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THE DISCHARGE OF YUKON RIVER AT EAGLE, ALASKA

BY

E. A. PORTER AND R. W. DAVENPORT

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THE DISCHARGE OF YUKON RIVER AT EAGLE, ALASKA.

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LOCATION AND SIZE OF THE YUKON BASIN.

Although the topographic and geographic features of the valley of Yukon River have been described by many writers, probably few people have an adequate conception of the size of the river and the characteristics of its flow. Brooks[1] gives the Yukon fifth place among the large rivers in North America and estimates its catchment area at about 330,000 square miles. The approximate length and drainage area of some of the chief rivers of North America are given in Table 1.

TABLE 1.—*Length and drainage area of the principal rivers of North America.*

River.	Approximate length.	Drainage area.
	Miles.	*Square miles.*
Mississippi to head of Missouri	6,000	1,238,000
Mackenzie	2,868	677,400
St. Lawrence	2,600	565,000
Winnipeg and Nelson	3,840	486,500
Yukon, with Lewes and Teslin	2,300	330,000
Colorado and Green	2,000	300,000
Columbia	1,200	259,000
Ohio and Allegheny	1,300	203,000

The Yukon heads in the northeastern part of British Columbia and meanders northwestward through the Yukon Territory of Canada to the Alaska-Canada boundary near Eagle, the first Alaskan settlement which the river passes on its journey to the sea. Near the Arctic Circle the river bends to the southwest, and it continues in this general course to its entrance into Bering Sea. Its basin, as shown on the map, figure 3, comprises the great region lying between the Pacific mountain system on the south and the Rocky Mountain system on the north. The record of discharge of the Yukon presented in this paper was obtained at Eagle. A view of the Yukon and the town of Eagle is given in Plate IV, *A*. The approximate drainage area of the Yukon at various points along its course is shown in Table 2.

[1] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 64, 1906.

TABLE 2.—*Drainage areas of Yukon River.*

Above—	Distance from mouth.	Drainage area.
	Miles.	*Square miles.*
Dawson, Yukon Territory	1,298	115,000
Eagle, Alaska	1,208	122,000
Fort Yukon	990	177,000
Rampart	750	206,000
Mouth	0	330,000

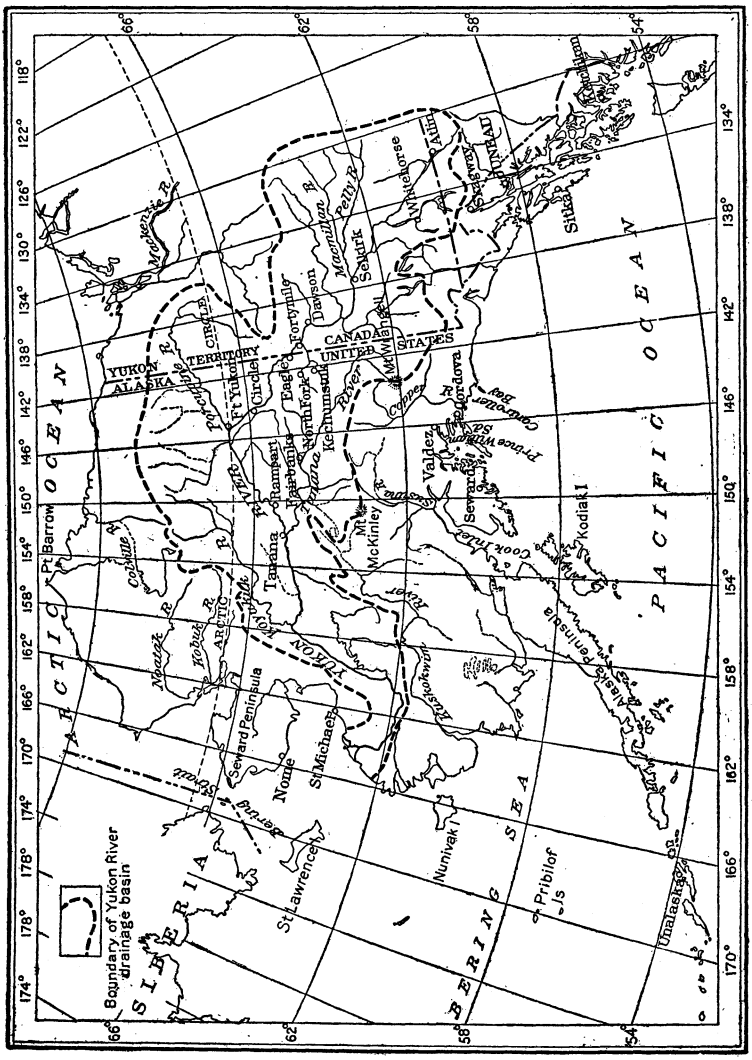

FIGURE 3.—Map of Alaska showing boundary of Yukon River drainage basin.

CLIMATIC CONDITIONS.

In order to comprehend the peculiar characteristics of stream flow in this far northern latitude it is necessary to know something of the climatic conditions. The temperature at Eagle may be considered typical of that prevailing throughout the interior region of Alaska. The maximum, minimum, and mean monthly temperatures at this place, as compiled from the Weather Bureau records for 1905 to 1912, are shown in Table 3. The mean annual temperature for this period is 23.7° F. Because of the low mean temperature to which the Yukon Valley is subject a very large part of its area is perpetually frozen to bedrock, with the exception of a shallow layer at the surface which can be thawed during the short, cool summers.

TABLE 3.—*Maximum, minimum, and mean monthly temperature (°F.) at Eagle, Alaska, 1905 to 1912.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum	36	45	51	64	85	92	91	82	79	63	42	35
Minimum	—69	—56	—54	—38	16	24	29	20	2	—21	—52	—53
Mean	—23.6	— 8.5	11.6	25.2	47.6	58.1	59.6	53.0	41.0	26.5	2.8	— 8.4

In general, the vegetation of the interior is sparse, as would be inferred from the condition of the ground and the shortness of the growing season. The vegetation consists principally of moss and a thin growth of wild grasses. In favorable localities, however, the heat and sunshine of the long summer days induce rapid growth of vegetation, and the wild hay and some flowering plants attain great luxuriance. The forest is also generally scanty and consists chiefly of stunted spruces, birches, and alder brush.

The mean annual precipitation, reduced to inches of rainfall, for representative localities in the Yukon River basin has been compiled from records of the Canadian Meteorological Service and the United States Weather Bureau. Table 4 shows the stations, their location, the mean annual precipitation, the length of the record in months, and the percentage of the mean annual precipitation that occurs in the four principal open-season months—June, July, August, and September.

TABLE 4.—*Mean annual precipitation at stations in Yukon River basin.*

Station.	Location.		Mean annual precipitation (inches).	Duration of record (months).	Percentage of annual precipitation falling June 1 to Sept. 30.
	Latitude.	Longitude.			
	° ′	° ′			
Atlin, British Columbia	59 45	133 46	11.39	99	38.4
Whitehorse, Yukon Territory	60 46	135 00	11.25	64	63.5
Dawson, Yukon Territory	64 05	139 28	12.94	148	44.9
Kechumstuk, Alaska	64 07	142 20	10.21	61	68.5
North Fork, Alaska	64 30	142 10	12.96	28	62.0
Eagle, Alaska	64 45	141 10	11.72	171	59.7
Fairbanks, Alaska	64 50	147 44	11.48	102	55.2
Tanana, Alaska	65 12	152 00	11.59	148	55.0
Rampart, Alaska	65 30	150 15	10.85	100	48.5

These records show clearly the marked uniformity of precipitation throughout the Yukon River basin. The average mean annual precipitation at these stations is about 11.5 inches, and the data at hand indicate that this is a reasonable estimate for the average precipitation throughout the Yukon basin at elevations below 2,000 feet. In some parts of the area increase of precipitation undoubtedly accompanies an increase of altitude above 2,000 feet. Allowing for this increase, the mean annual precipitation of the Yukon basin is estimated as 13 inches. The estimate is admittedly only approximate, but it is probably not greatly in error.

Thus it is evident that interior Alaska is a region of small rainfall. Indeed, Abbe [1] has observed in regard to this region that "the range of precipitation is characteristic of that portion of the United States which lies between the Sierra Nevada and the Rocky Mountains north of the latitude of Salt Lake City." The meagerness of the rainfall is impressed upon one who becomes acquainted with the status of placer mining in the interior. Large placer fields lie dormant for lack of water to work them, and in various localities hundreds of thousands of dollars have been spent in constructing canals that have been almost a total failure because of insufficient water supply.

During the period corresponding closely to that from October to March, inclusive, all precipitation occurs as snow, and it accumulates to depths of 2 to 5 feet in the different seasons. With the warm days of April and May the snow commences to thaw rapidly and soon disappears from the places most exposed to the rays of the sun, but on the north slopes and in the deep gulches snow banks remain until far into the summer. The influence of the melting snow on the streams is large in the early summer, but as the season advances it gradually decreases until the run-off derived from this source is practically inappreciable.

Navigation on the Yukon has so important a bearing on the commerce and the facility of travel in interior Alaska that it has given rise to a general recognition of two seasons—the "open season," the period during which the Yukon is open to navigation, and the "closed season," when the Yukon is either filled with floating ice or frozen over. Table 5 gives the dates of the break-up, or first movement of the ice in the spring, at Eagle, the freeze-up in the fall at the same locality, and the number of days the river was open, as recorded by the Northern Commercial Co.

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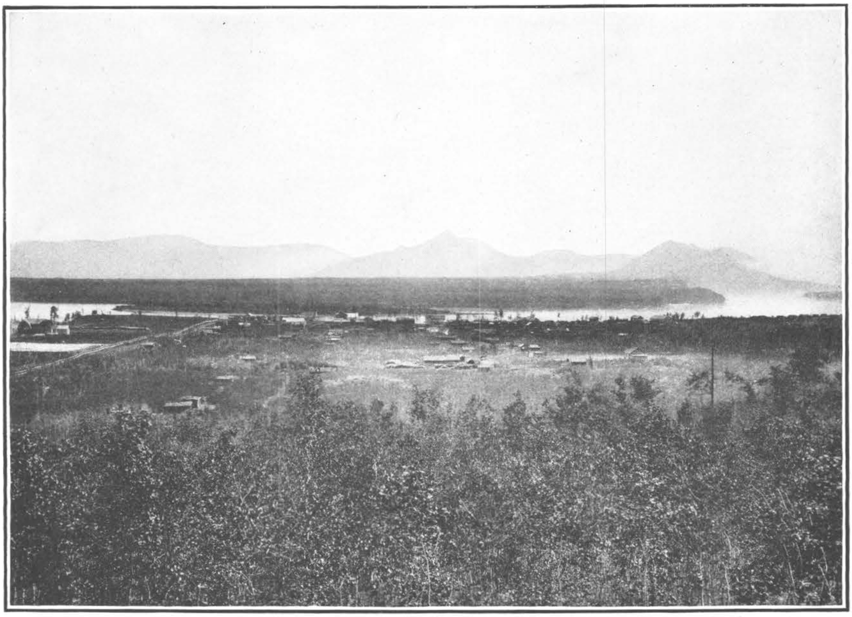
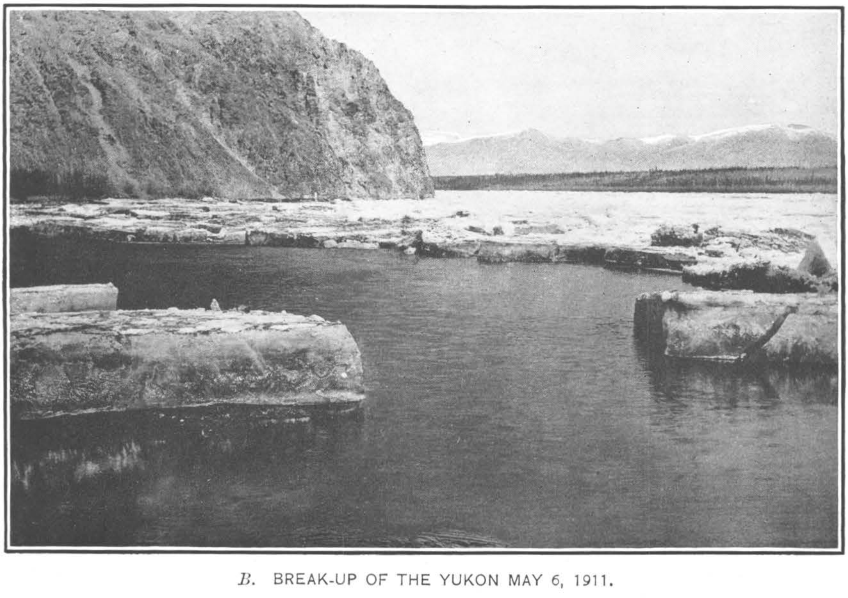
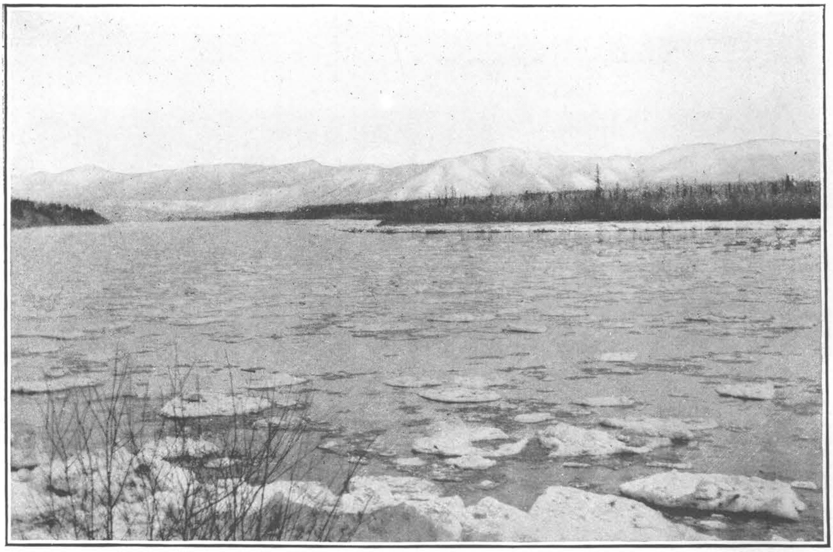
1 Brooks, A. H., and others, The geography and geology of Alaska, a summary of existing knowledge, with a section on climate by Cleveland Abbe, and a topographic map and a description thereof by R. U. Goode: U. S. Geol. Survey Prof. Paper 45, p. 156, 1906.



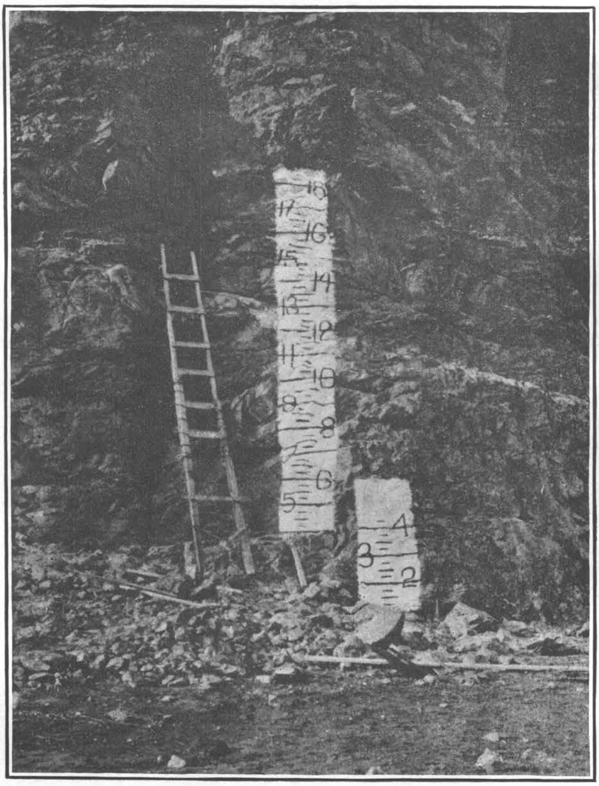
A. YUKON RIVER AND TOWN OF EAGLE, ALASKA.



B. BREAK-UP OF THE YUKON MAY 6, 1911.



A. YUKON RIVER AFTER THE BREAK-UP.



B. GAGE OF THE GEOLOGICAL SURVEY ON THE YUKON AT EAGLE, ALASKA.

TABLE 5.—*Dates of the break-up and freeze-up of Yukon River at Eagle, Alaska.*

Year.	Break-up.	Freeze-up.	Days open.	Year.	Break-up.	Freeze-up.	Days open.
1898	May 10	Nov. 8	182	1906	May 9	Nov. 14	189
1899	May 16	Nov. 2	170	1907	May 3	Nov. 4	185
1900	May 8	Nov. 13	189	1908	May 7	Oct. 29	175
1901	May 12	Nov. 15	187	1909	May 10	Nov. 22	196
1902	May 15	Nov. 19	188	1910	..do....	Nov. 8	182
1903	May 14	Nov. 13	183	1911	May 6	Nov. 15	193
1904	May 6	Nov. 14	194	1912	May 3	Nov. 16	197
1905	May 9	Oct. 9	153				

The break-up of the Yukon is not only an event of great economic significance to the inhabitants of interior Alaska, but it presents features of intense dramatic interest as well. One who has not witnessed the break-up can hardly imagine the impressiveness of the spectacle. From bank to bank the surface of the river is a solid mass of huge, moving ice cakes which are constantly grinding and disintegrating with an awe-inspiring exhibition of resistless force. During this break-up, which lasts from 7 to 12 days, the flow of the ice is sometimes obstructed, but finally the obstacles are overcome and the ice moves on, carrying away every movable thing in its path. (See Pls. IV, *B*, and V, *B*.)

The freeze-up is less spectacular. With the increasing cold of the autumn slush ice forms in the stream and as the cold becomes more intense it increases in volume until finally there is sufficient to bridge the stream with ice. This means the termination of navigation on the Yukon until the following May.

HYDROMETRIC DATA.

At various times estimates have been made of the discharge of Yukon River. Engineers of the Canadian Government have made discharge measurements of the Yukon and its tributaries within the Yukon Territory.[1] Brooks[2] reports an approximate measurement of discharge of the Yukon made by the United States Coast and Geodetic Survey at a section 73 miles from the mouth. In 1909 C. E. Ellsworth, assistant engineer in the United States Geological Survey, made three discharge measurements at Rampart, but no permanent gaging section was there available. These results and those of other investigations of the surface water supply of the Yukon-Tanana region, from 1907 to 1912, have been compiled for publication.[3]

Not until 1911 was it practicable to maintain a regular gaging station on Yukon River. This station was established at Eagle in

[1] Ogilvie, William, The Klondike official guide, p. 56, Buffalo, 1898. Canada Commission of Conservation, Water powers of Canada, p. 288, Ottawa, 1911.

[2] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 65, 1906.

[3] Ellsworth, C. E., and Davenport, R. W., U. S. Geol. Survey Water-Supply Paper 342 (in press).

May, 1911, by C. E. Ellsworth and E. A. Porter. During 1911 it was maintained under the personal supervision of E. A. Porter, and during 1912 under that of R. W. Davenport. Observations of daily gage heights were made by W. P. Thrall, agent of the Northern Commercial Co., at Eagle, during the open seasons of 1911, 1912, and a part of 1913.

The long, easily sloping gravel banks of the Yukon and the destructive action of ice to which they are subject make the selection of a permanent site for a gage a difficult problem. At Eagle, however, an admirable site was found on the high bluff that juts into the stream just below the town. On the vertical face of this bluff a white strip 3 feet wide and about 18 feet high was painted, as shown in Plate V, *B*. This white strip was graduated in black paint at intervals of a quarter of a foot and the even feet were marked with numbers large enough to be read by a telescope from the hotel piazza at Eagle, about half a mile distant. The gage was installed before the break-up of May 6, 1911, when the river was at a very low stage. The observer read the gage to one-eighth of a foot. A study of the rating curve shows that at medium stages the ratio of increase of discharge to increase of gage height is such that reading the gage to one-eighth of a foot does not introduce into the discharge an error of more than 1 per cent. This amount is well within the limits of accuracy ordinarily required for observations of gage heights.

The only feasible method for making open-channel discharge measurements of the Yukon is by floats. About 2 miles above Eagle a stretch of channel was selected which is straight for about 1,000 feet and through which its cross section was believed to be practically uniform. The river at this point is about 1,600 feet wide. About midlength of the proposed run for the floats the cross section was determined by cutting holes through the ice at intervals of 50 feet and making soundings at each hole. The exposed section was determined by levels and, with the section obtained by soundings, was referred to a permanent benchmark.

On April 22, 1911, the vertical velocity of the stream at each ice hole was determined by a Price current meter and the discharge was computed as 10,100 second-feet. This is considered to be the minimum discharge of the Yukon at Eagle for 1911, and it will probably represent very closely the minimum from year to year.

During May, 1911, seven discharge measurements were made by means of ice floats. About May 1 the Yukon began to rise rapidly from the melting snows, and by May 6 the river had become so high that the ice covering the river could no longer remain intact. On this date the "break-up" began and it continued for about ten days. Toward the end of this period the floating ice gradually became but thinly spotted across the surface of the river, while the banks on both sides were piled high with large blocks of ice varying in thickness from 3 to 8 feet. The condition of the river at the time when these discharge measurements were made is shown in Plate V, *A*. The instruments used were a transit and a stop watch. The passage of ice cakes was timed over a run of 500 feet and their location was determined by triangulation. Two men selected a cake as it crossed the upper range and while one man followed it with the transit telescope, the other went down to the lower range and when the float crossed signaled the transitman and noted the time.

In 1912 three measurements were made, two when driftwood was coming down the river in sufficient quantities to serve as floats and one by means of bottle floats. For the bottle floats beer bottles were weighted with sand and were marked with flags stuck in the necks. White flags were found to be best adapted to be seen at a distance over the water surface. These floats were dropped by a boatman in a rowboat at intervals of about 75 feet across the stream above the upper range line.

In 1912 observations were made to determine the coefficient to be applied to the surface velocities to reduce to the mean velocity. In a stream so large and swift as the Yukon the determination of the vertical velocity curve presents some interesting problems. The most serious of these problems was to find a method of holding one position in the stream long enough to measure velocities at the desired depths. The method which proved successful was by using a rowboat with a sack of rocks as an anchor. A rope was fastened to the sack of rocks, then it was secured to the bow of the boat and carefully arranged in a coil. The boat was hauled far above the measuring section and when all was ready it was energetically rowed out into the channel, the swift current carrying it rapidly downstream in the meantime. When the desired position in the channel was reached the sack of rocks was thrown over, and as soon as it held the boat the velocities were determined at the required depths with the current meter. It was found necessary to use about 200 pounds of rocks to furnish sufficient anchorage. When the observations at one point were completed the rope was cut, the boat pulled to shore, and the operation repeated. The results of these observations indicated a coefficient of 0.92, which has been used for the reduction of all discharge measurements, the results of which are tabulated in Table 6 and shown in figure 4. With one exception these measurements plot within 3 per cent of the mean curve of relation between gage heights and discharge. The measurement of May 19, 1911, plots 15 per cent greater than this curve, probably because of certain abnormal conditions of ice flow at the time of the measurement. It has been disregarded in the preparation of the rating curve.

TABLE 6.—*Discharge measurements on Yukon River at Eagle, Alaska, 1911 and 1912.*

Date.	Gage height.	Discharge.	Reference number on figure 4.
1911.	*Feet.*	*Second-feet.*	
Apr. 22	....	*a* 10,100	....
May 9	2.90	125,000	1
10	3.10	125,000	2
16	2.40	121,000	3
19	7.50	216,000	4
20	10.10	235,000	5
21	11.25	238,000	6
22	11.90	253,000	7
1912.			
May 21	3.45	127,000	8
July 29	9.65	223,000	9
Sept. 14	−2.00	68,200	10

a Discharge measured through ice.

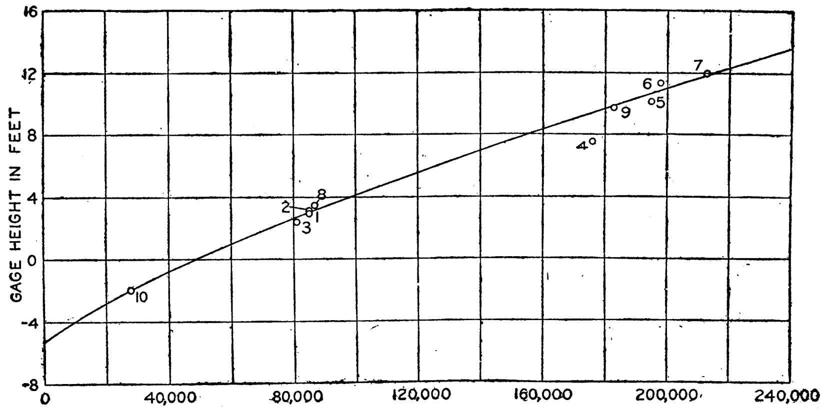


FIGURE 4.—Rating curve for Yukon River at Eagle, Alaska.

The maximum discharge measurement was made May 22, 1911, when the discharge was 253,000 second-feet. The width of the water surface at the measuring section was 1,645 feet, and the greatest depth was 28.7 feet. The surface velocity at this point of greatest depth was 9.52 feet per second and the mean surface velocity for the section was 8.55 feet per second, which corresponds to a current of 5.8 miles an hour. From Eagle to Whitehorse the grade of the river is higher than below Eagle, and steamboats can make but slow progress upstream. With the continual shifting of the channel near Circle and the Yukon Flats and the swift currents to be overcome in the upper section of the river, navigation on the Yukon is not easy.

Table 7 shows the mean monthly discharge, run-off in second-feet per square mile, and run-off in inches on the drainage area for 1911, 1912, and 1913. The gage-height record was kept for 145 days in 1911, for 155 days in 1912, and for 80 days in 1913. The monthly means for the remaining parts of this three-year period are obtained from estimates based on data of precipitation, a personal knowledge of the conditions, and such miscellaneous measurements of discharge as have been made in winter.

Over two-thirds of the estimated total run-off of this period was determined from the gage-height record, and the monthly mean should have a probable error not exceeding 10 per cent. The margin of error in the estimated portion of the run-off may therefore be fairly large without increasing the probable error of the total very appreciably. It seems reasonable to set the probable error of the mean results for the three years as shown in Table 7 at 10 per cent.

TABLE 7.—*Monthly discharge of Yukon River at Eagle, Alaska, 1911, 1912, and 1913.*

Month.	Discharge in second-feet.			Second-feet per square mile.			Run-off (depth in inches on drainage area).		
	1911	1912	1913	1911	1912	1913	1911	1912	1913
January	21,000	21,000	21,000	0.172	0.172	0.172	0.20	0.20	0.20
February	15,000	15,000	15,000	.123	.123	.123	.13	.13	.13
March	11,000	11,000	11,000	.090	.090	.090	.10	.10	.10
April	12,000	12,000	12,000	.098	.098	.098	.11	.11	.11
May	156,000	125,000	117,000	1.28	1.02	.959	1.48	1.18	1.11
June	184,000	160,000	199,000	1.51	1.32	1.63	1.68	1.47	1.82
July	178,000	147,000	164,000	1.46	1.20	1.34	1.68	1.38	1.54
August	139,000	127,000	133,000	1.14	1.04	1.09	1.31	1.20	1.26
September	106,000	73,600	90,000	.869	.603	.738	.97	.67	.82
October	60,000	51,000	55,000	.492	.418	.451	.57	.48	.50
November	37,000	37,000	37,000	.303	.303	.303	.34	.34	.34
December	28,000	28,000	28,000	.230	.230	.230	.27	.27	.27
The year	78,900	67,300	73,500	.647	.552	.602	8.84	7.53	8.20
Mean for 3 years	....	73,200	....	....	.600	....	....	8.19	....

COMPARISON OF RUN-OFF AND PRECIPITATION.

Although the data are insufficient for a comparison of run-off and precipitation that would afford conclusive results, they suffice to emphasize certain interesting characteristics of run-off in the Yukon drainage basin.

Table 8 shows the mean annual precipitation at stations in the drainage area above Eagle and other stations in the Yukon Valley for the period from November 1, 1910, to October 31, 1913, and its percentage of the mean record at the respective stations. This table shows a well-defined tendency for the precipitation of this period to be below the normal. Assuming that the mean of the percentages represents the prevailing condition throughout the basin and considering 13 inches as the normal rainfall in the same area, we find that the mean annual rainfall in the basin for the three water-years considered is approximately 12 inches. The same process of reasoning leads to the belief that the computed mean discharge of the Yukon at Eagle is also probably a little below the normal. The mean annual run-off in depth in inches on the drainage area is given in Table 7 as 8.19. Thus it appears that the run-off is approximately 65 per cent of the precipitation for the three water-years from November 1, 1910, to October 31, 1913.

TABLE 8.—*Annual precipitation in inches at stations in Yukon River basin, Nov. 1, 1910, to Oct. 31, 1913.*

Station.	Nov. 1, 1910, to Oct. 31, 1911.	Nov. 1, 1911, to Oct. 31, 1912.	Nov. 1, 1912, to Oct. 31, 1913.	Mean for period.	Mean annual precipitation from Table 4.	Per cent of mean annual precipitation.
Atlin, British Columbia	10.82	8.77	10.62	10.07	11.39	88
Dawson, Yukon Territory	15.33	9.80	[a] 9.52	11.32	12.94	88
Eagle, Alaska	12.90	10.94	8.63	10.82	11.72	92
Fairbanks, Alaska	11.73	10.52	10.13	10.79	11.48	94
Tanana, Alaska	12.30	12.75	10.19	12.08	11.59	104
Rampart, Alaska	8.62	11.12	8.18	9.31	10.85	86

[a] Records for March, April, and June lacking. To obtain the result the mean monthly precipitation for the respective months was substituted.

Comparing this result with that for various drainage basins throughout the United States, one is apt to question the accuracy of so high a percentage of run-off. The drainage area of the Yukon presents conditions decidedly different from those in most of the river basins of the United States. Except for the shallow layer at the surface, which can be thawed during the short, cool summer, practically the whole area above Eagle remains perpetually frozen to bedrock. Consequently when the thawed earth has become saturated the rainfall can only seek its way to the nearest stream. The topography and climate of the region are unfavorable for great losses by evaporation, the grades of the streams and slopes of the valleys are comparatively large, and the lake area is small. The growing period for vegetation is short and is too cool for a luxuriant growth, and losses due to vegetation are relatively small. Therefore a run-off of 65 per cent of the rainfall for interior Alaska is believed to at least approximate the true ratio.

On consideration of the small run-off and the intense cold of the winter season in interior Alaska it is evident that surface mining and power development of any large amount must cease for a large portion of the year. The records show that the greater part of the precipitation occurs during the open season and that much the greater part of the run-off occurs during the same period. The topography, climate, and vegetation of the area are such that the ratio of run-off to precipitation is abnormally large.

DISCHARGE OF SOME LARGE RIVERS IN THE UNITED STATES, THE YUKON, AND THE NILE.

An interesting table has been compiled by G. C. Stevens, of the United States Geological Survey, showing the discharge of some of the large rivers in the United States, of the Yukon, and of the Nile in Egypt. The sources of the various records are given in footnotes.

TABLE 9.—*Discharge of some large rivers in the United States and of the Yukon and the Nile.*

River.	Point.	Drainage area.	Discharge in second-feet.		
			Maximum.	Minimum.	Mean.
		Sq. miles.			
Mississippi [a]	Mouth	1,238,000	1,800,000	125,000	695,000
Do. [b]	Grafton, Ill.	171,500	360,000	25,000	127,000
Ohio [b]	Paducah, Ky	202,000	1,400,000	21,000	300,000
Missouri [b]	St. Charles, Mo	527,000	600,000	5,000	100,000
Susquehanna [c]	McCall Ferry, Pa	26,800	353,000	2,200	38,800
Rio Grande [d]	Brownsville, Tex	248,000	35,600	650	7,100
Colorado [c]	Yuma, Ariz	225,000	150,000	2,700	23,300
Columbia [e]	The Dalles, Oreg	237,000	1,390,000	48,500	235,000
Yukon [f]	Eagle, Alaska	122,000	254,000	10,100	73,200
St. Lawrence [g]	Ogdensburg, N. Y	383,300	330,000	185,000	252,000
Nile [h]	Assouan, Egypt	1,262,000	353,000	14,500	116,000

[a] Drainage area and mean discharge from U. S. Geol. Survey Water-Supply Paper 234; maximum and minimum values are conclusions from a paper by William Starling, The discharge of the Mississippi River: Am. Soc. Civil Eng. Trans., vol. 34, November, 1895.

[b] From reports United States Army Engineers.

[c] From United States Geological Survey records.

[d] From measurements by International Boundary Commission, Mexican section, published by United States Geological Survey.

[e] From United States Geological Survey records. Drainage area at mouth is 259,000 square miles.

[f] From United States Geological Survey records. Drainage area at mouth is 330,000 square miles.

[g] From a report of E. S. Wheeler, assistant engineer, United States Army. Chief Eng. Rept., 1903, part 4.

[h] Peale, Sidney, The binding of the Nile and the new Sudan.

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