Floods in the Skagit River Basin Washington

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FLOODS IN THE SKAGIT RIVER BASIN, WASHINGTON

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ABSTRACT

According to Indian tradition, floods of unusually great magnitude harassed the Skagit River basin about 1815 and 1856. The heights of these floods were not recorded at the time; so they are called historical floods. Since the arrival of white men about 1863, a number of large and damaging floods have been witnessed and recorded.

Data concerning and verifying the early floods, including those of 1815 and 1856, were collected prior to 1923 by James E. Stewart. He talked with many of the early settlers in the valley who had listened to Indians tell about the terrible floods. Some of these settlers had referenced the maximum stages of floods they had witnessed by cutting notches at or measuring to high-water marks on trees. In order to verify flood stages Stewart spent many weeks finding and levelling to high-water marks such as drift deposits, sand layers in coves, and silt in the bark of certain types of trees.

Gaging stations have been in operation at various locations on the Skagit River and its tributaries since 1909, so recorded peak stages are available at certain sites for floods occurring since that date. All peak discharge data available for both historical and recorded floods have been listed in this report.

The types of floods as to winter and summer, the duration of peaks, and the effect of reservoirs are discussed.

In 1899 Sterling Dam was constructed at the head of Gages Slough near Sedro Woolley. This was the beginning of major diking in the lower reaches of the Skagit River. Maps included in the report show the location of most of the dike failures that have occurred during the last 73 years and the area probably inundated by major floods. The damage resulting from certain floods is briefly discussed.

The report is concluded with a brief discussion of the U.S. Geological Survey method of computing flood-frequency curves as applied to the Skagit River basin. The treatment of single-station records and a means of combining these records for expressing regional significance are exemplified. Historical data are used in the development of both the single-station and the regional curves.

INTRODUCTION

Skagit River, the largest in northwestern Washington, rises in the main Cascade Range and empties into Skagit Bay near Mount Vernon. The total drainage area is about 3,100 square miles, of which 400 square miles are in Canada. A map of the area shows location and general features on plate 1.

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The date of the first exploration of the Skagit Valley is unknown, but Hudson's Bay and Northwestern fur trappers probably started working the Skagit Valley about 1810. The first white settlement on the delta at Mount Vernon occurred about 1863. The actual settlement of the valley upstream from the delta started about 1878 when gold was discovered on Ruby Creek, which empties into the Skagit River at the point where the river starts to break through the secondary Cascade barrier. With the impetus of excitement over gold, there was a comparatively rapid influx of population to the whole valley. However, the gold-boom settlement of about 5,000 people on Ruby Creek died out within a very few years. The main increases in permanent valley population have occurred since the Northern Pacific Railway pushed northward across the Skagit delta in 1890, and have been attributable mainly to logging and lumbering, mining, and agriculture.

The Skagit River valley has a history of floods that dates from about 1815. The basin has been subjected to several damaging floods since the year 1863 when it was first settled by white men. Indian legends indicate that even greater floods occurred in the nineteenth century prior to 1863. The exact elevations of all of these floods are not known, but their relative magnitudes have been fairly well determined by intensive research and study in the valley. A brief resume of the floods is as follows:

1. About 1815: Highest flood.
2. 1856: Second highest flood.
3. 1880, 1882, and 1894: Spring floods that inundated lower valley for long period.
4. November 16, 1896: Highest flood since the settlement of the valley in or about 1878 and probably the highest since 1856.
5. November 19, 1897: Floods everywhere higher than the 1896 flood, especially high from the mouth of the Cascade River to just below Birdsview. In general, in this section of the river the 1897 peak has not been exceeded to date (1958). The 1897 flood rose with remarkable suddenness, due to a very warm Chinook wind and heavy rain. The Cascade, Sauk, and Baker Rivers were very high and caused a high peak in the Skagit River near the mouth of each stream. Owing to the sudden starting and stopping of flood conditions, the peaks were rapidly reduced by channel storage as the crest moved downstream.
6. November 16, 1906: Flood exceeded the 1897 flood in the diked districts on the delta, because of the dikes. In all other sections of the river the flood of 1906 was lower than that of 1897.
7. November 30, 1909: Since the settlement of the valley, this flood has exceeded all floods from the headwaters in Canada to the mouth of the Cascade River; the same is true from just below Birdsview to the sea, except where log jams forced the floods of 1897 and 1921 to higher elevations.
8. December 30, 1917: Flood was remarkable for the length of time it remained high, rather than for its peak stage. Comparable to 1896 and 1906 flood in regard to height. The damage on the delta was due partly to the long flood period producing a great deal of overflow after the dikes had broken.

A, Aerial view of Conway and vicinity.

B, North Fork distributary below the bridge on U.S. Highway 99, showing the break in the dike. Photographs by U.S. Army Corps of Engineers.

FLOOD OF 1951 IN VICINITY OF CONWAY, WASH.

A, View upstream from Great Northern Railway bridge north of Mount Vernon.

B, Aerial view of town of Hamilton and valley downstream. Photographs by U.S. Army Corps of Engineers.

FLOOD OF FEBRUARY 1951 IN VICINITY OF MOUNT VERNON AND
HAMILTON, WASHINGTON

9. December 12, 1921: Flood was nearly as great as the flood of 1909 and in most of the basin was higher than the flood of 1917.
10. February 1932: Flood would have been much more serious if there had been no upstream storage. Peak at gaging station on Skagit River (in a canyon known locally as "The Dalles") near Concrete was estimated to have been reduced by 35,000 cfs. Natural discharge at The Dalles estimated to be about 40,000 cfs less than the 1917 flood.
11. November 1949: Upstream storage estimated to have reduced the peak at The Dalles near Concrete by 45,000 cfs. Under natural conditions this flood probably would have been greater than the 1932 flood and only slightly smaller than the 1917 flood.
12. February 1951: Estimated natural discharge less at The Dalles near Concrete than for any of the above floods. Because of the long duration of this flood, the crest reaching Mount Vernon had been reduced very little by channel storage and exceeded the 1949 flood at that location by about 2.5 feet.

Major floods have caused considerable monetary damage, especially in the lower reaches of the valley. Estimates of known flood losses compiled by the U.S. Army Corps of Engineers total $4,850,000 from 1894 to 1932. The number of lives lost is not known.

Floods of recent years have been less damaging because they have been of lesser magnitude and the power dams in the upper reaches of the river have provided some storage.

In 1922, as a result of damage from the 1921 and earlier floods, there was a desire by those suffering damage to have studies initiated as a preliminary step to possible flood protection measures. Dikes had been built to confine the lower reaches of the river but they offered protection only against the lesser floods. The first logical step was to determine the size of the floods to be controlled. Representatives of Skagit County made arrangements with G. L. Parker, then district engineer of the U.S. Geological Survey Surface Water Branch at Tacoma, to determine the sizes of the floods. J. E. Stewart was given the assignment of compiling field data and writing a preliminary report, which was completed in 1923 but not published.

In the study for the 1923 report, redeterminations were made of the peak discharge of such floods as had occurred on the streams in the area since the beginning of streamflow records. Also, approximate calculations were made of the peak discharge of all the great floods that occurred between the time of the first white settlement of the Skagit Valley and the beginning of the streamflow records. In addition, field investigations and computations were made of the stage, discharge, and approximate dates of two great floods that occurred prior to the arrival of the first white settlers. The conclusion was reached that the earlier and greater of these two floods probably was as large or nearly as large as the greatest flood that has occurred here within the last several hundred years. Information of floods, occurring before 1863,

was handed down orally by the Indians, and by finding silt and stains in the bark of trees and sand deposits in protected coves along the stream.

The 1923 report recommended that certain areas be given early flood protection and that a warning system be installed. Also, suggestions were made as to some preliminary steps toward permanent flood protection. The pertinent data from the report written by J. E. Stewart are included in this report. Interest in the report was revived in 1942 by F. M. Veatch, who succeeded G. L. Parker as district engineer. As a result, some work on it was done in the Washington office during the next few years, chiefly by W. S. Eisenlohr, Jr. In 1949 additional field data were obtained, and work was resumed to evaluate previous data. Most of this report was written by G. L. Bodhaine, Tacoma district. He used the basic data and reports of J. E. Stewart and recent data concerning floods in the Skagit River basin.

The present report contains discussions of many features bearing on the magnitudes of past and present floods, of the geologic history as it may affect floods and flood evidence, and of dike failures and inundated areas. It also contains a regional flood-frequency study based on the methods most recently developed by the U.S. Geological Survey.

Good photographs of the earlier historic floods are not available, but pictures were obtained by the U.S. Army Corps of Engineers during the flood of February 1951. These pictures were taken at noon a few hours after the peak, which occurred at about 7 a.m. on February 11 near Mount Vernon, and are presented as plates 3 and 4.

The photographs on plate 3 were taken in the area of the distributaries near the mouth of the river where dike breakage occurred. Plate 3A shows the inundated area in the town of Conway and vicinity. Levee break on the North Fork distributary is shown in plate 3B.

Plate 4A shows the inundated area between the railroad bridge north of Mount Vernon (just upstream from the gaging station near Mount Vernon) and the town of Sedro Woolley. The flood at the town of Hamilton, about 12 miles upstream from Sedro Woolley, is shown in plage 4B.

DESCRIPTION OF THE BASIN
GEOGRAPHY

The Skagit River may properly be said to head in Skaist Creek, its most upstream tributary, of which the most northerly branch begins on the slopes of Skaist Mountain in British Columbia, Canada, about 20 miles north of the international boundary. From there, the river flows in a generally southwestward direction for about 25 miles; thence about 7 miles in a generally southeastward direction to a point

about 2 miles north of the international boundary; thence in a generally southward direction to a place in the State of Washington about 20 miles south of the international boundary, where it turns southwestward and begins to break through the Skagit Range.

Through the Skagit Range the river flows in a deep, narrow, steep, and almost continuous canyon about 10 miles long. This section of the river is now the center of a great hydroelectric-power project of the city of Seattle. The project involves three major developments; namely, Ross (formerly Ruby), Diablo, and Gorge.

The Ross development at the head of the canyon involves a dam that, when completed, will raise the water more than 600 feet and create a reservoir with capacity of 3,450,000 acre-feet, completely controlling the normal river flow below that point and a powerhouse that ultimately will have a capacity of 360,000 kilowatts. At present, the dam is 540 feet high, provides 1,400,000 acre-feet of storage, and supplies water to 3 generators producing a total of 270,000 kilowatts.

The Diablo development is located at about the center of the 10-mile section of canyon. It involves a dam that raises the water 325 feet and backs it to the toe of Ross dam, but there is a reservoir capacity of only 90,000 acre-feet because of the narrowness of the canyon. A powerplant of 132,000 kilowatt capacity has been completed and is in operation.

The Gorge powerplant now has a capacity of 108,000 kilowatts. The development consists of a temporary masonry diversion dam and 11,000 feet of 20.5-foot diameter tunnel which furnishes a head of 294 feet at the powerhouse. The temporary diversion dam is now being replaced by a permanent dam more than 100 feet high which will back water to the toe of Diablo dam but will provide only about 6,000 acre-feet of storage. The head on the Gorge plant will thereby be increased to 385 feet and the plant capacity, including the additional units being installed, will be 153,000 kilowatts.

The foregoing developments, mainly Ross, will materially reduce flood flows downstream and particularly reduce the smaller floods.

The drainage area where the river emerges from its canyon section at the Gorge powerplant is about 1,160 square miles. After leaving the canyon section, the Skagit River within a distance of 20 miles is enlarged by the Cascade, the Sauk, and the Baker Rivers, its three largest tributaries. Near the mouth of the Sauk River, the Skagit River changes its general direction from southwest to west. It emerges upon its delta plain about 35 miles farther downstream near the city of Sedro Woolley, where the drainage area is about 3,000 square miles. At Sedro Woolley, the river again changes its course to southwest and flows along the southeastern and landward side of its delta. Finally, it divides into typical delta distributaries and

empties into Skagit Bay which lies nearly east of the Straits of Juan de Fuca. The Skagit River delta is about 45 miles south of the international boundary.

The following table shows the locations of various features with respect to the mouth of the Skagit River at Skagit Bay:

Location	Miles above mouth	Location	Miles above mouth
Mouth at Skagit Bay	0.0	Gage above Alma Creek	84.2
North Fork distributary	7.0	Gage at Newhalem	92.2
Mount Vernon	10.2	Gorge Dam	95.3
Gage near Mount Vernon	14.5	Stetattle Creek	98.5
Nookachamps Creek	17.4	Gage at Reflector Bar	99.3
Gage near Sedro Woolley	21.1	Diablo Dam	99.6
Day Creek	34.1	Thunder Creek	100.9
Alder Creek	40.2	Ross Dam	103.8
Birdsview	44.3	Gage below Ruby Creek	104.0
Gage near Concrete	52.6	Ruby Creek	104.8
Baker River	55.0	Gage near Newhalem	106.0
Sauk River	65.7	Beaver Creek	108.8
Cascade River	76.6	Gage above Devils Creek	116.1
Gage at Marblemount	77.2	International boundary	134.0
Bacon Creek	81.4	Gage near Hope, B.C	138.8

Many times in the past, the river in its lower course, even upstream from the delta, has abandoned its channel and many of these abandoned channels remain as sloughs through which a little water flows, even during low river stages.

CLIMATE

The climate of the North Pacific coastal region, in which lies the greater portion of the Skagit basin, is mild and moderately moist owing to the prevailing westerly air currents that advance inland from the Pacific Ocean, and to the shielding effects of the Cascade Range, which serve to exclude and deflect the cold continental air towards the east. The prevailing westerly air currents cross vast reaches of the ocean, and acquire much water vapor and a temperature near that of the sea. The air currents receive their warmth and moistness from the general currents of the ocean rather than from the Japanese current, the Kuroshio, which curves northward into Alaskan waters. As a result of the rather steady influx of marine air the winters are comparatively warm and the summers cool. Extremes of heat or cold are moderate and of short duration, and the daily range of temperatures is small.

The main river valley lies very nearly along latitude 48°30′ which is slightly north of the northern tip of Maine and approximately in the latitude of St. Johns, Newfoundland. The midwinter temperatures are similar to those on the Atlantic coast at latitudes several hundred miles farther south.

Heavy rains or snows, especially in winter, occur when the moisture-laden winds encounter the cool higher altitudes of the Coast and

Cascade Ranges.   Large quantities of snow seldom fall at sea level. During especially warm winter weather, rain may prevail up to elevations of nearly 6,000 feet.   When combined with melting snow, the rains often result in severe floods in the lower, heavily settled section of the Skagit River valley.

The climatological stations within the Skagit basin are, in general, at low elevations; therefore, the actual temperature and precipitation at high elevations are not known.   The following table shows meteorological data for stations in the Skagit basin, including data for the warmest, coldest, wettest, and driest months:

Station	Elevation in feet above mean sea level	Mean temperature (°F)			Mean precipitation (inches)		
		Jan.	Aug.	Annual	July	Dec.	Annual
Anacortes	30	39.1	61.6	50.6	0.67	4.00	26.6
Sedro Woolley	56	37.7	62.1	50.4	1.36	6.35	45.5
Concrete	270	35.2	64.9	50.9	1.13	9.32	60.8
Skagit Powerplant	525	33.5	65.8	50.3	1.29	12.00	72.6
Darrington	550	34.1	62.6	48.7	1.27	13.63	76.0

The average annual depth of runoff from the Skagit basin above Concrete is about 74 inches.   Therefore, the average annual rainfall over the basin must be about 94 inches because evaporation, transpiration and other losses generally are considered to consume approximately 20 inches of the rainfall in this type of country.

The upper or southward-flowing section of the Skagit River and its tributary basin lie between ridges of the Cascade Range and are somewhat isolated from the coastal marine climate.   The minimum altitude of that section of the river is about 1,200 feet; and, consequently, the winter snow is retained until spring and summer to a greater extent than in the lower section of the river.   Furthermore, before reaching the upper part of the basin, the atmosphere, in passing over the first ridges of the Cascade Range, becomes considerably depleted of its heat and moisture.   As a result of the natural isolation afforded the upper part of the basin, the runoff is much less than from the lower area.   For comparison the runoff at several gaging stations for the period 1941–55 is listed below:

Station	Runoff (inches)	Drainage area (square miles)
Skagit River near Hope	38.6	357
Skagit River at Newhalem	50.1	1,160
Skagit River near Concrete	74.2	2,700
Skagit River near Mount Vernon	70.7	3,060
Sauk River near Sauk	81.5	714
Cascade River at Marblemount	80.9	171
Baker River at Concrete	115.2	297

Several prominent mountain peaks border the Skagit basin in the ramifying branches of the Cascade Range. The two highest peaks are Mount Baker, 10,800 feet, and Glacier Peak, 10,400 feet. Several peaks are more than 9,000 feet and many more than 8,000 feet. Owing to the high altitude and heavy precipitation, the higher peaks are mantled with glaciers and snow fields which are productive of a heavy runoff during the summer and fall periods of low rainfall.

GEOLOGY

Prior to the glacial epochs, the Sauk and Suiattle Rivers formed a part of the Stillaguamish drainage basin.

During the glacial ages, the Skagit basin was much more heavily mantled with local ice than at present. In addition, the Skagit delta was overrun by an invasion of ice from Canada. The Canadian ice sheet, augmented by local glaciers in the State of Washington, pushed southward through the Puget Sound area between the Cascade Range and the Coast Ranges until it passed latitude 47° N., and established its terminal moraine a short distance north of Centralia, nearly 170 miles south of the Canadian border. The Skagit River was blocked not only by this tremendous glacier near its mouth, but also further upstream near the town of Concrete where a large local glacier came down the Baker River valley.

The dam formed by one of the glaciers forced the Skagit River to cross a pass, now occupied by the lower Sauk valley, into the Suiattle River basin. During a portion of this glacial epoch, while the ice dam held, the entire Skagit River above Concrete poured across the Skagit-Suiattle divide and thence down the Stillaguamish River. The ice dam probably held for many thousands of years and during this time the Skagit-Suiattle pass was rapidly cut down to form a regular river channel. After the glacial epoch, the Skagit River returned to its old lower valley and was able to capture the Suiattle and Sauk Rivers from the Stillaguamish River through the new channel cut through the Skagit-Suiattle divide.

In the Puget Sound region there were great changes in elevation during the glacial epochs. Geologists have stated that during various geologic eras this region probably has been as much as 1,000 feet higher and perhaps 300 feet lower than it is at the present time. During the various glacial actions the stream valleys became deeply filled with glacial drift. It may be nearly 1,000 feet to bedrock in the old river channel on the Skagit delta. Construction projects have shown about 110 feet of depth to bedrock at Gorge Dam and about 30 feet to bedrock at Ross Dam.

The most abundant rocks in the Skagit valley between Marblemount and Sedro Woolley are unmetamorphosed andesite and basalt

associated with unmetamorphosed to slightly metamorphosed sedimentary rocks such as slate, greywacke and subordinate amounts of limestone, and low-grade metamorphosed equivalents, such as phyllite and green schist. All these rocks are pre-Tertiary. Tertiary sandstones are less abundant. There are local small outcrops of serpentinite. Higher up in the valley—from Marblemount up—are metaquartz diorite, schist with minor serpentinite pods, quartz diorite and granodiorite, and gneiss of the Skagit volcanic formation of Daly (1912).

In many places the sandstones are completely covered by glacial debris. Throughout the valley, there are many clay deposits in the hillsides. Some coal is present in the lower reaches of the valley.

DESCRIPTION OF FLOODS

The Skagit River is subject to two distinct types of floods—winter and summer. In the past, most of the exceptional winter floods have occurred in November or December; the summer floods in May or June.

The largest flood during the winter of 1878–79 occurred on March 17, 1879, and the largest flood during the winter of 1914–15 occurred on April 2, 1915. Since the arrival of the first white settlers, these two floods, produced by factors that ordinarily bring about winter floods, occurred on the latest dates known for winter floods.

The earliest date that a crest of a true summer flood is known to have occurred was May 11, 1910. A recent early summer flood occurred on May 13, 1949. On the basis of the assumption that these are the latest winter and the earliest summer floods that are likely to occur, a time interval of about a month is all that exists between the two types of floods.

In summer when the lowlands are overflowed, the crops are damaged by the long continued high stages of the snow-melt floods. However, winter floods cause the greatest overall damage because the crest heights of the winter floods are higher on the average than those of the summer floods.

WINTER FLOODS

Large winter floods in the Skagit River basin are caused by water released through the action of strong and long-continued winds which bear warm moistureladen atmosphere from the Pacific Ocean to the Cascade Range; this action causes precipitation and snowmelt. These winds are known locally, at least, as "chinook" winds and are caused by air currents blowing toward the center of an area of low barometric pressure.

Dr. Charles F. Brooks, secretary of The American Meteorologic Society, in No. 117 of "Why the Weather," states,

The chinook is the warm wind of the northwest. Its name is that of a tribe of Indians from the direction of whose camp the warm southwest wind reached the trading post, Astoria, at the mouth of the Columbia River. The use of the name soon spread to all warm winds in winter in the Northwest; and now the term is applied mostly to warm winds descending onto the Great Plains after passing over the Rocky Mountains.

Precipitation is produced during a chinook when the air currents, as they are being forced up and over a mountain barrier, reach a higher altitude than the condensation level.

The floodwater released through the action of a chinook is composed of both rainwater and water from melted snow and ice. The rainwater and part of the water from snow and ice are from precipitation that occurs during the chinook in the form of rain, snow, and sleet. The remainder of the floodwater results from the melting of old snow and ice, which consists not only of snow but also of rainwater that has been absorbed and entrapped by the snow during earlier occurrences of precipitation.

A rainfall-runoff study for the Skagit River, based on discharge records at Sedro Woolley and precipitation records in the upper part of the basin, at and near Reflector Bar, was made by J. E. Stewart. This study shows that during the years 1909–23 the average yearly runoff in inches at Sedro Woolley was very nearly equal to the average precipitation at the upper basin sites. This indicates that a much heavier precipitation must have occurred at higher altitudes in order to provide the additional amount of water lost through evaporation, transpiration, retention, and ground water. These data show extremely heavy precipitation and high runoff during the months in which the greater floods occurred. For example, the precipitation in November 1909 was 27.7 inches and the runoff was 12.5 inches; in December 1917 the precipitation was 29.8 inches (7.4 inches occurring December 27–29) with a runoff of 14.1 inches; and in December 1921, 12.8 inches of precipitation (10.21 inches occurring December 10–12) produced a runoff of 13.3 inches, which indicates the melting of large quantities of snow accumulated during the previous two months of heavy precipitation. These examples show that winter floods result almost entirely from the large quantities of precipitation that occur during a storm, but are supplemented to some extent by the melting of previously deposited snow.

Four of the highest floods for which the exact date of occurrence is known were in November in the years 1896, 1897, 1906, and 1909. Two other high floods occurred in December in 1917 and 1921. Precipitation records at Vancouver, Wash., show that the great flood of 1856 also occurred in December.

The flood profiles of the great winter floods vary in shape depending upon the length of time the flood lasts (short- or long-duration storm) and on the time of day the flood crests from the larger tributaries enter the main river channel.

SUMMER FLOODS

The crests of summer floods are caused mainly by the hot summer sun melting the glaciers and the snowfields in the high sparsely timbered or open areas. The crests of the summer floods are probably swelled to a minor degree by snowmelt from the heavily timbered regions which lie just below the glaciers and adjacent snowfields.

The peak stages of the greatest summer floods are considerably lower than those for the great winter floods. The summer floods, however, are of much longer duration and are greater in volume than the winter floods. The crops are growing at the time of summer floods and, if the dikes break, the great damage done is accentuated by the fact that the long duration and great volume of the floods prevent repairing of the dikes. The greatest summer flood was that of 1894 comparing closely with those of 1880 and 1882. For two weeks the flood of 1894 remained higher than the highest peak of any of the recent summer floods. The flood of 1880 remained at a high stage for more than a month.

DURATION OF PEAKS

The duration of the flood peaks in the upper part of Skagit River is an important factor in determining whether the flood will be destructive in the lower reaches. This may be especially true of the large floods that do not quite reach the stages and discharges of the known great floods. The peaks of the floods of November 1949 and February 1951 were selected to demonstrate this point. The peaks would have been considerably higher had there been no storage in the power reservoirs upstream, but this would not affect the comparison of the duration of the two peaks.

SHORT-DURATION FLOOD OF NOVEMBER 1949

The flood of November 1949 is a good example of the flattening of a flood crest as it moves downstream. The hydrographs of the peak that occurred at the gaging stations near Concrete and near Mount Vernon are shown in figure 1. Channel storage had a marked effect on the sharpness of the peak by the time the crest reached Mount Vernon. The peak discharge of 153,000 cfs near Concrete was reduced to 114,000 near Mount Vernon.

Precipitation records in the basin at time of this flood partly explain the reduction in crest in the lower reaches of the channel. The Sedro Woolley precipitation gage indicates that very little rainfall occurred
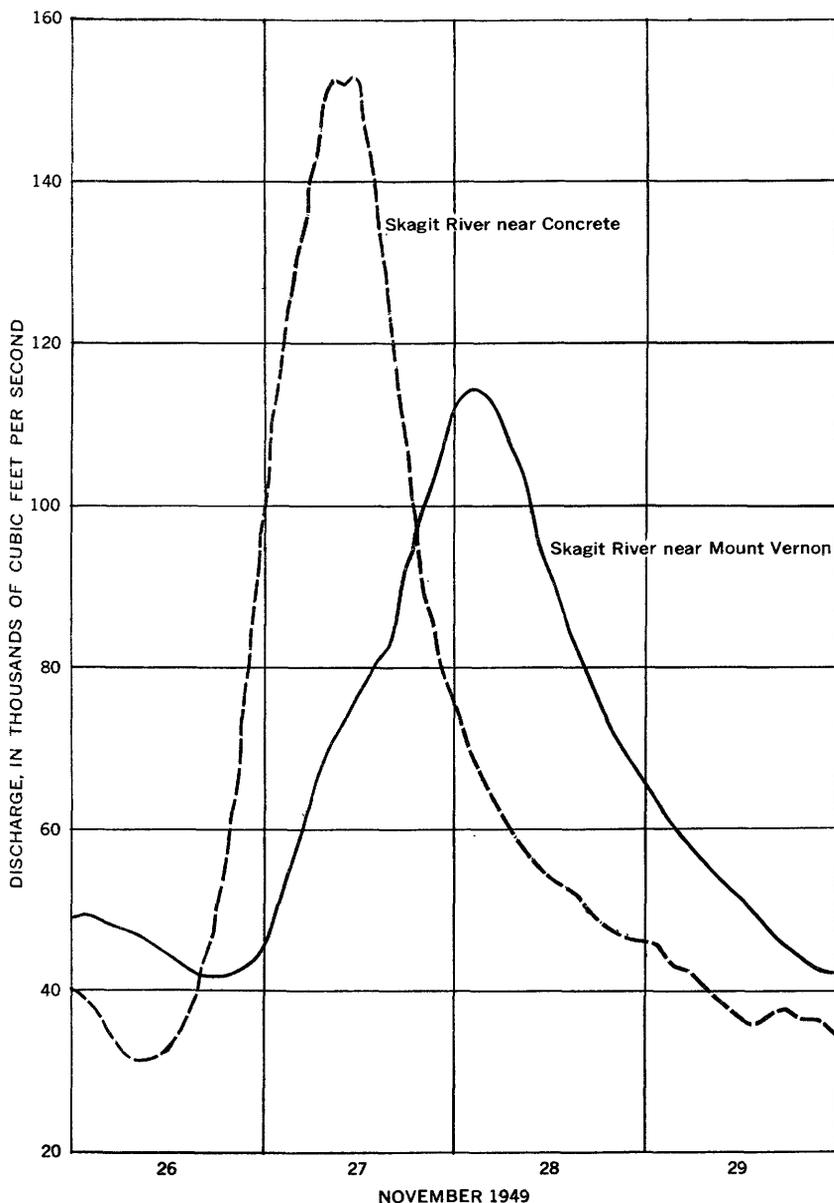
FIGURE 1.—Hydrographs of short-duration flood peaks.

in the lower part of the basin.   Weather records show that there was no snow on the ground as far upstream as Diablo Dam, and that the minimum and maximum temperatures at Diablo Dam were 39° and 58°, respectively.   The precipitation data are shown in the following table:

November 1949	Precipitation, in inches				
	Diablo Dam	Skagit powerplant	Marble-mount	Concrete	Sedro Woolley
23	2.00	1.03	0.65	0.43	0.09
24	1.50	.93	.60	.32	.37
25	1.67	.68	.75	1.17	.46
26	.95	4.21	2.57	1.43	.28
27 [1]	4.05	.72	1.18	1.73	.32
28 [2]	.71	.60	.81	.46	.29
29	.67	.46	.17	.20	.09

[1] Peak near Concrete.
[2] Peak near Mount Vernon.

LONG-DURATION FLOOD OF FEBRUARY 1951

The flood of February 1951 is a good example of a flood crest of long duration. The peak near Concrete lasted many hours longer than the peak of November 1949 although it did not reach as great a discharge. The hydrographs of the crests that occurred at the gaging stations near Concrete and near Mount Vernon are shown on figure 2. It can be
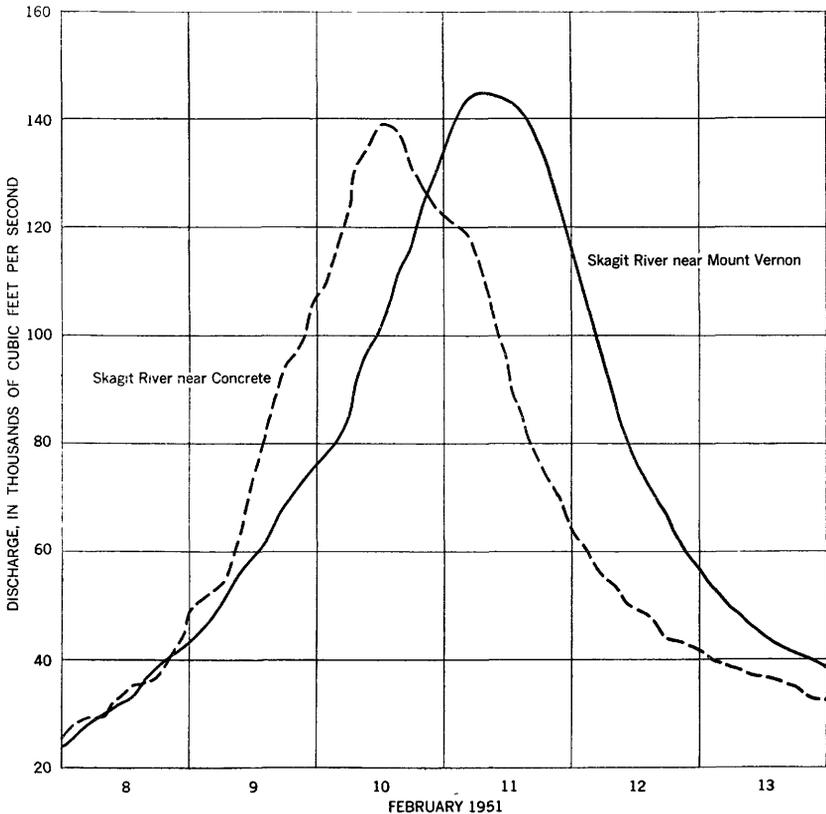
FIGURE 2.—Hydrographs of long-duration flood peaks.

seen that the duration of the peak reduced the effect of channel storage and that the peak downstream was increased by a large contribution from the low elevations.

Weather records show that on February 7, 15 inches of snow was on the ground. By February 11 this was reduced to 5 inches. No snow was on the ground at or downstream from Concrete. The temperature at Diablo Dam during the flood ranged from a minimum of 33° to a maximum of 53°. The precipitation data are shown in the following table:

| February 1951 | Precipitation, in inches | | | | |
	Diablo Dam	Skagit powerplant	Marble- mount	Concrete	Sedro Woolley
7_____	1.82	0.67	1.54	1.03	0.42
8_____	2.61	1.39	2.29	.80	.50
9_____	6.21	3.02	4.67	2.42	1.83
10 [1]_____	3.76	5.77	2.76	1.10	1.11
11 [2]_____	.61	2.89	.43	1.11	.28
12_____	0	T	0	0	0

[1] Peak near Concrete.
[2] Peak near Mount Vernon.

The large amount of precipitation in the lower reaches of the basin accounts for a part of the increase in peak discharge as the flood progresses downstream. Snowmelt would have added materially to the peak, if snow had been on the ground when the rain began.

EFFECT OF RESERVOIRS

The reservoirs in the upper Skagit River basin have had a material effect on the peak discharge of the river occurring since the dams were constructed. The dam on Baker River at Concrete was constructed in 1926 and has had an effect on many peak flows in Skagit River. Diablo Dam was constructed in 1930, and practically all peaks since that date have been reduced somewhat by storage in Diablo Reservoir. The first level in the construction of Ross Dam was completed in 1940, and all peaks since that date have been affected to some degree by storage in Ross Reservoir. By August 1949, Ross Dam had been raised two more levels and was capable of reducing the peak to a great extent on all but the largest floods at that point. If Ross Dam is ever raised to its proposed ultimate height, another 125 feet, it will be capable of almost completely controlling the entire flow from the 980 square miles of the Skagit River drainage basin upstream from the dam. The amount flood peaks would be diminished is not known, but it may be assumed that the flow of all except extreme peaks would be considerably reduced. In all probability even peak flows as great as those of 1815 and 1856 would be reduced by an appreciable amount.
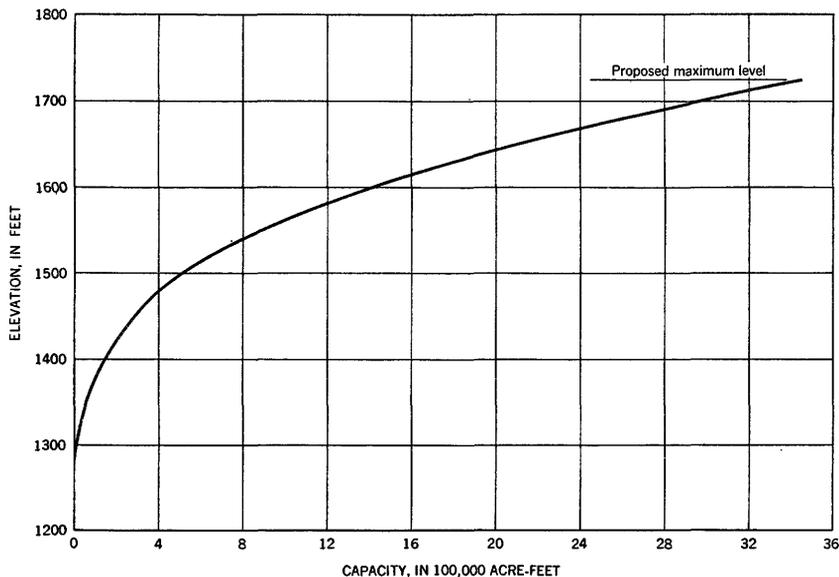
FIGURE 3.—Capacity curve for Ross Reservoir.

The storage capacity curve for Ross Reservoir at the present height of Ross Dam is shown in figure 3. The capacity at water-surface elevation 1,600 feet is 1,400,000 acre feet. The additions of only 125 feet of height, to elevation 1,725 feet, would increase the capacity to 3,450,000 acre-feet, or to more than double its present capacity.

During the floods of November 1949 and February 1951, Lake Shannon was held at practically a constant level at the time of the peaks, so the Baker River peaks were not appreciably reduced by storage. However, during both floods Diablo and Ross Reservoirs stored large volumes of flow, and the peak discharges on the Skagit River at the gaging station near Concrete were substantially reduced. It has been estimated that the peak flow of the November 1949 flood at the gage near Concrete was reduced by 45,000 cfs owing to storage in the two main-stem reservoirs. This indicates a natural peak discharge of 200,000 cfs near Concrete which probably would have been of disastrous proportions in the lower valley even if the effect of channel storage on the sharp peak was considered. An estimate has been made that the peak discharge of the February 1951 flood at the gage near Concrete was reduced 13,000 cfs by upstream storage. If this flow had not been stored, it probably would have increased the peak at Sedro Woolley and at Mount Vernon to about 158,000 cfs as a result of the long peak, which also might have proved disastrous to the lower valley. The crest of the February 1951 flood

was at the top of the dikes in several places so an additional 13,000 cfs probably would have caused a failure at some point.

A study of the effect of upstream storage on the peak of the February 1932 flood at the gaging station near Concrete was made by G. L. Parker. Figure 4 shows the computed results. Diablo Dam and Baker Dam were the only ones in existence in the basin at that time, but their reservoirs apparently reduced the peak by a large amount. Diablo Reservoir stored about 26,000 cfs of the peak flow and Lake Shannon accounted for about 35,000 cfs which shows a total reduction of 61,000 cfs. This peak, also, could have produced disastrous results downstream under natural conditions.

The more recent floods have been quite small in comparison to the great floods of the past. Even though the present dams could con-
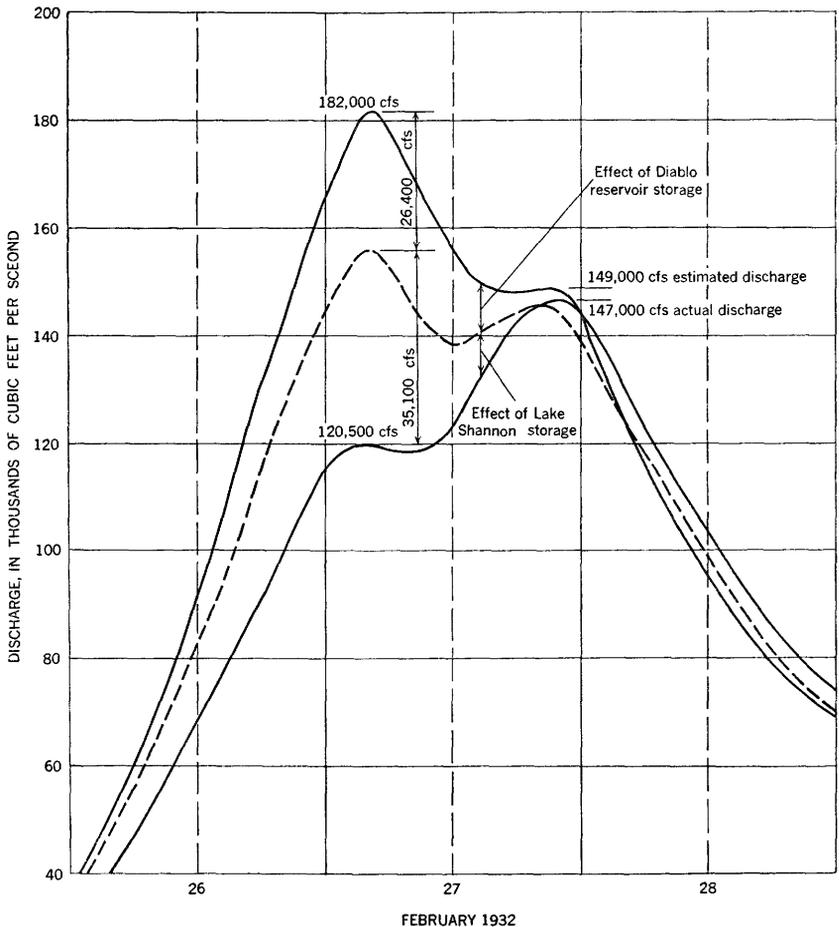
FIGURE 4.—Hydrographs showing effect of dams on flood peak.

ceivably reduce a great peak by many thousands of cubic feet per second, the total peak discharge of an extreme flood would be so great as to cause tremendous damage to the valley, especially to the area west of Sedro Woolley.

DIKES ON LOWER SKAGIT RIVER

Diking is known to have been practiced in the lower reaches of Skagit River in the early 1890's. In general, it was due to the efforts of individuals who were interested in keeping the summer floods away from their seeded farm land. Some areas near the river mouth were completely surrounded by dikes at an early date. In the beginning, the dikes were not very high but were raised to a sufficient elevation to confine minor floods to the river channel.

A map showing the locations of most of the major dike failures is shown as plate 2. Many breaks occurred downstream from Avon during the years 1894 and 1897.

In 1899 Sterling Dam was constructed at the head of Gages Slough which was a distributary of the Skagit River from the northern part of Sterling Bend. This was the commencement of major diking in the vicinity of Burlington and Sedro Woolley. Since that date, the entire river from near Burlington to Skagit Bay has been diked. These dikes have been strengthened almost continually and especially after each major flood.

During the February 1951 flood, the water surface was approximately at the top of the dike in two places near Burlington. Yet the peak discharge for this flood at the gaging station near Mount Vernon (at the highway bridge 1½ miles north of town) was only 144,000 cfs. This indicates the great possibility that future floods will breach these dikes and flood the lowlands. The dikes near the mouth did fail in several places in 1951.

The map of the lower reaches of Skagit River, plate 2, shows the location of most of the dike failures that have occurred during the last 73 years. From the location of these breaks, it is quite easy to determine approximately the areas that were inundated during each flood. The dike failures were not all detrimental to the landowners. Many dikes that normally protected low lying land along the shores of Puget Sound from salt water were breached to release Skagit River floodwater to Skagit and Padilla Bays, thereby preventing farmland from remaining submerged for a long period of time.

FLOOD PROFILE

Enough flood data are available to make a rough flood profile for the reach of channel from mile 7 to mile 21 (see log on page 6) and this profile can be extended to mile 50 (gage near Concrete).
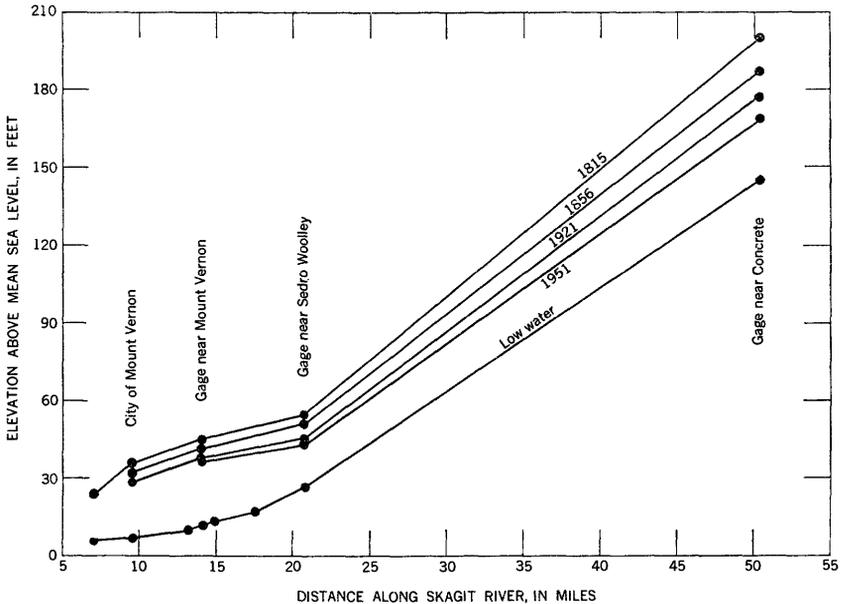
FIGURE 5.—Flood profiles.

Profiles for several floods are shown on figure 5. These profiles were obtained from the Corps of Engineers, U.S. Army, and are based on data obtained from the Great Northern Railway Company. A 1951 flood was confined by the dikes throughout this reach of channel, so below Sedro Woolley its profile is not parallel with the profile for the 1921 flood when the dikes in this area failed.

FLOOD PLAIN

A map showing the area that probably would be inundated by floods of the magnitude of those that occurred in 1815 and 1856 is shown on figure 6. Lesser floods would still cover a great part of this area as the flood of 1909 did inundate the greater part of it. This map was copied from a print of an old map obtained in 1945 from the Skagit County Engineer. The source of the map is unknown but it has been checked and found to be quite accurate in detail.

FLOOD DAMAGE

Considerable damage results from the greater floods in the valley. The area upstream from Concrete sustains a comparatively small amount of damage and the greatest amount occurs downstream from Sedro Woolley.

The U.S. Army Corps of Engineers, summarized the total flood damage at about $4,850,000 for the floods of 1894, 1906, 1909, 1917, 1921, and 1932. The two greatest losses were in 1894 and 1909
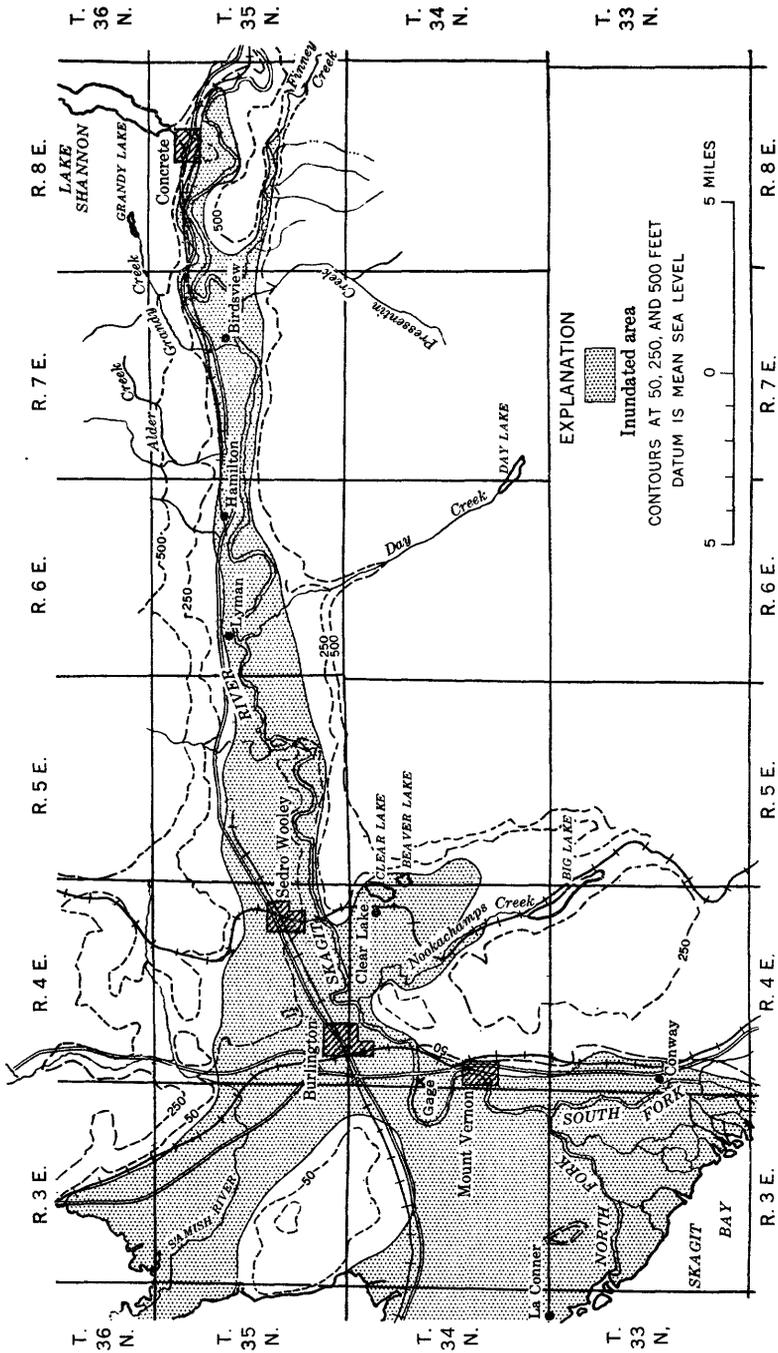
FIGURE 6.—Map showing area probably inundated by major flood.

with estimates of $1,500,000 for each flood. The average annual loss during the period 1894 to 1932 was $127,500. The above figures were obtained from House Document 187, 73d Congress (U.S. Congress, House of Representatives, 1933).

The damage from the flood of 1949 has been estimated as $587,000 based on 1951 prices. It is interesting to note that the 1909 flood damage, based on 1951 prices, has been estimated as $6,600,000, or about 4 times the original figure. This shows that floods of great magnitude would now cause large monetary damage and have a serious effect on the economy of the valley.

HISTORY OF FLOODS

Settlers first arrived in Skagit Valley about 1878. At that time they noticed that the bark on all of the larger fir and cedar trees, and on all of the spruce trees more than 1.5 feet in diameter was stained up to a certain height. The cause of this staining was the subject of much discussion until, in 1879, one of the oldest Sedro Woolley Indians described how the trees had been stained by an extremely high flood that occurred when he was a small boy.[1] The flood evidently made a deep impression upon him, because it came quickly and terribly one winter night. The flood probably caught the Indians asleep because in this old Indian's camp they barely escaped with their lives. They had no time to save their smoked salmon and dried venison. Apparently all the Indian camps along the river had the same experience because during that winter the Indians nearly starved. No doubt there was some loss of life, as there have been traditions handed down of drownings during the great flood.

From the estimated age of the Indian who remembered the flood, it was determined that this flood occurred between the years 1805 and 1825. The middle year of the period, 1815, is used as a convenient designation in referring to this flood of Indian legend.

The stain on the bark of the fir and cedar trees was quite clear in 1878 but it dimmed rapidly, so that by 1900, it was no longer noticeable except on a very few trees. From the rapid dimming of the stains it appears that those visible in 1879 must have been caused by a flood more recent than "about 1815." During the flood of 1909, Johnny Towne, an old Sauk Indian, told a white man that he had seen a much higher flood when he was a boy. In 1923 an Indian, thought to be 90 years old, told a Mr. James Cochraham that he remembered a flood several feet higher than the floods of 1909 and 1921. He did not remember any flood that had drowned Indians,

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[1] Story was told to J. E. Stewart in June 1918 by Mr. Hart who lived on the right bank, between wagon and railroad bridges, in Sedro Wolley and had heard the Indian's story in 1879.

although in his younger days he had known old Indians who remembered such a flood.

It would appear that a flood higher than that of 1909 had stained the fir and cedar trees prior to the coming of the white man but subsequent to the Indian legend flood of about 1815. Physical evidence of that flood was discovered in 1923 at The Dalles near Concrete. At that point there is a sandbar bench on the north side of the head of the canyon. The highest floods since the arrival of the white man have not covered this bar to a depth of more than two feet. On this bench were a number of young fir trees apparently all of the same age and much younger than the surrounding trees. A plausible explanation of this phenomena is that the bar was cleared of all trees during a large flood. In February 1923 one of the trees was cut down and found to have 62 rings at a stump height of 2.5 feet. It was estimated that it would take four years for such a tree to attain a height of 2.5 feet, and the tree would have been 66 years old in 1922, the last year of its growth. The flood that cleared the trees from the bar could have occurred as late as 1857, allowing a year for error, but probably occurred earlier. It is assumed that this flood caused the stains on the trees noted by the settlers in 1878.

At Vancouver, Wash., precipitation records are available for the years 1849–68, 1888–92, and 1898 to date (1958). During these 80 years of record the total monthly precipitation exceeded 10 inches only 19 times, and with one exception, it was always in either November, December, or January. Of these 19 months of high precipitation, 6 occurred in the 6-year period 1852–57 with the total precipitation for 2 consecutive months exceeding 20 inches 4 times during this period. Although there may be little direct relation between precipitation in the Skagit River basin and that at Vancouver, Wash., yet such unusually heavy precipitation at a point even that close lends support to the evidence of a large flood on the Skagit River "about 1856."

From the description by early settlers, the flood of November 16, 1896, was the highest that had occurred since the beginning of the settlement in 1878. The heights of the intermediate floods in the springs of 1880, 1882, and 1894 and the fall seasons of 1879, 1882, 1883, and 1887 are known only within a foot or two and principally in relation to the flood of 1896.

The flood of November 19, 1897 was higher than the flood of 1896 at all points. It was especially high in the reach from Cascade River to a short distance below Birdsview where, in general, it remains the highest flood since 1878.

The flood of November 16, 1906 is not well remembered although it severely damaged the draw span of the Great Northern Railway

bridge and destroyed one span of the highway bridge in Mount Vernon. It was on the latter bridge that a Mr. H. Peterson lost his life by running into the turning bar while trying to escape from the imperiled bridge. This flood was not so high as the flood of 1897 except in certain districts on the delta where the confining effects of the dikes caused higher stages.

The flood of November 1909 was the largest flood on the Skagit River since the coming of the white man in 1878, except for the reach from Cascade River to a short distance below Birdsview where it was surpassed by the flood of November 1897. Higher stages may also have occurred at other points during other floods as a result of log jams.

Evidence indicates that the flood of December 30, 1917 was comparable to those of 1896 and 1906 with respect to crest height. The damage on the delta was largely the result of the sustained flood flows inundating large areas after the dikes had broken.

The flood of December 12, 1921 was nearly as great as the flood of 1909 and was higher than that of 1917 except where some abnormal local condition prevailed.

It has been estimated that the natural discharge of the February 27, 1932 flood near Concrete (corrected for effect of upstream storage) would have been about the same as the discharge of the floods of 1896 and 1906 (U.S. Congress, 1933).

It has been estimated that the natural discharge of the November 27, 1949 flood near Concrete (corrected for effect of upstream storage) would have been about the same as the discharge of the 1917 flood.

The flood of February 10, 1951 reached a stage at the gage near Concrete only 1.8 feet lower than the flood of 1949 and 6.7 feet lower than the flood of 1917.

The long period since 1921 without the occurrence of a destructive flood does not indicate that the chances of a devastating flood have decreased in any way. The size of floods to be expected in the future are discussed in sections on flood types and frequencies.

HISTORIC FLOOD DATA

The data for historic floods were taken directly from notes and statements of J. E. Stewart, the co-author of this publication. He spent considerable time in the field obtaining high-water marks and making studies of flood flows. Some of the statements in this section are similar to those made previously under the section on history, but they are repeated here in order to present the data on how the stages were obtained with other pertinent data concerning the floods.

Available data for the 1917 and 1921 floods are included in this section for comparative purposes.

The gage heights for all floods at all stations are based on the maximum height reached by the surging water.   This method became necessary because the height of all the earlier and some of the recent floods could be determined only in this manner.   The resulting gage heights and discharges are somewhat greater than they would have been if the mean of the surges was used as is done at the present time. Data for several sites are given below.

Skagit River at Reflector Bar near Marblemount, Wash.

[See gaging station 10, page 38.]

Date of flood	Stewart's data		Gaging station data	
	Elevation (feet)	Discharge (cfs)	Gage height (feet)	Discharge (cfs)
1815_____	20. 5	115, 000	_____	_____
1856_____	18. 5	95, 000	_____	_____
November 18, 1897_____	12. 5	48, 000	_____	_____
November 29, 1909_____	15. 4	70, 000	_____	_____
December 29, 1917_____	12. 5	43, 000	12. 0	37, 300
December 12, 1921_____	14. 5	63, 000	14. 1	58, 000

The flood dated 1815 probably occurred between 1805 and 1825. This is based on the age of an Indian interviewed in 1879 concerning that flood.

The flood dated 1856 did not occur after 1857 and probably not before 1850.   This is known by precipitation data and by the age of trees on a bench that was cleared by this flood.

The stages of the 1815 and 1856 floods were determined near the gage from the elevation of high-water marks on canyon walls and from flood sand deposited by those floods.

The stage of the 1909 flood was determined from drift and flood sand at, and upstream from, the gage.

Cascade River near Marblemount, Wash,

[This site is about 6 miles upstream from Cascade River at Marblemount, gaging station 16, page 42.]

Date of flood	Elevation (feet)	Discharge (cfs)
1815_____	22. 0	46, 000
1897_____	20. 0	40, 000
November 29, 1909_____	15. 0	26, 000
December 1917_____	17. 2	32, 000

The 1909 flood peak was published in 1911 in Water-Supply Paper 272 (Stevens and others) as 31,700 cfs.

Early settlers stated that the river was much higher in 1897 than it was in 1909; also, that it was much higher in 1917 than in 1909.

The Cascade River emptied into the Skagit River at a point upstream from its present confluence until during the 1897 flood when its course was changed to the present location.

Sauk River at Darrington, Wash.

[Gaging station 19, page 44.]

Date of flood	Elevation (feet)	Discharge (cfs)
1815	18. 0	48, 000
1897	17. 0	44, 000
November 1909	16. 0	40, 000
December 29, 1917	15. 0	36, 000

Studies of river banks, including bars left from old channels, indicate that stages from 2 to 3 feet higher than 1917 have occurred. The flood of 1815 probably was not more than 1 foot higher than the 1897 flood.

The flood of 1897 was higher than the 1909 flood on the Cascade River to the north and the South Fork Skykomish River to the south, so it probably was higher on the Sauk.

The crest of the 1909 flood was obtained from a comparison by the gage observer of the relative stages of the 1909 and 1917 floods in his garden.

Baker River below Anderson Creek, near Concrete, Wash.

[Gaging station 22, page 47.]

Date of flood	Elevation (feet)	Discharge (cfs)
1815	16. 0	50, 000
1897	13. 5	36, 700
1909	15. 3	46, 200
December 29, 1917	13. 7	36, 800
December 12, 1921	10. 8	23, 600

The great flood of 1815 probably reached a gage height of 16.0 feet.

The flood of 1897 probably was about the same height as the 1917 flood, or possibly slightly lower.

The crest of the 1909 flood was obtained from drift marks on trees and from the high water beach line.

Skagit River near Concrete, Wash.

[Gaging station 25, page 50.]

Date of flood	Elevation (feet)	Discharge (cfs)
1815	56. 6	500, 000
1856	44. 6	350, 000
November 19, 1897	38. 4	275, 000
November 30, 1909	36. 4	260, 000
December 30, 1917	33. 0	220, 000
December 13, 1921	34. 9	240, 000

The stage for the 1815 flood was determined from the maximum height of flood sand found just above The Dalles and about 300 feet upstream from the present gage.

The stage of the 1856 flood was determined from its high-water mark left on the canyon wall in The Dalles at the present gage site.

The floods of 1897 and 1917 have been dated on the assumption that the floods occurred shortly after midnight.

The stages for the floods of 1897, 1909, and 1917 have been estimated from flood marks about 1 mile upstream. The stage of the 1897 flood is not as certain as the stages for the other two floods.

Skagit River near Sedro Woolley, Wash.

[Gaging station 28, page 52.]

Date of flood	Elevation (feet)	Discharge (cfs)
1815	63. 5	400, 000
1856	60. 0	300, 000
November 16, 1896	54. 8	185, 000
November 19, 1897	54. 9	190, 000
November 16, 1906	54. 7	180, 000
November 30, 1909	56. 5	220, 000
December 30, 1917	54. 1	195, 000
December 13, 1921	54. 3	210, 000

The stage for the 1815 flood has been estimated from the height of the flood plain, from the stage and discharge at The Dalles, and by comparison with the stages of the 1856 and 1909 floods.

The stages of floods from 1815 to 1869, except that of 1856, are unknown. However, they were all of a lower crest stage than the flood of 1856. It is fairly certain, also, that the stages of any floods between 1856 and 1869 were lower than that of the 1909 flood.

There were no floods from 1869 to 1895 as great as those in 1896 and 1906 according to statements of the early settlers.

The stage for the 1897 flood was determined from its relation to the 1896 flood about one quarter of a mile upstream.

The discharges for all floods except those in 1909, 1917, and 1921 are, to a large extent, based on comparative stages and discharges at other points.

INDIAN LEGEND FLOOD OF ABOUT 1815

Reflector Bar (Diablo Dam).—The stories which were told by the Indians support the evidence that the highest flood marks not associated with a more recent flood, and still visible when J. E. Stewart made his investigations over a hundred years later, were left by a flood that occurred "about 1815." Mr. Frank Davis found where sand had been deposited on the ground in a gulch near the present Diablo Dam at an elevation of 22 feet about the datum of the former gaging station at Reflector Bar. It was assumed from the nature of the deposit that the sediment had been left by the stream during a high flood. On the south side of Canyon Diablo opposite the gulch, J. E. Stewart found a dim mark on the canyon wall at an elevation of 21.3 feet that marked the height to which some flood had washed the rock clean. He also found deposits of flood sand in crevices of the rock wall at the mouth of Canyon Diablo as high as 20.8 feet, Reflector Bar gage datum, and a small piece of bark apparently left by a flood in a rock crevice nearly as high. A deposit of sand and gravel was

found on the right bank at the upper end of Reflector Bar that probably had been left by the river during a flood. This deposit was of clean material devoid of leaves, dirt, logs, and humus when viewed by Stewart in 1918. The cleanness was considered an indication that the deposit was not much more than 100 years old. An excavation was made on the bar near the ranger station quite a long distance from the point where the river would overflow the bank. Alternate layers of sand and charcoal were revealed which showed that floods large enough to deposit sand on the bar that far back from the river had occurred several times previously. The charcoal found between the layers of sand probably was produced by forest fires.

The deposit of fresh sand was very coarse, almost small gravel, and extended about 600 feet back from the bank. For a flood to carry the sand that far, it would have had to overtop the bank by a least a foot. An estimation that the flood overtopped the bank by 1.5 feet gives a gage height of 19.5 feet. A gage height of about 20 feet for the flood was obtained by averaging the flood evidence at Reflector Bar and by taking the slope of the water surface into consideration.

Rockport.—The magnitude of the 1815 flood is supported further by a legend among the Indians at Rockport that a number of their tribe were drowned on the bench where the Cuthbert ranch is located, during a great flood that occurred at night. This bench is at least 15 feet above the floodmark of 1917.

Concrete.—At The Dalles, L. J. Wright, Assistant County Engineer of Skagit County, found deposits of flood sand on the ground in the small northside gulch which lies back of an old cabin at the head of the canyon. This deposit corresponds to a gage height of 69.3 feet present datum.

Sedro Woolley.—Stewart estimated that this flood probably exceeded the flood of 1909 by about 7 feet and covered the highest ground in the town of Sedro Woolley with 1.5 feet of water. This would be equivalent to 10 feet of water in the present business district. Also, a stage of 63.5 feet (gage datum) is indicated for the 1815 flood.

TREE-STAINING FLOOD OF ABOUT 1856

During his investigations in 1918, Stewart found that the marks of the 1856 flood were so easily and frequently found that its crest could be traced throughout the valley more easily than those of the floods of 1896, 1897, and 1906. In most places it was marked only by sand in the deep crevices of the bark of old cedar trees. There was no mud in the bark of the fir trees, because of the rapid rate at which they shed their bark. The stains formerly in the bark of the cedar trees had apparently faded by weathering or had been dissipated by the growth of the trees.

Reflector Bar.—In 1923 near Reflector Bar, Stewart observed a deposit of fresh flood sand, 3.5 feet above the crest of the flood of 1909, that he believed indicated the crest of the flood of 1856. On that basis it was estimated that the flood reached a stage of 18.5 feet at the gage.

Concrete.—On the north rock wall close to the mount of The Dalles near Concrete a distinct high-water line at a gage height of 57.3 feet (present datum) was visible in 1923.

Birdsview.—Charles Presentine settled on his ranch above Birdsview in 1876. He found the ground surface, where his buildings now stand, underlain by very fresh-looking leaves and grass. The leaves and grass had been covered by sediment deposited by a flood that covered the flat to an unknown depth. The flat has not been overflowed since.

Mr. Kemmerick, an early settler, noted fresh flood sand inside hollow logs at his ranch below Birdsview. The logs were above any later floods. The fact that the logs were old and hollow when the sand was was deposited showed the flood to be recent; otherwise, the logs probably would have rotted away before Mr. Kemmerick saw them.

Sedro Woolley.—In 1897 the stain marks of 1856 still could be found on the trees with little difficulty. The crest heights of the floods of 1896 and 1897 were within 0.1 foot of each other. After one of those floods Mr. Hart [2] measured up from the high-water mark to the tree stains and found the distance to be exactly 4.0 feet. Mr. E. J. Woods, a former gage reader at the Northern Pacific Railway bridge, saw only one tree after the flood of 1909 with the crest mark of the old flood on it, and that was 3.5 feet higher than the 1909 floodmark. Later that tree was burned, but in January 1918 Stewart found an old cedar tree in which mud from the tree-staining flood was found in the bark 3.5 feet above the 1909 floodmark. Both the latter trees were about two miles downstream from the Hart ranch at Sedro Woolley. As the gage height of the 1909 flood is 56.5 feet, the gage height of the 1856 flood would be about 60 feet.

FLOODS OF 1880, 1882, AND 1894

The summer floods of 1880, 1882, and 1894 are remembered for the long periods during which the bottom lands around Mount Vernon were inundated.

FLOOD OF NOVEMBER 1897

This flood was the highest since the valley was settled in 1878. The river rose with remarkable suddenness, because a very warm chinook was accompanied by heavy rains. The Cascade, Sauk, and Baker Rivers were unusually high, which caused a high peak in the Skagit

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[2] See footnote p. 20.

River near the mouth of each stream.   The chinook stopped suddenly after 36 hours; and, as a result, the peaks were rapidly reduced by channel storage as they passed down the Skagit River.

Reflector Bar.—At Reflector Bar this flood was of about the same magnitude as that of 1917.   Both floods put about one foot of water over the floor of an old cabin on the Davis ranch 1.5 miles below Reflector Bar.

Marblemount.—Below Cascade River at Marblemount the flood of 1897 was 1.3 and 2.2 feet higher than the floods of 1909 and 1917, respectively, as measured between high-water marks made by residents at Marblemount during each flood.   The difference was caused by an enormous flood in Cascade River in 1897.

Rockport.—The flood of 1897 is the highest ever observed by white men; however the amount by which it exceeded the floods of 1909 and 1917 is unknown.

Concrete.—Stewart found two floodmarks near Concrete for the flood of 1897.   One, on a barn on the right bank about a mile upstream from Concrete, was transferred by levels to the footing of a hotel in Concrete on which the other floodmark had been made in 1909.   The difference between the two marks was 5 feet.   After allowing 2 feet for the slope of the water surface, the flood of 1897 was estimated to be 3 feet higher than the flood of 1909.   Later, in 1922, Stewart ran levels to a stump that a Mr. Magnus Miller stated was 1.5 feet out of water during the flood of 1897.   From these levels the flood of 1897 was found to be 3.6 feet higher than the flood of 1909 at Concrete.

The flood elevations in Concrete probably were affected to a considerable extent by the flow of Baker River.   The relationship between the two floods at that point may have been quite different from the relationship at the gaging station site.

<center>FLOOD OF NOVEMBER 1909</center>

When Stewart made his investigations in 1918, the drift from the 1909 flood still lay along the river and was but slightly rotted.   Drift for a previous higher flood could not be found; this indicated that none had occurred within the period required for drift to decay and disintegrate, perhaps 50 years.

Reflector Bar.—At Reflector Bar several distinct high-water marks were found by Stewart.   One, on the front door of the Davis ranch house 1½ miles below the gage, was found to be 2.4 feet higher than the crest elevation obtained for the 1897 and 1917 floods at a nearby cabin.   This stage was confirmed by the high-water mud lines still visible in 1918 on the rock wall of Canyon Diablo 700 feet above the gage and by the height of a drift log 100 feet below the gage.

Newhalem.—The observer at the gaging station at Newhalem (near Marblemount) estimated the crest gage height the following morning from drift at the gage. This stage was checked in 1918 by Stewart using a hand level.

Concrete.—In 1918 Stewart found many marks of the flood of 1909 in and near Concrete. The footing of a hotel near the cement plant was just reached by the water. There were oil marks 4.5 feet above the floor on the outside galvanized siding of an old Washington Cement Plant shop building; these marks were referred to as being "as plain as though made yesterday."

FLOOD OF DECEMBER 1917

The flood of December 1917 was remarkable for the length of time it remained high, rather than for the height which it reached.

The gaging station at Reflector Bar was in operation; therefore, a good record of the flood was obtained at that point. As shown in the description of the flood of 1909, the crest was 2.5 feet below that of 1909.

FLOOD OF DECEMBER 1921

Gaging stations were in operation below Ruby Creek, at Reflector Bar, at Newhalem, and near Sedro Woolley at the time of the 1921 flood. Gage heights for the flood at those places are part of the gaging-station records.

Concrete.—Stewart made extensive studies of this flood at The Dalles near Concrete. He visited the place while the floodmarks still were so clear that the profile of the flood could be determined within one or two tenths of a foot. At The Dalles the Skagit River flows through a relatively narrow canyon for a short distance. Conditions there are fairly satisfactory for the computation of the peak flow by the contracted-opening method. Just below The Dalles is a straight reach of channel which is suitable for the computation of flow by the slope-area method. Stewart obtained the data for both types of measurements; the upper end of the rating curve for this gaging station is based on those computations.

FLOOD OF FEBRUARY 1932

The flood of February 1932 would probably have been much more serious if there had been no upstream storage. The storage probably reduced the peak by about 35,000 cfs at the gaging station near Concrete. In the lower reaches of the river, between Sedro Woolley and Mount Vernon, the dikes failed in two places and caused flooding of farm land and many homes. Also, several dike failures occurred along the distributaries near the mouth.

Two gages were in operation along the main stem during this flood and good records were obtained at these points.   The gages were located at Newhalem and at The Dalles near Concrete.   The crest at Newhalem, which was affected to some extent by storage, was only 1.4 feet below that of the 1921 flood.   The crest at the gage near Concrete has been listed as being 5.7 feet lower than that of the 1917 flood, but again upstream storage was a factor.

FLOOD OF NOVEMBER 1949

The flood of November 1949 would probably have been among those causing considerable damage if there had been no upstream storage.   The storage in the power reservoirs has been estimated to have reduced the crest at the gaging station near Concrete by about 45,000 cfs.   The peak near Concrete was of short duration, and there was only a moderate amount of inflow between Concrete and Mount Vernon.   Channel storage reduced the peak in the lower reaches of the channel to a point where the diked channel was able to carry the peak flow without danger of a major dike failure.   There were two minor breaks near the mouth.

Several gages were in operation along the main stem during this flood so good records were obtained at those points.   Gages were in operation at Newhalem, at Marblemount, near Concrete, and near Mount Vernon.   The crest near Concrete was 4.9 feet lower than that of the 1917 flood and 0.8 foot higher than the crest of the 1932 flood.

Immediately following the 1949 flood, a slope-area reach was laid out and high-water and other field data obtained at the approximate site of J. E. Stewart's reach just below The Dalles near Concrete. These data were used to verify the value of the channel roughness coefficient, n, at this site for use in estimating the validity of the results obtained by Stewart.

FLOOD OF FEBRUARY 1951

The flood of February 1951 was almost as high as the flood of 1949 at the gage near Concrete and was higher at the gage near Mount Vernon.   The effect of upstream storage was much less for this flood than for some of the others and has been estimated to be about 13,000 cfs for the peak at the gage near Concrete.   However, this peak was of quite long duration and a large amount of inflow occurred between Concrete and Mount Vernon so that channel storage had very little effect in reducing the peak stage in the lower reaches of the channel. In at least two places between Sedro Woolley and Mount Vernon the river reached the top of the dike.   In one place the dike sprung a

leak, but this dike did not fail, and as a result there was only minor damage in that area.   However, several dike failures occurred on the distributaries near the mouth, and considerable areas of land and many homes were inundated.

Several gages were in operation along the main stem of the river during this flood so good records were obtained at those points. Gages were in operation at Newhalem, above Alma Creek near Marblemount, at Marblemount, near Concrete, near Sedro Woolley (unpublished), and near Mount Vernon.

FLOOD RECORDS

Records of maximum flood stages and discharges that have been obtained at gaging stations operated in the Skagit River basin for five or more years are presented in the following tables.   They are of two kinds: records of historic floods, based largely on the investigations of J. E. Stewart; and records obtained during the period of operation of the gaging stations, when continuous records were obtained.

The order of listing gaging-station records begins with the most upstream main-stem station, near Hope, British Columbia, and proceeds downstream along the main stem.   All stations on a tributary entering above a main-stem station are listed before that station, and if a tributary enters between two main-stem stations, it is listed between them.   The gaging stations are numbered in the above order and may be located by number on plate 1.

GAGING STATION RECORDS

The information on the following pages for each gaging station for which records are shown consists of a station description and a list of flood peaks.

The station description gives information as to location, drainage area, type of gage and elevation of gage datum, how well the stage-discharge relation is defined, remarks concerning effects of diversion and regulation, and other pertinent information.

Flood peaks listed for periods of gaging station operation are the maximum momentary peaks that occurred each water year, the year beginning October 1 and ending September 30.   Also listed are stages and discharges for historical floods, including all those that occurred prior to time of beginning of systematic collection of data.   A horizontal line across the year column indicates a break in the period of record and one across the gage height column indicates a change in datum.

1. *Skagit River near Hope, British Columbia, International gaging station*

Location.—Lat 49°02′50″, long 121°05′45″, on left bank just downstream from Galena Creek, 4 miles upstream from the international boundary, and 27 miles southeast of Hope, British Columbia.

Drainage area.—357 sq mi.

Gage.—Water-stage recorder. Altitude of gage is 1,670 ft (from topographic map). Prior to October 1934, water-stage recorder at site 550 ft downstream at different datum.

Stage-discharge relation.—Defined by current-meter measurements below 6,500 cfs.

Remarks.—Records furnished by Canadian Department of Resources and Development.

Annual peak stages and discharges of Skagit River near Hope, British Columbia

Water year	Date	Gage height (feet)	Discharge (cfs)
1915	Apr. 4, 1915		[1] 1,280
1916	June 17, 1916		[1] 7,560
1917	May 29, 1917		[1] 5,920
1918	June 10, 1918		[1] 5,980
1919	May 26, 1919		[1] 5,140
1921	June 7, 1921		[1] 6,920
1922	June 4, 1922		[1] 6,850
1935	Jan. 25, 1935	8.83	6,560
1936	May 31, 1936	7.90	5,070
1937	June 3, 1937	8.84	6,570
1938	May 26, 1938	8.71	6,370
1939	May 16, 1939	8.17	5,440
1940	May 24, 1940	6.52	2,990
1941	May 2, 1941	5.15	1,560
1942	May 26, 1942	7.49	4,440
1943	May 27, 1943	8.12	5,420
1944	May 29, 1944	6.46	2,510
1945	May 30, 1945	8.60	5,560
1946	May 27, 1946	8.85	5,960
1947	May 8, 1947	8.47	5,630
1948	May 28, 1948	10.75	9,720
1949	May 16, 1949	10.20	6,850
1950	June 21, 1950	12.20	10,200
1951	May 24, 1951	10.49	5,560
1952	May 19, 1952	10.21	4,970
1953	June 13, 1953	10.58	5,720
1954	May 19, 1954	11.95	6,820
1955	June 12, 1955	11.96	9,760

[1] Maximum daily.

2. *Skagit River above Devils Creek, near Newhalem, Wash.*

Location.—Lat. 48°50′30″, long 121°02′20″, in W½ sec. 30, T. 39 N., R. 14 E., on left bank 2 miles upstream from Devils Creek, 9½ miles upstream from Ross Dam, and 15 miles northeast of Newhalem.

Drainage area.—650 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Altitude of gage is 1,410 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 6,600 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Skagit River above Devils Creek, near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1940	May 24, 1940	5. 55	5,900
1941	Oct. 21, 1940	4. 58	4,210
1942	Dec. 3, 1941	6. 20	6,570
1943	June 10, 1943	6. 80	8,220
1944	May 16, 1944	4. 84	4,630
1945	May 31, 1945	7. 27	9,140

3. *Beaver Creek near Newhalem, Wash.*

Location.—Lat 48°46'40'', long 121°04'20'', in S½ sec. 14, T. 38 N., R. 13 E. (unsurveyed), on left bank three-quarters of a mile upstream from Ross Reservoir, 3 miles north of Ross Dam on Sakgit River, and 10½ miles northeast of Newhalem.

Drainage area.—52 sq mi, approximately.

Gage.—Water-stage recorder. Altitude of gage is 1,600 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 2,000 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Beaver Creek near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1940	May 24, 1940	4. 97	1,320
1941	Oct. 19, 1940	7. 34	3,540
1942	Dec. 2, 1941	7. 76	3,980
1943	July 4, 1943	5. 11	1,550
1944	Dec. 3, 1943	4. 63	1,280
1945	May 31, 1945	5. 32	1,680
1946	Oct. 26, 1945	7. 57	3,760
1947	Oct. 25, 1946	5. 33	1,760
1948	May 28, 1948	6. 37	2,490

4. *Skagit River near Newhalem, Wash.*

[Published as "above Ruby Creek, near Marblemount" 1930-31]

Location.—Lat 48°44'50'', long 121°01'50'', in S½ sec. 30, T. 38 N., R. 14 E. (unsurveyed), on right bank 1¼ miles upstream from Ruby Creek and 11 miles northeast of Newhalem.

Drainage area.—765 sq mi, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Altitude of gage is 1,250 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 13,000 cfs and extended by velocity-area studies.

Annual peak stages and discharges of Skagit River near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1922	Dec. 12, 1921	17.8	33,000
1930	June 11, 1930	9.5	8,270
1931	May 2, 1931	10.2	9,860
1932	Feb. 27, 1932	15.9	25,700
1933	June 16, 1933	13.1	17,300
1934	Apr. 24, 1934	12.0	14,300
1935	Nov. 5, 1934	13.05	17,000
1936	May 31, 1936	11.11	12,000
1937	June 3, 1937	11.39	12,700
1938	May 26, 1938	11.74	13,600
1939	May 29, 1939	11.13	12,100

5. Ruby Creek below Panther Creek, near Newhalem, Wash.

[Published as "Ruby Creek near Marblemount" prior to 1932 and as "Ruby Creek near Newhalem" 1932–49]

Location.—Lat 48°42′30′′, long 120°58′10′′, in NW ¼ sec. 10, T. 37 N., R. 14 E. (unsurveyed), on right bank 200 ft downstream from Panther Creek, 4 miles upstream from mouth, and 13 miles northeast of Newhalem.

Drainage area.—199 sq mi.   At sites prior to October 1948, 210 sq mi, approximately.

Gage.—Water-stage recorder.   Altitude of gage is 1,640 ft (by barometer).   Prior to Mar. 8, 1940, water-stage recorder at site 3½ miles downstream and Mar. 8, 1940, to Sept. 27, 1948 at site 2 miles downstream from present site, both at different datums.

Stage-discharge relation.—Defined by current meter measurements below 5,600 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Ruby Creek below Panther Creek, near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1929	May 22, 1929	12.57	3,460
1930	June 6, 1930	12.10	3,030
1931	May 14, 1931	12.47	3,570
1932	Feb. 27, 1932	14.15	6,730
1933	June 14, 1933	14.09	6,510
1934	Apr. 23, 1934	13.74	4,920
1935	Nov. 5, 1934		3,460
1936	June 2, 1936	13.92	4,850
1937	June 2, 1937	13.51	4,480
1938	May 25, 1938	13.12	4,530
1939	May 28, 1939	13.08	4,650
1940	May 23, 1940	6.91	3,070
1941	Oct. 20, 1940	5.88	1,630
1942	May 25, 1942	7.69	4,650
1943	June 9, 1943	7.45	4,160
1944	May 15, 1944	6.41	2,370
1945	May 30, 1945	7.56	4,360
1946	May 26–27, 1946	7.43	4,160
1947	May 8, 1947	7.50	4,260
1948	May 27, 1948	9.2	9,920
1949	May 15, 1949	8.42	5,170
1950	Nov. 29, 1949	10.95	8,640
1951	May 23, 1951	7.50	4,170
1952	May 18, 1952	6.38	3,150
1953	June 13, 1953	7.16	3,820
1954	July 1, 1954	7.82	4,630
1955	July 16, 1955	9.50	6,540
1956	Oct. 25, 1955	9.25	6,240

6. *Skagit River below Ruby Creek, near Newhalem, Wash.*
[Published as "near Marblemount"]

Location.—Lat 48°44'20'', long 121°03'40'', in SE¼ sec. 35, T. 38 N., R. 13 E., (unsurveyed), on right bank three-quarters of a mile downstream from Ruby Creek and 9 miles northeast of Newhalem.

Drainage area.—978 sq mi, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Altitude of gage is 1,190 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 11,000 cfs and extended by reducing discharge at Reflector Bar by measured inflow.

Annual peak stages and discharges of Skagit River below Ruby Creek, near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1920	July 1, 1920	9.39	12,600
1921	June 7, 1921	11.95	25,200
1922	Dec. 12, 1921	16.1	45,700
1923	June 8, 1923	10.75	19,200
1924	Feb. 12, 1924	12.2	26,200
1925	May 19, 1925	11.6	23,200
1926	Apr. 30, 1926	7.76	7,460
1927	June 7, 1927	11.35	22,200
1928	May 22, 1928	11.4	22,200
1929	May 23, 1929	9.65	13,600
1930	June 11, 1930	8.9	10,700

7. *Ross Reservoir near Newhalem, Wash.*
[Published as "Ruby Reservoir" prior to 1945]

Location.—Lat 48°44'00'', long 121°04'10'', in SE¼ sec. 35, T. 38 N., R. 13 E., at Ross Dam on Skagit River, 1 mile downstream from Ruby Creek, and 9 miles northeast of Newhalem.

Drainage area.—980 sq mi, approximately.

Gage.—Water-stage recorder. Datum of gage is at mean sea level (city of Seattle benchmark). Prior to Sept. 24, 1940, staff gage, and Sept. 24, 1940, to June 27, 1943, water-stage recorder at same site and datum. June 28, 1943, to Apr. 29, 1948, staff gage 500 ft upstream at same datum.

Remarks.—Reservoir is formed by concrete arch dam completed to elevation 1,615 ft in 1949; storage began Mar. 11, 1940. Capacity 1,202,920 acre-feet between elevations 1,250 ft (lowest outlet) and 1,582 ft (spillway crest).

Annual maximum elevation and storage of Ross Reservoir near Newhalem, Wash.

Water year	Date	Elevation (feet, m.s.l.)	Storage (acre-feet)
1941	July 19, 1941	1,384.6	112,600
1942	July 23, 1942	1,384.7	113,100
1943	June 30, 1943	1,384.05	111,800
1944	June 11, 1944	1,381.8	107,400
1945	July 31, 1945	1,384.0	111,700
1946	May 27, 1946	1,415.85	182,800
1947	Aug. 3, 1947	1,500.90	514,490
1948	July 1, 1948	1,562.52	1,004,600
1949	Aug. 5, 1949	1,580.13	1,184,000
1950	July 10, 1950	1,582.88	1,214,000
1951	July 27, 1951	1,582.37	1,208,000
1952	Aug. 11, 1952	1,582.06	1,205,000
1953	Aug. 16, 1953	1,600.00	1,405,300
1954	Aug. 23, 1954	1,600.10	1,406,500
1955	Aug. 15, 1955	1,599.86	1,404,100
1956	Aug. 1, 1956	1,600.00	1,405,300
1957	Aug. 25, 1957	1,599.91	1,404,100

8. *Thunder Creek near Newhalem, Wash.*

[Published as "near Marblemount" prior to 1931 and as "above Colonial Creek, near Marblemount" in 1931]

Location.—Lat 48°40'20'', long 121°04'20'', in SE¼ sec. 23, T. 37 N., R. 13 E. (unsurveyed), on right bank half a mile upstream from Diablo Reservoir, 8 miles east of Newhalem, and 20 miles northeast of Marblemount.

Drainage area.—98 sq mi, approximately. 111 sq mi at site prior to October 1930.

Gage.—Water-stage recorder. Altitude of gage is 1,220 ft (from river-profile map). Prior to October 1930, water-stage recorder at site 3 miles downstream at different datum.

Stage-discharge relation.—Defined by current-meter measurements below 2,900 cfs and extended by logarithmic plotting.

Remarks.—Discharges for period 1920–30 at lower site were adjusted to upper site by 0.8 power of ratio of drainage areas.

Annual peak stages and discharges of Thunder Creek near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1920	Sept. 11, 1920		4,490
1921	June 7, 1921		4,140
1922	Dec. 12, 1921		13,900
1923	June 9, 1923		2,880
1924	Feb. 12, 1924		5,760
1925	Dec. 12, 1924		3,800
1926	July 5, 1926		2,420
1927	Oct. 16, 1926		9,410
1928	May 22, 1928		3,280
1929	Oct. 9, 1928		7,960
1930	July 13, 1930	2	2,420
1931	June 26, 1931	8.2	3,630
1932	Feb. 26, 1932	11.3	8,150
1933	Nov. 13, 1932	9.27	5,010
1934	July 16, 1934	8.82	4,440
1935	Nov. 5, 1934	10.0	6,120
1936	May 30, 1936	8.30	3,800
1937	June 21, 1937	7.34	2,650
1938	Oct. 28, 1937	11.0	7,630
1939	May 28, 1939	9.14	4,740
1940	May 23, 1940	6.63	2,060
1941	Oct. 20, 1940	9.56	5,430
1942	Oct. 3, 1941	8.15	3,530
1943	July 10, 1943	7.10	2,300
1944	Sept. 20, 1944	7.43	2,780
1945	Sept. 4, 1945	7.67	3,080
1946	Oct. 25, 1945	8.68	4,220
1947	Oct. 25, 1946	9.74	5,550
1948	Oct. 19, 1947	8.90	4,410
1949	May 13, 1949	7.06	2,560
1950	Nov. 27, 1949	12.14	9,630
1951	Feb. 10, 1951	8.54	3,870
1952	June 4, 1952	7.02	2,580
1953	Sept. 28, 1953	7.14	2,690
1954	Aug. 23, 1954	7.48	2,850
1955	July 16, 1955	7.80	3,170
1956	Oct. 25, 1955	12.68	10,800
1957	June 11, 1957	7.38	2,790

9. *Diablo Reservoir near Newhalem, Wash.*

Location.—Lat 48°43′00″, long 121°08′00″, in SE¼ sec. 5, T. 37 N., R. 13 E. (unsurveyed), at Diablo Dam on Skagit River, 1 mile downstream from Thunder Creek, and 6 miles northeast of Newhalem.

Drainage area.—1,100 sq mi, approximately.

Gage.—Water-stage recorder. Datum of gage is at mean sea level, (City of Seattle bench mark). Prior to Oct. 12, 1931, staff gage at approximately same site and datum.

Remarks.—Reservoir is formed by concrete dam, completed in 1930; storage began in October 1929. Usable capacity, 76,220 acre-feet between elevations 1,040 ft (bottom of outlet pipes) and 1,205 ft (top of taintor gates). Crest of spillway is at elevation 1,187 ft. Maximum contents prior to 1943 from capacity table dated Oct. 10, 1930; maximum content on July 14, 1933 from table used subsequent to 1943 is 90,600 acre-feet.

Annual maximum elevation and storage of Diablo Reservoir near Newhalem, Wash.

Water year	Date	Elevation (feet, m.s.l.)	Storage (acre-feet)
1932	July 10, 1932	1,205.76	92,010
1933	July 14, 1933	1,206.5	92,720
1934	July 16, 1934	1,206.02	92,260
1935	July 24, 1935	1,206.08	92,230
1936	Sept. 1, 1936	1,206.20	92,430
1937	Sept. 6, 1937	1,206.00	92,240
1938	July 27, 1938	1,206.30	92,520
1939	Jan. 1, 1939	1,206.17	92,400
1940	Sept. 1, 1940	1,206.16	92,390
1941	Oct. 10, 1940	1,206.01	92,340
1942	July 13, 1942	1,206.2	92,430
1943	Sept. 18, 1943	1,205.9	90,050
1944	(¹)	1,206.0	90,140
1945	Aug. 28, 1945	1,205.1	89,310
1946	(²)	1,206.0	90,140
1947	May 7, 1947	1,206.0	90,140
1948	May 22, 1948	1,206.18	90,310
1949	Oct. 7, 1948	1,206.1	90,230
1950	Nov. 28, 1949	1,198.2	83,200
1951	Sept. 18, 28, 1951	1,205.0	89,220
1952	Aug. 1, 1952	1,205.9	90,050
1953	Nov. 17, 1952	1,205.6	89,770
1954	July 25, 1954	1,206.0	90,140
1955	Mar. 24, 1955	1,205.89	90,040
1956	Oct. 25, 1955	1,206.17	90,300
1957	Aug. 18, 1957	1,205.85	90,000

[1] Oct. 2 and Dec. 14, 1943, Mar. 16, 27, July 26, and Aug. 3, 7, 24, 1944.
[2] May 22 and June 14, 1946.

10. *Skagit River at Reflector Bar, near Newhalem, Wash.*

[Published as "near Marblemount" 1913-22]

Location.—Lat 48°42'50'', long 121°08'30'', in N½ sec. 8, T. 37 N., R. 13 E. (unsurveyed), on right bank just downstream from Canyon Diablo, a quarter of a mile downstream from later site of Diablo Dam, three-quarters of a mile upstream from Stetattle Creek, 1½ miles downstream from Thunder Creek, 6 miles northeast of Newhalem, and 19 miles northeast of Marblemount.

Drainage area.—1,100 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Altitude of gage is 880 ft (from river-profile map). Dec. 6, 1913 to Apr. 13, 1914, staff gage at same site and datum.

Stage-discharge relation.—Defined by current-meter measurements below 24,000 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Skagit River at Reflector Bar, near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		20.5	115,000
1856		18.5	95,000
1898	Nov. 18, 1897	12.5	48,000
1910	Nov. 29, 1909	15.4	70,000
1914	Jan. 6, 1914	7.8	16,800
1915	Apr. 3, 1915	6.52	11,800
1916	June 17, 1916	10.5	29,400
1917	June 16, 1917	8.19	19,700
1918	Dec. 29, 1917	12.0	37,300
1919	May 27, 1919	9.0	24,200
1920	July 1, 1920	7.0	15,600
1921	June 7, 1921	10.7	30,800
1922	Dec. 12, 1921	14.1	58,000

11. *Stetattle Creek near Newhalem, Wash.*

[Published as "near Marblemount" 1913-15]

Location.—Lat 48°43'30'', long 121°09'20'', in NE¼ sec. 6, T. 37 N., R. 13 E.,
  on left bank three-quarters of a mile upstream from mouth, 5½ miles northeast
  of Newhalem, and 18½ miles northeast of Marblemount.
Drainage area.—21.4 sq mi.
Gage.—Water-stage recorder   Altitude of gage is 925 ft (by barometer).   Sept. 7,
  1933, to Aug. 26, 1937, water-stage recorder 150 ft upstream at datum 1.69 ft
  higher.
Stage-discharge relation.—Defined by current-meter measurements below 1,500
  cfs and extended on basis of slope-area determination of the Nov. 26, 1949
  flood peak.

Annual peak stages and discharges of Stetattle Creek near Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1934	Oct. 23, 1933	7.17	2,020
1935	Nov. 5, 1934	10.4	5,640
1936	June 2, 1936	4.78	1,010
1937	June 18, 1937	5.50	1,370
1938	Oct. 28, 1937	7.34	3,220
1939	May 28, 1939	6.64	2,560
1940	Nov. 30, 1939	5.10	1,130
1941	Oct. 19, 1940	6.03	1,940
1942	Dec. 2, 1941	6.77	2,680
1943	June 17, 1943	4.70	870
1944	Dec. 3, 1943	5.62	1,510
1945	Feb. 7, 1945	6.10	1,980
1946	Oct. 25, 1945	7.16	3,210
1947	Oct. 24, 1946	5.85	1,740
1948	Oct. 19, 1947	6.80	2,730
1949	Oct. 6, 1948	5.87	1,740
1950	Nov. 26, 1949	9.70	8,580
1951	Feb. 10, 1951	----------	[1] 3,300
1952	June 4, 1952	4.76	1,480
1953	Sept. 30, 1953	5.20	1,820
1954	Oct. 30, 1953	5.08	1,710
1955	Nov. 22, 1954	4.88	1,540
1956	Oct. 25, 1955	7.34	4,330
1957	Oct. 21, 1956	5.08	1,710

[1] Estimated.

12. *Skagit River at Newhalem, Wash.*

[Published as "near Marblemount" 1909–14, 1921–31]

Location.—Lat 48°40'20'', long 121°14'45'', in SE¼ sec. 21, T. 37 N., R. 12 E., on right bank a quarter of a mile upstream from Newhalem Creek, half a mile downstream from city of Seattle powerplant at Newhalem, 11 miles upstream from Bacon Creek, and 13 miles northeast of Marblemount.

Drainage area.—1,160 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder.   Datum of gage is 401.5 ft above mean sea level (river-profile survey).   Dec. 21, 1908, to May 23, 1914, staff gages half a mile upstream at datum 91 ft higher, Nov. 15, 1920, to June 4, 1923, staff gage 500 ft upstream at present datum.

Stage-discharge relation.—Defined by current-meter measurements below 26,500 cfs.

Remarks.—Flow partly regulated by Gorge Dam since August 1924, by Diablo Reservoir since October 1929, and by Ross Reservoir since March 1940.

Annual peak stages and discharges of Skagit River at Newhalem, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		20.5	115,000
1856		18.5	95,000
1898	Nov. 19, 1897	12.5	48,000
1909	June 2, 1909	12.3	26,900
1910	Nov. 29, 1909	22.0	63,500
1911	June 14, 1911	11.9	25,500
1912	May 15, 1912	10.2	19,800
1913	June 3, 1913	12.6	27,900
1914	Jan. 6, 1914	10.5	20,700
1918	Dec. 29, 1917	19.0	47,400
1921	June 8, 1921	91.1	31,400
1922	Dec. 12, 1921	94.8	60,000
1923	June 9, 1923	89.14	21,400
1924	Feb. 12, 1924	90.85	31,400
1925	May 20, 1925	89.65	25,400
1926	Apr. 30, 1926	85.68	9,220
1927	June 8, 1927	89.56	26,000
1928	May 21, 1928	89.75	27,200
1929	Oct. 9, 1928	89.15	23,600
1930	June 11, 1930	86.90	13,400
1931	May 2, 1931	87.53	15,500
1932	Feb. 27, 1932	92.84	45,000
1933	June 15, 1933	90.15	28,200
1934	Apr. 23, 1934	89.64	25,000
1935	Jan. 25, 1935	90.82	30,300
1936	May 31, 1936	89.27	22,400
1937	June 3, 1937	89.32	22,500
1938	Oct. 28, 1937	89.69	24,400
1939	May 29, 1939	89.3	22,400
1940	May 23, 1940	87.56	15,100
1941	Oct. 20, 1940	88.12	17,100
1942	May 26, 1942	88.14	17,400
1943	May 27, 1943	88.82	20,400
1944	June 12, 1944	86.45	11,200
1945	May 31, 1945	88.89	20,700
1946	May 27, 1946	89.73	24,400
1947	May 25, 1947	87.11	13,500
1948	June 15, 1948	87.53	15,100
1949	May 15, 1949	86.59	11,800
1950	June 29, 1950	88.20	17,700
1951	Dec. 24, 1950	88.33	18,300
1952	Oct. 29, 1951	86.64	12,000
1953	July 14, 1953	88.66	19,700
1954	July 3, 1954	88.40	18,600
1955	July 16, 1955	88.75	20,100
1956	Oct. 25, 1955	88.14	17,500
1957	June 7, 1957	86.30	10,900

13. *Skagit River above Alma Creek, near Marblemount, Wash.*

Location.—Lat 48°36'25'', long 121°21'35'', in NE¼ sec. 15, T. 36 N., R. 11 E., on right bank three-quarters of a mile upstream from Alma Creek and 7 miles north of Marblemount.
Drainage area.—1,260 sq mi, approximately, of which 400 sq mi is in Canada.
Gage.—Water-stage recorder. Datum of gage is 358.8 ft above mean sea level (from river-profile survey).
Stage-discharge relation.—Defined by current-meter measurements below 21,000 cfs and extended by logarithmic plotting.
Remarks.—Flow partly regulated by powerplants on upper Skagit River, and by Ross and Diablo Reservoirs.

Annual peak stages and discharges of Skagit River above Alma Creek, near Marblemount, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1951	Feb. 10, 1951	14.40	28,000
1952	Oct. 29, 1951	10.26	12,900
1953	July 14, 1953	12.44	20,200
1954	July 3, 1954	12.24	19,400
1955	July 16, 1955	13.44	24,200
1956	Oct. 25, 1955	14.64	29,400
1957	Oct. 17, 1956	11.37	16,800

14. *Bacon Creek near Marblemount, Wash.*

Location.—Lat 48°35'20'', long 121°23'40'', on line between secs. 20 and 21, T. 36 N., R. 11 E., on highway bridge near right bank a quarter of a mile upstream from mouth and 4½ miles north of Marblemount.
Drainage area.—50.9 sq mi.
Gage.—Wire-weight gage read twice daily. Gage heights are from graphs based on gage readings, except that for the 1950 water year, which is from a highwater mark. Altitude of gage is 350 ft (from river-profile map).
Stage-discharge relation.—Defined by current-meter measurements below 2,000 cfs and extended on basis of slope-area determination of the Nov. 26, 1949 flood peak.

Annual peak stages and discharges of Bacon Creek near Marblemount, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1944	Dec. 3, 1943	4.25	3,050
1945	Feb. 7, 1945	5.62	5,510
1946	Oct. 25, 1945	6.20	7,000
1947	Oct. 24, 1946	5.88	6,480
1948	Oct. 19, 1947	5.67	5,670
1949	Oct. 7, 1948	4.65	3,300
1950	Nov. 26, 1949	7.13	18,100

15. *Skagit River at Marblemount, Wash.*

Location.—Lat 48°32′00″, long 121°25′40″, in NW¼ sec. 7, T. 35 N., R. 11 E., on right bank half a mile north of Marblemount and 0.6 mile upstream from Cascade River.

Drainage area.—1,360 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Datum of gage is 305.1 ft above mean sea level (river-profile survey).

Stage-discharge relation.—Defined by current-meter measurements below 20,000 cfs and extended by logarithmic plotting.

Remarks.—Flow partly regulated by powerplants on upper Skagit River, and by Diablo and Ross Reservoirs.

Annual peak stages and discharges of Skagit River at Marblemount, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1944	Dec. 3, 1943	5.66	16,800
1947	Oct. 25, 1946	6.98	24,600
1948	Oct. 19, 1947	8.52	35,400
1949	May 12, 1949	5.90	17,900
1950	Nov. 27, 1949	11.37	59,300
1951	Feb. 10, 1951	9.65	42,400
1952	Oct. 29, 1951	5.40	14,000
1953	July 14, 1953	6.64	20,500
1954	July 4, 1954	6.69	21,100
1955	July 16, 1955	7.37	25,600
1956	Oct. 25, 1955	9.25	38,900
1957	Oct. 17, 1956	7.01	23,000

16. *Cascade River at Marblemount, Wash.*

[Published as "near Marblemount" 1909–12]

Location.—Lat 48°31′25″, long 121°23′00′, in N½ sec. 16, T. 35 N., R. 11 E., on right bank 1½ miles downstream from Boulder Creek, 2 miles east of Marblemount, and 2½ miles upstream from mouth.

Drainage area.—171 sq mi. 140 sq mi, approximately, at site prior to May 1, 1913.

Gage.—Water-stage recorder. Datum of gage is 380.3 ft above mean sea level (river-profile survey). April 1909 to May 1, 1913, staff gages at site 5½ miles upstream from present site at different datums.

Stage-discharge relation.—Defined by current-meter measurements below 5,000 cfs and extended by logarithmic plotting.

Remarks.—Discharges for period 1909–12 at upper site were adjusted to lower site by 0.8 power of ratio of drainage areas.

Annual peak stages and discharges of Cascade River at Marblemount, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		22.0	46,000
1898	Nov. 19, 1897	20.0	40,000
1910	Nov. 29, 1909		26,000
1911	Oct. 10, 1910		17,300
1912	June 19, 1912		8,200
1918	Dec. 29, 1917	17.2	32,000
1929	Oct. 9, 1928	9.20	10,700
1930	June 7, 1930	5.43	2,740
1931	Jan. 27, 1931	6.55	4,480
1932	Feb. 26, 1932	9.88	12,900
1933	Nov. 13, 1932	9.02	10,400
1934	Nov. 2, 1933	8.06	8,050
1935	Nov. 5, 1934	9.40	11,500
1936	June 2, 1936	7.07	5,760
1937	June 3, 1937	6.59	4,760
1938	Oct. 28, 1937	8.62	8,810
1939	May 28, 1939	8.19	7,870
1940	Dec. 15, 1939	5.87	3,190
1941	Oct. 19, 1940	6.58	4,430
1942	Dec. 2, 1941	7.66	6,730
1943	June 17, 1943	6.26	3,820
1944	Dec. 3, 1943	6.98	5,210
1945	Jan. 7, 1945	6.62	4,430
1946	Oct. 25, 1945	8.84	9,620
1947	Oct. 25, 1946	9.54	11,600
1948	Oct. 19, 1947	9.33	11,000
1949	May 13, 1949	7.14	5,420
1950	Nov. 27, 1949	11.47	17,800
1951	Feb. 10, 1951	8.89	9,650
1952	June 4, 1952	6.43	4,280
1953	Jan. 31, 1953	6.70	4,750
1954	Aug. 23, 1954	7.09	5,470
1955	June 10, 1955	7.49	6,270
1956	Oct. 25, 1955	9.31	10,800
1957	Oct. 17, 1956	6.66	4,630

17. South Fork Sauk River near Barlow Pass, Wash.

Location.—Lat 48°03′45″, long 121°24′20″, in NE¼ sec. 29, T. 30 N., R. 11 E. (unsurveyed), 2¾ miles upstream from North Fork, 3½ miles northeast of Barlow Pass, and 16 miles southeast of Darrington.

Drainage area.—32.7 sq mi.

Gage.—Water-stage recorder. Altitude of gage is 1,550 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 1,400 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of South Fork Sauk River near Barlow Pass, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1918	Dec. 29, 1917	9.1	9,410
1919	Dec. 14, 1918	6.3	3,350
1920	Nov. 15, 1919	7.7	5,870
1922	Dec. 12, 1921	9.5	10,500
1929	June 15, 1929	5.37	1,100
1930	Feb. 5, 1930	6.37	2,080
1931	Jan. 27, 1931	7.22	3,210

18. *Sauk River above Whitechuck River, near Darrington, Wash.*

Location.—Lat 48°10'00", long 121°27'45", in NW¼ sec. 24, T. 31 N., R. 10 E., on right bank half a mile upstream from Whitechuck River and 9½ miles southeast of Darrington.

Drainage area.—152 sq mi.

Gage.—Water-stage recorder.   Altitude of gage is 930 ft (from river-profile map).

Stage-discharge relation.—Defined by current-meter measurements below 6,200 cfs and extended by logarithmic plotting.

Remarks.—Discharge for 1951 estimated by correlation with record for Sauk River near Sauk, Wash.

Annual peak stages and discharges of Sauk River above Whitechuck River, near Darrington, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1918	Dec. 29, 1917	13.3	24,400
1919	Dec. 14, 1918	7.9	8,430
1920	Nov. 15, 1919	9.0	11,400
1921	Oct. 4, 1920	8.1	8,960
1922	Dec. 12, 1921	14.65	29,100
1929	Oct. 9, 1928	7.50	7,030
1930	Feb. 5, 1930	6.35	5,060
1931	Jan. 27, 1931	7.72	7,410
1932	Feb. 26, 1932	13.0	22,900
1933	Nov. 13, 1932	10.3	13,000
1934	Dec. 21, 1933	12.05	18,600
1935	Jan. 25, 1935	10.41	13,200
1936	May 16, 1936	6.26	4,400
1937	June 3, 1937	6.19	4,310
1938	Apr. 18, 1938	8.23	8,240
1939	May 29, 1939	7.60	7,010
1940	Dec. 15, 1939	6.71	5,480
1941	Oct. 18, 1940	5.94	4,180
1942	Dec. 2, 1941	7.61	7,220
1943	Nov. 23, 1942	7.06	6,230
1944	Dec. 3, 1943	9.00	10,300
1945	Feb. 7, 1945	8.40	8,940
1946	Oct. 25, 1945	8.00	8,950
1947	Oct. 25, 1946	8.50	10,200
1948	Oct. 19, 1947	9.68	13,500
1949	May 13, 1949	6.52	5,660
1950	Nov. 27, 1949	14.90	30,200
1951			20,800
1952	June 5, 1952	6.41	5,080
1953	Jan. 31, 1953	8.17	9,360
1954	Oct. 31, 1953	6.56	5,600
1955	Nov. 18, 1954	6.76	5,990
1956	Nov. 4, 1955	9.86	14,400
1957	Dec. 10, 1956	8.19	9,650

19. *Sauk River at Darrington, Wash.*

Location.—Lat 48°15'00", long 121°35'00", in SW¼ sec. 24, T. 32 N., R. 9 E., on right bank half a mile southeast of Darrington and 2¼ miles downstream from Clark Creek.

Drainage area.—293 sq mi.

Gage.—Staff gage read once or twice daily.   Altitude of gage is 525 ft (from river-profile map).   July 1914 to Apr. 14, 1922, staff gage 700 ft upstream at different datum.   Gage heights are from graphs based on gage readings.

Stage-discharge relation.—Defined by current-meter measurements below 7,700 cfs and extended by velocity-area studies.

Annual peak stages and discharges of Sauk River at Darrington, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		18.0	48,000
1898	Nov. 1897	17.0	44,000
1910	Nov. 29, 1909	16.0	40,000
1915	Apr. 2, 1915	8.8	16,500
1916	Dec. 8, 1915	7.4	12,000
1917	Nov. 9, 1916	6.2	8,260
1918	Dec. 29, 1917	15.0	36,000
1919	Dec. 14, 1918	9.7	15,100
1920	Nov. 15, 1919	10.5	17,200
1921	Oct. 4, 1920	10.1	16,200
1922	Dec. 12, 1921	15.0	36,000
1923	Dec. 24, 1922	8.0	12,300
1924	Feb. 12, 1924	12.1	27,200
1925	Dec. 11, 1924	9.0	15,500
1926	Jan. 5, 1926	7.5	10,800
1929	Oct. 9, 1928	8.5	13,900
1930	Feb. 5, 1930	7.1	9,630
1931	Jan. 27–28, 1931	8.4	13,600
1932	Feb. 26, 1932	16.0	46,500

20. *Suiattle River near Mansford, Wash.*

Location.—Lat 48°21'50'', long 121°29'30'', in N½ sec. 10, T. 33 N., R. 10 E.,
left bank 2½ miles downstream from Big Creek and 4 miles north of Mansford.
Drainage area.—335 sq mi.
Gage.—Water-stage recorder. Altitude of gage is 530 ft (from river-profile map).
Stage-discharge relation.—Defined by current-meter measurements below 15,000
cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Suiattle River near Mansford, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1939	May 29, 1939	9.79	9,680
1940	Dec. 15, 1939	7.97	5,580
1941	Oct. 18–19, 1940	7.83	4,980
1942	Oct. 3, 1941	9.78	9,100
1943	June 30, 1943	8.82	7,200
1944	Dec. 3, 1943	9.47	8,850
1945	Feb. 8, 1945	9.70	9,520
1946	Oct. 25, 1945	10.90	12,600
1947	Oct. 25, 1946	12.86	19,200
1948	Oct. 19, 1947	12.33	18,000
1949	May 13, 1949	9.89	9,900
1950	Nov. 27, 1949	15.60	30,700

21. *Sauk River near Sauk, Wash.*

Location.—Lat 48°25'15'', long 121°34'00'', in NW¼ sec. 19, T. 34 N., R. 10 E., on left bank 5 miles upstream from mouth, 5 miles southeast of Sauk, and 8 miles downstream from Suiattle River.

Drainage area.—714 sq mi.

Gage.—Water-stage recorder.   Datum of gage is 266 ft above mean sea level (river-profile survey).

Stage-discharge relation.—Defined by current-meter measurements below 40,000 cfs and extended by logarithmic plotting.

Remarks.—Peak for 1912 from record obtained at several sites from 1 mile downstream to 5 miles upstream from present site during period 1910–12.

Annual peak stages and discharges of Sauk River near Sauk, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1912	Nov. 19, 1911	8.7	28,000
1929	Oct. 9, 1928	9.33	21,800
1930	Feb. 5, 1930	7.99	15,200
1931	Jan. 28, 1931	9.32	21,800
1932	Feb. 26, 1932	15.83	68,500
1933	Nov. 13, 1932	12.62	42,500
1934	Dec. 22, 1933	14.40	56,600
1935	Nov. 5, 1934	13.54	49,400
1936	June 3, 1936	8.33	16,600
1937	June 3, 1937	8.15	15,900
1938	Apr. 18, 1938	10.78	29,900
1939	Jan. 1, 1939	9.96	25,200
1940	Dec. 15, 1939	9.00	20,000
1941	May 17, 1941	6.80	7,980
1942	Dec. 2, 1941	8.85	19,000
1943	Nov. 23, 1942	9.02	19,500
1944	Dec. 3, 1943	10.80	29,900
1945	Feb. 8, 1945	10.28	26,800
1946	Oct. 25, 1945	9.96	25,000
1947	Oct. 25, 1946	11.41	33,200
1948	Oct. 19, 1947	11.74	35,900
1949	May 13, 1949	9.03	19,700
1950	Nov. 27, 1949	16.93	82,400
1951	Feb. 10, 1951	14.97	62,700
1952	June 5, 1952	7.65	13,600
1953	Jan. 31, 1953	10.56	28,400
1954	Dec. 20, 1953	8.17	15,600
1955	June 11, 1955	9.56	23,900
1956	Oct. 25, 1955	12.23	40,600
1957	Dec. 10, 1956	10.41	28,500

22. *Baker River below Anderson Creek, near Concrete, Wash.*

Location.—Lat 48°39′50″, long 121°40′25″, in SE¼ sec. 30, T. 37 N., R. 9 E., on right bank 100 ft downstream from Anderson Creek and 9½ miles northeast of Concrete.

Drainage area.—211 sq mi.

Gage.—Water-stage recorder. Altitude of gage is 560 ft (from river-profile map). October 22, 1910, to Sept. 23, 1915, staff gage and Sept. 24, 1915, to Nov. 11, 1931, water-stage recorder, 250 ft downstream from present site and at different datum.

Stage-discharge relation.—Defined by current-meter measurements below 8,000 cfs and extended by velocity-area studies.

Annual peak stages and discharges of Baker River below Anderson Creek, near Concrete, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		16. 0	50, 000
1898	Nov. 1897	13. 5	36, 700
1910	Nov. 29, 1909	15. 3	46, 200
1911	Nov. 20, 1910	10. 0	20, 000
1912	June 25, 1912	7. 0	6, 860
1913	Sept. 4, 1913	7. 6	8, 800
1914	Jan. 6, 1914	12. 6	24, 900
1915	Apr. 2, 1915	9. 6	17, 700
1916	Feb. 15, 1916	8. 8	14, 800
1917	July 16, 1917	7. 21	8, 210
1918	Dec. 29, 1917	13. 7	36, 800
1919	Dec. 4, 1918	9. 70	18, 700
1920	Nov. 15, 1919	9. 93	19, 600
1921	Oct. 4, 1920	9. 74	18, 700
1922	Dec. 12, 1921	10. 80	23, 600
1923	Dec. 24, 1922	8. 1	11, 800
1924	Jan. 31, 1924	11. 9	28, 500
1925	Dec. 12, 1924		17, 000
1929	Oct. 8, 1928	10. 15	20, 900
1930	Feb. 18, 1930	6. 88	7, 390
1931	Jan. 23, 1931	9. 90	19, 600
1956	Nov. 3, 1955	14. 37	20, 100
1957	Oct. 20, 1956	11. 78	12, 200

23. *Lake Shannon at Concrete, Wash.*

Location.—Lat 48°32'55'', long 121°44'25'', in SW¼ sec. 2, T. 35 N., R. 8 E., at Baker Dam on Baker River near left bank half a mile north of Concrete and 1 mile upstream from mouth of Baker River.

Drainage area.—297 sq mi.

Gage.—Staff gage or water-stage indicator. Datum of gage is at mean sea level, subject to adjustment to datum of 1929.

Remarks.—Reservoir is formed by concrete dam completed to elevation 405.00 ft in November 1925 and to 435.00 ft in June 1927. Storage began in November 1925. Capacity, 132,500 acre-feet between elevation 360 ft (lowest elevation for capacity operation) and 435 ft (spillway crest). Records furnished by Puget Sound Power and Light Co.

Annual peak stages and storage on last day of month of Lake Shannon at Concrete, Wash.[1]

Water year	Date	Elevation (feet, m.s.l.)	Storage (acre-feet)
1926	June 1926	404.64	93,350
1927	July 1927	434.68	155,520
1928	July 1928	434.44	154,980
1929	May 1929	434.80	155,790
1930	June 1930	434.95	156,130
1931	Jan. 1931	434.80	155,790
1932	July 1932	434.90	156,020
1933	Nov. 1932	434.80	155,790
1934	July 1934	435.00	156,240
1935	Oct. 1934	434.71	155,590
1936	June 1936	434.97	156,170
1937	June 1937	433.53	152,940
1938	Nov. 1937	434.93	156,080
1939	July 1939	435.00	156,240
1940	May 1940	434.12	154,260
1941	May 1941	434.61	155,360
1942	June 1942	435.60	157,600
1943	July 1943	435.86	158,180
1944	June 1944	435.60	157,600
1945	June 1945	435.59	157,570
1946	Oct. 1945	435.26	156,830
1947	Nov. 1946	435.85	158,160
1948	Dec. 1947	435.88	158,230
1949	Nov. 1948	435.82	158,090
1950	Nov. 1949	435.83	158,120
1951	June 1951	435.89	158,250
1952	July 1952	436.16	158,860
1953	Sept. 1953	436.86	160,450
1954	June 1954	436.55	159,750
1955	Nov. 1954	436.75	160,200
1956	Oct. 1955	436.72	160,130
1957	Aug. 1957	434.81	155,810

[1] Figures shown for each water year are maximums of 12 end of month figures.

24. *Baker River at Concrete, Wash.*

Location.—Lat 48°32′35″, long 121°44′35″, on line between secs. 10 and 11, T. 35 N., R. 8 E., on left bank 800 ft downstream from Baker River power-plant, a quarter of a mile northeast of Concrete, and three-quarters of a mile upstream from mouth.

Drainage area.—297 sq mi.

Gage.—Water-stage recorder. Datum of gage is 172.6 ft above mean sea level (from river-profile survey). Prior to 1915, staff gage at site half a mile downstream at different datum.

Stage-discharge relation.—Defined by current-meter measurements below 16,000 cfs and extended on basis of computation of peak flow over dam and through power plant of 35,200 cfs, made by Puget Sound Power and Light Co. for flood of November 27, 1949.

Remarks.—Flow regulated since November 1925 by Baker River powerplant and Lake Shannon.

Annual peak stages and discharges of Baker River at Concrete, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1911	Nov. 21, 1910	10.8	24,600
1912	Nov. 18, 1911	8.7	14,800
1913	Sept. 4, 1913	9.3	18,100
1914	Jan. 6, 1914	12.2	31,000
1944	Dec. 3, 1943	10.7	14,100
1945	Feb. 8, 1945	12.45	20,000
1946	Oct. 25, 1945	14.90	27,000
1947	Oct. 24, 1946	12.40	20,000
1948	Oct. 18, 1947	13.40	23,000
1949	May 10, 1949	10.30	12,600
1950	Nov. 27, 1949	20.32	35,200
1951	Feb. 10, 1951	16.20	29,700
1952	Oct. 19, 1951	9.87	11,000
1953	Jan. 12, 1953	11.22	16,200
1954	Oct. 31, 1953	10.55	14,200
1955	Nov. 18, 1954	11.99	18,500
1956	Nov. 4, 1955	15.07	26,900
1957	Oct. 17, 1956	12.67	20,400

25. *Skagit River near Concrete, Wash.*

Location.—Lat 48°31'30", long 121°46'10", in NE¼ sec. 16, T. 35 N., R. 8 E., on right bank at The Dalles 1½ miles southwest of Concrete and 2½ miles downstream from Baker River.

Drainage area.—2,700 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder. Datum of gage is 130.0 ft above mean sea level, datum of 1929. Dec. 10, 1924, to Oct. 27, 1937, water-stage recorder at present site, at datum 12.69 ft higher. Gage heights given herein are to datum of present gage.

Stage-discharge relation.—Defined by current-meter measurements below 135,000 cfs and extended by logarithmic plotting.

Remarks.—Flow partly regulated by powerplants on Baker and upper Skagit Rivers and by Lake Shannon Reservoir since 1926, Diablo Reservoir since 1930, and Ross Reservoir since 1940.

Annual peak stages and discharges of Skagit River near Concrete, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		69.3	500,000
1856		57.3	350,000
1898	Nov. 19, 1897	51.1	275,000
1910	Nov. 30, 1909	49.1	260,000
1918	Dec. 30, 1917	45.7	220,000
1922	Dec. 13, 1921	47.6	240,000
1925	Dec. 12, 1924	32.44	92,500
1926	Dec. 23, 1925	26.3	51,600
1927	Oct. 16, 1926	32.03	88,900
1928	Jan. 12, 1928	32.9	95,500
1929	Oct. 9, 1928	29.94	74,300
1930	June 7, 1930	22.70	32,200
1931	June 26, 1931	27.78	60,600
1932	Feb. 27, 1932	39.99	147,000
1933	Nov. 13, 1932	35.6	116,000
1934	Dec. 22, 1933	33.6	101,000
1935	Jan. 25, 1935	37.9	131,000
1936	June 3, 1936	27.7	60,000
1937	June 19, 1937	28.97	68,300
1938	Oct. 28, 1937	32.16	89,600
1939	May 29, 1939	30.7	79,600
1940	Dec. 15, 1939	25.70	48,200
1941	Oct. 19, 1940	26.20	51,000
1942	Dec. 2, 1941	30.17	76,300
1943	Nov. 23, 1942	26.69	54,000
1944	Dec. 3, 1943	28.49	65,200
1945	Feb. 8, 1945	29.35	70,800
1946	Oct. 25, 1945	34.0	102,000
1947	Oct. 25, 1946	31.14	82,200
1948	Oct. 19, 1947	32.99	95,200
1949	May 13, 1949	26.97	55,700
1950	Nov. 27, 1949	40.8	154,000
1951	Feb. 10, 1951	38.99	139,000
1952	June 5, 1952	24.80	43,500
1953	Feb. 1, 1953	28.61	66,000
1954	Oct. 31, 1953	27.39	58,000
1955	June 11, 1955	26.99	55,600
1956	Nov. 3, 1955	34.48	106,000
1957	Oct. 20, 1956	27.84	61,000

26. *Alder Creek near Hamilton, Wash.*

Location.—Lat 48°31'40'', long 121°57'00'', in NE¼ sec. 18, T. 35 N., R. 7 E., on left bank at railroad trestle a quarter of a mile upstream from highway bridge, three-quarters of a mile upstream from mouth, and 2 miles east of Hamilton.

Drainage area.—10.7 sq mi.

Gage.—Water-stage recorder. Altitude of gage is 125 ft (by barometer). Prior to Nov. 15, 1945, water-stage recorder at site 80 ft upstream at datum 2.46 ft higher. Nov. 15, 1945, to Jan. 7, 1947, water-stage recorder at present site at datum 2.56 ft higher. Jan. 8, 1947, to Aug. 24, 1951, water-stage recorder at same site at datum 0.98 ft higher. Gage heights given herein are to datum of present gage.

Stage-discharge relation.—Defined by current-meter measurements below 400 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Alder Creek near Hamilton, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1944	Dec. 3, 1943	5.38	137
1945	Jan. 7, 1945	6.74	670
1946	Oct. 25, 1945	5.93	265
1947	Dec. 11, 1946	5.17	450
1948	Oct. 19, 1947	3.55	241
1949	Dec. 1, 1948	3.75	256
1950	Dec. 27, 1949	4.24	477
1951	Feb. 10, 1951	4.90	654
1952	Feb. 4, 1952	3.56	212
1953	Jan. 31, 1953	4.23	364
1954	Dec. 11, 1953	3.80	239
1955	Feb. 8, 1955	3.84	295
1956	Nov. 3, 1955	4.11	363
1957	Dec. 9, 1956	5.38	360

27. *Day Creek near Lyman, Wash.*

Location.—Lat 48°30'05'', long 122°02'45'', in NW¼ sec. 28, T. 35 N., R. 6 E., on left end of county highway bridge, 1 mile upstream from mouth, and 1¾ miles southeast of Lyman.

Drainage area.—36.3 sq mi.

Gage.—Water-stage recorder. Altitude of gage is 90 ft (from topographic map).

Stage-discharge relation.—Defined by current-meter measurements below 3,000 cfs and extended by logarithmic plotting.

Annual peak stages and discharges of Day Creek near Lyman, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1944	Dec. 3, 1943	7.60	4,370
1945	Jan. 7, 1945	7.85	4,310
1946	Nov. 14, 1945	7.77	4,310
1947	Oct. 24, 1946	8.12	4,530
1948	Oct. 18, 1947	7.94	4,420
1949	Feb. 16, 1949	6.85	3,330
1950	Dec. 28, 1949	8.35	5,570
1951	Feb. 9, 1951	7.72	4,510
1952	Oct. 2, 1951	6.55	3,350
1953	Jan. 2, 1953	6.81	3,890
1954	Oct. 30, 1953	7.07	4,180
1955	Feb. 7, 1954	6.47	3,750
1956	Nov. 3, 1955	8.27	4,750
1957	Dec. 9, 1956	8.80	5,360

28. *Skagit River near Sedro Woolley, Wash.*

Location.—Lat 48°29′05″, long 122°14′30″, in NW¼ sec. 36, T. 35 N., R. 4 E.,
at Northern Pacific Railway bridge, three-quarters of a mile downstream
from entrance to Beatty Slough, and 1½ miles south of Sedro Woolley.

Drainage area.—3,000 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Staff or chain gages. Datum of gage is extreme low sea level in Puget
Sound (levels by Corps of Engineers), which is 8.93 ft below mean sea level,
unadjusted.

Stage-discharge relation.—Defined by current-meter measurements below 91,000
cfs and extended by logarithmic plotting.

Remarks.—Flow in Beatty's slough is included in this record.

Annual peak stages and discharges of Skagit River near Sedro Woolley, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		63. 5	400, 000
1856		60. 0	300, 000
1897	Nov. 16, 1896	54. 8	185, 000
1898	Nov. 19, 1897	54. 9	190, 000
1907	Nov. 16, 1906	54. 7	180, 000
1908	June 11, 1908	47. 8	48, 200
1909	Nov. 18, 1908	52. 0	97, 000
1910	Nov. 30, 1909	56. 5	220, 000
1911	Nov. 21, 1910	52. 1	114, 000
1912	Nov. 19, 1911	48. 4	66, 600
1913	June 3, 1913	46. 4	70, 800
1914	Jan. 7, 1914	49. 6	104, 000
1915	Apr. 3, 1915	45. 4	67, 300
1916	June 18, 1916	46. 5	75, 800
1917	June 16, 1917	44. 4	60, 400
1918	Dec. 30, 1917	54. 1	195, 000
1919	Dec. 4, 1918	47. 0	80, 200
1922	Dec. 13, 1921	54. 3	210, 000
1923	Dec. 25, 1922	45. 2	71, 000

29. *East Fork Nookachamps Creek near Clear Lake, Wash.*

Location.—Lat 48°25′30″, long 122°12′30″, in NE¼ sec. 19, T. 34 N., R. 5 E.,
at county road bridge, 3 miles southeast of Clear Lake, and 3½ miles upstream
from mouth.

Drainage area.—20.5 sq mi.

Gage.—Staff gage. Gage heights are from graph based on gage readings. Altitude of gage is 70 ft (from topographic map).

Stage-discharge relation.—Defined by current-meter measurements below 1,900
cfs and extended by logarithmic plotting.

*Annual peak stages and discharges of East Fork Nookachamps Creek near Clear
Lake, Wash.*

Water year	Date	Gage height (feet)	Discharge (cfs)
1945	Jan. 7, 1945	8. 59	2, 000
1946	Oct. 25, 1945	10. 3	2, 710
1947	Oct. 24, 1946	[1] 10. 0	[1] 2, 120
1948	Oct. 19, 1947	10. 33	2, 220
1949	Feb. 17, 1949	10. 05	2, 130
1950	Dec. 28, 1949	9. 39	2, 010

[1] Estimated.

30. *Skagit River near Mount Vernon, Wash.*

Location.—Lat 48°26'40'', long 122°20'00'', in SE¼ sec. 7, T. 34 N., R. 4 E., on drawrest of and 150 ft downstream from bridge on U.S. Highway 99 and 1 mile north of Mount Vernon.

Drainage area.—3,060 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Water-stage recorder and, since Sept. 28, 1951, a crest-stage indicator. Datum of gage is at mean sea level, datum of 1929.

Stage-discharge relation.—Defined by current meter measurements below 144,000 cfs.

Remarks.—Flow partly regulated by powerplants on Baker and upper Skagit Rivers, and by Lake Shannon, Diablo, and Ross Reservoirs.

Annual peak stages and discharges of Skagit River near Mount Vernon, Wash

Water year	Date	Gage height (feet)	Discharge (cfs)
1907		37	180,000
1941	Oct. 20, 1940		[1] 44,000
1942	Dec. 3, 1941	25.99	65,300
1943	June 18, 1943	22.92	47,000
1944	Dec. 3, 1943	24.40	55,700
1945	Feb. 8, 1945	25.77	59,800
1946	Oct. 26, 1945	30.25	94,300
1947	Oct. 25, 1946	27.8	64,900
1948	Oct. 19, 1947	28.68	69,400
1949	May 13, 1949	26.05	56,200
1950	Nov. 28, 1949	34.21	114,000
1951	Feb. 11, 1951	36.85	144,000
1952	June 5, 1952	22.43	41,400
1953	Feb. 1, 1953	27.76	65,700
1954	Nov. 1, 1953	26.37	57,900
1955	Nov. 20, 1954	27.10	62,000
1956	Nov. 4, 1955	33.52	107,000
1957	Oct. 21, 1956	27.47	64,000

[1] Maximum day.

FREQUENCY OF FLOODS

SINGLE STATION FREQUENCY

Studies made by Benson (1960), and others, indicate that a long record is necessary before a reliable flood-frequency curve can be drawn. In order to come within 10 percent of the correct value 95 percent of the time for a 50-year flood, a length of record of about 110 years is required. In fact, to obtain this accuracy for even a 10-year flood required 90 years of record. However, to come within 25 percent of the correct value 95 percent of the time only about 39 years are required. To obtain this accuracy for a 10-year flood required only 18 years. This study points out the undesirability of using a short record at a single station for constructing a frequency curve. For this reason historic data have been included whenever possible to lengthen the record. By using certain floods back to 1815, a synthetic 143-year record was obtained.

Two types of flood series are the partial-duration series, based upon all floods above a selected base discharge without regard to the number of floods that occur in any one year, and the annual-flood series, based upon the highest flood that occurs each year.   There are objections to both types.   The partial-duration series may include floods that are not independent events, that is, the first flood sets the stage for the one closely following.   The annual-flood series, however, may omit a second independent flood in a year that may be greater than many annual floods of other years.   Both series give essentially the same results for recurrence intervals greater than 10 years.

The following table, derived from the statistical relationship between the two series, shows comparative values of recurrence intervals by the two methods:

Recurrence intervals, in years

Annual-flood series	Partial-duration series	Annual-flood series	Partial-duration series
1.16	0.50	10.5	10.0
1.58	1.00	20.5	20.0
2.00	1.45	50.5	50.0
2.54	2.0	100.5	100.0
5.52	5.0		

There is an important distinction between the recurrence intervals of the two series.   In the annual-flood series the recurrence interval is the average interval of time in which a flood of given size will be equalled or exceeded as an annual maximum.   In the partial-duration series the recurrence interval is the average interval of time in which a flood of given size will be equaled or exceeded without regard to its relation to any period of time.

The annual-flood series has been used in this study.   When it is important to know how often, on the average, a stream will exceed a certain discharge (as when designing a low fill, which will be overflowed during high floods), the partial duration series must be used. In such a case the use of the relationship expressed in the preceding table for converting the annual-flood series to the partial-duration series recurrence intervals will be entirely adequate.

For plotting data based on the annual-flood series, the highest observed peak in each water year is listed in chronological order. Only complete years of stream-flow records should be used except in cases where a flood that occurs during a period of partial record is known to be the highest during the year.   Also, historical flood data

can often be used to advantage, and particularly to assist in defining the upper end of the frequency curve.

Numbers are assigned to each flood in the order of decreasing magnitude; the largest is designated as number one. Appropriate recurrence intervals are then assigned to each flood; they depend upon the order number, the period of record, and any additional historical information indicating the frequency recurrence.

Recurrence intervals, T (time in years), are computed from the formula $(n+1)/m$, where n equals the number of years of record and m equals the order of relative magnitude of the flood beginning with the highest as one. This formula is simple to compute, is applicable both to the annual-flood series and the partial-duration series, and gives results that conform with some of the latest theories.

Annual floods are plotted on a special graph based on the theory of extreme values for analysis of flood frequencies. On this plot the discharge having a recurrence interval of 2.33 years is the same as the arithmetical mean of an infinitely long series of annual floods and is known as the "mean annual flood." With relatively short records, such as are treated here, the "mean annual flood" is determined graphically from the gaging-station flood-frequency curves as the value of the discharge at a recurrence interval of 2.33 years.

HISTORICAL DATA

Historical data are of particular value where there is an account of all floods above a certain stage over a long period antedating the beginning of the stream-gaging record. The minimum or base stage covered by a historical account is generally high; more often it corresponds to flood stage, the stage where damage begins. Such a list of historical floods is in the nature of a partial-duration series above a high base; but, as there generally is only one flood of such magnitude in any one year, it may also be considered to be a partial list of annual floods. In either case the treatment is the same.

All floods, both historical and recorded, should be listed together and assigned recurrence intervals in the same manner as previously discussed, except that for individual historical floods the period of time for which they are known to be the highest must be considered.

In this report a 143-year base period (1815–1957) was used for the historical data because the flood of 1815 was known to have been higher than any since that date. It was assigned order number 1. In some cases the flood of 1856 was known to be the second highest flood and was given the order number 2. All other floods were assigned order numbers based on the period of time they were known to be 1st, 2nd, 3rd, highest, and so on.

In this report the historical floods were included in the data for the definition of frequency curves even though in some cases the natural regimen of the streams has been changed somewhat by the construction of dams to create storage reservoirs. As it has been stated previously, the Skagit River can now be almost completely controlled at Newhalem by Ross Reservoir.

The six stations where historic data are available for use are as follows:

> Skagit River at Newhalem, Wash.
> Cascade River at Marblemount, Wash.
> Sauk River at Darrington, Wash.
> Baker River below Anderson Creek, near Concrete, Wash.
> Skagit River near Concrete, Wash.
> Skagit River near Sedro Woolley, Wash.

Historic information was obtained for Skagit River at Reflector Bar, near Newhalem, but data for this station are for all practical purposes identical to that obtained at Newhalem so they were not used. Examples of the plotting of data for single station frequency curves, using historic information, are shown in the last part of this report. (See figs. 12 to 17.)

FITTING FREQUENCY GRAPHS

A curve must be fitted to the data after a frequency diagram has been plotted. Many frequency curves tend to plot as straight lines on special plotting paper, which is a desirable feature if extrapolation can be justified. However, the use of the frequency graph for purposes of extrapolation may lead to fallacious results because the linear distance from 25 to 200 years is deceptively short on the plotting diagram and the error of a curve fitted by any method may be extremely great at its outer end. The data, not the functional theory, are used to define the graph so extrapolation can be justified only when the phenomena have proved to conform to the underlying law.

It is the practice of the Geological Survey to draw a visually-fitted line, either straight or curved, depending upon which best fits the plotted points. Sharp breaks in a curve are avoided by not giving full weight to the floods with the larger recurrence intervals because their true recurrence interval is seldom, if ever, accurately known. Thus it will be found that the curve as drawn may not pass through points that represent the one or two floods of largest magnitude.

REGIONAL FREQUENCY

A single-station frequency curve, particularly for the short records available, is a random sample and may not be truly representative of a region of like characteristics. For this reason a method of combining records for a number of stations has been developed to define a

composite curve of median values to be applied to a basin or region as a whole.

<center>SELECTION OF BASE PERIOD</center>

In order that records of different lengths may be compared, it is necessary to select a common base period of record, either one that is common to all records or one to which such records may be extended. The base used herein is the 143-year period, 1815–1957; records for six stations were available. The 29-year period 1929–57 was also considered as a base for combining other station records in the basin, but it was not used because there was not enough record for the 1929–57 period at the six long-term stations to develop a reliable method of combining the results from the two base periods. The short-term period was used in the determination of mean annual floods.

<center>COMPARABLE MEANS</center>

The value of the mean annual flood will vary with the length of the record from which it is derived and will be dissimilar for different periods of record even though the same number of years is being considered. For example, the mean annual flood obtained for the 10-year period of record 1936–45 for Cascade River at Marblemount would be lower than the mean annual flood for the period 1946–55 because the peaks are of lesser magnitude during the earlier period. Also, the mean annual flood for the 20-year period 1936–55 would differ from both of the two 10-year period values and be somewhere between them. As the record increases in length, the mean annual flood can be determined more accurately.

The mean annual flood is the average of the maximum annual floods. It is determined graphically for each frequency distribution by the intersection of the visually best-fitting frequency curve and the mean line (the line corresponding to the 2.33-year recurrence interval).

For a flood record of length equal to that of the selected base period, the mean annual flood is obtained directly from the frequency graph. For stations where only a few years of record are missing, the mean annual flood is obtained for the base period in the following manner: peak discharges for the missing years of record are estimated by the correlation of floods at that station with those of nearby long-term stations. Order numbers may then be assigned to all peaks, but only those for actual years of record are plotted on the graph. The mean annual flood (adjusted) is then determined graphically in the usual manner. For short-term stations the method used is to compute the mean annual flood for the actual period of the short-term station and then to adjust this value to the base period on the basis of the ratio of the mean annual flood for the same short period

at a nearby long-term station to the mean annual flood of the base
period for the long-term station.

TEST FOR HOMOGENEITY

A test for homogeneity of records is necessary before a group of
stations are combined. The test is statistical and is applied to the
slopes of the individual frequency graphs to determine whether devia-
tions from an average slope are such as may be due to chance alone.

The test was based upon the slope of the frequency curve deter-
mined by the ratio of the flood with a 10-year recurrence interval to
the mean annual flood (2.33-year recurrence interval) at each station.
The ratios thus obtained were averaged and the mean annual flood
at each station was multiplied by the average value. The recurrence
interval for this flood discharge was then determined and tested by
statistical methods to determine that it would fall between permissible
limiting values 95 percent of the time.

The six stations considered were found to be within these limits
which indicated that they were homogeneous and could be combined.

COMBINING RECORDS

In order to combine the records to get a single median frequency
curve it was necessary to express the frequency curve data in dimen-
sionless terms. This was done by dividing the discharge at certain
recurrence intervals at each station by the adjusted mean annual
flood. This provided, at each station, a list of ratios for the desig-
nated recurrence intervals.

Median values for each of these recurrence intervals were computed
for the 143-year base period. The medians were plotted on the fre-
quency chart to define a composite flood-frequency curve, based upon
the combined records and applicable to all streams within the basin;
this curve is presented as figure 7. The composite curve is considered
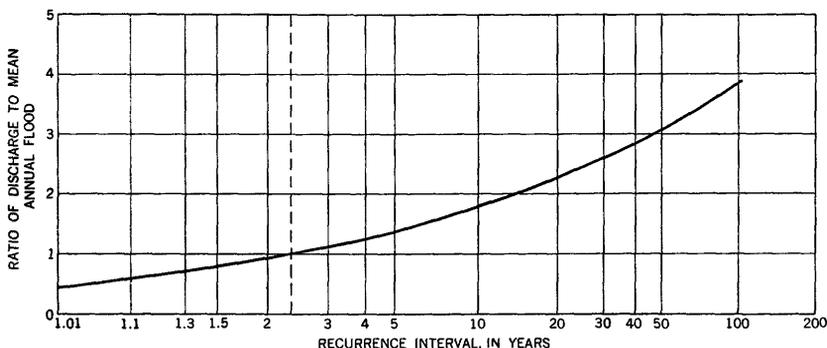
FIGURE 7.—Composite flood-frequency curve, Skagit River basin.

reliable to 50 years and fairly reliable to 100 years, but it should be extended further only with extreme caution.

Bodhaine and Robinson (1952) developed a composite frequency curve from the combination of 131 records from western Washington. The curve was based on a 40-year base period and, therefore, is different from the curve in this report. The change in the curve results from the use of the historic data. The Skagit River basin is the only area in the State where data have been collected for the historic floods of 1815 and 1856; additional data were also obtained at several stations in the basin for unrecorded extreme floods of November 1897 and November 1909. These data could not be used in a statewide analysis because they were only known to have occurred in the Skagit River basin. Since the composite curve of this report varies considerably from the curves computed for other areas, its use should be confined to the Skagit River basin.

FLOOD-FREQUENCY RELATIONSHIPS

In order that the composite curve may be used anywhere within the Skagit River basin, it is necessary to correlate the mean annual flood with some readily determinable physical characteristic of the drainage areas. Many characteristics that affect runoff (and consequently the mean annual flood) have been found by other investigators. Among these characteristics are size of drainage area, topography, type of soil, vegetation, stream slopes, lakes, elevation, rainfall, shape of basin, and others. Of these, the major characteristic and the one most easily determined is the size of the drainage area. Lack of adequate topographic maps prevents the determination and, consequently, the use of some of the above characteristics in a statistical study. The effects of others, such as rainfall and shape of basin, show such poor relations that they are of no material value.

The values of the mean annual floods mentioned previously under "Comparable means" were plotted against drainage area, on logarithmic graph paper, for each of the stations used in this study. The plotted points scatter considerably but may be divided into groups in which the relations vary in accordance with a series of three curves, each defined by various combinations of main stem and tributary stations; these curves are presented as figure 8, and areas to which each apply are shown on plate 1. The fact that three curves, rather than one, are defined reflects the influence of drainage basin characteristics, other than size of area, that may or may not be definable.

Bodhaine and Robinson (1952) show the same general grouping of streams as does this study. Size of drainage area was considered the primary factor in the present study because it has the greatest effect on the mean annual floods. The other characteristics that were
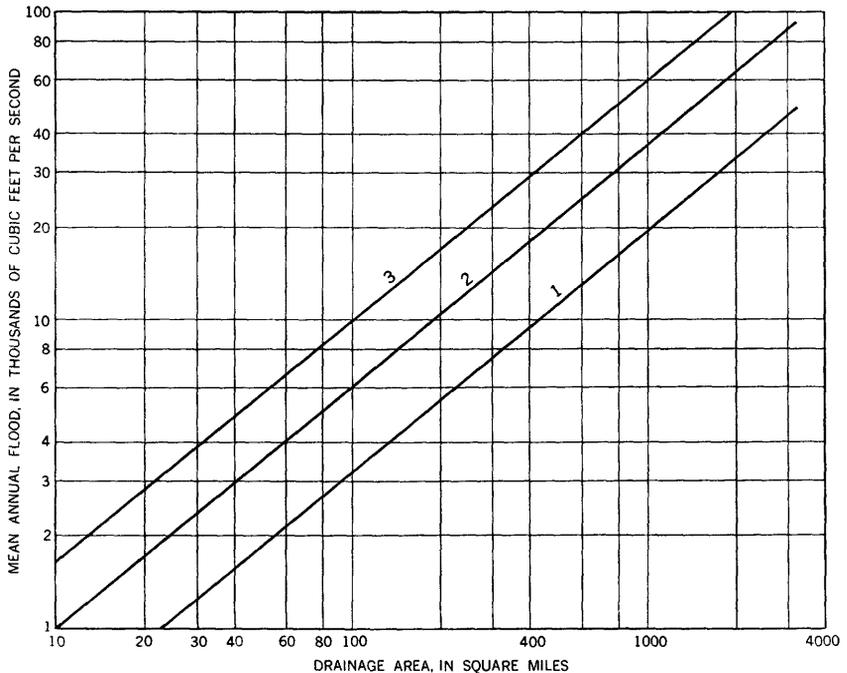
FIGURE 8.—Variation of mean annual flood with drainage area.

used—elevations of drainage basin, geographical factor, and area of lakes and ponds—also have an effect on the mean annual floods.   The range in mean elevation of the drainage areas of the streams under consideration in the Skagit River basin is so small that a correlation with this factor cannot be made.   The geographical factor is portrayed by the three curves shown in figure 8.   The effect of lakes and ponds is small so this factor has not been considered.

The curves shown in figure 8 should not be extrapolated beyond the limits of the available data because to do so may lead to serious error. For additional study of drainage basin characteristics, see the publications listed in the bibliography.

FLOOD-FREQUENCY CURVES

To define a frequency curve at any place in the Skagit River basin:
1. Measure size of drainage basin, in square miles, above place where information is wanted.
2. Locate stream in one of the three mean annual flood areas (pl. 1).
3. Determine mean annual flood, in cubic feet per second, from proper curve of figure 8.

4. Determine discharge in ratio to mean annual flood for several recurrence intervals, from figure 7.
5. Multiply the mean annual flood determined in step 3, by the ratios determined in step 4, to get the discharge corresponding to various recurrence intervals.
6. Plot discharges determined in step 5 and draw frequency curve.

Flood-frequency curves for six stations where historical data are available are presented in figures 9–14. The curves shown on each plot are computed from the composite frequency curve, shown on figure 7. The mean annual flood curve, shown on figure 8, serves as a means of comparing the actual data for each station with the average or computed curve.
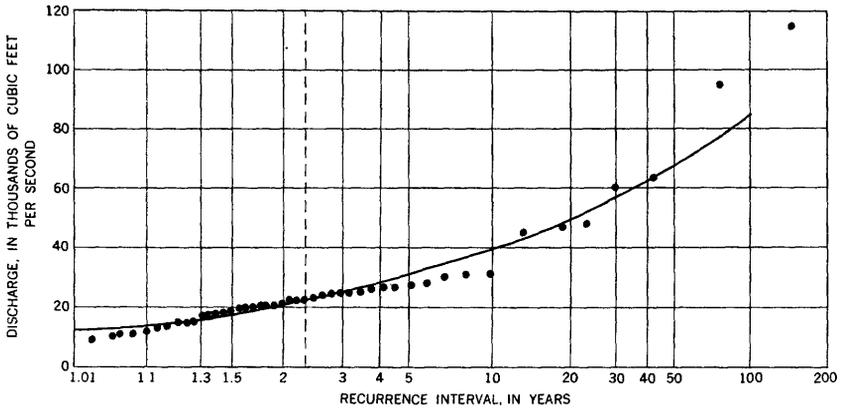
FIGURE 9.—Frequency of annual floods, Skagit River at Newhalem, Wash.
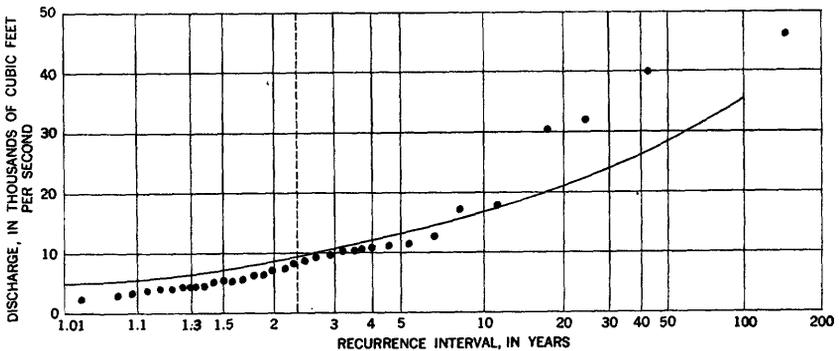
FIGURE 10.—Frequency of annual floods, Cascade River at Marblemount, Wash.
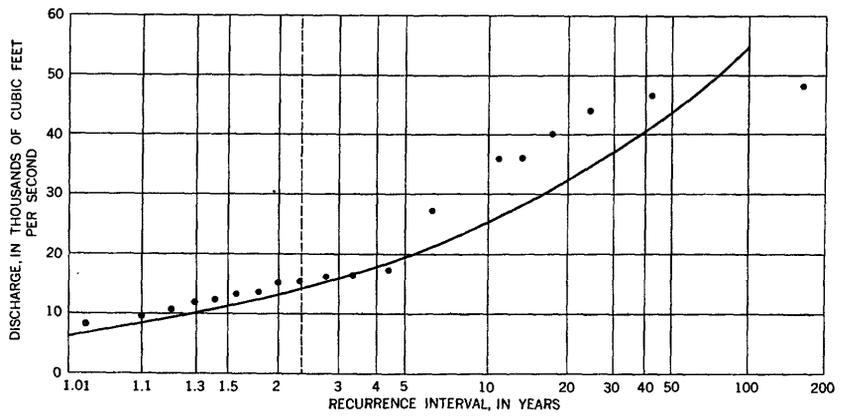
FIGURE 11.—Frequency of annual floods, Sauk River at Darrington, Wash.
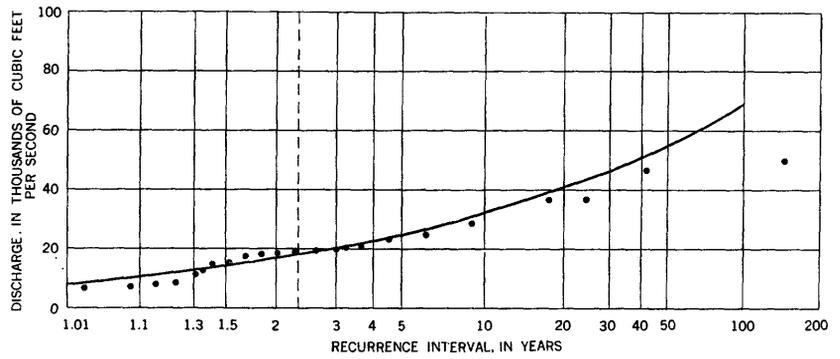
FIGURE 12.—Frequency of annual floods, Baker River below Anderson Creek, near Concrete, Wash.
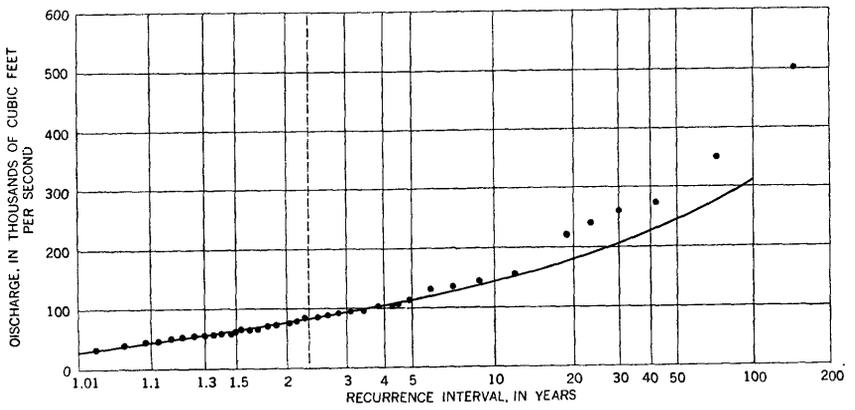
FIGURE 13.—Frequency of annual floods, Skagit River near Concrete, Wash.
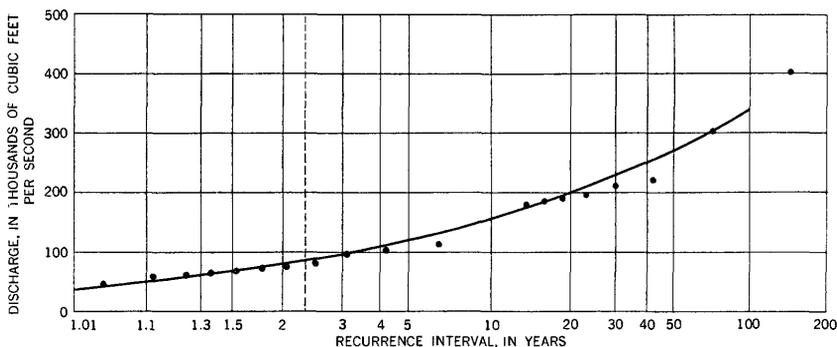
FIGURE 14.—Frequency of annual floods, Skagit River near Sedro Woolley, Wash.

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