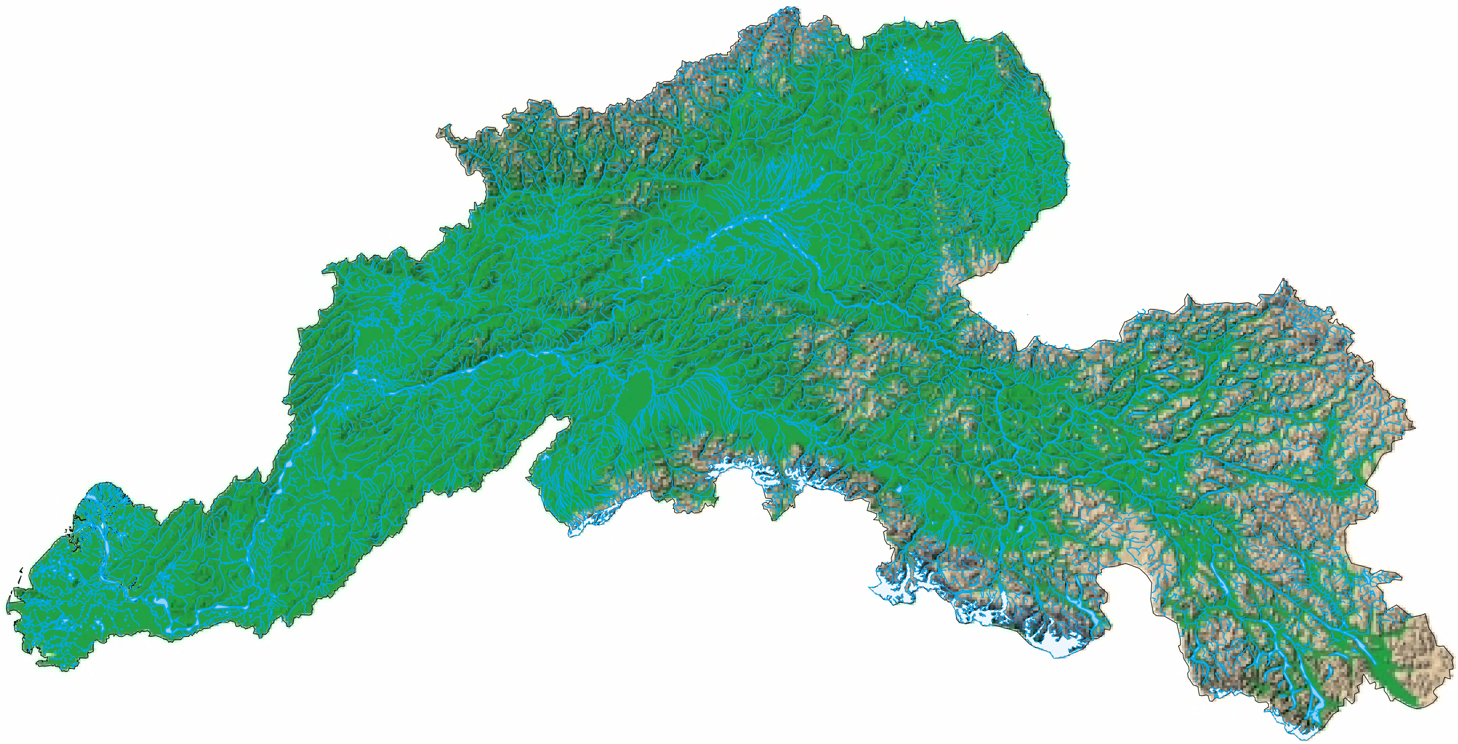
Environmental and Hydrologic Overview of the Yukon River Basin, Alaska and Canada

Water-Resources Investigations Report 99-4204



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

Cover: Digital elevation model of the Yukon River Basin

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By Timothy P. Brabets, Bronwen Wang, and Robert H. Meade

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 99-4204

Anchorage, Alaska
2000

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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Multiply	by	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch per year (in/yr)	25.4	millimeter per year
ton	0.9072	megagram
ton per day (ton/d)	0.9072	megagram per day
ton per year (ton/d)	0.9072	megagram per year
foot per mile (ft/mi)	0.1894	meter per kilometer

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

$$°C = (°F-32)/1.8$$

OTHER ABBREVIATED UNITS

mg/L, milligram per liter

µg/L, microgram per liter

µS/cm, microsiemen per centimeter at 25 degrees Celsius

mm, millimeter

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.

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ABSTRACT

The Yukon River, located in northwestern Canada and central Alaska, drains an area of more than 330,000 square miles, making it the fourth largest drainage basin in North America. Approximately 126,000 people live in this basin and 10 percent of these people maintain a subsistence lifestyle, depending on the basin's fish and game resources. Twenty ecoregions compose the Yukon River Basin, which indicates the large diversity of natural features of the watershed, such as climate, soils, permafrost, and geology.

Although the annual mean discharge of the Yukon River near its mouth is more than 200,000 cubic feet per second, most of the flow occurs in the summer months from snowmelt, rainfall, and glacial melt. Eight major rivers flow into the Yukon River. Two of these rivers, the Tanana River and the White River, are glacier-fed rivers and together account for 29 percent of the total water flow of the Yukon. Two others, the Porcupine River and the Koyukuk River, are underlain by continuous permafrost and drain larger areas than the Tanana and the White, but together contribute only 22 percent of the total water flow in the Yukon.

At its mouth, the Yukon River transports about 60 million tons of suspended sediment annually into the Bering Sea. However, an estimated 20 million tons annually is deposited on flood plains and in braided reaches of the river. The waters of the main stem of the Yukon River and its tributaries are predominantly calcium magnesium bicarbonate waters with specific conductances generally less than 400 microsiemens per centimeter. Water quality of the Yukon River Basin varies temporally between summer and winter. Water quality also varies spatially among ecoregions.

INTRODUCTION

Few rivers have the intrinsic allure of the Yukon River. Its history, people, and mystique have innate appeal. The Yukon is a transportation corridor in a vast area of roadless Alaska. Salmon species migrate the entire length of the river to spawn and are also a staple of the subsistence lifestyle of rural villages. Villages and towns obtain water for drinking from the river and associated aquifers. Recreational activities abound for both residents and tourists. However, the river is not benign: flooding and erosion are hazards to people, buildings, roads, and airfields.

The Yukon River Basin (figs. 1 and 2) is located in northwestern Canada and central Alaska, and is approximately 330,000 mi^2 in area. The basin represents one of the largest and most diverse ecosystems in North America. Despite its remoteness and perceived invulnerability, the Yukon River Basin is changing. For example, from 1991 to 1999, the number of growing days in

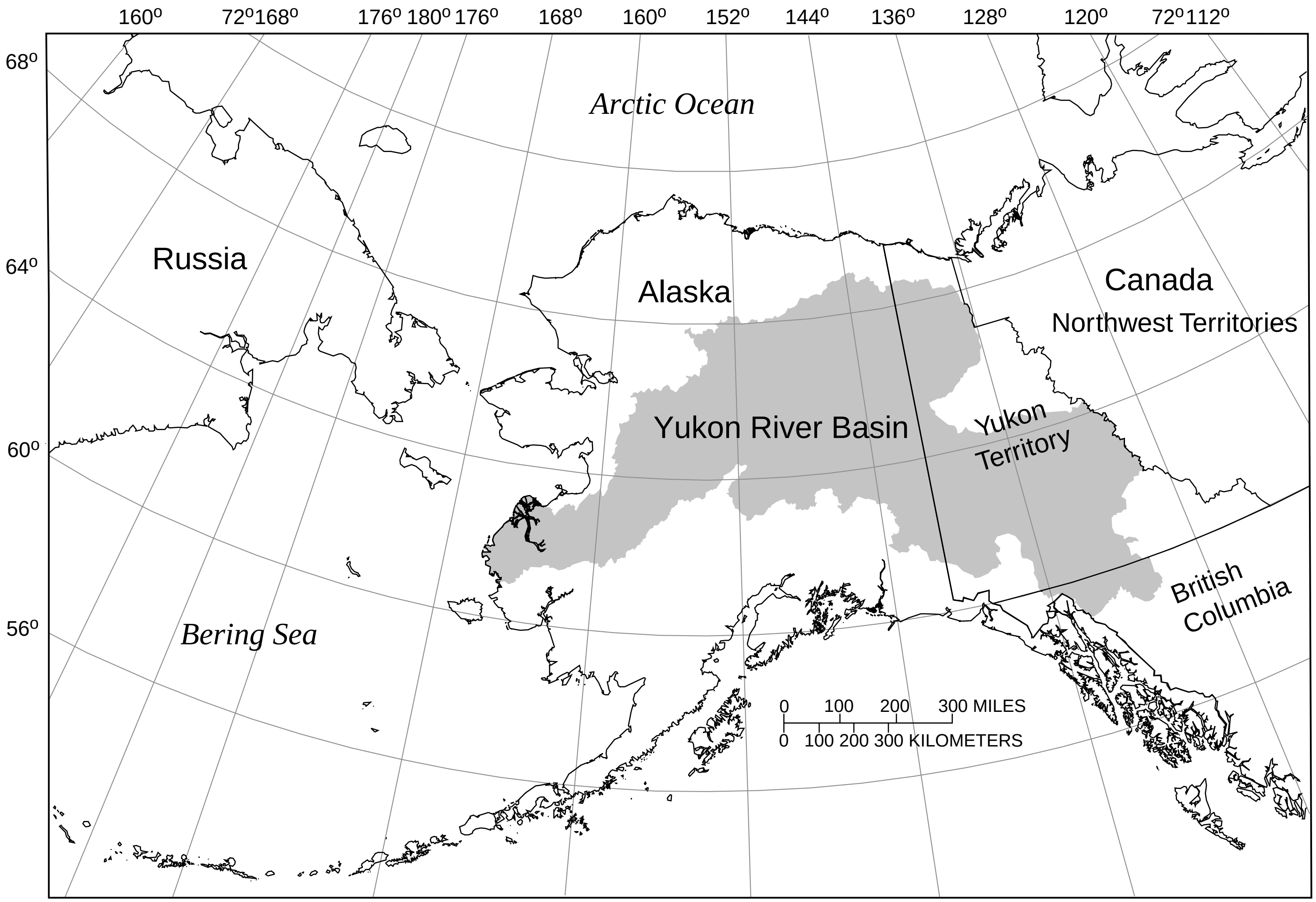


Figure 1. Location of the Yukon River Basin in Canada and Alaska.

DIGITAL ELEVATION MODEL

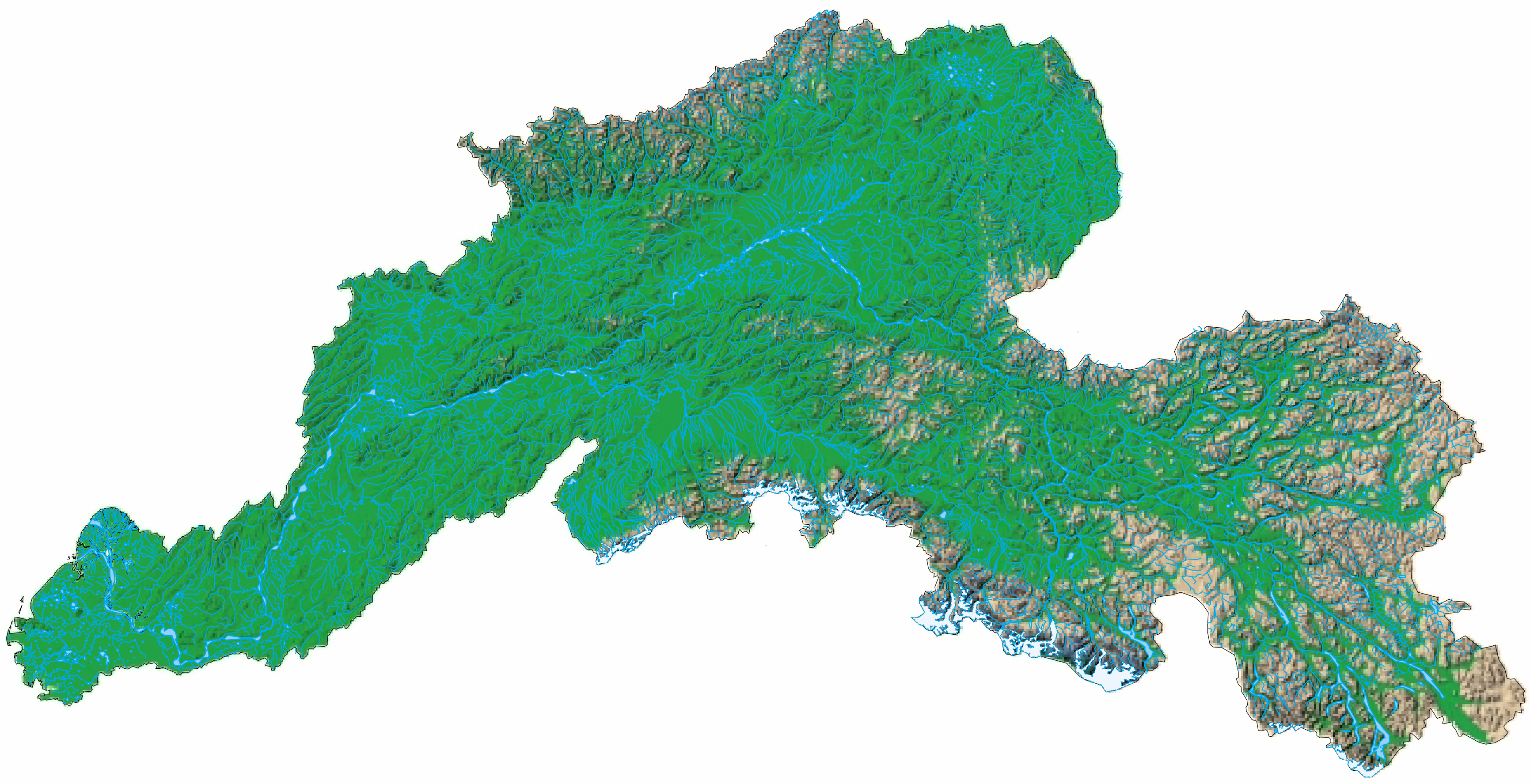


Figure 2. Digital elevation model of the Yukon River Basin.

Alaska for four ecoregions has ranged from 130 to 194 days (fig. 3). Air temperature records from 1961-90 indicate a warming trend on the order of 1.4 °F (0.75 °C) per decade at latitudes where the Yukon River is located (fig. 4) (Chapman and Walsh, 1993). If this warming trend continues, the growing season will likely increase. Climate changes will also influence the permafrost distribution, glacial runoff, and biogeochemical fluxes within and from the basin (BESIS, 1997). The Yukon River is also fundamental to the Bering Sea ecosystem (fig. 1), providing most of the fresh water runoff, sediments, and dissolved solutes in the eastern part of the sea (Lisitsysn, 1969). Thus, processes that influence the Yukon River could in turn influence the Bering Sea.

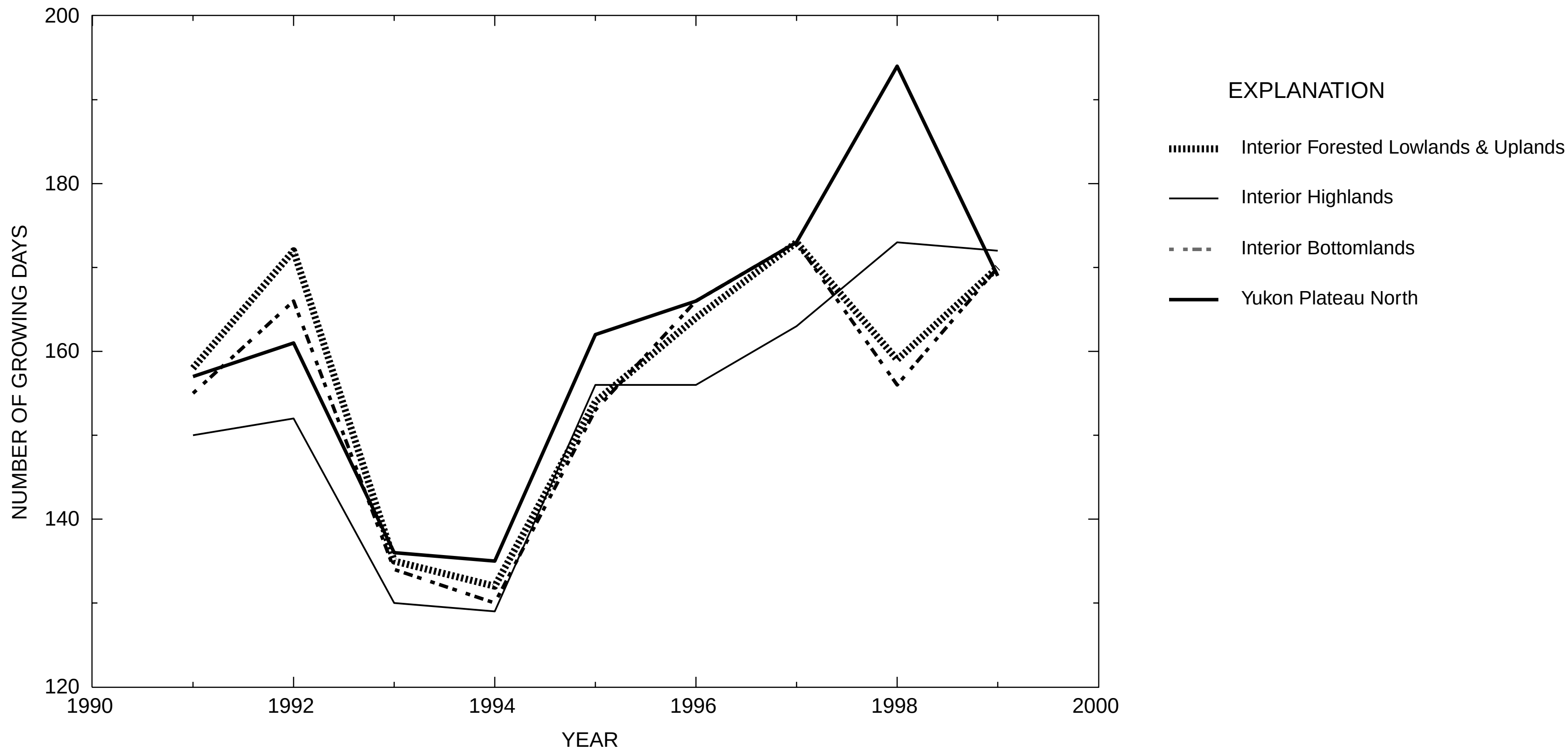


Figure 3. Number of growing days for four ecoregions of the Yukon River Basin, 1991-99 (data provided by Carl Markon, USGS, 1999; see figure 16 for location of ecoregions).

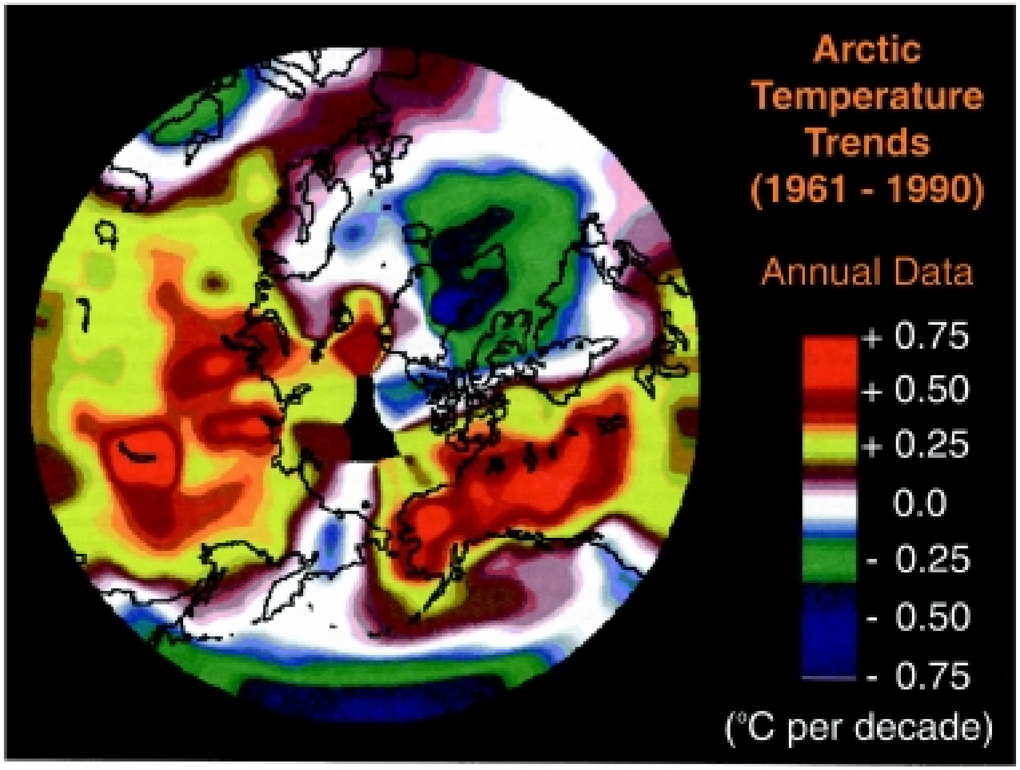


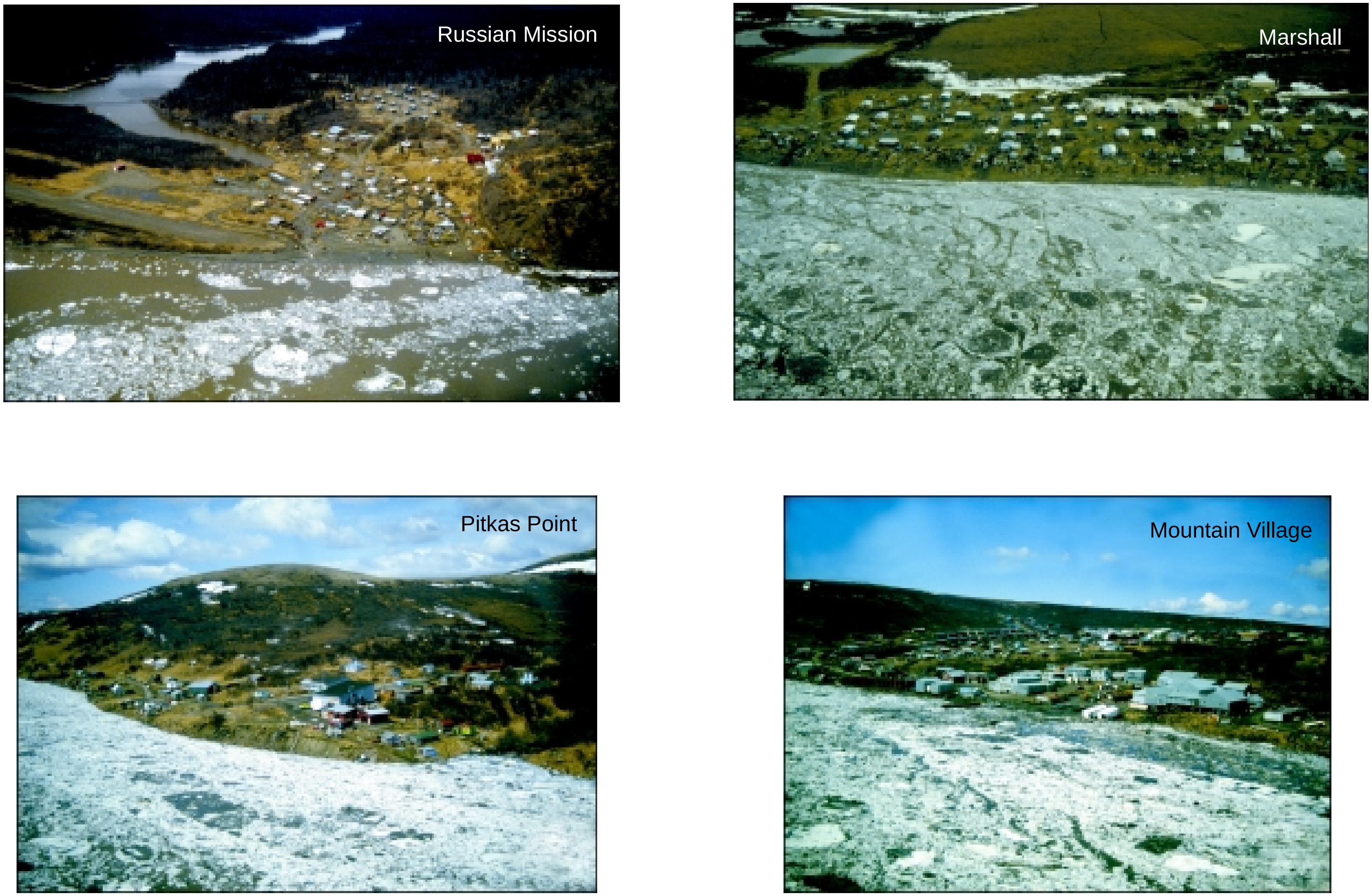
Figure 4. Observed trends of Arctic annual mean temperatures from 1961-90 (from Chapman and Walsh, 1993).

Purpose and Scope

This report summarizes the environmental, flow, and water-quality characteristics of the Yukon River Basin. The purpose of this summary is twofold: (1) to gain a more complete understanding of the currently known surface-water and water-quality characteristics of the Yukon River and (2) to provide background information needed to design a sound water-quality sampling program for the basin. The scope of this study includes the entire Yukon River Basin. Only historical data were used in this compilation. Although ground water is an important water resource in the Yukon River Basin, it is described in this report only in general terms.

Acknowledgments

The authors gratefully acknowledge the efforts of the Water Survey of Canada/Environment Canada in providing streamflow and water-quality information for use in this report. Lynne Campo provided discharge and suspended-sediment data and Andrea Ryan provided access via the web to water-quality data. Carl Markon (USGS) provided data on the growing seasons in Alaska and combined the land cover characteristics from Canada and Alaska data sets into one cohesive map of the entire basin.



Four villages along the lower Yukon River that were flooded from ice jams in 1988. Many villages located along the banks of the Yukon River and its major tributaries are subject to flooding during ice breakup. (photographs courtesy of Larry Rundquist, National Weather Service).

DESCRIPTION AND HISTORY OF THE YUKON RIVER BASIN

The Yukon River and its Major Tributaries

The Yukon River Basin is the fourth largest basin in North America and the fifth largest in terms of average discharge (Schumm and Winkley, 1994). Although no universal agreement exists as to the source of the Yukon River, it is believed to originate from the Llewellyn Glacier, near Atlin Lake, in northwestern British Columbia (Parfit, 1998) (fig. 5A). From this point, the river flows for more than 2,000 mi in a broad arc through the Yukon Territory of Canada and central Alaska, emptying into the Bering Sea.

From its headwaters, the Yukon River generally flows northwestward to the Canada/Alaska boundary. Near the outlet of Lake Laberge (fig. 5A) above Frank Creek, the river is approximately 300 ft wide (fig. 6A), but downstream from the junction of the Teslin River at Carmacks, the width increases to about 600 ft (fig. 6B). Below Carmacks, the Dawson Range lies on the west and the Ogilvie and Pelly Mountains lie on the east. The Pelly and Stewart Rivers (fig. 5A), whose sources are along the Yukon Territory/Northwest Territories border, drain about 38,000 mi^2. The White River (fig. 5A) drains about 18,000 mi^2, and includes the extensive snowfields and glaciers of the Wrangell–St. Elias Mountains. The inflow from these three large rivers increases the width of the Yukon to approximately 1,000 ft at Dawson (fig. 6C).

At Fortymile, in Canada, about 60 river miles upstream from Eagle (fig. 5B), the Yukon River flows between bluffs of the Tanana Uplands on the south and the Ogilvie Mountains on the north. At Eagle, the width of the Yukon has increased to about 1,500 ft (fig. 6D). From Eagle, the Yukon flows for about 150 mi through the Yukon-Charley Rivers National Preserve to Circle (fig. 5B). This national park encompasses parts of the valley on both sides of the Yukon and all of the drainage of the Charley River, a designated National Wild and Scenic River. The Nation and Kandik Rivers, entering from the north, are the other major tributaries between Eagle and Circle.

At Circle, the altitude of the Yukon River is approximately 600 ft above sea level and yet the river is still more than 1,000 mi inland. Circle marks the beginning of the Yukon Flats, a large lowland area crisscrossed by meandering river channels that are constantly shifting. Much of the lowland is part of the Yukon Flats National Wildlife Refuge. The landscape is characterized by flat terrain and is encircled by mountains, which trap the heat and the cold. This feature results in extreme air temperatures in the summer (as high as 100 °F) and winter (as low as -30 °F).

Approximately 60 mi downstream from Circle is the village of Fort Yukon (fig. 5B), where the Porcupine River enters the Yukon River from the northeast (fig. 5A). The Porcupine River drains about 45,000 mi^2 of the northeast part of the Yukon River Basin and is about 500 mi long. Downstream from Fort Yukon, the Chandalar River, which drains the Brooks Range, enters the Yukon from the north. The Yukon River reaches its northernmost point at the Arctic Circle at this location, and begins to flow westward and southward to the Bering Sea.

Stevens Village (fig. 5B) marks the approximate end of the Yukon Flats. The Yukon River flows in a more confined area, sometimes referred to as Rampart Canyon. At this point, the river is approximately 2,000 ft wide (fig. 6E) and is the location where the trans-Alaska oil pipeline crosses the river. Approximately 150 mi downstream from Stevens Village, the Tanana River enters the Yukon from the southeast (fig. 5A). The Tanana River is a large tributary to the Yukon and drains approximately 44,000 mi^2. Included in the Tanana drainage is the north side of the Alaska Range, an extensively glaciated area.

RIVERS, LAKES AND GLACIERS

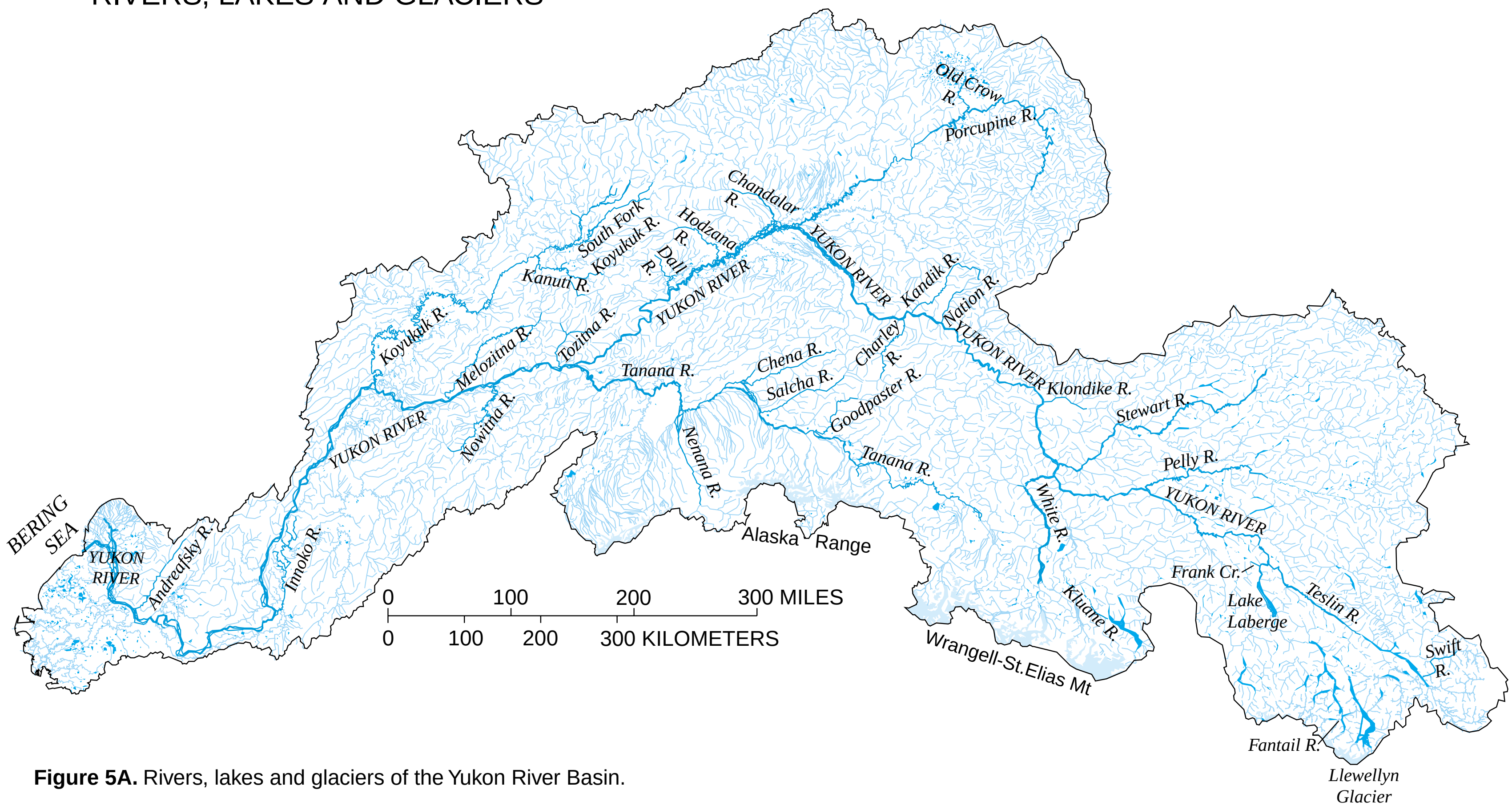


Figure 5A. Rivers, lakes and glaciers of the Yukon River Basin.

ROADS & TOWNS

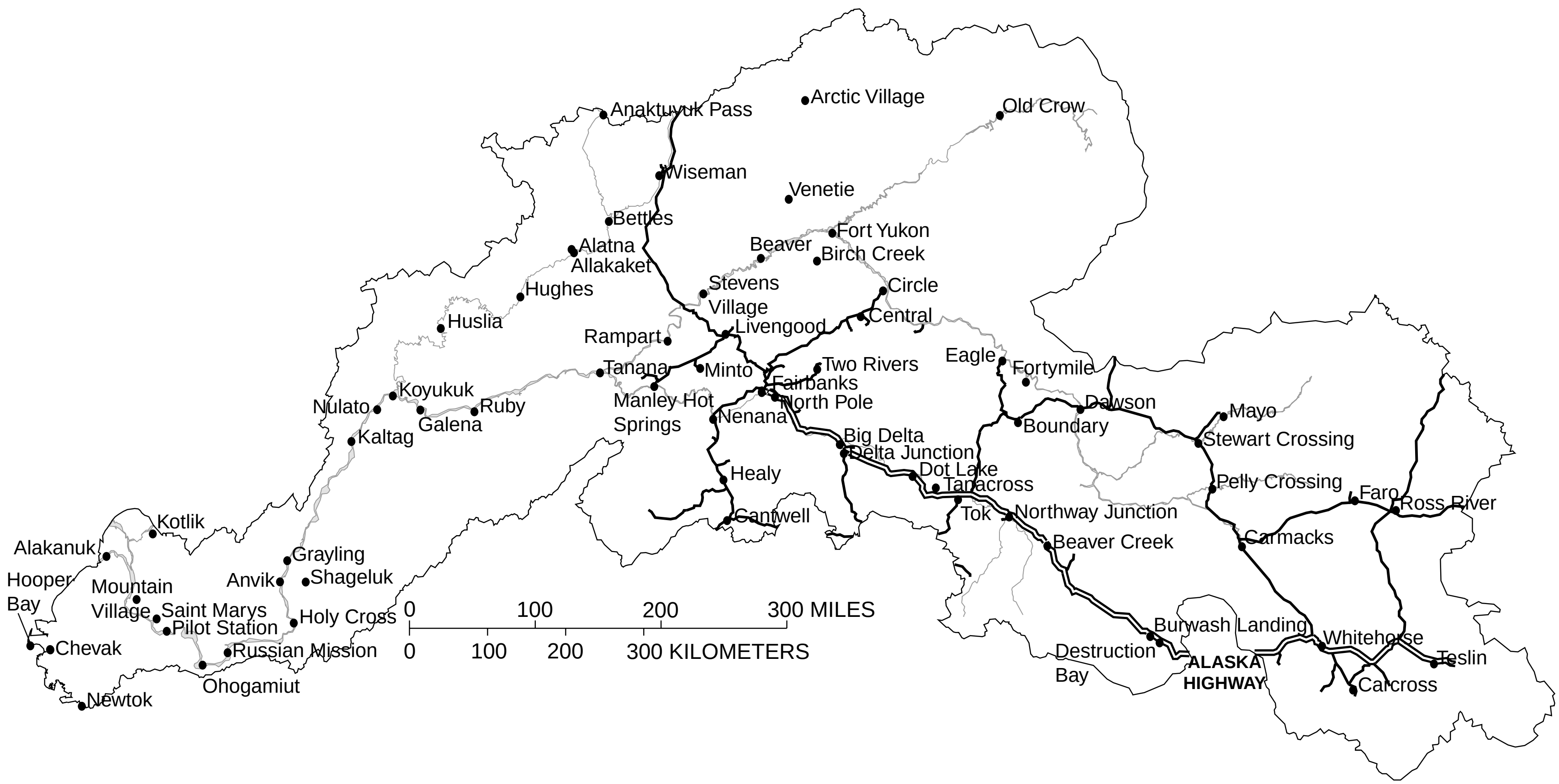


Figure 5B. Roads and towns in the Yukon River Basin.

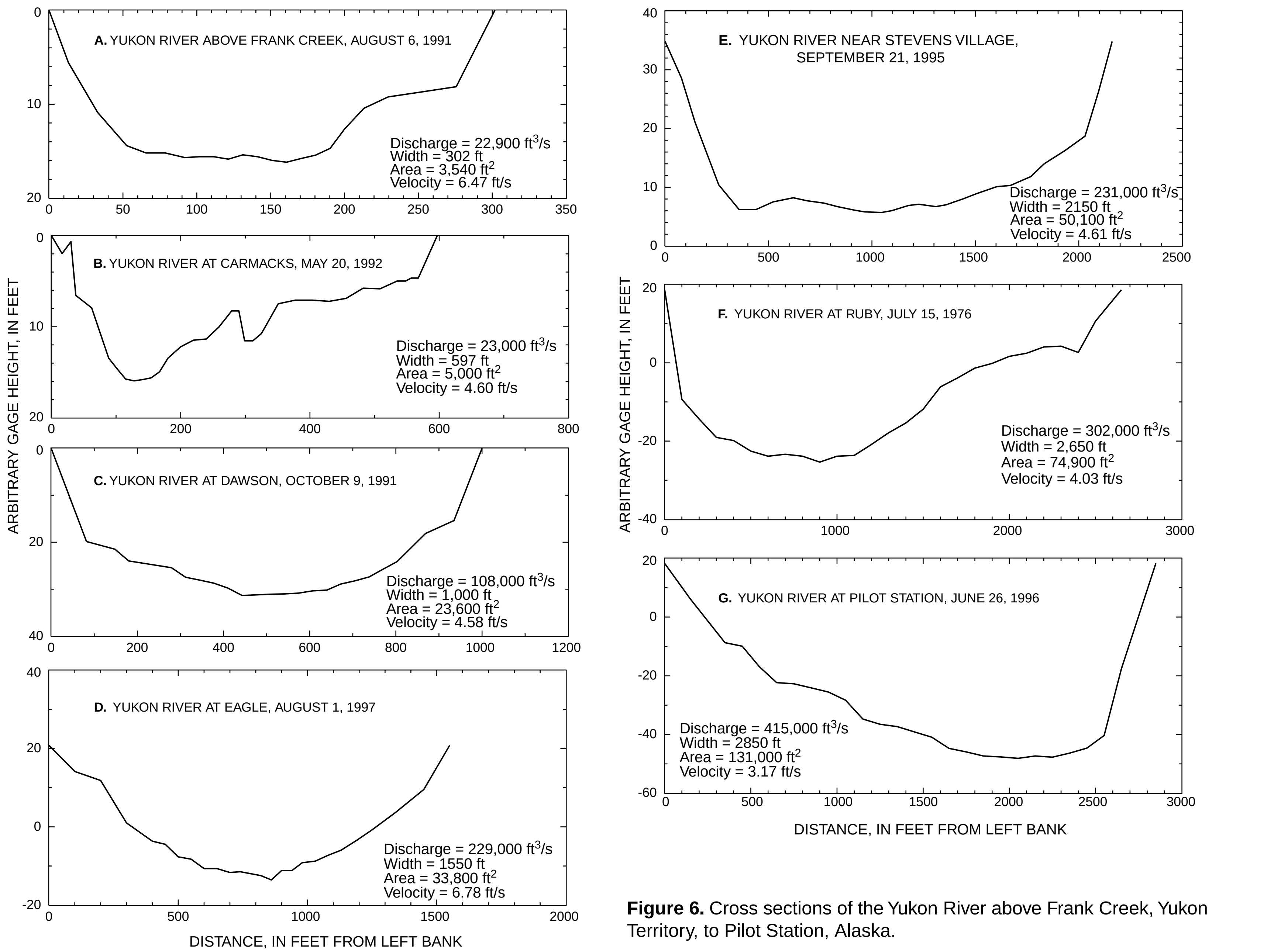


Figure 6. Cross sections of the Yukon River above Frank Creek, Yukon Territory, to Pilot Station, Alaska.

Past the Tanana River, the Nowitna National Wildlife Refuge is located on the south side of the Yukon River for approximately 70 mi. The Nowitna River, a National Wild and Scenic River, enters the Yukon from the southeast. Past the wildlife refuge is the village of Ruby, where the Melozitna River enters from the north (fig. 5A). The width of the Yukon is approximately 2,500 ft at Ruby (fig. 6F). Galena, a village located about 50 mi downstream from Ruby is the largest community in this part of the Yukon River Basin.

Downstream from Galena, the Koyukuk River, a major tributary of the Yukon River, enters the Yukon from the north. The Koyukuk, which drains much of the north-central part of the Yukon River Basin, has a drainage area of about 35,000 mi^2 and is about 400 mi in length. At this point, the Yukon changes direction, flowing almost due south for about 160 mi. The Innoko National Wildlife Refuge is located on the east side of the river and near the end of this stretch of the Yukon, the Innoko River enters the Yukon near the village of Holy Cross. The Innoko River drains much of the area between the Yukon and Kuskokwim Rivers and flows in a broad S for about 500 mi.

Holy Cross is located about 280 mi upstream from the mouth of the Yukon. Several miles downstream from this village, the Yukon River begins to flow to the west, between hills and bluffs approximately 2,000 ft high. At Ohogamiut, an abandoned fishing village, the river turns northward. As the Yukon passes Pilot Station, the channel is about 3,000 ft wide (fig. 6G). Near Saint Marys, the Andreafsky River enters. The Andreafsky River is relatively small but has been designated a National Wild and Scenic river. From Saint Marys, the Yukon River flows through many channels in a large wetland area and then to the Bering Sea.

Exploration of the Yukon River Basin

The following history of the Yukon River Basin is summarized from publications by the Alaska Geographic Society (1987, 1990, and 1991). The aboriginal people of the Yukon River Basin may be among the oldest known residents of North America. After crossing Beringia, the land bridge that once linked Asia and America, these early people occupied Alaska and the western part of the Yukon Territory. Those who did not trade with the coastal Tlingits of southeastern Alaska remained free of influence from other cultures until the 19th century.

Interest in furs, not gold, lured the first outsiders to the Yukon. One of the earliest explorations of the Yukon Basin by Europeans was undertaken by Robert Campbell of the Hudson's Bay Company. In 1840, Campbell explored the Pelly River and in 1848 established an outpost at the junction of the Pelly and Yukon Rivers. John Bell, also of the Hudson's Bay Company, explored the Porcupine River in 1844 and established an outpost at Fort Yukon.

Beginning in the 1870's, Leroy McQuesten, Arthur Harper, and Alfred Mayo, established a number of trading posts up and down the Yukon River. The threesome spent some time each summer and fall prospecting and began to realize the potential mineral wealth of the Yukon. Foreseeing the passing of the fur trader and the rise of the prospector, they gradually changed their stock from the needs of Natives and fur traders to equipment and supplies for miners. In 1885, miners found placer gold on the Stewart River and in 1886, gold was discovered on the Fortymile River. Additional discoveries were made in the Circle and Rampart areas in 1893. However, these first paying strikes in the Yukon River Basin were only a trickle compared to the tidal wave of miners that would come with the Klondike discoveries at Dawson in 1897.

Between 1897 and 1900, people from virtually every corner of the world and from every conceivable background headed toward the Klondike. At its peak, Dawson was home to as many as 25,000 people. Although only a few "struck it rich," the 1897 gold rush to the Klondike in the Yukon Territory, more than any other event, led to commercial mining in the Yukon River Basin. Many prospectors who arrived too late began to explore all through the Yukon River Basin, setting off mini-stampedes to areas reporting new gold strikes.

The construction of the Alaska Highway (fig. 5B) in 1942, to provide a road link from the Lower 48 to Alaska as a defense measure during World War II, signaled an end to a way of life in the Yukon. Commercial river traffic ended a few years later. Gradually, a network of roads was constructed that today links many of the communities.

People and Land

Approximately 126,000 people live in the Yukon River Basin and 10 percent of these people maintain a subsistence lifestyle, depending on the basin's fish and game resources. In the Canadian part of the Yukon River Basin, Whitehorse (fig. 5B) is the center of population with just over 23,000 residents in 1998 (Environment Canada, 1999). The towns of Dawson and Faro have just over 2,000 and 1,000 residents respectively. The remaining towns have populations ranging from 100 to 500 residents. In Alaska, the greater Fairbanks area (Fairbanks and North Pole) is the center of population and had approximately 84,000 residents in 1996 (Alaska Department of Labor, 1999). About 12,000 other residents are located in 43 villages scattered across the Yukon River Basin from the Canadian border to the mouth of the Yukon River. Village populations range from approximately 30 to 800 people, with typical villages having fewer than 300 residents. Two major ethnic groups historically occupied the Yukon River Basin: the Yupik Eskimos who live along the Bering Sea Coast and inland up the river approximately 250 mi, and the Athabaskan Indians who occupy the remainder of the basin.

The Canada segment of the Yukon River Basin includes parts of two Canadian National Parks, Vuntut and Kluane (fig. 7), in addition to several Habitat Protection Areas. Atlin Provincial Park is located near the headwaters of the Yukon River. These lands compose about 9 percent of the land area of the Canadian Yukon. In the Alaska part of the Yukon River Basin, about 68 percent of the land is owned by the Federal government. Four national parks cover 10 percent of the area, 8 wildlife refuges cover 32 percent of the area, and Bureau of Land Management (BLM) land covers 22 percent (fig. 7). The U.S. military and Native corporations each own approximately 1 percent of the land.

The Yukon River at Dawson, Yukon Territory. At this point the river is 1,000 feet wide. Today, the population of Dawson is about 2,000, but at the height of the Klondike Gold Rush, the population was 25,000.

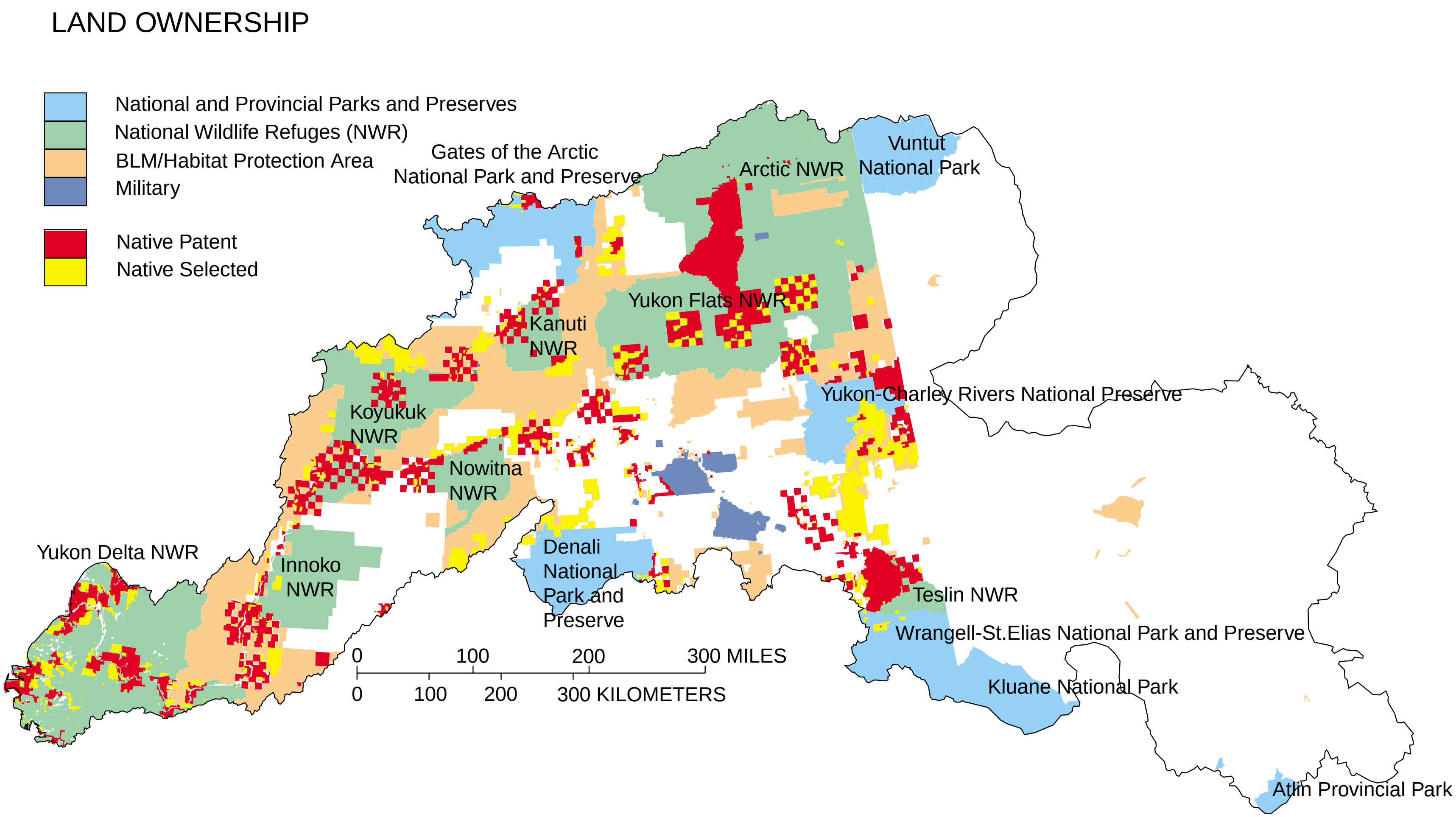


Figure 7. Land ownership of the Yukon River Basin.

Economic Activity

To a large extent in Alaska, and to a smaller extent in Canada, nearly all the people who reside in the Yukon River Basin villages are dependent to varying degrees on fish and game resources for their livelihood (Holder and Senecal-Albrecht, 1998). Subsistence salmon fishing is commonly undertaken by extended family groups of two or more households cooperating to harvest, cut, preserve, and store salmon for personal use. Many people who fish for subsistence salmon also fish commercially. The development of the commercial export salmon fishery has enabled many area residents to obtain a cash income. In many cases, the cash income provides a means for fishermen to maintain a subsistence lifestyle. Income from commercial fishing is commonly used to obtain hunting and fishing gear used for subsistence activities. Thus, in many of these villages, the commercial and subsistence sectors of the economy are complementary and mutually supported. Households have been required to convert to a cash-oriented economy because payments for mortgages, water, sewer, electric, telephone, and groceries require cash. Yet, even the most modern villages have remained subsistence-based because of the intrinsic value of subsistence activities and because local renewable resources form the most reliable base of the economy from year to year.

Two commercial fishing seasons in the Yukon River Basin are the summer season, which targets chinook and summer chum salmon, and the fall season, which targets fall chum salmon with an incidental harvest of coho salmon. Yukon River salmon stocks have generally remained healthy, primarily because their spawning, rearing, and migration habitat remain undisturbed. However, in 1997 and 1998, runs of the chum salmon in the Yukon River Basin declined sharply (table 1) and many of the villages suffered from the effects. Not only have commercial fisherman taken huge

Table 1. Comparison of salmon harvests for various time periods, Yukon River Basin, Alaska

[Data from Holder and Senecal-Albrecht, 1998; --, data not available]

Year	Subsistence	Commercial	Sport	Total
Chinook salmon				
1961-86 average	24,452	109,401	753	134,606
1987-91 average	49,634	109,302	763	159,699
1992-96 average	51,669	110,276	2,017	163,962
1997	66,278	121,732	1,913	189,923
1998	53,733	43,699	779	98,211
Summer chum salmon				
1961-86 average	192,003	466,459	672	659,134
1987-91 average	155,754	978,726	1,105	1,135,585
1992-96 average	117,529	491,610	1,050	610,189
1997	97,109	230,842	475	328,426
1998	86,004	28,798	488	115, 290
Fall chum salmon				
1961-86 average	106,897	182,251	--	289,148
1987-91 average	210,392	173,539	--	383,931
1992-96 average	113,673	84,408	--	198,081
1997	102,937	67,122	--	170,059
1998	62,867	0	--	62,867
Coho salmon				
1961-86 average	17,199	21,292	405	38,896
1987-91 average	55,517	68,399	2,049	125,965
1992-96 average	34,288	23,724	1,521	59,533
1997	24,593	35,820	1,470	61,883
1998	12,904	0	951	13,855

losses (with a corresponding effect on local businesses), but many villages that depend on salmon as a main staple of their diet now find them in short supply.

Mining activity was, and remains, an important economic industry within the basin (table 2). Most historical mining activity occurred on localized, discrete, headwater streams using manual labor which helped to minimize impacts on salmon spawning habitat. Mining operations have to cope with short operating seasons, difficult transportation conditions, and high freight and labor costs. Both small and large mining operations exist today. Rigid enforcement of environmental regulations since the mid-1980's has resulted in mining operations that are less detrimental to fish habitat than in the past. In 1999, two large hard-rock mines were operating: the Illinois Creek mine in the Upper Innoko drainage near Galena and the Fort Knox mine near Fairbanks. A third site, the Pogo Mine, was being assessed for development in the Goodpaster River Basin (fig. 5A) near Big Delta.

Another natural resource activity in the Yukon River Basin is logging. Although not as large an industry as fishing or mining, logging could increase as large tracts of Federal land are transferred into Native corporations and State ownership, and both local and export timber demands increase. Primary areas of logging are the Tanana River Basin (Alaska) and the southeastern part of the Yukon Territory near Teslin.

Other economic activities complement the natural resource activities in the Yukon River Basin. These include tourism in both Alaska and Canada, government, and service industries. The U.S. military also has a strong presence in Alaska with two Army reservations and one Air Force base. During the Cold War, the military also operated several radar sites along the Yukon River at Fort Yukon and Galena.

Table 2. Watersheds where mining has occurred in the Yukon River Basin

Watershed	Nearest village or town (fig. 5B)
American Creek	Tanana
Beaver Creek	Fort Yukon
Birch Creek	Fort Yukon
Chatanika River	Fairbanks
Chena River	Fairbanks
Coal Creek	Circle
Eureka Creek	Nenana
Fortymile River	Eagle
Goldstream Creek	Fairbanks
Hogatza River	Alatna
Iditarod River	Shageluk
Innoko River	Shageluk
Livengood Creek	Livengood
Middle Fork Koyukuk River	Wiseman
Minook Creek	Rampart
Nome Creek	Livengood
South Fork Koyukuk River	Wiseman
Sulatna Creek	Ruby
Woodchopper Creek	Circle

ENVIRONMENTAL CHARACTERISTICS OF THE YUKON RIVER BASIN

Physiography

The purpose of physiographic classification is to divide an area into smaller regions that are topographically distinct from surrounding regions. Thus, the boundaries of the physiographic regions are typically drawn where the topography changes in character. Physiographic divisions of the Yukon River Basin for Alaska were classified by Wahrhaftig (1965) and for Canada by Bostock (1970). Five general physiographic regions are present in the Yukon River Basin (fig. 8): (1) rolling topography and gentle slopes, 37 percent; (2) low mountains, generally rolling, 24 percent; (3) plains and lowlands, 20 percent; (4) moderately high rugged mountains, 17 percent; and (5) extremely high rugged mountains, 2 percent. The following specific descriptions are modified from Wahrhaftig (1965) and can be inferred from the digital elevation map of the Yukon River Basin (fig. 2).

Alaska Range (Central and Eastern Part)—The central and eastern part of the Alaska Range consists of two or three parallel rugged glaciated ridges, 6,000-9,000 ft in altitude, surmounted by groups of extremely rugged snow-capped mountains more than 9,500 ft in altitude. Mount McKinley, 20,320 ft high and the highest mountain in North America, is located in this part of the Alaska Range. Most of the rivers and streams flow into the Tanana River. Rivers are swift and braided, and most rivers head in glaciers. The high mountains are sheathed in ice, and valley glaciers as much as 40 mi long and 5 mi wide radiate from them.

Central and Eastern Brooks Range—The Central and Eastern Brooks Range is a wilderness of rugged glaciated east-trending ridges that rise to summits 7,000-8,000 ft in altitude in the northern part and 4,000-6,000 ft in altitude in the southern part. The eastern part of the range has belts of hard and soft sedimentary and volcanic rocks. The mountains have cliff-and-bench slopes characteristic of glacially eroded bedded rocks. Major rivers flow southward to the Yukon and Koyukuk Rivers in flat-floored glaciated valleys ranging from 0.5 to 2 mi in width. Small cirque glaciers are common in the higher parts of the range.

Indian River Uplands—This region consists of groups of low gentle ridges having rounded accordant summits at 1,500-2,000 ft altitude interspersed with irregular lowlands and broad flat divides. A few mountains rise to 4,000 ft in altitude. The Koyukuk and Kanuti Rivers cross the upland in narrow canyons a few hundred feet deep. Most of the region is drained by the Koyukuk River and its tributaries. Numerous thaw lakes are in the lowlands, valleys, and broad passes. Although there are no glaciers, the entire land area is underlain by permafrost.

Innoko Lowlands—The Innoko Lowlands are a group of flat flood plains, dendritic in pattern, whose bounding slopes are generally steep banks cut into the surrounding hills. The Yukon River and a large tributary, the Innoko River, cross the lowlands. The main part of the lowlands has a complex intersecting network of meandering sloughs of these two streams. Oxbow and meander-scroll lakes are abundant in recently abandoned flood plains and partly silted sloughs. Thaw lakes also abound in old flood plains and on gentle silt-covered slopes.

Kokrine-Hodzana Highlands—This region consists of even-topped rounded ridges rising to 2,000-4,000 ft in altitude surmounted by isolated areas of more rugged mountains. A rugged compact highland in the northeastern part has many peaks between 4,500 and 5,700 ft in altitude. The irregular drainage divide between the Yukon River and its large tributary, the Koyukuk River, passes through these highlands. Drainage to the Yukon

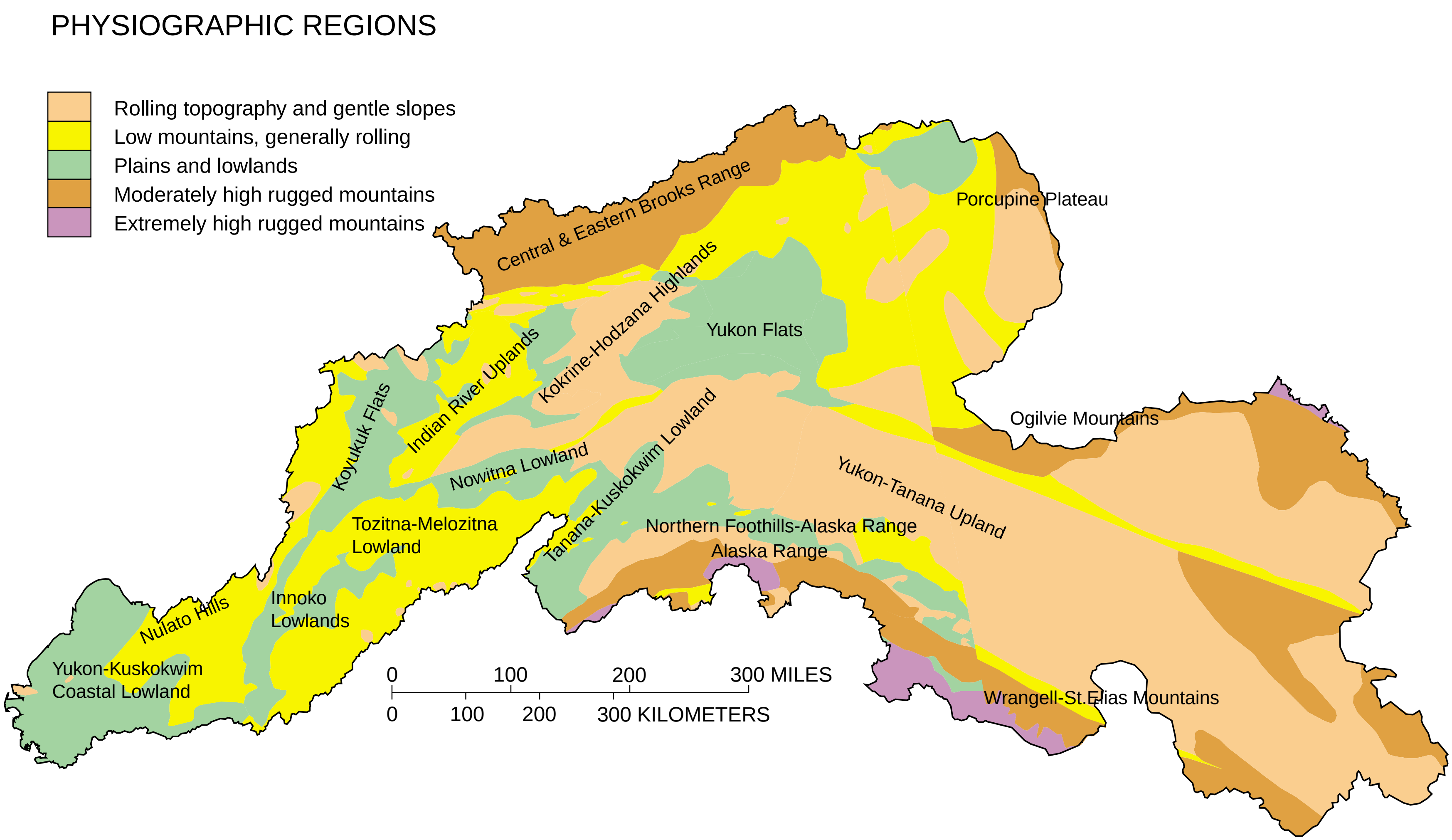


Figure 8. Physiographic regions of the Yukon River Basin (modified from Wahrhaftig, 1965 and Bostock, 1970).

River is by way of the Hodzana, Tozitna, Melozitna, and Dall Rivers and many shorter streams. Drainage to the Koyukuk River is by the Kanuti River and the South Fork Koyukuk River.

Koyukuk Flats—The Koyukuk Flats form an extensive lowland of irregular outline at the junction of the Yukon and Koyukuk Rivers. The central part of the Koyukuk Flats are flat plains 5-20 mi wide, along the major rivers. The parts immediately adjacent to the rivers are meander belts 5-10 mi wide and the parts farther away are dotted by thaw lakes. Broad rolling silt plains stand 100-200 ft above these central plains and merge with the surrounding uplands. The Flats are drained by the Yukon River.

Northern Foothills of the Alaska Range—The topography of this region consists of flat-topped east-trending ridges 2,000-4,500 ft in altitude, 3-7 mi wide, and 5-20 mi long that are separated by rolling lowlands 700-1,500 ft in altitude and 2-10 mi wide. All rivers and streams in this region flow into the Tanana River. No glaciers are present in this region.

Nowitna Lowland—The Nowitna Lowland is a rolling silt-covered tableland ranging from 250-900 ft in altitude and having a local relief of 50-250 ft and slopes of 100-150 ft/mi into which flat flood plains of the major rivers have been incised 150-300 ft. The entire lowland is drained by the Yukon River, which follows the northern boundary. The confluence of the Yukon River with the Tanana River is in the eastern part of the lowland. The southern part of the lowland is drained by the Nowitna River, a tributary of the Yukon River.

Nulato Hills—The Nulato Hills consist of northeast-trending even-crested ridges, 1,000-2,000 ft in altitude, having gentle slopes. Valleys are narrow and have flat floors that are generally trenched in their upstream parts to depths of about 30 ft. Streams flow to the Yukon River.

Ogilvie Mountains—The Ogilvie Mountains have steep slopes and deep narrow valleys. Mountain peaks rise to 5,000 ft in altitude, and local relief is as much as 4,000 ft. The ridges are interconnected and passes are few. The narrow valleys are interrupted by gorges where rivers cross cliff-forming layers of rock. The major river drainages are the Kandik, Nation, and Tatonduk Rivers, all tributaries of the Yukon River. No glaciers are present, but most of this region is underlain by permafrost.

Porcupine Plateau—The Porcupine Plateau is dominated by low ridges having gentle slopes and rounded to flat summits 1,500-2,500 ft in altitude. A few mountains rise to 3,500 ft. Valley floors are broad and valley patterns are irregular. The Chandalar, Sheenjek, and Coleen Rivers rise in the Brooks Range and flow southward across the plateau in broad valley floors with moraines and outwash terraces. The Porcupine River crosses the plateau in a narrow cliff-lined canyon 50-500 ft deep. The Black and Little Black Rivers, which drain the southeastern part of the area, meander through broad irregular flats. The Porcupine Plateau has no glaciers, but the entire area is underlain by continuous permafrost.

Tanana-Kuskokwim Lowland—This lowland is a broad depression bordering the Alaska Range on the north. The central and eastern parts of the lowland are drained by the Tanana River. Braided glacial streams rising in the Alaska Range flow northward across the lowland. Thaw lakes are present in areas of fine alluvium and the entire area consists of permafrost.

Tozitna-Melozitna Lowland—This long narrow rolling plain, 5-10 mi wide, is drained by the Tozitna and Melozitna Rivers. These two rivers flow southward from the lowland in narrow gorges across the Kokrine-Hodzana Highlands to the Yukon River. The lowland contains numerous thaw and oxbow lakes. Discontinuous areas of permafrost are present.

Wrangell–St. Elias Mountains—The Wrangell Mountains are an oval group of shield and composite volcanoes that rise above a low plain on the north and west and above heavily glaciated cliffed and castellated ridges on the south and east. About 25 percent of the region drains into the Tanana River by way of the Nabesna and Chisana Rivers and into the Yukon River by way of the White River. The St. Elias Mountains are probably the most spectacular mountains of North America. Massive isolated block-like mountains 14,000-19,000 ft in altitude rise at intervals of 5-30 mi from a network of narrow ridges and sharp peaks. The average altitude of icefields in the interconnected valley system is 3,000-7,000 ft. Local relief is extreme and jagged cliffs abound.

Yukon Flats—The Yukon Flats region consists of marshy lake-dotted flats rising from 300 ft in altitude on the west to 600-900 ft on the north and east. The northern part of the flats is made up of gently sloping outwash fans of the Chandalar, Christian, and Sheenjek Rivers. The southeastern part of the flats is the broad gentle outwash fan of the Yukon River. Other areas are flat flood plains. Rolling silt and gravel-covered marginal terraces having sharp escarpments 150-600 ft high rise above the flats and slope gradually up to altitudes of about 1,500 ft at the base of surrounding uplands and mountains. The region is drained by the Yukon River, which has a braided course southeast of the bend at Fort Yukon and a meandering course, containing many sloughs, southwest of the bend at Fort Yukon. Most tributaries rise in surrounding uplands and mountains and have meandering courses through the flats.

Yukon-Kuskokwim Coastal Lowland—The Yukon-Kuskokwim Coastal Lowland is a triangular lake-dotted marshy plain rising from sea level on its west margin to 100-300 ft at its east end. Low beach ridges, marked by lines of thaw lakes, lie along part of the west coast. The lowland is crossed by meandering streams of extremely low gradient, many of them distributaries or former channels of the Yukon River. The Yukon River flows along the base of hills on the north side of the lowland and is building a delta into the Bering Sea. This region is dotted with innumerable thaw lakes, many of them 10 or more miles long. Probably 30-50 percent of the lowland is lake surface.

Yukon-Tanana Upland—The Yukon-Tanana Upland is characterized by rounded even-topped ridges. In the western part, these rounded ridges trend northwestward to eastward and have altitudes of 1,500-3,000 ft. The ridges are surmounted by compact rugged mountains 4,000-5,000 ft in altitude. Ridges in the eastern part have no preferred direction, are 3,000-5,000 ft in altitude and rise 1,500-3,000 ft above adjacent valleys. Valleys in the western part are generally flat, alluvium floored, and 0.25-0.50 mi wide to within a few miles of headwaters. Streams in the eastern part that drain to the Yukon River flow in narrow V-shaped terraced canyons. Streams flow southward to the Tanana River or northward to the Yukon River. No glaciers are in the region, but the entire section is underlain by discontinuous permafrost.

Climate

The Yukon River Basin has a variable climate because of its large size and range in altitude of the land surface. Climate zones have been broadly defined primarily by variations in precipitation and temperature (Searby, 1968; Hartman and Johnson, 1978). With the exception of the Yukon River Delta, the Yukon River Basin lies in the continental zone. Temperature extremes are greater in this zone than in the other climatic zones. Air temperatures average about 22 °F. The Yukon Delta is located in the transition zone. Temperature in this zone averages about 27 °F, slightly higher than that in the continental zone.

Precipitation in the Yukon River Basin ranges from 10 to 130 in. annually (fig. 9). Averaged over the entire basin, the annual precipitation is approximately 19 in. The amount of precipitation is directly related to topography: high rugged mountains receive the greatest amounts of precipitation and lowland areas receive the least. About half of the precipitation falls as snow from November through March. Snow may fall year-round in the high mountains, where much of it is stored for long periods in glaciers and icefields.

The climate in the Yukon River basin has been undergoing significant long-term change. Tree-ring studies and 20th century weather records indicate that the temperatures at Fairbanks and in the surrounding area of Interior Alaska have been warming steadily since about 1840, with a brief interruption of this trend from about the mid 1940's to the mid 1970's (Juday and others, 1998). During the period 1949–96, the rate of warming has been about 0.4 °F per 100 years. This warming also manifests itself as an increase in the length of the growing season and in earlier onset of snowmelt and "break up" of the ice cover on the rivers. Precipitation at Fairbanks has been generally decreasing during the 81 years from 1906–96 at a rate of about 1 in. per 100 years. Glaciers are receding as a result of both warmer temperatures and locally decreased precipitation. The 30-year record for Gulkana Glacier in the Alaska Range indicates that ablation has exceeded precipitation for 27 out of the past 32 years. Although other long-term records are not available for the Yukon River Basin, Gulkana Glacier is commonly thought to be representative of other glaciers in the basin.

View of a valley glacier. Extensive systems of valley glaciers are present in the Alaska Range and the Wrangell–St. Elias Mountains. Although glaciers compose only one percent of the Yukon River Basin, they have significant effects on the runoff characteristics.

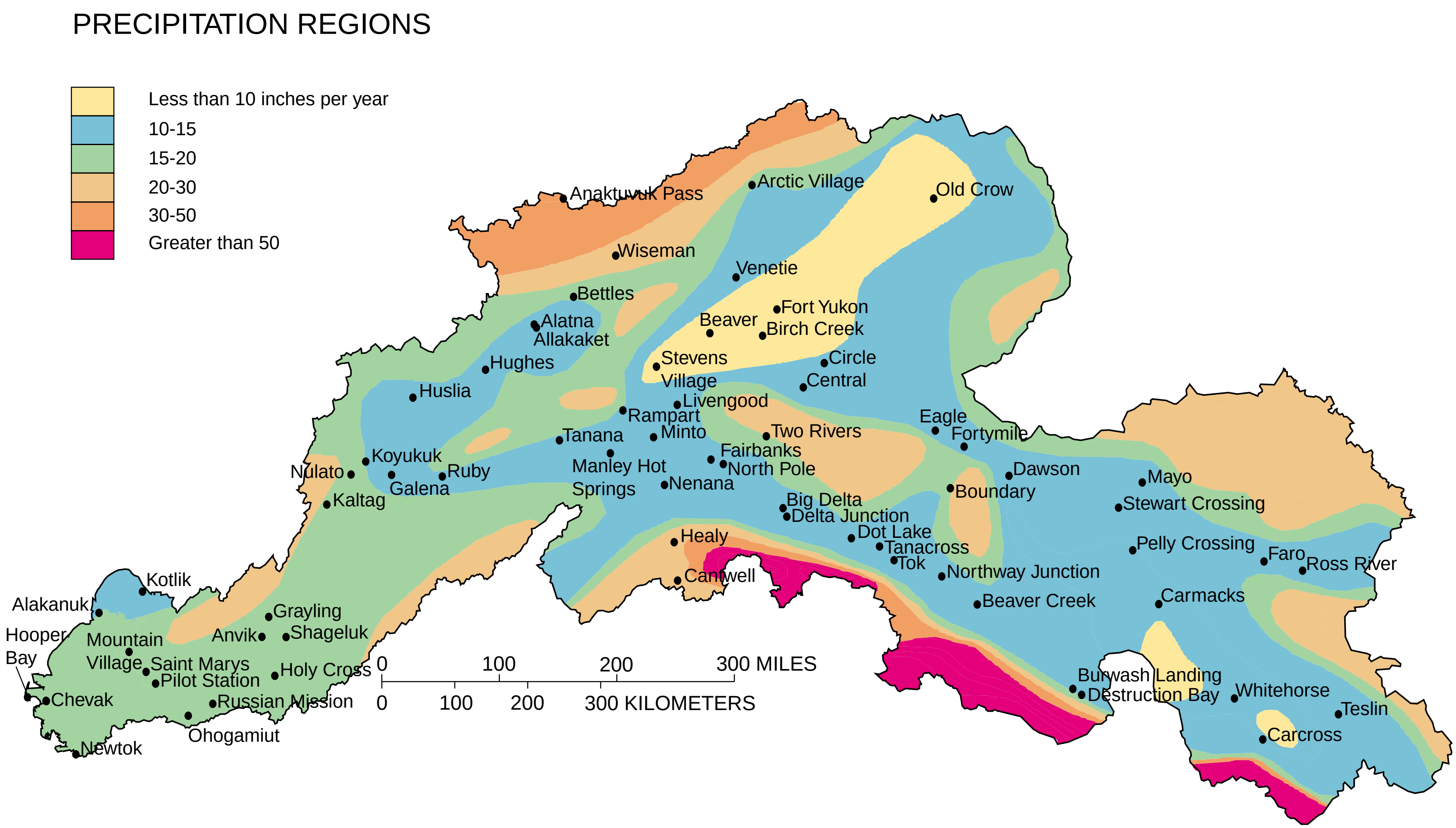


Figure 9. Precipitation regions in the Yukon River Basin (from Jones and Fahl, 1994).

Geology

Water-quality characteristics of surface water and ground water are strongly affected by surficial and bedrock geology. The geology of the Yukon River Basin is complex and the interpretation of the geology is based on the concept that the Yukon River Basin is a mosaic of geologic terranes (Silberling and others, 1994; Gordey and Makepeace, 1999). A terrane is a body of rock of regional extent that is bounded by faults, and whose geologic history is different from that of adjacent terranes. The terranes in the Yukon River Basin represent blocks of the Earth’s crust that have moved large or small distances relative to each other. The pattern of terranes in the Yukon River Basin reflects the interactions of oceanic crustal plates with the North American plate; large-scale lateral and rotational movements, rifting, and volcanic activity result from these interactions.

Because of the size of the Yukon River Basin and the complexity of its geology, the following description is limited to the rock type. The rocks range in age from Precambrian to Holocene and consist of both unconsolidated deposits and consolidated rocks (fig. 10). Major deposits are described in the following section (see figure 8 for locations of physiographic regions).

Cenozoic unconsolidated deposits are present in lowland areas of the Yukon River Basin. The most prominent areas are the upper Porcupine River, the Yukon Flats, the Tanana-Kuskokwim Lowland, the Nowitna Lowland, the Tozitna-Melozitna Lowland, the Innoko Lowlands, and the Yukon Delta. The deposits are considered thick accumulations and consist primarily of alluvium but also include glacial deposits and locally include eolian and beach deposits. In the Yukon Delta area, deltaic and marine deposits of Quaternary age are included in this map category.

Cenozoic sedimentary rocks are found in the foothills of the Alaska Range and near Eagle. These rocks are composed primarily of sandstone, siltstone, and shale, but also contain coal, mudstone, and conglomerate.

Cenozoic volcanic rocks ranging in composition from rhyolite to basalt are found in the foothills of the Wrangell–St. Elias Mountains, in the lower part of the Yukon River near Holy Cross, and in scattered locations in the Koyukuk River Basin.

Cenozoic intrusive rocks ranging in composition from granite to quartz are found in the southeastern part of the Yukon River Basin near the base of the Wrangell–St. Elias Mountains and the Coast Mountains.

Mesozoic sedimentary rocks are found mainly in the southeastern part of the Yukon River Basin, the upper Porcupine River Basin, the Indian River Upland, and the Nulato Hills. These rocks are mostly shale, siltstone, and sandstone, but locally include limestone and large deposits of coal.

Mesozoic volcanic rocks crop out in scattered areas of the Yukon River Basin. Most of these rocks are found in the western part of the basin near the Yukon Flats and Koyukuk Flats. Composition of the rocks ranges from andesite to basalt.

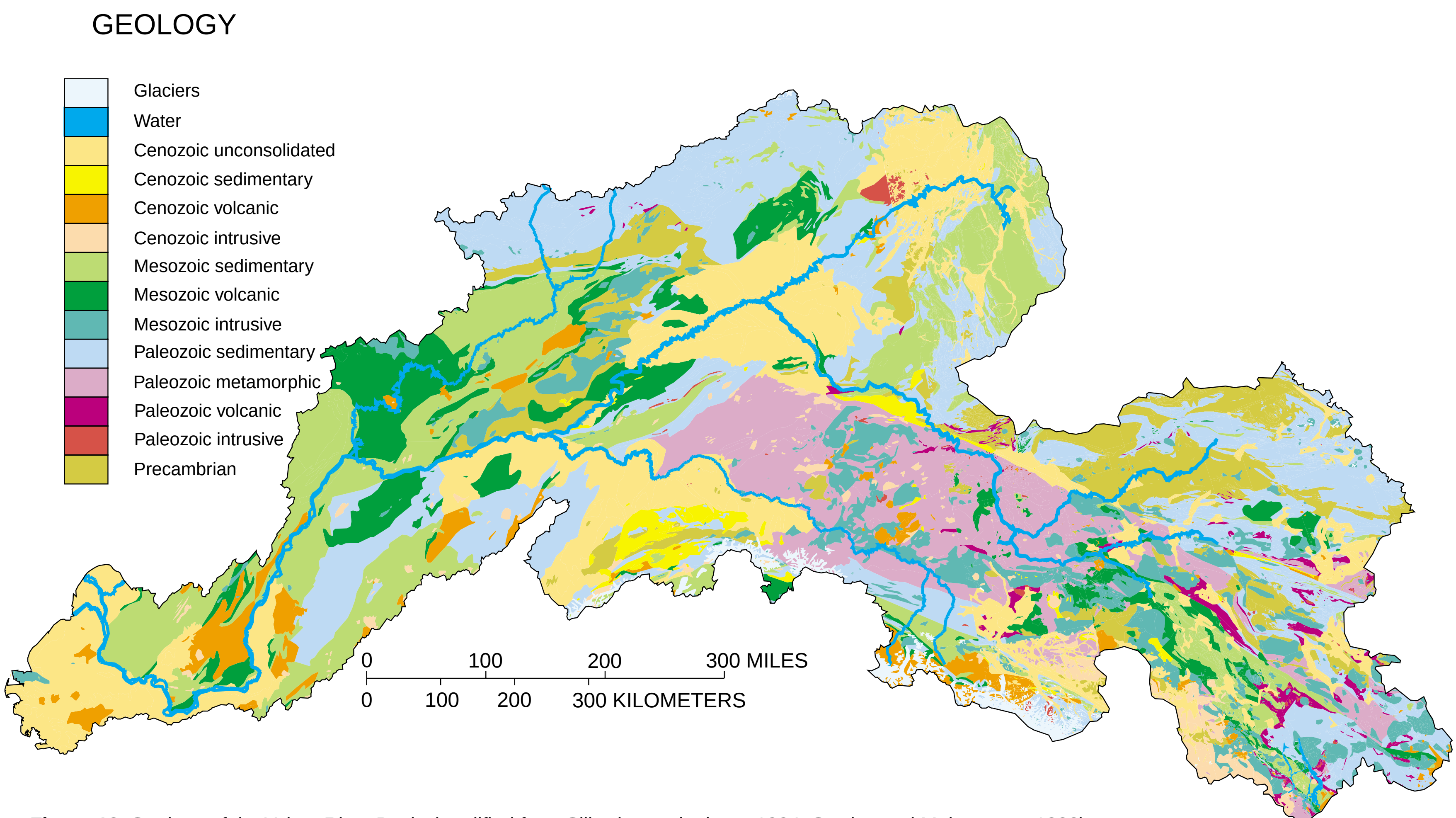


Figure 10. Geology of the Yukon River Basin (modified from Silbering and others, 1994; Gordey and Makepeace, 1999).

Mesozoic intrusive rocks are present primarily in the southern part of the Yukon River Basin in British Columbia, the Yukon-Tanana Upland, and the Kokrine-Hodzana Highlands. These rocks are mostly in upland and mountainous areas and range in composition from granite to gabbro.

Paleozoic sedimentary rocks are present throughout the Yukon River Basin. These rocks are found in the eastern part of the basin in the Selwyn Mountains, along the northern flanks of the Brooks Range, in the eastern part of the Porcupine River Basin, and in the Innoko Lowlands. Composition of the rocks is mostly limestone, shale, siltstone, and sandstone, but can include beds of conglomerate, dolomite, and chert.

Paleozoic metamorphic rocks are prominent in the Yukon-Tanana Upland. These rocks are primarily gneiss, schist, phyllite, and quartzite, but locally include argillite, marble, and several kinds of metasedimentary rocks.

Paleozoic volcanic rocks are scattered throughout the Yukon River Basin in small isolated areas near the Alaska/Canada border. Larger areas are found in the southeastern part of the basin. These volcanic rocks consist of sandstone, basalt, rhyolite, and chert.

Paleozoic intrusive rocks are found near the Porcupine River near the Alaska/Canada border. These rocks of various kinds are faulted against lower Paleozoic and Precambrian metamorphic rocks.

Precambrian rocks are found primarily in the eastern and central part of the Yukon River Basin. Rocks consist of phyllite, slate, and siltstone.

Land Cover

Land cover influences a number of hydrologic factors, such as snow accumulation, soil moisture depletion, surface runoff, infiltration, and erosion. These factors, in turn, can affect the water quality of a particular stream or river. For example, certain types of vegetation can prevent erosion, thus reducing the quantity of sediment that enters a stream. Also, the composition of certain types of vegetation will in turn affect the chemistry of the water quality.

Land cover also has a direct influence on the permafrost because of the thermal properties that determine the quantity of heat entering and leaving the underlying ground in which the permafrost exists. Vegetation exerts an indirect influence on permafrost by affecting climatic and other terrain features, which in turn have a direct influence on the permafrost. These direct and indirect influences vary with time and space.

A land classification system developed by the Alaska Geospatial Data Clearinghouse (1998), describes eight types of land cover, six of which compose about 90 percent of the Yukon River Basin (table 3; fig. 11): needleleaf forest, tall and low shrublands, broadleaf forest, lichens, barren, and wet herbaceous. The other two, dwarf shrublands and dry herbaceous, compose about 7 percent of the basin. The remaining land cover is mainly ice, snow, and water. Specific descriptions of these land covers are taken from Talbot and Markon (1988).

Table 3. Types and areas of land cover in the Yukon River Basin

[Data from Alaska Geospatial Data Clearinghouse, 1998]

Type of land cover (fig. 11)	Area	
	Square miles	Percent
Needleleaf forest	176,970	53.5
Tall and low shrublands	29,004	8.8
Broadleaf forest	28,627	8.6
Lichens	20,923	6.3
Barren	20,452	6.2
Wet herbaceous	19,960	6.0
Dwarf shrublands	12,875	3.9
Dry herbaceous	10,517	3.2
Ice and snow	9,211	2.8
Water	1,498	<1
Other	765	<1
Total	*331,000*	*100*

Needleleaf forest (53.5 percent)—These areas are composed of two subclasses, closed needleleaf forest and open needleleaf forest. Closed needleleaf forests are dominated by white spruce on well-drained sites and along drainages, or black spruce on lowland sites. The tree canopy ranges from 60 to 100 percent. Open needleleaf forests are similar to the closed needleleaf forest except that the tree canopy ranges from 25 to 59 percent.

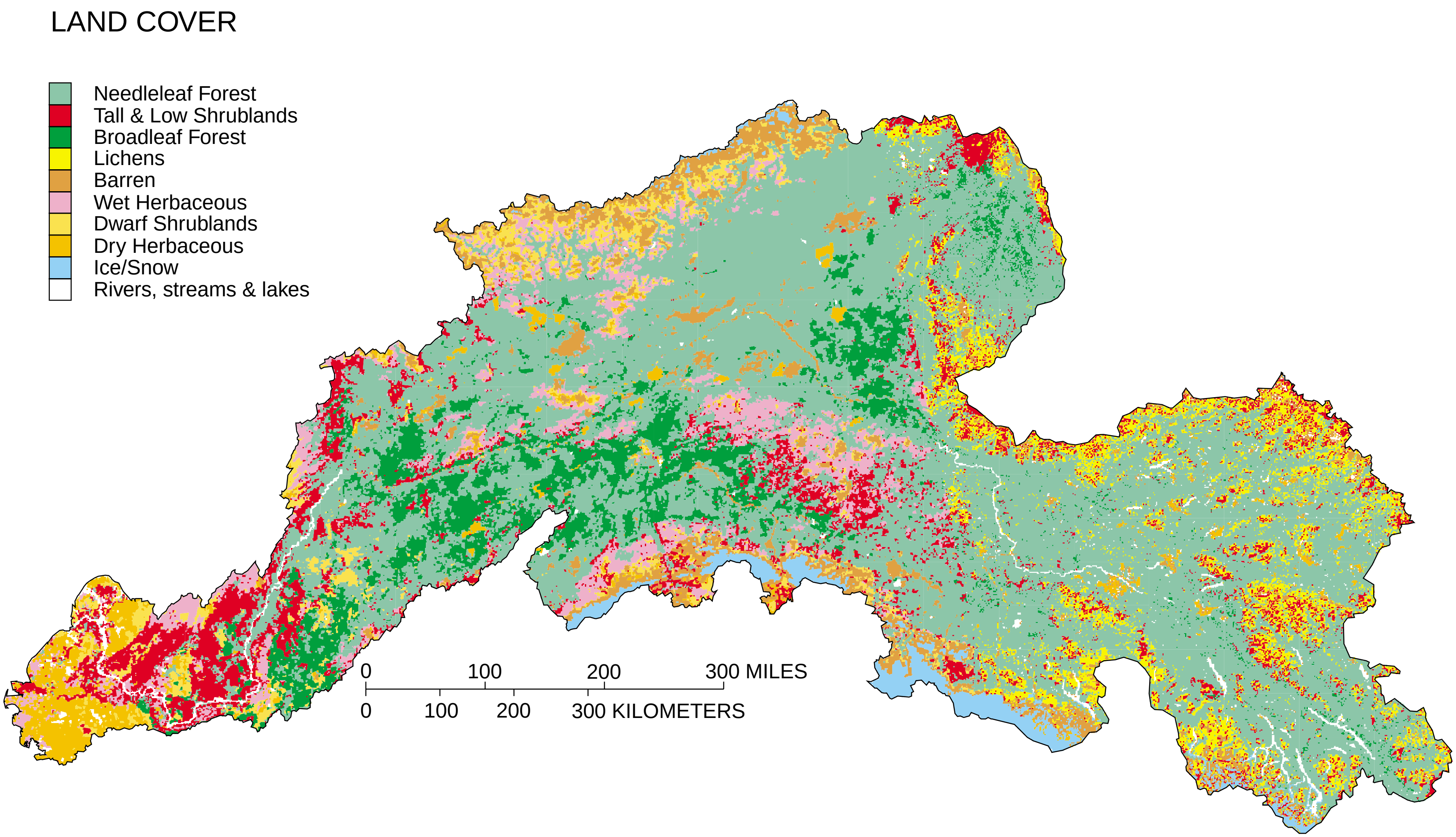


Figure 11. Land cover classes of the Yukon River Basin (from Alaska Geospatial Data Clearinghouse, 1998).

Tall and low shrubland (8.8 percent)—These areas are composed of two subclasses, closed and open. Closed tall and low shrubland occurs primarily on upper hillslopes; mid-mountain slopes; or along rivers, streams, and small wet or waterlogged basins. It may also be found on mid- to higher altitude slopes. The shrub canopy is 75 percent or greater with heights ranging from 8 to 59 in. Alders and willows are the more common species present. Open tall and low shrubland is similar to the closed tall and low shrubland except that the shrub cover is generally less than 75 percent. Stands of open alder or small clumps of willow may be found on a variety of mountains and altitudes, on upper slopes of rounded hills, and on steep mid-slopes of hills.

Broadleaf forest (8.6 percent)—Similar to needleleaf forests and to tall and low shrubland, the two subclasses of broadleaf forest are closed and open. Closed broadleaf forests have tree canopies ranging from 60 to 100 percent. The primary tree species are white birch found on both hillsides and alluvial sites, and balsam found only on alluvial sites. Open broadleaf forests have tree canopies ranging from 25 to 59 percent and are composed of the same tree species as the closed broadleaf forests.

Lichens (6.3 percent)—These areas are common in the Yukon River Basin, some of which cover extensive areas, and most of which are associated with a number of low and dwarf shrubs.

Barren (6.2 percent)—These areas consist primarily of sand, gravel, rocks, and boulders of various sizes often associated with active flood plains, hill summits, and mountain tops. Vascular plant cover is normally less than 5 percent. However, varying amounts of lichens may be present.

Wet herbaceous (6.0 percent)—These areas are similar to grasslands but are generally found in areas containing soils that are moist to saturated throughout the season. They are found primarily in low basins, tidal areas, and tundra areas where water has been impounded.

Dwarf Shrublands (3.9 percent)—These areas generally have few plants greater than 8 in. high and are dominated by dwarf birch. Lichens may also be present in mountainous and lowland areas.

Dry Herbaceous (3.2 percent)—These areas are dominated by sedges, normally with greater than 60 percent cover. Most areas have other grass or grass-like plants as well as scattered shrubs. Mosses and lichens may also be present in varying amounts.

Soils

The formation of soils depends primarily on five factors: type of parent material, climate, relief or topography, living organisms, and time (Singer and Munns, 1987). The type of soil depends on which factor is the most dominant. In the Yukon River Basin, type of material, climate, and relief have been the most dominant factors in the development of soils. Soil type can affect water quality as precipitation infiltrates the soil, reacts with the minerals that are present, and then discharges into a stream. Soil type and distribution are also factors that affect the amount of soil erosion.

In the soil taxonomy of the U.S. Department of Agriculture (1975), soils are grouped at six levels or categories. The two broadest categories are the **order**, followed by the more narrowly defined category, the **suborder**. Of a possible 12 soil orders, 5 soil orders are found in the Yukon River Basin: Entisols, Gelisols, Inceptisols, Mollisols, and Spodosols (fig. 12). Gelisols are a recently developed new classification for permafrost soils (Joe Moore, National Resources Conservation Service, 1999). In addition, one other area, **rough mountainous lands**, is not classified as an order because it is largely unvegetated (Rieger and others, 1979).

Entisols—These are recently formed soils with little soil horizon development and are found in areas of glacial outwash or alluvium. Suborders and soils of Entisols found in the Yukon River Basin are:

- <u>Orthents Suborder</u>

  Lithic Cryorthents—Soils with texture finer than loamy fine sand. There is no stratification of the soil and bedrock is less than 20 in. from the top of the surface.

  Typic Cryorthents—Soils that are thicker than 20 in. over bedrock and have a mean annual temperature above freezing. They have a wide range in texture and their colors are dominantly gray. The parent material is loess blown from the braided beds of rivers that have a heavy silt load.

  Pergelic Cryorthents—Soils with mean annual temperatures below freezing and with no bedrock within 20 in. The soil is gravelly and has rapid internal drainage. The permafrost is commonly many feet deep.

  Pergelic Ruptic-Histic Cryorthents—Soils that have been subject to frost-stirring processes to the extent that much of the surface is barren or covered only with lichens or a few tundra plants. Commonly, these soils have polygonal surface patterns and thick organic mats.

- <u>Fluvents Suborder</u>

  Typic Cryofluvents—Soils with alternating layers of sand and silt loam. Many are underlain by a thick deposit of water and sand. Color is typically gray.

Gelisols—These are soils that have permafrost within about 40 in. of the soil surface and (or) have gelic materials within about 40 in. of the soil surface and have permafrost within about 80 in. Gelic materials are mineral or organic soil materials that have evidence of frost churning in the active layer (seasonal thaw layer) and (or) in the upper part of the permafrost. Suborders and soils are:

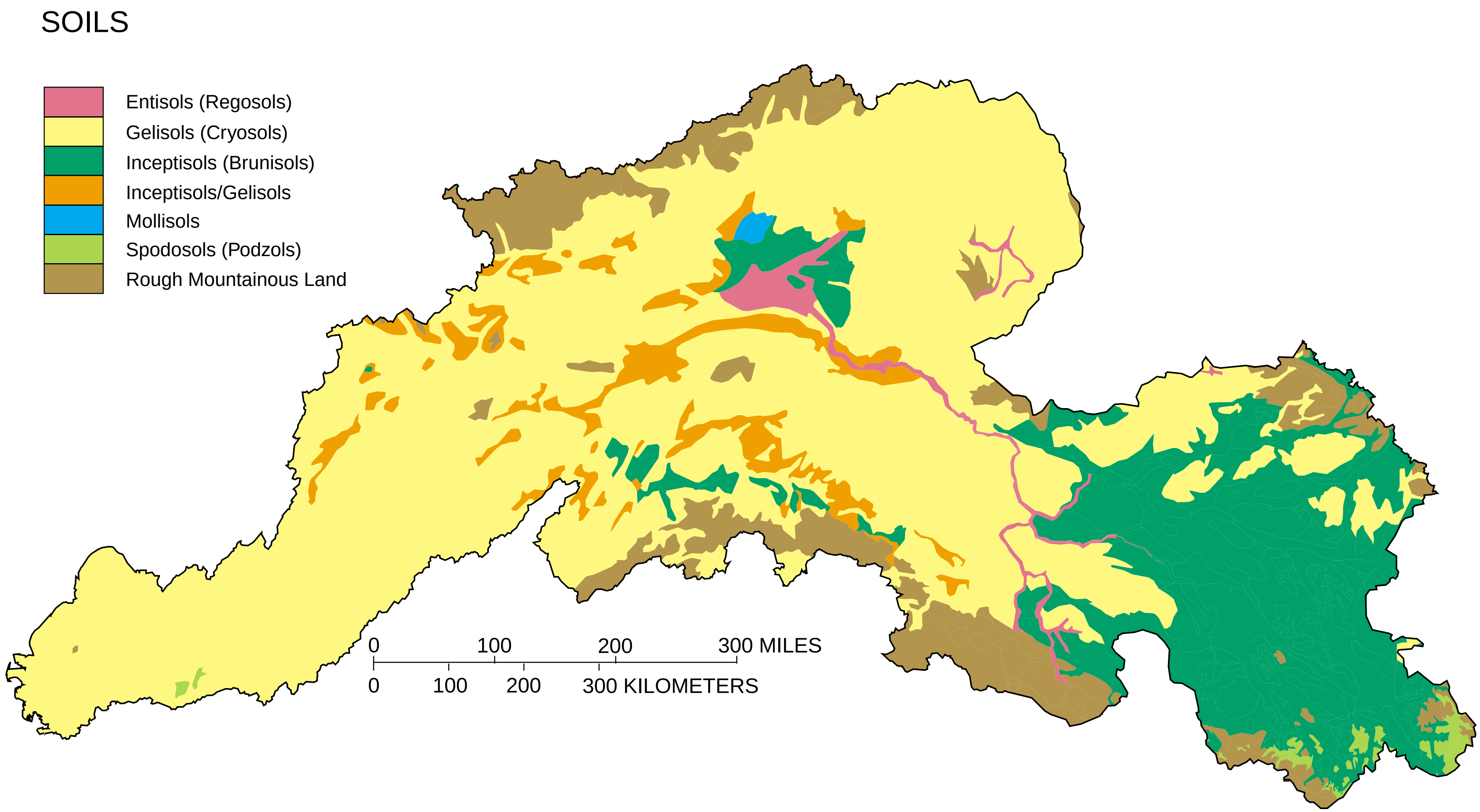


Figure 12. Soils of the Yukon River Basin.

• Histels Suborder

Pergelic Cryofibrists—Organic soils that have mean annual soil temperatures below freezing. The permafrost table is commonly less than 30 in. deep in these soils. The soils are composed of peat and the thickness of the peat ranges from 16 in. to more than 10 ft.

Histic Pergelic Cryaquepts—These soils have thick accumulations of organic matter on the soil surface, commonly in the form of a mat of slightly or partly decomposed mosses, sedges, and associated plants. Because the mat is effective insulation against summer heat, the permafrost table in these soils is normally very shallow. The upper part of the soils that thaws each summer and refreezes during the winter, known as the active layer, is almost constantly saturated during the thaw period.

Pergelic Cryochrepts—Soils with mean annual temperatures below freezing, and a deep permafrost table. These soils are gravelly.

Pergelic Cryaquepts—Soils that have many characteristics in common with the *Histic Pergelic Cryaquepts*, but they normally have somewhat longer periods during which the soil is not completely saturated. They are commonly found on alluvial plains, glacial moraines, or outcrops of coarse-grained rocks.

Inceptisols—These are recently formed soils but, in contrast to Entisols, have a greater degree of soil horizon development than the Entisols. At the present time, some Inceptisols (*Andic Cryochrepts, Typic Cryochrepts*) have some characteristics of Gelisols and are classified as "Inceptisols/Gelisols." Predominant suborders and soils are:

• Ochrepts Suborder

Aquic Cryochrepts—Poorly drained, weakly developed non-permafrost soils. Commonly, the restricted drainage is only during spring breakup, when seasonal frost perches meltwater near the soil surface.

Typic Cryochrepts—Soils that are nonacid—that is, they have the capacity to hold mineral elements. Most of these soils have silt loam or loam texture although some are gravelly.

• Aquepts Suborder

Pergelic Cryaquepts—Soils that have permafrost at some depth, but do not have thick peaty accumulations on the surface.

Typic Cryaquepts—Gray or olive-gray soils with a high water table during most or all of the summer. They have a wide variety of texture, but are never made up completely of sand or gravelly sand and are not stratified.

• Umbrepts Suborder

Pergelic Cryumbrepts—Soils that have mean annual temperatures below freezing. These soils occur in locations with good surface drainage, in areas above treeline.

Typic Cryumbrepts— Well-drained soil with brown horizons and mean annual temperatures above freezing. These soils will support low shrubby vegetation.

Mollisols—These are primarily thick, dark, and soft mineral soils. In the Yukon River Basin, they occur principally in material derived from limestone or other basic rock, such as basalt. Suborders of Mollisols that are present are the Borolls. The predominant soil is *Typic Cryoborolls* which is a brownish colored, well-drained soil formed in nonacid material. The only area where this soil is found in the Yukon River Basin is just north of the Yukon Flats.

Spodosols—These soils have light-colored surface horizons, and organic and aluminum-rich subsurface horizons. Suborders of Spodosols that are present are the Orthods. The predominant soil is *Typic Cryorthods*, which have moderate accumulations of organic carbon in the horizon and no permafrost. Aluminum and iron are also present in the soil.

The Canadian soil classification system is similar, though not identical to the U.S. soil classification system. In the Canadian system, an **order** is followed by the more narrowly defined category, the **great group** (Agriculture Canada, 1976). Of a possible nine orders, four are present in the Canadian part of the Yukon River Basin (similar U.S. classification in parenthesis):

Regosols (Entisols)—These soils either have no horizon development or have soil horizon development insufficient to be classified in any of the other orders.

Cryosols (Gelisols)—These mineral or organic soils have perennially frozen material within 3 ft of the surface in some part of the soil body. The mean annual soil temperature is less than 32 °F. Their maximum development occurs in organic and poorly drained, fine textured materials. Three great groups are associated with this order and are all found in the Yukon River Basin.

Turbic Cryosols—Generally composed of mineral soils that display marked frost action such as frost heaving, and generally occurring on patterned ground.

Static Cryosols—Mineral soils without noticeable frost action.

Organo Cryosols—Organic soils.

Brunisols (Inceptisols)—These soils have horizons that are sufficiently developed to be excluded from the Regosolic order but are not sufficiently developed to be classified in other orders. Two great groups are found in the Yukon River Basin: *Dystric Brunisols*, which are soils with horizons less than 2 in. thick consisting of organic matter and minerals, and *Eutric Brunisols*, which are soils similar to Dystric Brunisols but not as acidic.

Podzols (Spodosols)—These soils have surface horizons consisting of organic matter, iron, and aluminum. One of the great groups, *Humo-Ferric Podzolic*, is found in the Yukon River Basin. The upper 4 in. of this soil contains between 0.5 and 5 percent organic carbon and 0.6 percent or more extractable aluminum and iron.

View of the Interior Bottomlands ecoregion, which is composed of flat to nearly flat bottomlands along large rivers of the Yukon River Basin. These bottomlands are dotted with thaw and oxbow lakes.

Permafrost

Permafrost is defined exclusively on the basis of temperature, not on the presence of ice. A mass of material is considered to be permafrost if it has a temperature continually at or below 32 °F for 2 or more years (Ferrians, 1965). Permafrost is present to a large extent in the Yukon River Basin (fig. 13). Ferrians (1965) and Brown and others (1997), designated six regions of permafrost in the Yukon River Basin (fig. 13): (1) generally underlain by continuous permafrost—16 percent, (2) generally underlain by discontinuous permafrost—40 percent, (3) generally underlain by moderately thick to thin permafrost (50 to 600 ft)—24 percent, (4) underlain by discontinuous permafrost—6 percent, (5) generally underlain by numerous isolated masses of permafrost—5 percent, and (6) sporadic masses of permafrost—9 percent. Because thermal data for permafrost regions in Alaska and Canada are limited, some of the regions are combined into one.

Permafrost has a very low permeability and commonly acts as a barrier to infiltration and as a confining layer to aquifers. Because it is a barrier to infiltration, permafrost increases the likelihood of flash floods in streams draining permafrost areas. This tendency for rapid runoff is partly offset by the common presence of an organic mat, which can retard runoff briefly. Once the organic mat is saturated, however, floods occur very quickly.

Even in the zone of continuous permafrost, ground water can find paths through "taliks," or unfrozen zones in the permafrost. Taliks commonly occur under large lakes, under large rivers, and in areas where warm summer streamflow infiltrates into coarse alluvium. Taliks can also advect large amounts of heat into an aquifer.

If permafrost melts, the upper layers of soil become drier and well aerated. Even if permafrost remains as temperatures increase, the shallow soils that thaw and freeze each year (the active layer) thaw more deeply and develop a thicker unsaturated zone. Soil microbes increasingly oxidize the organic carbon sequestered in the soils. This increased respiration releases carbon, in the form of dissolved carbon, into a stream and the atmosphere. Changes in dissolved organic carbon (DOC) could affect stream aquatic communities at all trophic levels that rely on DOC as a food source.

The melting of the permafrost may increase recharge of aquifers, thus increasing base flow in streams. By increasing summer recharge, melting of permafrost will also decrease summer peak flows. Wetlands, which occupy about 30 percent of the Yukon River Basin (fig. 14), could be affected and in turn affect waterfowl habitat in the Yukon Flats and Yukon Delta areas. Wetlands are lands transitional between terrestrial and deepwater habitats where the water table usually is at or near the land surface, or the land is covered by shallow water (Cowardin and others, 1979).

Another natural factor that can affect permafrost is fire. Wildfires disturb thousands of acres of land in the Yukon River Basin each year (fig. 15). Foote (1976) has estimated the natural fire cycle range from 70 to 130 years. After a fire, the change in surface conditions results in soil warming and increased active depths. The soil may become well drained and may no longer have a perched water table. Thus, the hydrology changes and areas that were once wetlands become completely drained.

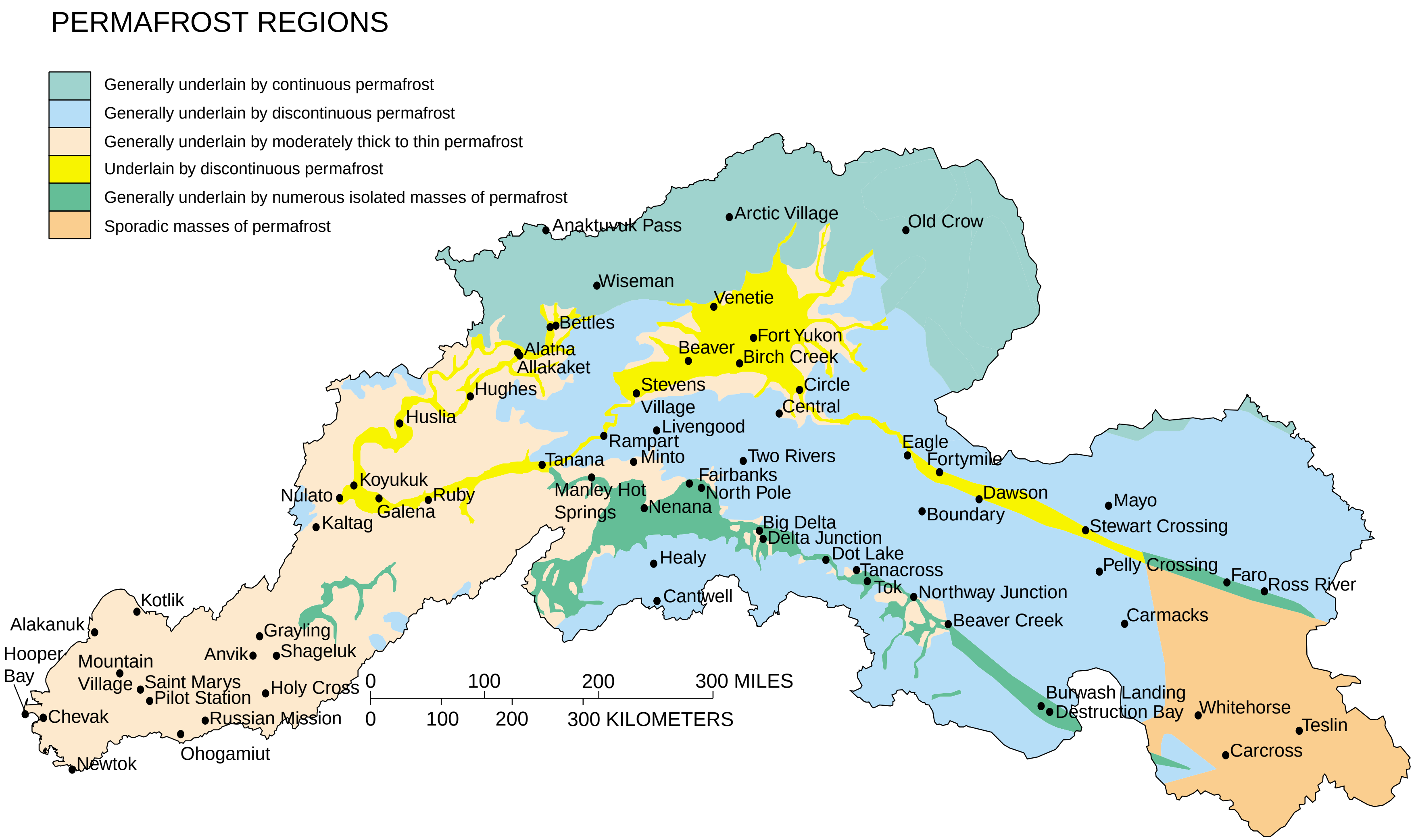


Figure 13. Permafrost regions of the Yukon River Basin (modified from Ferrians and others, 1965, and Brown and others, 1997).

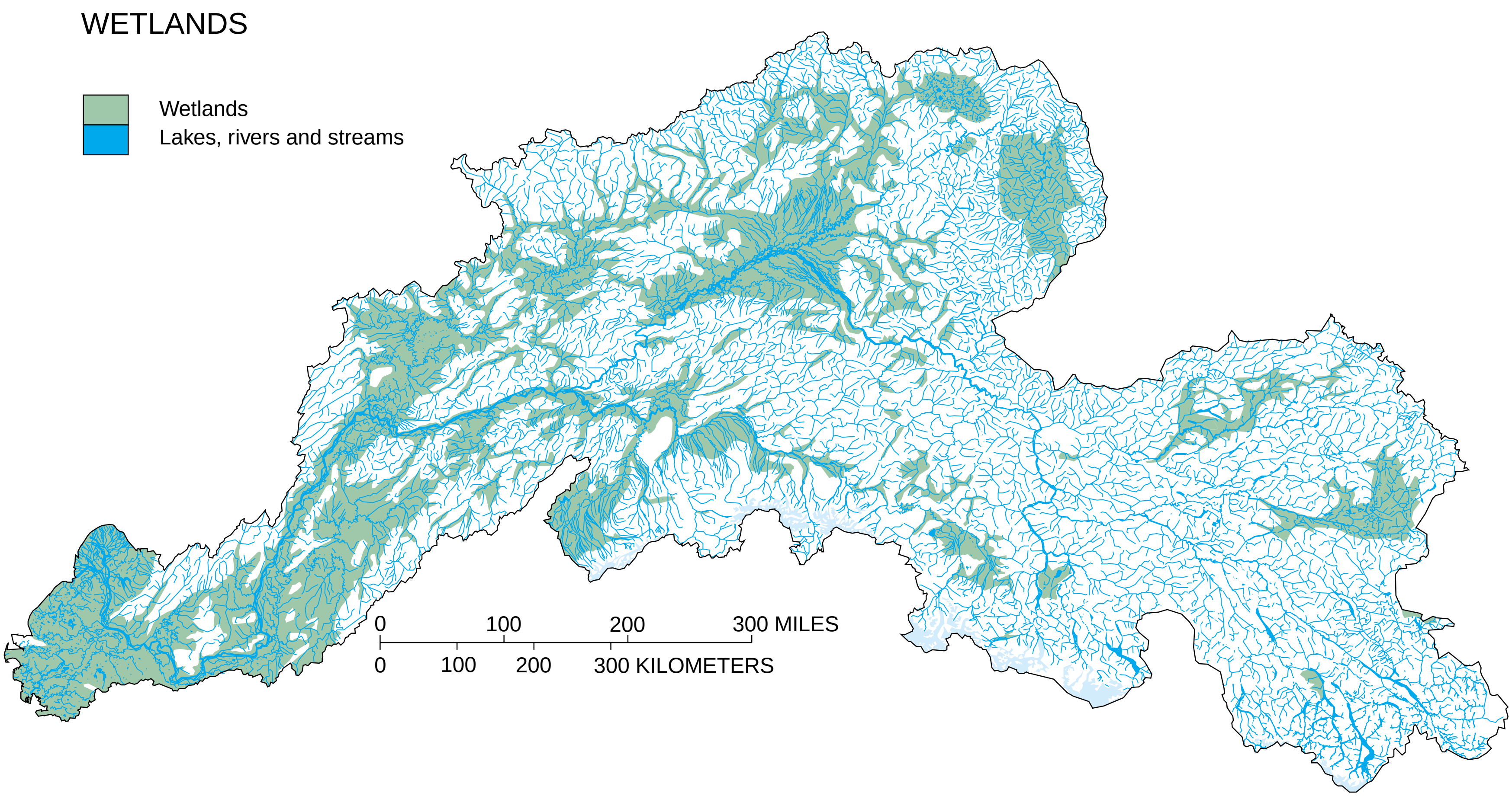


Figure 14. Wetland areas of the Yukon River Basin (modified from Fretwell and others, 1996).

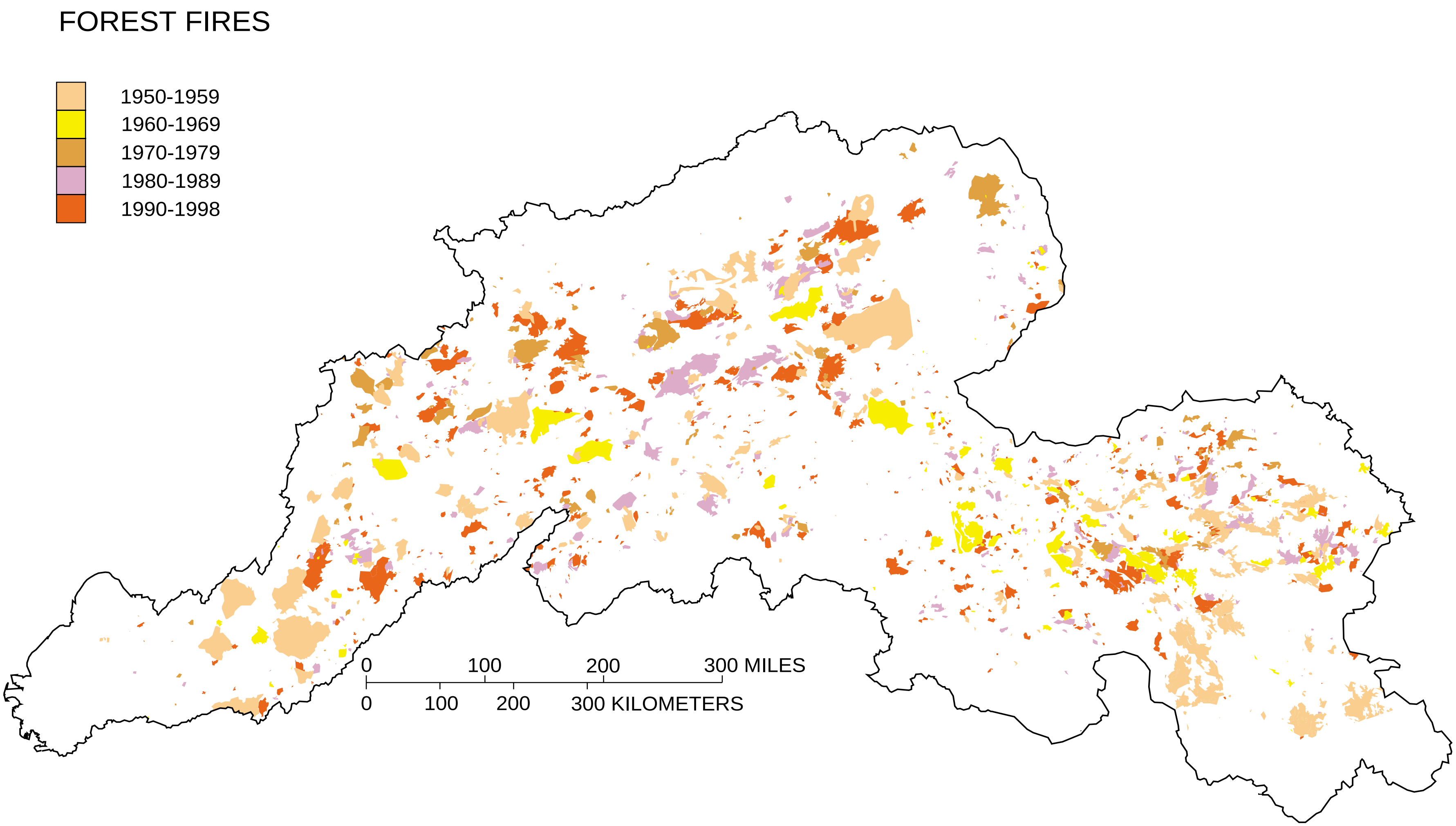


Figure 15. Areas of forest fires in the Yukon River Basin (from T. Hammond, Bureau of Land Management, 1999, written comm., and Indian and Northern Affairs Canada, 1999).

Ecoregions

Ecoregions are areas with common ecological settings that have relatively homogeneous features such as natural vegetation, geology, mineral availability from soils, physiography, and land use and land cover (Omernik, 1995). The Yukon River Basin has been classified into 20 ecoregions (Gallant and others, 1995; Ecological Stratification Working Group, 1995) (table 4; fig. 16). The Interior Forested Lowlands and Uplands ecoregion and the Interior Highlands ecoregion are the most dominant ecoregions in the basin. Descriptions of the ecoregions follow and are taken from Gallant and others and the Ecological Stratification Working Group.

Alaska Range—The mountains of south-central Alaska, the Alaska Range, are very high and steep. This ecoregion is covered by rocky slopes, icefields, and glaciers. Much of the area is barren of vegetation. The Alaska Range has a continental climate, but because of the extreme height of many of the ridges and peaks, annual precipitation at higher altitudes is similar to that measured for some ecoregions having maritime climate.

Climate is influenced by the mountains. Weather data for the region indicate that winter daily low temperatures average about -12 °F and daily high temperatures about 27 °F at lower altitudes. Summer daily low temperatures average about 36 °F and daily high temperatures about 64 °F. Mean annual precipitation in lowlands is approximately 15 in. and snowfall ranges from 59 to 120 in. Average annual precipitation for the mountain peaks is estimated at 80 in. and snowfall is estimated at 400 in.

The terrain of the ecoregion consists of steep, rugged mountain ridges separated by broad valleys. Altitudes are 2,000 ft in the lower valleys and commonly rise to greater than 13,000 ft on mountain peaks. Slope gradients, which are almost always greater

Table 4. Areas of ecoregions in the Yukon River Basin

Ecoregion (fig. 16)	Area	
	Square miles	Percent
Alaska Range	12,234	3.7
Boreal Mountains and Plateaus	5,931	1.8
Brooks Range	21,128	6.4
Eagle Plains	6,640	2.0
Interior Bottomlands	32,079	9.7
Interior Forested Lowlands & Uplands	70,117	21.2
Interior Highlands	55,957	16.9
Mackenzie Mountains	5,718	1.7
Ogilvie Mountains	12,917	3.9
Old Crow Flats	2,318	0.7
Pelly Mountains	8,240	2.5
Ruby Ranges	5,529	1.7
Selwyn Mountains	9,204	2.8
Subarctic Coastal Plains	11,503	3.5
Wrangell Mountains	9,653	2.9
Yukon Flats	12,897	3.9
Yukon Plateau Central	10,412	3.2
Yukon Plateau North	21,753	6.6
Yukon Southern Lakes	12,807	3.9
Yukon Stikine Highlands	3,251	1.0
Other	318	<1
Total	*330,606*	*100*

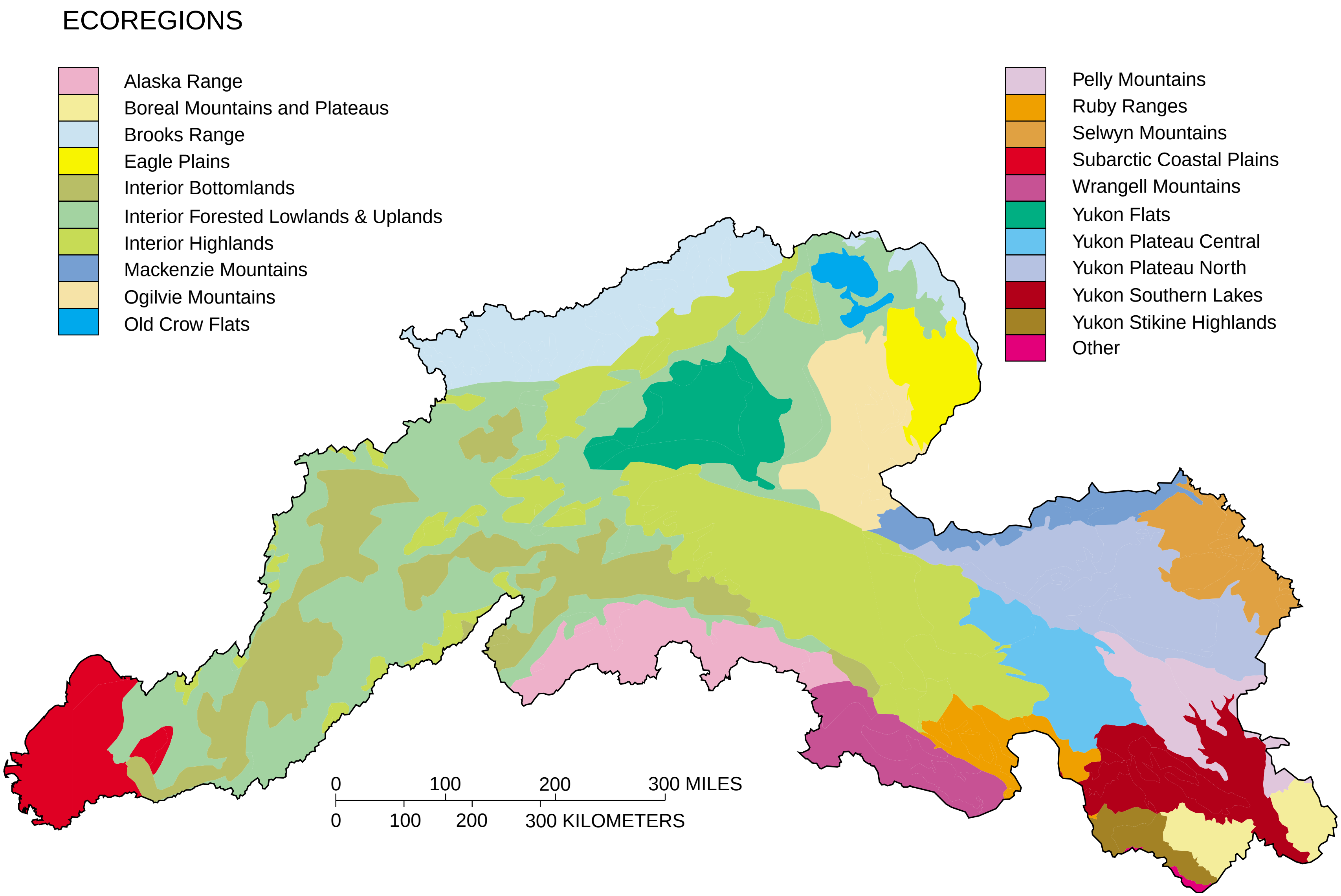


Figure 16. Ecoregions of the Yukon River Basin (modified from Gallant and others, 1995 and Ecological Stratification Working Group for Canada, 1995).

than 5 degrees on hillslopes, exceed 25 degrees on some mountains. The part of the ecoregion contained in the Yukon River Basin is part of a broad syncline having Cretaceous rocks in the center and Paleozoic and Precambrian rocks on the flanks. An extensive system of valley glaciers still exist. Permafrost is discontinuous in this ecoregion; however, its full extent is unknown. Streams are swift and braided, and most headwaters are in glaciers.

Much of the ecoregion consists of rocky slopes, icefields, and glaciers. Where soil development has occurred, principal soils are Lithic Cryorthents, Pergelic Cryaquepts, Pergelic Ruptic-Histic Cryorthents, Typic Cryaquepts, Pergelic Cryumbrepts, and Typic Cryumbrepts. Most soils are stony and shallow over bedrock, or bouldery colluvial, or glacial deposits. Soils on lower slopes and in valleys are typically poorly drained, and have a shallow permafrost table. Most of the region is barren of vegetation. Dwarf scrub communities are most common where vegetation does occur, growing on well-drained, windswept sites. More protected slopes provide moist to mesic sites that support low or tall scrub communities. Open needleleaf forests and woodlands occur on well-drained sites in some valleys and on lower hillslopes.

Boreal Mountains and Plateaus—This ecoregion covers most of northwestern British Columbia and a small area in the extreme southwestern part of the Yukon Territory. The ecoregion is composed of a complex of rugged mountains, high plateaus, and lowlands. Temperature and precipitation vary with altitude. The climate tends to be more moderate in the western half of the ecoregion and becomes more continental towards the eastern part. The typical mean annual temperature for the area is approximately 28 °F with a summer mean of 50 °F and a winter mean of 5 °F. The mean annual precipitation ranges from 16 to 28 in.

The vegetation is a complex mosaic, ranging from alpine vegetation and bare bedrock at higher mountain altitudes to alpine fir with some white spruce and deciduous shrubs dominating subalpine forests at middle altitudes in the southern Cassiar and northern Omineca Mountains. Closed canopied forests of lodgepole pine, and white and black spruce dominate the boreal forests of the Stikine and Yukon Plateaus. The most common soils are Humo-Ferric Podzolic soils on upland sites in subalpine regions, and Gray Luvisolic with Dystric Brunisolic soils in the boreal forest regions. Permafrost with low ice content occurs sporadically in the northern part of the ecoregion and is confined to isolated patches in the southwest.

Brooks Range—The Brooks Range ecoregion consists of several groups of rugged deeply dissected mountains carved from uplifted sedimentary rock. Altitudes of the mountain peaks range from 2,600 to 7,900 ft. An arctic climate regime and unstable hillslopes maintain a sparse cover of dwarf scrub vegetation throughout the mountains. The ecoregion is influenced by arctic climate. A weather station located at Anaktuvuk Pass is at an altitude of 2,500 ft. Winter temperatures average a daily minimum of -22 °F and a daily maximum of -8 °F, whereas summer temperatures average a daily minimum of 37 °F and a daily maximum of 61 °F. Mean annual precipitation at Anaktuvuk Pass is 11 in. and annual snowfall is 63 in.

Continuous thick permafrost underlies the ecoregion. The principal soils of the Brooks Range are Pergelic Cryaquepts, Pergelic Cryumbrepts, and Lithic Cryorthents. Hillslope soils were formed from local colluvium, whereas most valley soils generally developed from glacial till. Soils throughout this ecoregion typically have poor drainage because of the shallow depth to permafrost. Because of highly erodible hillslope sediments, shallow soils, high winds, and harsh climate in this ecoregion, vegetation cover is sparse and generally limited to valleys and lower hillslopes. Drier sites support dwarf scrub communities.

Eagle Plains—This ecoregion is almost an entirely unglaciated rolling plateau; it includes the Eagle Plain, Bell Basin, and part of the Porcupine Plateau. The mean annual temperature for the area is 20 °F with a summer mean of 50 °F and a winter mean of -10 °F. Mean annual precipitation ranges from 16 to 18 in. The vegetative cover of this ecoregion is typical subarctic forest. Open, very stunted stands of black spruce and tamarack with secondary stands of white spruce and ground cover of dwarf birch, willow, heath shrubs, cottongrass, lichen, and moss are predominant.

On the southern part of the ecoregion, long, even-topped ridges along the Porcupine Plateau have broad, gently rounded summits typical of unglaciated terrain. Relief is low; altitude ranges from 1,000 to 2,000 ft and the highest peak is 3,000 ft. The plain is underlain by Cretaceous and older sandstone and shale. A discontinuous veneer of eolian material covers much of the more stable upper slopes in the region. Permafrost is continuous. High ice content permafrost in the form of ice wedges is common in basin areas. Turbic Cryosols on loamy, inclined, and dissected colluvial material are most common. Regosols on gravelly alluvial material and Dystric Brunisols on sandy colluvium occur on non-permafrost sites. Characteristic wetlands covering 25 to 50 percent of the land area consist of peat plateau bogs, palsa bogs, and ribbed and horizontal fens.

Interior Bottomlands—This ecoregion is composed of flat to nearly flat bottomlands along large rivers of interior Alaska. The bottomlands are dotted with thaw and oxbow lakes. Soils are poorly drained and shallow, commonly over permafrost. Predominant vegetation communities include forests dominated by spruce and hardwood species, tall scrub thickets, and wetlands. The ecoregion is characterized by a continental climate. The bottomlands in the west receive more annual precipitation than those in the east. Annual precipitation ranges from 11 to 16 in., and annual snowfall ranges from 37 to 80 in. Average daily minimum temperatures in winter range from -27° F to -15 °F. Average daily maximum winter temperatures range from -8 °F to 1 °F. Summer temperatures have lows of about 45 °F and highs of about 72 °F.

The terrain of the ecoregion is typified by flat to nearly flat bottomlands, with some inclusions of local hills. Most areas in the bottomlands have a slope gradient of less than 1 degree. Altitudes range from 1,400 ft in the west to 2,000 ft in the east. Fluvial and eolian deposits of mixed origin cover most of the region, but outwash gravel and morainal deposits are in some areas. Meandering streams and side sloughs are prevalent and oxbow lakes and thaw lakes are numerous.

Principal soils are Histic Pergelic Cryaquepts, Pergelic Cryaquepts, Aquic Cryochrepts, Typic Cryochrepts, and Typic Cryofluvents. On flat areas away from the main river channels, soils are shallow over permafrost, poorly drained, and nearly always wet. On the slightly higher levees, soils are well drained and permafrost is deep or absent. Soils with permafrost are very susceptible to alteration upon disturbance of the organic mat. Needleleaf, broadleaf, and mixed forest stands occur on a variety of sites in the Interior Bottomlands ecoregion. Tall scrub communities form thickets on flood plains. The wettest sites support a variety of wetland communities, such as low scrub bogs, wet graminoid herbaceous meadows, and wet forb herbaceous marshes and meadows.

Interior Forested Lowlands and Uplands—This ecoregion has a continental climate, with short warm summers, and long very cold winters. Because this ecoregion is so large, temperature and precipitation vary widely from west to east. Total annual rainfall and snowfall generally increase with altitude. Temperature, while affected by altitude, is also influenced by distance from the ocean; maximum summer temperatures increase from west to east, and minimum winter temperatures decrease in the same pattern. Mean annual precipitation over most of the region ranges from 10 to 22 in. with contributions from snowfall ranging from 49 to 81 in. Most precipitation occurs during summer, mainly as a result of convective storms. Average minimum winter temperatures range from 0 °F in the west to -31 °F in the east; average maximum winter temperatures range from 12 °F in the west to -8 °F in the east. Summer temperatures, ranging from 46 to 72 °F with daily fluctuations of 15 to 20 °F, have less regional variation than winter temperatures.

The terrain of the ecoregion consists of rolling lowlands, dissected plateaus, and rounded low to high hills. Most of the region lies between altitudes ranging from sea level to 1,600 ft, but some hills rise more than 2,300 ft. Slope gradients are generally from 0 to 5 degrees. The predominant geologic formations are derived from Mesozoic and Paleozoic sedimentary rocks, but extensive areas of volcanic deposits also occur. The region is surficially mantled by undifferentiated alluvium and slope deposits. Streams originating from within this ecoregion tend to be short, whereas larger and longer streams originate from adjacent glaciated mountainous regions. Although thaw lakes and oxbow lakes occur throughout the ecoregion, lakes are not a predominant landscape feature. The western part of the ecoregion is underlain by thin to moderately thick permafrost, and the eastern part has a discontinuous distribution of permafrost.

Dominant soils are Histic Pergelic Cryaquepts, Pergelic Cryaquepts, Aquic Cryochrepts, Pergelic Cryochrepts, Typic Cryochrepts, Typic Cryorthents, and Pergelic Cryumbrepts. The interrelationships among permafrost, surface water, fire, hillslope aspect, and soil characteristics result in a finely textured, complex pattern of vegetation across the ecoregion. Soil temperatures may differ greatly from air temperature, so patterns in vegetation may not correspond with expected site conditions. Needleleaf, broadleaf, and mixed forests occur over a variety of site conditions. Tall shrub communities grow in areas of newly exposed alluvium, such as flood plains, streambanks, drainageways, and lake margins, on burned or otherwise disturbed areas, and near timberline. Low scrub communities occur in moist areas and on north-facing slopes. The wettest sites support tall scrub swamps, low scrub bogs, or scrub-graminoid communities. Recently burned areas display a succession of recovery stages that include mesic forb herbaceous communities, mesic graminoid herbaceous communities, scrub communities, and broadleaf, needleleaf, and mixed forests.

Interior Highlands—This ecoregion is composed of rounded, low mountains, often surmounted by rugged peaks. Although no long-term weather data are available, certain generalizations can be made regarding temperature and precipitation. First, an orographic effect on precipitation causes the highlands to receive more precipitation than the surrounding, lower altitude areas. Second, summer temperatures probably decrease with altitude.

Altitudes range from 1,600 ft in the valleys to more than 4,900 ft on the peaks. Slope gradients commonly range from 5 to 15 degrees. The mountains have much more exposed bedrock than the surrounding hills of the Interior Forested Lowlands and Uplands ecoregion. Geologic formations consist of Paleozoic and Precambrian metamorphic rocks, felsic volcanic rocks, and intrusive rocks. The northern part of the ecoregion is underlain by continuous permafrost.

Dominant soils are Histic Pergelic Cryaquepts, Typic Cryochrepts, Pergelic Cryumbrepts, Lithic Cryorthents, and Typic Cryorthods. Most soils are shallow, formed in very stony or gravelly material weathered from local rock. The permafrost table is shallow and soils are poorly drained; however, they are generally too shallow over bedrock for ground ice to form. Soils with permafrost are very susceptible to alteration upon disturbance of the organic mat because of the relatively warm (more than 29 °F) permafrost temperature. Organic mat disturbance, such as from wildfires, can result in warmer soil temperatures, lowered permafrost tables, and significant changes in soil physical properties and hydrology. The highest altitudes are barren of vegetation. Dwarf scrub communities, dominated by species of mountain avens, ericads, and willow, are widespread in sites exposed to wind. Lower altitudes are generally more protected from wind and have a denser vegetation cover that can include open needleleaf forests and woodlands. Areas of poor soil drainage support mesic graminoid herbaceous communities.

Mackenzie Mountains—This extremely rugged heterogeneous ecoregion spans the Yukon Territory/Northwest Territories border from Alaska to the Mackenzie Valley. It includes the Ogilvie and Wernecke Mountains in its westernmost section, the Backbone Ranges in its interior, and the Canyon Ranges to the east. The eastern ranges of the Mackenzie Mountains that lie in the rain shadow of the higher Selwyn Mountains to the west are also included. The ecoregion shows evidence of localized alpine and valley glaciation. The mean annual temperature for the area is approximately 23 °F with a summer mean of 48 °F and a winter mean of -2 °F. Mean annual precipitation is highly variable with the highest amounts, greater than 24 in., occurring in the southwestern part of the ecoregion. Moving westward towards Alaska and the southern Ogilvies, precipitation decreases to approximately 16 in.

The region is characterized by alpine tundra at higher altitudes and subalpine open woodland vegetation at lower altitudes. Alpine vegetation consists of lichens, mountain avens, intermediate to dwarf heath shrubs, sedge, and cottongrass in wetter sites. Barren talus slopes are common. Subalpine vegetation consists of discontinuous open stands of stunted white spruce and occasional alpine fir in a matrix of willow and dwarf birch. Permafrost is continuous and of low ice content in most of the Yukon part of the ecoregion. Turbic Cryosols with some Dystric Brunisols and Regosols occur on steeply sloping colluvium.

Ogilvie Mountains—The Ogilvie Mountains ecoregion, located along the eastern edge of the Yukon River Basin, consists of flat-topped hills eroded from a former plain and broad pediment slopes built up from mountains that are much subdued from their former stature. Karst topography is common, and mesic graminoid herbaceous communities and tall scrub communities are widespread throughout the region.

The ecoregion has a continental climate. No perennial weather stations are located in this region and thus precipitation and temperature characteristics are interpolated from outside the region. These interpolations indicate that annual precipitation is about 20 in. in the hills to about 26 in. in the higher mountains. Annual snowfall ranges from 51 to 81 in. across the region. Daily winter temperatures range from lows of -26 °F to highs of -8 °F, and daily summer temperatures range from 46 °F to 72 °F.

The terrain of the region consists of predominantly flat-topped hills eroded from a former plain. Pediment slopes, extending across broad valleys to the foothills of the current, subdued mountains, are characteristics of the plateaus. Erosional scarps in sedimentary rock occur in many localities. Weathered limestone is exposed at higher altitudes, and talus and rubble mantle the lower mountainsides. Altitudes range from 2,900 ft to more than 4,200 ft and slope gradients are generally less than 5 degrees. The region is composed of metamorphic and sedimentary rocks, primarily dolomite, phyllite, argillite, limestone, shale, chert, sandstone, and conglomerate. Karst topography is common and most of the region is underlain by permafrost.

Principal soils of the Ogilvie Mountains ecoregion are Histic Pergelic Cryaquepts, Typic Cryochrepts, and Pergelic Cryorthents. Soils were formed in gravelly or stony material weathered from local rock. Soils in valleys were formed from deep, loamy, alluvial sediments from the surrounding uplands. Vegetation is dominated by mesic graminoid herbaceous communities and tussock-forming sedges. Needleleaf, broadleaf, and mixed forest communities occupy lower hillslopes and valleys. Tall scrub communities occur extensively at lower altitudes and can extend above the timberline.

Old Crow Flats—Old Crow Flats is the largest wetland complex in the Yukon Territory. Located on the Old Crow River system north of the Arctic Circle, the Flats contain more than 2,000 ponds and marshes ranging in size from 100 ft^2 to 18 mi^2. The area is an important breeding and molting ground for 500,000 water birds. Waterfowl, muskrats, and other wildlife of the Flats are of great importance to the Native residents.

The ecoregion is unglaciated and incorporates the area of wetlands and lakes that occupy a glaciolacustrine plain that makes up the lowest part of the Old Crow River Basin. This level, low-relief ecoregion, locally referred to as “The Flats” lies at about 1,000 ft. The climate is strongly continental. Mean monthly air temperature ranges are as extreme as anywhere in North America. Short warm summers contrast with long very cold winters. The mean annual temperature for the area is approximately 14 °F with a summer mean of 46 °F and a winter mean of -17 °F. Mean annual precipitation ranges from 8 to 10 in.

Wetlands, which cover most of the ecoregion, are made up of polygonal peat plateau bogs with basin fens and locally occurring shore fens. Organic Cryosols are the most common wetland soils. Better drained parts of the land support open, very stunted stands of black spruce and tamarack with minor stands of white spruce and ground cover of dwarf birch, willow, cottongrass, lichen, and moss. Static Cryosols on sandy alluvial material and Turbic Cryosols on loamy, ice-rich lacustrine material dominate the mineral soils of the ecoregion. Permafrost is continuous with a high ice content in the form of ice wedges and massive ice bodies.

Pelly Mountains—This ecoregion encompasses the Pelly and northern Cassiar Mountains spanning the British Columbia/Yukon Territory border. The mean annual temperature for the area is approximately 37 °F with a summer mean of 51 °F and a winter mean of -1 °F. Mean annual precipitation is 20 to 39 in. varying with altitude. Boreal forests of white spruce, black spruce, lodgepole pine, and aspen cover the lower altitude valley bottoms. Much of the ecoregion lies above the treeline and is characterized by alpine tundra communities of lichens, dwarf heath shrubs, birch, and willows. Grasses, sedges, cottongrass, and some mosses occupy wet sites. Open-growing black and white spruce, and alpine fir are prevalent in the subalpine region.

The Pelly and Cassiar Mountains, composed of crystalline Mesozoic and Paleozoic strata, are of moderately high relief, ranging from about 4,900 ft to the highest peak at 7,900 ft. Relief is greater in the Pelly Mountains than in the Cassiar Mountains. Permafrost is sporadically distributed. Dystric and Eutric Brunisols are codominant in the ecoregion. Dystric Brunisols are associated with coarse igneous rocks at higher altitudes. Plateau areas with sandy loam morainal parent materials are associated with Eutric Brunisols. Turbic Cryosolic soils are found in alpine areas and in some poorly drained areas.

Ruby Ranges—This ecoregion covers the Kluane River–Kluane Plateau. The climate is characterized by short cool summers and long cold winters. Winter temperature inversions are common, giving milder temperatures at higher altitude. Maritime air from the Gulf of Alaska periodically invades the ecoregion during the winter to produce mild spells with near-thawing temperatures. The mean annual temperature for the area is approximately 27 °F with a summer mean of 50 °F and a winter mean of 2 °F. Mean annual precipitation ranges from 10 to 12 in.

Northern boreal forests occupy lower slopes and valley bottoms. Open white and black spruce occur in a matrix of dwarf willow, birch, heath shrubs, and some lodgepole pine. Black spruce, scrub willow, birch, and mosses are found on poorly drained sites. Alpine fir and lodgepole pine occur in higher subalpine sections, whereas the highest altitudes consist of sparsely vegetated alpine communities of mountain avens, dwarf willow, birch, shrubs and mosses. The terrain consists of rolling to undulating hills above 2,900 ft and the highest peak is 7,560 ft.

The most common soils in this ecoregion are Eutric Brunisols on sandy loam morainal or colluvial materials. Regosolic soils are associated with active deposition of gravelly fluvioglacial outwash materials on braided flood plains. Volcanic ash from the 1,300-year-old White River eruption is up to 40 in. thick on lower slopes. In these cases, the soils are classified as either Regosols or Regosolic Turbic Cryosols, depending on the presence or absence of permafrost. Permafrost is extensive and discontinuous over most of the ecoregion decreasing to sporadic along the western side of the ecoregion.

Selwyn Mountains—This ecoregion is located in the Selwyn and southern Mackenzie Mountains that span the Yukon Territory/Northwest Territories border. For the most part, this is a rugged mountain wilderness, a northern extension of the Rocky Mountains. Climate conditions vary with altitude. The mean annual temperature for major valley systems is approximately 24 °F with a summer mean of 49 °F and a winter mean of -3 °F. Mean annual precipitation is highly variable ranging from 24 in. at lower altitudes on the perimeter of the ecoregion up to 30 in. at high altitudes.

The ecoregion is characterized by alpine tundra at higher altitudes and by subalpine open vegetation at lower altitudes. Alpine vegetation consists of crusoe lichens, mountain avens, dwarf willow, and heath shrubs. Sedge and cottongrass are associated with wetter sites. Barren talus slopes are common. Subalpine vegetation consists of discontinuous open stands of stunted white spruce, and occasional alpine fir and lodgepole pine, in a matrix of willow and dwarf birch. Sedge, cottongrass, and mosses occur in wet sites. The Selwyn Mountains, which have been extensively glaciated, are composed of Paleozoic and Precambrian strata intruded by granite stocks. They are divided into several ranges by broad, northwesterly trending valleys. Some ranges contain alpine and valley glaciers. Permafrost is extensive but discontinuous in the western part and continuous with low ice content in the eastern part of the ecoregion. Dystric and Eutric Brunisols on alluvial, fluvioglacial, and morainal veneers and blankets are dominant in the region. Static and Turbic Cryosols with Dystric Brunisols or Regosols are developed on higher altitude, steeply sloping colluvium.

Subarctic Coastal Plains—This ecoregion includes the Yukon River Delta area. Flat, lake-dotted coastal plains and river deltas are characteristics of the region. Streams have very wide and serpentine meanders. Soils are wet and the permafrost table is shallow, providing conditions for wet graminoid herbaceous communities, the predominant vegetation type.

Climate in this ecoregion is transitional between maritime and continental influences. In general, the southern part of the region has warmer temperatures and receives more precipitation than the northern part. Average annual precipitation is about 20 in. and annual snowfall is about 59 in. Temperatures in winter range from average daily minimums of -13 °F to average daily maximums of 14 °F. Average daily temperatures in summer range from a minimum of 43 °F to a maximum of 55 °F.

The terrain of this ecoregion consists primarily of flat poorly drained coastal plains with shallow permafrost tables. Low hills of basalt surmounted by cinder cones and broad shallow volcanic craters occur in some locations, creating a range in regional altitude from sea level to more than 400 ft. Slopes in the plains are generally less than 1 degree. The region is predominantly covered by older coastal deposits of interstratified alluvial and marine sediments.

Predominant soils are Histic Pergelic Cryaquepts and Pergelic Cryofibrists. Soils are shallow over permafrost and are constantly wet. Soils have formed from stratified silty and sandy alluvial deposits that, in many areas, have additionally incorporated deposits of volcanic ash and loess. Standing water is almost always present in the ecoregion and wet graminoid herbaceous communities, such as wet meadows and bogs, predominate in saturated soils. Peat mounds, barren sand dunes, and volcanic soils support dwarf scrub communities dominated by ericaceous species.

Wrangell Mountains—The Wrangell Mountains ecoregion consists of steep, rugged mountains of volcanic origin that are extensively covered by ice fields and glaciers. Most slopes are barren of vegetation. Dwarf scrub tundra communities, consisting of mats of low shrubs, grasses, and lichens, predominate where vegetation does occur.

Climate is primarily affected by continental influences. Winter low temperatures average -29 °F, and winter highs average 16 °F. Mean summer low temperature is 37 °F, and mean summer high is 72 °F. Average annual precipitation is about 16 in., and annual snowfall is about 69 in. Higher altitudes may receive 80 in. of precipitation annually, including 100 in. of snow.

The Wrangell Mountains ecoregion represents a large group of shield and composite volcanoes of Cenozoic age. These volcanic formations lie over Paleozoic and Mesozoic sedimentary and volcanic rocks. The terrain is steep and rugged; most slope gradients exceed 7 degrees and many surpass 15 degrees. Altitudes start at 2,000 ft, most of the largest peaks are 13,000 ft or higher, and several peaks exceed 16,000 ft. Extensive glaciation persists and permafrost is discontinuous.

Much of the landscape consists of steep rocky slopes, icefields, and glaciers. Soil development has resulted in thin, stony soils that are shallow over bedrock or bouldery deposits. Most soils have formed in very stony and gravelly colluvial material. Soils in valleys and on footslopes have formed in glacial till, with a thin mantle of volcanic ash or loess in some places. Principal soils are Lithic Cryorthents, Typic Cryorthents, Pergelic Cryochrepts, and Pergelic Cryumbrepts. Most slopes in the mountains are barren of vegetation. Dwarf scrub communities dominate where vegetation does occur, growing on well-drained, windy sites. Tall scrub communities occur along drainages and on flood plains. Broad ridges, valleys, and hilly moraines at lower altitudes support needleleaf forests dominated by white spruce, or broadleaf forests dominated by paper birch or aspen.

Yukon Flats—The Yukon Flats ecoregion is a relatively flat, marshy basin floor in east-central Alaska that is patterned with braided and meandering streams, numerous thaw and oxbow lakes, and meander scars. In many ways, the ecoregion is similar to the Interior Bottomlands region except that the Yukon Flats ecoregion differs in climatic characteristics. Forests dominated by spruce and hardwood species, tall scrub communities, and wet graminoid herbaceous communities are the predominant vegetation type.

The Yukon Flats ecoregion has a continental climate. The mountains surrounding the ecoregion isolate it from the weather systems affecting the neighboring regions. Consequently, summer temperatures tend to be higher than at other places of comparable latitude and winter temperatures tend to be colder. Average daily temperatures in winter range from lows of about -29 °F to highs of about -11 °F. Average daily temperatures in summer range from lows of just about freezing to highs of about 72 °F. Annual precipitation is low, averaging 6.5 in. and average snowfall is 45 in. (water content of about 4 in.). Local precipitation is not sufficient to maintain water levels in many lakes. Levels are primarily maintained by the yearly flooding of the region by the Yukon River that accompanies spring breakup of ice (Gallant and others, 1995).

The central part of the ecoregion is flat, whereas the edges of the region range from 300 ft to more than 600 ft. Slope gradient is generally less than 1 degree in the center and 1 to 2 degrees at the edges. The region is mantled by Quaternary-age alluvial deposits. The Yukon River drains the ecoregion, assisted by numerous meandering and braided tributaries and side sloughs. Permafrost is present in most areas, except beneath rivers and large thaw lakes. Thaw lakes and oxbow lakes are abundant.

Principal soils are Histic Pergelic Cryaquepts, Pergelic Cryaquepts, Aquic Cryochrepts, and Pergelic Cryochrepts. Most soils were formed from silty alluvium and loess from the flood plains of the Yukon River. On flat areas away from the main river channels, soils are poorly drained, are commonly overlain by peat, and have a shallow permafrost table. Soils on natural levees are better drained and consist of silty and sandy sediments. Needleleaf, broadleaf, and mixed forests are widespread and occupy sites representing an array of soil drainage characteristics. Tall scrub thickets occur on alluvial deposits subject to periodic flooding. Tall scrub swamps and wet graminoid herbaceous communities occupy the wettest sites.

Yukon Plateau Central—This ecoregion extends northward from Lake Laberge to the lower Stewart River in the central Yukon. The Yukon Plateau Central ecoregion is composed of several groups of rolling hills and plateaus separated by deeply cut, broad valleys. The climate is cold and semiarid. The mean annual temperature for the area is approximately 26 °F with a summer mean of 54 °F and a winter mean of -2 °F. Mean annual precipitation ranges from 10 in. in the southern areas near Carmacks to 16 in. at higher altitudes in the north and east.

White and black spruce form the most common forest types. Black spruce is usually dominant in wetter areas. Lodgepole pine commonly invades burnt-over areas and very dry sites. In some places, alpine fir forms the treeline but is sparse and is usually associated with white spruce and occasionally with paper birch. Sedge tussocks and sphagnum are common in wetlands. Scrub birch and willow occur in subalpine sections that extend up to the treeline. A significant vegetative feature of this ecoregion is the presence of extensive grasslands on all low-altitude, south-facing slopes. The forests suffer frequently from recurring natural fires such that series of ecological communities are most common.

Altitudes are above 3,300 ft, except for major river valleys, which lie below 2,000 ft in the northwestern part. Several mountains reach heights of 4,900 ft. Eutric Brunisols, which developed on steeply sloping, ridged-to-hummocky, loamy morainal and sandy fluvioglacial material, are dominant in the ecoregion. Much of the ecoregion is covered by a veneer of recent volcanic ash 4-

12 in. thick. Permafrost is discontinuous to sporadic with high ice content associated with fine-textured valley deposits. Turbic Cryosols are confined to wet depressions and beneath mature forests on lower, north-facing slopes.

Yukon Plateau North—This ecoregion lies within the Stewart, Macmillan, and Pelly Plateaus and the southern foothills of the Selwyn Mountains. The terrain includes rolling uplands, small mountain groups, and nearly level tablelands dissected by deeply cut, generally broad, U-shaped valleys. The Tintina Trench, a straight, steep-sided valley 3-12 mi wide, traverses the ecoregions from southeast to northwest. The mean annual temperature for the area is approximately 25 °F with a summer mean of 51 °F and a winter mean of -4 °F. Mean annual precipitation ranges from 12 in. in the major valleys up to 24 in. in the mountains to the northeast.

Northern boreal forests exist at altitudes up to 4,900 ft. White spruce in a matrix of dwarf willow, birch, heath shrubs, and occasionally lodgepole pine, form extensive open forests, particularly in the northwestern part of the ecoregion. Black spruce, scrub willow, birch, and mosses are found on poorly drained sites. Alpine fir and lodgepole pine occur in higher subalpine sections. Extensive discontinuous permafrost with a medium ice content is widespread, decreasing to sporadic discontinuous permafrost along the southwestern edge of the region. Turbic Cryosolic and Eutric Brunisolic soils predominate, and occasional pockets of Dystric Brunisols occur on coarse-textured morainal and fluvioglacial materials.

Yukon Southern Lakes—This ecoregion extends from Lake Laberge south to the boundary with British Columbia. The climate is cold and semiarid. In major valleys, the mean annual temperature is about 28 °F with a summer mean of 50 °F and a winter mean of 2 °F. Lying within the rain shadow of the St. Elias Mountains, mean annual precipitation ranges from 9 to 12 in. in the major valleys.

Boreal forests are composed of open white spruce and lodgepole pine intermixed with aspen. South-facing slopes at low altitude are occupied by grassland communities. Subalpine altitudes above 4,000 ft support open forest communities of alpine fir, white spruce, and some lodgepole pine. Most of the terrain lies 2,000 to 4,900 ft in altitude, but a few peaks are higher than 5,900 ft. Underlain by Mesozoic sedimentary strata and Paleozoic metamorphic slates and schists, the topography is characterized by dissected plateaus and rolling hills. Eutric Brunisolic soils on sandy loam and rolling morainal to steep colluvial material are dominant. Low ice content permafrost occurs in a sporadic discontinuous pattern. Cryosolic soils are scattered throughout the landscape on some poorly drained areas and on north-facing slopes.

Yukon Stikine Highlands—This ecoregion covers a zone of climate transition from coastal to interior conditions in northwestern British Columbia and southern Yukon. The ecoregion falls within the rain shadow of the Coast Mountains. Precipitation decreases moving inland, and temperatures are moderated throughout the year by the influence of maritime air masses. The mean annual temperature for the area is approximately 30 °F with a summer mean of 50 °F and a winter mean of 8 °F. Mean annual precipitation ranges from 20 to 24 in. The ecoregion is composed of a combination of three distinct vegetation zones: alpine tundra dominated by low-growing heather, dwarf birch, willow, grass, and lichen; subalpine forests of alpine fir, white spruce, and an occasional Engelmann spruce; and closed boreal forests of black and white spruce. Permafrost is discontinuous and sporadic with generally low ice content. Soils range from Brunisolic and Regosolic with some Cryosolic soils in alpine regions to Dystric and Eutric Brunisols in subalpine and boreal sections of the ecoregion.

View of the Interior Forested Lowlands and Uplands ecoregion, which composes 21 percent of the Yukon River Basin. The terrain consists of rolling lowlands, dissected plateaus, and rounded low to high hills. Climate is characterized by short warm summers and long cold winters.

View of the Interior Highlands ecoregion, which is the second largest ecoregion of the Yukon River Basin. Rounded mountains, often surmounted by rugged peaks, are typical of the ecoregion. Vegetation communities consist of alpine tundra and open spruce stands.

HYDROLOGIC CHARACTERISTICS OF THE YUKON RIVER BASIN

Surface Water

Streamflow quantity and variability have considerable influence on the quality of surface water. The quantity of water in a stream or river influences its ability to support aquatic communities, to assimilate or dilute waste discharges, and to carry suspended sediment and geochemical weathering products. Temporal variability of streamflow may, in turn, cause temporal variability of water quality. Thus, knowledge of streamflow is important to understand the water-quality and ecological dynamics of a watershed.

The Yukon River is composed of many streams and rivers. Utilizing the Alaska Hydrologic Unit Classification system (U.S. Geological Survey, 1987) and a somewhat similar classification system for Canada, the Yukon River Basin can be divided into 13 major basins (table 5; fig. 17). These basins represent the eight major tributaries to the Yukon River and the major lowland areas that drain directly into the Yukon River.

Table 5. Major drainage basins in the Yukon River Basin

Basin (fig. 17)	Area		Comments
	Square miles	Percent	
Yukon Headwaters[a]	13,000	4.0	Drains an extensive lake system in the headwaters of the basin. Glaciers are present above the lakes
Teslin River	13,100	4.1	East of the Yukon Headwaters subbasin. Most runoff is from snowmelt. Teslin Lake is near the outlet of the basin
Pelly River[a]	18,600	5.8	Drains the most eastern part of the Yukon River Basin
Stewart River[a]	19,800	6.2	North of the Pelly River watershed and drains the eastern part of the Yukon River Basin
White River[a]	18,100	5.6	Most significant feature is presence of glaciers in the upper part of the basin. Drains part of the Wrangell–St. Elias Mountains
Upper Yukon[a]	28,200	8.8	Primarily drains low-lying streams and rivers
Porcupine River	45,000	14.0	Drains the northeastern part of the Yukon River Basin. Most of the basin is underlain by continuous permafrost
Chandalar River	13,700	4.3	Drains the south side of the Brooks Range. Underlain by continuous permafrost
East Central Yukon[a]	27,300	8.5	Drains low-lying streams. Main tributaries are the Porcupine and Chandalar Rivers
Tanana River[a]	44,300	13.7	Primarily drains the north side of the Alaska Range. Glaciers are present in the basin
Koyukuk River	35,000	10.9	Drains part of the Brooks Range and is underlain by continuous permafrost
West Central Yukon	20,900	6.5	Drains low-lying streams along the main stem of the Yukon River. Main tributaries are the Tanana and Koyukuk Rivers
Lower Yukon	24,500	7.6	Drains low-lying streams. Main tributary is the Innoko River. Much of this area consists of wetlands
Total	321,500	100	

[a]Basin contained active gaging station in 1999

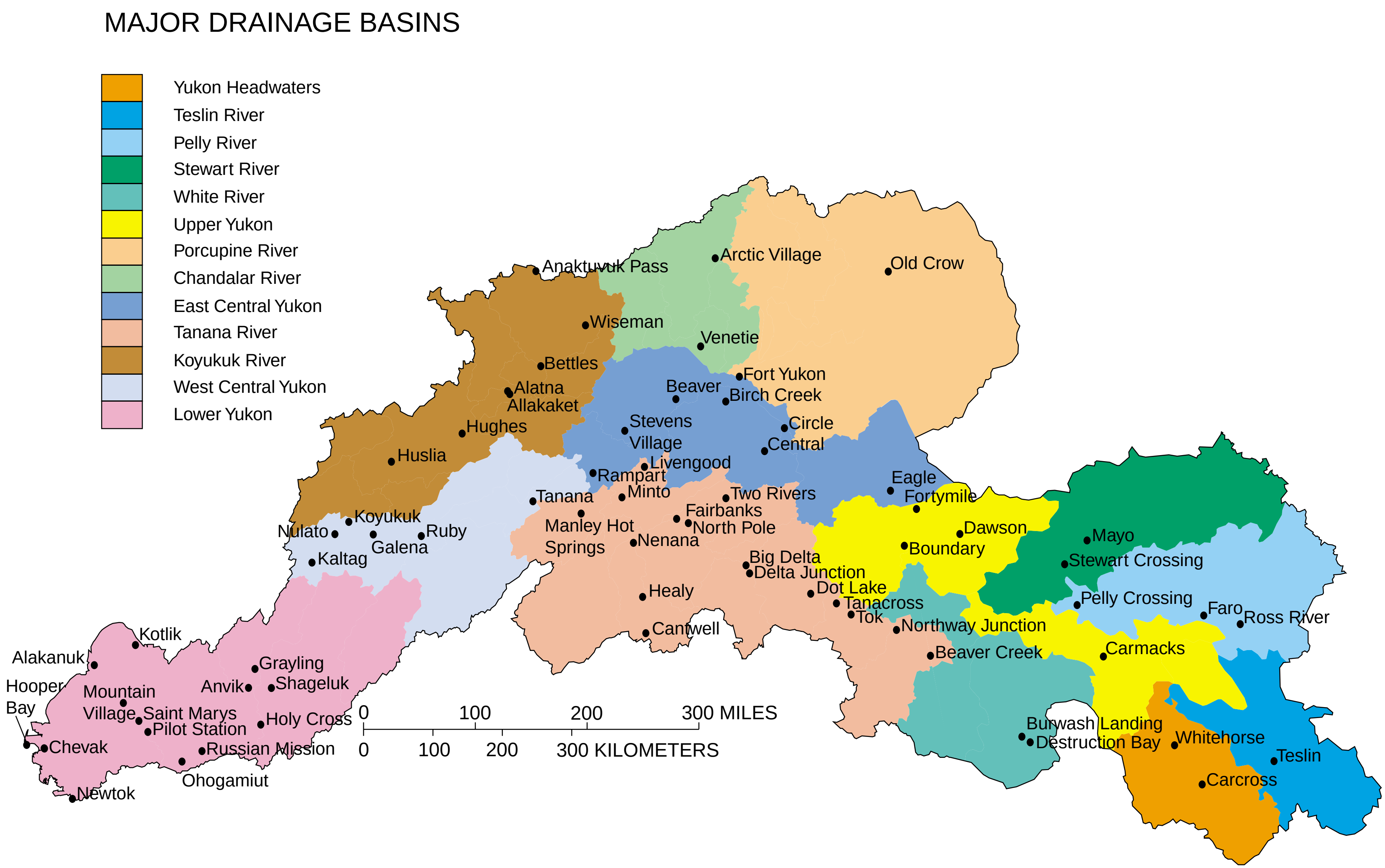


Figure 17. Major drainage basins in the Yukon River Basin. (See table 5 for more information.)

Snow and Ice

In the high mountain ranges that surround the Yukon River Basin, most of the precipitation is in the form of snow. Approximately 1 percent of the Yukon River Basin consists of perennial snowfields. When the quantity of annual snowfall exceeds average annual snowmelt, the snow begins to change into ice or glaciers. The transformation of snow to ice is a process that is commonly long and complex (Paterson, 1994). Temperature is an important factor because snow will develop into ice much more rapidly on glaciers where periods of melting alternate with periods of freezing (Paterson, 1994).

Approximately 3,500 mi^2, or 1 percent of the Yukon River Basin, is covered by glaciers. Glaciers are presently found in the Alaska Range and Wrangell–St. Elias Mountains. These glaciers are classified as temperate glaciers because they have a year-round ice temperature close to 32 °F. The importance of these glaciers to the basin hydrology cannot be emphasized enough. Glaciers store an enormous quantity 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). Hot summers will cause rapid melting and high runoff, whereas a cool summer will have low runoff.

Streamflow

Generally, most stream-gaging stations in the Yukon River Basin are located on rivers that drain areas larger than 1,000 mi^2. Sixty-eight stream-gaging stations operated by the USGS in Alaska and the Water Survey of Canada in the Yukon Territory and British Columbia have 10 or more years of record (fig. 18; table 6). Stream-gaging stations have been located on most of the main tributaries to the Yukon River. In 1999, 26 stream-gaging stations were active in the Yukon River Basin: 17 in Canada and 9 in Alaska (fig. 18). Active stream-gaging stations were located on seven of the 13 major basins (4 in Canada, 3 in Alaska).

Three basic patterns of runoff are exhibited throughout the Yukon River Basin: lake runoff, snowmelt runoff, and glacier runoff. Generally, beginning in October and ending in late April to mid-May, runoff is minimal and streamflow gradually decreases. Most runoff occurs from May to September; however, the timing of runoff in the rivers is different, depending on the particular basin characteristics.

Discharge hydrographs of three rivers in the headwaters of the Yukon River Basin (fig. 19) represent these types of runoff patterns. Lake or “combined” runoff: The Atlin River drains a large lake system in the headwaters of the Yukon River Basin. During the runoff season, the lakes fill from snowmelt, rainfall, and ice melt. Once filled, the lakes begin to empty with the highest discharges occurring in August and September. Snowmelt runoff: The Swift River drains an undisturbed area having no glaciers present. Most of the runoff occurs in June from snowmelt. Additional runoff may occur in late summer from rainstorms. Glacier runoff: The Fantail River is a glacier-fed river. Runoff begins in June primarily from snowmelt (such as the Swift River), but is sustained throughout most of the summer from glacier icemelt.

Discharge hydrographs for the headwaters of the Yukon River and its major tributaries (fig. 20) exhibit the three basic patterns of runoff. The Yukon River above Frank Creek (headwaters) and the Teslin River near Teslin exhibit the lake-runoff pattern. The Pelly and Stewart Rivers exhibit the snowmelt-runoff pattern. Although the Porcupine, Chandalar, and Koyukuk Rivers also exhibit the snowmelt pattern, the baseflows of these rivers approach zero flow during the winter. This low-flow characteristic is likely due to the presence of continuous permafrost in the headwaters of the Yukon River Basin which acts as a barrier to ground water inflow. Finally, the White and Tanana Rivers exhibit the glacier-runoff pattern of sustained flow through most of the summer.

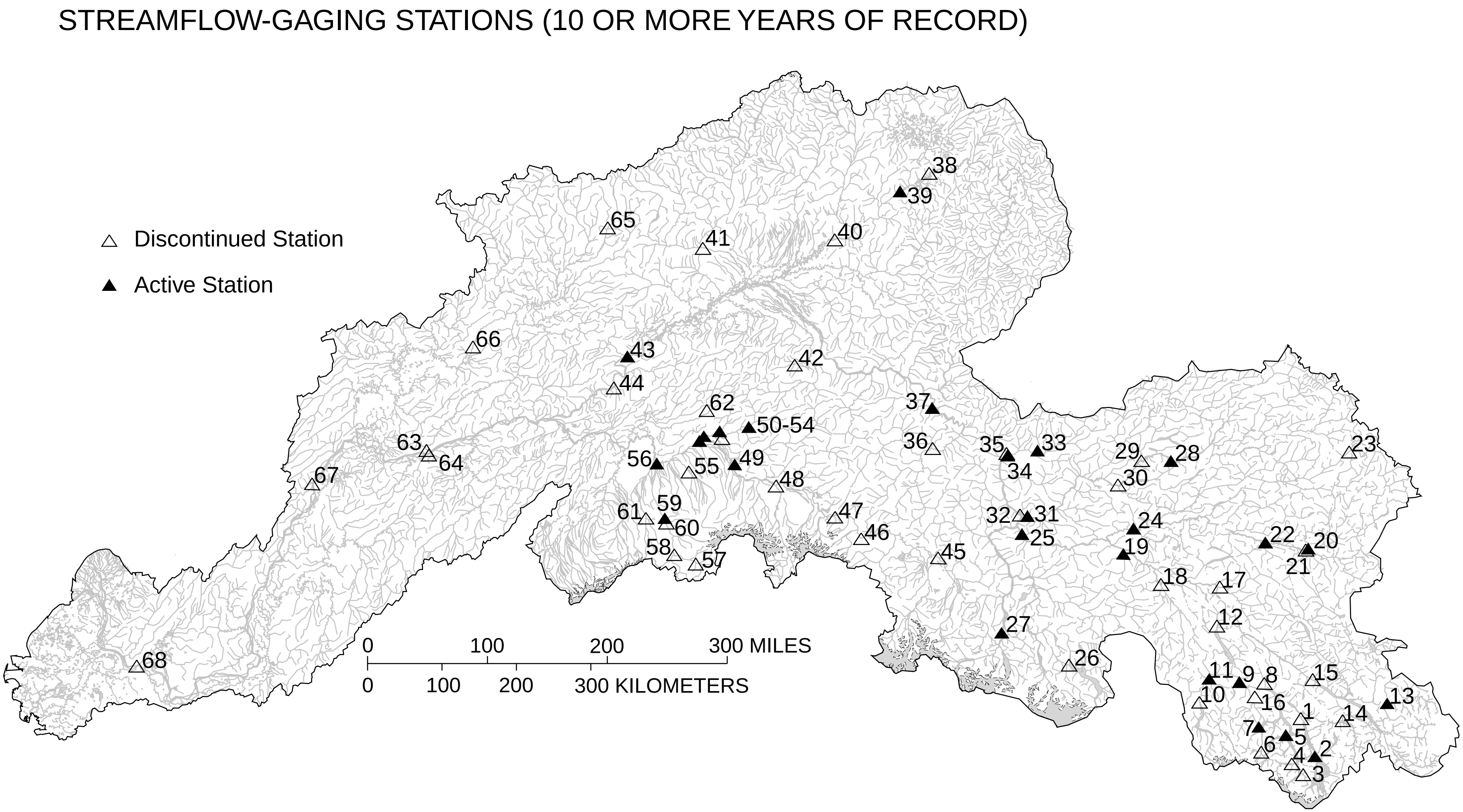


Figure 18. Location of streamflow-gaging stations with 10 or more years of record in the Yukon River Basin. (See table 6 for station names.)

Table 6. Streamflow-gaging stations in the Yukon River Basin with 10 or more years of record

Map No. (fig. 18)	USGS station No.	Name	Drainage area (square miles)	Period of record
1	15304520	Lubbock River near Atlin, BC	683	1960-93
2	15304600	Atlin River near Atlin, BC	2,630	1950-
3	15304650	Wann River near Atlin, BC	104	1958-94
4	15304700	Fantail River at outlet of Fantail Lake near Atlin, BC	277	1957-94
5	15304750	Tutshi River at outlet of Tutshi Lake near Atlin, BC	320	1958-
6	15304800	Lindeman River near Bennett, BC	92.7	1955-94
7	15304850	Wheaton River near Carcross, YT	338	1958-
8	15304950	Maclintock River near Whitehorse, YT	656	1956-94
9	15305000	Yukon River at Whitehorse, YT	7,490	1944-
10	15305030	Takhini River at Kusawa Lake at Whitehorse, YT	1,570	1953-86
11	15305050	Takhini River near Whitehorse, YT	2,700	1949-
12	15305100	Yukon River above Frank Creek, YT	11,900	1955-94
13	15305150	Swift River near Swift River, BC	1,280	1958-
14	15305200	Gladys River at outlet of Gladys Lake near Atlin, BC	737	1958-93
15	15305250	Teslin River near Teslin, YT	11,700	1948-94
16	15305260	Teslin River near Whitehorse, YT	14,100	1956-73
17	15305300	Big Salmon River near Carmacks, YT	2,610	1955-95
18	15305350	Yukon River at Carmacks, YT	31,600	1965-95
19	15305360	Big Creek near mouth near Minto, YT	676	1976-
20	15305390	Ross River at Ross River, YT	2,800	1962-
21	15305400	Pelly River at Ross River, YT	7,100	1955-74
22	15305406	Pelly River at Faro, YT	8,530	1973-
23	15305412	South MacMillan River at Canol Road near Ross River, YT	385	1975-95
24	15305420	Pelly River at Pelly Crossing, YT	18,900	1953-
25	15305450	Yukon River above White River near Dawson, YT	57,900	1957-
26	15305500	Kluane River at outlet of Kluane Lake, YT	1,910	1953-95
27	15305540	White River at Alaska Highway near Koidern, YT	2,410	1975-
28	15305582	Stewart River above Fraser Falls near Mayo, YT	11,810	1980-
29	15305590	Stewart River at Mayo, YT	12,200	1949-64
30	15305620	Stewart River at Stewart Crossing, YT	13,500	1961-73
31	15305650	Stewart River at mouth, YT	19,700	1964-
32	15305670	Yukon River at Stewart, YT	96,900	1957-65
33	15305695	North Klondike River near mouth near Dawson, YT	425	1975-
34	15305698	Klondike River above Bonanza Creek near Dawson, YT	3,010	1966-
35	15305700	Yukon River at Dawson, YT	102,000	1945-80
36	15348000	Fortymile River near Steele Creek, AK	5,880	1911-12, 1964, 1976-82
37	15356000	Yukon River at Eagle, AK	113,500	1911-12, 1950-
38	15388950	Porcupine River at Old Crow, YT	21,400	1962-89
39	15388960	Porcupine River near International Boundary, YT	23,100	1988-

Table 6. Streamflow-gaging stations in the Yukon River Basin with 10 or more years of record--Continued

Map No. (fig. 18)	USGS station No.	Name	Drainage area (square miles)	Period of record
40	15389000	Porcupine River near Fort Yukon, AK	29,500	1965-79
41	15389500	Chandalar River near Venetie, AK	9,330	1964-73
42	15439800	Boulder Creek near Central, AK	31.3	1966-82, 1984-86
43	15453500	Yukon River near Stevens Village, AK	196,300	1976-
44	15468000	Yukon River at Rampart, AK	199,400	1956-67
45	15470000	Chisana River at Northway Junction, AK	3,280	1950-71
46	15476000	Tanana River near Tanacross, AK	8,550	1953-90
47	15476300	Berry Creek near Dot Lake, AK	65.1	1971-81
48	15478000	Tanana River at Big Delta, AK	13,500	1949-57
49	15484000	Salcha River near Salchaket, AK	2,170	1909-10, 1949-
50	15485500	Tanana River at Fairbanks, AK	(a)	1973-
51	15493000	Chena River near Two Rivers, AK	941	1967-
52	15493500	Chena River near North Pole, AK	1,440	1972-80
53	15511000	Little Chena River near Fairbanks, AK	372	1967-
54	15514000	Chena River at Fairbanks, AK	1,980	1947-
55	15514500	Wood River near Fairbanks, AK	855	1969-78
56	15515500	Tanana River at Nenana, AK	25,600	1962-
57	15515800	Seattle Creek near Cantwell, AK	36.2	1966-75
58	15516000	Nenana River near Windy, AK	710	1951-56, 1959-81
59	15518000	Nenana River near Healy, AK	1,910	1951-79
60	15518080	Lignite Creek above mouth near Healy, AK	48.1	1986-
61	15518350	Teklanika River near Lignite, AK	490	1965-74
62	15535000	Caribou Creek near Chatanika, AK	9.2	1970-86
63	15564600	Melozitna River near Ruby, AK	2,693	1962-73
64	15564800	Yukon River at Ruby, AK	259,000	1957-78
65	15564875	Middle Fork Koyukuk River near Wiseman, AK	1,200	1971-80, 1984-87
66	15564900	Koyukuk River at Hughes, AK	18,700	1961-82
67	15565200	Yukon River near Kaltag, AK	296,000	1957-66
68	15565447	Yukon River at Pilot Station, AK	321,000	1976-96

[a]Undefined: part of the river flows through Salchaket Slough and is not gaged.

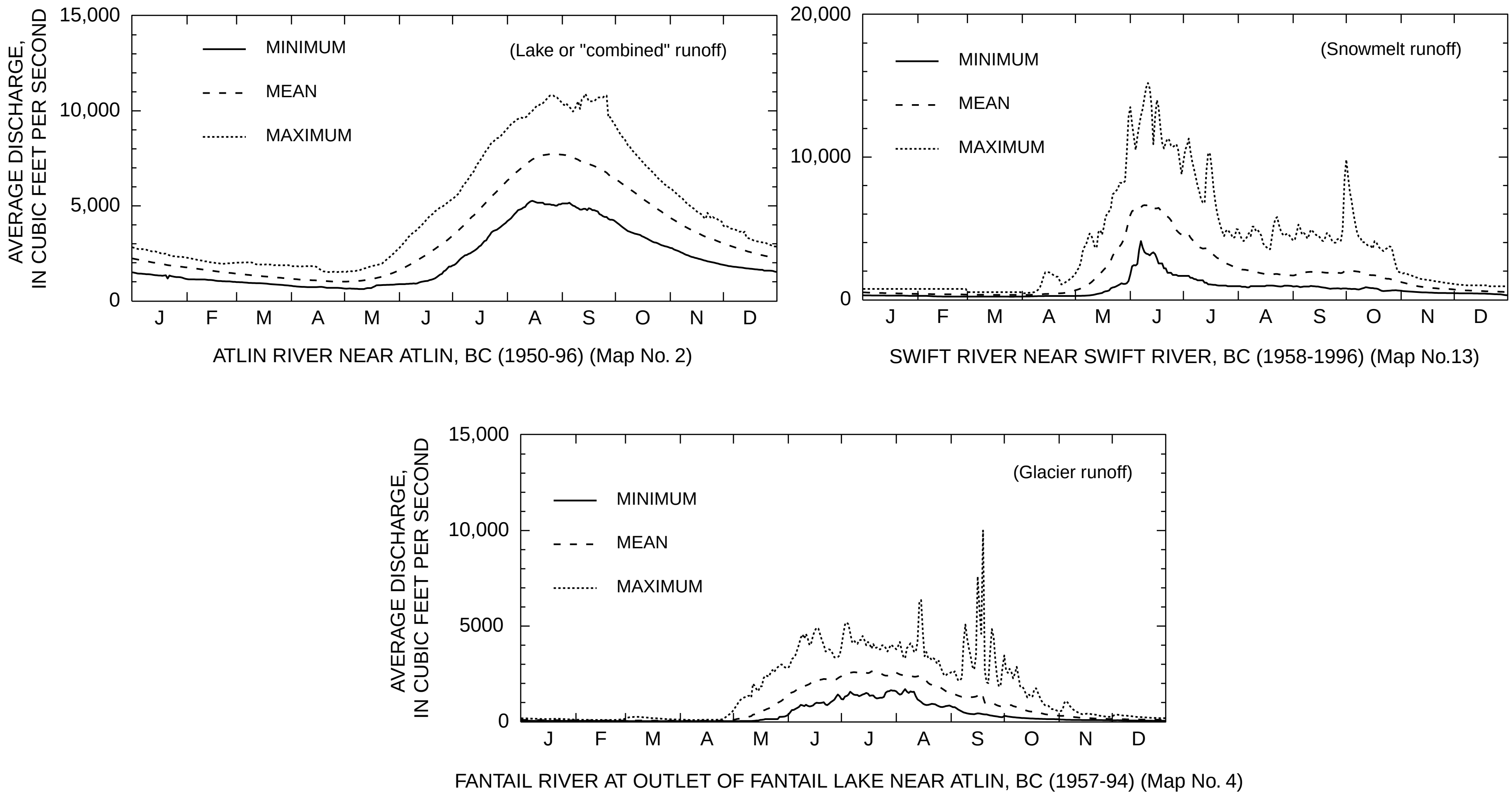


Figure 19. Flow statistics of three rivers near the headwaters of the Yukon River. (See figure 18 for site location.)

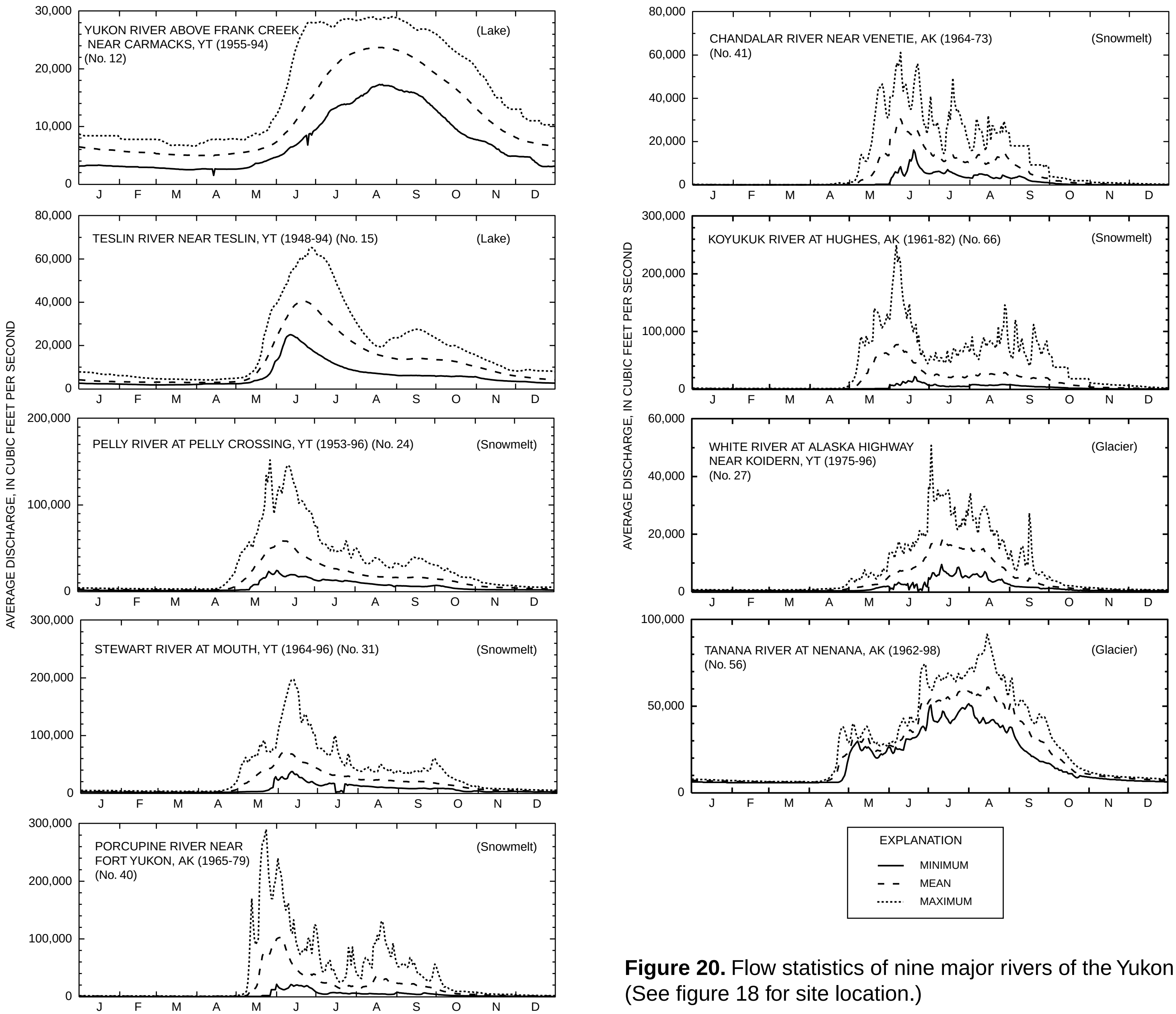


Figure 20. Flow statistics of nine major rivers of the Yukon River Basin. (See figure 18 for site location.)

The discharge hydrographs of several stream-gaging stations located along the main stem of the Yukon River (fig. 21) indicate the contributions of the various rivers to the Yukon River. Most of the increase in flow of the Yukon River between Carmacks and Dawson is primarily from input from the White River and the Stewart River. Between Eagle and Stevens Village, flow increases from input from the Porcupine and Chandalar Rivers. The Yukon River at Ruby includes input from the Tanana River, and the Yukon River at Kaltag includes the inflow from the Koyukuk River. Between Kaltag and Pilot Station, some of the flow of the Yukon River goes into storage during June. Most of the area between Kaltag and Pilot Station is low-lying wetlands.

The average discharge for the Yukon River at Pilot Station is 227,000 ft^3/s, based on the period of record, 1976-96. Using the discharge records for the main tributaries of the Yukon, the relative contribution of discharge for each of the major drainage basins was computed (table 7; fig. 22). The percentage of flow from the two glacier basins, the Tanana and White, was higher than the percentage of their respective drainage areas (fig. 22). Conversely, the percentage of flow from the Porcupine and Chandalar Rivers (non-glacier basins) was less than the percentage of their drainage areas.

The waters of the Yukon River enter the Bering Sea and move northward to the Arctic Ocean. Of the 10 largest inputs into the Arctic Ocean, the Yukon River ranks fifth behind the Yenisei, Ob, and Lena Rivers of Russia, and the Mackenzie River of Canada, and contributes 8 percent of the total discharge to the Arctic Ocean (fig. 23) (Aagaard and Carmack, 1989). Thus, the Yukon River is a major contributor of water and solutes to the Arctic Ocean and the Bering Sea ecosystems. Changes in the Yukon River—either in flow or water quality—could influence these ecosystems.

Table 7. Flow contributions of major drainage basins to the Yukon River Basin

Basin	Flow (cubic feet per second)	Percentage of Yukon River flow at Pilot Station
Yukon Headwaters	11,500	5.1
Teslin River	11,800	5.2
Pelly River	14,000	6.2
Stewart River	16,400	7.2
White River	21,000	9.2
Upper Yukon	9,700	4.3
Porcupine River	22,000	9.7
Chandalar River	7,400	3.2
East Central Yukon	14,800	6.5
Tanana River	44,600	19.6
Koyukuk River	27,200	12.0
West Central Yukon	15,600	6.9
Lower Yukon	11,100	4.9
Total	*227,000*	*100*

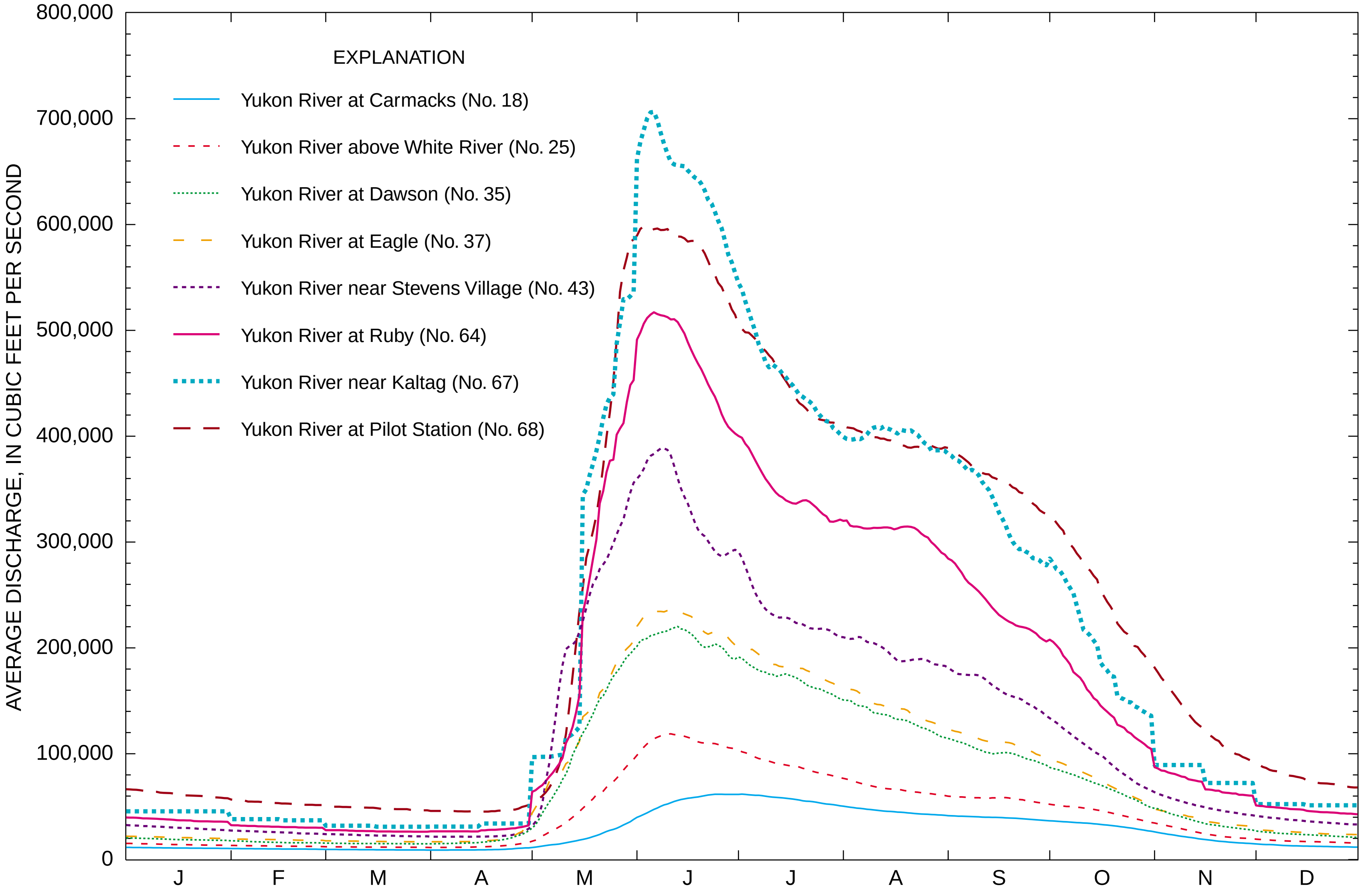


Figure 21. Average discharge of the Yukon River at eight locations (see figure 18 for locations).

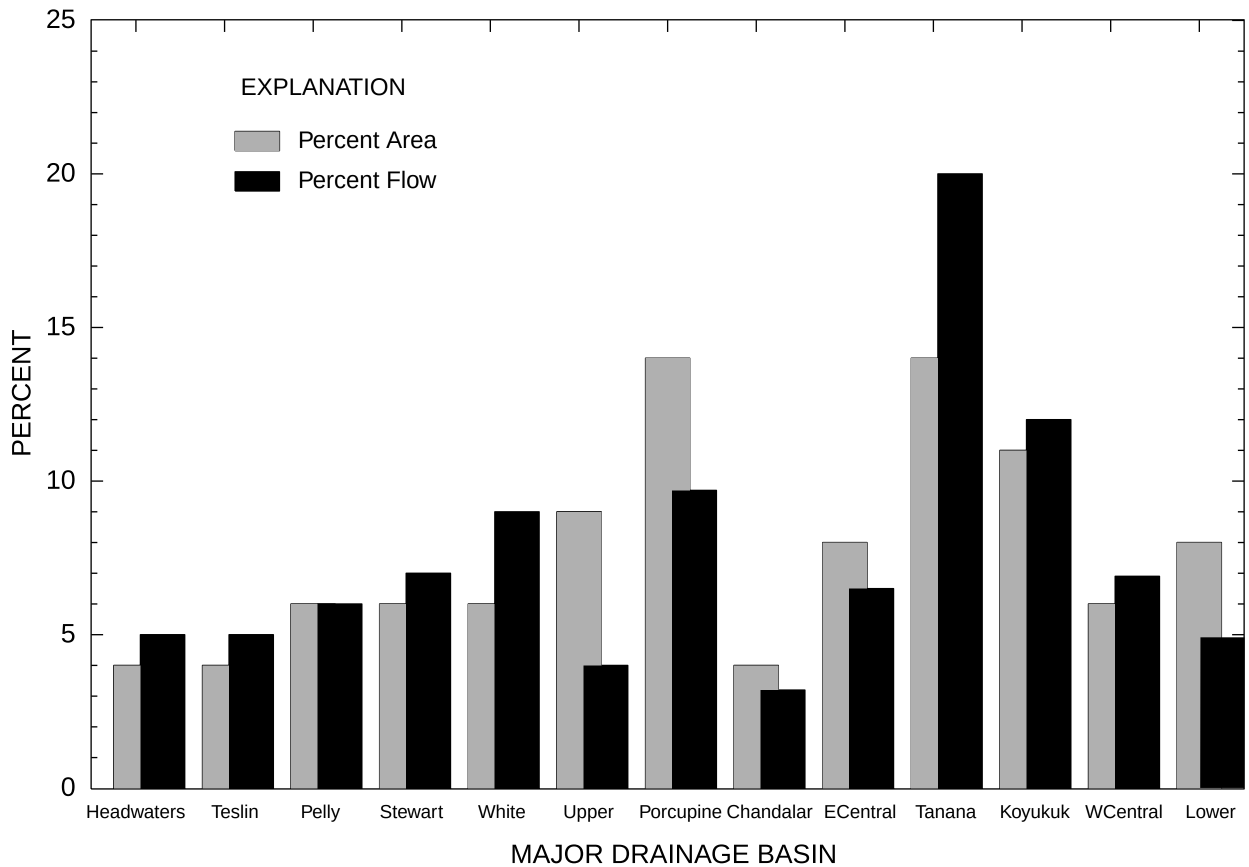


Figure 22. Percent contributions of area and flow of the major drainage basins of the Yukon River Basin.

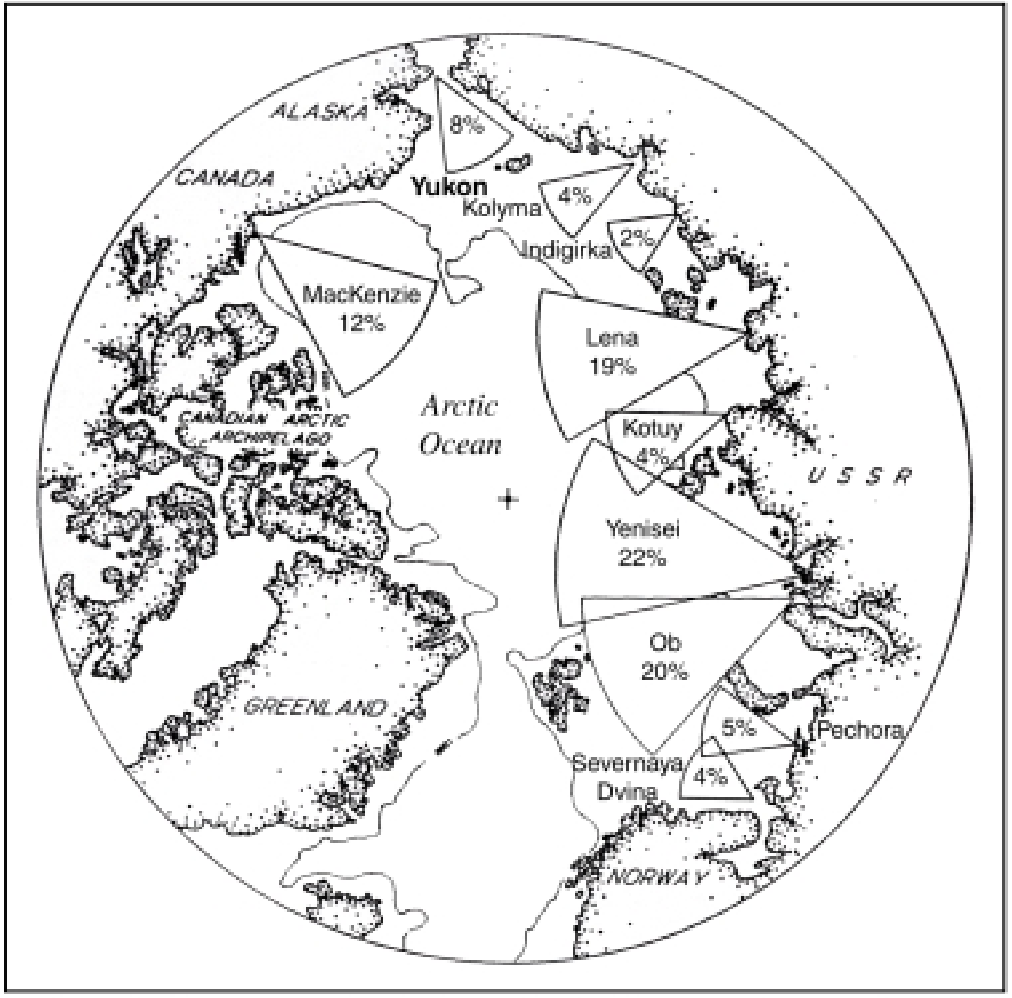


Figure 23. Percentage of major river outflows into the marginal seas of the Arctic Ocean (from Aagaard and Carmack, 1989).

Floods

Floods, as extreme hydrologic events, can affect water quality. The largest loads of many constituents from nonpoint sources occur during flooding. Floodwaters may scour gravels and deposit fine-grained sediment, damaging spawning beds for some fish species. Floods also wash young juvenile fish out of the river.

In the Yukon River Basin, annual high flows for most of the major rivers occur during the summer rainy season. However, on the main stem of the Yukon, flooding commonly occurs from ice jams in the spring. Although levees have been built at Dawson to prevent flooding from ice jams, villages located along the lower part of the Yukon River are still subject to flooding each spring.

The history of flooding in the Yukon River Basin is virtually unknown before the establishment of a network of streamflow-gaging stations in the late 1940’s and early 1950’s. A few identified historical floods in the upper Porcupine and Yukon Rivers during the Pleistocene era were caused by the sudden release of water from glacial lakes in the Yukon Territory (Thorson and Dixon, 1983). In addition, a flood history of the Chena River at Fairbanks began with a major flood in 1905. Since 1949, three major floods have occurred in the Yukon River Basin: in 1964, 1967, and 1994. These floods covered large areas of the basin and caused considerable property damage.

Flood of June and July 1964—Large snowpacks located in the Yukon River Basin caused several streams to reach peak discharges of record. The floods were caused by rapid snowmelt from these large snowpacks and, in some places, by rain on water-saturated snow. Flooding occurred mainly in sparsely populated areas of the upper Yukon (in Alaska) and the Koyukuk River Basin. In many small streams, peak discharges were minor; in others, if the conditions of snow cover were right, peak discharges were the largest of record. The dates of the peak discharges ranged from early June to early July, depending on the air temperature, the aspect and altitude of the contributing basins, and the dates of substantial rainfall.

Flood of August 12-18, 1967—Beginning on August 8, 1967, a series of widespread general rains occurred in the middle and lower Tanana River Basin near Fairbanks. Locally, storm rainfall totaled 10 in., which is nearly the average annual precipitation for the area. Floods of the Salcha River and the Chena River at Fairbanks were extremely large, and the maximum discharge of the Salcha River was almost twice that of a flood peak that has a 100-year recurrence interval (fig. 24). About 95 percent of Fairbanks was under water (Childers and others, 1972). Nenana, which is downstream from Fairbanks on the Tanana River, also was inundated. This flood caused about $85 million in damage.

Flood of August 1994—Beginning on August 15, 1994, severe storms began in western Alaska and moved eastward. Flooding occurred in the Koyukuk River Basin when more than 5 in. of rain fell in the upper part of the basin (Meyer, 1995). A second storm on August 24-27, with an additional 5 in. of rain, also occurred in the upper part of the Koyukuk Basin. This storm caused major flooding at Wiseman, washed out the Dalton Highway in three places, and forced the evacuation of three villages located along the Koyukuk River: Allakaket, Alatna, and Hughes. These villages were declared disaster areas and approximately $70 million was needed to relocate Allakaket and Alatna to higher ground. The peak discharge of the Koyukuk River was estimated to have a recurrence interval of 100 years.

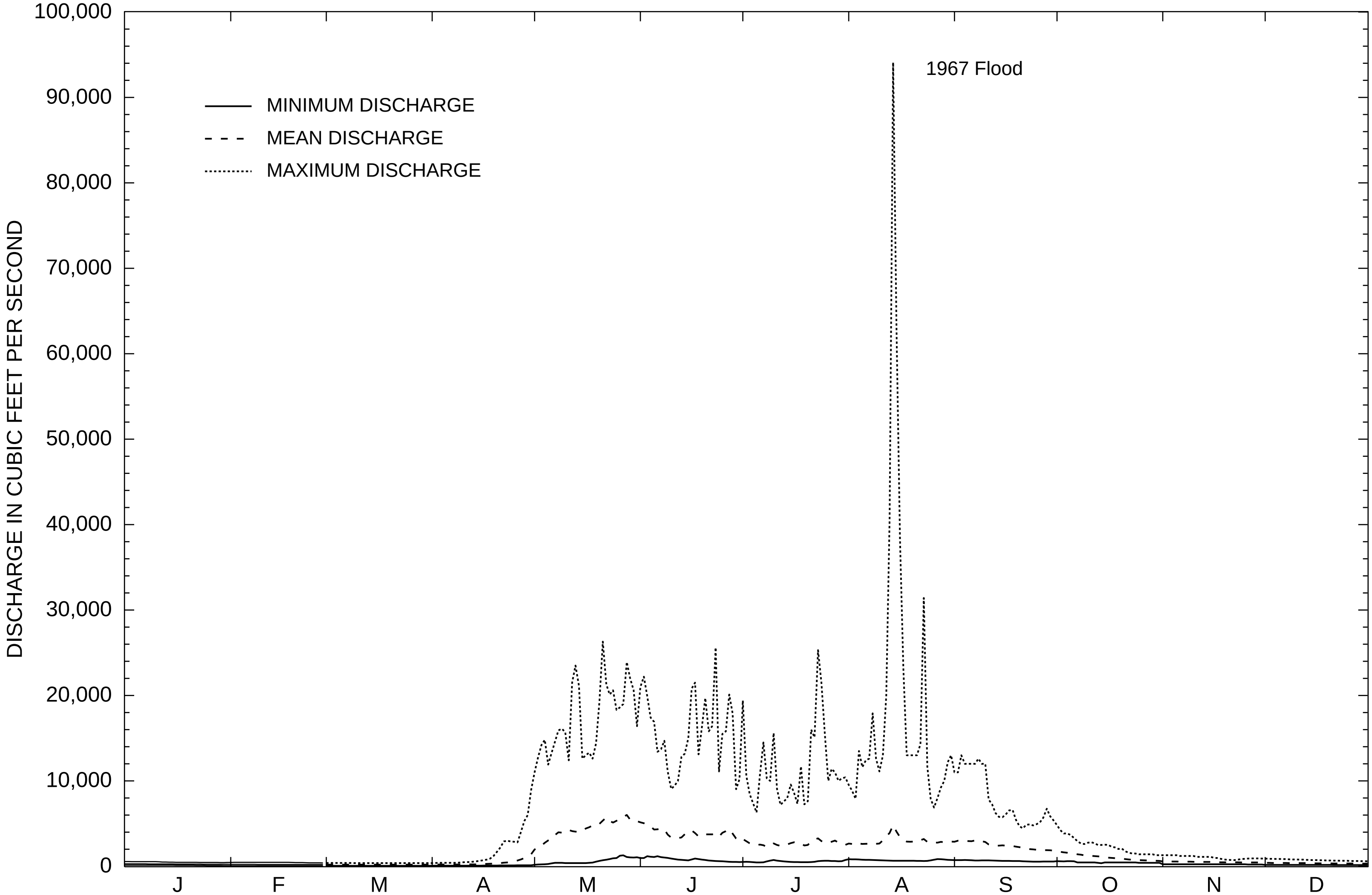


Figure 24. Flow statistics of the Salcha River near Salchaket, Alaska (1949-98).

Droughts

Like floods, droughts are also extreme hydrologic events that affect water quality. Droughts or deficit streamflows in the Yukon River Basin primarily affect anadromous fish, which may not have sufficient streamflow to migrate upstream to spawn, or affect the eggs after spawning, which may not survive if they are exposed as stream levels decline. During low flows, water temperatures of streams tend to increase and concentrations of dissolved oxygen tend to decrease. Long periods of deficit rainfall commonly lead to declines in ground-water levels, which, in turn, decrease baseflow of streams, decrease available supply from small-yield wells, and lower water levels in lakes.

In the Yukon River Basin, annual low flow occurs during the winter when there is no surface runoff and inflow is primarily from ground water. During the runoff season, discharge is higher than in the winter period even if snowfall and rainfall are below average. In addition, glacier-fed streams add icemelt as input to a stream. Thus, assigning a time period as a drought is somewhat subjective. An approach used by Lamke (1991), which analyzes the departure of the annual discharge from the long-term mean, provides a good indication of the trend of streamflow. By analyzing the streamflow at eight long-term gaging stations (fig. 25), four droughts or periods of deficit flow were identified in the Yukon River Basin since 1949.

Drought of 1950-57—Most of the upper Yukon River Basin and the upper Tanana River Basin were affected during this period. The drought was less severe farther west along the Alaska Range. On the main stem of the Yukon River, deficit flows began in June 1950 at Eagle (fig. 25A). The cumulative deficit in the almost 7 years of drought was equivalent to about 1 year of average flow.

Drought of 1969-70—This period of low flow affected primarily the Alaska part of the Yukon River Basin. The largest deficit flow for the period of record occurred on the Koyukuk River at Hughes (fig. 25B). Deficit flow was also evident on the Tanana River (fig. 25C) and the lower part of the Yukon River at Ruby (fig. 25D).

Drought of 1973-80—This period is considered to be the most severe low flow period in terms of deficit flow and length. Similar to the 1969-70 period, only the Alaska part of the Yukon River Basin was affected (the records from Whitehorse to Eagle (fig. 25E, F, A) do not indicate any trend). The Koyukuk and Tanana Rivers (fig. 25B, C) and the lower part of the Yukon River were most affected.

Drought of 1996 to present—In the winter of 1995-96, snowfall was significantly less than normal in large parts of the Yukon River Basin. Relatively large deficit flows occurred along the Yukon River above the White River, at Eagle, near Stevens Village, and at Pilot Station (fig. 25F, A, G, H) and on the Tanana River (fig. 25C). For three stations where flow data are available (the Yukon River at Eagle and near Stevens Village, and the Tanana River at Nenana, figs. 25A, G, C) deficit flows again occurred in 1998, which may signal another period of low flow.

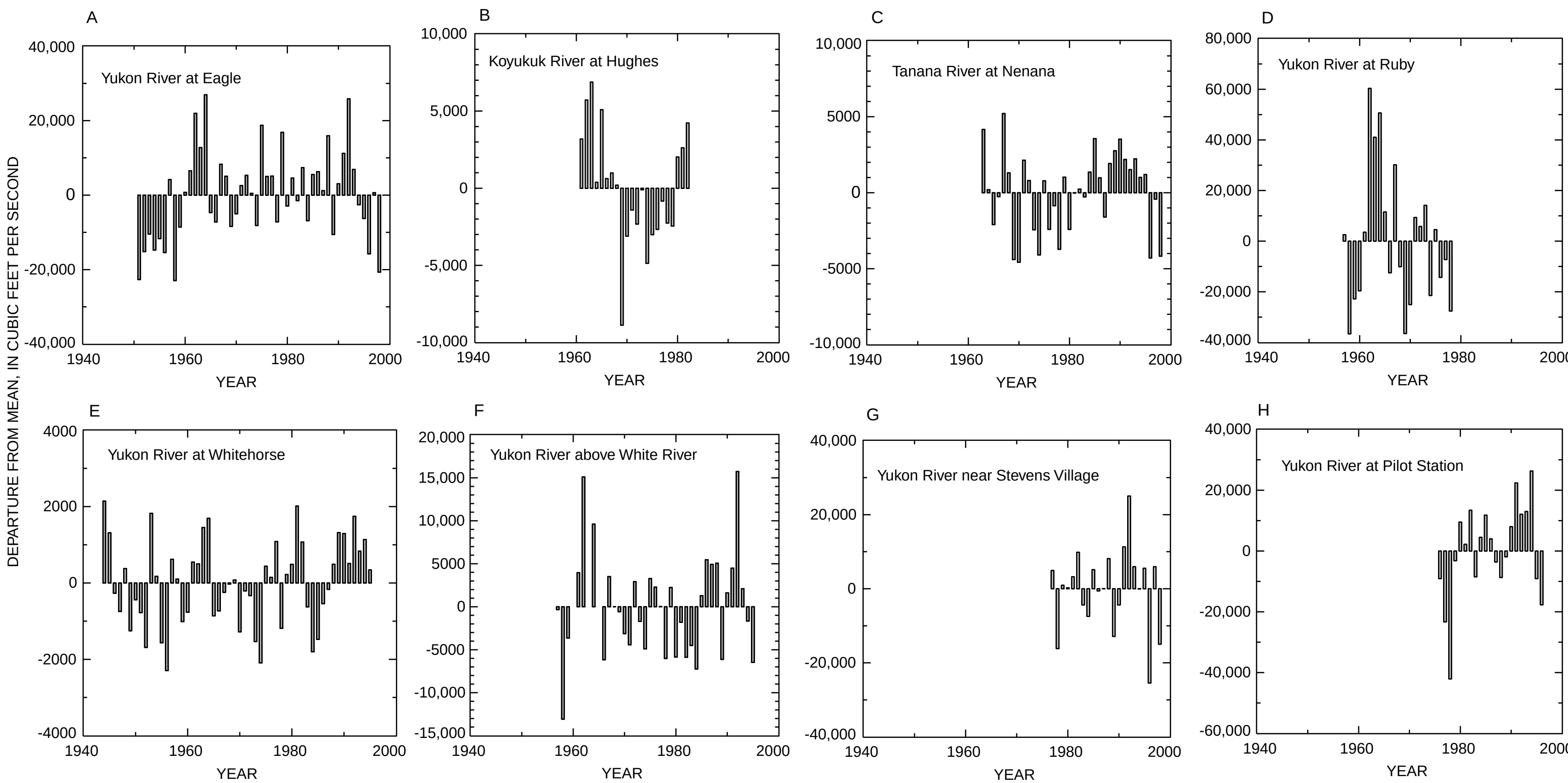


Figure 25. Departure from average discharge for several long-term streamflow-gaging stations in the Yukon River Basin (refer to figure 18 for locations).

Sediment

Sediment is an important water-quality constituent. Particle size determines to a large extent whether a stream carries the sediment as suspended load or as bedload. Elevated suspended-sediment concentrations can adversely affect aquatic life by clogging gills, covering fish spawning sites, or by altering habitat of benthic organisms (U.S. Environmental Protection Agency, 1977). Metals and organic contaminants also commonly adsorb on suspended sediment (U.S. Environmental Protection Agency, 1977).

Collection of suspended-sediment samples in the Canadian part of the Yukon River Basin began in 1970 by Environment Canada as part of a basic monitoring program (Russ Gregory, Environment Canada, written commun., 1998). Samples have been collected during various years at six sites (table 8) that represent the major basins in the Canadian part of the Yukon. In most years, three suspended-sediment samples were collected at these sites during the open-water season. Currently, sediment samples are collected at four sites each year.

Table 8. Suspended-sediment stations in the Yukon River Basin

Map No. (fig. 18)	USGS Station No.	Name	Period of record
		Canada	
9	15305000	Yukon River at Whitehorse, YT	1970-77
24	15305420	Pelly River at Pelly Crossing, YT	1970-
25	15305450	Yukon River above White River near Dawson, YT	1977-
27	15305540	White River at Alaska Highway near Koidern, YT	1975-
31	15305650	Stewart River at mouth, YT	1968-
35	15305700	Yukon River at Dawson, YT	1971-79
		Alaska	
37	15356000	Yukon River at Eagle, AK	1954-79
40	15389000	Porcupine River near Fort Yukon, AK	1967-75
41	15389500	Chandalar River near Venetie, AK	1967-75
44	15468000	Yukon River at Rampart, AK	1954-67
45	15470000	Chisana River at Northway Junction, AK	1953-67
46	15476000	Tanana River near Tanacross, AK	1953-75
48	15478000	Tanana River at Big Delta, AK	1971
		Alaska--Continued	
49	15484000	Salcha River near Salchaket, AK	1967-76
50	15485500	Tanana River at Fairbanks, AK	1975-82
51	15493000	Chena River near Two Rivers, AK	1968-71
52	15493500	Chena River near North Pole, AK	1972-75
54	15514000	Chena River at Fairbanks, AK	1954-75
55	15514500	Wood River near Fairbanks, AK	1968-73
56	15515500	Tanana River at Nenana, AK	1966-96
59	15518000	Nenana River near Healy, AK	1953-68
63	15564600	Melozitna River near Ruby, AK	1967-72
64	15564800	Yukon River at Ruby, AK	1968-73
65	15564875	Middle Fork Koyukuk River near Wiseman, AK	1971-73
66	15564900	Koyukuk River at Hughes, AK	1966-72
68	15565447	Yukon River at Pilot Station, AK	1975-96

Collection of suspended-sediment data in the Yukon River Basin in Alaska began in 1953 (table 8). For the next decade, most of the sediment data-collection effort focused on two rivers, the Tanana River near Tanacross and the Nenana River near Healy. At these two sites, daily suspended-sediment samples were collected during the 4 to 5 months of the runoff season, May to September. In 1962, daily suspended-sediment sample collection also began at two more stations, Yukon River at Eagle and Chena River at Fairbanks. For the next 5 years, daily sediment samples were collected through most of the runoff seasons at all four stations. Sampling was discontinued at three of the stations at the end of the 1966 water year. At the remaining station, Chena River at Fairbanks, daily sampling continued until 1971. Since 1971, no daily suspended-sediment sampling programs have been undertaken.

In 1967, the focus of sediment sampling in the Alaskan part of the Yukon basin shifted from daily samplings at a few selected stations to sporadic samplings at a larger number of stations (table 8). This program consisted of collecting three to five sediment samples (ideally, one per month) through the runoff season at about 12 stations in the Alaskan part of the Yukon River Basin. This program lasted only a few years and essentially ended by the end of 1975.

The most recent phase of sediment data collection, from the late 1970's until 1996, has centered on two stations supported by the USGS National Stream Quality Accounting Network (NASQAN) program, the Tanana River at Nenana and the Yukon River at Pilot Station. Although only a few samples were collected each year, the length and consistency of these sampling efforts give added value to the sediment data. Also, from 1977-82, bedload data were collected along a reach of the Tanana River near Fairbanks

Records of all the suspended-sediment measurements are available in USGS publications (U.S. Geological Survey 1954-62, 1971, 1976, 1972-75, 1976-96). Data are also stored in electronic format in the USGS National Water Information System (NWIS). Bedload data for the Tanana River are available in reports by Burrows (1980), Burrows and others (1979, 1981), Burrows and Harrold (1983), Emmett and others (1978), and Harrold and Burrows (1983). Data from the Canadian Yukon are published in the series "Sediment Data: Canadian Rivers," issued by the Water Survey of Canada and are also available in electronic format from the worldwide web *(http://www.ec.gc.ca/water/index.htm)*.

Sources of Sediment

Sediment in streams and rivers is the result of natural erosion, a process that can be accelerated by land cover disturbance such as mining. In the Yukon River Basin, the sources of and subsequent erosion of sediment are due primarily to natural factors. However, distinctions can be made depending on whether a particular river is non-glacier fed or glacier fed.

Non-glacier-fed tributaries of the Yukon River have beds composed of sand, gravel, and cobbles. The coarser material is found in the upper reaches of these rivers and the finer material in the lower reaches. Banks consist of poorly sorted cobbles and gravel in the steep upper reaches, but change to sand and gravel in the lower reaches. River channels are braided in the upper reaches, but become less pronounced as the river becomes less steep and sediment is deposited in the lower reaches. Bed material is gradually sorted and rounded progressively downstream and consists of gravel and cobbles in the thalweg and gravel and sand on the bars.

Glacier-fed rivers in the Yukon River Basin have vast quantities of unconsolidated material downstream from the glacier termini. These rivers have wide flood plains cut with braided channels. Boulders, cobbles, gravel, sand, and large quantities of fine silt make up the streambank and bed, and provide a ready source of sediment. Streambanks are barren with little vegetation and have large boulders rounded from the previous advances of the glacier. Steep reaches create high stream velocity, which transports gravel and cobble-size material downstream as bedload, and sand and silt in suspension. Braiding is pronounced and extends far downstream because of high sediment loads.

As in non-glacier-fed streams, material is sorted downriver in the main channels of glacier-fed rivers as the slope of the river decreases. When flows are low enough for bars to be visible, most bars are covered with silt and fine sand, deposited on recession from higher flows. The fine sediment in suspension from the glacier basins may be transported even at low flows, but the within-channel deposits augment the sediment load at higher flows. Except where constrained by bedrock walls, broad alluvial plains left from the last glacial retreat characterize the valleys downstream from the montane regions. In the Yukon River Basin, these areas are large wetlands that are cut by numerous old channels and sloughs, and covered with tussocks, brush, willows, aspen, birch, and spruce trees.

In areas of the Yukon River Basin where permafrost is discontinuous, riverbanks may be perennially frozen at depth and overlain with a seasonally frozen layer of organic material and vegetation. This condition creates an additional source of sediment in the summer when the permafrost is thermally eroded by flowing water. The result is undercut banks, overhanging vegetation, and finally failure of the upper bank, causing trees, brush, and sediment to fall into the river.

Suspended-Sediment Concentrations

Suspended-sediment concentration data are available for most of the major tributaries to the Yukon River and for several sites along the Yukon River itself. These data were summarized graphically by the use of boxplots (fig. 26). Although only a limited number of samples have been collected at some sites, general observations can still be made.

Most of the measured suspended-sediment concentrations for the main stem of the Yukon River were less than 1,000 mg/L. The two major glacier-fed rivers, the White and the Tanana, had the highest concentrations. Concentrations at the Yukon River at Whitehorse, the farthest upstream site, were all less than 50 mg/L. Going downstream, the median sediment concentrations in the Yukon River at Dawson and at Eagle were higher, reflecting the input of the White River. From Eagle to Rampart, no major changes in median concentration seemed apparent until Ruby. At this site, the median concentration was higher, reflecting the input from the Tanana River. From Ruby to Pilot Station, the median concentration decreased slightly.

A number of analyses show that virtually all sediment particles carried in suspension in the Yukon River and its main tributaries are finer than 0.5 mm. Within the suspended sand fraction itself, 90 percent is finer than 0.25 mm—that is, between 0.062 and 0.25 mm in nominal diameter. For some sites, a number of complete particle-size analyses indicate that grain size consists predominantly of silt and clay (table 9).

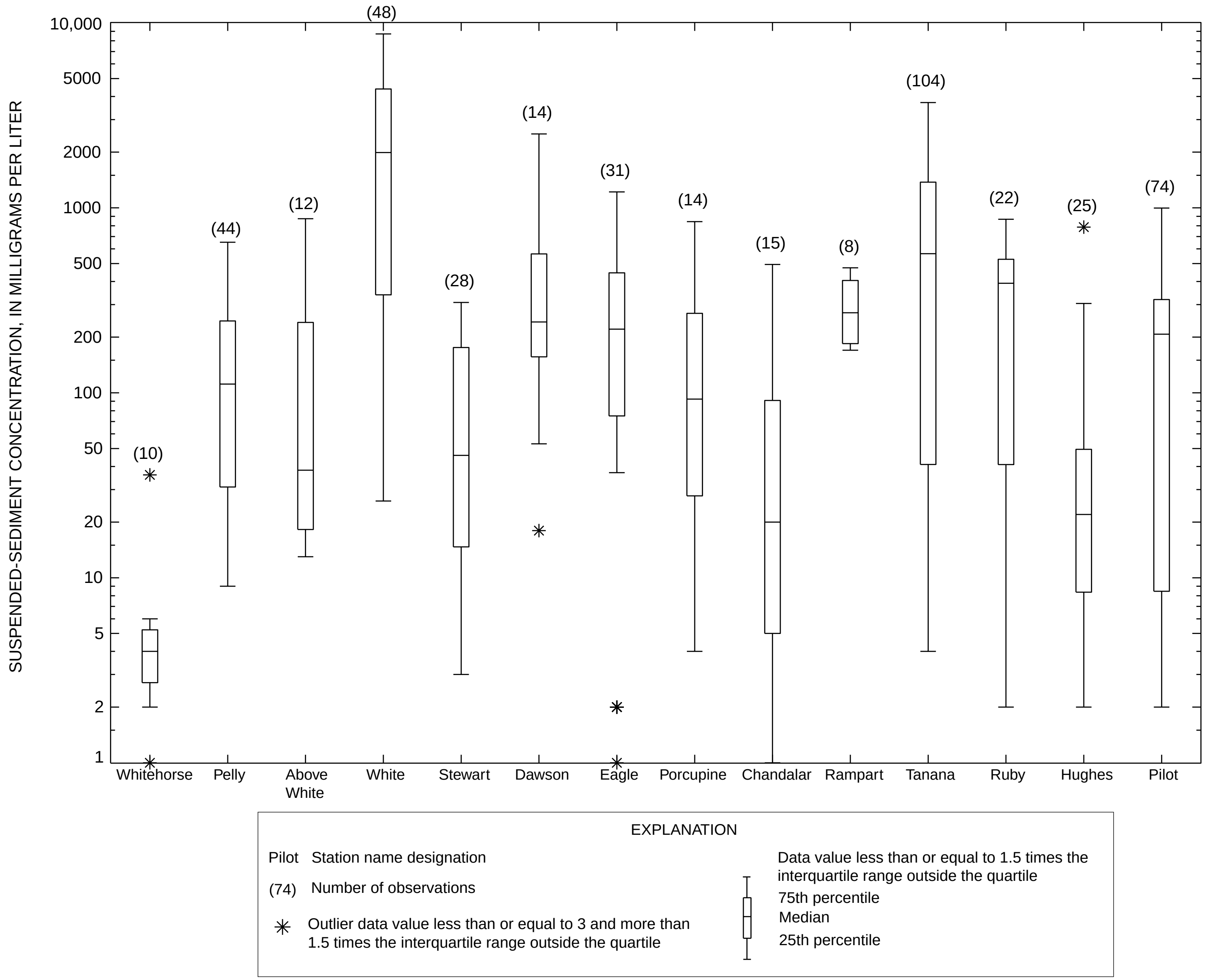


Figure 26. Boxplots of suspended-sediment concentrations at 14 sites in the Yukon River Basin.

Table 9. Mean grain-size composition of suspended sediment for stations in the Yukon River Basin

Map No. (fig. 18)	USGS Station No.	Name	No. of samples	Percentage		
				Clay	Silt	Sand
24	15305420	Pelly River at Pelly Crossing, YT	30	18	48	34
25	15305450	Yukon River above White River near Dawson, YT	9	35	51	14
27	15305540	White River at Alaska Highway near Koidern, YT	141	28	46	26
31	15305590	Stewart River at mouth, YT	19	21	57	22
37	15355600	Yukon River at Eagle, AK	8	34	50	16
44	15468000	Yukon River at Rampart, AK	7	26	50	24
68	15565447	Yukon River at Pilot Station, AK	5	26	53	21

Relation Between Suspended-Sediment Concentration and Water Discharge

Suspended-sediment concentrations in the Yukon River and most of its tributaries generally increase with increasing water discharge, although a high correlation does not always exist (fig. 27). Much of the scatter of points is related to the well-known "clockwise-looped" relation (Meade and others, 1990, p. 257), in which sediment concentrations measured while a river is rising are usually higher than those measured at the same water discharges as the river is falling. The clockwise-looped relation is usually explained as showing a depletion effect: fine-grained sediment, which is stored on the bed or along the banks of river channels during low-water periods, is in plentiful supply as the river begins to rise, but the stored material is soon resuspended, and it eventually becomes depleted as (or before) the river reaches its maximum discharge. Additionally, the particle-size distribution of the suspended sediment may influence the correlation with water discharge (fig. 28). For example, concentrations of suspended sand are less correlated with water discharge than concentrations of suspended silt and clay.

In rivers that directly drain the montane regions of the Yukon River Basin, the concentrations and discharges of sediment are coupled closely with water discharge. For example, at the Tanana River near Tanacross (fig. 29A), each pulse of increased water discharge is accompanied by an increase in sediment concentrations. The closeness of this correlation suggests either that the sources of water and sediment are identical (melting glaciers, perhaps) or that large quantities of excess sediment are stored in the system waiting to be mobilized by each pulse of water discharge.

Farther from the montane sources, the correlations between daily water discharges and sediment concentrations become weaker. The Yukon River at Eagle (fig. 29B), demonstrates a poorer relation with water discharge than that shown for the Tanana River near Tanacross. Sediment concentrations are generally highest between mid-July and mid-August, a month or more after the greatest discharge of water. At this location on the Yukon main stem, the most likely source of large concentrations of suspended sediment is the White River and its tributaries that drain the Wrangell–St. Elias Mountains.

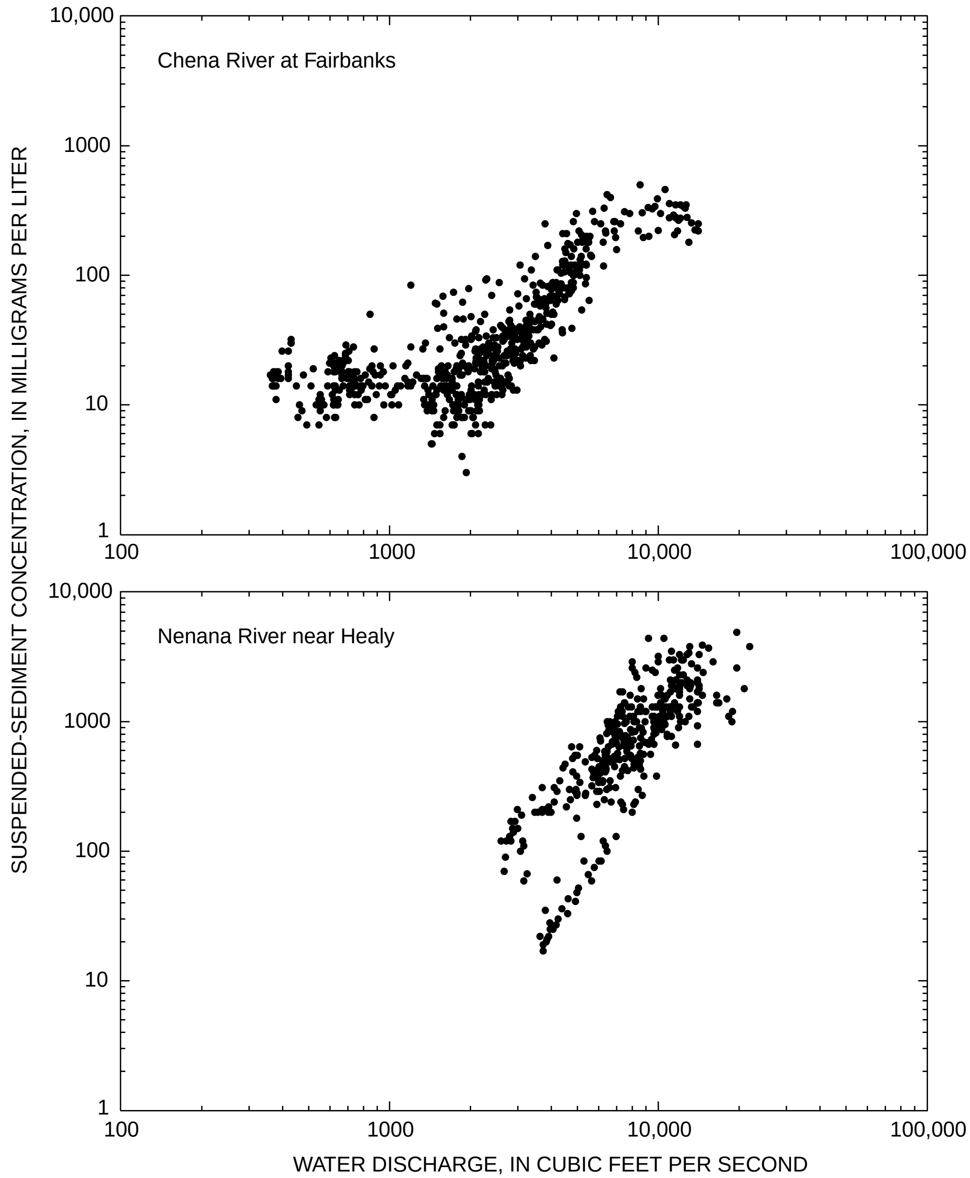


Figure 27. Water discharge and suspended-sediment concentrations for Chena River at Fairbanks, Alaska, and Nenana River near Healy, Alaska, for 1964-66 runoff seasons.

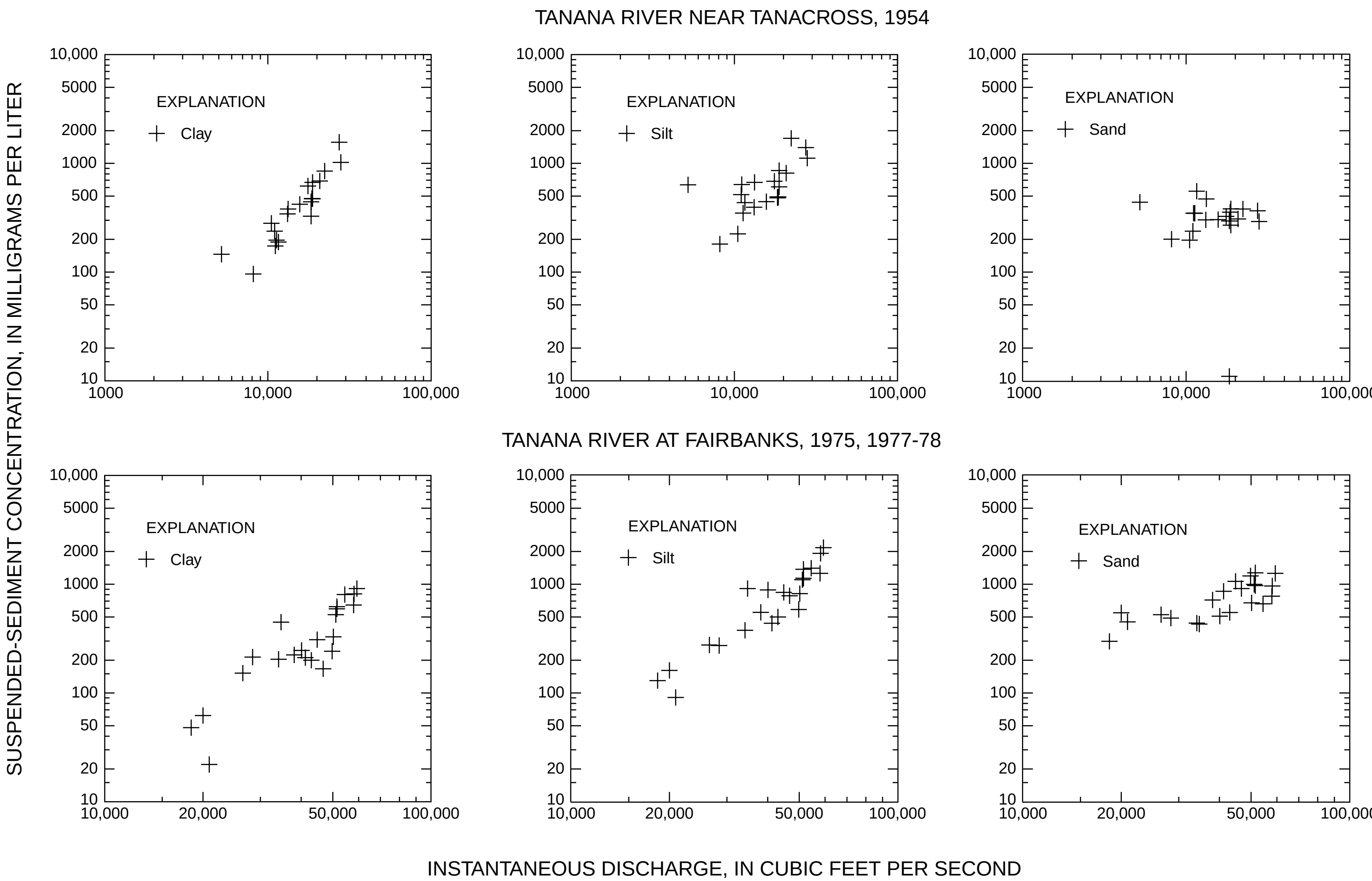


Figure 28. Instantaneous discharge and suspended-sediment concentrations for different particle sizes for Tanana River near Tanacross, Alaska, and Tanana River at Fairbanks, Alaska.

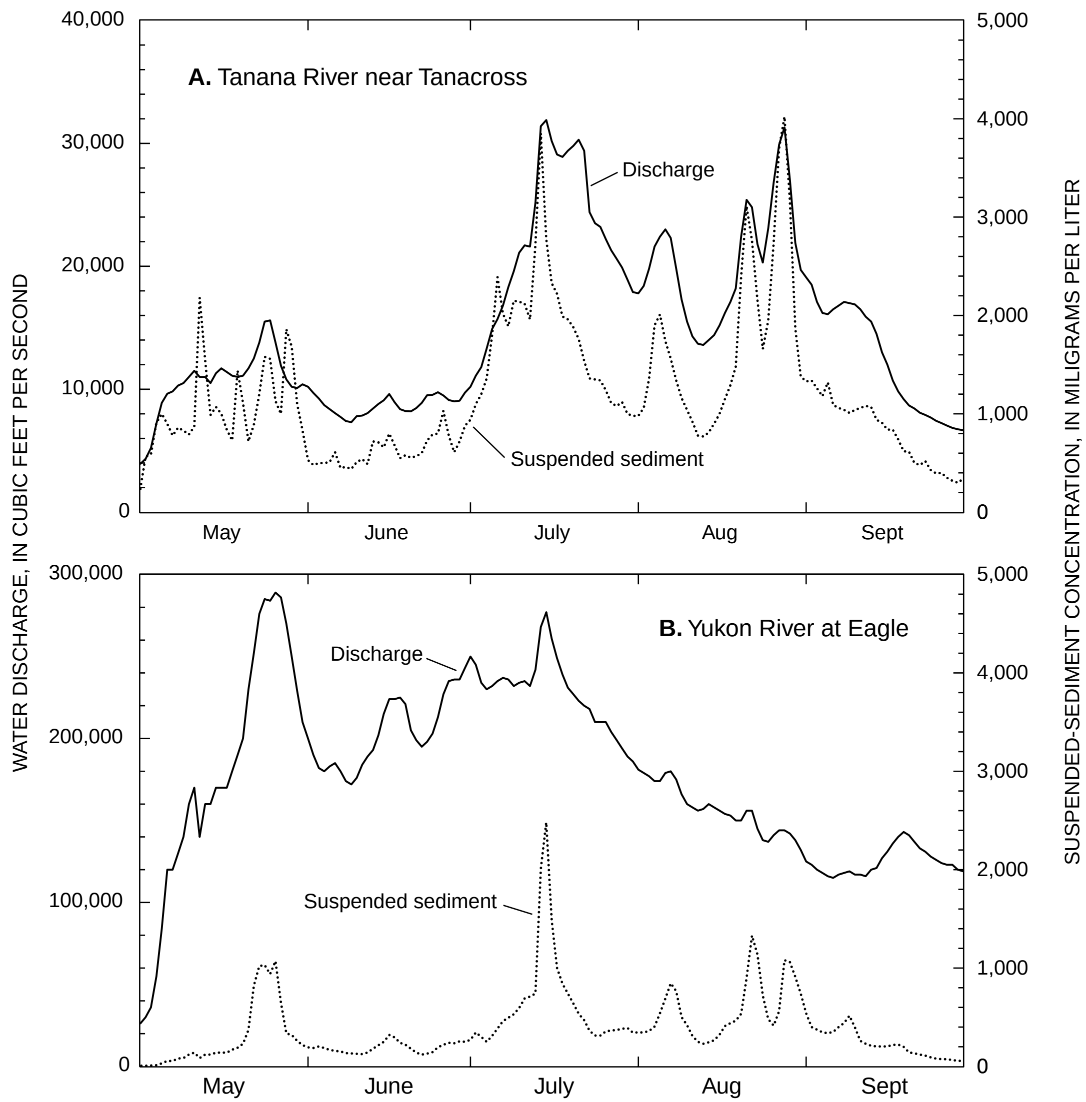


Figure 29. Average daily water discharge and suspended-sediment concentration for Tanana River near Tanacross, Alaska, and Yukon River at Eagle, Alaska, during 1963 runoff season.

Suspended-Sediment Discharge

The most striking characteristic of sediment discharge in the Yukon River Basin is its seasonality. More than 95 percent of all the sediment discharged during an average year is moved during the months of May through September (fig. 30). In some instances, more than half of the suspended-sediment load may be transported in 10 percent of the year during high flows (Burrows and others, 1981) As conveyors of sediment, the rivers are virtually dormant during the other seven months, October through April. In its annual cycle of warm-season flow and cold-season freeze-up, the entire river system shuts down and goes into storage mode in autumn, to be reactivated and remobilized in late spring or early summer. Although some degree of seasonality is typical of most large rivers elsewhere, in temperate and even tropical regions, it is especially pronounced in the arctic and subarctic rivers.

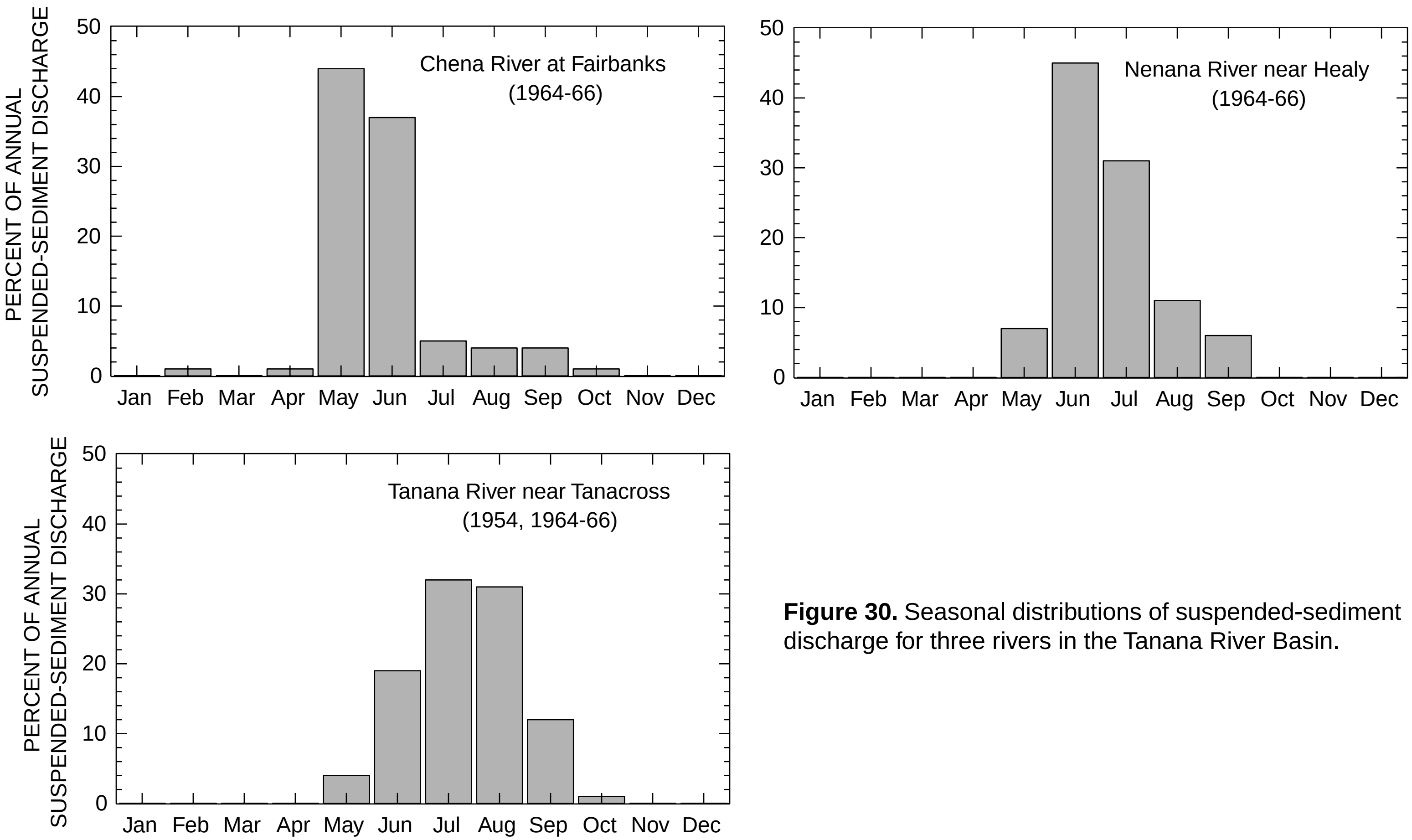


Figure 30. Seasonal distributions of suspended-sediment discharge for three rivers in the Tanana River Basin.

Differences in sediment discharge from the rivers in the Yukon River Basin depend on the type of watershed. A quantitative comparison of montane (glacier) versus lowland (non-glacier) sediment loads is provided by the extensive records collected in the Nenana River near Healy and the Chena River at Fairbanks. Especially useful are the year-long records of daily sediment discharge measured (and partially estimated) at both stations during three consecutive water years, 1964-66 (U.S. Geological Survey, 1970-71a). Although the daily values for the seven coldest months (October to April) were mostly estimated, the estimation procedures entailed only a small error overall because cold-weather discharge constitutes such a small proportion of the totals for the year.

Contrasts in water discharge and sediment load shown by the two records are striking (fig. 31). Although the drainage areas above the two gaging stations differ by only 4 percent, the water discharge from the montane area (Nenana River) was 2.5 times greater than that from the lowland area (Chena River). Furthermore, sediment load from the Nenana River Basin was 30 times the sediment load from the Chena River Basin. Reasons for the greater water discharges from montane areas are most likely the greater precipitation that falls at higher altitudes, and the partial but significant coverage of the drainage area by glaciers that contribute a steady flow of meltwater during

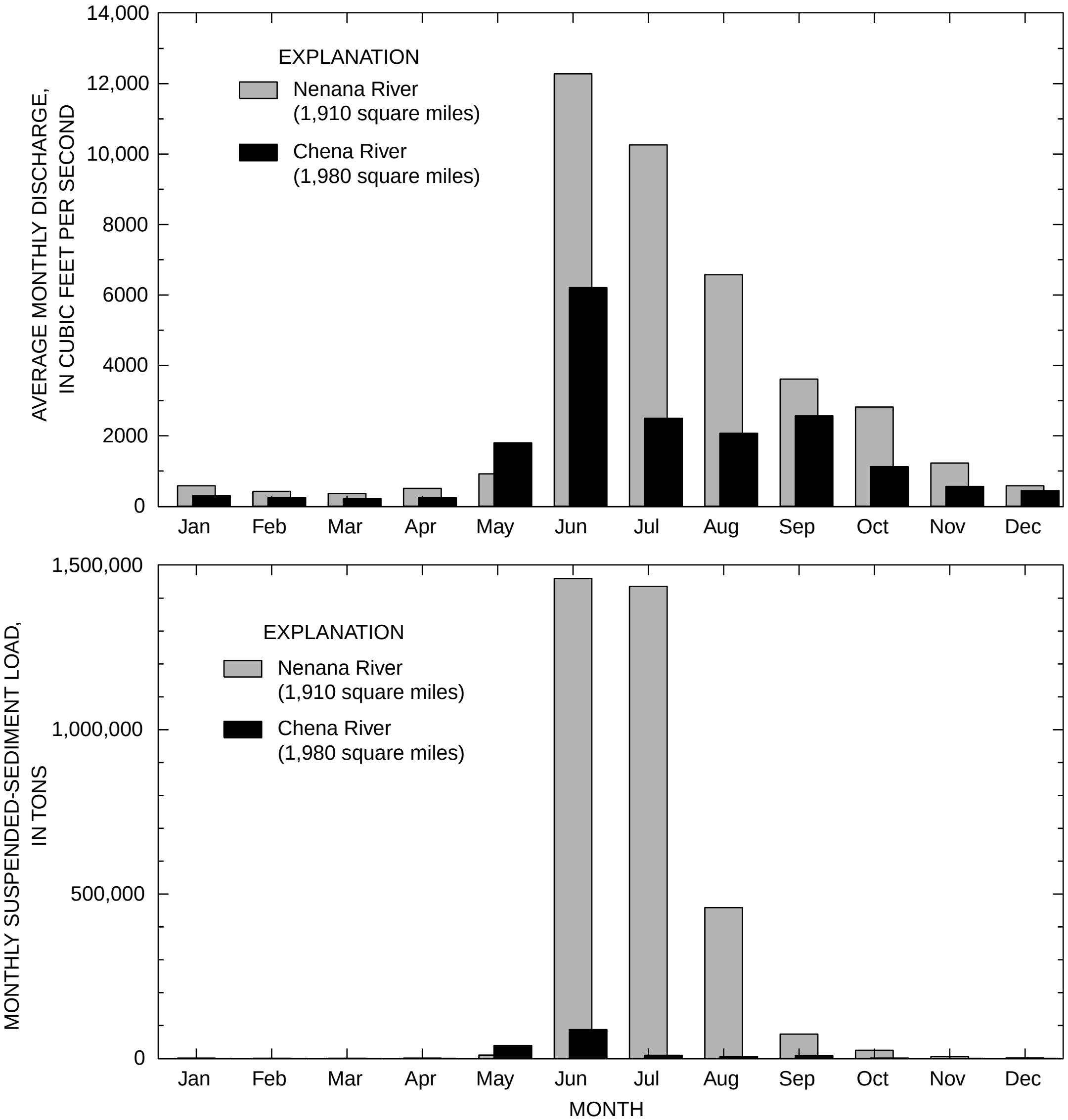


Figure 31. Differences in water discharge and suspended-sediment load during water years 1964-66 for Nenana River near Healy, Alaska and Chena River at Fairbanks, Alaska.

warmer months. Reasons for the greater sediment discharges are the more intensive tectonism in the montane areas, producing such features as over-steepened slopes on fractured bedrock, and more coverage by glaciers, whose basal grindings greatly increase the rates of mechanical erosion.

The particle-size distribution of the sediment load varies during the runoff season. Sand may compose half or more of the sediment in suspension in some river reaches during the early and later months of the runoff season when overall concentrations are lower (fig. 32). However, it composes only one-third to one-quarter (considerably less, at times) of the sediment in suspension in mid-season when total suspended concentrations are usually highest.

Using the available suspended-sediment data, annual sediment loads were determined for most of the major drainage basins of the Yukon River. A method described by Colby (1956) was used to compute the annual suspended-sediment loads for these rivers. This method requires defining a relation between instantaneous sediment discharge and water discharge and applying this relation to daily discharge. Also, it was assumed that the sediment data represent today's conditions, and that no interim changes in climate, land use, and other factors have significantly altered sediment

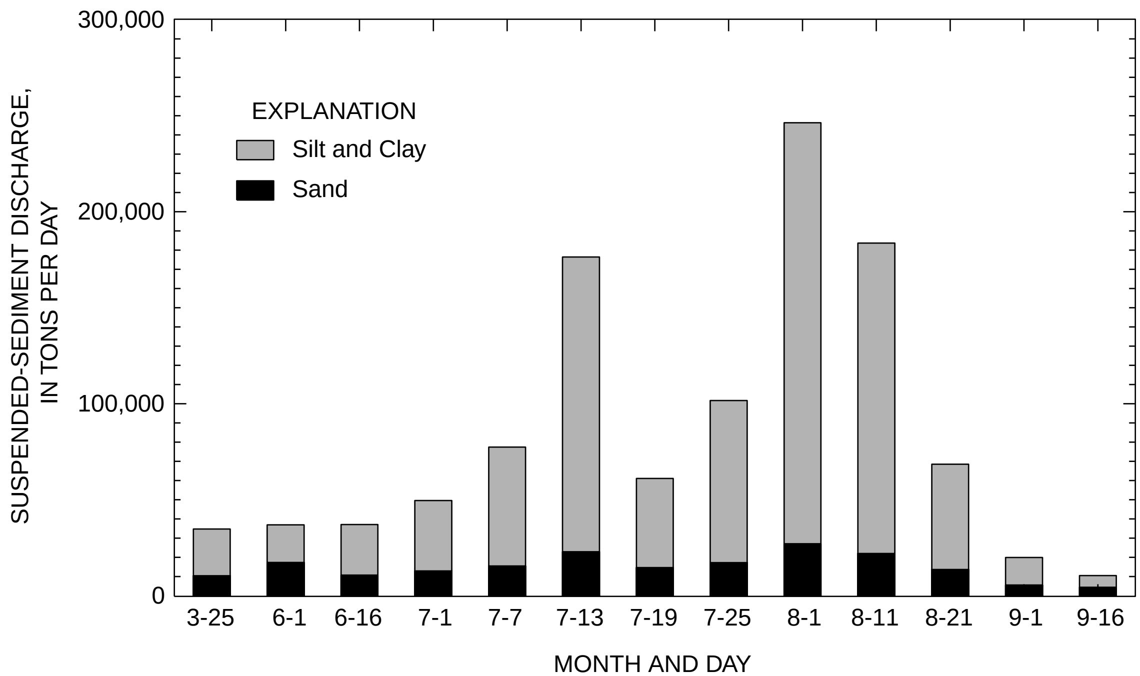


Figure 32. Changing proportions of suspended-sediment discharge during 1954 runoff season in Tanana River near Tanacross, Alaska.

yields during the last several decades. The sediment loads are considered to be subject to large errors since they are based mostly on limited data. However, they provide some insight on the suspended-sediment characteristics of the Yukon River Basin.

Approximately 60 million tons of suspended sediment are transported annually by the Yukon River at Pilot Station near its mouth (table 10; fig. 33). The overwhelming importance of source areas in the Alaska Range drained by tributaries of the Tanana River, and of the Wrangell–St. Elias Mountains drained by the White River and its tributaries is clearly shown. All other tributaries flowing from the Brooks Range and the more lowland areas of the Yukon Basin contribute fairly minor quantities of sediment. Thus, the Yukon River functions mainly as a conveyance system that gathers sediment from the high mountain ranges and transports it hundreds, even thousands, of miles to the Bering Sea.

Storage of Sediment

At Ruby, about 450 mi upstream from Pilot Station, the Yukon River transports about 66 million tons of suspended sediment per year, about 6 million tons more than at Pilot Station (table 10). The Koyukuk River adds 2 million tons to the Yukon below Ruby (table 10). Some of the sediment load is probably deposited on the flood plains and delta plains that lie along the Yukon between Ruby and Pilot Station. Deposition of sediment is expected because part of the water discharge of the Yukon River goes into storage during the runoff season.

A similar calculation can be made for the approximately 200-mile-long reach of the Yukon between Rampart and Ruby. The river transports about 33 million tons of sediment past Rampart during an average year. About 68 mi below Rampart, the Tanana River adds another 38 million tons, bringing the total to 71 million tons annually. Comparing this total to the 66 million tons measured at Ruby suggests that a quantity of about 5 million tons of sediment is being deposited out of the channel each year, most likely in the flood plain that fringes the south side of the Yukon River below its confluence with the Tanana River.

Table 10. Estimated annual suspended-sediment loads for selected sites in the Yukon River Basin

Map No. (fig. 18)	USGS Station No.	Name	Annual load (tons)
9	15305000	Yukon River at Whitehorse, YT	62,000
24	15305420	Pelly River at Pelly Crossing, YT	1,200,000
25	15305450	Yukon River above White River near Dawson, YT	3,500,000
27	15305540	White River at Alaska Highway near Koidern, YT	16,000,000
31	15305590	Stewart River at the mouth, YT	1,000,000
35	15305700	Yukon River at Dawson, YT	33,000,000
37	15356000	Yukon River at Eagle, AK	33,000,000
40	15389000	Porcupine River at Fort Yukon, AK	8,000,000
41	15389500	Chandalar River near Venetie, AK	1,000,000
44	15468000	Yukon River at Rampart, AK	33,000,000
56	15515500	Tanana River at Nenana, AK	38,000,000
64	15564800	Yukon River at Ruby, AK	66,000,000
66	15564900	Koyukuk River at Hughes, AK	2,000,000
68	15565447	Yukon River at Pilot Station, AK	60,000,000

The segment of the Yukon River between Eagle and Rampart is also a significant reach for sediment storage. Average annual sediment loads at Eagle and Rampart are virtually identical at 33 million tons despite two intervening tributaries, the Porcupine and Chandalar Rivers, that annually contribute another 9 million tons of sediment between the two main stem stations. In addition, the drainage area of the Yukon increases about 75 percent. The Eagle-Rampart reach includes Yukon Flats, an enormous tectonically controlled lowland, that can easily accept and store sediment.

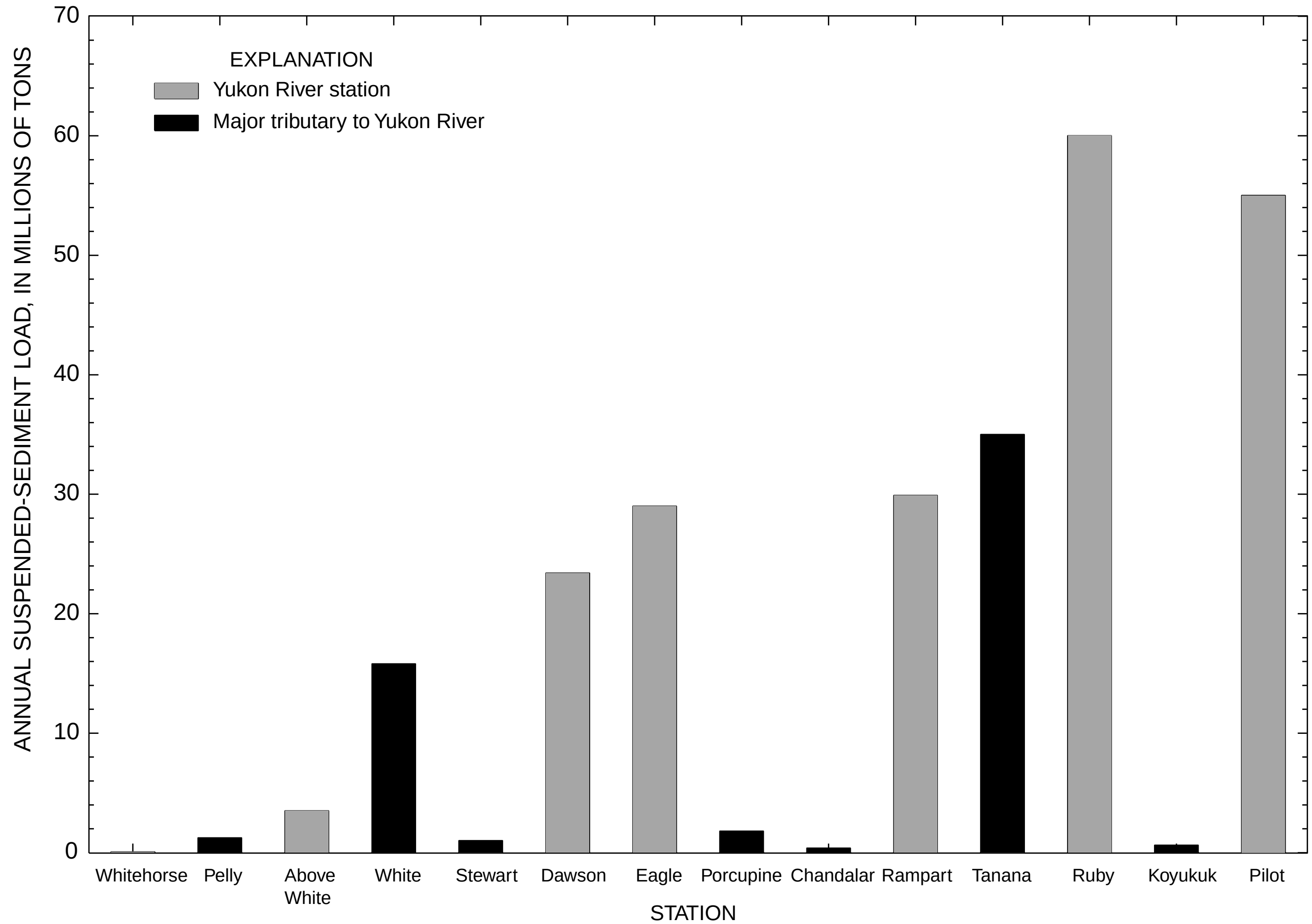


Figure 33. Annual suspended-sediment loads for 14 sites located in the Yukon River Basin.

In summary, the Yukon River system is depositing and storing an average annual net quantity of about 20 million tons of sediment between the principal montane sources and the sea, most likely on fringing flood plains and in braided reaches of the river. This net quantity represents a minimum because riverbank erosion is not included in the sediment budget. If bank erosion is, in fact, a significant contributor of sediment to the Yukon River, as it is in other large rivers (Dunne and others, 1998, for example), then a balanced budget would require even greater quantities of sediment to be leaving the river channel and being stored in the flood plains and meander bars.

Although the sediment load numbers are approximate and subject to large errors (they are based mostly on limited data), it is evident that a large proportion of the total sediment being transported out of the principal (mostly montane) source areas is not reaching the sea within the same year, decade, or even century. At least one-quarter, perhaps one-third, of the sediment is being deposited along the way, mostly as overbank sediment on the extensive flood plains that fringe large reaches of the Yukon River. Implications of this factor are enormous for the sequestration of organic carbon, contaminants, and other materials that are absorbed onto, or otherwise associated with, alluvial sediments.

Bedload

The only known area in the Yukon River Basin where bedload transport has been measured intensively is the Tanana River at Fairbanks. This site represents one of the few large rivers in the world where bedload has been measured directly by sampling rather than computed by standard formulas. At this site, bedload is equivalent to one or two percent of suspended load (fig. 34). This proportion is well within the error of suspended-load measurement and therefore is not usually included in any accounting of total sediment transport. Although bedload movement is important in the formation and stability of river channels, it is not a significant part of the overall sediment load.

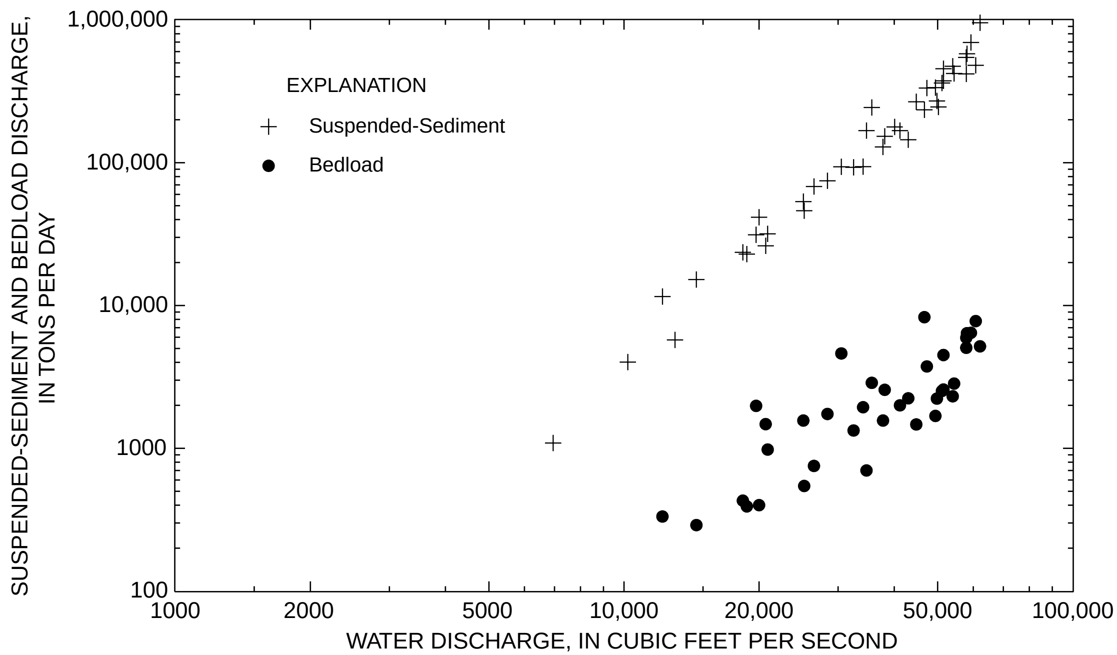


Figure 34. Suspended-sediment and bedload discharges measured in the Tanana River at Fairbanks, Alaska, 1977-82 (data from Burrows, 1981; Burrows and Harrold, 1983).

Water Quality

The water quality of the Yukon River Basin is important for many reasons. Residents who live along the main stem of the Yukon or its tributaries use the surface water for drinking. Salmon and other fish species require adequate water quality for their survival as does the abundant wildlife present in the basin.

Water-quality samples have been collected at more than 400 sites in the Yukon River Basin (fig. 35). In the Canadian part of the Yukon, Environment Canada began collecting water-quality data in 1980. Water chemistry samples were generally analyzed for nutrients and major ions. Some samples were analyzed for organic carbon and trace elements. Common field properties (water temperature, specific conductance, pH, and dissolved oxygen) were usually collected at the time of sampling. Currently, Environment Canada is not collecting water-quality samples in the Yukon River Basin.

In the Alaska part of the Yukon River Basin, water-quality sampling began in the 1950's. Many of the sites were sampled only once and some of the samples were collected by other Federal agencies or residents of a village who provided the results to the USGS. Before and during the construction of the trans-Alaska oil pipeline in the 1970's, water-quality samples were collected at many sites along the route of the pipeline (fig. 35). In the mid to late 1970's, when the USGS implemented the NASQAN program, three sites were established in the Yukon River Basin: the Yukon River at Eagle, the Tanana River at Nenana, and the Yukon River at Pilot Station. The site at Eagle was operated from 1978-79, whereas the sites at Pilot Station and Nenana were operated from 1976-96. Currently, no water-quality samples are collected routinely by the USGS in the Yukon River Basin.

To gain a basic understanding of the water-quality characteristics of streams in the Yukon River Basin, the existing water-quality data were analyzed. Before the interpretive analysis of the data began, efforts were made to assess the quality and type of the data. The water-quality data were not obtained using the same collection techniques at all sites. Laboratory analytical methods have improved in recent years, resulting in lower detection limits for some analytes. In addition, the distribution of sites is uneven and site density is greater in the eastern and southern part of the Yukon River Basin than in the northern and western parts (fig. 35). The set of chemical determinations was not uniform for all sites, the period of record differs for each site, and the data are not always distributed over the entire hydrologic cycle. Although somewhat subjective, only sites that had 10 or more samples were used in the analysis (fig. 36; table 11). Despite these limitations, the data provide an interesting description of both the main stem of the Yukon River and some its major tributaries.

Similar to the suspended-sediment data, records of all water-quality measurements are available in USGS publications (U.S. Geological Survey 1954-62, 1971, 1976, 1972-75, 1976-97). Data are also stored in electronic format in the USGS National Water Information System (NWIS). Water-quality data from the Canadian Yukon are available in electronic format from the world wide web (*http://www.ec.gc.ca/water/index.htm*).

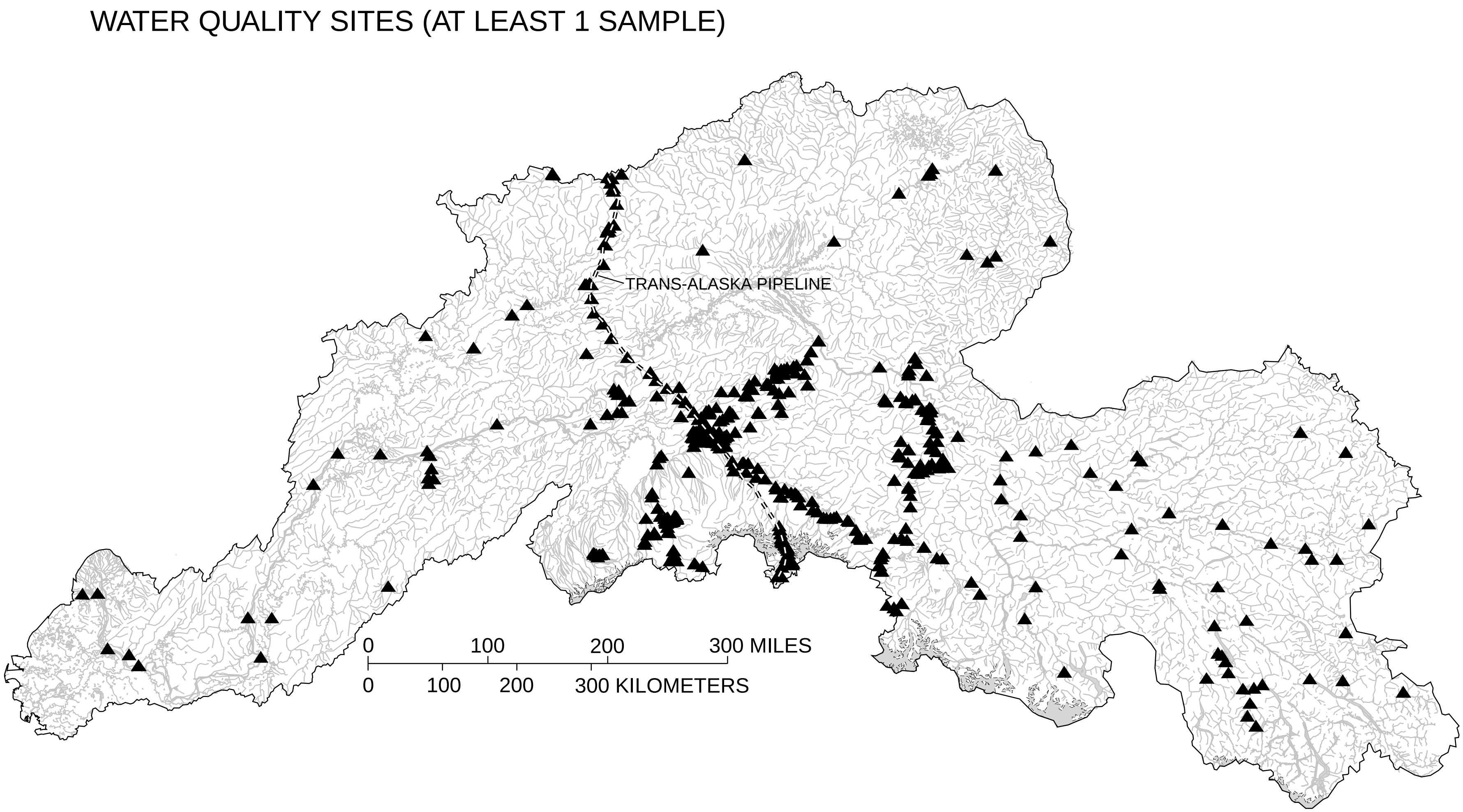


Figure 35. Location of water-quality sampling stations where one or more samples have been collected in the Yukon River Basin.

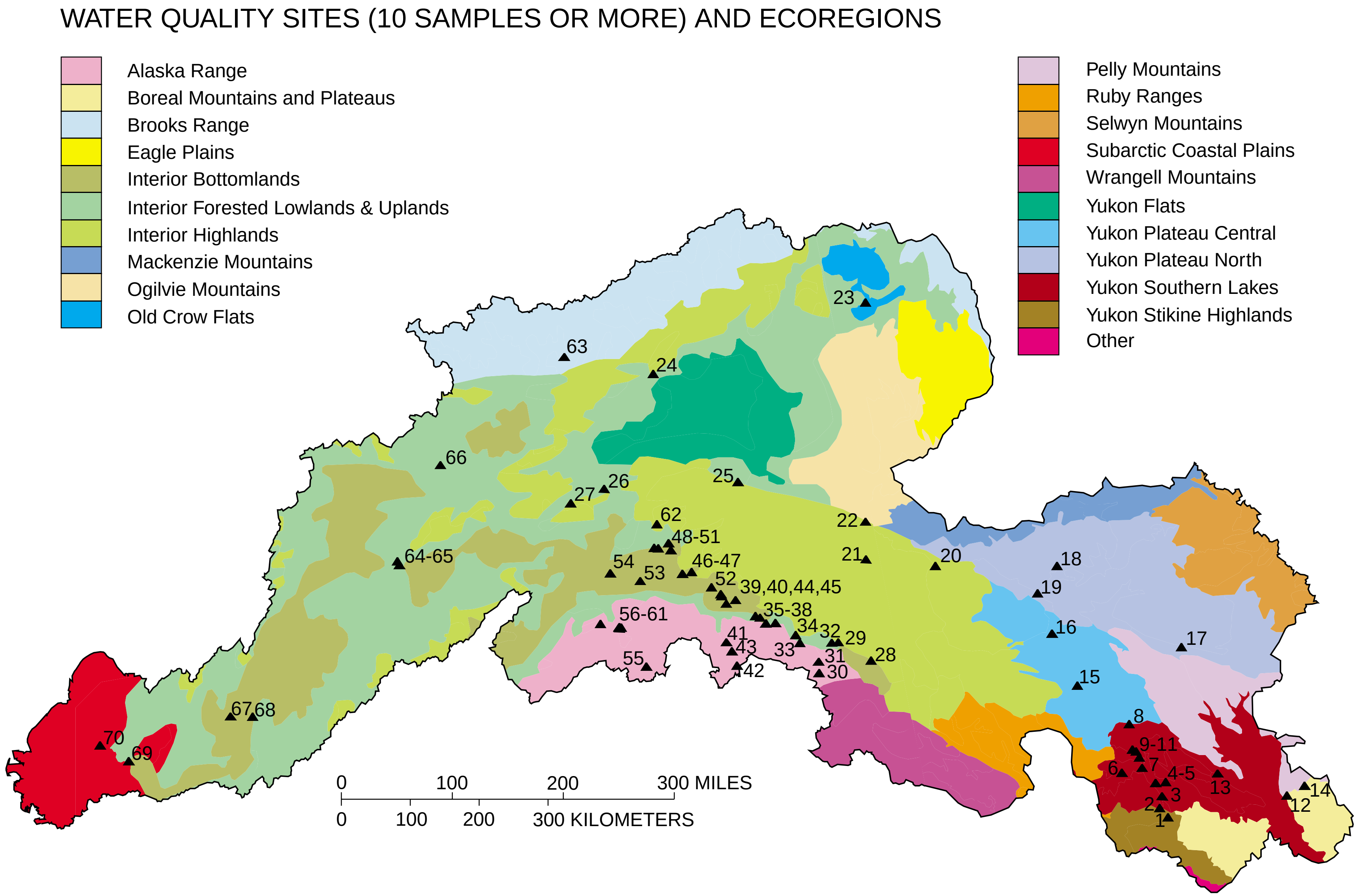


Figure 36. Location of water-quality sampling stations where 10 or more samples have been collected in the Yukon River Basin (see table 11 for station names).

Table 11. Water-quality stations in the Yukon River Basin with 10 or more years of record
[--, watershed drains more than two ecoregions]

Map No. (fig. 36)	USGS station No. or latitude/longitude	Station name	Primary ecoregions drained by watershed
1	15304850	Wheaton River near Carcross, YT	Yukon Stikine Highlands
2	6016421350156	Wheaton River at Annie Lake Road, YT	Yukon Stikine Highlands
3	6025001345300	Watson River at Annie Lake Road, YT	Yukon Southern Lakes
4	15305000	Yukon River at Whitehorse, YT	--
5	6036231345646	Wolf Creek at Alaska Highway near Whitehorse, YT	Yukon Southern Lakes
6	15305050	Takhini River near Whitehorse, YT	Yukon Southern Lakes
7	6050301351103	Takhini River at Klondike Highway, YT	Yukon Southern Lakes
8	15305100	Yukon River above Frank Creek, YT	--
9	6106151351730	Fox Creek at Klondike Highway, YT	Yukon Southern Lakes
10	6104001351300	Deep Creek at Klondike Highway, YT	Yukon Southern Lakes
11	6058451351030	Horse Creek at Klondike Highway, YT	Yukon Southern Lakes
12	15305150	Swift River near Swift River, BC	Boreal Mountains and Plateaus
13	15305250	Teslin River near Teslin, YT	Boreal Mountains and Plateaus
14	5958181311439	Partridge Creek at mile 734 Alaska Highway, YT	Boreal Mountains and Plateaus/Pelly Mountains
15	15305350	Yukon River at Carmacks, YT	--
16	15305420	Pelly River at Pelly Crossing, YT	Yukon Plateau North/ Selwyn Mountains
17	6211111331108	Blind Creek at Faro, YT	Yukon Plateau North/Pelly Mountains
18	6339281355530	Mayo River at Power Dam, YT	Yukon Plateau North/Pelly Mountains
19	15305620	Stewart River at Stewart Crossing, YT	Yukon Plateau North/ Selwyn Mountains/Mackenzie Mountains
20	15305698	Klondike River above Bonanza Creek near Dawson, YT	Yukon Plateau North/Mackenzie Mountains
21	15348000	Fortymile River near Steele Creek, AK	Interior Highlands
22	15356000	Yukon River at Eagle, AK	--
23	15388950	Porcupine River at Old Crow, YT	Eagle Plains/Old Crow Flats/Oglivie Mountains

Table 11. Water-quality stations in the Yukon River Basin with 10 or more years of record--Continued
[--, watershed drains more than two ecoregions]

Map No. (fig. 36)	USGS station No. or latitude/longitude	Station name	Primary ecoregions drained by watershed
24	15389500	Chandalar River near Venetie, AK	Brooks Range
25	15439800	Boulder Creek near Central, AK	Interior Highlands
26	15457800	Hess Creek near Livengood, AK	Interior Forest Lowlands and Uplands
27	15468000	Yukon River at Rampart, AK	--
28	15470000	Chisana River at Northway Junction, AK	Wrangell Mountains/Interior Bottomlands
29	15472000	Tanana River near Tok Junction, AK	Wrangell Mountains/Interior Bottomlands
30	15473500	Little Tok River near Tok Junction, AK	Alaska Range
31	15473900	Tok River on Slana Tok Highway near Tok Junction, AK	Alaska Range
32	15474000	Tok River near Tok Junction, AK	Alaska Range/ Interior Forest Lowlands and Uplands
33	15476000	Tanana River near Tanacross, AK	Wrangell Mountains/ Interior Bottomlands
34	15476100	Robertson River near Tanacross, AK	Alaska Range
35	15476300	Berry Creek near Dot Lake, AK	Alaska Range
36	15476500	Johnson River near Dot Lake, AK	Alaska Range
37	15476600	Little Gerstle River near Big Delta, AK	Alaska Range
38	15476700	Gerstle River near Big Delta, AK	Alaska Range
39	15477500	Clearwater Creek near Delta Junction, AK	Interior Bottomlands
40	15478000	Tanana River at Big Delta, AK	--
41	15478100	Delta River at Black Rapids, AK	Alaska Range
42	6312441453813	Phelan Creek at Richardson Highway near Paxson, AK	Alaska Range
43	6324121454355	Castner Creek near Black Rapids, AK	Alaska Range
44	6401251454325	Jarvis Creek near Delta Junction, AK	Alaska Range/Interior Bottomlands
45	6407351455000	Delta River near Big Delta, AK	Alaska Range/Interior Bottomlands
46	15484000	Salcha River near Salchaket, AK	Interior Highlands
47	6429101463900	Salcha River 8 mile above gage near Salchaket, AK	Interior Highlands

Table 11. Water-quality stations in the Yukon River Basin with 10 or more years of record--Continued
[--, watershed drains more than two ecoregions]

Map No. (fig. 36)	USGS station No. or latitude/longitude	Station name	Primary ecoregions drained by watershed
48	15493500	Chena River near North Pole, AK	Interior Highlands
49	15511000	Little Chena River near Fairbanks, AK	Interior Highlands/Interior Forest Lowlands and Uplands
50	15514000	Chena River at Fairbanks, AK	Interior Highlands/Interior Forest Lowlands and Uplands
51	6450001473430	Chena River at Fort Wainwright, AK	Interior Highlands/Interior Forest Lowlands and Uplands
52	15479500	Shaw Creek near Delta Junction, AK	Interior Highlands/Interior Bottomlands
53	15514500	Wood River near Fairbanks, AK	Alaska Range
54	15515500	Tanana River at Nenana, AK	Alaska Range
55	15515800	Seattle Creek near Cantwell, AK	Alaska Range
56	15518000	Nenana River near Healy, AK	Alaska Range
57	15518040	Nenana River at Healy, AK	Alaska Range
58	15518350	Teklanika River near Lignite, AK	Alaska Range
59	6351061485322	Healy Creek below Moody Creek near Healy, AK	Alaska Range
60	6351291485659	Nenana River at Power Plant Intake near Healy, AK	Alaska Range
61	6351321485658	Nenana River 300 feet below Power Plant Intake near Healy, AK	Alaska Range
62	15535000	Caribou Creek near Chatanika, AK	Interior Highlands
63	15564877	Wiseman Creek at Wiseman, AK	Brooks Range
64	15564600	Melozitna River near Ruby, AK	Interior Forest Lowlands and Uplands
65	15564800	Yukon River at Ruby, AK	--
66	15564900	Koyukuk River at Hughes, AK	Brooks Range/Interior Forest Lowlands and Uplands
67	6239301601120	Yukon River at Anvik, AK	--
68	15565300	Innoko River at Shageluk, AK	Interior Bottomlands
69	15565447	Yukon River at Pilot Station, AK	--
70	6205051634345	Yukon River at Mountain Village, AK	--

Yukon River Main Stem

Ten or more water-quality samples have been collected at 70 sites in the Yukon River Basin (fig. 36; table 11). Twenty-one sites are located in Canada and 49 in Alaska. Eight sites are located along the main stem of the Yukon River between Whitehorse, Yukon Territory, and Mountain Village, Alaska. Eleven sites are located along rivers that discharge directly into the Yukon River, although these sites are not necessarily located at the mouth. The Yukon River at Pilot Station has been the longest continuously monitored site on the main stem of the Yukon River.

The water of the main stem of the Yukon River has relatively low specific conductance ranging from about 60 to 257 μS/cm (table 12). The conductance increases downstream between Whitehorse, Yukon Territory and Rampart, Alaska, and decreases slightly from Rampart to Mountain Village. Conductance increases of about 50 percent between Carmacks, Yukon Territory and Eagle, Alaska, are most likely due to the input of dissolved solutes from three major tributaries between Carmacks and Eagle: the Pelly, White, and Stewart Rivers.

Specific conductance can also be used as a general measure of the dissolved ion concentration and the same pattern is reflected in both the major ion concentrations and the dissolved solids concentrations. Calcium and magnesium are the primary cations (table 12) with calcium accounting for about 70 percent of the cationic charge. Bicarbonate (calculated from alkalinity) and sulfate are the dominant anions, with bicarbonate accounting for about 80 percent of the anionic charge.

Nutrient concentrations in the Yukon River are generally low (less than 0.5 mg/L) throughout the river (table 12). Dissolved nitrate generally increases downstream with the highest concentrations measured at Pilot Station. Concentrations for total phosphorus were also relatively low (less than 0.5 mg/L). The highest concentrations and greatest variability for total phosphorus were measured at Eagle.

Total organic carbon concentrations (TOC) increase along the course of the lower Yukon, nearly doubling from a median concentration of 2.3 mg/L at Yukon River at Carmacks to 4.2 mg/L at Eagle and doubling again between Eagle and Pilot Station (table 12). Dissolved organic carbon (DOC) data are available only for the Yukon River at Pilot Station. DOC concentrations are slightly lower than TOC concentrations at Pilot Station and have a median concentration of 6.4 mg/L.

Total iron concentrations increase downstream in the Yukon River, from a median of 46 μg/L at Whitehorse to 5,900 μg/L at Pilot Station (table 12). The increase is greatest between Carmacks and Eagle where the median concentration increases by an order of magnitude from 280 to 2,200 μg/L. Dissolved iron data are available only for the Yukon River at Pilot Station where the concentration is an order-of-magnitude less than that for total iron (table 12), indicating that the most iron is transported on the sediment.

Total manganese concentrations in the Yukon River decrease about fourfold between Whitehorse and Frank Creek (table 12). From this point, the concentration increases downstream. As with iron, the dissolved manganese concentration is about an order-of-magnitude less than the total concentration, indicating that most of the manganese is transported either in the mineral or in the oxide form (table 12) with sediment.

Additional trace elements that show some trends are total barium, total strontium, total arsenic, and total aluminum. Values of total barium and total strontium nearly double between Carmacks and Eagle (table 12). Total arsenic gradually increases downstream from a median concentrations of 0.4 μg/L at Whitehorse to 3 μg/L at Pilot Station. Total aluminum concentrations at Carmacks are three times higher than those at Whitehorse.

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River

[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Specific conductance, microsiemens per centimeter at 25 degrees Celsius						
4	At Whitehorse, YT	1155	79	60	88	94
8	Above Frank Creek, YT	21	100	96	100	103
15	At Carmacks, YT	1208	144	125	140	153
22	At Eagle, AK (Canadian)	202	214	188	213	235
22	At Eagle, AK (USGS)	81	213	187	204	231
27	At Rampart, AK	120	230	207	234	257
65	At Ruby, AK	106	216	189	217	236
69	At Pilot Station, AK	111	209	173	202	220
70	At Mountain Village, AK	18	198	108	198	203
Dissolved solids, residue on evaporation at 180 degrees Celsius, milligrams per liter						
4	At Whitehorse, YT	144	78	58	67	87
8	Above Frank Creek, YT	17	62	60	60	60
15	At Carmacks, YT	553	104	84	96	113
22	At Eagle, AK (Canadian)	144	153	133	151	170
22	At Eagle, AK (USGS)	69	130	113	143	143
27	At Rampart, AK	118	136	123	138	153
65	At Ruby, AK	107	126	108	127	138
69	At Pilot Station, AK	105	123	102	119	130
70	At Mountain Village, AK	17	113	104	112	118

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
pH, standard units						
4	At Whitehorse, YT	1160	7.6	7.3	7.7	7.9
8	Above Frank Creek, YT	17	7.8	7.8	7.9	7.9
15	At Carmacks, YT	113	7.9	7.6	7.9	8.1
22	At Eagle, AK (Canadian)	46	7.9	7.8	8.0	8.1
22	At Eagle, AK (USGS)	75	7.6	7.3	7.6	7.9
27	At Rampart, AK	115	7.5	7.4	7.6	7.8
65	At Ruby, AK	103	7.7	7.6	7.7	8.0
69	At Pilot Station, AK	106	7.5	7.3	7.6	7.8
70	At Mountain Village, AK	17	7.1	6.8	6.9	7.2
Water temperature, degrees Celsius						
4	At Whitehorse, YT	1080	12.5	2.1	14	21.6
8	Above Frank Creek, YT	18	6.2	1	3	12
15	At Carmacks, YT	1055	12.5	4	13	21.3
22	At Eagle, AK (Canadian)	292	11.9	1	13.8	21.1
22	At Eagle, AK (USGS)	49	9.6	6.5	11.5	14
27	At Rampart, AK	25	6.9	0	6.0	12.0
65	At Ruby, AK	39	7.8	0.5	7.0	13.0
69	At Pilot Station, AK	91	9.1	0	10.5	14.5
70	At Mountain Village, AK	--	--	--	--	--

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River--Continued

[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data 25	50	75
Dissolved-oxygen concentration, milligrams per liter						
4	At Whitehorse, YT	--	--	--	--	--
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	--	--	--	--	--
22	At Eagle, AK (Canadian)	--	--	--	--	--
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	68	8.1	7.7	9.1	10.1
70	At Mountain Village, AK	--	--	--	--	--
Calcium concentration, milligrams per liter						
4	At Whitehorse, YT	459	13.8	13.3	13.9	14.3
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	412	19.7	18.1	19.6	21.1
22	At Eagle, AK (Canadian)	106	31	28	30	33
22	At Eagle, AK (USGS)	69	31	26	28	34
27	At Rampart, AK	118	31	28	32	35
65	At Ruby, AK	107	32	27	32	36
69	At Pilot Station, AK	109	31	25	29	32
70	At Mountain Village, AK	17	28	25	28	30

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data 25	50	75
Magnesium concentration, milligrams per liter						
4	At Whitehorse, YT	100	2.4	2.3	2.4	2.5
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	79	4.3	3.6	4	4.4
22	At Eagle, AK (Canadian)	106	7.8	7	8.2	9.3
22	At Eagle, AK (USGS)	69	8.0	6.5	7.4	8.4
27	At Rampart, AK	118	8.8	7.5	8.4	10
65	At Ruby, AK	108	6.2	5.1	6.3	7.3
69	At Pilot Station, AK	109	6.7	5.0	6.4	7.6
70	At Mountain Village, AK	17	5.5	5.1	5.4	5.7
Sodium concentration, milligrams per liter						
4	At Whitehorse, YT	460	1.1	1	1.1	1.1
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	412	1.6	1.4	1.6	1.7
22	At Eagle, AK (Canadian)	110	2.6	2.3	2.5	2.7
22	At Eagle, AK (USGS)	53	2.6	2.2	2.4	2.8
27	At Rampart, AK	118	3.3	2.6	3.2	3.9
65	At Ruby, AK	108	2.6	2.1	2.7	3.1
69	At Pilot Station, AK	109	2.5	2.0	2.5	3.0
70	At Mountain Village, AK	18	3.3	2.3	3.0	3.6

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River--Continued
[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Potassium concentration, milligrams per liter						
4	At Whitehorse, YT	460	0.6	0.6	0.6	0.7
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	412	0.8	0.6	0.7	0.8
22	At Eagle, AK (Canadian)	108	1.3	0.97	1.1	1.3
22	At Eagle, AK (USGS)	52	1.4	0.95	1.2	1.7
27	At Rampart, AK	118	1.1	1.0	1.1	1.3
65	At Ruby, AK	108	1.2	1.1	1.2	1.4
69	At Pilot Station, AK	109	1.3	1.0	1.2	1.4
70	At Mountain Village, AK	18	1.0	0.7	0.95	1.3
Total alkalinity, as $CaCO_3$, milligrams per liter						
4	At Whitehorse, YT	633	40	37	41	42
8	Above Frank Creek, YT	18	43	41	42	43
15	At Carmacks, YT	648	62	57	62	66
22	At Eagle, AK (Canadian)	197	93	79	88	102
22	At Eagle, AK (USGS)	73	89	75	82	99
27	At Rampart, AK	108	88	79	89	96
65	At Ruby, AK	116	91	77	91	101
69	At Pilot Station, AK	87	83	64	76	84
70	At Mountain Village, AK	18	76	66	76	83

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Sulfate concentration, milligrams per liter						
4	At Whitehorse, YT	634	5.8	5.4	5.7	6.1
8	Above Frank Creek, YT	18	5.6	5.6	5.9	6.2
15	At Carmacks, YT	648	8.1	7	8	9.1
22	At Eagle, AK (Canadian)	197	25	22	25	28
22	At Eagle, AK (USGS)	70	26	21	24	29
27	At Rampart, AK	118	29	25	29	34
65	At Ruby, AK	116	20	17	21	23
69	At Pilot Station, AK	107	22	19	22	26
70	At Mountain Village, AK	18	20	18	22	24
Chloride concentration, milligrams per liter						
4	At Whitehorse, YT	634	0.3	0.2	0.2	0.3
8	Above Frank Creek, YT	18	0.3	0.3	0.3	0.3
15	At Carmacks, YT	648	0.5	0.3	0.3	0.5
22	At Eagle, AK (Canadian)	197	0.9	0.6	0.7	0.9
22	At Eagle, AK (USGS)	69	1.1	0.5	0.8	1.1
27	At Rampart, AK	101	1.2	0.8	1.0	1.4
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	110	1.1	0.9	1.0	1.2
70	At Mountain Village, AK	18	1.2	1.0	1.0	1.5

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River--Continued

[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Dissolved silica concentration, milligrams per liter						
4	At Whitehorse, YT	160	1.5	1.4	1.4	1.6
8	Above Frank Creek, YT	18	1.7	1.6	1.7	1.8
15	At Carmacks, YT	215	2.8	2.6	2.8	3.04
22	At Eagle, AK (Canadian)	197	3.6	3.3	3.6	4.0
22	At Eagle, AK (USGS)	69	7.3	6.2	7.2	8.1
27	At Rampart, AK	118	6.6	5.8	6.5	7.6
65	At Ruby, AK	108	7.1	6.1	7.1	8.1
69	At Pilot Station, AK	109	7.5	5.9	6.9	8.1
70	At Mountain Village, AK	17	7.4	6.8	7.0	7.5
Dissolved nitrate plus nitrite concentration, as nitrogen, milligrams per liter						
4	At Whitehorse, YT	2074	0.08	0.006	0.017	0.031
8	Above Frank Creek, YT	47	0.019	0.006	0.022	0.031
15	At Carmacks, YT	2070	0.06	0.024	0.05	0.07
22	At Eagle, AK (Canadian)	661	0.21	0.046	0.093	0.17
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	62	0.15	0.10	0.10	0.20
70	At Mountain Village, AK	--	--	--	--	--

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total phosphorus concentration, as phosphorus, milligrams per liter						
4	At Whitehorse, YT	1991	0.008	0.004	0.005	0.009
8	Above Frank Creek, YT	50	0.019	0.003	0.004	0.006
15	At Carmacks, YT	1984	0.03	0.008	0.014	0.032
22	At Eagle, AK (Canadian)	596	0.28	0.013	0.092	0.412
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	84	0.02	0.01	0.02	0.02
70	At Mountain Village, AK	--	--	--	--	--
Total organic carbon, as carbon, milligrams per liter						
4	At Whitehorse, YT	515	1.9	1.0	1.4	2.2
8	Above Frank Creek, YT	17	1.7	0.8	1.0	1.8
15	At Carmacks, YT	531	3.0	1.5	2.3	3.6
22	At Eagle, AK (Canadian)	154	5.4	2.3	4.2	6.9
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	15	10.5	6.7	8.4	14
70	At Mountain Village, AK	--	--	--	--	--

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River--Continued

[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total iron concentration, as iron, micrograms per liter						
4	At Whitehorse, YT	428	102	25	46	100
8	Above Frank Creek, YT	17	54	28	42	48
15	At Carmacks, YT	449	646	116	280	712
22	At Eagle, AK (Canadian)	141	6812	100	2200	9620
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	27	7620	1600	5900	11000
70	At Mountain Village, AK	--	--	--	--	--
Total manganese, as manganese, micrograms per liter						
4	At Whitehorse, YT	428	6.5	2	4	9.2
8	Above Frank Creek, YT	17	2.1	1.2	1.7	2.7
15	At Carmacks, YT	449	19	5	10	22
22	At Eagle, AK (Canadian)	141	155	5	69	240
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	27	206	120	160	280
70	At Mountain Village, AK	--	--	--	--	--

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Dissolved iron, as iron, micrograms per liter						
4	At Whitehorse, YT	--	--	--	--	--
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	--	--	--	--	--
22	At Eagle, AK (Canadian)	--	--	--	--	--
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	76	238	90	195	310
70	At Mountain Village, AK	--	--	--	--	--
Dissolved manganese, as manganese, micrograms per liter						
4	At Whitehorse, YT	--	--	--	--	--
8	Above Frank Creek, YT	--	--	--	--	--
15	At Carmacks, YT	--	--	--	--	--
22	At Eagle, AK (Canadian)	--	--	--	--	--
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	76	46	10	16.5	71
70	At Mountain Village, AK	--	--	--	--	--

Table 12. Summary statistics for selected properties and constituents of surface-water samples from stations along the Yukon River--Continued
[--, no data]

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total barium, as barium, micrograms per liter						
4	At Whitehorse, YT	175	27	26	27	28
8	Above Frank Creek, YT	17	26	24	26	26
15	At Carmacks, YT	238	38	33	35	38
22	At Eagle, AK (Canadian)	80	104	57	86	133
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	--	--	--	--	--
70	At Mountain Village, AK	--	--	--	--	--
Total strontium, as strontium, micrograms per liter						
4	At Whitehorse, YT	175	74	73	74	77
8	Above Frank Creek, YT	17	79	76	79	81
15	At Carmacks, YT	238	95	87	96	103
22	At Eagle, AK (Canadian)	141	168	152	167	194
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	--	--	--	--	--
70	At Mountain Village, AK	--	--	--	--	--

Map No. (fig. 36)	Yukon River station name	Number of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total arsenic, as arsenic, micrograms per liter						
4	At Whitehorse, YT	374	0.4	0.4	0.4	0.5
8	Above Frank Creek, YT	17	0.3	0.3	0.3	0.3
15	At Carmacks, YT	398	0.4	0.4	0.5	0.6
22	At Eagle, AK (Canadian)	144	2.6	0.4	1.2	3.6
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	27	4	2	3	6
70	At Mountain Village, AK	--	--	--	--	--
Total aluminum, as aluminum, micrograms per liter						
4	At Whitehorse, YT	175	67	12	22	37
8	Above Frank Creek, YT	17	51	26	39	48
15	At Carmacks, YT	238	408	69	178	480
22	At Eagle, AK (Canadian)	80	4458	70	199	6910
22	At Eagle, AK (USGS)	--	--	--	--	--
27	At Rampart, AK	--	--	--	--	--
65	At Ruby, AK	--	--	--	--	--
69	At Pilot Station, AK	--	--	--	--	--
70	At Mountain Village, AK	--	--	--	--	--

The chemistry of the Yukon River reflects the chemical inputs from its major tributaries. The waters of the tributaries to the Yukon are predominantly calcium magnesium bicarbonate waters with specific conductance ranging from 54 to 373 µS/cm (table 13). Of the 11 tributaries with water-quality data, 6 sites have data for constituents other than the major ions. These limited data show that nitrate concentrations are highest in the Tanana and Porcupine Rivers (table 13). The Tanana River also has the highest total-phosphorus concentrations with a median concentration of 0.17 mg/L phosphorous. Median TOC concentrations range from 1.2 mg/L for the Stewart and Klondike Rivers to 5.5 mg/L for the Porcupine River (table 13). Concentrations of both total iron and total manganese, with median concentrations of 7,000 and 200 µg/L respectively (table 13), are highest in the Tanana River, perhaps reflecting the presence of glaciers.

Table 13. Summary statistics for selected properties and constituents of surface-water samples from tributaries of the Yukon River
[--, no data]

Map No. (fig. 36)	Stream-gaging station	No. of analyses	Mean	Percentile values calculated from the data		
				25	50	75
	Specific conductance, microsiemens per centimeter at 25 degrees Celsius					
13	Teslin River near Teslin, YT	124	127	123	129	136
16	Pelly River at Pelly Crossing, YT	46	274	237	288	361
19	Stewart River at Stewart Crossing, YT	59	306	277	322	370
20	Klondike River above Bonanza Creek near Dawson, YT	86	253	201	245	295
21	Fortymile River near Steele Creek, AK	13	145	119	149	166
23	Porcupine River at Old Crow, YT	89	262	191	276	373
24	Chandalar River near Venetie, AK	28	221	189	225	252
54	Tanana River at Nenana, AK	213	243	211	235	284
64	Melozitna River near Ruby, AK	28	86	54	72	127
66	Koyukuk River at Hughes, AK	43	213	171	215	258
68	Innoko River at Shageluk, AK	16	101	80	97	139
	Calcium concentration, milligrams per liter					
13	Teslin River near Teslin, YT	86	18	17	18	18
16	Pelly River at Pelly Crossing, YT	46	38	32	41	46
19	Stewart River at Stewart Crossing, YT	59	43	38	44	53
20	Klondike River above Bonanza Creek near Dawson, YT	85	35	29	34	41
21	Fortymile River near Steele Creek, AK	11	20	16	21	22
23	Porcupine River at Old Crow, YT	89	40	27	41	58
24	Chandalar River near Venetie, AK	16	39	33	37	50
54	Tanana River at Nenana, AK	151	35	29	34	43
64	Melozitna River near Ruby, AK	18	10	6.4	8.7	16
66	Koyukuk River at Hughes, AK	23	29	24	27	35
68	Innoko River at Shageluk, AK	16	13	9.8	13	17

Table 13. Summary statistics for selected properties and constituents of surface-water samples from tributaries of the Yukon River--Continued

[--, no data]

Map No. (fig. 36)	Stream-gaging station	No. of analyses	Mean	Percentile values calculated from the data		
				25	50	75
	Magnesium concentration, milligrams per liter					
13	Teslin River near Teslin, YT	63	4.6	4.6	4.8	4.9
16	Pelly River at Pelly Crossing, YT	46	12	10	12	15
19	Stewart River at Stewart Crossing, YT	59	13	12	15	16
20	Klondike River above Bonanza Creek near Dawson, YT	85	11	7.9	9.9	13
21	Fortymile River near Steele Creek, AK	11	5.8	4.8	5.5	6.7
23	Porcupine River at Old Crow, YT	89	8.6	6.3	9.3	11
24	Chandalar River near Venetie, AK	16	5.8	4.8	6.2	7.1
54	Tanana River at Nenana, AK	151	7.4	6.0	7.2	9.0
64	Melozitna River near Ruby, AK	18	3.4	2.2	2.6	4.9
66	Koyukuk River at Hughes, AK	23	7.7	6.2	7.4	9.0
68	Innoko River at Shageluk, AK	16	3.5	2.6	3.7	4.3
	Total alkalinity, as $CaCO_3$, milligrams per liter					
13	Teslin River near Teslin, YT	119	59	55	58	59
16	Pelly River at Pelly Crossing, YT	46	99	79	104	117
19	Stewart River at Stewart Crossing, YT	59	100	81	98	129
20	Klondike River above Bonanza Creek near Dawson, YT	85	82	66	79	95
21	Fortymile River near Steele Creek, AK	13	50	43	52	56
23	Porcupine River at Old Crow, YT	89	98	51	82	156
24	Chandalar River near Venetie, AK	16	107	90	105	128
54	Tanana River at Nenana, AK	139	96	81	92	118
64	Melozitna River near Ruby, AK	19	36	21	29	57
66	Koyukuk River at Hughes, AK	24	86	57	78	79
68	Innoko River at Shageluk, AK	15	41	31	41	55

Map No. (fig. 36)	Stream-gaging station	No. of analyses	Mean	Percentile values calculated from the data		
				25	50	75
	Sulfate concentration, milligrams per liter					
13	Teslin River near Teslin, YT	33	6.2	5.6	6.0	6.5
16	Pelly River at Pelly Crossing, YT	46	41	34	46	50
19	Stewart River at Stewart Crossing, YT	59	58	50	63	68
20	Klondike River above Bonanza Creek near Dawson, YT	85	47	37	46	53
21	Fortymile River near Steele Creek, AK	11	24	17	21	32
23	Porcupine River at Old Crow, YT	89	32	27	34	39
24	Chandalar River near Venetie, AK	16	16	15	16	20
54	Tanana River at Nenana, AK	155	29	26	30	32
64	Melozitna River near Ruby, AK	18	7.8	3.9	6.5	10
66	Koyukuk River at Hughes, AK	23	26	19	25	29
68	Innoko River at Shageluk, AK	15	7.4	5.2	7.0	10
	Dissolved nitrate plus nitrate concentration, as nitrogen, milligrams per liter					
13	Teslin River near Teslin, YT	427	0.012	0.017	0.041	0.059
16	Pelly River at Pelly Crossing, YT	77	0.038	0.012	0.028	0.096
19	Stewart River at Stewart Crossing, YT	91	0.086	0.04	0.07	0.12
20	Klondike River above Bonanza Creek near Dawson, YT	84	0.109	0.017	0.05	0.17
21	Fortymile River near Steele Creek, AK	--	--	--	--	--
23	Porcupine River at Old Crow, YT	109	0.100	0.02	0.07	0.21
24	Chandalar River near Venetie, AK	--	--	--	--	--
54	Tanana River at Nenana, AK	39	0.18	0.11	0.15	0.2
64	Melozitna River near Ruby, AK	--	--	--	--	--
66	Koyukuk River at Hughes, AK	--	--	--	--	--
68	Innoko River at Shageluk, AK	--	--	--	--	--

Table 13. Summary statistics for selected properties and constituents of surface-water samples from tributaries of the Yukon River--Continued

[--, no data]

Map No. (fig. 36)	Stream-gaging station	No. of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total phosphorus concentration, as phosphorus, milligrams per liter						
13	Teslin River near Teslin, YT	420	0.013	0.006	0.008	0.013
16	Pelly River at Pelly Crossing, YT	100	0.114	0.009	0.022	0.050
19	Stewart River at Stewart Crossing, YT	115	0.111	0.005	0.020	0.076
20	Klondike River above Bonanza Creek near Dawson, YT	151	0.034	0.003	0.005	0.015
21	Fortymile River near Steele Creek, AK	--	--	--	--	--
23	Porcupine River at Old Crow, YT	166	0.017	0.002	0.007	0.018
24	Chandalar River near Venetie, AK	--	--	--	--	--
54	Tanana River at Nenana, AK	80	0.240	0.12	0.17	0.2
64	Melozitna River near Ruby, AK	--	--	--	--	--
66	Koyukuk River at Hughes, AK	--	--	--	--	--
68	Innoko River at Shageluk, AK	--	--	--	--	--
Total organic carbon, as carbon, milligrams per liter						
13	Teslin River near Teslin, YT	15	4.68	3.3	4.1	4.7
16	Pelly River at Pelly Crossing, YT	44	4.5	1.7	3.2	4.9
19	Stewart River at Stewart Crossing, YT	59	2.1	0.5	1.2	2
20	Klondike River above Bonanza Creek near Dawson, YT	84	3.3	0.5	1.2	2.3
21	Fortymile River near Steele Creek, AK	--	--	--	--	--
23	Porcupine River at Old Crow, YT	85	6.3	0.5	5.5	10.9
24	Chandalar River near Venetie, AK	--	--	--	--	--
54	Tanana River at Nenana, AK	14	5.8	2.8	5.3	7.5
64	Melozitna River near Ruby, AK	--	--	--	--	--
66	Koyukuk River at Hughes, AK	--	--	--	--	--
68	Innoko River at Shageluk, AK	--	--	--	--	--

Map No. (fig. 36)	Stream-gaging station	No. of analyses	Mean	Percentile values calculated from the data		
				25	50	75
Total iron concentration, as iron, micrograms per liter						
13	Teslin River near Teslin, YT	109	101	35	57	106
16	Pelly River at Pelly Crossing, YT	46	2047	187	420	966
19	Stewart River at Stewart Crossing, YT	59	1860	103	538	13200
20	Klondike River above Bonanza Creek near Dawson, YT	97	538	22	68	140
21	Fortymile River near Steele Creek, AK	--	--	--	--	--
23	Porcupine River at Old Crow, YT	86	567	44	148	744
24	Chandalar River near Venetie, AK	--	--	--	--	--
54	Tanana River at Nenana, AK	19	13613	810	7000	20000
64	Melozitna River near Ruby, AK	--	--	--	--	--
66	Koyukuk River at Hughes, AK	--	--	--	--	--
68	Innoko River at Shageluk, AK	--	--	----	----	--
Total manganese, as manganese, micrograms per liter						
13	Teslin River near Teslin, YT	86	5.0	3.7	9.0	18
16	Pelly River at Pelly Crossing, YT	109	72	12	21	37
19	Stewart River at Stewart Crossing, YT	59	60	16	26	39
20	Klondike River above Bonanza Creek near Dawson, YT	97	24	7.7	9.4	14
21	Fortymile River near Steele Creek, AK	--	--	--	--	--
23	Porcupine River at Old Crow, YT	86	14	3.7	9.0	19
24	Chandalar River near Venetie, AK	--	--	--	--	--
54	Tanana River at Nenana, AK	19	362	130	200	350
64	Melozitna River near Ruby, AK	--	--	--	--	--
66	Koyukuk River at Hughes, AK	--	--	--	--	--
68	Innoko River at Shageluk, AK	--	--	--	--	-

Temporal Variations in Water Quality

The rivers of the Yukon Basin are generally ice covered from mid-to-late October to mid-to-late May. During this period of low flow, glacial and surface runoff is minimal to non-existent and baseflow predominates. Comparing the water-quality data collected during periods of ice cover with the water-quality data collected during open-water periods indicated a slight basinwide increase in median specific conductance under ice compared to that in the open water (fig. 37). Specific conductance increases down the Yukon River from Whitehorse to Pilot Station during both the open-water and ice-covered periods (fig. 37).

Substantial differences are found between the two seasons at the Yukon River at Pilot Station (table 14). Concentrations of calcium, magnesium, silica, and bicarbonate are almost twice as high during ice cover than during open water (probably due to ion exclusion under freezing conditions). However, sulfate concentrations do not increase significantly. Dissolved oxygen decreases significantly between the two seasons with a median open-water and under-ice dissolved oxygen concentrations of 9.3 and 2.7 mg/L, respectively. The median DOC concentration also decreases under ice from 7.5 to 4.3 mg/L. The trace elements total iron, dissolved iron, and total arsenic decreased under ice conditions, but concentrations of the trace elements dissolved manganese and dissolved strontium increased under ice (table 14).

View of the water-worked basin of the Yukon Flats ecoregion, which is covered by numerous thaw and oxbow lakes. Annual precipitation is insufficient to maintain many lakes, which are replenished by yearly flooding of the Yukon River (center, flowing from east to west).

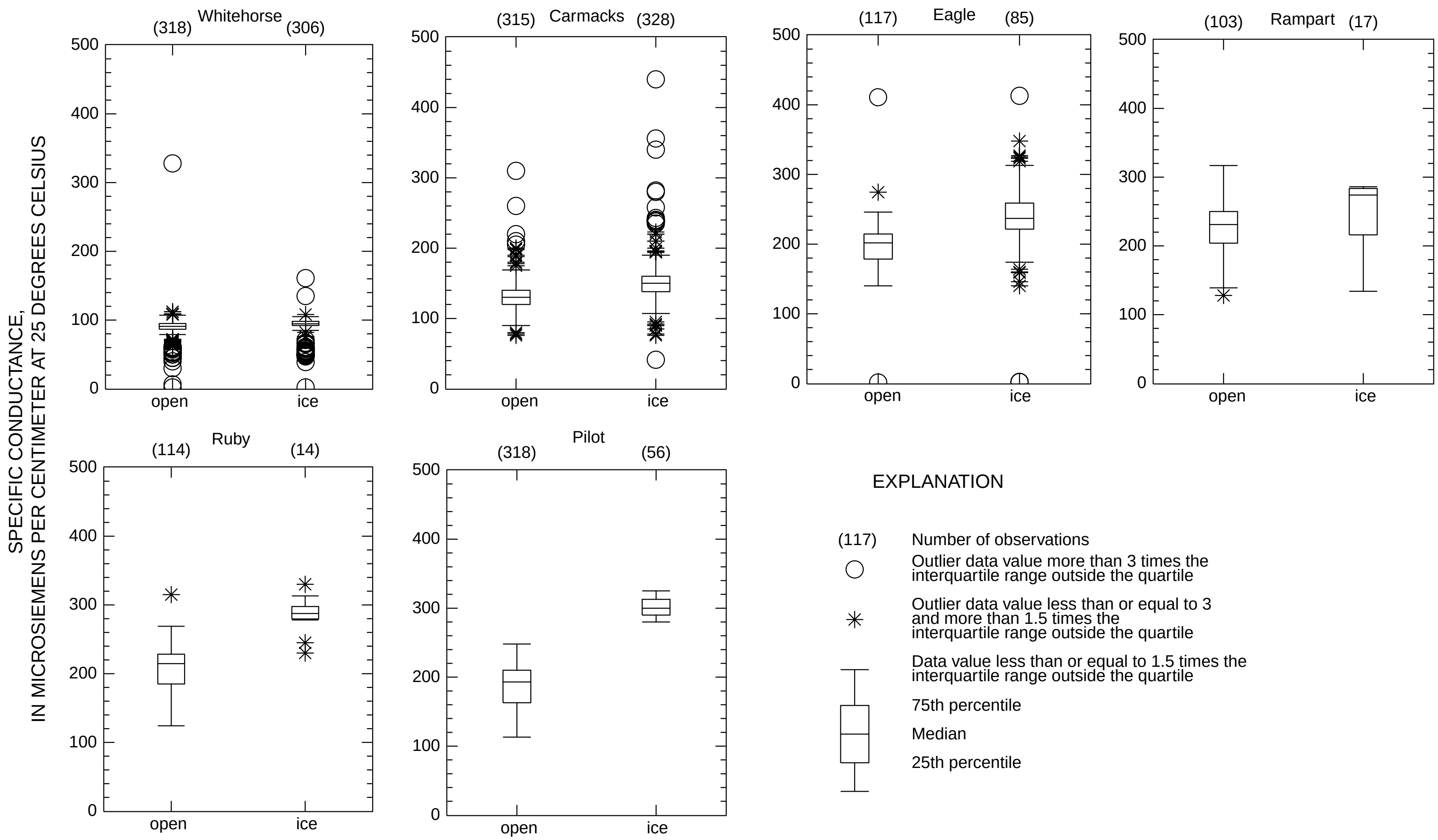


Figure 37. Boxplots of specific conductance from samples taken during open water and under ice cover on the Yukon River.

Table 14. Comparison of samples taken during open water and under ice cover, Yukon River at Pilot Station (map No. 69, fig. 36)

[mg/L, milligram per liter; µg/L, microgram per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Property or constituent (unit)	Season	No. samples	Mean	Median	[a]Q_1	[b]Q_3	[c]p
Suspended sediment (mg/L)	Ice	19	5.8	5	4	7	0.0001
	Open	48	309	279	201	386	
Specific conductance (µS/cm)	Ice	24	299	299	289	305	0.0001
	Open	87	184	190.6	163.5	210	
pH	Ice	23	7.1	7.1	7.0	7.3	0.0001
	Open	83	7.6	7.7	7.5	7.8	
Dissolved oxygen (mg/L)	Ice	17	3.4	2.7	2.4	3.6	0.0001
	Open	51	9.6	9.3	8.7	10.3	
Alkalinity (mg/L as $CaCO_3$)	Ice	17	139	140	134	144	0.0001
	Open	70	70	73.5	61	82	
Calcium (mg/L as Ca)	Ice	23	45.4	46	45	47	0.0001
	Open	86	26.9	27	24	30	
Magnesium (mg/L as Mg)	Ice	23	10.1	10	9.9	11	0.0001
	Open	86	5.8	6.1	4.4	6.8	
Sulfate (mg/L as SO_4)	Ice	22	21.8	21.2	20.5	24	0.3999
	Open	85	23.1	23	18	27	
Silica (mg/L as SiO_2)	Ice	23	12	12	12	13	0.0001
	Open	86	6.3	6.7	5.6	7.1	
Arsenic, total (µg/L as As)	Ice	7	1.6	2	1	2	0.0011
	Open	20	4.7	4	3	6	
Iron, total (µg/L as Fe)	Ice	7	1419	1500	1300	1500	0.0001
	Open	20	9791	8332	4850	13000	
Iron, dissolved (µg/L as Fe)	Ice	19	201	90	60	230	0.0216
	Open	57	250	220	140	310	
Manganese, total (µg/L as Mn)	Ice	7	138.6	130	120	150	0.1077
	Open	20	230	200	130	325	
Manganese, dissolved (µg/L as Mn)	Ice	19	133	130	110	170	0.0001
	Open	57	17.8	10	10	20	
Strontium, dissolved (µg/L as Sr)	Ice	13	189	190	190	190	0.0001
	Open	37	106.8	110	89	120	
Nitrate + nitrite, dissolved (mg/L as N)	Ice	17	0.21	0.21	0.20	0.23	0.0001
	Open	45	0.12	0.1	0.11	0.1	
Phosphorus, total (mg/L as P)	Ice	24	0.02	0.02	0.01	0.02	0.0001
	Open	60	0.21	0.18	0.095	0.295	
Dissolved organic carbon (mg/L as C)	Ice	4	4.4	4.3	2.9	5.9	0.0511
	Open	15	9.46	7.5	5.1	13	

[a]25^{th} percentile
[b]75^{th} percentile
[c]The attained significance level of the data

Spatial Variations in Water Quality

In the Yukon River Basin, most, if not all, of the chemical composition of the water is influenced by natural features such as geology, soils, and climate. One of the central concepts of ecoregions is to define areas that have these same natural features. As a means of describing the water quality of the Yukon River Basin, both spatially and in relation to the natural features, the existing water-quality data were grouped and analyzed within the ecoregions of the Yukon River Basin. Although there is not sufficient data for statistical analysis, some general observations can be made.

The primary ecoregions composing the watershed area of the rivers in the Yukon River Basin (fig. 16) where water-quality data are available were determined (table 11). Drainage basins for 42 sites reside in only one ecoregion. Watershed areas for the remaining 29 sites reside in two or more ecoregions. Water-quality data for these 29 sites were not used in this analysis. Of the 42 sites having drainage basins in only one ecoregion, 8 of the 20 ecoregions of the Yukon River Basin are represented: Yukon Stikine Highlands, Yukon Southern Lakes, Boreal Mountains and Plateaus, Interior Highlands, Interior Bottomlands, Brooks Range, Alaska Range, and Interior Forested Lowlands and Uplands. Nineteen sites received drainage from the Alaska Range, seven from the Yukon Southern Lakes, six from the Interior Highlands, and two each from the other five ecoregions.

Calcium is the dominant cation in waters from all ecoregions and bicarbonate is the dominant anion in all ecoregions except the Boreal Mountains and Plateaus ecoregion, where sulfate is the main anion (table 15). The major ion composition for eight ecoregions is consistent with the dissolution of carbonate minerals, such as calcite and dolomite, with a greater contribution from sulfate-containing minerals, such as gypsum, in the Boreal Mountains and Plateaus ecoregion.

Nutrient concentrations were low in all ecoregions evaluated for the Yukon River Basin. Dissolved nitrate concentrations are higher in the Interior Bottomlands, Interior Highlands, and the Alaska Range ecoregions than in the Yukon Stikine Highlands, the Yukon Southern Lakes, and the Boreal Mountains and Plateaus ecoregions of the upper basin (table 15). Total phosphate concentrations were lower in the Yukon Stikine Highlands relative to the other ecoregions.

The TOC concentrations were higher in the Interior Highlands and the Boreal Mountains and Plateaus ecoregions than in the Yukon Stikine Highlands, the Yukon Southern Lakes, and Alaska Range ecoregions. One possibility for the relatively high concentrations of TOC is the fact that these two ecoregions are dominated by organic soils. The only ecoregions with DOC data available are the Interior Highlands and the Alaska Range. The DOC concentrations are highest in the Interior Highlands ecoregion, most likely reflecting the presence of organic soils (table 15).

Iron is an essential trace element for both plant and animals, and concentrations in water are strongly dependent on the pH and oxidation intensity of the water. Total iron concentrations vary widely between the ecoregions, with an inner quartile range ranging from 14 to 126 μg/L for the Yukon Stikine Highlands to 420 to 11,000 μg/L for the Alaska Range (table 15). Because the waters of the Yukon River Basin are generally well oxygenated and near neutral, the total iron concentrations most likely reflect the iron concentration transported as mineral material or as iron oxyhydroxide. Concentration data for both total and dissolved iron are available only for the Brooks Range and the Alaska Range ecoregions. The dissolved concentrations for the two ecoregions are an order-of-magnitude to several orders-of-magnitude lower than their total iron concentrations (table 15).

Table 15. Summary statistics for selected properties and constituents of surface-water samples by ecoregion

[--, no data]

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Specific conductance, microsiemens per centimeter at 25 degrees Celsius					
Yukon Stikine Highlands	139	105	72	108	140
Yukon Southern Lakes	641	195	108	185	288
Boreal Mountains and Plateaus	163	115	100	125	133
Interior Highlands	177	116	83	122	150
Interior Bottomlands	31	203	97	153	312
Brooks Range	37	245	194	233	291
Alaska Range	1044	241	200	234	282
Interior Forested Lowlands & Uplands	50	153	72	154	225
Dissolved solids, residue on evaporation at 180 degrees Celsius, milligrams per liter					
Yukon Stikine Highlands	94	71	58	70	90
Yukon Southern Lakes	593	141	100	130	200
Boreal Mountains and Plateaus	53	84	70	90	94
Interior Highlands	114	71	52	75	91
Interior Bottomlands	25	106	51	79	179
Brooks Range	23	148	115	137	174
Alaska Range	966	148	121	142	173
Interior Forested Lowlands & Uplands	34	91	46	88	128
pH, standard units					
Yukon Stikine Highlands	222	7.6	7.5	7.7	7.8
Yukon Southern Lakes	751	7.9	7.6	7.8	8.0
Boreal Mountains and Plateaus	174	7.6	7.2	7.8	8.0
Interior Highlands	137	7.2	7.0	7.3	7.5
Interior Bottomlands	29	7.2	7.0	7.3	7.6
Brooks Range	28	7.9	7.8	7.9	8.1
Alaska Range	994	7.6	7.4	7.6	7.8
Interior Forested Lowlands & Uplands	36	7.4	7.0	7.5	7.9

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Water temperature, degrees Celsius					
Yukon Stikine Highlands	159	5.9	0.2	3.9	10
Yukon Southern Lakes	394	6.0	0.5	6.0	10
Boreal Mountains and Plateaus	174	5.3	7.2	7.8	8.0
Interior Highlands	157	5.5	0	4.0	10
Interior Bottomlands	16	3.8	2	3.3	5.5
Brooks Range	34	6.8	1.5	6.3	10.5
Alaska Range	516	5.8	0.5	5.5	11
Interior Forested Lowlands & Uplands	37	6.7	1.5	8	10.8
Dissolved-oxygen concentration, milligrams per liter					
Yukon Stikine Highlands	--	--	--	--	--
Yukon Southern Lakes	--	--	--	--	--
Boreal Mountains and Plateaus	--	--	--	--	--
Interior Highlands	49	10.3	9.5	10.2	11.5
Interior Bottomlands	--	--	--	--	--
Brooks Range	3	12.4	11	11.8	14.4
Alaska Range	138	11	9.1	11.2	12.4
Interior Forested Lowlands & Uplands	--	--	--	--	--
Calcium concentration, milligrams per liter					
Yukon Stikine Highlands	12	11.7	9.5	10.9	14.5
Yukon Southern Lakes	499	34.5	25.2	32.6	44.3
Boreal Mountains and Plateaus	115	16.6	15.8	17.6	18.3
Interior Highlands	117	15.2	11	16	20
Interior Bottomlands	26	24.7	12	19	43
Brooks Range	23	41	32	41	52
Alaska Range	968	33.9	28	33	40
Interior Forested Lowlands & Uplands	34	24	8.3	21	34

Table 15. Summary statistics for selected properties and constituents of surface-water samples by ecoregion--Continued

[--, no data]

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Magnesium concentration, milligrams per liter					
Yukon Stikine Highlands	12	1.1	0.9	1.0	1.4
Yukon Southern Lakes	499	8.9	5.8	7.9	11.9
Boreal Mountains and Plateaus	78	4.2	3.9	4.7	4.9
Interior Highlands	117	3.9	2.6	4.3	5.2
Interior Bottomlands	26	5.4	3.4	4.6	8.5
Brooks Range	23	7.5	5.1	6.7	8.1
Alaska Range	969	8.2	5.7	7.3	9.3
Interior Forested Lowlands & Uplands	34	4.4	2.5	4.7	6.7
Sodium concentration, milligrams per liter					
Yukon Stikine Highlands	12	1.4	1.1	1.4	1.7
Yukon Southern Lakes	--	--	--	--	--
Boreal Mountains and Plateaus	115	1.3	1.3	1.4	1.5
Interior Highlands	107	1.7	1.2	1.6	1.9
Interior Bottomlands	26	2.7	1.8	2.3	3.7
Brooks Range	23	1.0	0.7	0.8	1.2
Alaska Range	846	3.9	2.4	3.8	5.1
Interior Forested Lowlands & Uplands	34	1.8	0.8	1.3	2
Potassium concentration, milligrams per liter					
Yukon Stikine Highlands	12	0.5	0.5	0.6	0.6
Yukon Southern Lakes	201	1.2	0.9	1	1.3
Boreal Mountains and Plateaus	115	0.5	0.5	0.6	0.6
Interior Highlands	107	0.9	0.7	0.9	1
Interior Bottomlands	26	1.3	0.8	1	2.1
Brooks Range	23	0.70	0.4	0.6	1
Alaska Range	846	1.7	1.3	1.7	2.1
Interior Forested Lowlands & Uplands	34	0.6	0.3	0.5	0.9

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Total alkalinity, as $CaCO_3$, milligrams per liter					
Yukon Stikine Highlands	149	40	29	42	51
Yukon Southern Lakes	676	87	45	83	134
Boreal Mountains and Plateaus	163	53	51	58	61
Interior Highlands	136	41.5	30	43	55
Interior Bottomlands	28	79	40	65	120
Brooks Range	27	100	88	100	120
Alaska Range	981	88	67	87	110
Interior Forested Lowlands & Uplands	35	68	26	63	100
Sulfate concentration, milligrams per liter					
Yukon Stikine Highlands	149	13	9	14	17
Yukon Southern Lakes	674	16	6	14	23
Boreal Mountains and Plateaus	163	5.7	51	58	61
Interior Highlands	117	15	7	15	19
Interior Bottomlands	25	18	6.6	12	32
Brooks Range	23	32	15	17	41
Alaska Range	983	36	23	31	42
Interior Forested Lowlands & Uplands	34	12	6	12	17
Chloride concentration, milligram per liter					
Yukon Stikine Highlands	149	0.3	0.2	0.3	0.3
Yukon Southern Lakes	675	0.6	0.3	0.4	0.6
Boreal Mountains and Plateaus	163	0.3	0.2	0.3	0.3
Interior Highlands	117	0.8	0.4	0.8	1
Interior Bottomlands	26	0.6	0	0.3	1.2
Brooks Range	23	0.7	0.4	0.6	1
Alaska Range	979	1.9	1	1.6	2.5
Interior Forested Lowlands & Uplands	34	1.1	0.4	0.7	1.4

Table 15. Summary statistics for selected properties and constituents of surface-water samples by ecoregion--Continued

[--, no data]

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data 25	50	75
Dissolved-silica concentration, milligrams per liter					
Yukon Stikine Highlands	123	2.9	2.6	3	3.4
Yukon Southern Lakes	429	4.1	3.0	3.9	5.2
Boreal Mountains and Plateaus	116	3.5	3.4	3.5	3.8
Interior Highlands	119	7.2	5.8	7.3	8.3
Interior Bottomlands	20	10.6	6.35	12	14
Brooks Range	23	2.9	2.4	2.8	3.3
Alaska Range	974	9.0	6.1	8.8	11
Interior Forested Lowlands & Uplands	34	5.3	2.7	4.9	7.3
Dissolved nitrate plus nitrate concentration, as nitrogen, milligrams per liter					
Yukon Stikine Highlands	299	0.09	0.04	0.08	0.13
Yukon Southern Lakes	532	0.04	0.01	0.03	0.06
Boreal Mountains and Plateaus	588	0.06	0.01	0.04	0.06
Interior Highlands	21	0.19	0.1	0.16	0.26
Interior Bottomlands	10	0.25	0.18	0.24	0.27
Brooks Range	--	--	--	--	--
Alaska Range	139	0.18	0.1	0.17	0.2
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total phosphorus concentration, as phosphorus, milligrams per liter					
Yukon Stikine Highlands	114	0.01	0.002	0.003	0.008
Yukon Southern Lakes	1063	0.05	0.008	0.02	0.10
Boreal Mountains and Plateaus	572	0.13	0.006	0.008	0.014
Interior Highlands	37	0.08	0.01	0.03	0.07
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	102	0.23	0.02	0.08	0.3
Interior Forested Lowlands & Uplands	--	--	--	--	--

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data 25	50	75
Total organic carbon, as carbon, milligrams per liter					
Yukon Stikine Highlands	145	1.4	0.5	0.6	1.6
Yukon Southern Lakes	180	1.3	0.7	1.1	1.6
Boreal Mountains and Plateaus	15	4.9	3.3	4.1	4.7
Interior Highlands	8	10.5	5.5	9.0	15.5
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	30	1.7	0.8	1	1.3
Interior Forested Lowlands & Uplands	--	--	--	--	--
Dissolved organic carbon, as carbon, milligrams per liter					
Yukon Stikine Highlands	--	--	--	--	--
Yukon Southern Lakes	--	--	--	--	--
Boreal Mountains and Plateaus	--	--	--	--	--
Interior Highlands	4	4.5	3	4.5	6.1
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	26	1.4	1.1	1.2	1.4
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total iron concentration, as iron, micrograms per liter					
Yukon Stikine Highlands	154	169	14	32	126
Yukon Southern Lakes	692	699	128	230	478
Boreal Mountains and Plateaus	151	136	42	85	174
Interior Highlands	16	225	70	135	355
Interior Bottomlands	--	--	--	--	--
Brooks Range	4	127	60	125	195
Alaska Range	71	6740	420	1000	11000
Interior Forested Lowlands & Uplands	--	--	--	--	--

Table 15. Summary statistics for selected properties and constituents of surface-water samples by ecoregion--Continued

[--, no data]

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Dissolved iron concentration, as iron, micrograms per liter					
Yukon Stikine Highlands	--	--	--	--	--
Yukon Southern Lakes	--	--	--	--	--
Boreal Mountains and Plateaus	--	--	--	--	--
Interior Highlands	40	216	115	210	285
Interior Bottomlands	10	62	10	10	50
Brooks Range	5	18	0	10	30
Alaska Range	119	73	10	30	72
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total manganese, as manganese, micrograms per liter					
Yukon Stikine Highlands	154	5	0.5	1.5	4.0
Yukon Southern Lakes	692	31	10	18	34
Boreal Mountains and Plateaus	151	7	2.2	5	10
Interior Highlands	16	27.5	0	25	45
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	71	171	20	60	220
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total barium, as barium, micrograms per liter					
Yukon Stikine Highlands	142	41	33	44	50
Yukon Southern Lakes	691	43	22	35	56
Boreal Mountains and Plateaus	48	25	18	29	30
Interior Highlands	--	--	--	--	--
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	86	46	39	45	54
Interior Forested Lowlands & Uplands	--	--	--	--	--

Ecoregion (fig. 36)	No. of analyses	Mean	Percentile values calculated from the data		
			25	50	75
Total strontium, as strontium, micrograms per liter					
Yukon Stikine Highlands	142	127	90	138	162
Yukon Southern Lakes	692	240	86	207	418
Boreal Mountains and Plateaus	48	62	62	69	72
Interior Highlands	--	--	--	--	--
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	85	216	160	190	290
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total arsenic, as arsenic, micrograms per liter					
Yukon Stikine Highlands	99	0.8	0.1	0.1	0.2
Yukon Southern Lakes	--	(<25 percent of data above detection limit)			
Boreal Mountains and Plateaus	148	0.5	0.3	0.4	0.6
Interior Highlands	--	--	--	--	--
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	21	7.4	1	2	9
Interior Forested Lowlands & Uplands	--	--	--	--	--
Total lithium, as lithium, micrograms per liter					
Yukon Stikine Highlands	141	1.0	1.1	1.3	1.5
Yukon Southern Lakes	193	1.0	1.0	1.2	1.6
Boreal Mountains and Plateaus	151	0.8	0.8	0.9	1
Interior Highlands	--	--	--	--	--
Interior Bottomlands	--	--	--	--	--
Brooks Range	--	--	--	--	--
Alaska Range	--	--	--	--	--
Interior Forested Lowlands & Uplands	--	--	--	--	--

Data for three other trace elements, manganese, barium and strontium, were also analyzed. Total manganese concentrations vary widely throughout the basin but are generally highest in the Alaska Range ecoregion and lowest in the Yukon Stikine Highlands ecoregion. Barium and strontium were detected throughout the Yukon River Basin. Barium is relatively constant, but strontium varies widely (table 15). The highest concentrations and the greatest variability of strontium concentrations are in the Yukon Southern Lakes ecoregion, whereas the lowest concentrations and least variability of strontium were found in the Boreal Mountains and Plateaus ecoregion.

Anthropogenic Effects on Water Quality

Discussions of the water quality of the Yukon River Basin are based on limited data and indicate that water chemistry differences throughout the basin are due more to natural factors than to human-induced factors. However, the basin has been affected by human activities, both from within the basin and from outside the basin. The difficulty arises in determining to what degree humans have affected the water quality, because a suitable water-quality data base does not exist at the present time.

The Yukon River Basin is not subject to the intense application of organic pollution found in some rivers of the lower 48 states. It is, however, more vulnerable to global atmospheric transport. Global transport of pollutants is well recognized. In the northern hemisphere, transport occurs primarily in the winter months when temperature and pressure gradients are the steepest. Pollutants from mid-latitudes are transported northward, where greater precipitation and colder temperature cause deposition from a "warm-cold distillation" effect (Majewski and Capel, 1995). Chlorinated pesticides, such as HCH, HCS, DDT, toxaphene, and chordanes, have been observed in the Arctic and are believed to have been transported in the atmosphere. Many of the compounds are lipophilic, concentrating in the fat and fatty tissues of fish and game animals.

In 1991, elevated levels of toxaphene, DDT, and PCB's were found in burbot liver, and lake trout and whitefish muscle in Lake Laberge near the headwaters of the Yukon River (Muir and Lockhart, 1992). Analysis of archived fish tissue from 1974 found concentrations similar to those of the 1991 sampling. The concentrations in Lake Laberge whitefish were 3 to 42 times higher than those in whitefish from other lakes in the region (Muir and Lockhart, 1992). Atmospheric transport was determined to be the source of the toxaphene and an exceptionally long food chain served to concentrate the pollutants in the predatory fish (Kidd and others, 1995).

Mining activity has, and continues to be, an important economic industry in the Yukon River Basin. Probably the biggest concern of mining is the possible harm to fish-spawning areas. Although today's mining practices are highly regulated to prevent damage to fish habitat, many old abandoned mine areas remain. One example is Coal Creek, located in Yukon-Charley Rivers National Preserve. This particular watershed was mined extensively in the early 1900's and the mining practices used at the time had a severe impact on the watershed. The site was declared a Superfund site by the U.S. Environmental Protection Agency and cleanup was completed in 1998.

During the Cold War, the military had a strong presence in Alaska. In addition to the military bases located near Fairbanks and Delta Junction, early warning radar sites were located at some villages along the Yukon River. At the U.S. Air Force Base at Galena, 250,000 drums containing potentially toxic materials are currently spread out across the tundra as a result of a flood. The effect on water quality has yet to be determined.

SUMMARY

This report describes the environmental and hydrologic setting of the Yukon River Basin, the fourth largest drainage basin in North America. The primary environmental and hydrologic features of the Yukon River Basin are as follows:

- The population of the Yukon River Basin is approximately 126,000 people. Approximately 10 percent of these people have a subsistence lifestyle and depend on the fish and game resources of this 330,000-square-mile basin.
- The climate of the Yukon River Basin is variable because of its large size and range in altitude. Precipitation ranges from 10 to 130 in. annually and the mean average air temperature is about 22 °F. The upstream part of the basin is rolling topography or moderately high rugged mountains, whereas the downstream part of the basin is primarily low mountains, plains, and lowlands. The geology is complex and consists of many types of consolidated rocks in the mountain ranges surrounding the basin and unconsolidated sediments deposited in the lowland areas.
- Wetlands account for about 30 percent of the Yukon River Basin. The primary land cover is needleleaf forest and the primary soils are Gelisols. Many of the Gelisols are frozen organic soil. These soils are located in the northern third of the basin which is underlain by continuous permafrost.
- The Yukon River Basin consists of 20 ecoregions, distinct areas delineated by the integration of their natural features. Interior Forested Lowlands and Uplands is the largest ecoregion of the basin and accounts for 21 percent of the drainage area. The Interior Highlands ecoregion is the second largest ecoregion of the basin and accounts for about 17 percent of the drainage area.
- Discharge from streams and rivers in the Yukon River Basin varies depending on the presence of glaciers. Two major tributaries that drain glacier areas of the Yukon River, the Tanana River and the White River, account for 29 percent of the flow of the Yukon River but only account for about 20 percent of the drainage area. Melting glaciers add more water to these rivers and sustain runoff through the summer season. The average annual discharge of the Yukon River near its mouth is 227,000 ft^3/s. However, most of the flow occurs from May through September.
- Near its mouth, the Yukon River transports about 60 million tons of suspended sediment toward the Bering Sea annually. However, each year, about 20 million tons of sediment are deposited on flood plains and in braided reaches of the river. Implications of this deposition are enormous for the sequestration of organic carbon, contaminants, and other materials that are absorbed onto, or otherwise associated with, alluvial sediments.
- The waters of the main stem of the Yukon River and its tributaries are predominantly calcium magnesium bicarbonate waters with specific conductance ranging from 54 to 373 µS/cm. Concentrations of the nutrients nitrogen and phosphorus are generally less than 0.5 mg/L. Temporal trends in water quality between summer and winter are evident at some sites along the Yukon River. Comparison of water-quality data within ecoregions indicates that total organic carbon concentrations were highest in ecoregions dominated by organic soils.
- Some anthropogenic effects to water quality of the Yukon River Basin have been documented. These effects are due to atmospheric processes, pre-regulation mining, and old military sites used during the Cold War. The cumulative effects on the Yukon River Basin cannot be made because of a lack of water-quality data.

REFERENCES CITED

Aagaard, K., and Carmack, E.C., 1989, The role of sea ice and other fresh water in the Arctic circulation: Journal of Geophysical Research, v. 94, p. 14485-14498.

Agriculture Canada, 1976, Glossary of terms in soil science: Agriculture Canada, Research Branch, Publication 1459, 44 p.

Alaska Department of Labor, 1999, Research & analysis, demographics unit, population estimates: accessed January 1999 at URL *www.labor.state.ak.us/ research/pop/popmain.htm*

Alaska Geographic Society, 1987, The upper Yukon Basin: Alaska Geographic Society Quarterly, v. 14, no. 4, 117 p.

Alaska Geographic Society, 1990, The middle Yukon River: Alaska Geographic Society Quarterly, v. 17, no. 3, 96 p.

Alaska Geographic Society, 1991, The lower Yukon River: Alaska Geographic Society Quarterly, v. 17, no. 4, 96 p.

Alaska Geospatial Data Clearinghouse, 1998, Preliminary vegetation classes: accessed December 1998 at URL *agdc.usgs.gov/data/usgs/ erosafo/ veg/veg.html*

Alaska Geospatial Data Clearinghouse, 1999, Fire history: accessed December 1998 at URL *agdc.usgs.gov/data/projects/fhm*

BESIS (Bering Sea Impacts Study), 1997, The impacts of global climate change in the Bering Sea region: Girdwood, Alaska, September 18-21, 1996, 42 p.

Bostock, H.S., 1970, Physiographic regions of Canada: Geological Survey of Canada, Map 1254A, scale 1:5,000,000.

Brown, J., Ferrians, Jr., O.J., Heginbottom, J.A., and Melnikov, E.S., 1997, Circum-Arctic map of permafrost and ground ice conditions: U.S. Geological Survey Circum-Pacific Map Series, Map CP-45.

Burrows, R.L., 1980, Cross-section, velocity, and bedload data at two erosion sites on the Tanana River near Fairbanks, Alaska, 1979: U.S. Geological Survey Open-File Report 80-699, 32 p.

Burrows, R.L., Emmett, W.W., and Parks, Bruce, 1981, Sediment transport in the Tanana River near Fairbanks, Alaska, 1977-79: U.S. Geological Survey Water-Resources Investigations 81-20, 42 p.

Burrows, R.L., and Harrold, P.E., 1983, Sediment transport in the Tanana River near Fairbanks, Alaska, 1980-81: U.S. Geological Survey Water-Resources Investigations Report 83-4064, 116 p.

Burrows, R.L., Parks, Bruce, and Emmett, W.W., 1979, Sediment transport in the Tanana River in the vicinity of Fairbanks, Alaska, 1977-78: U.S. Geological Survey Open-File Report 79-1539, 37 p.

Chapman, W.L., and Walsh, J.E., 1993, Recent variations of sea ice and air temperatures in high latitudes: Bulletin of American Meteorology Society, v. 74, no. 1, p. 33-47.

Childers, J.M., Meckel, J.P., and Anderson, G.S., 1972, Floods of August 1967 in east-central Alaska, *with a section on* Weather features contributing to the floods, by E.D. Diemer, U.S. Weather Bureau: U.S. Geological Survey Water-Supply Paper 1880-A, 77 p.

Colby, B.R., 1956, Relationship of sediment discharge to streamflow: U.S. Geological Survey Open-File Report, 170 p.

Cowardin, L.M., Carter, Virginia, Golet, F.C., and LaRoe, E.T., 1979, Classification of wetlands and deepwater habitats of the United States: U.S. Fish and Wildlife Service Report FWS/OBS-79/31, 131 p.

Dunne, T., Mertes, L.A.K., Meade, R.H., Richey, J.E., and Forsberg, B.R., 1998, Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil: Geological Society of America Bulletin, v. 110, p. 450-467.

Ecological Stratification Working Group, 1995, A national ecological framework for Canada: Hull, Ottawa, Agriculture and Agri-Food Canada and Environment Canada, Report and National Map, scale 1:7,500,000.

Emmett, W.W., Burrows, R.L., and Parks, Bruce, 1978, Sediment transport in the Tanana River in the vicinity of Fairbanks, Alaska, 1977: U.S. Geological Survey Open-File Report 78-290, 28 p.

Environment Canada, 1999, Yukon SOE [state of the environment] highlights—Land and people: accessed January 1999 at URL *www.taiga.net/ yukonsoe/hilp.html*

Ferrians, O.J., Jr., 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-445, scale 1:2,500,000.

Foote, M.J., 1976, Classification, description, and dynamics of plant communities following fire in the taiga of interior Alaska—Fire effects study: Fairbanks, Alaska, U.S. Department of Agriculture Forest Service, Institute of Northern Forestry report.

Fretwell, J.D., Williams, J.S., and Redman, P.J., compilers, 1996, National water summary on wetland resources: U.S. Geological Survey Water-Supply Paper 2425, 431 p.

Gallant, A.L., Binnian, E.F., Omernik, J.M., and Shasby, M.B., 1995, Ecoregions of Alaska: U.S. Geological Survey Professional Paper 1567, 73 p., 1 plate.

Gordey, S.P., and Makepeace, A.J. (compilers), 1999, Yukon digital geology: Geological Survey of Canada, Open File D3826, Exploration and Geological Services Division, Yukon, Indian and Northern Affacirs Canada, Open File 1999-1(D), CD-ROM.

Harrold, P.E., and Burrows, R.L., 1983, Sediment transport in the Tanana River near Fairbanks, Alaska, 1982: U.S. Geological Survey Water-Resources Investigations Report 83-4213, 53 p.

Hartman, C.W., and Johnson, P.R., 1978, Environmental atlas of Alaska (2^{d} ed.): University of Alaska, Institute of Water Resources, 95 p.

Holder, R.R., and Senecal-Albrecht, D., 1998, Yukon River comprehensive salmon plan for Alaska: Alaska Department of Fish and Game Report for the Yukon River Regional Planning Team, 162 p.

Indian and Northern Affairs Canada, 1999, Yukon Territory, Canada, forest fire history database, 1946-1997: Whitehorse, Yukon, Indian and Northern Affairs Canada, Forest Management, CD-ROM.

Jones, S.H., and Fahl, C.B., 1994, Magnitude and frequency of floods in Alaska and conterminous basins of Canada: U.S. Geological Survey Water-Resources Investigations Report 93-4179, 122 p. + 2 pl.

Juday, G.P., Ott, R.A., Valentine, D.W., and Barber, V.A., 1998, Forests, climate stress, insects, and fire, *in* Weller, G. and Anderson, P.A. (eds.), Implications of global change in Alaska and the Bering Sea Region: University of Alaska, Fairbanks, Center for Global Change and Arctic System Research, Proceedings of a Workshop, June 1997, p. 23.

Kidd, K.A., Schindler, D.W., Muir, D.C., Lockhart, W.L., and Hesslein, R.H., 1995, High concentrations of toxaphene in fishes from a subarctic lake: Science, v. 269, p. 240-241.

Lamke, R.D., 1991, Alaska floods and droughts, *in* Paulson, R.W., and others, National water summary, 1988-89—Hydrologic events and floods droughts: U.S. Geological Survey Water-Supply Paper 2375, p. 171-180.

Lisitsysn, A.P., 1969, Recent sedimentation in the Bering Sea: Washington, D.C., National Science Foundation, The Israel Program for Scientific Translations (translated from Russian).

Majewski, M.S., and Capel, P.D., 1995, Pesticides in the atmosphere—Distribution, trends, and governing factors: Chelsea, Michigan, Ann Arbor Press, 214 p.

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

Meier, M.F., 1969, Glaciers and water supply: Journal of the American Water Works Association, v. 61, no. 1, p. 8-12.

Meyer, D.F., 1995, Flooding in the Middle Koyukuk River Basin, Alaska, August 1994: U.S. Geological Survey Water-Resources Investigations Report 95-4118, 8 p. + 2 plates.

Muir, D., and Lockhart, W.L., 1992, Food chain accumulation and biochemical effects of organochlorine contaminants in fish from Lake Laberge and other Yukon lakes, *in* Murray, J.L., and Shearer, R.G., eds., Synopsis of research conducted under the 1991/1992 Northern Contaminants Program: Ottawa, Minister of Indian Affairs and Northern Development, Environmental Studies No. 68, p. 173-177.

Omernik, J.M., 1995, Ecoregions—A spatial framework for environmental management, *in* Davis, W.S. and Simon, T., eds., Biological assessment and criteria—Tools for water resource planning and decisions making: Boca Raton, Florida, Lewis Publishers, p. 49-62.

Parfit, Michael, 1998, The untamed Yukon River: National Geographic Magazine, v. 194, no. 1, July 1998, p. 100-127.

Paterson, W.S.B., 1994, The physics of glaciers (3^{d} ed.): New York, Elsevier Science Inc., 480 p.

Rieger, S., Schoephorster, D.B., and Furbish, C.E., 1979, Exploratory soil survey of Alaska: U.S. Department of Agriculture, Soil Conservation Service, 213 p.

Schumm, S.A., and Winkley, B.R., 1994, The character of large alluvial rivers, *in* Schumm, S.A., and Winkley, B.R., eds., The variability of large alluvial rivers: New York, American Society of Civil Engineers, p. 1-9.

Searby, H.W., 1968, Climates of the States—Alaska: Environmental Data Service ESSA, Climatology of the United States, No. 60-49.

Silberling, N.J., Jones, D.L., Monger, J.W.H., Coney, P.J., Berg, H.C., and Plafker, George, 1994, Lithotectonic terrane map of Alaska and adjacent parts of Canada, *in* Plafker, George, and Berg, H.C., eds., The geology of Alaska: Geological Society of America, The geology of North America, v. G-1, plate 3, 1 sheet, scale 1:7,500.000.

Singer, M.J., and Munns, D.N., 1987, Soils—An introduction: New York, Macmillan Publishing Company, 492 p.

Talbot, S.S., and Markon, C.J., 1986, Vegetation mapping of the Nowitna National Wildlife Refuge, Alaska using Landsat MSS digital data: Photogrammetric Engineering and Remote Sensing, v. 52, no. 6, p. 791-799.

Thorson, R.M., and Dixon, E.J., Jr., 1983, Alluvial history of the Porcupine River, Alaska—Role of glacial lake overflow from northwest Canada: Geological Society of America Bulletin, v. 94, no. 5, p. 576-589.

U.S. Department of Agriculture, 1975, Soil taxonomy—A basic system of soil classification for making and interpreting soil surveys: Soil Conservation Service, U.S. Department of Agriculture Handbook 436, 754 p.

U.S. Environmental Protection Agency, 1977, Quality criteria for water, 1976: U.S. Government Printing Office, 256 p.

U.S. Geological Survey, 1954-62, Quantity and quality of surface waters of Alaska. Annual reports as follows: water years 1951-53, Water-Supply Paper 1466; water years 1954-56, Water-Supply Paper 1486; water year 1957, Water-Supply Paper 1500; water year 1958, Water-Supply Paper 1570; water year 1959, Water-Supply Paper 1640; and water year 1960, Water-Supply Paper 1720.

U.S. Geological Survey, 1970-71a, Quality of surface waters of Alaska. Annual reports as follows: water years 1964, Water-Supply Paper 1959; water year 1965, Water-Supply Paper 1966; water year 1966, Water-Supply Paper 1996.

U.S. Geological Survey, 1971b, Surface-water supply of the United States, 1961-65, Part 15, Alaska: U.S. Geological Survey Water-Supply Paper 1936.

U.S. Geological Survey, 1976, Surface-water supply of the United States, 1966-70, Part 15, Alaska: U.S. Geological Survey Water-Supply Paper 2136.

U.S. Geological Survey, 1972-75, Water resources data for Alaska, 1971-74, Part 1, Surface water records: U.S. Geological Survey Water-Data Reports AK-71 to AK-74 (published annually).

U.S. Geological Survey, 1976-97, Water resources data for Alaska, water years 1975-96: U.S. Geological Survey Water-Data Reports AK-75-1 to AK-96-1 (published annually).

U.S. Geological Survey, 1987, Hydrologic unit map—1987, State of Alaska: U.S. Geological Survey map, 1 sheet, scale 1:2,500,000.

Wahrhaftig, C., 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 51 p., 6 plates.