

# Transport of Water, Carbon, and Sediment Through the Yukon River Basin

## Introduction

In 2001, the U.S. Geological Survey (USGS) began a water-quality study of the Yukon River. The Yukon River Basin (YRB), which encompasses 330,000 square miles in northwestern Canada and central Alaska (fig. 1), is one of the largest and most diverse ecosystems in North America. The Yukon River is more than 1,800 miles long and is one of the last great uncontrolled rivers in the world, and is essential to the eastern Bering Sea and Chukchi Sea ecosystems, providing freshwater runoff, sediments, and nutrients (Brabets and others, 2000). Despite its remoteness, recent studies (Hinzman and others, 2005; Walvoord and Striegl, 2007) indicate the YRB is changing. These changes likely are in response to a warming trend in air temperature of 1.7°C from 1951 to 2001 (Hartmann and Wendler, 2005). As a result of this warming trend, permafrost is thawing in the YRB, ice breakup occurs earlier on the main stem of the Yukon River and its tributaries, and timing of streamflow and movement of carbon and sediment through the basin is changing (Hinzman and others, 2005; Walvoord and Striegl, 2007).

One of the most striking characteristics in the YRB is its seasonality. In the YRB, more than 75 percent of the annual streamflow runoff occurs during a five month period, May through September.



Yukon Flats near Ft. Yukon. The Black River (high DOC) mixing with the sediment-laden water of the Porcupine River during peak flow in June



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

This is important because streamflow determines when, where, and how much of a particular constituent will be transported. As an example, more than 95 percent of all sediment transported during an average year also occurs during this period (Brabets and others, 2000). During the other 7 months, streamflow, concentrations of sediment and other water-quality constituents are low and little or no sediment transport occurs in the Yukon River and its tributaries.

Streamflow and water-quality data have been collected at more than 50 sites in the YRB (Dornblaser and Halm, 2006; Halm and Dornblaser, 2007). Five sites have been sampled more than 30 times and others have been sampled twice during peak- and low-flow conditions as part of synoptic sampling campaigns. Although the synoptic data do not provide a complete picture of water quality of a particular river through the year, the data do provide a snapshot of water-quality conditions at a particular time of year.

Two constituents of interest are suspended sediment and dissolved organic carbon (DOC). Suspended sediment is important because elevated concentrations can adversely affect aquatic life by obstructing fish gills, covering fish spawning sites, and altering habitat of benthic organisms. Metals and organic contaminants also tend to adsorb onto fine-grained sediment. Permafrost thawing has major implications for the carbon cycle. It is critical to understand the processes related to the transport of DOC to surface waters and how long-term climatic changes may alter these processes (Schuster and others, 2004).

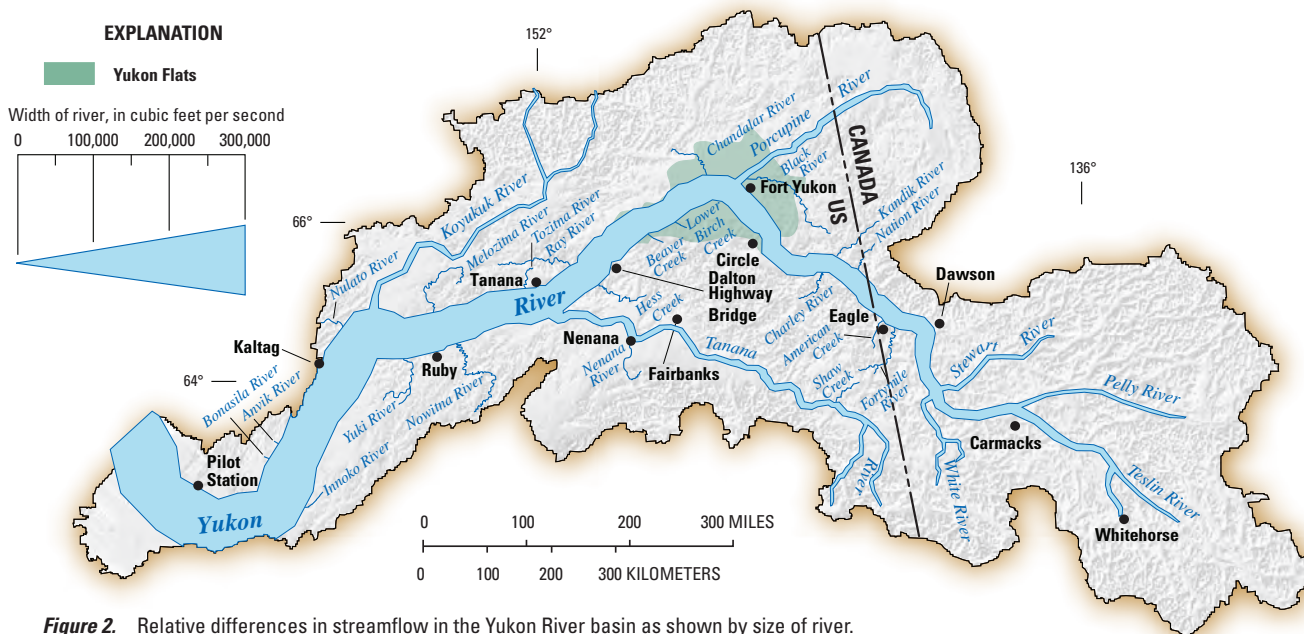


Figure 2. Relative differences in streamflow in the Yukon River basin as shown by size of river.

## Transport of Water, Carbon, and Sediment

The following description of the suspended sediment, DOC, and streamflow characteristics of the YRB starts near the headwaters of the Yukon River at Whitehorse, Yukon Territory, Canada (fig. 2), about 1,800 miles from the mouth of the Yukon River. Suspended sediment, DOC, and streamflow data collected since 2001, and historical streamflow and water-quality data, were used to explain these characteristics.

**Yukon River at Whitehorse, Yukon Territory, Canada**—At Whitehorse (fig. 2), the Yukon River drains less than 4 percent of the basin and streamflow averages 8,600 cubic feet per second ( $\text{ft}^3/\text{s}$ ). Streamflow primarily is through large headwater lakes that trap much of the sediment before it enters the Yukon River. Suspended sediment concentrations generally are less than 15 milligrams per liter ( $\text{mg/L}$ ) and the annual suspended sediment load is about 0.1 percent (62,000 tons) of the total annual load at Pilot Station, Alaska (fig. 3). DOC concentrations generally are low in the Yukon River because this part of the YRB contains only sporadic masses of permafrost and only a few wetland areas.

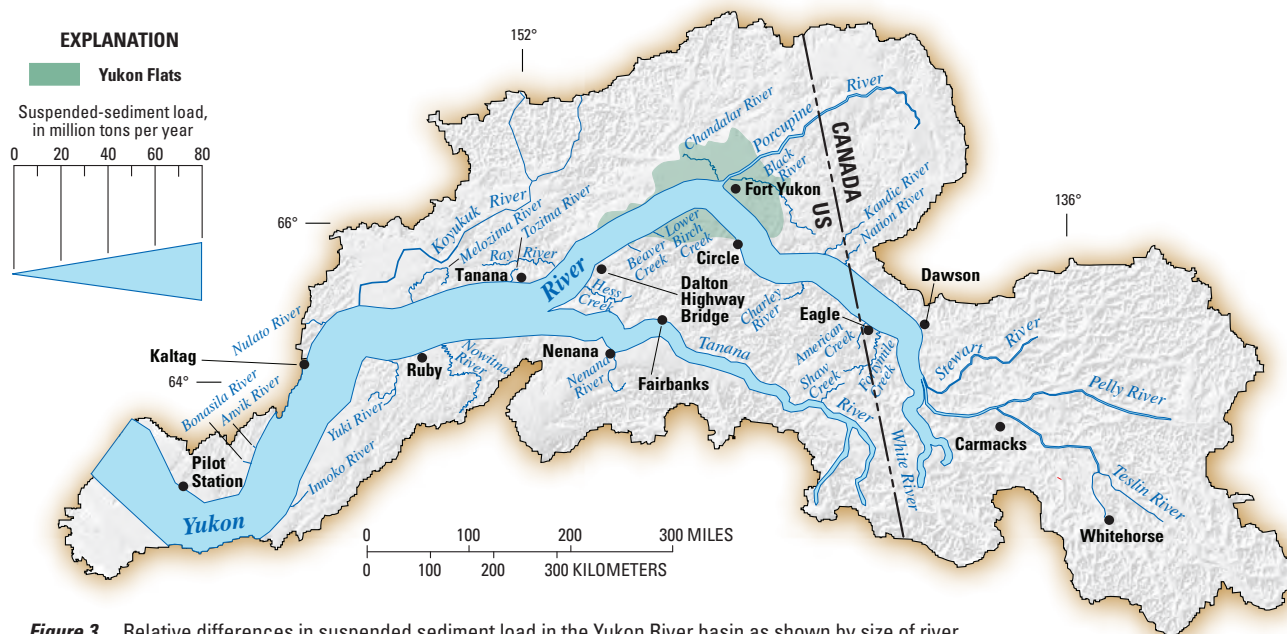
**Yukon River at Dawson, Yukon Territory, Canada**—At Dawson (fig. 2), about 1,300 miles from the mouth, the Yukon River drains almost one-third of the basin and streamflow averages 78,000  $\text{ft}^3/\text{s}$ . The major tributaries between Whitehorse and Dawson are the Teslin, Pelly, White, and Stewart Rivers. The White River, the smallest of these basins, is glacier-fed and has the greatest average streamflow (20,000  $\text{ft}^3/\text{s}$ ) (fig. 2). Glacier-fed rivers such as the White River transport higher amounts of suspended sediment than non-glacier-fed rivers. The White River transports 19 million tons of suspended sediment per year in the upper part of its basin (fig. 3). In comparison, non-glacier-fed rivers, such as the Pelly and Stewart Rivers transport 2.5 and 2.0 million tons of suspended sediment per year, respectively (fig. 3). Downstream of the confluence of the White and Yukon Rivers, the clarity of the Yukon River changes dramatically, remaining sediment laden for its entire reach to the Bering Sea. Synoptic samples from the Teslin, Pelly, White, and Stewart Rivers, and other small tributaries showed DOC concentrations at about 5  $\text{mg/L}$  in this reach of the Yukon River. However, DOC was not measured during the snowmelt peak, usually the time of largest DOC concentrations.

**Yukon River at Eagle, Alaska**—About 100 miles downstream of Dawson, Yukon Territory, the Yukon River flows past the town of Eagle, Alaska. From Whitehorse to Eagle, the average streamflow of the Yukon River increases about 1 order of magnitude to 84,000  $\text{ft}^3/\text{s}$ , representing about 37 percent of the total annual average YRB streamflow (fig. 2). Suspended sediment loads increase to nearly 70 percent of the total annual average from the YRB (about 45 million tons per year), one order of magnitude greater than the Yukon River upstream of the White River (fig. 3). This is the first location on the Yukon River where annual DOC loads can be calculated: 450,000 tons per year, representing about 25 percent of the total annual DOC load from the YRB (Striegl and others, 2007). DOC concentrations were smallest during winter months (less than 2  $\text{mg/L}$ ) and highest during mid-May (8.5–14  $\text{mg/L}$ ), the beginning of snowmelt. Relatively large DOC concentrations (about 20  $\text{mg/L}$  in June 2004 and about 16  $\text{mg/L}$  in August 2004) were measured in the Fortymile River between Dawson and Eagle, possibly indicating a significant source of DOC from this tributary.



USGS personnel preparing to sample the Yukon River just above Eagle, Alaska





**Figure 3.** Relative differences in suspended sediment load in the Yukon River basin as shown by size of river.



*USGS personnel sampling the Yukon River just above the Dalton Highway bridge*

**Yukon River at Circle, Alaska**—Between Eagle and Circle the Yukon River flows through a somewhat narrow stretch of the basin. The major tributaries—Nation, Kandik, and Charley Rivers—are relatively clear streams in small watersheds, and add little suspended sediment to the Yukon River. However, DOC concentrations greater than 10 mg/L during June 2003 were measured in these tributaries, perhaps indicating the presence of wetlands or initial thawing of the permafrost in these basins. About 1,100 miles from the mouth of the Yukon River, the town of Circle, Alaska, marks the beginning of the Yukon Flats, an extensive wetland about the size of Connecticut.

**Yukon River at Fort Yukon, Alaska**—About 1,000 miles from the mouth of the Yukon River, this is the mid-point of the Yukon Flats. No major tributaries to the Yukon River are between Circle and Fort Yukon. The Porcupine River, the largest tributary basin in the YRB (45,000 mi<sup>2</sup>) enters the Yukon River at Fort Yukon and has an average streamflow of 17,100 ft<sup>3</sup>/s. The Porcupine River basin is underlain mostly by permafrost and is a major source of DOC into the Yukon River. Although DOC concentrations are less than 2.0 mg/L during the winter, large DOC concentrations (28 mg/L) were measured during peak discharge from spring snowmelt. Measured suspended-sediment concentrations have been about 200 mg/L during spring snowmelt, about one-fifth of the concentrations measured in the White River.

The Porcupine River's average annual suspended-sediment load (4 million tons per year) is less than one-tenth that of the Yukon River at Eagle (fig. 3). However, the annual DOC load for the Porcupine River is 139,000 tons per year, which increases the DOC load from the Yukon River at Eagle by 25 percent, suggesting that the Porcupine River is the first major source of DOC to the Yukon River.

**Yukon River at Dalton Highway Bridge, Alaska**—The Yukon River exits the Yukon Flats at the Dalton Highway Bridge, about 800 miles from its mouth. Here, the Yukon River drains about 60 percent of the YRB with an average streamflow of 119,000 ft<sup>3</sup>/s, representing about one-half the total annual average discharge from the YRB (fig. 2). Major tributaries between the Yukon River at Fort Yukon and the Dalton Highway Bridge are the Chandalar River, Beaver Creek, and Lower Birch Creek. Concentrations of DOC for these tributaries were greater than 10 mg/L, reflecting extensive wetlands, organic-rich soils, and possibly thawing permafrost of the Yukon Flats region. At the Dalton Highway Bridge, suspended sediment loads decrease from a combined annual average of 49 million tons at Eagle and at the mouth of the Porcupine River to 41 million tons per year (fig. 3). Although suspended sediment loads are highly variable, this decrease suggests that the Yukon Flats may act as a sediment sink. DOC loads, however, are about double that from Eagle at 860,000 tons per year, suggesting that tributaries such as the Porcupine River that enter the Yukon River between Eagle and the Dalton Highway Bridge are major sources of DOC to the Yukon River.

**Yukon River at Ruby, Alaska**—At Ruby, about 600 miles from its mouth, the Yukon River drains about 73 percent of the Yukon Basin (259,000 mi<sup>2</sup>) and has an average streamflow of 167,000 ft<sup>3</sup>/s, representing nearly 75 percent of the streamflow from the YRB (fig. 2). The Tanana River, a glacier-fed river, is the second largest tributary basin (44,300 mi<sup>2</sup>) and flows into the Yukon River about 100 miles upstream of Ruby. Between the Dalton Highway Bridge and Ruby, streamflow in the Yukon River increases about 37 percent, mostly due to the Tanana River (average streamflow 41,400 ft<sup>3</sup>/s) (fig. 2). Other major tributaries are Hess Creek, and the Tozitna, Nowitna, and Melozitna Rivers. DOC concentrations measured at these sites were greater than 10 mg/L, indicating this part of the Yukon River may be a

significant source of DOC. The annual suspended sediment load of the Tanana River is about 37 million tons, about one-half the annual average sediment load from the entire YRB, indicating that the Tanana River is a significant source of suspended sediment to the Yukon River (fig. 3). The annual DOC load of the Tanana River at Nenana is 88,000 tons, much less than the DOC load from the Porcupine River, and only about 5 percent of the annual average DOC load from the YRB, indicating that this large glacier-fed river does not provide a large amount of DOC to the Yukon River.

**Yukon River at Kaltag, Alaska**—At Kaltag, about 450 miles from its mouth, the Yukon River drains nearly 90 percent of the YRB (296,000 mi<sup>2</sup>) and the average annual streamflow represents 95 percent of the total from the YRB (216,500 ft<sup>3</sup>/s) (fig. 2). A major tributary to the Yukon River in this area is the Koyukuk River, the third largest drainage in the YRB (31,400 mi<sup>2</sup>). Other major tributaries are the Yuki and Nulato Rivers. Average streamflow of the Koyukuk River is about 10 percent of the Yukon River's streamflow at Kaltag (fig. 2). Annual sediment load is 2 million tons per year (fig. 3). The Koyukuk River also may be a significant source of DOC to the Yukon River. The Koyukuk River is similar to the Porcupine River; both basins are underlain by continuous permafrost. During spring snowmelt, DOC concentrations were greater than 10 mg/L at streamflows greater than 100,000 ft<sup>3</sup>/s (June 2003), similar to the Porcupine River, and provided a large amount of DOC to the Yukon River.

**Yukon River at Pilot Station, Alaska**—The lower reach of the Yukon River between Kaltag and Pilot Station is in a narrow part of the basin and the drainage is increased by only 25,000 mi<sup>2</sup> to a total of 321,000 mi<sup>2</sup>. Major tributaries between these two villages are the Anvik, Bonasila, and Innoko Rivers. The Innoko River drains a large wetland area (14,000 mi<sup>2</sup>) and measured concentrations of DOC were 15 mg/L near peak snowmelt discharge in June 2003, indicating this basin may be a significant source of DOC to the Yukon River. The Yukon River at Pilot Station, about 120 miles from its mouth, is considered the lowest reach of the river where streamflow is not affected by the Bering Sea. Here, the Yukon River is considered the outflow point for the entire YRB. Average streamflow is 227,500 ft<sup>3</sup>/s at the Yukon River at Pilot Station. Suspended-sediment load averages 74 million tons per year and DOC loads average 1.7 million tons per year.

## Summary

The Yukon River provides a daily average of about 228,000 ft<sup>3</sup>/s of water to the Bering Sea. This large North American river also transports an average of 74 million tons of suspended sediment and 1.7 million tons of DOC each year (based on a 5-year record, 2001–05). Downstream of the confluence of the White River and the Yukon River, the clarity of the Yukon River changes markedly, remaining sediment laden for its entire reach to the Bering Sea. The White and Tanana Rivers, the two largest glacier-fed rivers in the basin, supply most of the suspended sediment to the Yukon River. A number of tributaries are characterized by concentrations of DOC greater than 10 mg/L, possibly indicating that these streams and rivers may provide significant amounts of DOC to the Yukon River. The Porcupine River basin underlain by continuous permafrost, contributes about 50 percent more DOC than the Tanana River, a basin of similar size underlain by discontinuous permafrost. Basins dominated by permafrost or wetlands may be the largest contributors of DOC to the Yukon River.

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*Yukon Flats near Ft. Yukon—Photograph courtesy of Paul Schuster, USGS*

*USGS personnel at Eagle, Alaska—Photograph courtesy of Paul Schuster, USGS*

*USGS personnel at Dalton Highway Bridge—Photograph courtesy of Mark Dornblaser, USGS*

*Banner—Yukon River at Eagle, Alaska. Photograph courtesy of Dan Long, USGS*

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