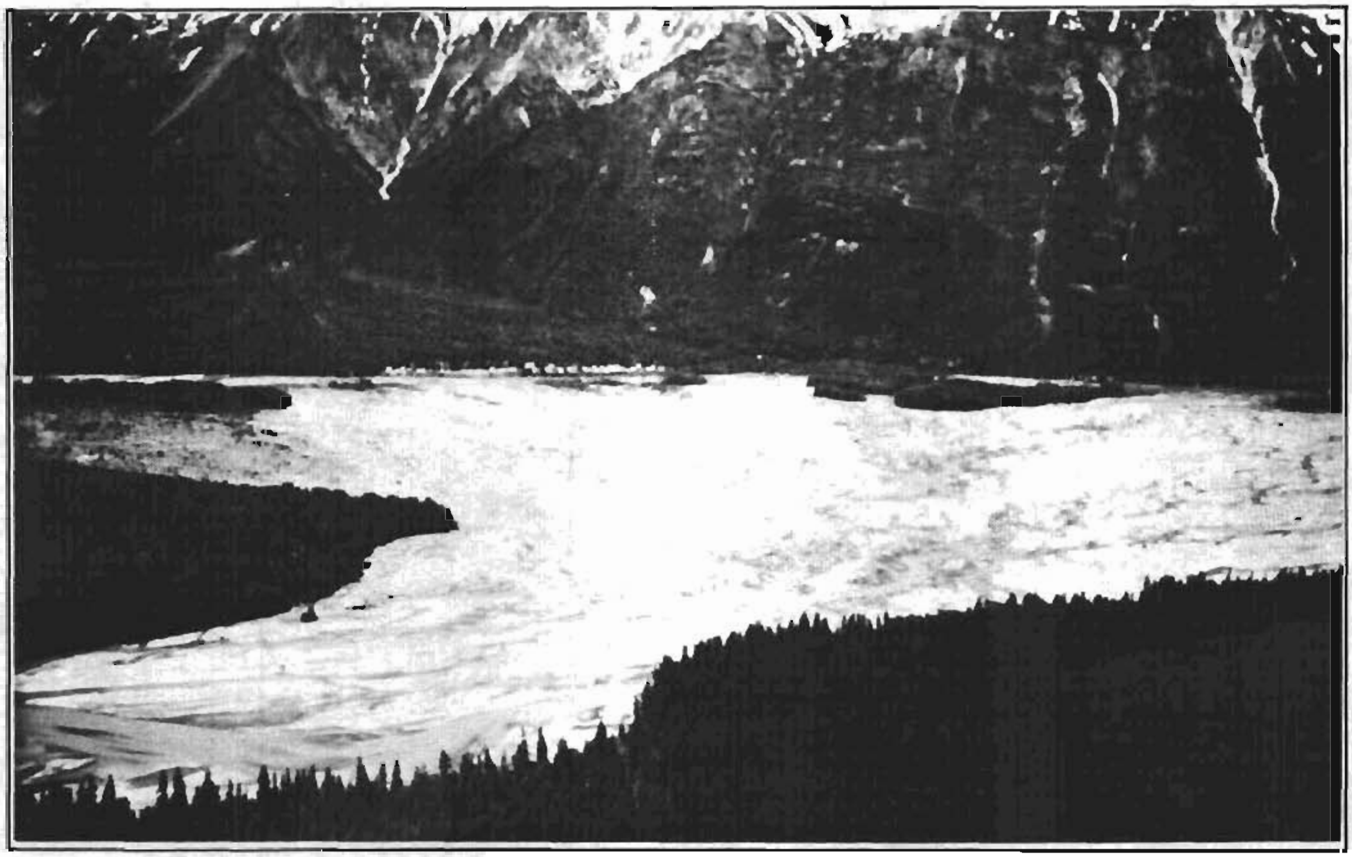

Figure 24. – Tsirku alluvial fan, June 6, 1981. View northeast toward toe of fan and the Takshanuk Mountains shows multiple channels on the fan, and flat terrain. The village of Klukwan is at base of Takshanuk Mountains just left of the center of the photograph.

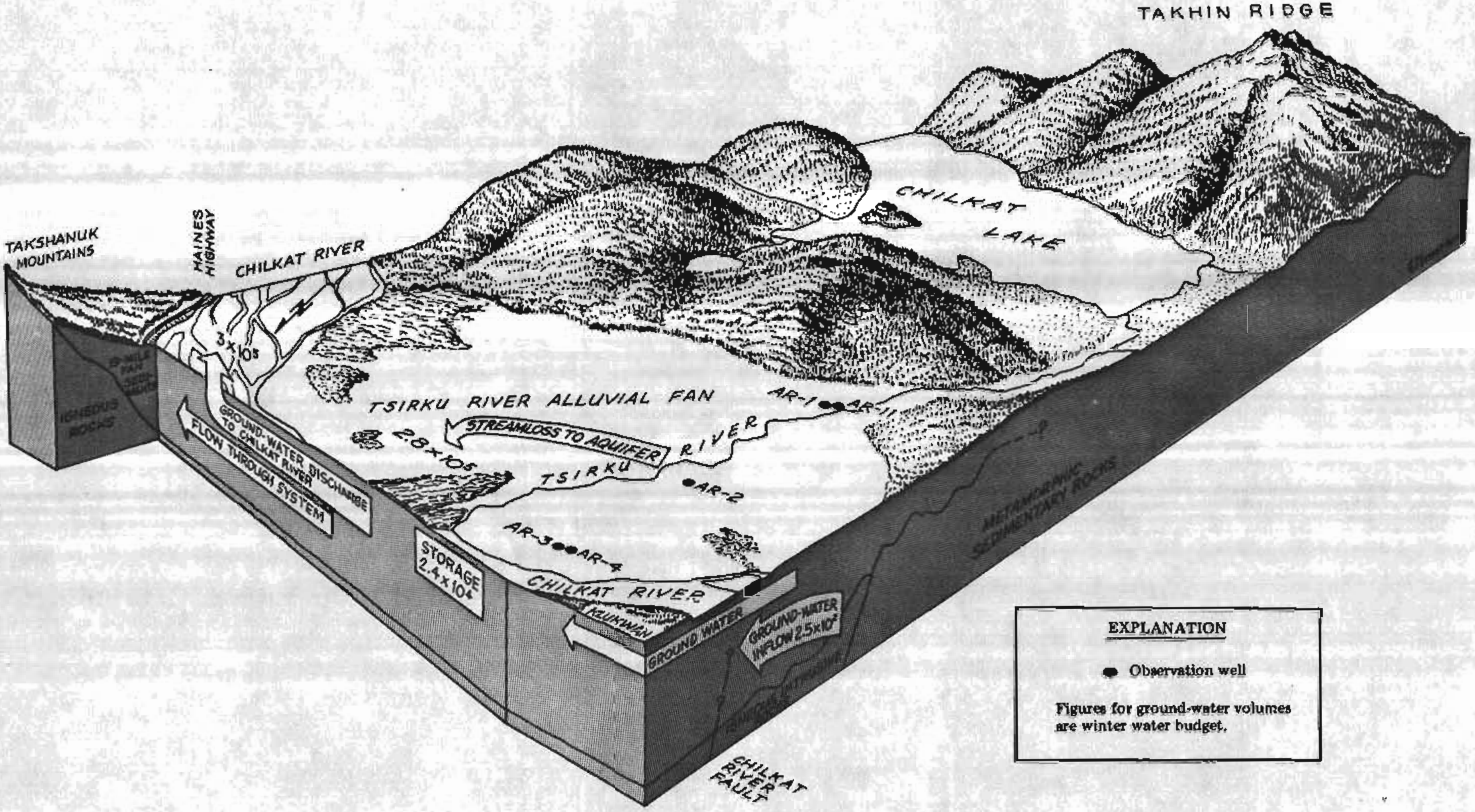

Figure 25. – Block diagram of Tsirku River alluvial fan and vicinity, showing elements of the water budget for the period October 1982 through May 1983 (numbers are in acre-feet).

except for a small, unnamed tributary (site C-8) on the Klukwan alluvial fan, which has a calcium sulfate water.

Chilkat Lake was thermally stratified during the August 18, 1981 sampling and was fairly well mixed during the March 15, 1983 sampling. The mixing is assumed to be a normal occurrence. The water in Chilkat Lake is a calcium bicarbonate type as are the tributaries that feed it. At a high stage in summer 1981, the Tsirku River discharged silt-laden water into Chilkat Lake. It is not known if such an influx of suspended sediment occurs periodically or to what extent it might alter the productivity of the lake.

The ground-water and surface-water systems of the Tsirku alluvial fan are closely linked. The principal source of recharge to the ground-water system is loss of water from stream channels across the fan surface. Water from the unconfined aquifer discharges into the Chilkat River near the toe of the fan at about 6° C, allowing reaches of the river to remain open during winter. Water-budget calculations indicate that for the period October 1982 through May 1983, the average rate of such ground-water discharge was 640 ft^3/s.

During the winter, ground water discharging to the surface and into the Tsirku River from the Little Salmon drainage and the area between Chilkat Lake and the Tsirku River (Clear Creek area) contributes about 70 percent of the flow of the Tsirku River at the head of the fan. Most of the other 30 percent is outflow from Chilkat Lake.

Geochemical stable-isotope analysis of water from a deep (260 ft) observation well at the toe of the Tsirku alluvial fan suggests that water at this depth is derived from precipitation originating at high-altitude, interior locations. Shallower ground water (40-ft deep wells) is derived from a lower altitude, near-coastal enviroment.

Seismic-refraction surveys indicate that the depth to bedrock at the axis of Chilkat Valley is more than 850 ft. The survey results were confirmed by test drilling 20 ft into bedrock at the head of the Tsirku alluvial fan, and by comparison with an earlier gravimetric survey.

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