MR. PEASE

73D CONGRESS 2d Session } HOUSE OF REPRESENTATIVES { DOCUMENT No. 187

SKAGIT RIVER, WASH.

LETTER

FROM

THE SECRETARY OF WAR

TRANSMITTING

PURSUANT TO SECTION 1 OF THE RIVER AND HARBOR ACT APPROVED JANUARY 21, 1927, A LETTER FROM THE CHIEF OF ENGINEERS, UNITED STATES ARMY, DATED SEPTEMBER 12, 1933, SUBMITTING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, CONTAINING A GENERAL PLAN FOR THE IMPROVEMENT OF SKAGIT RIVER, WASH., FOR THE PURPOSES OF NAVIGATION AND EFFICIENT DEVELOPMENT OF ITS WATER POWER, THE CONTROL OF FLOODS, AND THE NEEDS OF IRRIGATION

JANUARY 3, 1934.—Referred to the Committee on Rivers and Harbors and ordered to be printed, with 11 illustrations

WAR DEPARTMENT,
Washington, September 14, 1933.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

DEAR MR. SPEAKER: I am transmitting herewith a report dated September 12, 1933, from the Chief of Engineers, United States Army, on Skagit River, Wash., made under the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications in section 1 of the River and Harbor Act of January 21, 1927, together with accompanying papers and illustrations.

Sincerely yours,

GEO. H. DERN,
Secretary of War.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, September 12, 1933.

Subject: Report on Skagit River, Wash.
To: The Secretary of War.

1. I submit for transmission to Congress my report, with accompanying papers and illustrations, on Skagit River, Wash., made under

the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications in section 1 of the River and Harbor Act of January 21, 1927.

2. Skagit River has its source in the Cascade Mountains in Canada, 28 miles by river, north of the international boundary, flows in a general southwestward direction about 163 miles, and enters Skagit Bay, an arm of Puget Sound. Below Mount Vernon, about 10 miles above the mouth, the river flows through a delta in two main channels, the North Fork and the South Fork, and a number of minor channels. The drainage area of the basin is about 3,140 square miles, 390 square miles of which are in Canada. Two thirds of the area is included in national forests. Elevations range up to 10,000 feet and more in the headwater regions. The streams in the watershed flow through canyons and narrow valleys with steep gradients. The river is tidal for about 15½ miles above its mouth, the mean tidal range at the mouth being 11.1 feet. The average fall of the river for 80 miles above tidewater is about 6 feet per mile.

3. Precipitation varies from over 100 inches per year in the mountainous portions to less than 30 inches in the lowlands. About 80 percent of the precipitation usually occurs during the wet season from October to April and much of it is in the form of snow. The run-off is erratic and flashy. The maximum, minimum, and average discharges of the main stream at Sedro Woolley (drainage area, 2,970 square miles) for the period of record (1908–31) are 220,000, 2,830, and 15,700 cubic feet per second, respectively. The population of the watershed is about 23,000, most of which is concentrated in the agricultural areas near the mouth of the river. Farming, including dairying, poultry raising, and truck gardening, is the principal industry. The important crops are oats, vegetable seed, vegetables, and fruits. Other important industries are lumbering and cement manufacturing. The timber stand is estimated at over 14½ billion feet board measure. The developed sections of the basin are fairly well provided with railroads and highways.

4. Improvements for navigation have been directed to affording suitable channels for light-draft vessels in the delta section at the mouth of the river. A wide shoal extends out into Skagit Bay at the mouths of the river. Inside this bar the depths in the principal channels are generally adequate. To secure a dependable channel through these shoals a training dike, about 2 miles in length, was completed in 1911 at the mouth of the South Fork, with dikes and mattresses to concentrate the flow in this fork, at a cost for new work of approximately $100,000. The works have not been successful in maintaining a suitable channel at low water. The North Fork has enlarged, and is now largely used. A modification of the project was authorized in 1919 to improve a bar in the river at Skagit City, near the head of the South Fork, by dikes and dredging, subject to the requirement that local interests assume the payment of all damage claims resulting from the improvement. Local interests have not met the requirement, and no work has been done on the bar. Because of the wide tidal range, light-draft vessels can cross the bar at the mouths of the river by taking advantage of the tide. Snagging and emergency dredging done under the general project for the maintenance of the rivers tributary to Puget Sound afford reasonably satisfactory navigation conditions in the river.

5. The average annual water-borne commerce on the river for the 5 years prior to 1930 was about 350,000 tons. In 1931 this dropped to about 182,000 tons due to general economic conditions. The bulk of the normal traffic is in logs which are towed by small launches to points on Puget Sound. About 95 percent of the traffic in logs and all of the general commerce is on the section below Mount Vernon. The district engineer is of the opinion that with the return of normal business conditions, the log traffic will return to about the average amount prior to 1930, and that movements of farm products would increase somewhat with improved river conditions. Prospective benefits to commerce are not regarded as sufficient to warrant the large cost of a radical improvement of the channels in the delta sections; and improvement of the river by locks and dams is not considered either practicable or advisable.

6. Six hydroelectric plants have been constructed in the basin with a total installed capacity of 218,300 kilowatts. Of these, 2 plants with a total capacity of 174,000 kilowatts are owned by the city of Seattle and 1 plant with a capacity of 40,000 kilowatts is owned by a public utility. Provisions have been made in these 3 plants for additional installations when up-river storage has been developed which will bring the total ultimate capacity of the 6 existing plants to 564,300 kilowatts.

7. The district engineer has considered 18 potential power projects, the total capacity of which would be about 1,100,000 kilowatts. Plans for 14 of these projects are regarded as preliminary due to insufficiency of available data. The remaining four projects are the most important due to the large storage available at each reservoir and because of their possible use in a plan for combined power development and flood control. These developments, known as the "Ruby", "Cascade", "Lower Sauk", and "Upper Baker" projects, would have a total useful storage of 3,100,000 acre-feet and a proposed capacity of about 547,000 kilowatts. The following table gives a summary of existing and potential power developments in the basin.

	Kilowatts
(1) Existing installed capacity	218, 300
(2) Future additional capacity for existing plants	346, 000
(3) Proposed capacity in 14 potential plants	571, 150
(4) Proposed capacity in 4 major potential projects	546, 900
Total	1, 682, 350

8. The Skagit River is subject to destructive floods which frequently cause great damage. The floods are caused by warm, moisture-laden winds known as "Chinooks", which melt the glaciers and accumulated snow with great rapidity. They may occur at any time of the year but the largest are generally in November and December. Since 1869 there have been five major floods with peak discharges at The Dalles (mile 54) varying from 180,000 to 270,000 cubic feet per second. The flood which occurred about 1815 is estimated to have had a peak discharge at The Dalles of 480,000 cubic feet per second.

9. Most of the damage from floods occurs below Sedro Woolley (mile 22) although the towns in the upper valley are liable to damage from the large floods. The district engineer estimates the average annual flood damages during the past 40 years at about $150,000, the greater part of which is to farm lands, improvements, and crops. He

states that as the valley becomes developed the occurrence of a flood such as that of 1815 would cause great suffering and large monetary losses. The only existing flood-control works consist of dikes supplemented by drainage ditches, constructed below Sedro Woolley, but these works are entirely inadequate to withstand major floods.

10. The district engineer has given consideration to plans for further control of floods. The cost of increasing the capacity of present channels by dredging and raising dikes so as to carry large floods would greatly exceed the possible benefits. The most economical plan for diverting excess flood waters is to construct a by pass from Avon (mile 13) to Skagit Bay at an estimated cost of about $4,500,000, which is somewhat more than is considered justified by probable benefits. Reduction of flood heights can be secured by storing flood flows in storage reservoirs, but the costs of flood-control reservoirs of sufficient capacity to control the maximum flood of record (1909) would be excessive. The district engineer discusses a plan which provides for reserving storage for flood control in the proposed Ruby, Cascade, Lower Sauk, and Upper Baker power reservoirs, totaling about 472,000 acre-feet. He states that this storage would probably have been sufficient to have reduced the 1909 flood discharge at Sedro Woolley from the recorded crest of 220,000 cubic feet per second to an amount that could have been carried by the existing diked channels. He is of the opinion that when the power projects are developed, local beneficiaries of flood storage should be permitted to secure protection at least to the extent they are willing to pay for. Pending such storage developments he suggests that local interests should improve the channel and diking system below Burlington so that it will carry at least 140,000 cubic feet per second and give protection against the smaller floods. He also recommends that diking off of the Nookachamps Creek district, which furnishes flood storage, be prohibited; and that a flood warning system be installed.

11. Precipitation is abundant for all crops now raised in the basin so irrigation is not necessary. Silt is not a serious problem except on the Suiattle and Whitechuck Rivers which are tributaries to the Sauk River. Bank erosion along the Skagit River is continuous over nearly the entire length of the stream and at all stages of flow. Generally, the most extensive erosion occurs along the north bank below the town of Concrete (mile 56). The diking districts and the railroad companies have taken steps to prevent damages by the construction of bank revetment, groins, and drift barriers to close secondary channels. Some of these works have given relatively permanent relief. Protection is a matter of local concern and should be left to the particular interests which are affected.

12. The district engineer is of the opinion that power storage reservoirs will increase low-water flows, will reduce flood discharges, and will reduce bank erosion and the deposition of snags but that the resulting benefits would not be sufficient to justify the United States in sharing in their cost.

13. The division engineer concurs in the views of the district engineer. He recommends that further development of water resources in the Skagit River Basin be left to the initiative of local interests

under the provisions of the Federal Water Power Act wherever that act applies; that in connection with applications for licenses under the Federal Water Power Act, full consideration be given to the provision of storage for control of winter floods; and that the report together with its appendices and accompanying maps be printed.

14. The reports of the district and division engineers have been referred, as required by law, to the Board of Engineers for Rivers and Harbors. Except for a nominal traffic in logs on the upper river, navigation is confined to the tidewater section below Mount Vernon. Snagging and minor dredging under the general project for such work on the rivers tributary to Puget Sound afford reasonably adequate facilities for present and prospective commerce. Hydroelectric power can be produced at several sites at costs which are considered to warrant the developments when market conditions permit. This development should be left to local interests. Protection against flood damages can best be secured by reserving flood storage in certain potential power reservoirs and by improving the river channel and dikes below Burlington, but the Federal Government would not be justified in participating in the cost thereof. Irrigation is not required and silt is not a problem except on tributaries of the Sauk River. Erosion of banks causes considerable damage and necessary corrective measures should be taken by the local interests which are affected. The regulating effect of power-storage reservoirs in the basin would be of some value to navigation but the benefits would not warrant Federal contributions to reservoir costs. In view of the foregoing, I therefore report that, in my opinion, improvement of the Skagit River for navigation, either alone or in connection with power development, flood control or irrigation or any combination thereof, other than as authorized by existing law, is not deemed advisable at the present time.

LYTLE BROWN,
Major General,
Chief of Engineers.

REPORT OF THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS

SYLLABUS

The Board of Engineers for Rivers and Harbors is of the opinion that no further improvement of this stream for navigation, either alone or in connection with power development, flood control, or irrigation or any combination thereof other than as provided for under existing projects, should be undertaken by the United States at the present time.

[Second endorsement]

THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
Washington, D.C., July 31, 1933.

To the CHIEF OF ENGINEERS, UNITED STATES ARMY:

1. The following is in review of the reports on Skagit River, Wash., submitted under the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications, in section 1 of the River and Harbor Act of January 21, 1927.

2. Attention is invited to the reports herewith, which contain information concerning existing and prospective developments on this river

for navigation, power development, flood control, and irrigation. The reporting officers concur in the opinion that the further improvement of this stream in the interest of navigation other than that now authorized is not warranted at the present time and that further development of the water resources of the basin should be left to the initiative of local interests.

3. The Board concurs in general in the views of the district and division engineers. The existing project for navigation improvement, while it has not given the anticipated depths at low tide, is considered adequate for present needs. There are several sites where additional power can be produced at costs which are considered to warrant the development when market conditions permit. Protection against flood damage can best be secured by the retention of flood storage space in reservoirs built primarily for power, in combination with improvement of the channel and the dyke system below Burlington, but Federal participation in the cost thereof would not be justified. Irrigation is not now required and silt is not a serious problem except to possible reservoirs on the lower Sauk River. The erosion of banks is a serious problem in the lower 50 miles of the river and corrective measures should be taken by the local interests which are affected. The regulating effect of power-storage reservoirs would be of some value to navigation above the tidal section of the river, but the benefits would not warrant Federal contributions to the cost of reservoirs. In view of the foregoing, the Board is of the opinion that no further improvement of this stream for navigation, either alone or in connection with power development, flood control, or irrigation or any combination thereof other than as provided for under existing projects, should be undertaken by the United States at the present time.

For the Board:

W. J. Barden,
Colonel, Corps of Engineers,
Senior Member.

REPORT OF THE DIVISION ENGINEER

SYLLABUS

The division engineer reports that in the formulation of plans for conservation of water resources in the Skagit Basin power development, with special regard to the interests of flood control and due regard to the interests of navigation, is the primary consideration. The quantity and distribution of rainfall are such that there is no need for irrigation. Further improvement in the interest of navigation is not warranted at the present time, but regulation of stream flow for power will have a beneficial effect upon existing navigable channels. Flood protection is a serious local problem to be solved mainly by reserving storage in power reservoirs for control of winter run-off. Pending the further development of power reservoirs, local interests in the delta area should install a flood-warning system and make provision for carrying safely a discharge of 140,000 second-feet by increasing channel capacities and improving the existing levee system.

The division engineer recommends: That further development of water resources in the Skagit Basin be left to the initiative of local interests under the provisions of the Federal Water Power Act, wherever that act applies; that in connection with applications for licenses under the Federal Water Power Act, full consideration be given to the provision of storage for control of winter floods; that this report together with its appendixes and accompanying maps be printed.

WAR DEPARTMENT,
OFFICE OF THE DIVISION ENGINEER, PACIFIC DIVISION,
San Francisco, Calif., April 25, 1933.

Subject: Report on the Skagit River, Wash.

To: The Chief of Engineers, United States Army, Washington, D.C.

AUTHORITY

1. A report in accordance with the provisions of House Document No. 308, Sixty-ninth Congress, first session, on the Skagit River, Wash., was authorized in the River and Harbor Act of January 21, 1927. The district engineer has made the necessary investigations and has submitted a report which is enclosed.

DESCRIPTION

2. The Skagit River, with a drainage area of 3,140 square miles, rises in the Cascade Mountains in British Columbia, 28 miles north of the international boundary, flows southward for a distance of 57 miles; thence southwestward and westward for 96 miles to the head of its delta at Mount Vernon, 10 miles above its mouth. Below Mount Vernon the river flows in two main channels, the north and south forks, and a number of lesser ones emptying into Skagit Bay, an arm of Puget Sound. The main tributaries are the Sauk, with a drainage area of 729 square miles, and the Baker, with a drainage area of 270 square miles. Other important tributaries are Cascade River, Thunder Creek, and Ruby Creek, all of which have their sources in the high Cascades.

3. The portion of the drainage basin below the mouth of Cascade River has been mapped by the United States Geological Survey and these maps are published to scales of 1 to 62,500, 1 to 125,000, and 1 to 250,000. The remainder of the watershed has not been surveyed except for small portions mapped by private interests or covered by National Forest maps. The district engineer's field investigations included topographic surveys of the Cascade and Lower Sauk Reservoir sites and of the river proper between the Gorge plant of the City of Seattle and the mouth; borings at the Cascade and Lower Sauk proposed dam sites, and near Faber ferry on the main stream; and stream gagings at six stations.

4. The streams in the watershed flow through canyons and narrow valleys with steep gradients. The slope of the main stream averages about 13 feet per mile for the first 30 miles of its course south of the Canadian border. It then drops abruptly 700 feet in the next 12 miles, below which it averages about 6 feet per mile for the next 80 miles, to tidewater. The river is tidal to the Great Northern Railway bridge 15.4 miles above the mouth, the mean diurnal range at the mouth being 11.1 feet and the extreme range 19 feet.

5. Elevations within the drainage basin range from sea level at the mouth to over 10,000 feet in the headwater regions. Two thirds of the watershed area is included in national forests and large stands of timber are found below elevation 6,000. Above the timber line

much of the upper area lies within the zone of perpetual ice and snow, and many glaciers are found in this region. The delta, 59,000 acres in area, is extensively cultivated and above Sedro Woolley small farms, totaling 24,000 acres, are found near the rivers.

RAINFALL AND RUN-OFF

6. Temperatures in the basin range from −11° to over 100°, with a mean annual of about 50° throughout the valley. Precipitation varies from over 100 inches per year in the mountainous portions to less than 30 inches in the lowlands, 80 percent of which usually falls during the wet season from October to April. Much of the precipitation falls as snow, the snowfall varying from less than 12 inches along the coast to about 500 inches at the higher elevations.

7. Rugged topography, large and concentrated precipitation, numerous glaciers, and absence of natural reservoirs combine to produce an erratic and flashy run-off. Floods may occur at any time of the year due to warm weather and rains melting the accumulated snow. In the lower valley where floods cause the only extensive inundation, the maximum rates of flow occur during the winter months but the maximum monthly run-off usually occurs in June. Low-water periods occur during cold weather or in the autumn. Stream-flow data are summarized in the following table:

Stream	Drainage area	Discharge in second-feet		
		Mean [1]	Maximum 24 hours	Minimum month
	Square miles			
Skagit at a point below Ruby Creek	978	2,980	45,700	500
Cascade below Marble Creek	148	930	31,700	145
Sauk, near Sauk	714	4,340	21,800	724
Baker at a point below Anderson Creek	184	2,150	36,800	387
Skagit at Sedro Woolley	2,970	15,700	220,000	3,720

[1] Estimated for period 1908–31.

POPULATION AND INDUSTRIES

8. The population of the watershed is about 23,000, over 80 percent of whom reside west of Sedro Woolley. The principal industry is farming, including dairying, poultry raising, and truck gardening. The annual value of farm products in Skagit County, with the resultant canning operations, was estimated in 1930 at $8,710,000. Other important industries are lumbering and cement manufacturing. The timber stand in the watershed below elevation 5,000 is estimated at 14,700 million feet board measure, 50 percent of which is Government owned. The average annual output of the mills, which have a daily capacity of 2.5 million board feet, is estimated to be between 250 and 300 million board feet, and the estimated possible sustained yield is 375 million board feet per year. Large deposits of limestone and clay are found in the vicinity of Concrete and a cement plant, with an annual capacity of 1,800,000 barrels, is located at that place. Its output during past years has averaged about 1,250,000 barrels an-

nually. There are some coal deposits in the valley not being worked at present.

9. The Northern Pacific Railway crosses the lower valley at Sedro Woolley and the coast line of the Great Northern Railway crosses at Mount Vernon, a branch line extending up the valley to Rockport. From Rockport a construction railroad, owned and operated by the city of Seattle, continues on up the valley to Diablo Dam (mile 100). The Pacific Highway from Seattle to British Columbia passes through Mount Vernon. An improved highway parallels the river from Mount Vernon to Marblemount and up the Cascade River to Marble Creek, a total distance of 60 miles. A number of logging railroads are found throughout the basin and numerous gravel and dirt roads lead to the outlying sections.

NAVIGATION

10. Improvement of Skagit River by the Federal Government began in 1880 and undertook the removal of snags and obstructions to facilitate navigation. This work has been carried on since 1882 under the general appropriation for the improvement of Puget Sound and its tributary waters.

11. The existing project, adopted in 1910 and modified in 1919, provides for a low-water channel on the South Fork between Skagit Bay and deep water on the river, by the construction of regulating and training dikes and by dredging of the bar at Skagit City. The work below the Skagit City bar was completed in 1911 but the results expected have not materialized and the controlling depth over the bar at the mouth of the South Fork is only about 1½ feet at low water. No work has been done on the bar at Skagit City, pending the acceptance of terms requiring local interests to assume all claims for damage. The controlling depth over this bar is from 1½ to 2 feet at low water. The expenditures under the present project have been about $100,000 for new work and $29,258 for maintenance.

12. The South Fork has been deteriorating and for the past few years the two freight boats operating between Seattle and Mount Vernon (mile 11) have used the North Fork. One of these boats draws 4½ feet and the other 7 feet when fully loaded. During the low-water period the boats plying the stretch of the river above Mount Vernon make use of stream fluctuations due to the operation of the power plant at the mouth of Baker River.

COMMERCE

13. The bulk of water-borne traffic is in the floating or rafting of logs, destined for Puget Sound points, and towed by steam and gasoline driven boats drawing 1½ to 2½ feet when loaded. This traffic averaged about 284,000 tons a year previous to 1930; since 1930 it has fallen off over 50 percent. About 95 percent of the tonnage originates at or below Mount Vernon and 65 percent of it is the output of a lumber company located on Tom Moore Slough which empties into the South Fork about 4 miles above the mouth.

14. The navigable portion of the main stream is crossed by 8 swing bridges, limiting the horizontal clearance to 80 feet. There is also a fixed bridge of 60 feet horizontal clearance and 3 feet vertical clearance at high water over Tom Moore Slough.

POWER

15. Climatic and physical conditions in the Skagit River watershed are such that the stream flow is well maintained during the summer months by the snow fields and the numerous glaciers found at the higher elevations. Steep gradients on the tributaries and on certain portions of the main stream combined with feasible dam sites offer extensive opportunities for power development, but only a few sites have been utilized. Developed hydro-power in the basin is shown in the following table:

Stream	Owner or operator	Storage	Operating head	Number of units	Installed capacity
		Acre-feet	*Feet*		*Kilowatts*
Baker River	Puget Sound Power & Light Co.	156,400	[1] 255	2	40,000
			[2] 180	[3] 4	[3] 80,000
Bear Creek	Superior Portland Cement Co.	None	420	3	[4] 1,950
Do	do	None	74	1	[4] 350
Newhalem Creek	City of Seattle	None	500	1	2,000
Skagit River (Gorge plant)	do	None	270	3	54,000
			[3] 375	[3] 5	[3] 240,000
Skagit River (Diablo plant)	do	90,000	307	[5] 2	[5] 120,000
				[3] 4	[3] 240,000
Total					[3] 564,300

[1] Maximum. [2] Minimum. [3] Ultimate development. [4] Kilovolt amperes. [5] Under construction.

16. For the purposes of this report, consideration was given first to four major storage projects. Fourteen minor projects were also studied to a lesser extent. The estimated combined installed capacity of these 18 projects is about 1,100,000 kilowatts. The minor projects are briefly outlined in the report of the district engineer, but the extent of available data and of the investigations made are so limited that the plans outlined are regarded as preliminary.

17. The four major projects investigated consist of the Ruby Reservoir on the Skagit, the Cascade Reservoir on the Cascade River, the Lower Sauk Reservoir on the Sauk, and the Upper Baker Reservoir on the Baker River. These proposed developments have a combined usable storage capacity of over 3,100,000 acre-feet and control the run-off from about 65 percent of the watershed. The location of these reservoirs is shown on plates 4 and 5 of the district engineer's report and pertinent data relating to them are given in the following table:

Reservoir	Ruby	Cascade	Lower Sauk	Upper Baker
Drainage area, square miles	978	148	714	184
Mean discharge, second-feet	3,160	870	4,200	1,970
Regulated 90-percent flow [1], do	2,450	580	3,140	1,300
Regulated 100-percent flow, do	1,030	530	2,950	1,140
Maximum head, feet	505	740	218	269
Maximum drawdown, do	200	100	83	40
Useful storage, acre-feet	2,428,000	96,700	541,900	115,800
Mean static head [1], feet	428	700	175	250
Primary power [2], kilowatts	63,000	24,300	33,000	19,500
Proposed installation, do	360,000	54,000	86,400	
Estimated cost of dam and reservoir		$4,500,000	$10,590,000	
Estimated cost of power plant		$4,350,000	$4,020,000	
Total cost		$8,850,000	$14,610,000	
Cost per kilowatt installed		$164	$169	

[1] Regulation for power only. [2] 0.06 by flow 90 percent of time by mean static head.

Under existing law the above projects come within the jurisdiction of the Federal Power Commission as development of the Ruby, Cascade, or Upper Baker sites involves the use of Government land while the Lower Sauk development affects navigation below.

18. The proposed Ruby reservoir and power plant is part of a comprehensive plan of power development undertaken on the Skagit River by the city of Seattle. When constructed, the regulated flow will also be utilized through the city's present Gorge and Diablo power plants. The city has made filings on the site with the Federal Power Commission and the State supervisor of hydraulics. The ultimate plan will develop 835,000 kilowatts at the three plants at an estimated total cost of $74,500,000, including transmission lines to Seattle, or $89.20 per installed kilowatt.

19. The Upper Baker site has been investigated by the Puget Sound Power & Light Co., including surveys and borings, but no definite steps have been taken toward its development. With the construction of this reservoir, the additional storage and regulation would benefit the present Baker River power plant, 11 miles downstream.

20. The cost of developing the Cascade and the Lower Sauk sites, as estimated by the district engineer, would be relatively high, even if the full-flood-control value of the reservoirs were charged to those benefited. The estimated first cost of the former project is about $400 per kilowatt of continuous primary power, and of the latter about $470, not including transmission costs to the market areas on Puget Sound, which are from 50 to 100 miles distant. The Lower Sauk site has a further disadvantage in the fact that much glacial silt is brought down during the summer by the streams and without diversion works the reservoir might fill up in a period roughly estimated at from 40 to 125 years.

21. The market for the electric power generated on the Skagit River will be limited to the Puget Sound area. The present total installed capacity of the three main producers—namely, the Puget Sound Power & Light Co., the city of Seattle, and the city of Tacoma—is 518,000 kilowatts, all of which is for local demand. The records of the United States Census Bureau indicate that from 1902 up to the recent slackening demand the installed capacity has about doubled each 5 years, and that the output each year has increased about 10 percent over the previous year. All three of the producers noted above are installing new units, the total capacity of which will be 205,000 kilowatts.

FLOOD CONTROL

22. The Skagit River is subject to severe and destructive floods caused by warm chinook winds melting the glaciers and accumulated snow with abnormal rapidity. Floods may occur at any time of the year, but the largest usually occur in November and December, and they can be closely predicted by a study of temperature and precipitation records.

23. Since the settlement of the valley in 1869, five major floods have occurred with peak discharges at The Dalles (mile 54) varying from 180,000 second-feet to 270,000 second-feet. This corresponds to a run-off of from 65 second-feet to 100 second-feet per square mile. The maximum flood, which occurred in 1815, had an estimated peak discharge of about 480,000 second-feet at this station. Below The

Dalles these major floods break through the levees and overflow the banks, the overflow districts acting as storage basins materially reducing the crest at Mount Vernon.

24. The discharge in second-feet per square mile for the upper Skagit Valley above the main tributaries is less than for the major portion of the watershed, due to the fact that the upper valley lies in the wind and rain shadow of the high divide to the west. Of the total flood discharge at Sedro Woolley, about 16 percent is contributed by the run-off of the Skagit below Ruby Creek, about 12 percent by Cascade River, from 25 to 35 percent by the Sauk, and about 15 percent by the Baker River.

25. Bank erosion along the Skagit is continuous, cutting occurring over nearly the entire length of the stream and at all stages. Above Concrete the bed and banks of the stream consist of glacial gravel, and erosion is purely local and of small consequence; below Concrete, the material the stream traverses changes from gravel to sand and alluvium, and erosion endangers the railroads and transmission lines and affects tracts of developed agricultural land. In some instances there is danger of complete channel diversion.

26. Local and private interests affected have constructed bank revetments, groins, and drift barriers, and in some cases these works have given relatively permanent relief, but others have been partially or wholly destroyed during flood stages. The problem is local and the interests of the Federal Government are remote.

27. No diversions of the river for flood-control purposes have ever been made, the flood-control works other than existing storage reservoirs consist of dikes supplemented by drainage ditches constructed below Sedro Woolley. The total expenditures by local interests for protection and reclamation of the delta lands may be conservatively estimated at about $3,000,000. There are two storage reservoirs in Skagit Basin, Shannon Lake with a capacity of 156,000 acre-feet on the lower Baker River, and Diablo Reservoir with a capacity of 90,000 acre-feet on the upper Skagit. Both of these reservoirs were operated during the flood of February 1932 so as to reduce the crest discharge. It is estimated that the crest of this flood, with an unregulated discharge of 182,000 second-feet, was reduced 34 percent by the operation of these reservoirs at no sacrifice to their power output.

28. Although flood damages are great, they are difficult to evaluate, especially in estimating intangible losses due to interruption and disruption of business. As the valley becomes developed, flood damages will increase, and with the occurrence of a flood such as occurred in 1815 great suffering and enormous monetary damage will ensue. The flood of 1932, a relatively minor flood (peak discharge at The Dalles of 147,000 cubic feet per second), in comparison to others that have occurred, entailed a tangible loss of about $600,000 below Sedro Woolley, over 80 percent of which resulted from damages to farm lands, improvements, and crops. The district engineer estimates the average annual flood damage during the past 40 years at about $150,000, and that the maximum expenditure justified for flood control with present conditions of development would not exceed the value of $150,000 capitalized at 4 percent, or $3,750,000.

29. The district engineer has given consideration to plans for further flood control by means of increasing the capacity of present flood channels by diversions and by storage of headwaters. Above

the delta, the cost of channel improvements or diversions would far exceed the resultant benefits. The most economical plan of diversion in the delta for a flood of 220,000 second-feet appears to be a by-pass channel with a capacity of 120,000 second-feet from Avon (mile 13) to Skagit Bay, a distance of 5.6 miles. The cost of such a by-pass, estimated at $4,500,000, is somewhat more than is considered justified by probable benefits.

30. With the construction of storage reservoirs on the tributaries primarily in the interest of power as outlined in the discussion on power developments, some of the reservoir capacity may be reserved at the various sites to reduce crest flows, without unduly restricting the power output. A summary of the storage that it appears desirable to reserve for flood control at the major developments proposed is as follows:

Reservoir	Drainage area	Usable storage capacity	Storage for flood control	Percent for flood control	Amount of cost charged to flood control
	Square miles	*Acre-feet*	*Acre-feet*		
Ruby	978	2,428,000	200,000	8.2	
Cascade	148	96,700	32,300	33.4	$880,000
Lower Sauk	714	541,900	200,000	36.8	790,000
Upper Baker	184	115,800	39,500	34.2	
Total	2,024	3,182,400	471,800	14.8	

31. From the limited data available on flood hydrographs and time of arrival of flood crests, it is estimated that with these reservoirs operated in the combined interests of power and flood control, a flood with a crest discharge of 220,000 second-feet at Sedro Woolley could be reduced about 36 percent, and that this reduced crest would not overtop the existing dikes on the lower river.

32. A study was undertaken to determine the effect on the power output at the various sites with storage reservation for flood control as tabulated in paragraph 30. Power output was based on streamflow records for the 17 years previous to 1932 and on three methods of reservoir operations: (1) Operating for power alone with no reservation for flood control; (2) reservation for flood control over the three winter months, November to January, inclusive; and (3) flood-control reservation throughout the year. As a result of this study it appears that the reservation of storage for control of winter floods will not decrease materially the power capacity of the plants.

33. All of the floods that occurred in the 17-year period considered occurred during the winter months, but the advisability of limiting flood-control reservation to these 3 months is debatable in view of the fact that floods may be expected and have occurred in other months. Definite decisions as to the amount of storage to be reserved for flood control and the period of time it should be reserved are not practicable at present, because of the length of time before these developments will be undertaken, the indeterminate future value of the power to be developed, and the uncertainty as to the participation in the cost by the parties benefited by flood storage.

IRRIGATION

34. No irrigation works have been constructed in the drainage area, and it is not likely that irrigation will ever be practiced to any great extent as the precipitation is abundant for all crops now raised.

VIEWS AND RECOMMENDATIONS OF THE DISTRICT ENGINEER

35. The district engineer concludes that snagging and dredging are meeting the present and prospective needs of navigation and that operation of reservoirs for power will aid transportation of logs in low-water periods and could be operated to reduce the crests of flood discharges but that the benefits to navigation are not sufficient to justify participation of United States in the cost. He believes power will ultimately be developed and that the reservoirs could be operated for the benefit of power and flood control and that those to be benefited by flood control should participate in the cost; that pending the further development of power reservoirs those interested in flood protection in the delta area should improve the channel and diking system to care for a discharge of 140,000 second-feet; and that a flood-warning system should be provided.

36. The district engineer recommends that no change be made in the existing navigation project; that the development of the lower Sauk River power site be governed by the provisions of the Federal Water Power Act; that local beneficiaries of flood storage be given opportunity to secure the amount of protection for which they are willing to participate in the cost of the storage reservoirs, and that regulation of storage be in accordance with rules prescribed by the Federal Power Commission; that the lower river channel and dikes be improved by those interested so as to carry a discharge of 140,000 second-feet; that no reservation or storage of water be made for irrigation; that stream gagings be continued by those interested; and that the Federal Government not contribute to the cost of power developments or flood control.

37. The district engineer concurs in the recommendations of Mr. J. E. Stewart of the United States Geological Survey, who made a study of the Skagit River in 1923, that a flood-warning system be installed; and that the diking off of the Nookachamps Creek district which furnishes flood storage be prohibited.

VIEWS AND RECOMMENDATIONS OF THE DIVISION ENGINEER

38. I concur in the report of the district engineer. In the formulation of plans for the conservation of water resources of the Skagit River Basin, power development, with special regard to the interests of flood control and due regard to the interests of navigation, is the primary consideration. The quantity and distribution of rainfall are such that there is no need for irrigation. Further improvement in the interest of navigation is not warranted at the present time, but regulation of stream flow for power will have a beneficial effect upon existing navigable channels. Protection from destructive floods is a serious local problem to be solved mainly by reserving storage in power reservoirs for control of winter run-off. Pending further development of power reservoirs, local interests in the delta area should install a

flood-warning system and make provision for carrying safely a discharge of 140,000 second-feet by increasing channel capacities and improving the existing levee system.

39. It is recommended that further development of water resources in the Skagit River Basin be left to the initiative of local interests under the provisions of the Federal Water Power Act, wherever that act applies; that in connection with applications for licenses under the Federal Water Power Act, full consideration be given to the provision of storage for control of winter floods; that this report together with its appendixes and accompanying maps be printed.

THOMAS M. ROBINS,
Lieutenant Colonel, Corps of Engineers, Division Engineer.

REPORT OF THE DISTRICT ENGINEER

SYLLABUS

The district engineer finds that irrigation is of no importance in the Skagit Valley; that benefits to navigation and flood control from power development would be so small that participation by the Federal Government in such development would not be justified. He shows how storage of water can be regulated in the combined interest of power and flood control and suggests that those affected by floods be given an opportunity to participate in any such developments. He is of the opinion that no modifications of the existing projects for improvement of the river in the interest of navigation are necessary at this time.

WAR DEPARTMENT,
UNITED STATES ENGINEER OFFICE,
Seattle, Wash., May 18, 1932.

Subject: Report on Skagit River, Wash.
To: The Chief of Engineers, United States Army (through the division engineer).

CHAPTER I. INTRODUCTION

AUTHORITY AND PURPOSE

1. *Authority.*—Section 3 of the River and Harbor Act of March 3, 1925, authorized and directed the Secretary of War, through the Corps of Engineers, and the Federal Power Commission to prepare an estimate of the cost of making certain investigations on broadly defined navigable streams of the United States. This section of the the act reads as follows:

SEC. 3. The Secretary of War, through the Corps of Engineers of the United States Army and the Federal Power Commission are jointly hereby authorized and directed to prepare and submit to Congress an estimate of the cost of making such examinations, surveys, or other investigations as, in their opinion, may be required of these navigable streams of the United States, and their tributaries, whereon power development appears feasible and practicable, with a view to the formulation of general plans for the most effective improvement of such streams for the purposes of navigation and the prosecution of such improvement in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation: *Provided,* That no consideration of the Colorado River and its problems shall be included in the consideration or estimate provided herein.

2. The estimates called for by this act were submitted to Congress and published in House Document 308, Sixty-ninth Congress, first

session. The streams recommended for investigation are listed in paragraph 5 thereof which includes the following item:

> Streams draining into Pacific Ocean north of Columbia River as follows: Skagit, Snohomish, Stillaguamish, Puyallup, Chehalis, $104,000.

3. The River and Harbor Act of January 21, 1927, authorized the recommended investigation and surveys in the following language:

> *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* That the following works of improvement are hereby adopted and authorized to be prosecuted under the direction of the Secretary of War and supervision of the Chief of Engineers, in accordance with the plans recommended in the reports hereinafter designated: * * *
>
> Surveys in accordance with House Document numbered 308, Sixty-ninth Congress, first session.

4. The following report on Skagit River is submitted, with 12 plates, 14 figures, and 17 photographs, in compliance with the foregoing items of law.[1]

HISTORY AND SCOPE OF REPORT

5. *Preliminary investigation.*—As a prerequisite to a complete survey, a reconnaissance of the basin was made to determine the justifiable extent, scope, and cost of a more detailed investigation. This reconnaissance consisted principally in assembling, reconciling, and compiling existing data from all available sources. The work was assigned to the district office April 4, 1928, and completed on February 1, 1929.

6. Much valuable assistance was obtained from the United States Geological Survey, the United States Forest Service, the city of Seattle, the University of Washington, and many individuals and agencies.

7. *Detailed investigation.*—The preliminary studies of the various problems, having shown a more detailed investigation of the Skagit to be warranted and more information to be needed before plans could be formulated for the best utilization of the river, authority and funds to make this study were obtained and a formal investigation of the river initiated in March 1929 and completed as of the date of this report. The results of this investigation are embodied herein. The scope of the field investigation was limited by the available funds to the following principal items of work: Topographic surveys of the Cascade and lower Sauk Reservoirs and of the river proper from the Gorge plant of the city of Seattle to the mouths, including detailed surveys of portions of the delta area; borings at the Cascade and lower Sauk Dam sites, and near the Faber Ferry on the main river; and the establishment and maintenance of six stream gages. The scope of the office work will be apparent from a perusal of the succeeding text.

8. *General plan of investigation.*—The preliminary investigation of the problems involved in formulating general plans for the improvement of the upper river for power and for prosecution of such improvement in combination with the most efficient development of navigation and flood control indicated:

[1] Only plates 1, 4, 5 and figures 4, 6, 8, 9, 11, 12, 13, 14 printed in this document. Copies of unpublished illustrations may be procured from the district engineer, U.S. Engineer Office, Seattle, Wash., at cost of reproduction. (See p. 110 for list of all illustrations.)

First. That no improvement of the Skagit River for navigation, except to a very limited extent by snagging on the lower river, is justified by present or prospective commerce.

Second. That the upper river and certain of its tributaries are well suited to power development due to the steep slope and heavy run-off which could be, at least partially, regulated by reservoirs, provided dam sites could be found with favorable foundation conditions.

Third. That flood control is relatively important because of the extent and high productivity of the agricultual lands in the delta area that are periodically subjected to inundation. The developments of the river in the interests of power and flood control and, to a minor extent, navigation are so closely related and interdependent that they might be economically combined to the mutual benefit of all. The principal object of this report is the determination of the plan that most fully satisfies these interests.

Fourth. That irrigation is not a problem for consideration, as the precipitation is adequate for any crops now raised in the basin.

9. *Available data.*—The principal maps, plans, and reports available at the inception of this study were as given in the following list.

MAPS

United States Geological Survey topographic sheets covering that portion of the drainage basin lying downstream from the mouth of Cascade River, on scales of 1 to 62,500, 1 to 125,000, and 1 to 250,000 with 25-, 50-, and 100-foot contour intervals.

Water Supply Paper No. 419 published by the United States Geological Survey showing profiles of the Skagit from Concrete to the international boundary, and of the lower reaches of the following tributaries for the distances stated: The Baker River for 23 miles, the Cascade River for 15 miles, the Sauk River for 41 miles, the north and south forks of the Sauk for 3 miles each, the Suiattle for 33 miles, and the Whitechuck for 11 miles.

Various topographic maps, profiles, and studies of possible plant lay-outs on the Sauk River and its tributaries prepared about 1916–18 by the now defunct American Nitrogen Products Co.

Detailed survey of the Skagit River from its mouth to Sedro Woolley, made under the direction of the district engineer, United States Engineer Office, Seattle, Wash., in 1907. Scale 1 in 4,800.

Detailed survey of the river from Sedro Woolley to the mouth of Baker River, made under the direction of the district engineer, United States Engineer Office, Seattle, Wash., in 1911. Scale 1 in 4,800.

REPORTS

Various river and harbor and flood control preliminary examinations and surveys. (See par. 76.)

Discharge records, both published and unpublished, for various gaging stations of the United States Geological Survey.

An unpublished and incomplete report on Skagit River floods by Mr. J. E. Stewart, of the United States Geological Survey, prepared in cooperation with Skagit County.

Various bulletins treating of mineral resources of the basin, as published by the State of Washington Geological Survey.

Unpublished report by Robert Howes to city of Seattle on power sites on Sauk and Suiattle Rivers, 1914.

Various data regarding the city of Seattle's power developments of the upper Skagit, both published and unpublished.

Report on geology of dam sites on Skagit and Sauk Rivers, by Mr. J. T. Pardee, of the United States Gelogical Survey, dated March 1927, unpublished.

Unpublished studies by G. L. Parker, district engineer of the United States Geological Survey, Tacoma, Wash.

10. *Work done.*—The field work done during the period of the study was as follows: Topographic surveys were made of the Cascade River Reservoir and dam site, and of the lower Sauk Reservoir and dam site including the saddle leading over into the Stillaguamish Basin; subsurface investigation by drilling was made of possible dam sites on the Cascade River, lower Sauk River, and at the upper and lower Faber sites on the Skagit River; transit-stadia survey of the river was made from the city of Seattle's Gorge power plant to the mouths, including a plane table and stadia survey of possible locations for a bypass channel in the delta area.

11. Six stream gaging stations were established and maintained by the United States Geological Survey at the request of and with funds furnished by the War Department at the locations shown in table 1. All of these stations were constructed during the period of the preliminary investigation.

TABLE 1.—*Stream gaging stations established with War Department funds*

Station and location	Equipment
Sauk River near Sauk, Wash., in sec. 19, T. 34 N., R. 10 E., Willamette meridian; 5 miles southeast of town of Sauk, Wash.	Water-stage recorder in concrete structure. Cable and car.
Cascade River near Marblemount, Wash., in SW. ¼, sec. 9, T. 35 N., R. 11 E., Willamette meridian; 2 miles east of town of Marblemount, Wash.	Water-stage recorder in timber structure. Cable and car.
Sauk River above Whitechuck River near Darrington, Wash., in NW. ¼ sec. 24, T. 31 N., R. 10 E., Willamette meridian; 1½ miles above mouth of Whitechuck River and 9½ miles southeast of town of Darrington, Wash.	Water-stage recorder in timber house over timber and concrete well. Cable and car.
Sauk River at Darrington, Wash., in SE. ¼ sec. 24, T. 32 N., R. 9 E., Willamette meridian; ½ mile southeast of town of Darrington, Wash.	Staff gage. Cable and car.
South Fork of Sauk River near Barlow Pass, Wash., in NE. ¼ sec. 29, T. 30 N., R. 11 E., Willamette meridian; 2¾ miles above junction with North Fork, 5 miles northeast of Barlow Pass.	Water-stage recorder in wooden structure. Cable and car.
Baker River below Anderson Creek near Concrete, Wash., in SE. ¼ sec. 30, T. 37 N., R. 9 E., Willamette meridian; ¼ mile above Baker River Ranger Station, 11 miles northeast of town of Concrete, Wash.	Do.

12. Stream-flow studies were made for both power development and flood control, and for a combination of the two, using various capacities for the reservoirs. The most economical height of dam at each site was determined by making comparative designs and estimates for at least three separate elevations. Different types of dams were also compared for some of the sites. Alternate locations of a flood bypass channel in the delta area were made and the costs estimated. The cost of improving, enlarging and diking the main river channel to carry a larger flood flow was also investigated.

CHAPTER II. GENERAL DESCRIPTION OF DRAINAGE BASIN

13. *Topography and drainage.*—Skagit River, the largest single stream tributary to Puget Sound, has its source in British Columbia, 28 miles by river north of the Canadian line, and thence flows southward 29 miles to Ruby Creek in Whatcom County, Wash.; southwestward 41 miles to the mouth of Sauk River in Skagit County; westward 43 miles to Sedro Woolley; and southwestward again 22 miles to Skagit Bay, an arm of the sound, which it enters at a point about 10 miles below Mount Vernon. The total length from source to mouth is 163 miles. The entire drainage basin is shown on the

general map (pl. 1) topography along the river on plates 2[1] and 3[1], and profiles of the main river and principal tributaries on plate 4.

14. Below Mount Vernon the waters of the river pass through the delta land into Skagit Bay by way of two main channels and several lesser ones. The two main channels, designated respectively north Fork and South Fork, are navigable for light-draft vessels. At the present time, the North Fork is the one principally used and, unless otherwise noted, will be the one considered in this report to be the river's mouth. The tidal effect extends to the Great Northern Railway bridge 15.4 miles above the mouth. The tidal range between mean low water and mean high water at La Conner, adjacent to the mouth of the river, is 7.7 feet, the diurnal range, which shows the average height of the higher high waters above the datum of mean lower low water is 11.1 feet and the extreme range is about 19 feet.

15. The drainage basin of Skagit River and its tributaries, comprising an area of 3,140 square miles, of which 390 square miles is in Canada, lies on the western slope of the Cascade Mountains. It is roughly T shaped in outline, and is bordered on the south and southwest by the basin of the Stillaguamish River, and on the north and northwest by the basins of the Samish and Nooksack Rivers in the United States, and of the Fraser River in British Columbia, and on the east by the basins of the Similkameen, Methow, Chelan, and Wenatchee Rivers, the four latter of which are tributaries of the Columbia River. Between outermost points it extends between latitudes 47°58′ and 49°18′ (Canadian boundary follows the forty-ninth parallel), an over-all north-and-south distance of 92 miles, and from longitude 120°40′ to 122°29′, an east-and-west distance of 83 miles. Within its borders are included a length of 125 miles, measured along the Divide, of the western escarpment of the Cascade Range, and also extensive portions of the slopes of glacier-clad Mounts Baker, Shuksan, and 2 so-named "Glacier Peaks", 1 in Snohomish and 1 in Whatcom County.

16. The two largest tributaries of the Skagit are Sauk and Baker Rivers. Other important streams are Cascade River, Thunder, and Ruby Creeks, all of which head in the high Cascades.

17. Sauk River enters the Skagit from the south near the town of Rockport, 65.5 miles from salt water. It occupies a narrow valley, averaging 6 miles in width, lying between the Stillaguamish Basin on the west and the Suiattle, the principal tributary of the Sauk, on the east. From its mouth to its most distant source at Indian Pass, on the Cascade Divide, the Sauk is 46 miles long, and with its tributaries drains an area of 729 square miles, mostly in the northeastern part of Snohomish County. The Suiattle River is an important tributary of the Sauk, which it enters at mile 12.5 above the mouth of the latter. The Sauk and the Suiattle completely surround Glacier Peak in Snohomish County, taking all of the run-off from its extensive glacial fields.

18. Baker River, the tributary of the Skagit second in importance, has its source on the eastern slope of Mount Shuksan, and flows southward about 24 miles, passing through Baker and Shannon Lakes, the former on the southeastern slope of Mount Baker, and the latter, an artificial storage reservoir for power uses of the Puget

[1] Not printed.

Sound Power & Light Co., near the river's mouth. Baker River joins the Skagit at the town of Concrete, 56 miles above the mouth of the latter. The drainage basin of Baker River is 270 square miles in extent, the greater part of which is situated in Whatcom County, on the southeasterly slopes of Mounts Baker and Shuksan, within the Mount Baker National Forest. Consequently, the river derives a considerable portion of its flow from the glacial fields of those mountains.

19. Altitudes within the Skagit Basin range from sea level to 8,000 feet at the crest of the Cascade Range, and to 10,750 feet at the summit of Mount Baker, 10,436 feet at Glacier Peak (Snohomish County), 9,038 feet at Mount Shuksan, 8,894 feet at Glacier Peak (Whatcom County). Part of the upper basin above the town of Concrete lies above the timber line and within the zone of perpetual ice and snow.

20. Up to elevations of about 4,000 feet, the area is, in general, timbered with Douglas fir, hemlock, and some cedar. At the lower elevations are found the heaviest stands of Douglas fir, but with increase of altitude the trees of all species become smaller and less numerous. Above the timber line, which is at approximately elevation 6,000 feet, much of the surface is barren rock. On all of the more lofty summits there are many glaciers. Two thirds of the entire basin lies within the Mount Baker and Snoqualmie National Forests.

21. The delta area of the Skagit Basin, that is, the bottom land downstream from Sedro Woolley, as well as many pockets in the upstream valleys, is composed of a rich alluvial soil. Here are to be found many fine farms. At higher elevations the prevailing soil is coarse glacial gravel. In the vicinity of the mouth of Baker River are usable deposits of limestone and clay which furnish the raw materials for the portland cement plant located at the town of Concrete. Underbrush is thick on the lower levels and along the stream courses, becoming thinner up the slopes and dying out altogether before reaching the timber line.

22. *Geology.*—Various publications of the Washington State Geological Survey have been freely drawn upon for the following notes pertaining to the geology of the Skagit drainage area. The eastern sections of the Skagit drainage area are very rugged and mountainous; much of the surface is barren rock, and all of the higher summits are clad with glaciers, which, rising as they do to elevations of 8,000 to nearly 11,000 feet, stand out in sharp contrast with the flat lowland country of the western alluvial, or delta, section. The intervening lower lands and hills are more rolling and, underneath the growth of vegetation, are largely covered with a vast mantle of unconsolidated glacial gravel, sand, and clay left there by the advance and retreat of the great ice sheets of the past.

23. The prevailing rocks of the Skagit area are serpentines, schists, slates, crystalline limestones, and other metamorphic varieties, all filled with numerous quartz veins and stringers. Lying above these at several places are true sedimentary rocks, such as sandstones and shales. The sandstones are in some cases exposed through glacial erosion, but more often are completely covered from sight by glacial debris. In some instances the sandstones and shales contain coal seams, as at Hamilton and the Cokedale coal area near Sedro Woolley.

Fossil vegetation is a characteristic feature of the coal measures wherever coal seams are present. Occasionally there are dikes of andesite and basalt which have been forced up through fissures from below.

24. Conglomerates in some localities are very common; in the hills between Mount Vernon and Big Lake they are especially noticeable. The size of the pebbles varies from very small ones up to boulders several feet in diameter. The material of which they are composed may be of igneous and metamorphic rocks or quartz vein matter; but usually the characteristics of the older schist formation are present.

25. Throughout the valley there are many clay patches located above the level of the alluvial plains and in the sides of the hills about 100 feet above the river level. They show distinct stratification as if formed in the quiet waters of lakes. These clays, together with the limestones, are of commercial importance in connection with the cement-making industry centered about the town of Concrete.

26. During some past age a profound deformation of the rocks took place in the form of a great rise in a more or less east-and-west direction through the center of Skagit County. Later on, erosion removed a vast quantity of the sediments, leaving remnants of the strata flanking the sides of this great upheaval. The uprise was not without complications, and wrinkles were formed across the great raised area. Then, at a time subsequent to this deformation period, there came the glacial epoch, which has left a marked impression upon the topography of the basin, there being a number of channels of prehistoric streams as well as numerous fresh-water lakes, the most of which are the results of glaciation.

27. At one time the Suiattle and the lower Sauk reached tidewater through the North Fork of the Stillaguamish River, and the South Fork of Sauk River above Barlow Pass was once the head of the South Fork of the Stillaguamish. There is some evidence that the upper Skagit was at one time diverted into the North Fork of the Stillaguamish along with the Suiattle and the lower Sauk. There is some evidence, too, that these streams flowed into the Stillaguamish drainage during two widely separated periods. The present divide between the Sauk and the North Fork of the Stillaguamish at Darrington is apparently a glacial moraine, the water-tightness of which is questionable.

28. *Temperatures.*—Regarding temperatures of the Puget Sound region, of which the Skagit Basin forms a part, a summary by the United States Weather Bureau states:

> The climate of the region is equable; it is mild in winter, because of the winds blowing from off the ocean, and cool in summer for the same reason. The mean temperature of the Puget Sound country ranges from 38° in midwinter to 62° in midsummer, while near the coast the range is considerably less, being from 40° in winter to 60° in summer. The average daily march of temperature in the Puget Sound region is from 33° to 43° in midwinter and from 50° to 74° in midsummer. The average daily range is noticeably small in winter, showing the equability of temperature, while in summer the much larger range is evidence of the coolness of the nights, even following the warmest days. Frequently, in winter the difference between the day and night temperatures is only 5°, or less, while in the warmest days of summer it is sometimes as much as 30° or 40°.

29. From table 2, it will be noted that the range of temperature in the Skagit Basin is from −1° to +99° in the lower portion, and from −11° to +109° in the foothills, with a mean annual temperature of

about 48° to 50° throughout the valley. In latitude, this basin is comparable with Newfoundland and central Ontario.

TABLE 2.—*Meteorological data for stations in or near Skagit River Basin*

[Compiled from reports of U.S. Weather Bureau to Dec. 31, 1931]

Station	Elevation above mean sea level	Number of years observed		Temperature			Mean annual precipitation	Average annual snowfall
		Temperature	Precipitation	Mean annual	Maximum	Minimum		
	Feet			*°F.*	*°F.*	*°F.*	*Inches*	*Inches*
Anacortes	60	26 (1931)	38 (1893–1931)	50.0	95	+7	27.2	7
Baker Lake	670		5 (1927–31)				91.9	48.5
Concrete [1]	243	17 (1906–31)	17 (1906–31)	50.2	106	−1	60.3	32.7
Darrington	500	12 (1931)	14 (1912–31)	47.7	105	−11	73.3	32.7
Davis Ranch, near Diablo Dam.	872	10 (1924)	13 (1909–24)	47.7	106	−2	78.2	112.6
Diablo Dam	892	4 (1927–31)	4 (1927–31)	47.2	105	−1	61.6	55.4
Mount Baker Lodge	4,200	5 (1926–31)	5 (1926–31)	40.7	85	−6	105.1	478.0
Monte Cristo	2,872		5 (1895–1901)				118.5	
Sedro Woolley [2]	48	35 (1896–1931)	35 (1896–1931)	50.1	99	−1	46.2	9.3
Skagit Power Plant	505	7 (1925–31)	7 (1925–31)	46.8	109	0	66.0	42.4

[1] Average growing season 189 days.
[2] Average growing season 173 days.

30. *Rainfall.*—The Skagit Basin shares in the abundant precipitation common to the Pacific slope of the Cascade Mountains in western Washington. This general situation is described in the following brief statement summarized from reports of the United States weather Bureau.

31. The amount of precipitation is unequally distributed seasonally, there being a "wet" season beginning in October or November, and ending in March or April, or occasionally as late as May. On the average, about 80 percent of the annual precipitation occurs during the wet season, the greater part usually falling during the night. Even in the wet season there are many days in which rain does not fall during the hours of daylight, and many days in which it does fall that contain intervals of several hours of fair weather.

32. The vapor-laden atmosphere coming from the ocean into higher elevations produces a greater amount of precipitation on the westerly slopes of the Cascade Mountains than on the low-lying shores of Puget Sound, so that the mean annual rainfall in the mountainous portion of the Skagit Basin exceeds 100 inches, and decreases gradually to about 30 inches or even less in the lowlands. November, December, and January are the months with greatest precipitation; June, July, and August are the driest. On the summits and higher slopes, the greater part of the winter precipitation is in the form of snow. The snowfall at elevations between 5,000 and 10,000 feet probably exceeds 500 inches annually, decreasing to less than 12 inches near the coast.

33. Average precipitation by months and years for various localities in the Skagit Basin where stations are maintained by the United States Weather Bureau, together with records of extreme and mean temperatures, are shown by graphs on plate 5.

34. In table 2 are embodied various meteorological data for the Skagit Basin, a study of which shows how temperature and precipita-

tion are affected by altitude and by location with respect to mountains, and also by proximity to Puget Sound.

35. *Gaging stations and stream-flow records*.—Records available: Stream gaging in the Skagit Basin was inaugurated by the United States Geological Survey May 1, 1908, with the establishment of a gaging station near Sedro Woolley. On December 21, 1908, a station was established on the upper Skagit, 1 mile above Goodell Creek, near the site of the present Gorge hydroelectric plant of the city of Seattle. On March 8, 1909, a station was established on Cascade River below Marble Creek. On September 10, 1910, stations were established on Baker River at Concrete and at a site below Anderson Creek 11 miles above Concrete. Continuous records in the Sauk Basin were begun June 15, 1914, with the establishment of a gaging station on the Sauk River at the town of Darrington. In subsequent years gaging stations at other locations in the basin were maintained for varying lengths of time, from which fragmentary records are available.

36. In 1928 the United States Geological Survey, in cooperation with this Department, established gaging stations at Cascade River near the town of Marblemount, South Fork of Sauk River near Barlow Pass, Sauk River above Whitechuck River, Sauk River at the town of Darrington, Sauk River near the town of Sauk, and Baker River below Anderson Creek; and maintained them until September 30, 1931, with funds provided by this Department. For additional descriptions and locations of these stations, see paragraph 11.

37. Figure 1[1] shows duration of stream-flow records in the Skagit Basin, more detailed information being given in tables 5 to 28 following. Records of stream discharge in the Skagit Basin have been published by the United States Geological Survey to September 30, 1930, only. For the period October 1, 1930, to September 30, 1931, data are taken from unpublished records of the Geological Survey, which records are subject to revision prior to publication.

38. Period selected for study: The first step in analyzing the water supply of the Skagit Basin was to select for study a period of years that should utilize as much of the available stream-flow data as possible, and at the same time keep at a minimum the necessity of estimating run-off for those streams for which data are incomplete. It has been shown that of the four major tributary streams (upper Skagit, Baker River, Cascade River, and Sauk River), the Sauk was the last to be gaged; continuous records there being started in June 1914, or 4 years later than on Baker River. Accordingly, the period chosen for study was the period for which records of the Sauk are available. The "year" used in this analysis is the storage year: that is, the year from the end of one low-water period to the next. In the Skagit Basin, this year corresponds approximately to the period from April 1 to March 31. The period selected for study, therefore, was from April 1, 1914, to March 31, 1931, and all flow-durations given herein are for that period. This period was marked by two rather severe floods—those of 1917 and 1921. The analysis was made on the basis of monthly flow, as a study based on daily values would have involved an expenditure of time entirely disproportionate to the added accuracy that could have been realized. Figure 2[1] (see par. 43) indicates that

[1] Not printed.

the mean discharge for the period selected is somewhat below the mean for the entire period of record. This figure, and the tables of natural discharge which follow, are based on the climatic year (the period Oct. 1 to Sept. 30) to conform with the published records of the United States Geological Survey and to make them more readily usable for subsequent investigations.

39. Estimate of stream flow for periods of missing records: Figure 1[1] indicates that at no point in the basin are stream-flow records continuous for the period selected. It was necessary, for the purpose of this report, to estimate as accurately as possible the monthly discharge for those periods for which records are not available. In the case of the gaging stations on the Skagit River below Ruby Creek, at Reflector Bar, and at the Gorge, such estimates had previously been made by the United States Geological Survey and published in Water Supply Bulletin No. 4 of the State of Washington. For other stations, such estimates were made by this office.

40. The method followed in estimating discharges was alike for each station to be estimated. To illustrate the procedure, the estimate for one station, Baker River below Anderson Creek, will be explained in detail. Figure 1 shows that records of Baker River below Anderson Creek are not available for the period October 1925 to August 1928. For this period records are available for the station on Thunder Creek at its mouth, Skagit River at Concrete, Skagit at Gorge, and Skagit below Ruby Creek. Of these stations the one on Thunder Creek most nearly resembles Baker in general drainage-area characteristics, both streams arising in glaciers. Accordingly, ratios showing $\frac{\text{discharge of Baker}}{\text{discharge of Thunder}}$ were derived for each month of the period of simultaneous record (March 1919 to September 1925 and September 1928 to September 1931). The mean of these ratios for January, February, March, etc., was computed. A few of the ratios showed such wide deviation from the monthly mean as to suggest some unusual climatic condition, not likely to recur in the short period to be estimated, and these values were dropped. New monthly mean ratios, based on the remaining values, were computed. Thus, of the 103 months of simultaneous record, ratios for 7 were dropped and the final ratios based on 96 months record. Similar ratios were derived relating discharge of Baker River with discharge of Skagit River below Ruby Creek and with discharge of Skagit River at Gorge. The relationship with Thunder Creek, however, was most consistent; hence, the monthly discharge of Baker River for the period of missing record was estimated from the corresponding discharge of Thunder Creek. For stations used to estimate discharge at other points, see tables 5 to 28.

41. Stream-flow characteristics: Rugged topography, abundant and concentrated precipitation, numerous glaciers, and absence of natural reservoirs, combine to produce an erratic and flashy run-off in the Skagit Basin. In general, the maximum discharge of the year occurs either in the period November-December, when the early accumulation of snow is melted by sudden warm weather, or in the period April to June, when the winter's snow is melted by advancing summer. Annual maxima have occurred, however, in nearly every month of the year. The greatest monthly run-off occurs, almost

[1] Not printed.

without exception, in May, June, or July. The minimum discharge of the year may occur at any time except the early summer months.

42. Table 3 illustrates the wide difference between maximum and minimum discharges at typical points in the basin, and, for purpose of comparison, of the Columbia River at Vernita. It will be noted that, in general, the ratio of maximum to minimum discharge varies inversely as the drainage area, the only exception being in the case of Cascade River. It is probable that if records for Thunder Creek were available for the same period as for the Cascade River, the ratios would be in uniformly diminishing order throughout the column.

TABLE 3.—*Extreme variation in stream flow, Skagit Basin*

Station	Drainage area	Maximum discharge of record	Minimum discharge of record	Ratio of maximum to minimum discharge
	Square miles	*Second-feet*	*Second-feet*	
Thunder Creek at mouth	111	9,720	50	194
Cascade River below Marble Creek	148	31,700	[1] 115	276
Baker River below Anderson Creek	184	36,800	219	168
Sauk River at Darrington	293	36,000	262	137
Skagit River below Ruby Creek	978	45,700	390	117
Skagit River at Sedro Woolley	2,970	220,000	2,830	78
Columbia River at Vernita	95,500	740,000	21,000	35

[1] Estimated by comparison with Cascade River near Marblemount, drainage area, 180 square miles.

43. In addition to the fluctuation of discharge throughout the year, there is a wide variation from year to year in the total yearly run-off. A record of a few years on any stream is of small value in showing the water resources of that stream unless it can be known how the run-off during the period of record compares with a long-time mean. For the purpose of such comparison there is reproduced herewith as figure 2 [1] a graph showing the yearly discharge of Skagit River at Reflector Bar, Sauk River at Darrington, Cascade River below Marble Creek, and Baker River below Anderson Creek, as percentages of the mean, for the 17-year period October 1, 1914, to September 30, 1931. The climatic year was chosen for this figure to facilitate its use in connection with water-supply papers of the United States Geological Survey. This figure shows, also, that the discharge for the period selected for study is slightly below the mean for the period of record, and that, as a consequence, estimates of water power based on the period studied will be conservative.

44. Figure 3 [1] shows daily hydrographs of Skagit River at Sedro Woolley for a high, an average, and a low year, together with crest discharges for certain extreme floods, and mean monthly discharges for the period of record. This figure illustrates the wide fluctuation in daily discharge and the extreme yearly variation. It will be observed that whereas the extreme crest discharges occur in November or December, the greatest monthly run-off comes in June and the minimum monthly run-off in September; and that the greatest variation between mean monthly yields is many times less than the variation from day to day in times of flood.

[1] Not printed.

45. In considering the characteristics of stream flow of the lower Skagit it is of value to know the relative contribution of the various upstream tributaries. Table 4 gives, for the four main tributaries, the mean monthly percentages for the period of record.

TABLE 4.—*Stream flow of the upper Skagit and principal tributaries in percent of the flow at Sedro Woolley. Period, October 1908 to September 1931*

Month	Mean discharge at Sedro Woolley	Percent of yield at Sedro Woolley				
		Skagit River below Ruby Creek	Cascade River below Marble Creek	Sauk River near Sauk	Baker River below Anderson Creek	Total
	Sec.-feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
January	13, 400	12. 3	4. 4	29. 6	12. 2	58. 5
February	12, 200	13. 2	4. 3	28. 2	11. 7	57. 4
March	10, 700	15. 5	4. 2	26. 8	11. 5	58. 0
April	14, 400	23. 4	4. 9	26. 6	12. 5	67. 4
May	24, 400	31. 1	5. 7	25. 6	11. 9	74. 3
June	30, 000	29. 9	6. 5	26. 2	12. 2	74. 8
July	21, 200	23. 2	8. 3	27. 7	14. 7	73. 9
August	11, 100	19. 6	8. 3	26. 2	16. 2	70. 3
September	8, 700	17. 7	7. 5	27. 6	16. 7	69. 5
October	11, 200	15. 5	6. 1	27. 4	17. 6	66. 6
November	14, 500	13. 3	5. 6	29. 9	13. 8	62. 6
December	15, 600	13. 2	4. 8	29. 3	13. 0	60. 3
Mean, annual	15, 700	19. 0	5. 9	27. 6	13. 7	66. 2

46. It will be seen from the table that about two thirds of the total yield at Sedro Woolley is contributed by the four major tributaries; hence, storage regulation on these tributaries could exercise a pronounced effect on the regimen of the lower river. It will be noted, too, that the maximum monthly run-off at Sedro Woolley occurs in June and the minimum in September. Observe also that the yield of the tributaries, expressed in percentage of yield at Sedro Woolley, varies quite markedly from month to month. For instance, the percent of yield at Sedro Woolley of Skagit River below Ruby Creek varies from a minimum of 12.3 in January to a maximum of 31.1 percent in May; that of Cascade River below Marble Creek varies from 4.3 in February to 8.3 percent in July; that of the Sauk River near Sauk was more constant, varying from a minimum of 25.6 in May to a maximum of 29.9 percent in November; that of Baker River below Anderson Creek varies from a minimum of 11.5 in March to a maximum of 17.6 percent in October; and the total for the four tributaries varies from a minimum of 58 in March to a maximum of 74.8 percent in June. The relative contribution of these tributaries in periods of extreme flood is shown in table 37.

47. Tables: Tables 5 to 28, which follow, summarize all available stream-flow data in Skagit Basin to September 30, 1931, together with estimates of flow for periods of missing record, as determined by the United States Geological Survey or by this office. Each table includes data pertaining to location of gaging station, drainage area, period of record, method of deriving estimated flow, and extremes of recorded discharge. The tables are based on the climatic year to conform with the published records of the United States Geological Survey.

TABLE 5.—*Skagit River above Ruby Creek, near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1929	------	------	------	------	------	------	------	------	5,530	2,330	1,260	750	------
1930	------	------	------	------	------	1,690	5,030	4,300	4,860	2,750	1,390	980	------
1931	860	873	627	1,290	1,650	1,850	2,330	6,200	4,400	2,090	1,110	1,280	2,050

NOTE.—Water-stage recorder in Whatcom County, 1¼ miles above Ruby Creek, 7 miles above Reflector Bar, and 25 miles northeast of Marblemount. Drainage area, 765 square miles, of which 390 square miles is in Canada. Records available, Oct. 1, 1928, to Apr. 20, 1929 (fragmentary); June 1 to Sept. 30, 1929; Mar. 1, 1930, to Sept. 30, 1931. See also table 6 for records of earlier station nearby. Maximum discharge during period of record, 9,860 second-feet, May 2, 1931. Minimum discharge during period of record, 435 second-feet, Jan. 19, 1931.

TABLE 6.—*Skagit River below Ruby Creek, near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1909 [1]	930	2,530	1,080	1,380	1,190	1,330	2,280	5,960	11,400	5,650	2,360	1,720	3,150
1910 [1]	1,450	5,520	2,960	1,420	1,240	3,550	6,100	12,200	8,380	5,720	2,310	1,310	4,350
1911 [1]	4,020	4,630	2,060	1,180	760	1,430	2,750	6,440	11,200	5,460	2,300	1,750	3,660
1912 [1]	850	1,320	1,130	1,090	1,690	920	2,180	7,520	8,800	3,900	2,120	1,020	2,710
1913 [1]	830	1,550	1,070	760	1,130	1,150	3,060	8,100	12,800	6,180	2,660	2,080	3,450
1914 [1]	1,930	2,150	1,480	2,870	1,040	2,320	4,490	7,980	7,040	4,450	2,020	1,270	3,250
1915 [1]	1,430	3,070	1,400	720	630	1,290	4,370	3,930	3,250	2,660	2,190	980	2,160
1916 [1]	1,370	1,620	1,510	690	960	1,430	2,540	7,140	12,900	7,700	3,000	1,780	3,550
1917 [1]	920	1,110	750	730	1,020	770	1,680	7,120	10,200	6,650	2,390	1,440	2,900
1918 [1]	1,180	1,470	4,120	5,780	2,070	1,640	4,430	7,290	10,500	4,900	2,330	1,570	3,940
1919 [1]	1,780	1,570	2,700	1,680	1,160	1,010	4,330	8,960	------	------	------	------	------
1919	------	------	------	------	------	------	------	------	9,870	7,380	2,990	1,510	3,740
1920	779	2,140	2,190	2,230	2,210	1,270	1,350	4,790	7,260	6,370	2,250	2,050	2,910
1921	3,960	1,880	1,540	1,790	2,570	2,320	2,740	8,830	13,500	5,790	2,650	1,720	4,110
1922	3,060	2,840	5,250	1,200	750	657	1,670	6,870	12,200	4,070	2,120	1,600	3,540
1923	1,420	1,120	1,660	2,040	934	1,130	4,350	8,400	9,940	5,780	2,160	1,320	3,360
1924	965	748	1,460	983	4,810	1,650	1,880	10,400	6,070	3,210	1,660	1,280	2,930
1925	2,020	2,050	4,500	1,660	2,700	1,750	4,810	11,900	8,640	4,380	1,920	1,050	3,960
1926	577	605	2,160	1,250	1,220	1,460	3,900	3,770	2,870	1,920	1,290	818	1,820
1927	1,980	1,190	1,710	1,290	909	1,060	2,530	6,130	11,500	4,360	2,140	2,320	3,100
1928	3,250	3,150	2,790	3,940	1,500	2,060	2,480	10,500	6,020	3,480	1,510	1,060	3,500
1929	2,090	1,160	976	619	497	928	1,710	7,110	7,410	3,140	1,630	919	2,360
1930	826	500	591	500	2,280	1,830	6,230	5,680	6,650	3,760	1,700	1,160	2,630
Mean	1,710	2,000	2,050	1,630	1,510	1,500	3,270	7,590	9,020	4,860	2,170	1,440	3,230

[1] Estimated; see note below.

NOTE.—Water-stage recorder in Whatcom County, ¾ mile below Ruby Creek, 5 miles above Reflector Bar, and 23 miles northeast of Marblemount. Drainage area, 978 square miles, of which 390 square miles is in Canada. Records available, June 1, 1919, to Sept. 30, 1930. Monthly discharge prior to June 1919 is estimated by comparison with monthly discharges at Reflector Bar and Gorge power plant. See also table 5 for records of subsequent station nearby, Mar. 1, 1930, to Sept. 30, 1931. Maximum discharge during period of record, 45,700 second-feet, Dec. 12, 1921; minimum discharge during period of record, 390 second-feet, Dec. 11–12, 1929.

TABLE 7.—*Skagit River at Reflector Bar, near Marblemount (Diablo Canyon)*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1909 [1]	1,240	3,160	1,330	1,720	1,450	1,600	2,720	6,860	13,700	7,640	3,740	2,640	3,980
1910 [1]	1,940	6,910	3,660	1,780	1,510	4,280	7,260	14,000	10,100	7,730	3,670	2,020	5,400
1911 [1]	5,360	5,790	2,540	1,470	930	1,720	3,280	7,400	13,500	7,380	3,660	2,700	4,640
1912 [1]	1,130	1,650	1,400	1,360	2,060	1,110	2,600	8,760	10,600	5,280	3,370	1,570	3,410
1913 [1]	1,110	1,940	1,320	950	1,380	1,390	3,640	9,310	15,400	8,360	4,230	3,200	4,350
1914 [1]	2,580	2,690											
1914			1,830	3,590	1,270	2,800	5,350	9,180	8,490	6,010	3,200	1,960	4,100
1915	1,910	3,840	1,730	899	769	1,560	5,200	4,520	3,920	3,590	3,480	1,500	2,750
1916	1,830	2,030	1,870	860	1,170	1,720	3,020	8,210	15,600	10,400	4,760	2,740	4,520
1917	1,230	1,390	930	910	1,250	925	2,000	8,180	12,300	8,990	3,800	2,220	3,690
1918	1,580	1,840	5,090	7,220	2,530	1,980	5,270	8,380	12,700	6,620	3,700	2,420	4,960
1919	2,370	1,960	3,330	2,100	1,410	1,220	5,150	10,300	12,000	9,320	4,510	2,340	4,680
1920	1,020	2,780	2,690	2,810	2,710	1,570	1,670	5,480	8,750	8,470	3,690	3,100	3,730
1921	4,950	2,270	1,850	2,240	3,210	2,760	3,220	10,400	16,700	7,650	4,030	2,430	5,140
1922	4,070	3,510	6,700	1,420	876	785	2,000	8,150	14,500	5,700	3,490	2,530	4,490
1923 [1]	1,970	1,390	2,060	2,570	1,150	1,390	5,180	9,450	11,400	7,760	3,520	2,160	4,170
1924 [1]	1,390	960	1,830	1,240	5,950	1,930	2,220	11,900	7,400	4,630	2,760	2,000	3,680
1925 [1]	2,580	2,440	5,200	1,950	3,200	2,060	5,500	13,300	10,200	6,140	3,040	1,670	4,770
1926 [1]	811	762	2,740	1,520	1,520	1,780	4,540	4,640	4,170	3,320	2,460	1,360	2,470
1927 [1]	2,900	1,600	2,100	1,600	1,140	1,300	2,980	7,040	13,600	6,020	3,490	3,400	3,930
1928 [1]	4,140	3,860	3,270	4,720	1,790	2,460	2,860	12,000	7,590	5,080	2,510	1,740	4,350
1929 [1]	2,820	1,410	1,150	706	570	1,100	1,990	8,260	9,090	4,310	2,660	1,460	2,970
1930 [1]	1,110	597	720	606	2,900	2,260	6,980	6,430	7,660	4,980	2,720	1,920	3,230
1931 [1]	1,420	1,200	844	1,960	2,260	2,530	3,350	9,360	7,480	3,940	2,220	2,260	3,240
Mean	2,240	2,430	2,440	2,010	1,870	1,840	3,830	8,760	10,700	6,490	3,420	2,230	4,030

[1] Estimated; see note below.

NOTE.—In sec. 8, T. 37 N., R. 13 E., Whatcom County, at Reflector Bar ranger station, 75 feet below mouth of Diablo Canyon, ¾ mile above Stetattle Creek, 1½ miles below Thunder Creek, and 19 miles northeast of Marblemount. Staff gage prior to Apr. 13, 1914; water-stage recorder Apr. 13, 1914, to Sept. 30, 1922, when station was discontinued. Drainage area, 1,100 square miles, of which 390 square miles is in Canada. Records available, Dec. 6, 1913, to Sept. 30, 1922. Estimated, Oct. 1, 1908, to Dec. 5, 1913, and Oct. 1, 1922, to Sept. 30, 1931, by interpolating between the discharge below Ruby Creek plus the discharge of Thunder Creek, and the discharge of the river at Gorge power plant. Maximum discharge during period of record, 58,000 second-feet, Dec. 12, 1921, as given by Water Supply Paper No. 552. J. E. Stewart found the 1921 crest to be 63,000 second-feet and the Nov. 29, 1909, crest to be 70,000 second-feet. Minimum discharge during period of record, 665 second-feet, Nov. 11–12, 1919; estimated, 570 second-feet, as the average for the month of February 1929.

TABLE 8.—*Skagit River near Marblemount (Gorge power plant)*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1909 [1]	1,380	3,600	1,540										
1909				1,980	1,590	1,740	3,020	7,270	14,100	8,170	3,960	2,820	4,270
1910	2,150	7,880	4,250	2,050	1,660	4,660	8,060	14,800	10,400	8,270	3,890	2,160	5,870
1911	5,950	6,600	2,940	1,690	1,020	1,880	3,640	7,850	13,900	7,890	3,880	2,890	5,030
1912	1,250	1,880	1,620	1,560	2,270	1,210	2,890	9,290	10,900	5,650	3,570	1,680	3,650
1913	1,230	2,210	1,530	1,090	1,520	1,520	4,040	9,870	15,900	8,950	4,480	3,430	4,650
1914	2,860	3,070	1,860	4,080	1,430	3,080	5,900						
1914 [1]								9,730	8,740	6,430	3,390	2,100	4,390
1915 [1]	2,120	4,380	2,010	1,030	850	1,700	5,770	4,790	4,040	3,840	3,690	1,600	2,980
1916 [1]	2,030	2,310	2,170	990	1,290	1,880	3,350	8,700	16,100	11,100	5,040	2,930	4,820
1917 [1]	1,370	1,580	1,080	1,050	1,380	1,010	2,220	8,670	12,700	9,620	4,030	2,380	3,920
1918 [1]	1,750	2,100	5,900	8,300	2,780	2,160	5,850	8,880	13,100	7,080	3,920	2,590	5,370
1919 [1]	2,630	2,230	3,860	2,420	1,550	1,330	5,720	10,900	12,400	9,980	4,780	2,500	5,020
1920 [1]	1,130	3,170	3,120	3,230	2,980	1,710	1,850	5,810	9,010	9,060	3,910	3,320	4,020
1921	5,740	2,660	2,310	2,810	3,970	3,350	3,810	11,400	17,600	8,560	4,160	2,720	5,760
1922	4,680	4,170	7,680	1,530	938	809	2,290	8,850	14,600	5,960	3,680	2,690	4,840
1923	2,150	1,460	2,510	2,840	1,190	1,480	5,530	9,590	11,700	8,230	3,800	2,250	4,420
1924	1,440	1,090	2,180	1,440	6,270	2,010	2,340	12,400	7,700	4,930	2,930	2,090	3,900
1925	2,900	2,660	5,660	2,150	3,480	2,240	5,850	13,500	10,500	6,520	3,200	1,720	5,040
1926	863	851	3,170	1,680	1,670	1,920	4,810	4,890	4,270	3,500	2,640	1,460	2,650
1927	3,220	1,850	2,410	1,830	1,260	1,430	3,270	7,360	13,700	6,460	3,690	3,630	4,190
1928	4,550	4,330	3,550	5,210	1,940	2,670	3,070	12,400	7,670	5,340	2,590	1,790	4,610
1929	2,930	1,590	1,300	771	598	1,210	2,160	8,580	9,190	4,460	2,720	1,470	3,100
1930	1,160	606	767	744	3,110	2,580	7,400	6,620	7,870	5,150	2,520	1,470	3,320
1931	1,420	1,420	1,110	1,750	2,520	2,850	3,690	9,930	7,710	4,110	2,310	2,540	3,450
Mean	2,470	2,770	2,810	2,270	2,060	2,020	4,200	9,220	11,000	6,920	3,600	2,360	4,310

[1] Estimated; see note below.

NOTE.—Water-stage recorder in S.E. ¼ Sec. 21, T. 37 N., R. 12 E., at City of Seattle power plant, about 1 mile above Goodell Creek, one fourth mile above Newhalem Creek, and 16 miles above Marblemount. Drainage area, 1,160 square miles, of which 390 square miles is in Canada. Records available, Dec. 21, 1908, to May 23, 1914, and Oct. 1, 1920, to Sept. 30, 1931. Discharge estimated October to December 1908, by comparison with Skagit River at Sedro Woolley; May 1914 to September 1920 by comparison with Skagit River at Reflector Bar. Maximum discharge during period of record, 60,000 second-feet, Dec. 12, 1921, as given by Water Supply Paper No. 672. To be consistent with J. E. Stewart's data for the station at Reflector Bar (table no. 7), the discharge of the Nov. 29, 1909, flood would have been about 76,500 second-feet, and that of the Dec. 12, 1921, flood about 69,000 second-feet. Minimum discharge during period of record, 136 second-feet, Aug. 24, 1930.

TABLE 9.—*Skagit River near Concrete*

[Natural discharge in second-feet]

Year ending Sept 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							18,000	26,000	24,000	18,000	10,000	8,500	
1915 [1]	9,300	22,000	6,500	5,500	4,900	8,400	20,000	13,000	11,000	11,000	11,000	5,100	10,600
1916 [1]	10,000	11,000	12,000	4,500	13,000	14,000	13,000	22,000	41,000	32,000	17,000	9,400	16,600
1917 [1]	4,400	9,200	5,100	5,200	7,400	4,600	9,100	24,000	37,000	34,000	15,000	8,200	13,600
1918 [1]	6,000	10,000	37,000	36,000	12,000	9,800	16,000	22,000	34,000	20,000	12,000	8,000	18,600
1919 [1]	13,000	12,000	18,000	14,000	9,100	7,400	18,000	29,000	31,000	29,000	15,000	7,800	17,000
1920 [1]	4,000	18,000	15,000	17,000	12,000	7,500	6,700	16,000	24,000	24,000	11,000	18,000	14,400
1921 [1]	22,000	11,000	10,000	13,000	17,000	12,000	11,000	28,000	46,000	25,000	13,000	12,000	18,300
1922 [1]	18,000	18,000	28,000	5,900	3,900	3,500	7,900	23,000	38,000	17,000	11,000	9,500	15,400
1923 [1]	8,900	6,800	13,000	16,000	6,100	6,700	16,000	24,000	30,000	23,000	11,000	7,300	14,100
1924 [1]	5,800	7,500	13,000	9,500	28,000	8,000	8,400	30,000	21,000	14,000	9,100	7,900	13,500
1925	14,000	13,800	21,300	12,700	17,800	9,160	17,600	36,300	29,700	19,600	9,330	5,300	17,200
1926	3,810	4,430	18,600	9,530	9,380	8,100	14,000	14,400	12,300	9,400	7,410	5,680	9,760
1927	14,900	10,500	12,700	10,400	8,900	7,750	10,200	20,600	36,800	19,900	10,400	12,300	14,600
1928	16,600	19,900	14,400	22,600	8,340	11,500	11,000	31,900	22,500	16,000	8,190	5,710	15,800
1929	13,100	8,460	6,850	4,670	3,190	6,220	8,990	24,100	28,000	15,000	8,880	5,690	11,100
1930	5,140	3,540	5,290	4,490	15,400	10,100	20,300	17,600	21,400	14,900	7,670	5,530	10,900
1931	7,010	6,570	5,550	11,900	10,900	12,400	14,300	26,500	25,400	13,300	7,670	9,600	12,600
Mean	10,400	11,300	14,300	11,900	11,000	8,650	13,400	23,800	28,500	19,700	10,800	8,420	14,400

[1] Estimated; see note below.

NOTE.—Water-stage recorder in sec. 16, T. 35 N., R. 8 E., at The Dalles, 2 miles below Baker River and 2½ miles southwest of Concrete. Drainage area, 2,700 square miles. Records available, Sept. 15, 1924, to Sept. 30, 1931. Estimated for the period from Apr. 1, 1914, to Sept. 14, 1924, by comparison with sum of discharges of Skagit River at Gorge power plant, Cascade River below Marble Creek, Sauk River near Sauk, and Baker River near Concrete. Maximum discharge during period of record, 95,500 second-feet, Jan. 12, 1928; minimum discharge, probably less than 2,160 second-feet, Oct. 1–24, 1925, when recorder was not operating and the gates at Baker River Dam were closed for the first time.

TABLE 10.—*Skagit River near Sedro Woolley*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1908								15,700	26,000	25,100	10,500	5,570	-------
1909	5,520	18,700	8,370	10,600	7,890	6,360	8,360	14,600	28,100	17,900	9,380	7,300	11,900
1910	7,010	33,200	23,600	11,800	9,220	19,400	22,800	35,100	24,900	19,900	10,700	6,500	18,700
1911	23,900	29,500	17,600	11,600	5,470	8,430	11,400	21,700	35,500	23,400	11,400	10,800	17,600
1912	4,930	17,500	11,500	12,800	15,300	5,990	8,870	25,200	33,200	19,300	11,600	6,490	14,400
1913	5,930	15,100	11,600	9,200	11,000	8,720	14,300	25,700	42,900	30,100	15,200	13,100	16,900
1914	14,000	16,700	8,870	22,000	8,470	15,000	19,800	26,100	23,700	19,500	10,300	9,360	16,200
1915	9,920	19,600	7,930	7,120	6,060	8,580	19,700	13,700	11,700	10,400	9,220	4,500	10,700
1916	10,000	12,100	14,300	5,460	16,400	19,100	16,900	24,000	39,400	33,300	17,600	8,620	18,100
1917	5,920	11,400	7,290	7,650	9,320	6,280	11,000	26,100	40,100	37,600	16,500	10,000	15,800
1918	8,140	11,100	36,300	32,800	14,100	11,500	16,800	23,200	36,900	22,100	12,800	8,260	19,600
1919	14,400	12,600	21,400	15,300	10,000	9,110	18,100	28,900	30,000	27,800	13,800	8,220	17,500
1920	5,990	19,100	16,900	[1] 18,000	[1] 14,100	[1] 9,400	[1] 7,200	[1] 16,300	[1] 25,100	[1] 25,500	[1] 11,900	[1] 17,300	[1] 15,600
1921	[1] 23,100	[1] 11,900	[1] 11,700	[1] 13,100	18,100	13,000	12,000	27,700	45,800	25,400	14,700	13,200	19,100
1922	15,700	19,500	34,500	6,950	5,410	5,540	9,330	24,200	41,700	18,800	11,300	10,700	17,000
1923	10,400	7,090	15,000	20,600	6,700	7,710	16,800	25,500	31,200	23,900	10,600	7,440	15,300
1924	6,370	6,900	13,700	[1] 11,000	[1] 34,600	[1] 10,500	[1] 9,540	[1] 32,600	[1] 21,500	[1] 14,700	[1] 9,370	[1] 8,330	[1] 14,900
1925 [1]	16,000	14,500	24,900	15,400	21,400	11,400	19,500	37,800	30,600	20,600	9,420	5,600	18,900
1926 [1]	4,460	4,650	21,800	11,500	11,300	10,000	16,000	15,000	12,700	9,900	7,480	5,960	10,900
1927 [1]	17,400	11,000	14,900	12,600	10,700	9,610	11,300	21,400	37,900	20,900	10,500	12,900	15,900
1928 [1]	19,400	20,900	16,800	27,300	10,000	14,300	12,200	33,200	23,200	16,800	8,270	6,000	17,400
1929 [1]	15,300	8,880	8,010	5,650	3,830	7,710	9,980	25,100	28,800	15,800	8,970	5,970	12,100
1930 [1]	6,010	3,720	6,190	5,430	18,500	12,500	22,500	18,300	22,000	15,600	7,750	5,810	12,000
1931 [1]	8,200	6,900	6,490	14,400	13,100	15,400	15,900	27,600	26,200	14,000	7,750	10,100	13,800
Mean	11,200	14,500	15,600	13,400	12,200	10,700	14,400	24,400	30,000	21,200	11,100	8,700	15,700

[1] Estimated; see note below.

NOTE.—In NW¼ sec. 36, T. 35 N., R. 4 E., at Northern Pacific Railway bridge, 1½ miles south of Sedro Woolley. Drainage area, 2,970 square miles. Records available, May 1, 1908, to Dec. 31, 1919, and Feb. 1, 1921, to Dec. 31, 1923. Discharge estimated for periods January 1920 to January 1921 and January 1924 to September 1924, by comparison with sum of discharges of Skagit River at Reflector Bar, Sauk River at Darrington, and Baker River below Anderson Creek. Discharge for period October 1924 to September 1931 estimated by comparison with discharge of Skagit River at The Dalles near Concrete. Maximum discharge during period of record, 220,000 second-feet, Nov. 30, 1909. Minimum discharge during period of record, 2,830 second-feet, Sept. 29–30 and Oct. 10–11, 1915. Earlier floods are known to have occurred about as follows: Between 1805 and 1825, as estimated from Indian tradition, and from a deposit of flood sand; a discharge of about 400,000 second-feet; about 1856, probably December, a discharge of about 300,000 second-feet; Nov. 16, 1896, discharge, 185,000 second-feet; Nov. 19, 1897, discharge 190,000 second-feet; Nov. 16, 1906, discharge 180,000 second-feet.

TABLE 11.—*Ruby Creek near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1919	------	------	------	------	------	------	------	------	1,990	1,550	610	309	------
1920	135	356	257	281	319	212	------	------	------	------	------	------	------
1928	------	------	------	------	------	------	------	------	------	------	------	170	------
1929	357	197	233	------	------	------	287	1,630	1,750	616	245	131	------
1930	------	------	------	------	------	------	1,040	1,220	1,500	762	284	175	------
1931	143	130	90	172	250	283	493	1,860	1,230	498	226	214	467
Mean	212	228	193	226	284	248	607	1,570	1,620	856	341	200	------

NOTE.—Water-stage recorder one half mile above mouth, 23½ miles northeast of Marblemount. Drainage area, 210 square miles. Records available, June 1, 1919, to Mar. 31, 1920; Sept. 1, 1928, to Jan. 12, 1929; Apr. 1 to Sept. 30, 1929; Apr. 1, 1930, to Sept. 30, 1931. Maximum discharge during period of record, 3,570 second-feet, May 14, 1931; minimum discharge during period of record, 65 second-feet, Dec. 27 1930, to Jan. 2, 1931.

TABLE 12.—*Thunder Creek above Colonial Creek*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1931	360	179	95.2	278	212	222	333	985	1,350	1,140	825	664	555

NOTE.—Water-stage recorder in Whatcom County, in SE¼ sec. 23, T. 37 N., R. 13 E. Drainage area, 98 square miles. Records available, Oct. 1, 1930, to Sept. 30, 1931. Maximum discharge during period of record, 4,160 second-feet, June 26, 1931; minimum discharge during period of record, about 65 second-feet, Jan. 1–7, 1931.

TABLE 13.—*Thunder Creek at mouth, near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]	546	421.0	256.0	468.0	156.0	341.0	576	888	1,000	1,340	1,050	593	640
1915 [1]	403	601.0	241.0	116.0	95.0	192.0	556	436	462	800	1,150	447	461
1916 [1]	386	320.0	263.0	110.0	143.0	206.0	322	792	1,860	2,320	1,570	826	762
1917 [1]	260	218.0	131.0	117.0	156.0	110.0	214	785	1,450	2,010	1,250	671	618
1918 [1]	336	289.0	708.0	936.0	313.0	241.0	563	807	1,520	1,480	1,220	731	766
1919 [1]	496	304.0	460.0	273.0	170.0								
1919						148.0	515	988	1,070	1,570	1,260	666	664
1920	202	490.0	381.0	346.0	317.0	185.0	196	536	887	1,860	1,340	899	639
1921	721	296.0	244.0	289.0	402.0	330.0	355	1,010	1,970	1,560	1,230	573	750
1922	920	486.0	865.0	149.0	82.6	77.5	196	763	1,660	1,430	1,210	860	728
1923	477	233.0	305.0	362.0	173.0	189.0	546	905	1,330	1,680	1,220	740	684
1924	369	162.0	280.0	173.0	751.0	236.0	269	1,230	1,020	1,240	996	646	614
1925	443	315.0	563.0	196.0	323.0	208.0	522	1,300	1,400	1,560	1,030	598	708
1926	234	135.0	435.0	225.0	214.0	239.0	587	680	1,050	1,320	1,060	463	556
1927	811	312.0	294.0	205.0	147.0	154.0	305	658	1,560	1,410	1,230	919	671
1928	778	597.0	425.0	639.0	199.0	264.0	289	1,290	1,200	1,500	971	665	739
1929	709	206.0	135.0	73.6	58.9	103.0	205	921	1,240	1,140	1,000	539	531
1930	275	90.6	87.5	84.7	407.0	267.0	690	617	970	1,140	927	674	519
1931 [1]	396	197.0	105.0	306.0	233.0	244.0	366	1,080	1,480	1,250	908	730	610
Mean	487	315.0	343.0	282.0	241.0	207.0	404	871	1,280	1,480	1,150	680	648

[1] Estimated; see note below.

NOTE.—Water-stage recorder in Whatcom County, one-fourth mile above mouth, 3½ miles from Reflector Bar (Diablo), and 20 miles northeast of Marblemount, Skagit County. Drainage area, 111 square miles. Records available, Feb. 15, 1919, to Sept. 30, 1930. Estimated for period from Oct. 1, 1913 to Feb. 14, 1919, using ratios derived by comparison of difference of yield of Skagit River below Ruby Creek and at Reflector Bar with that of Thunder Creek, based on 67 months comparative record (March 1919 to September 1924). Discharge for period October 1930, to September 1931, estimated from discharge at new station on Thunder Creek below Colonial Creek. Maxiumm discharge during period of record, 9,720 second-feet, Dec. 12, 1921; minimum discharge during period of record, 50 second-feet (estimated), Feb. 1 to 10, 1929.

TABLE 14.—*Stetattle Creek near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	December	January	February	March	April
1914	37.8(19–31)	192	39	126	----------
1915	56.9	37.2	41	106	259

NOTE.—Staff gage in sec. 6, T. 37 N., R. 13 E., in Whatcom County, one-fourth mile above mouth, and 22½ miles by trail northeast of Marblemount; below all tributaries. Drainage area not measured. Records available, Dec. 19, 1913, to Mar. 31, 1914; Dec. 1, 1914, to May 5, 1915; fragmentary records during intervening time and afterward until Nov. 14, 1915. Maximum discharge during period of record, 1,800 second-feet, Jan. 6, 1914; minimum discharge during period of record, 23.6 second-feet Feb. 11–12, 1914.

TABLE 15.—*Cascade River below Marble Creek, near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1909						421	543	1,180	2,320	1,800	983	836	
1910	647	3,530	1,100	498	355	976	1,270	1,860	1,220	2,250	1,010	674	1,280
1911	2,560	2,270	816	446	275	376	516	1,350	3,130	2,380	1,080	848	1,340
1912	312	729	423	500	705	274	393	2,050	3,760	2,120	1,370	473	1,090
1913	324	626	350	278	382	326	738						
1913 [1]								1,500	2,700	2,200	1,100	870	950
1914 [1]	710	880	550	1,000	340	650	940	1,400	1,500	1,600	830	530	910
1915 [1]	530	1,300	520	260	210	360	920	710	680	930	900	410	650
1916 [1]	510	660	560	250	320	400	530	1,300	2,700	2,700	1,200	750	990
1917 [1]	340	460	280	260	340	220	350	1,300	2,100	2,300	980	600	800
1918 [1]	440	600	1,500	2,100	680	460	930	1,300	2,200	1,700	960	660	1,130
1919 [1]	660	640	1,000	600	380	280	910	1,600	2,100	2,600	1,200	630	1,0[illegible]0
1920 [1]	290	880	810	800	730	360	280	860	1,500	2,200	920	860	870
1921 [1]	1,500	770	570	640	850	650	580	1,600	2,800	2,000	1,100	720	1,1[illegible]0
1922 [1]	1,100	1,200	1,900	430	250	180	350	1,200	2,600	1,400	870	670	1,0[illegible]0
1923 [1]	530	460	610	730	310	320	910	1,500	2,100	2,000	890	550	910
1924 [1]	360	310	540	350	1,600	460	390	1,900	1,300	1,100	680	540	790
1925 [1]	750	840	1,700	600	890	490	1,000	2,100	1,800	1,500	790	440	1,0[illegible]0
1926 [1]	210	250	800	450	400	410	820	680	600	670	530	340	510
1927 [1]	730	490	630	460	300	300	530	1,100	2,400	1,500	880	970	8[illegible]0
1928 [1]	1,200	1,300	1,000	1,400	500	580	520	1,900	1,300	1,200	620	307	9[illegible]0
1929 [1]	755	342	261	165	120	257	419	1,270	1,540	995	575	208	590
1930 [1]	252	145	275	173	797	502	1,070	954	1,280	1,090	595	454	6[illegible]0
1931 [1]	524	391	289	660	525	560	696	1,370	1,450	912	457	611	700
Mean	690	870	750	590	510	430	680	1,390	1,960	1,700	890	610	920

[1] Estimated; see note below.

NOTE.—Staff gage 8 miles above Marblemount. Drainage area, 148 square miles. Records available, Mar. 8, 1909, to Apr. 30, 1913. Discharge for period May 1913 to August 1928, estimated by comparison with Skagit River below Ruby Creek; for period September 1928 to September 1931, by comparison with Cascade River at new station near mouth. Maximum discharge during period of record, 31,700 second-feet, Nov. 29, 1909; minimum discharge during period of record, 212 second-feet, Mar. 7, and Oct. 6, 1911.

TABLE 16.—*Cascade River near Marblemount*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1928												373	
1929	918	416	317	201	146	313	509	1,540	1,870	1,210	699	362	713
1930	307	176	335	210	969	610	1,300	1,160	1,560	1,330	724	552	766
1931	638	476	352	803	639	681	847	1,670	1,760	1,110	556	743	857
Mean	621	356	335	405	585	535	885	1,460	1,730	1,220	660	508	779

NOTE.—Water-stage recorder in SW¼ sec. 9, T. 35 N., R. 11 E., 2 miles east of Marblemount. Established Sept. 4, 1928, by the U.S. Geological Survey with funds provided by the War Department. Drainage area, 180 square miles. Records available, Sept. 4, 1928, to September 1931. Maximum discharge during period of record, 3,700 second-feet Jan. 27, 1931; minimum discharge during period of record, 140 second-feet Jan. 28 to Feb. 10, 1929.

TABLE 17.—*North Fork of Sauk River, near Barlow Pass*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							590	1,000	940	590	230	270	
1915 [1]	340	790	160	140	130	210	670	450	400	310	220	120	330
1916 [1]	340	370	440	110	460	440	500	850	1,600	1,200	500	260	590
1917 [1]	110	330	170	140	220	120	340	900	1,700	1,500	460	220	520
1918	132	254	1,290	757	283	238	565	831	1,450	663	308	175	581
1919	438	349	562	406	220	171	524	997	1,080	1,010	403	212	533
1920	121	571	565	698	391	244	234	594	882	738	307	643	499
1921	807	402											
1921 [1]			340	380	510	360	420	1,100	1,900	990	420	460	670
1922 [1]	590	610	1,100	180	120	120	290	950	1,500	560	280	230	550
1923 [1]	270	210	440	530	180	190	500	900	1,200	760	250	170	470
1924 [1]	200	310	520	290	760	170	270	1,100	770	440	220	210	440
1925 [1]	620	480	560	460	530	210	550	1,300	1,200	700	230	130	580
1926 [1]	150	180	600	340	340	240	410	600	460	260	180	240	330
1927 [1]	570	340	340	250	290	170	390	950	1,800	860	320	560	570
1928 [1]	700	1,100	480	680	180	340	360	1,200	940	540	180	150	570
1929 [1]	440	210	190	100	60	160	270	1,000	1,200	580	210	110	380
1930 [1]	100	90	260	110	590	240	640	660	790	440	150	120	350
1931 [1]	230	190	170	450	330	360	490	1,000	1,100	440	130	210	420
Mean	360	400	480	350	330	230	450	910	1,160	700	280	250	490

[1] Estimated; see note below.

NOTE.—Water-stage recorder in sec. 14, T. 30 N., R. 11 E., 2¼ miles above junction with South Fork, and 7 miles northeast of Barlow Pass. Drainage area, 76 square miles. Records available, Oct. 1, 1917, to Dec. 9, 1920. Discharge for periods April 1914 to September 1917 and December 1920 to September 1931 estimated by comparison with Sauk River above Whitechuck River on basis of 3 years comparative records. Maximum discharge during period of record, 11,000 second-feet, Dec. 29, 1917. Minimum discharge during period of record, 75 second-feet, Oct. 20, 1917.

TABLE 18.—*Sauk River above Whitechuck River, near Darrington*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							1,400	2,000	1,700	1,100	440	530	
1915 [1]	820	1,800	400	360	350	620	1,600	890	720	570	420	230	730
1916 [1]	840	840	1,100	280	1,200	1,300	1,200	1,700	2,900	2,300	940	500	1,260
1917 [1]	280	760	430	380	570	350	820	1,800	3,100	2,800	860	430	1,050
1918	421	545	3,510	2,160	954	732	1,290	1,570	2,390	1,230	680	323	1,320
1919	1,130	978	1,580	1,190	591	572	1,280	2,080	2,120	1,970	770	384	1,230
1920	260	1,430	1,200	1,560	827	603	555	1,200	1,680	1,310	508	1,500	1,050
1921	1,770	743	841	1,010	1,350	1,060	1,000	2,200	3,400	1,830	784	911	1,410
1922	1,430	1,390	2,660	464	321	340	692	1,900	2,680	1,030	529	458	1,160
1923 [1]	660	480	1,100	1,400	480	550	1,200	1,800	2,100	1,400	480	330	1,000
1924 [1]	490	710	1,300	770	2,000	510	640	2,100	1,400	820	410	420	960
1925 [1]	1,500	1,100	1,400	1,200	1,400	610	1,300	2,600	2,100	1,300	440	260	1,270
1926 [1]	360	420	1,500	890	900	700	970	1,200	830	490	340	480	760
1927 [1]	1,400	770	860	670	770	500	920	1,900	3,200	1,600	600	1,100	1,190
1928 [1]	1,700	2,400	1,200	1,800	480	1,000	860	2,400	1,700	1,000	340		
1928												288	1,270
1929	1,070	482	468	250	167	481	654	2,020	2,150	1,070	392	217	790
1930	240	210	657	284	1,540	700	1,520	1,310	1,430	809	291	239	763
1931	564	424	433	1,180	869	1,060	1,160	2,020	1,980	819	251	416	931
Mean	880	910	1,210	930	870	690	1,060	1,820	2,090	1,300	520	500	1,070

[1] Estimated; see note below

NOTE.—Water-stage recorder in NW¼ sec. 24, T. 31 N., R. 10 E., 1½ miles above mouth of Whitechuck River, and 9½ miles southeast of Darrington. Established Oct. 1, 1917, by the U.S. Geological Survey, and maintained until Sept. 30, 1922. Reestablished Aug. 17, 1928, by the U.S. Geological Survey, with funds provided by the War Department. Drainage area, 152 square miles. Records available Oct. 1, 1917, to Sept. 30, 1922, and Aug. 17, 1928, to Sept. 30, 1931. Discharge for periods April 1914 to September 1917 and October 1922 to August 1928 estimated by comparison with Sauk River at Darrington. Maximum discharge during period of record, 23,000 second-feet, Dec. 12, 1921. Minimum discharge during period of record, 146 second-feet, Sept. 25, 1930.

TABLE 19.—*Sauk River above Clear Creek, near Darrington*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1910	------	------	------	------	------	------	------	------	------	------	------	523	------
1911	3,100	4,470	2,860	1,490	660	901	1,250	2,590	4,030	2,410	952	948	2,140
1913	------	------	------	957	1,060	807	1,400	4,640 (23–28)	5,460 (3–19)	3,760	1,580	1,610	------

NOTE.—Staff gage in the SW¼ of sec. 31, T. 32 N., R. 10 E., just above mouth of Clear Creek, and about 2½ miles above Darrington. Drainage area, 259 square miles. Records available, Aug. 28, 1910, to Sept. 30, 1913 (fragmentary). Maximum discharge recorded during period of record, 12,500 second-feet, Sept. 4 1913; minimum discharge recorded during period of record, 350 second-feet, Oct. 5, Oct. 25–27, 1911.

TABLE 20.—*Sauk River, at Darrington*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]	------	------	------	------	------	------	2,600	3,400	2,900	------	------	------	------
1914	------	------	------	------	------	------	------	------	------	2,010	876	1,020	------
1915	1,570	3,820	841	755	739	1,190	3,030	1,510	1,220	1,020	844	449	1,410
1916	1,620	1,760	2,340	586	2,490	2,590	2,140	2,900	4,870	4,100	1,880	962	2,350
1917	541	1,590	893	795	1,190	679	1,520	3,110	5,240	5,050	1,710	836	1,930
1918	632	1,130	7,430	4,430	1,970	1,560	2,070	2,570	4,050	2,210	1,270	665	2,519
1919	2,390	2,100	3,350	2,830	1,790	1,490	2,980	3,870	3,860	3,450	1,640	747	2,550
1920	582	2,960	2,710	2,830	1,500	1,130	1,030	2,080	2,770	2,290	999	2,690	1,960
1921	3,500	1,590	1,750	2,080	2,430	1,740	1,630	3,490	5,640	3,050	1,350	1,440	2,470
1922	2,640	2,680	4,510	808	531	479	1,240	3,140	4,410	1,880	980	920	2,030
1923	1,260	996	2,360	2,990	1,010	1,060	2,150	2,980	3,490	2,560	963	641	1,880
1924	938	1,470	2,640	1,600	4,210	984	1,190	3,560	2,440	1,460	821	817	1,830
1925	2,870	2,360	2,860	2,590	2,980	1,170	2,340	4,350	3,490	2,320	881	506	2,390
1926	691	865	3,180	1,860	1,870	1,340	1,790	2,110	1,400	874	672	929	1,460
1927 [1]	2,600	1,500	1,800	1,400	1,600	960	1,700	3,300	5,400	2,800	1,200	2,200	2,210
1928 [1]	3,200	5,100	2,400	3,700	1,000	2,000	1,600	4,000	2,800	------	------	------	------
1928	------	------	------	------	------	------	------	------	------	1,830	684	470	2,410
1929	1,930	1,040	1,030	590	377	1,110	1,320	3,450	3,750	1,860	779	420	1,480
1930	497	417	1,320	651	3,890	1,440	2,870	2,220	2,500	1,600	689	507	1,530
1931	1,120	855	919	2,360	1,670	2,220	2,220	3,400	3,390	1,540	609	1,020	1,780
Mean	1,680	1,900	2,490	1,930	1,840	1,360	1,970	3,080	3,530	2,330	1,050	960	2,010

[1] Estimated; see note below.

NOTE.—Staff gage in SE¼ sec. 24, T. 32 N., R. 9 E., ½ mile southeast of Darrington. Established June 15, 1914, by the U.S. Geological Survey and maintained until Oct. 15, 1926. Reestablished June 22, 1928, by the U.S. Geological Survey with funds provided by the War Department. Drainage area, 293 square miles. Records available, June 15, 1914, to Oct. 15, 1926, and June 22, 1928, to Sept. 30, 1931. Discharge prior to July 1914 and for period October 1926 to June 1928 estimated by comparison with discharge of South Fork of Skykomish River near Index. Maximum discharge during period of record, 36,000 second-feet, Dec. 29, 1917, and Dec. 12, 1921. Minimum discharge during period of record, 262 second-feet, Sept. 25, 1930.

TABLE 21.—*Sauk River near town of Sauk (1911–12)*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1911	------	------	------	------	------	2,420	2,690	5,500	8,520	5,630	2,360	2,350
1912	1,100	5,320	3,170	4,000	4,430	1,520	2,410	6,760	9,580	5,180	------	------

NOTE.—Chain gage in sec. 13, T. 34 N., R. 9 E., 4 miles above town of Sauk. Drainage area, 716 square miles. Records available, Mar. 3, 1911, to Aug. 3, 1912. Also, fragmentary records from Aug. 27, 1910, to Oct. 24, 1910, for other gages in this vicinity which were successively washed away; these records are not included here but may be found in U.S. Geological Survey Water Supply Paper No. 292. See also table 22 for records of subsequent station nearby. Maximum discharge during period of record, 20,500 second-feet, Nov. 19, 1911; minimum discharge duing period of record, 780 second-feet, Oct. 30 to Nov. 3, 1911.

TABLE 22.—*Sauk River near town of Sauk*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							5,000	6,800	6,300	5,000	2,500	2,700	
1915 [1]	3,000	7,200	1,500	1,500	1,400	2,300	5,800	3,000	2,600	2,500	2,400	1,200	2,900
1916 [1]	3,100	3,300	4,300	1,200	4,600	4,900	4,100	5,800	11,000	10,000	5,500	2,600	5,000
1917 [1]	1,000	3,000	1,600	1,600	2,200	1,300	2,900	6,200	11,000	12,000	5,000	2,200	4,200
1918 [1]	1,200	2,100	14,00	8,900	3,700	3,000	4,000	5,100	8,700	5,500	3,700	1,800	5,200
1919 [1]	4,500	3,900	6,100	5,700	3,300	2,800	5,700	7,700	8,300	8,500	4,800	2,000	5,300
1920 [1]	1,100	5,600	5,000	5,700	2,800	2,100	2,000	4,200	6,000	5,700	2,900	7,200	4,200
1921 [1]	6,600	3,000	3,200	4,200	4,500	3,300	3,100	7,000	12,000	7,500	3,900	3,900	5,200
1922 [1]	5,000	5,000	8,300	1,600	990	910	2,400	6,300	9,500	4,600	2,800	2,500	4,200
1923 [1]	2,400	1,900	4,300	6,000	1,900	2,000	4,100	6,000	7,500	6,300	2,800	1,700	3,900
1924 [1]	1,800	2,800	4,800	3,200	7,800	1,900	2,300	7,100	5,300	3,600	2,400	2,200	3,800
1925 [1]	5,400	4,400	5,200	5,200	5,500	2,200	4,500	8,700	7,500	5,700	2,600	1,400	4,900
1926 [1]	1,300	1,600	5,800	3,700	3,500	2,500	3,400	4,200	3,000	2,200	1,900	2,500	3,000
1927 [1]	4,900	3,000	3,300	2,800	3,000	1,800	3,200	6,600	12,000	6,900	3,500	5,900	4,700
1928 [1]	6,000	9,600	4,400	7,400	1,900	3,800	3,100	8,000	6,000	4,500			
1928											2,000	1,410	4,900
1929	3,490	1,980	1,930	1,280	793	2,030	2,630	6,650	7,810	4,450	2,210	1,220	3,050
1930	993	724	2,290	1,310	5,620	2,960	5,260	4,580	5,670	4,130	1,960	1,400	3,050
1931	2,090	1,700	1,740	4,300	3,390	4,050	4,250	6,830	7,230	3,700	1,820	2,150	3,600
Mean	3,200	3,600	4,600	3,900	3,300	2,600	3,800	6,200	7,600	5,700	3,000	2,600	4,200

[1] Estimated, see note below.

NOTE.—Water-stage recorder in sec. 19 T. 34 N R. 10 E., Willamette Meridian, 5 miles southeast of town of Sauk. Established July 24, 1928, by the U.S. Geological Survey with funds provided by the War Department. Drainage area, 714 square miles. Records available, July 24, 1928, to Sept. 30, 1931. Discharge for period April 1914 to July 1928 estimated by comparison with yield of Sauk River at Darrington Maximum discharge during period of record, 21,800 second-feet, Jan .28, 1931. Minimum discharge during period of record, 578 second-feet, Dec. 4, 1930.

TABLE 23.—*South Fork Sauk River near Barlow Pass*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							350	500	440	310	130.0	160.0	
1915 [1]	250	540.0	110	90.0	80.0	160	400	220	190	160	130.0	70.0	200
1916 [1]	250	250.0	310	70.0	260.0	320	300	420	750	640	280.0	150.0	330
1917 [1]	80	230.0	120	100.0	130.0	90	200	450	810	780	260.0	130.0	280
1918	118	202.0	963	498.0	213.0	176	322	376	575	322	209.0	93.5	340
1919	373	238.0	459	313.0	126.0	136	377	654	620	517	203.0	102.0	345
1920	70	480.0	291	431.0	163.0	134	126	291	410	326	133.0	487.0	278
1921	480	202.0	192	228.0								294.0	
1921 [1]					300.0	260	250	550	880	510	240.0		370
1922 [1]	430	420.0	740	120.0	70.0	80	170	480	700	290	160.0	140.0	320
1923 [1]	200	140.0	310	350.0	110.0	140	300	450	550	390	140.0	100.0	270
1924 [1]	150	210.0	360	190.0	440.0	130	160	520	360	230	120.0	130.0	250
1925 [1]	450	330.0	390	300.0	310.0	150	320	650	550	360	130.0	80.0	340
1926 [1]	110	130.0	420	220.0	200.0	180	240	300	220	140	100.0	140.0	200
1927 [1]	420	230.0	240	170.0	170.0	120	230	480	830	450	180.0	330.0	320
1928 [1]	510	720.0	340	450.0	110.0	250	220	600	440	280	100.0	90.0	340
1929 [1]	320												
1929		159.0	149	62.9	30.8	129	162	454	578	335	133.0	49.5	210
1930	75	59.2	195	72.7	475.0	195	376	317	351	233	90.3	82.2	208
1931	204	135.0	121	493.0	393.0	430	296	468	503	218	105.0	180.0	295
Mean	260	280.0	340	240.0	210.0	180	270	450	540	360	160.0	160.0	290

[1] Estimated; see note below.

NOTE.—Water-stage recorder in NE¼ sec. 27, T. 30 N., R. 11 E., Willamette meridian, 2¾ miles above junction with North Fork and 5 miles northeast of Barlow Pass. Established Oct. 1, 1917, by the U.S. Geological Survey, and maintained until Oct. 16, 1921. Reestablished Oct. 19, 1928, by the U.S. Geological Survey with funds provided by the War Department. Drainage area, 32.7 square miles. Records available, Oct. 1, 1917, to Feb. 8, 1921; Aug. 20, 1921, to Oct. 16, 1921; Oct. 19, 1928, to Sept. 30, 1931. Monthly discharge for periods April 1914 to September 1917; February 1921 to August 1921; October 1921 to October 1928, estimated by comparison with discharge of Sauk River above Whitechuck River. Maximum discharge during period of record, 5,800 second-feet, Dec. 29, 1917. Minimum discharge during period of record, 18 second-feet, Sept. 30, 1929.

TABLE 24.—*Whitechuck River near Darrington*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1914 [1]							580	840	740	780	400	390	
1915 [1]	330	570	190	160	160	290	730	490	420	520	440	260	380
1916 [1]	430	290	280	120	360	400	450	710	1,200	1,200	610	440	540
1917 [1]	200	230	130	140	220	150	330	820	1,100	1,300	520	390	460
1918 [1]	300	350	830	1,000	340	300	560	720	1,100	890	460	410	610
1919 [1]	480	290	450	290	210	190	560	900	800	960	470	360	500
1920 [1]	150	500	380	430	350	240	250	520	760			650	470
1920										950	488		
1921	679	323	278	306	366	300	300	727	1,410	946	591	362	550
1922	461	438											
1922 [1]			700	140	100	110	260	730	1,100	800	460	510	490
1923 [1]	410	200	320	360	190	220	550	800	950	930	420	410	480
1924 [1]	280	170	280	250	840	290	340	1,000	750	670	380	390	470
1925 [1]	470	320	580	250	460	270	570	1,100	1,000	870	390	310	550
1926 [1]	190	130	450	260	270	300	690	630	760	750	390	260	420
1927 [1]	690	310	300	240	180	190	370	600	1,100	800	460	520	480
1928 [1]	660	600	430	750	250	330	340	1,200	870	850	360	350	580
1929 [1]	590	220	150	100	80	180	270	860	920	650	360	280	390
1930 [1]	220	90	150	110	520	340	720	600	730	650	340	370	400
1931 [1]	340	210	140	430	290	390	480	920	1,000	670	310	450	470
Mean	410	310	360	310	310	260	460	790	930	840	440	400	480

[1] Estimated; see note below.

NOTE.—Water-stage recorder in NW¼ sec. 16, T. 31 N., R. 11 E., 4½ miles above junction with Sauk River and 11 miles southeast of Darrington. Drainage area, 75 square miles. Records available, Oct. 19, 1919, to Dec. 12, 1921 (fragmentary). Discharge for periods April 1914 to June 1920; September 1920 and December, 1921 to September 1931 estimated by comparison with Baker River below Anderson Creek and with Thunder Creek. Maximum discharge during period of record, 4,540 second-feet, Dec. 12, 1921 Minimum discharge during period of record, 111 second-feet, Nov. 4–14, 1919.

TABLE 25.—*Clear Creek near Darrington*

[Natural discharge, in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1910												27.8
1911	558			132	44.1	179	230	424	301	91.8	30.7	199.0

NOTE.—Staff gage in sec. 31, T. 32 N., R. 10 E., at the ranger station at mouth of creek, 2½ miles southeast of Darrington. Drainage area, about 30 square miles. Records available, Aug. 28, 1910, to Dec. 19, 1911 (fragmentary). Maximum discharge during period of record, 4,900 second-feet, Nov. 21, 1910; minimum discharge during period of record, 2 second-feet, Aug. 8, 1911.

TABLE 26.—*Suiattle River below Lime Creek, near Darrington*

[Natural discharge, in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1921	1,490	802	690	744	924	775	741	1,840	3,380	2,390	1,410	827	1,340
1922	1,020 [1]												

NOTE.—Water-stage recorder in sec. 18, T. 32 N., R. 12 E. (unsurveyed) ½ mile below Lime Creek and 14 miles east of Darrington. Drainage area, 213 square miles. Records available, Oct. 1, 1920, to Nov. 11, 1921. Maximum discharge during period of record, 5,890 second-feet, June 7, 1921. Minimum discharge during period of record, 469 second-feet, Feb. 6, 1921.

TABLE 27.—*Baker River below Anderson Creek, near Concrete*

[Natural discharge in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1911	3,400	3,500	1,900	909	503	943	1,380	2,660	4,040	3,710	2,060	1,930	2,250
1912	926	1,970	1,440	1,610	1,920	736	1,160	2,830	4,140	2,980	2,190	1,370	1,940
1913	1,120	2,360	936	688	1,190	764	1,830	3,830	5,030	4,690	2,330	1,590	2,200
1914	1,790	2,170	1,090	2,720	962	1,560	1,900	3,010	2,690	2,590	1,610	1,610	1,970
1915	1,810	2,800	777	884	856	1,300	3,040	1,990	1,800	1,900	1,810	893	1,660
1916	2,340	1,380	1,710	633	2,330	2,080	1,940	2,430	3,920	3,650	2,490	1,350	2,190
1917	730	1,270	713	734	1,050	632	1,470	3,250	4,490	4,960	2,230	1,400	1,910
1918	1,320	2,100	5,230	5,280	1,240	1,180	1,800	2,460	4,080	3,080	1,850	1,400	2,610
1919	2,300	1,430	2,410	1,370	977	790	1,960	3,100	2,910	3,350	1,890	1,130	1,980
1920	603	2,650	2,090	2,290	1,370	980	998	1,910	3,160	3,170	1,740	3,030	2,000
1921	3,510	1,470	1,490	1,450	2,230	1,360	1,400	2,880	5,050	3,110	2,020	2,240	2,350
1922	3,350	2,050	3,070	604	465	471	1,100	2,700	4,290	2,540	1,830	1,790	2,030
1923	1,820	922	1,840	1,580	732	847	1,830	2,700	3,340	2,990	1,500	1,300	1,790
1924	1,000	952	1,590	1,470	3,310	1,110	1,360	3,460	2,720	2,010	1,510	1,480	1,830
1925	2,510	1,650	3,260	1,360	2,220	1,110	2,030	3,860	3,280	2,730	1,550	927	2,210
1926 [1]	830	690	2,500	1,300	1,200	1,200	2,600	2,200	2,700	2,400	1,500	840	1,670
1927 [1]	2,900	1,600	1,700	1,200	790	780	1,400	2,100	4,100	2,600	1,800	1,700	1,890
1928 [1]	2,800	3,100	2,400	3,800	1,100	1,300	1,300	4,100	3,100	2,700	1,400		
1928												1,030	2,350
1929	2,430	1,260	960	558	387	883	1,140	3,070	3,370	2,120	1,390	832	1,540
1930	924	462	1,140	620	2,290	1,340	2,450	2,190	2,700	2,110	1,280	1,190	1,550
1931	1,460	1,140	935	2,540	1,250	1,820	1,960	2,960	3,660	2,050	1,070	1,750	1,880
Mean	1,900	1,760	1,870	1,600	1,350	1,100	1,720	2,840	3,550	2,930	1,760	1,470	1,990

[1] Estimated; see note below.

NOTE.—Staff gage prior to Sept. 24, 1915; water-stage recorder thereafter, in SE¼ sec. 30, T. 37 N., R. 9 E., 350 feet below Anderson Creek, 11 miles northeast of town of Concrete. Established Sept. 10, 1910, by the U.S. Geological Survey and maintained until Oct. 3, 1925. Reestablished Aug. 31, 1928, by the U.S. Geological Survey with funds provided by the War Department. Drainage area, 184 square miles Records available, Sept. 10, 1910, to Oct. 3, 1925; Aug. 31, 1928, to Sept. 30, 1931. Discharge for period October 1925 to August 1928 estimated by comparison with yield of Thunder Creek. Maximum discharge for period of record, 36,800 second-feet, Dec. 29, 1917. Minimum discharge for period of record, 219 second-feet, Dec. 15–16, 1919.

TABLE 28.—*Baker River at Concrete*

[Natural discharge, in second-feet]

Year ending Sept. 30—	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Mean for year
1911	4,560	4,630	2,560	1,420	736	1,280	1,630	3,210	4,470	3,770	2,170	2,550	2,760
1912	1,260	3,060	1,740	2,260	2,680	992	1,380	3,460	4,570	2,980	2,100	1,250	2,310
1913	1,360	3,080	1,800	980	1,740	1,230	1,970	3,540	5,610	5,030	2,630	2,320	2,610
1914	2,690	2,990	1,160	3,370	1,050	2,280	2,740	3,280	2,950	2,740	1,730	1,780	2,400
1915	2,190	3,260	1,010	1,280	1,070								
1915 [1]						1,900	3,700	2,200	2,000	2,000	1,900	1,100	2,000
1916 [1]	3,100	1,900	2,300	900	3,100	3,000	2,400	2,700	4,400	3,800	2,600	1,600	2,600
1917 [1]	960	1,700	980	1,000	1,400	910	1,800	3,600	5,000	5,200	2,300	1,700	2,200
1918 [1]	1,700	2,800	7,200	7,500	1,600	1,700	2,200	2,700	4,500	3,200	1,900	1,700	3,200
1919 [1]	3,100	1,900	3,300	1,900	1,300	1,100	2,400	3,400	3,200	3,500	2,000	1,400	2,400
1920 [1]	800	3,600	2,900	3,300	1,800	1,400	1,200	2,100	3,500	3,300	1,800	3,600	2,400
1921 [1]	4,600	2,000	2,000	2,100	3,000	2,000	1,700	3,200	5,600	3,200	2,100	2,700	2,800
1922 [1]	4,400	2,800	4,200	860	620	680	1,300	3,000	4,800	2,600	1,900	2,100	2,400
1923 [1]	2,400	1,200	2,500	2,200	970	1,200	2,200	3,000	3,700	3,100	1,600	1,600	2,100
1924 [1]	1,300	1,300	2,200	2,100	4,400	1,600	1,700	3,800	3,000	2,100	1,600	1,800	2,200
1925 [1]	3,300	2,200	4,500	1,900	3,000	1,600	2,500	4,300	3,600	2,800	1,600	1,100	2,700
1926 [1]	1,100	930	3,400	1,800	1,600	1,700	3,200	2,400	3,000	2,500	1,600	1,000	2,000
1927 [1]	3,800	2,200	2,300	1,700	1,100	1,100	1,700	2,300	4,600	2,700	1,900	2,000	2,300
1928 [1]	3,700	4,000	3,300	5,400	1,500	1,900	1,600	4,800	3,400	2,800	1,500	1,200	2,900
1929 [1]	3,200	1,700	1,300	790	510	1,300	1,400	3,400	3,700	2,200	1,500	1,000	1,800
1930 [1]	1,200	620	1,600	880	3,000	1,900	3,000	2,400	3,000	2,200	1,300	1,400	1,900
1931 [1]	1,900	1,500	1,300	3,600	1,700	2,600	2,400	3,300	4,100	2,100	1,100	2,100	2,300
Mean	2,500	2,400	2,600	2,200	1,800	1,600	2,100	3,100	3,900	3,000	1,800	1,800	2,400

[1] Estimated; see note below.

NOTE.—Staff gage in NW¼ sec. 11, T. 35 N., R. 8 E., at highway bridge at Concrete, ¼ mile above mouth of river. Drainage area, 270 square miles. Records available, Sept. 11, 1910, to Mar. 4, 1915. Discharge for period March 1915 to September 1931 estimated from discharge of Baker River below Anderson Creek. Maximum discharge during period of record, about 31,000 second-feet, Jan. 6, 1914; minimum discharge during period of record, 634 second-feet, Jan. 22–23, 1913.

48. *Cities and population.*—The population within the Skagit Basin is about 22,800 (1930 census), an average density of 7 to the square mile, about 80 percent of whom reside west of Sedro Woolley. The 170 square miles of the basin lying west of Sedro Woolley has a population of 17,300, or a density of 102 to the square mile. East of Sedro Woolley, area 2,970 square miles, the population is about 5,500, or 2 persons to the square mile. There are six incorporated towns or cities in the basin, all of them below the mouth of the Sauk. Mount Vernon is the county seat. These six towns are:

	Population		Population
Burlington	1, 407	Lyman	441
Concrete	736	Mount Vernon	3, 690
Hamilton	252	Sedro Woolley	2, 719

49. La Conner, with a population of 549, is located within the broadly defined delta area, although strictly speaking it is just outside the drainage basin proper. Everett, population 30,567, and Seattle, population 365,583, 38 miles and 66 miles, respectively, to the southward of Mount Vernon, and Bellingham, population 30,823, 28 miles to the northward, are the principal nearby cities.

50. *Railways.*—The coast line of the Great Northern Railway between Everett, Wash., and Vancouver, British Columbia, crosses the western end of the Skagit Valley in a north-and-south direction for a distance of 14 miles, passing through Mount Vernon and Burlington; and a branch line runs westward from Burlington to Anacortes, 16 miles, partly within the Skagit Basin, and eastward from Burlington to Rockport, 37 miles, paralleling the river. From Rockport a private railroad, owned and operated by the city of Seattle for construction purposes, continues on up the river to the Diablo Dam, a distance of 30 miles.

51. The Northern Pacific Railway between Seattle, Wash., and Vancouver, British Columbia, also crosses the western end of the valley a few miles eastward of the Great Northern, passing through Sedro Woolley. A branch line extends into Darrington from the Stillaguamish Valley.

52. The Pacific Northwest Traction Co., which is affiliated with the Puget Sound Power & Light Co., has an electric interurban line between Mount Vernon and Bellingham. Passenger service between these points was discontinued in October 1928. Service on this line is now restricted to occasional freight haulage between Burlington and Mount Vernon. It is understood that the line is entirely out of commission in Bellingham.

53. The Puget Sound & Cascade River Railway parallels the south bank of the river from Mount Vernon to Finney Creek, a distance of 28 miles, while the Puget Sound & Baker River Railway follows the north bank from Sedro Woolley to near Concrete, and thence by means of switchbacks crosses over the divide and down into the Nooksack Basin to the northward. Under State law both of these railways are common carriers, but are operated almost exclusively for the transportation of logs. There are several other logging railways in the basin that are not common carriers. The most important are those which extend up the Sauk River from a point near its mouth to a point about 20 miles above the town of Darrington. Branch lines also extend up the Suiattle and Whitechuck for considerable distances.

54. *Highways.*—The Pacific Highway, the principal thoroughfare of the Pacific Coast States, crosses the western end of the Skagit Valley in a general north-and-south direction for a distance of 14 miles, paralleling the Great Northern Railway, passing through Mount Vernon and Burlington. Other paved highways aggregating about 70 miles in length, as well as numerous gravel and improved dirt roads, lie within the basin and lead to some of the outlying sections. From Mount Vernon a paved highway parallels the river upstream as far as Hamilton, 22 miles; thence, a good gravel road continues through Concrete, 34 miles, to Rockport, 44 miles, Marblemount, 52 miles, and up Cascade River to Marble Creek, 60 miles, all mileages being measured from Mount Vernon. Above Marblemount on the main Skagit River, present transportation is afforded principally by the City of Seattle Railroad as far as the Gorge and Diablo plants of the Skagit power project, a total distance of 74 miles above Mount Vernon.

55. *National and departmental reservations.*—Portions of two national forests—Mount Baker and Snoqualmie—lie within and comprise two thirds of the Skagit Basin, their respective areas within the basin being 1,800 and 300 square miles. There are no other reservations involved.

56. *Resources and local industries.*—Agriculture and allied industries: Farming, with its allied pursuits of dairying, poultry raising, and vegetable growing is the principal industry of the Skagit Basin, followed in importance by lumbering and cement making.

57. The delta of the river—that is, the lowlands lying west of Sedro Woolley, 59,000 acres in extent—contains some of the richest and most productive farming land in the State. Although the farms above Sedro Woolley are small and lie close to the rivers, yet the total as classed by the 1930 census amounts to about 24,000 acres. The uplands are either rocky or covered with glacial drift and are more valuable for forestation than for agriculture.

58. Oats and vegetable seed, the principal crops produced in the Delta area, are estimated to have a combined value of $3,500,000 annually. It is stated that 85 percent of the cabbage seed, 50 percent of the garden-beet seed, and 30 percent of the turnip and rutabaga seed used in the United States is grown in the Skagit delta.

59. The dairying industry in Skagit County (which is not exactly coextensive with the Skagit drainage basin, being somewhat larger) is estimated to have an annual output valued at $3,500,000. An important outlet for much of the production is afforded by two large milk-condensing plants at Mount Vernon and one at Burlington, but the form in which the milk products are shipped varies with market conditions. Up to 1927 most of the milk was shipped as canned milk, milk powder, or butter. Following 1927, due to the growth of Seattle and other Puget Sound cities, combined with the increasing ease of motor freight transportation, milk has been shipped in varying amounts in the raw or pasteurized state, at times to such an extent as materially to affect the output of the condensaries. Another item of growing importance in the dairying industry, due to the excellent breed of the herds in the Skagit Valley, is the shipment of milch cows to California and the Hawaiian Islands.

60. The poultry industry in Skagit County is estimated to have a productive value of $1,250,000 net annually. According to United

States census returns for 1930, the production of eggs increased from 774,000 dozen in 1919 to over 3,000,000 dozen in 1929, and the chickens raised increased from 144,000 to 462,000 in the same period. This increase comes not from large flocks, but from relatively small ones, and probably will be still further increased as the larger farms are subdivided into smaller holdings.

61. There are two fruit and vegetable canneries located in the valley, one of which alone in 1930 canned about one third of the vegetables packed in the State of Washington, and three others located in adjoining areas which draw upon the valley for part of their raw material. The combined output for 1930 of the two canneries located in the valley was valued at about $460,000 and was as follows:

	Pounds		*Pounds*
Blackberries	655, 000	Beets	1, 084, 000
Loganberries	51, 000	Carrots	189, 000
Raspberries	261, 000	Pumpkin	120, 000
Strawberries	570, 000	Pole beans	409, 000
Cherries	390, 000	Bush beans	403, 000
Apples (not locally grown)	2, 315, 000	Spinach	113, 000
Pears (not locally grown)	93, 000	Sauer-kraut	896, 000
Peas	4, 468, 000		

62. *Forest resources.*—No thoroughly reliable estimates have ever been made of the forest resources of the Skagit Basin. Hugo Winkenwerder, dean of the College of Forestry, University of Washington, has prepared a brief report on the subject for this office. His report, together with data collected from all other known sources of pertinent information, has been used in the preparation of the matter contained in table no. 29 and the subsequent discussion.

TABLE No. 29.—*Standing timber in the Skagit River drainage area*

[Million feet board measure]

Ownership	Douglas fir	Cedar	All other kinds	Total stand
United States (national forest)	1, 700	1, 600	4, 200	7, 500
Private	3, 500	1, 300	2, 000	6, 800
State	200	100	100	400
Total	5, 400	3, 000	6, 300	14, 700

63. Estimates of the national forest include timber up to an elevation of about 5,000 feet, although it is realized that much of this timber cannot be profitably marketed for years to come, owing to the composition of the stand and its relative inaccessibility. In the national forest the valleys of the Skagit river and its tributaries are for the most part narrow with steep slopes and present rather unfavorable conditions for logging. The privately owned and State timber is accessible and can be brought to market without unusual difficulty.

64. In 1931 the daily capacity of logging companies operating within the Skagit Basin amounted to 2½ million feet board measure. Due to the periodic activity of the logging industry, it is difficult to obtain dependable figures on the annual cut of logs, but it is believed to be between 250 and 300 million feet board measure. An estimate of the acreage logged within the Skagit Basin for the period March 1, 1919, to March 1, 1931, is given in table no. 30. This estimate was

derived from a tabulation of acreage logged in Skagit County, prepared by Porteous & Co., forest engineers, Seattle, Wash.

TABLE No. 30.—*Acreage logged in Skagit County and Skagit Basin*

Period	Acreage logged in Skagit County	Estimated acreage logged in Skagit Basin
From Mar. 1, 1919 to Mar. 1, 1923	27,880	18,587
From Mar. 1, 1923 to Mar. 1, 1924	11,840	7,892
From Mar. 1, 1924 to Mar. 1, 1925	10,370	6,914
From Mar. 1, 1925 to Mar. 1, 1926	7,350	4,900
From Mar. 1, 1926 to Mar. 1, 1927	9,360	6,241
From Mar. 1, 1927 to Mar. 1, 1928	10,400	6,933
From Mar. 1, 1928 to Mar. 1, 1929	7,756	5,171
From Mar. 1, 1929 to Mar. 1, 1930	6,440	4,294
From Mar. 1, 1930 to Mar. 1, 1931	5,918	3,946
Total	97,314	64,878

65. With the exception of lumber cut at Clear Lake, Lyman, and Sedro Woolley by mills having a combined daily capacity of 385,000 feet b.m., practically all lumber is cut on tidewater since the principal markets are largely reached by water shipment. It is probable that the greater part of the timber in Skagit Basin will be taken out by logging railroads. A portion of it will be transferred to the Skagit River at points below Marblemount and thence shipped to mills on Puget Sound. Due to the relatively low towing charges, pulp and paper mills at Anacortes, Everett, Bellingham, Port Angeles, and many other points on Puget Sound, are potential markets for the pulpwood resources of Skagit Basin. With the further development of power on the Skagit, there is a possibility of construction of pulp and paper mills in the lower Skagit Valley.

66. There are about 570,000 acres of standing timber and about 190,000 acres that should be reforested in the Skagit Basin. Most of the State and privately owned timber and part of the national forest is so situated that a merchantable crop of timber can be regrown in about 80 years, but the reproduction of a forest in the higher elevations of the national forest is a matter of centuries rather than decades. Table no. 31 gives the estimated annual yield of the national forest in Skagit Basin which is being developed on a sustained yield basis insuring perpetual productivity.

TABLE 31.—*Sustained yield of national forest in Skagit Basin*

Basin	Estimated annual yield in feet board measure	Basin	Estimated annual yield in feet board measure
Sauk River	25,000,000	Baker River	30,000,000
Suiattle River	25,000,000	Total	150,000,000
Cascade River	20,000,000		
Main Skagit and small tributaries	50,000,000		

67. Unfortunately, the private lands are not as yet handled in a satisfactory way to secure permanent productivity, but a gradual im-

provement appears to be under way in this respect. If the private lands are ever put on a sustained yield basis, they would be capable of yielding approximately 225,000,000 feet b.m. annually. The growth of the pulp and paper industry, box and container industry, and others using small-size material, will result in a large increase in the output from the forests of the Skagit Basin in addition to the above amounts which are based on sawed timber yields.

68. *Mineral resources.*—Information about the mineral resources of the Skagit Basin is meager. The various publications of the geological surveys of the United States and of the State of Washington, together with a brief summary prepared for this office by Joseph Daniels, Milnor Roberts, and Hewitt Wilson, all of the College of Mines of the University of Washington, have been freely drawn upon for the following subject matter.

69. Prospecting has been carried on intermittently in this region since about 1863, and, while some gold and small amounts of other minerals have been produced, there are no producing mines in operation at the present time with the exception of those near Concrete yielding cement materials. Poor transportation facilities and also an overlying mantle of gravel, sand, and glacial drift, have been serious obstacles to prospecting and mining development. Faulting is very common in the great complex of igneous and metamorphic rocks which make up the Cascade Mountains, and in the development work of many properties the search for the ore body after encountering a fault has been costly, and generally without favorable results.

70. Many minerals are reported as having been found in the Skagit drainage basin; but, with the exception of cement materials, sand and gravel, none of them have as yet been found in paying quantities, although so little development work has been done in connection with the others that no opinion can be expressed as to their ultimate possibilities. Those minerals reported as occurring in the basin are cement materials, sand and gravel, coal, marble and building stone, gold, silver, nickel, copper, lead, iron, zinc, arsenic, sulphur, strontium, molybdenum, asbestos, and talc.

71. Very large deposits of cement materials (limestone and clay) have been blocked out and partly developed in an extensive area in the vicinity of Concrete. The plant of the Superior Portland Cement Co. at that place has a capacity of 1,800,000 barrels of cement per year, and an average annual output of about 1,250,000 barrels. The developed holdings of the company in the immediate vicinity of this plant are said to contain 40,000,000 tons of cement material, or enough for 150 years continuous operation at the present capacity.

72. Sand and gravel deposits are of quite general occurrence in the valley except in the lower delta region, where the predominating material is silt. They are largely of glacial origin and consist of clean, fresh unweathered material that is especially well-suited for various kinds of construction work. Many of the deposits are worked by the county to furnish material for road building and necessarily are located near the line of the road being built. Other deposits are worked by local contractors for building construction, pits being operated near Mount Vernon and Sedro Woolley.

73. Coal mining and the production of coke at the Cokedale Mine 4 miles northeast of Sedro Woolley was at one time an important industry, but at present is discontinued. Undoubtedly, it will be

revived at some future time. The extent of the coal measures in the Skagit drainage area is not great. The outcrops of coal seams are few in number, but the quality in most instances is good. There are three principal areas covered by coal measures, the most significant one being the Cokedale area, which extends about 8 miles in a northwesterly direction from the bottom lands of the Skagit River near Lyman. Another area, embracing the Cumberland Creek and Day Creek Basins, which might be considered continuations of the Cokedale area, lies on the south side of the river and extends southeastward from a point opposite Hamilton for a distance of 8 miles. The third area extends southeastward from Mount Vernon for a distance of 10 miles.

74. The following statements relative to iron ores are taken from Bulletin No. 30, Division of Geology, State of Washington:

> Iron ores occur along the Skagit River from Hamilton to Marblemount, a distance of about 25 miles. The ore in this district is a mixture of hematite and magnetite. Chemical analyses of the ore show that it is not very high in metallic iron, ranging from about 30 to 46.6 percent. The amount of silica, alumina, manganese, and phosphorus are also high in most of the samples analyzed. On the whole, the iron ore in this district is not very high grade.

Chapter III. History and Present Status

NAVIGATION

75. *Original condition.*—Originally extensive shoals at the mouths of both the North and South Forks prevented access from Skagit Bay to the river channels except on tides. Inside the mouths ample depths were in general available to the forks. The least depth was at the Skagit City Bar, about 6 miles from the mouth of the South Fork. In the early days that branch of South Fork known as the "Old Main River" was the principal channel. When first officially examined in 1875, the river was much obstructed by snags and navigation was completely blocked at and above the forks by two large timber jams or rafts. These rafts were removed mainly by the efforts of early settlers in 1877–79, after which the river was navigable for boats of about 3 feet draft at most stages to Avon, 13 miles above the mouth, and during ordinary high water to the Sauk River, 66 miles above the mouth. During extreme high water, boats occasionally ascended the river as far as Portage, about 86 miles above the mouth. (See pls. nos. 2[1] and 3[1] for source of listed distances.)

76. *Examinations and surveys.*—Examinations and surveys of this waterway and reports thereon have been made as follows:

a. A report on examination of "Skagit River", ordered by the River and Harbor Act of June 23, 1874, was made on February 11, 1875, and is published on page 791 of the Annual Report of the Chief of Engineers for 1875. It was favorable for improvement by the removal of snags and log jams and by some bank protection, at an estimated cost of $15,000.

b. A report on examination of "Skagit River", made on July 14, 1881, is published on page 2603 of the Annual Report of the Chief of Engineers for 1881. It was favorable for the construction of a snagboat at an estimated cost of $15,000, and for $10,000 a year for its

[1] Not printed.

operation, for snagging in this and other streams entering Puget Sound.

c. A report on preliminary examination, made on November 8, 1890, is published in House Executive Document No. 38, Fifty-first Congress, second session. It was unfavorable, except for more efficient removal of snags.

d. A report on survey of "Skagit River from mouth to the town of Sedro, Wash.", ordered by the River and Harbor Act of June 3, 1896, was made on December 11, 1897, and is published in House Document No. 204, Fifty-fifth Congress, second session. It was unfavorable.

e. Reports on preliminary examination and survey of "Skagit River, Wash., up to Sedro Woolley" were ordered by the River and Harbor Act of March 2, 1907. The report on preliminary examination was made April 15, 1907, and the report on survey was made March 31 and November 3, 1908, and they are published in House Document No. 1188, Sixtieth Congress, second session. These reports were favorable for securing a reliable channel through the delta at the mouth of the river by the construction of a training dike and closing subsidiary channels and by the construction of regulating dikes and a mattress sill at the head of North Fork, at an estimated cost of $100,000.

f. Reports on preliminary examination and survey of "Skagit River, Wash., from Sedro Woolley to Baker", ordered by the River and Harbor Act of June 25, 1910, were made on November 5, 1910, and February 29, 1912, respectively, and are published in House Document No. 909, Sixty-second Congress, second session. The survey report was unfavorable.

g. Reports on preliminary examination and survey of "Skagit River, Wash.," ordered by the River and Harbor Act of July 25, 1912, were made on December 6, 1912, and January 26, 1914, respectively, and are published in House Document No. 935, Sixty-third Congress, second session. The reports were favorable for the improvement of Skagit City Bar by combined dredging operations and training walls at not to exceed $30,000.

h. A report of the Board of Engineers for Rivers and Harbors dated December 9, 1919, and a related report by the district engineer dated October 10, 1919, on the previous report (*g*) were ordered by the River and Harbor Act of March 2, 1919. These reports are published in House Document No. 591, Sixty-sixth Congress, second session, and were favorable for the same work as the previous report, but at an estimated cost of $45,000 and require local cooperation to the extent of assuming all claims for damages.

i. A report on preliminary examination of Skagit River, Wash, ordered by the River and Harbor Act of September 22, 1922, and Department letter of October 5, 1922, was made on February 8, 1928, and is published in House Document No. 311, Seventieth Congress, first session. The report was favorable for a small amount of dredging.

77. *Previous project*.—The removal of snags and other obstructions in this river was first undertaken in 1880 under an appropriation of $2,500 made by the act of June 14, 1880. Since 1882 this work has been continued by the snagboat maintained and operated under

the general appropriation for the improvement of Puget Sound and tributary waters.

78. *Existing project.*—The existing project, based on the report printed in House Document No. 1188, Sixtieth Congress, second session, was adopted by the River and Harbor Act of June 25, 1910, and provides for a low-water channel in the South Fork between Skagit Bay (Saratoga Passage) and deep water in the river by the construction of a training dike at the mouth of the river, regulating dikes and a mattress sill at the head of the North Fork, and sills to close subsidiary channels in the delta, at an estimated cost of $100,000. This project was modified by the act of March 2, 1919, which provided for increasing the available depth at Skagit City Bar by dredging and the construction of training dikes at an estimated cost of $30,000 as proposed in House Document No. 935, Sixty-third Congress, second session.

This act required "that before work on this project is commenced, the report shall be referred to the Board of Engineers for Rivers and Harbors for review as to whether the project should be modified to meet existing conditions or whether conditions of local cooperation should be imposed." This review was published in House Document No. 591, Sixty-sixth Congress, second session, and recommended an increase in the estimate to $45,000 and that no work be done until local interests assume responsibility for the payment of all damages claimed or alleged to result from any work that may be done under this project. The length of the section included in the project is 9½ miles. The estimated annual cost of maintenance is $5,000.

79. *Work done and present condition.*—(See pls. nos. 8–12, inclusive.)[1] The mattress sill at the head of North Fork, the dikes closing off subsidiary sloughs, and the training dike at the mouth of the South Fork were completed in 1911 with the exception that the latter dike is 5,550 feet shorter than the project length of 16,000 feet. This shortening was occasioned by the increased cost of the work. Since completion, minor repairs have been made to the dikes as required, and they are in general in good condition. The expected results were not, however, secured, and the controlling depth over the bar at the mouth of the South Fork does not exceed 1½ feet at mean lower low water. The expenditures under this project to March 31, 1932, have been $99,829.80 for new work and $29,257.81 for maintenance, a total of $129,087.61.

80. No work has been done on the bar at Skagit City pending the acceptance of the terms of local cooperation as imposed by Congress. The depth over this bar at low water in the river and at low tide is from 1½ to 2 feet.

81. The river has been kept cleared of snags and other obstructions by the operation of the snagboat under the general appropriation for the improvement of Puget Sound and tributary waters, but no separate record has been kept of the cost of this work. The boat is equipped with a clamshell bucket and has done a limited amount of dredging in connection with its main work of removing obstructions.

82. The larger part of the flow of Skagit River was formerly carried by the South Fork; but in later years this condition has

[1] Not printed.

become reversed, so that for several years past freight boats plying on the Skagit River have ceased to use the South Fork on account of shallows therein and have used the North Fork. The mattress sill across the North Fork was intended to throw more water down the South Fork, but apparently did not do so, or at least was not effective in improving the depths in it; consequently, the sill was partially removed to facilitate navigation in the North Fork. Deterioration of the South Fork appears to date from about 1896, when a series of floods widened and shoaled the channel considerably at Skagit City Bar, and to some extent at other points. It is possible, however, that a decrease in gradient resulting from the construction of the dike at the mouth of the South Fork has been a contributing cause to shoaling in that fork.

83. *Bridges.*—The navigable portion of the river is crossed by eight bridges, as shown by table 32. In addition to the bridges shown in the table, there is a fixed bridge of 60 feet horizontal clearance and 5 feet vertical clearance at high water over Tom Moore slough on the South Fork, but this slough is not a main channel of the river. It is used only for the floating of logs.

TABLE 32.—*Bridges over Skagit River*

No.	Miles above mouth	Owner	Character	Clear width	Vertical clearance at high water
				Feet	*Feet*
1	North Fork 4	Skagit County	Swing	80	7
	South Fork:				
2	5½	do	do	115	10
3	10¾	do	do	109	6
4	15	Skagit County and State of Washington	do	100	10
5	15⅛	Pacific Northwest Traction Co	do	98	8
6	15½	Great Northern Ry. Co	do	80	12
7	21¾	Northern Pacific Ry. Co	do	91	10
8	22	Skagit County	do	100	13

84. *Terminal and transfer facilities.*—There are no modern terminal and transfer facilities on the river. There is one wharf at Mount Vernon which is open to general public use and is considered adequate for existing commerce. Bank landings are made at other points on the river. Logs are dumped into booms in the river from pile trestles, then rafted and the rafts towed to destinations.

85. *Steamship lines.*—The only company now operating freight boats on a regular schedule is the Skagit River Navigation Co. This company operates 1 boat regularly between Seattle and Mount Vernon, making 3 trips a week, the times of arriving and departing from the Skagit River being variable according to the stage of the tide. A second boat is put on the river in the fall of the year when the grain and hay shipments are heavy. These vessels are stern-wheel freighters. One draws 2½ feet light and 7 feet loaded, and the other 20 inches light and 4½ feet loaded. No freight boats now go above Mount Vernon.

86. The bulk of the water-borne traffic has always been the floating or rafting of logs. This reached a maximum of 674,492 tons in 1918 and the average for the 5 years prior to 1930 was approximately 284,000 tons a year. The tonnage for 1930 and 1931 has been less than one half that average on account of the general business de-

pression. The traffic in logs for the entire river amounted to 122,385 tons in 1931 divided, with respect to various portions of the river, as follows:

Internal, 1,673 tons towed from Rockport to Sedro Woolley.

Coastwise, 4,500 tons towed from Rockport to Everett; 34,822 tons towed from Mount Vernon to Everett; 80,397 tons towed from Tom Moore slough to Seattle and Stanwood; 690 tons towed to Anacortes; 303 tons towed to La Conner.

The first three of the items listed above, amounting to 40,995 tons, can be credited to that part of the river above the forks. The item of 80,397 tons constituted the year's output of the English Logging Co., the only firm now operating on the lower river. This firm dumps its logs into Tom Moore slough about 4 miles above the lower end of the training dike at the mouth of South Fork; so that only a short stretch of that fork is involved in their operations. The item of 34,822 tons represents the first year's operations of the Puget Sound Pulp & Timber Co., of Everett, in timber situated near Clear Lake. Their log dump is about 4 miles above the forks, just above the city limits of Mount Vernon. There are 2 towing companies that operate 4 boats on the river above Mount Vernon towing logs from points between the mouth of the Baker River and Rockport to salt water. These boats are small steam and gasoline boats designed for use on this river. They have drafts from 18 to 28 inches. During low stages of the river these boats make use of the fluctuations in the river due to the operations of the power plant of the Puget Sound Power & Light Co., at the mouth of the Baker River, to float the log rafts over the bars below. These fluctuations amount to as much as 10 inches or more at The Dalles, 2 miles below the Baker River.

87. *Prospective commerce.*—With a return to normal business conditions, it may be expected that the log traffic will again equal in volume the annual average of 284,000 tons that obtained for 5 years prior to 1930. There is a possibility of that average being exceeded in some of the years to come; but the rapidly diminishing stand of privately owned timber ultimately portends a progressive decrease in that traffic. Only a limited portion of the heavier agricultural products is now or will ever be transported by water; however, better boat service, following river improvements, would tend to increase the tonnage in farm products. Incoming supplies, brought in by boat, are greater in value and but little less in tonnage than the outbound products, and any increase in the latter will naturally result in a corresponding increase in the former.

88. *Adjacent ports.*—Bellingham, population 30,823 in 1930, is the principal port to the northward of the lower portion of Skagit River. Bellingham is the fourth city in the State. It is 36 miles by water and 24 miles by State highway from Mount Vernon. For 1931, its commerce was reported as 446,389 tons, valued at $19,408,668, carried in vessels, in addition to 679,558 tons of floated logs, valued at $2,457,203.

89. Anacortes, with a population of 6,564, is 18 miles by the highway to the westward of Mount Vernon, and 28 miles by water by way of Deception Pass. Its vessel traffic in 1931 amounted to 77,494 tons, valued at $2,581,886, in addition to 182,589 tons of floated logs, valued at $642,634.

90. Everett, with a population of 30,567, is the fifth city in the State and the nearest port to the southward of Skagit River. In 1931, Everett reported a vessel traffic of 1,172,361 tons, valued at $15,518,291, and floated logs amounting to 1,685,703 tons, valued at $6,029,523. Everett is 32 miles by water south of the entrance to North Fork of the Skagit and 36 miles by highway south of Mount Vernon.

91. *Views of local interests.*—Stated in general terms the desires of the community are for easier access to the Sound than at present exists so that the water-borne commerce may be carried on with greater regularity and certainty. Various local interests are not in agreement as to the means of accomplishing this object. The committee representing Mount Vernon Commercial Club and Mount Vernon Rotary Club suggested in 1923 that a comprehensive plan for the entire river length could be devised that would promise relief from flood damage in its upper reaches and free navigation in its lower reaches, and that a drainage district could be formed to cooperate with the Federal Government in carrying out such plans. This committee expressed a belief that North Fork would be easier of improvement than South Fork under existing conditions, and suggested that a better navigable channel as well as some lessening of flood danger would be secured by (1) rock jetties at the mouth to confine and direct the current, with resultant scour and increased depth; (2) the removal of obstructions and dredging, using the dredged material for levees; and (3) bank protection.

92. The Tom Moore Boom Co., which operates in Tom Moore slough, requested further improvement of the channel in South Fork at the mouth, and suggested the removal of the outer portion of the present jetty and its extension in a straight line to a connection with the outer section of the channel of the West Pass of Stillaguamish River, also dredging the channel 6 feet deep by 150 feet wide, and forming a jetty on the south side by using the dredged material and some brush.

WATER POWER

93. *Introduction.*—The basin of the Skagit River offers extensive opportunities for power development, but only a few sites have been utilized. The Cascade Mountains, where this stream rises, constitute the most important element in the water-power resources of the basin. The Skagit drains an area receiving a considerable part of its precipitation in the form of snow and is fed by the glacial fields of the higher mountain peaks. This snow storage tends to regulate the stream flow by preserving for a time a portion of the heavy winter precipitation until later released by warm summer temperatures, thus insuring a well-maintained flow during the summer season. Climatic conditions are such that ice has never been known to cause serious interruption in the operation of hydroelectric plants on the western Cascade slope. This stream reaches sea level from the mountains in a comparatively short distance, making available the rapid fall essential for the economic development of water power.

94. *Prior reports.*—No comprehensive reports have been published on the power possibilities of the Skagit Basin. An unpublished study, prepared about 1925, by G. L. Parker, district engineer of the United States Geological Survey, is the only known reliable informa-

tion on this subject. Mr. Parker estimated that the total power available on the Skagit and its tributaries, with 70 percent efficiency on a basis of natural flow, to be 251,520 kilowatts 90 percent of the time, and 626,640 kilowatts 50 percent of the time; and on a basis of regulated flow to be 545,640 kilowatts 90 percent of the time, and 727,270 kilowatts 50 percent of the time. Certain individual sites have been investigated and reported upon by private companies and municipalities, but these private reports have not as a rule been available for study.

95. The city of Seattle has started a series of developments on the upper Skagit. The various annual reports of the city light department furnish some information on these developments. The Skagit Engineering Commission was appointed by the city to make a study of the city's proposed developments. Its report, made in 1925, has never been published in full, but a copy has been available for use and study by this office.

96. The Puget Sound Power & Light Co. has made a number of investigations on Baker River, and has already constructed one plant on this tributary of the Skagit. The American Nitrogen Products Co., now defunct, made investigations on the Sauk and Suiattle in 1916 and 1917. Copies of their maps have been secured and were used in making the studies of proposed works as presented in later portions of this report.

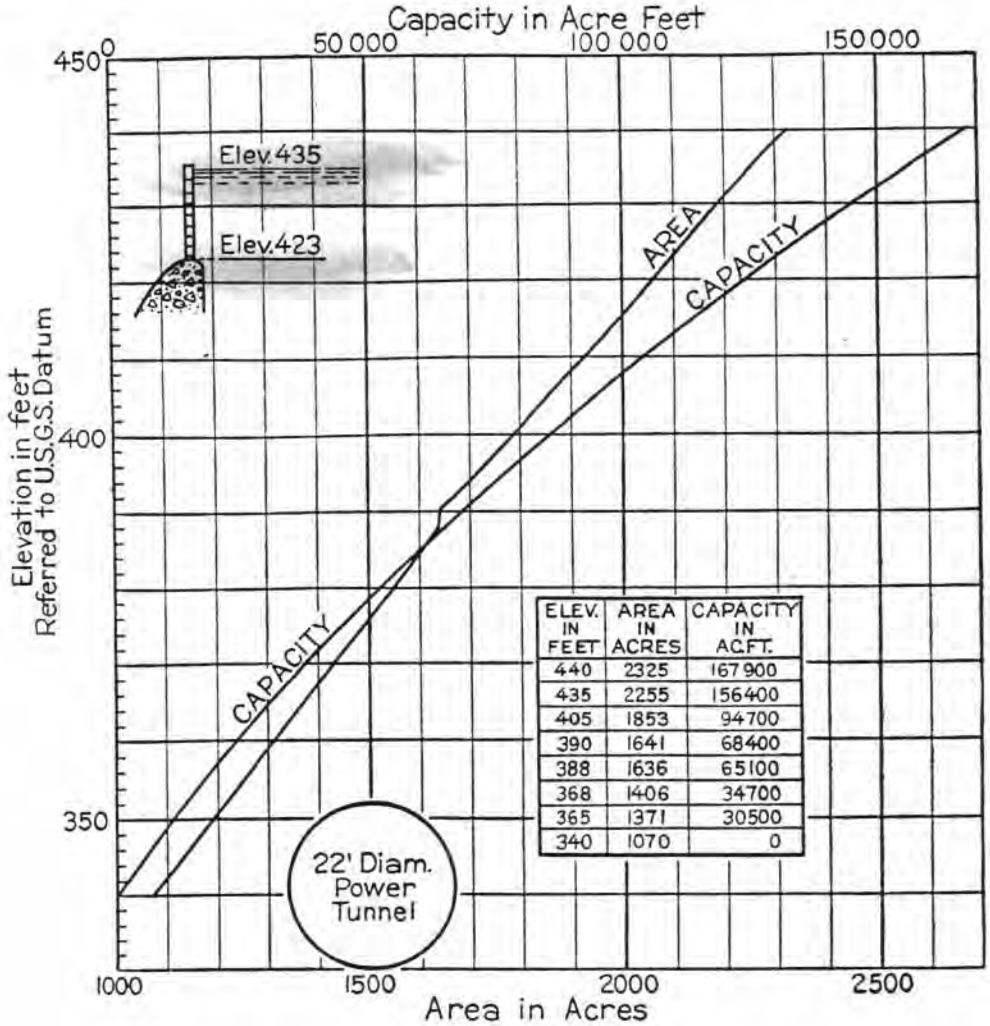
97. *Developed power.*—The developed power on the Skagit River and its tributaries is summarized in table 33. Both the city of Seattle and the Puget Sound Power & Light Co. have secured numerous rights from the State of Washington for the diversion and storage of water for their existing and proposed plants. Some of these rights were acquired prior to the enactment of the State water code in 1917; some were acquired since 1917 under the provisions of that code.

TABLE 33.—*Developed power on Skagit River and its tributaries*

Name of stream	Nearest town to plant location	Owner or operator	Operating head (feet)	Number of units	Total rated capacity (kilowatts)	Use of power
Baker River	Concrete	Puget Sound Power & Light Co.	[1] 255 [2] 180	2 [3] 4	40,000 [3] 80,000	General; fed into Puget Sound Power & Light system.
Bear Creek	do	Superior Portland Cement Co.	420	3	[4] 1,950	Cement mill operation.
Do	do	do	74	1	[4] 350	Cement mill operation—auxiliary to above plant.
Newhalem Creek.	Newhalem	City of Seattle.	500	1	2,000	Originally for construction of Gorge plant; now adds to capacity of Gorge.
Skagit River	Newhalem (Gorge plant).	do	[3] 270 375	3 [3] 6	54,000 [3] 240,000	General; fed into city-light system.
Do	Newhalem (Diablo plant).	do	307	[5] 2 [3] 4	[5] 120,000 [3] 240,000	General; to feed into city-light system.

[1] Maximum.
[2] Minimum.
[3] Ultimate development.
[4] Kilovolt-ampere.
[5] Under construction.

98. Baker River development: The Puget Sound Power & Light Co. has a partially developed project on lower Baker River about half a mile from the confluence of that stream with Skagit River, near the town of Concrete. This project has an initial installation of 2 units with a total capacity of 40,000 kilowatts; and has an ultimate



ELEV. IN FEET	AREA IN ACRES	CAPACITY IN AC.FT.
440	2325	167900
435	2255	156400
405	1853	94700
390	1641	68400
388	1636	65100
368	1406	34700
365	1371	30500
340	1070	0

FIGURE 4
BAKER RIVER
SHANNON LAKE RESERVOIR
AREA & CAPACITY CURVES & TABLE
(Data furnished by Puget Sound Power & Light Co.)
U.S. Engineer Office Seattle, Washington

proposed development of 4 units which will about double the initial capacity.

99. The Baker River development has a gravity type, arch form, concrete dam, with spillway section, 286 feet from bedrock to the deck above the spillway piers. The elevation of the upper pool is 435 feet (mean sea level), and the tailwater elevation varies between 175.5 and 186 feet. Between elevations 435 and 360 feet there is an

available storage of about 132,060 acre-feet in Shannon Lake, which is equivalent to a net output of 21,000,000 kilowatt-hours (see fig. 4). The diverted water is led to the power house through a circular, concrete-lined tunnel in rock, approximately 900 feet long and with a finished internal diameter of 22 feet. The power house is a reinforced concrete building.

100. The dam was originally constructed in 1924–25 with spillway crest at elevation 393 feet and top of gates at elevation 405 feet. At this elevation (405 feet) the forebay was entirely on private land. In 1927 the dam was raised to its present ultimate height, with spillway crest at elevation 423 feet and top of gates at elevation 435 feet. At this latter elevation (435 feet) there is some backwater within the Mount Baker National Forest. To cover this situation, the Federal Power Commission issued a 50-year license (project no. 777) on April 13, 1927, to the Puget Sound Power & Light Co. The license authorizes the occupancy and use for reservoir purposes of lands of the United States within the Mount Baker National Forest. The lands constitute a minor part of the project. This plant is one of many connected to the transmission system of the Puget Sound Power & Light Co. Two 110-kilovolt transmission lines supply current to the Sedro Woolley and Beverly Park substations.

101. Bear Creek: The Superior Portland Cement Co. has two small plants near the town of Concrete on Bear Creek, a tributary of Baker River. One of these plants is an auxiliary and discharges into the forebay of the other. Their combined rated capacity is 2,300 kilovolt-amperes. There is no storage of moment, and the power is used for the operation of the company's cement mill at Concrete.

102. Upper Skagit development: The city of Seattle has started a series of three major power developments on the upper Skagit. Two of these, the Gorge and Diablo developments, are already constructed or are under construction and will be discussed immediately hereafter. The third, the Ruby project, has not been developed yet and will be discussed in a later chapter (see par. 226 et seq.). On March 3, 1927, under the Federal Water Power Act of 1920, the Federal Power Commission issued a preliminary permit to the city of Seattle for a proposed power project on Skagit River, designated as project no. 553 by the Commission. Before the granting of the above permit, the city of Seattle had constructed Gorge power plant which was completed in 1924 under a permit issued in 1918 by the Secretary of Agriculture.

103. The scope of the development undertaken by the city is described by article 1 of the preliminary permit:

ARTICLE 1. The priority granted hereunder shall be for a period of three (3) years from the date of issuance hereof and for a proposed project described as follows:

A series of reservoirs and power plants to regulate the flow of Skagit River and utilize the entire head from the Canadian boundary to the city's constructed gorge plant in T. 37 N., R. 12 E., Willamette base and meridian, the main features thereof being: (a) A concrete dam at the Ripraps or Ruby site to raise the water level approximately 400 feet and create a reservoir of 1,300,000 acre-feet capacity; (b) A concrete dam in Diablo Canyon to raise the water level approximately 300 feet and create a 90,000 acre-foot reservoir, extending upstream to the Ruby plant; (c) A concrete dam at the intake of the Gorge plant to raise the water level approximately 100 feet above the present diversion dam to the level of the Diablo plant tailrace; (d) Power plants at Ruby and Diablo Dams to utilize the

head at each; (e) A transmission line connecting these plants with the constructed line from the gorge plant;
all as located and described by certain maps and data filed with and made a part of said application for preliminary permit.

104. This preliminary permit was issued subject to the special condition of its paragraph (3), article 7:

(3) That the licensee shall, if so required by the Commission, provide for storage of flood waters in said Ruby Reservoir in connection with any plans for flood relief that may be adopted by the State or by the United States on such terms of cooperation as may be deemed just and equitable by the Commission.

105. Upper Skagit development (Gorge): The initial development of the city of Seattle is located at what is known as the "Gorge" site on Skagit River near the town of Newhalem, about 16 miles above Cascade River and 12 miles below Ruby Creek. This project has an installation of three generating units designed for a head of 375 feet but operating on a head of 270 feet until a high dam is built and their combined capacity at the reduced head is 54,000 kilowatts.

106. The Gorge development has a timber crib diversion dam, about 30 feet high, with crest at elevation 776 feet (mean sea level), near the mouth of Gorge Creek. The diverted water is carried to the power house by a concrete-lined horseshoe section tunnel through solid granite, 11,000 feet long, with a finished internal diameter of 20 feet 6 inches. The power house is a reinforced concrete building.

107. This plant is the first unit of the city of Seattle's proposed million horsepower Skagit River development. Current is carried to Seattle over a 165,000-volt transmission line. The ultimate head for the Gorge plant will be obtained by the construction of a high concrete dam with crest at elevation 880 feet, the location of which has not yet been determined. The ultimate proposed development will bring the capacity of the Gorge plant up to 240,000 kilowatts.

108. Upper Skagit development (Newhalem Creek): The city of Seattle has a small power plant on Newhalem Creek near the Gorge power plant. Its installation is one 2,000-kilowatt unit supplied with water under a 500-foot head by means of a timber crib dam and an unlined rock tunnel. This plant was built primarily to produce power for the construction of the Gorge plant, but now the Newhalem unit connects with and adds to the capacity of the Gorge plant.

109. Upper Skagit development (Diablo): On October 28, 1927, the Federal Power Commission issued a license to the city of Seattle for the development of power at Diablo Canyon on Skagit River (Commission project no. 553) about 8 miles above the Gorge plant and 4 miles below Ruby Creek. The scope of the Diablo development, which is now under construction, is described by article 6 of the license:

ART. 6. Subject to the provisions of section 13 of the act, the licensee shall begin the construction of Diablo Dam and Reservoir on or before January 1, 1928, and complete the same on or before July 1, 1930; and shall begin the construction of the first power tunnel and power house for three units at Diablo Dam, the installation of said units and the construction of the transmission line on or before January 1, 1930, and complete the same on or before December 31, 1935. The remaining half of the Diablo power plant herein authorized shall be constructed at such time as may be approved by the Commission as necessary to keep pace with the growth of the licensee's requirements for power.

110. The dam was completed in 1930 with a maximum height of 389 feet and crest at elevation 1,218. It is, for the time being, the highest of all existing dams. The type is a constant angle arch, with

gravity wings the length being 588 feet and the crest length 1,180 feet. Behind the dam a total of 90,000 acre-feet of water can be stored, forming a lake 6 miles long. The storage in 30 feet drawdown amounts to 24,000 acre-feet (see fig. 5.)[1] Until the Diablo power house is completed, the entire 90,000 acre-feet of storage will be available for the use of the Gorge plant. After completion of the Diablo power house, the drawdown will probably be limited to about 30 feet. The power tunnel is 2,000 feet long and 19 feet 6 inches in internal diameter.

111. The initial installation will be two 60,000-kilowatt generating units. The ultimate development as now planned calls for the construction of a second tunnel and the addition of 2 more units to the Diablo power house to bring its ultimate capacity up to 4 units totaling 240,000 kilowatts instead of the 6 units called for by the license.

112. The United States reserves the use of the water in the interest of navigation and flood control, as is shown by article 17 of the license:

ART. 17. The United States specifically retains and safeguards the right to use water in such amount, to be determined by the Secretary of War, as may be necessary for the purposes of navigation and the operations of the licensee so far as they affect the use, storage, and discharge from storage of waters affected by this license, shall at all times be controlled by such reasonable rules and regulations as the Secretary of War may prescribe in the interests of navigation and as the Federal Power Commission may prescribe in the interests of flood control and of the fullest practicable use of said waters for power purposes.

113. *Markets.*—The developed and potential power in adjacent localities and the distance to which power can be economically transmitted limit the present and prospective territory which can be served by Skagit River developments to the Puget Sound and contiguous regions. These regions are rich in natural resources; timber, agricultural lands, and fish being the most important. The forest belts contain a great wealth of fir, cedar, spruce, hemlock, and other varieties of timber, much of which is usable only as pulp; the valleys are peculiarly well adapted to specialized forms of agriculture such as berry raising, dairying, truck farming, orchard culture, and chicken raising; and the adjacent waters supply fish for world-wide sale which forms a substantial contribution to the economic balance of this region. In addition, the water-borne commerce of this region ranks high in economic importance. There are many fine harbors on Puget Sound, ranging in size from those which accommodate small fishing boats to the great water fronts of Seattle, Tacoma, Bellingham, Everett, and Olympia, which can accommodate the largest ships afloat.

114. As an indication of the present market for power, the total installed capacity of the Puget Sound Power & Light Co., the city of Seattle, and the city of Tacoma is 723,000 kilowatts (including plant under construction), all of which is used to supply the local demand in the Puget Sound and contiguous regions. Data from the United States Census Bureau indicate that the installed capacity has practically doubled in this locality every five years since 1902. In terms of energy output, the increase each year has been about 10 percent of the preceding year's total, neglecting the present depression years.

115. As an indication of the prospective market for power, it is interesting to note that the city of Tacoma added the second 27,000-

[1] Not printed.

kilowatt unit to its Lake Cushman hydroelectric plant no. 2 in 1931, and will place one turbine of 25,000-kilowatt capacity in operation at its steam plant no. 2 during 1932. The city of Seattle is engaged in the construction of the first unit of its development at the Diablo site on Skagit River, where two 60,000-kilowatt generators will be installed. In 1932 the Puget Sound Power & Light Co. will complete the first stage of installation at its new hydroelectric plant at Rock Island on the Columbia River, which will have an initial capacity of 60,000 kilowatts.

FLOODS AND FLOOD CONTROL

116. *Prior reports.*—There is only one published report concerning flood control, viz, the preliminary examination of Skagit River which was ordered by the Flood Control Act of May 31, 1924. This report, dated January 31, 1925 (H.Doc. No. 125, 69th Cong., 1st sess.), was favorable for a survey at an estimated cost of $20,000 contigent on local interests contributing half of the amount. In addition, there are two unpublished reports. In 1923, Mr. J. E. Stewart, of the United States Geological Survey, collected data for and partially completed a report on Skagit River, jointly for his bureau and Skagit County. Mr. Stewart's work contains flood data, and information on the climate and geology of the Skagit Basin. In 1922 Mr. Robert Herzog, assistant engineer of the Great Northern Railway, made a report to his company on flood control of the Skagit River, recommending relief by diversion.

117. *Floods.*—The Skagit River, in common with other rivers similarly located in this section, is subject to severe floods which frequently cause great damage. The whole of the Pacific Northwest is subject to a peculiar warm, moist wind, known as the chinook, blowing off the ocean, usually from the southwest. A chinook may occur at any time of the year and may cover a large extent of territory. A chinook striking a snow field causes the snow to melt with abnormal rapidity. The conditions surrounding the source of the Skagit are therefore such that a flood is liable to occur at almost any time. For example, in the year 1896, there was a flood in January, 22 feet high near Mount Vernon; one in June, 20 feet high; and one in November of 24 feet. A chinook will usually cause a marked rise in the lower river about 36 hours after it begins to blow, the amount of the rise depending upon the intensity and warmth of the wind, and the amount of fresh snow on the mountains. The highest floods usually occur in November and December, when the winds carry a large amount of moisture, causing heavy precipitation, and when the snow is loose and porous.

118. The first white people arrived in this valley about 1869. High-water marks since then have been recorded from time to time, with increasing accuracy, of course, in later years. Prior to that time the records of floods depend upon testimony and traditions of the Indians, upon certain direct and indirect evidence of high-water marks, and upon flood records elsewhere. Gages have been established and regularly read and actual discharge measurements taken only since 1908, and these are not in general complete over any extended periods. Mr. Stewart made a careful study and analysis of all data and evidence available and reached the conclusion that "a flood about 1815 was nearly a maximum, but there had been, prior

to that time, several floods approximately as large. This latter fact was determined at Reflector Bar, where alternate layers of flood sand and charcoal were found. The flood sand could have been deposited only by floods approximating the maximum size; while the charcoal could have been left only by forest fires which occurred during the time intervening between maximum floods." These maximum floods had, he believes, about twice the discharge of recent floods and he also found evidence of a flood in 1856 about one and one half times as great. The following data, with the exception of those for the 1932 flood, are taken from his report:

LIST OF FLOODS

About 1815: Maximum flood.

1856: Next highest and higher than any since settlement of the valley.

December 14, 1879; 1880; 1882; November 3, 1883; October 30, 1887; May 27, 1894; no specific record.

November 16, 1896: Highest, up to then, since settlement of the valley and probably since 1856.

November 19, 1897: Everywhere higher than that of 1896. Especially high from Cascade River to below Birdsview. In general in this section of the river the 1897 peak has not been exceeded since the settlement of the valley. This flood rose with remarkable suddenness due to a very warm chinook and heavy rain. Both stopped suddenly after about 36 hours. The Cascade, Sauk, and Baker were very high and caused a high peak in the Skagit near the mouth of each stream, but due to sudden starting and stopping of flood conditions the peaks were rapidly reduced by storage in traveling down the Skagit.

November 16, 1906: Exceeded that of 1897 in the diked district, due to recent construction of dikes. Elsewhere lower.

November 30, 1909: Exceeded all previous since settlement, and exceeded all subsequent floods above the Cascade River and below Birdsview to the sea, except where logs jams affected the 1897 and 1921 floods.

December 30, 1917: Remarkable for length rather than peak height. Comparable in height to 1896 and 1906. Damage on the delta was due partly to the long period of overflow after the dikes had been broken.

December 13, 1921: Nearly as great as 1909.

February 27–28, 1932: Estimated natural discharge (corrected for effect of upstream storage) at The Dalles about the same as the discharge of the 1896 and the 1906 floods. Measured discharge at The Dalles 35,000 second-feet less than estimated natural discharge. Occurred later in winter season than usual.

119. Flood heights and peak discharges as determined by Mr. Stewart are shown in tables 34 to 36 together with data on the recent flood of February 27–28, 1932.

TABLE 34.—*Skagit River at Reflector Bar; 22.5 miles above Marblemount, 4.5 miles below Ruby Creek and immediately below Diablo Dam. Above the main tributaries, Cascade, Sauk, and Baker. Drainage area, 1,100 square miles.* (*See table 7*)

Date	Gage height	Peak discharge (cubic feet per second)	Discharge in second-feet per square mile	Probable error
	Feet			*Percent*
Unknown	21.0	120,000	109	20
About 1815	20.5	115,000	105	20
About 1856	18.5	95,000	86	15
Nov. 18, 1897	12.5	48,000	44	10
Nov. 29, 1909	15.4	70,000	64	10
Dec. 29, 1917	12.5	43,000	39	10
Dec. 12, 1921	14.5	63,000	57	10
Feb. 28, 1932		[1] 45,000	39	
Do		[2] 47,400	41	

[1] Measured discharge of Skagit River below Gorge power plant.
[2] Estimated natural discharge of Skagit River below Gorge power plant.

TABLE 35.—*Skagit River at The Dalles; 2 miles below the Baker River and 54 miles above the mouth. Drainage area, 2,700 square miles. (See table 9)*

Date	Gage height, upper Dalles gage	Peak discharge (cubic feet per second)	Discharge in second-feet per square mile	Probable error
	Feet			*Percent*
About 1815	56.6	480,000	178	10
About 1856	44.6	350,000	130	10
Nov. 19, 1897	38.4	270,000	100	15
Nov. 30, 1909	36.4	260,000	96	10
Dec. 30, 1917	33.0	220,000	81	10
Dec. 13, 1921	34.9	240,000	89	5
Feb. 27, 1932		[1] 147,000	55	
Do		[2] 182,000	68	

[1] Measured.
[2] Estimated natural, corrected for effect of upstream storage.

TABLE 36.—*Skagit River near Sedro Woolley; 25 miles above the mouth. Drainage area, 2,970 square miles. (See table 10)*

Date	Gage height	Peak discharge (cubic feet per second)	Discharge in second feet per square mile	Probable error
	Feet			*Percent*
About 1815	33.5	400,000	134	15
About 1856	30.0	300,000	101	15
Nov. 16, 1896	24.8	185,000	62	15
Nov. 19, 1897	24.9	190,000	64	15
Nov. 16, 1906	24.7	180,000	61	15
Nov. 30, 1909	26.5	220,000	74	10
Dec. 30, 1917	24.1	195,000	66	10
Dec. 13, 1921	24.3	210,000	71	10
Feb. 28, 1932	21.1			

120. *Skagit River at Mount Vernon (11 miles above the mouth; drainage area, 3,062 square miles).*—The discharge of the 1921 flood was approximately determined by Mr. Stewart, but this determination was unsatisfactory, due to breaking dikes, bridge obstructions, small slope, etc. The discharge in the river channel proper, below the break in the dikes just above the Great Northern Railway bridge, was 140,000 cubic feet per second (probable error, 20 percent), and the total discharge was roughly estimated at 190,000 second-feet. The discharge of the 1932 flood at Mount Vernon has not been determined. So far as could be ascertained, the dikes were not overtopped, although the crest of the flood came within an average of 1 foot of the top of the dikes. The discharge at Mount Vernon before the dikes broke by "boils" was probably less than the 140,000 second-feet found by Stewart for the 1921 flood, as the crest discharge at The Dalles was only 147,000 second-feet and it has been found that the crest discharge at Mount Vernon is always less than at The Dalles, due to the effect of channel storage.

121. It will be noted that for the 1921 flood the peak discharge at The Dalles is given as 240,000 cubic feet per second; at Sedro Woolley, 210,000 cubic feet per second; and at Mount Vernon, 190,000 cubic feet per second. This decrease in peak discharge as the floods advance down the river is due to the overflow of the banks. The overflow district acts as a storage basin and cuts down the peak, but

increases the length of the flood. For comparison, it will be noted that the extreme low-water discharge at Sedro Woolley is about 2,830 cubic feet per second and the mean yearly discharge about 15,700 cubic feet per second.

122. *Flood discharge of tributaries.*—The periods during which stream-flow records have been collected are shown on figure 1,[1] and all the available data (monthly basis) for all stations have been collected in tables 5 to 28. The annual and monthly discharges of the Skagit River below Ruby Creek, and of the Cascade, Sauk, and Baker Rivers in percent of the discharge at Sedro Woolley have been given in table 4. Exact records of the flood discharges at these same places are not available for all major floods, but table 37 gives the best available data, recorded or estimated. In the absence of any better data a flat allowance of 24 hours was made between the date of the crest at Sedro Woolley and the date of the crest at the various tributaries; for instance, the flow given for the Skagit River below Ruby Creek is for November 29 for the 1909 flood. It will be noted that the Skagit River below Ruby Creek contributes 19 percent of the annual run-off at Sedro Woolley (see table 4) but that in no case does the 24-hour flood discharge reach that figure, the variation, as given by table 37, being from 14.1 to 18.7 percent. However, for the Cascade, the annual run-off is 5.9 percent of that at Sedro Woolley but the 24-hour contribution reached as high as 16 percent. For the Sauk River, the mean annual contribution is 27.6 percent and the maximum 24-hour contribution is estimated at 36.8 percent. The maximum 24-hour contribution of the Sauk for the February 1932 flood was about 40 percent of the maximum 24-hour flow at The Dalles. For the Baker, the mean annual contribution is 13.7 percent and the maximum 24-hour contribution is 17.7 percent.

TABLE 37.—*Contribution of upstream tributaries to flood discharge of Skagit River at Sedro Woolley*

Year	Skagit River at Sedro Woolley		Skagit River below Ruby Creek		Cascade River below Marble Creek		Sauk River near Sauk		Baker River below Anderson Creek		4+6+8+10 (percent of total)
	Date	24-hour discharge (second-feet)	24-hour discharge (second-feet)	Percent of total	24-hour discharge (second-feet)	Percent of total	24-hour discharge (second-feet)	Percent of total	24-hour discharge (second-feet)	Percent of total	
	1	2	3	4	5	6	7	8	9	10	11
1909	Nov. 30	198,000	[1] 37,000	18.7	31,700	16.0	[2]	[2]	[2]	[2]	[2]
1910	Nov. 21	89,100	[1] 14,000	15.7	10,800	12.1	[2]	[2]	[2]	[2]	[2]
1917	Dec. 30	155,000	[1] 21,900	14.1	[1] 17,000	11.0	[1] 57,000	36.8	27,400	17.7	79.6
1921	Dec. 13	188,000	29,200	15.5	[1] 20,000	10.6	[1] 50,000	26.6	19,600	10.4	63.1

[1] Estimated.
[2] No record.

123. *Relative discharge from different sections.*—It will be noted from tables 34 to 36 that the flood discharge in second-feet per square mile for the upper Skagit Valley above the main tributaries is less than for the major portion of the watershed as measured at The Dalles and Sedro Woolley. The same is true for mean annual discharge.

[1] Not printed.

This is unusual and is largely due to the fact that the valley of the upper Skagit lies in the wind and rain shadow of the high divide to the west, of which divide Mount Baker and Mount Shuksan are the two highest points. The discharge per square mile for the other portions of the watershed, and particularly of the tributaries that head in the mountains, must necessarily be far more than for the upper valley. Table 38 shows the conditions for the small flood of November 1910 (the only year for which records exist for all 5 for the stations listed). (See also table 43.) Table 39 gives the maximum discharge of record for each of these same stations.

TABLE 38.—*Data for flood of November 1910*

Station	Drainage area (square miles)	Discharge, 24 hours (second-feet)	Discharge (second-feet per square mile)
Upper Skagit, 1 mile above Goodell Creek	1,150	21,300	19
Cascade	148	10,800	73
Sauk, above Clear Creek	259	22,600	85
Baker, at mouth	270	17,400	65
Sedro Woolley	2,970	89,100	30

TABLE 39.—*Maximum discharge of record for areas listed in table 38*

Station	Date	Discharge (second-feet)	Discharge (second-feet per square mile)
Upper Skagit, 1 mile above Goodell Creek (see table 8)	Nov. 29, 1909	[1] 76,500	66.5
Cascade	do	[2] 31,700	214.0
Sauk, at Darrington (drainage area, 293 square miles)	Dec. 29, 1917 / Dec. 12, 1921	[1] 36,000	122.3
Baker, at mouth	Dec. 29, 1917	[1] 43,000	158.0
Sedro Woolley	Nov. 30, 1909	[1] 220,000	74.0

[1] Peak. [2] 24 hours.

124. *Diversity of time in occurrence of crest.*—Different floods have exhibited different time relations with respect to each other, but exact data on this point are not available except for the February 1932 flood. In that flood (see fig. 6 and table 43) the Sauk reached its crest discharge about 10 p.m., February 26, about 24 hours before the crest from the upper river reached The Dalles measuring station. This latter crest passed Sedro Woolley about 7 a.m., February 28, and passed the Great Northern Railway bridge about 10:30 a.m., February 28. It has always seemed probable that two crests would occur during each major flood of the Skagit, the first being due to the maximum flood of the Sauk reaching the main river earlier than the maximum flow from the upper reaches of the Skagit. Considerable evidence seems to indicate that in former floods the height of the two crests were not far apart in time or in discharge. In the February 27, 1932, flood, however, the maximum flow of the Sauk seems to have caused a much higher crest than that from the upper Skagit. Also, the two peaks appear to be separated by a longer time interval than previously anticipated.

125. *Meteorological data.*—Temperatures and precipitation data for the 1909, 1917, and 1921 floods are given by J. E. Stewart (see par. 116) and are summarized in tables 40 and 41. Similar data for the recent flood of 1932 are given in table 42. Study of these data

indicates that a flood can be expected whenever the maximum daily temperature at the city of Seattles Gorge and Diablo power plants reaches approximately 50° (Fahrenheit) and is accompanied by a precipitation amounting to at least 3 inches per 24 hours. The continuation of these or worse conditions for 48 hours would produce a severe flood and if continued for a longer period or at a higher temperature and at a greater rate of precipitation for the same period would produce a very severe flood. During floods there is a pronounced diurnal fluctuation in discharge in the tributaries due to changes in temperature. This fluctuation, so far as the current precipitation is concerned, is caused by the night precipitation occurring as snow in the higher regions. A great part of this night snow in the forested regions is deposited on the trees and is in an ideal state to be melted by the high temperature of the succeeding day.

TABLE 40.—*Meteorological conditions at site of city of Seattles Gorge power plant during flood of November 1909*

Date	Temperature in degrees Fahrenheit			Precipitation in inches
	Maximum	Minimum	Mean	
Nov. 19	42	41	41.5	1.57
Nov. 20	42	37	39.5	.42
Nov. 21	41	37	39.0	.15
Nov. 22	42	36	44.0	1.97
Nov. 23	48	40	38.5	3.05
Nov. 24	41	36	34.0	1.35
Nov. 25	36	32	34.0	.12
Nov. 26	38	33	35.5	.05
Nov. 27	36	33	34.5	.40
Nov. 28	40	33	36.5	4.00
Nov. 29	52	39	45.5	3.85
Nov. 30	40	36	38.0	.20

TABLE 41.—*Meteorological conditions at Davis ranch, about 1 mile below Reflector Bar and Diablo Canyon, during the flood of December 1921*

Date	Temperature in degrees Fahrenheit			Precipitation in inches
	Maximum	Minimum	Mean	
Dec. 9	42	32	37.0	0.20
Dec. 10	49	37	43.0	2.59
Dec. 11	45	38	41.5	3.92
Dec. 12	51	36	43.5	3.70
Dec. 13	48	35	41.5	.00

TABLE 42.—*Meteorological conditions during flood of February 1932*

Date	Sedro Woolley, elevation 48.0, 6 p.m.[1]				Concrete, elevation 243, 4 p.m.[1]				Baker Lake, elevation 670, 4:30 p.m.[1]
	Temperature °F.			Precipitation (inches)	Temperature °F.			Precipitation (inches)	Precipitation (inches)
	Maximum	Minimum	Mean		Maximum	Minimum	Mean		
Feb. 20	45	36	40.5	0.42	38	33	35.5	0.46	1.31
Feb. 21	43	35	39.0	.40	(2)	(2)	(2)	(2)	.81
Feb. 22	55	41	48.0	--------	46	33	39.5	.25	.09
Feb. 23	53	37	45.0	(3)	52	33	42.5	--------	--------
Feb. 24	56	48	52.0	.11	49	39	44.0	.50	1.60
Feb. 25	57	46	51.5	.70	45	39	42.0	.76	2.60
Feb. 26	62	46	54.0	1.02	57	40	48.5	1.94	3.71
Feb. 27	63	49	56.0	.50	58	43	50.5	1.34	3.40
Feb. 28	53	35	44.0	--------	54	33	43.5	--------	--------
Feb. 29	48	36	42.0	.39	55	35	45.0	.11	.04
Total Feb. 24-27, inclusive	--------	--------	--------	2.33	--------	--------	--------	4.54	11.31

Date	Darrington, elevation 500, 5 p.m.[1]				Gorge plant, elevation 505, 4 p.m.[1]				Diablo, elevation 892, 4 p.m.[1]			
	Temperature °F.			Precipitation (inches)	Temperature °F.			Precipitation (inches)	Temperature °F.			Precipitation (inches)
	Maximum	Minimum	Mean		Maximum	Minimum	Mean		Maximum	Minimum	Mean	
Feb. 20	37	32	34.5	0.60	38	32	35.0	0.19	39	33	36.0	1.33
Feb. 21	39	33	36.0	1.66	38	32	35.0	.78	39	32	35.5	.67
Feb. 22	51	32	41.5	.09	48	25	36.5	.08	48	35	41.5	.05
Feb. 23	45	29	37.0	--------	48	30	39.0	--------	44	30	37.0	(3)
Feb. 24	44	35	39.5	.61	43	34	38.5	1.35	45	35	40.0	[4] 1.23
Feb. 25	42	36	39.0	2.05	40	35	37.5	2.29	45	36	40.5	2.74
Feb. 26	60	38	49.0	3.10	40	35	37.5	4.66	39	36	37.5	4.50
Feb. 27	58	44	51.0	1.60	46	35	40.5	2.67	50	37	43.5	3.05
Feb. 28	49	32	40.5	.01	49	32	40.5	--------	49	33	41.0	(3)
Feb. 29	44	32	38.0	.16	43	35	39.0	.13	47	35	41.0	.04
Total, Feb. 24-27, inclusive	--------	--------	--------	7.36	--------	--------	--------	10.97	--------	--------	--------	11.52

[1] End of record day for given date.
[2] No record.
[3] Trace.
[4] Rain began to fall during the night of the 23d and continued without interruption to 1 p.m. on the 27th.

126. *The February 1932 flood.*—The United States Weather Bureau report for January 1932 states that the average depth of snow on the west slope of the Cascades was 46 percent above normal at the end of the month. In the latter part of February there occurred the necessary meteorological conditions to produce a major flood. As shown in table 42, the total precipitation for the 24th to 27th, inclusive, was observed to be 11.5 inches at Diablo and slightly less at other stations and was accompanied by a chinook wind that reached its maximum temperature on the 27th. Rather sharp-crested floods resulted on the various tributaries and were recorded at the gaging

stations, the locations of which are shown on plate 5. The discharge and the time of occurrence of the peaks are shown in table 43.

TABLE 43.—*Crest discharges of Skagit River and principal tributaries during the flood of Feb. 26–27, 1932*

Stream and locality	Drainage area (square miles)	Measured discharge		Estimated natural discharge in second-feet		
		Time	Second-feet	Time	Total	Per square mile
Skagit River below Gorge power plant.	1,160	4:30 p.m. Feb. 27	45,000	4:30 p.m. Feb. 27	47,400	40.9
Skagit River at The Dalles, below Baker River.	2,700	9:30 p.m. Feb. 27	147,000	4:30 a.m. Feb. 27	182,000	67.4
Cascade River	180	10 p.m. Feb. 26	9,000	10 p.m. Feb. 26	9,000	50.0
Sauk River above Whitechuck River.	152	5 p.m. Feb. 26	20,000	5 p.m. Feb. 26	20,000	131.6
Sauk River near mouth	714	10 p.m. Feb. 26 [1]	68,500	10 p.m. Feb. 26 [1]	68,500	95.9
Baker River at mouth	270	6:30 p.m. Feb. 27 [2]	[2] 27,300	7:30 a.m. Feb. 27 [2]	[2] 40,400	149.6
Skagit River at Sedro Woolley	2,970	7 a.m. Feb. 28				
Skagit River at Mount Vernon.		11:30 a.m. Feb. 28 [3]				

[1] Time estimated by observer on basis of frequent check of water height during night on stakes set opposite his house, about half a mile below gage. Recorder clock was not running.
[2] Estimated by Puget Sound Power & Light Co.
[3] High tide at the mouth of the river occurred about 8:40 a.m.

127. The continuous discharge at The Dalles for February 26, 27, and 28 is shown in figure 6. At the beginning of this period Shannon Lake had been drawn down to a stage that provided 66,550 acre-feet of flood storage; similarly, Diablo Reservoir provided 47,900 acre-feet of flood storage. Both of these reservoirs were filled by the evening of the 27th, Shannon about 7 p.m. and Diablo about 9 p.m. The effect of this storage has been computed by G. L. Parker, district engineer of the United States Geological Survey, Tacoma, Wash., and is shown in figure 6 and in table 43. It was assumed that the effect of the Diablo storage was felt 5 hours later at The Dalles. No time correction was made for Shannon storage, as it was only a few miles distant.

128. Two peaks occurred at The Dalles. The first was caused by the Sauk, the Baker, and the Cascade, and would have reached approximately 182,000 second-feet under natural flow. The second peak was caused by the crest from the upper Skagit and was not materially affected by regulation. The recorded peak was 147,000 second-feet.

129. The high-water profile for this flood is shown on plate 4. The surface velocity in midstream between the highway and the Northern Pacific Railway bridges near Sedro Woolley at the crest of the flood was approximately 9 miles per hour.

130. Four major breaks occurred in the river dikes. The first, on the evening of the 27th, on the right bank of the South Fork a mile north of Fir. Failure was caused by a boil and occurred about the time of high tide (10:20 p.m.). The break in the dike was about 500 feet long. About five acres of good tillable land were badly eroded and strewn with snags and gravel. One residence was knocked from its foundation and about three sections of farm land were inundated.

131. The second break occurred about 5 a.m. of the 28th, on the right bank of Deer Slough, locally known as "Dry Slough", about

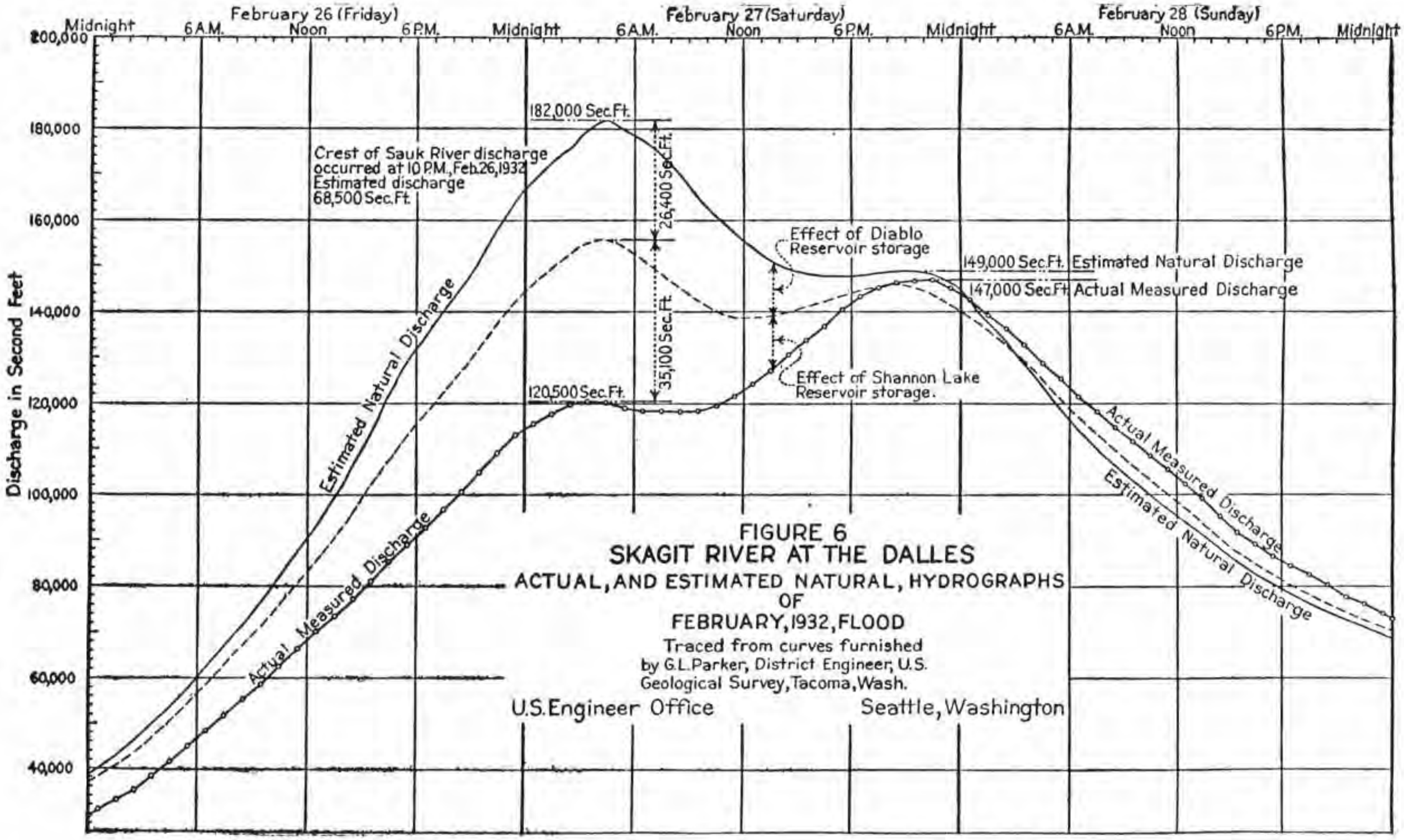


FIGURE 6
SKAGIT RIVER AT THE DALLES
ACTUAL, AND ESTIMATED NATURAL, HYDROGRAPHS
OF
FEBRUARY, 1932, FLOOD
Traced from curves furnished by G.L. Parker, District Engineer, U.S. Geological Survey, Tacoma, Wash.

U.S. Engineer Office Seattle, Washington

2 miles below its confluence with the North Fork. This break also started with a boil. About 90 feet of dike was cut out. A large barn directly in the path of the flood, was undermined and so badly damaged that it was later torn down and moved away. At least two sections of tillable land were flooded.

132. The third break occurred on the right bank of the Skagit near Burlington, about a half mile above the Great Northern Railway bridge, about noon of the 28th. It started from a boil in a rather deep borrow pit and washed out 150 feet of dike and some 400 feet of the Great Northern Railway grade. A break also occurred at this same place during the 1921 flood. The released water crossed the Pacific Highway, spread out on the farms and finally found its way to the sound, mainly via Fredonia and Whitney. The fourth break occurred on the left bank of the lower North Fork. The time of this break is not definitely known. (See pl. 3.)[1]

133. Examination of the dikes after the flood showed the high-water mark generally about a foot below the top of the dikes. At no point were the river dikes overtopped. Some 8 or 10 breaks in the sea dikes along the sound permitted the water to escape from the fields to the west of Fir.

134. The first two and the fourth breaks occurred so far downstream that they probably did not materially affect the stage of the river above Mount Vernon. The third break did not occur until after the crest had reached Mount Vernon, hence it is evident that the diked channel above this city was of sufficient capacity to carry the crest of the flood, which was 147,000 second-feet at The Dalles. The peak discharge at Mount Vernon is unknown, due to the large amount of intervening channel storage.

135. The estimate of the damages sustained because of this flood are given in paragraph 141 et seq.

136. *Existing flood-control works.*—The only existing flood-control works consist of dikes supplemented by drainage ditches. No diversions of the river for flood-control purposes have ever been made.

137. *Detention and storage reservoirs.*—There are two existing storage reservoirs in Skagit Basin, viz, Shannon Lake, formed by the Puget Sound Power & Light Co.'s dam on the lower Baker River, and Diablo Reservoir, formed by the city of Seattle's dam at Diablo Canyon on the upper Skagit River. Both of these reservoirs have the development of power for their primary purpose, but both were operated to reduce the crest discharge of the February 1932 flood, at no sacrifice of power.

138. *Dikes and diking districts.*—The upper valley is generally narrow, with little low land. Near Sedro Woolley the hills recede and the valley widens into the delta, comprising an area of approximately 100 square miles of highly cultivated and valuable farming land. It is here that the greatest damage from flood occurs, though the towns in the upper valley are liable to damage from the larger floods. Below Sedro Woolley the channels have been generally diked (leveed), but the work has been done at various times by individuals and by some 16 different diking districts organized under the State law. Over 1¾ million dollars have been expended by these districts in the construction and maintenance of the dikes. In the absence, however,

[1] Not printed.

of any well-studied or properly coordinated plans they have in many cases been improperly designed and located, the distance apart varying from 650 feet to over 2,000 feet along the main river above the forks. In general, in an effort to enclose as much land as possible, they have been placed close to the river bank without reference to the area required for the passage of flood waters. As a result frequent breaks have occurred due both to overtopping and undermining river bank and dikes. The channel is also unduly restricted by the bridges above Mount Vernon, particularly at the Great Northern Railway bridge, which is located immediately below a right-angled bend. The existing dikes and diking districts are shown on plate 3 [1] accompanying this report, and additional data concerning them are given in table 44.

[1] Not printed.

31875—34——5

Table 44.—*Diking districts, Skagit County*

District	Date organized	Acres in district (1931)	Houses in district	Population	Estimated value of land: For district	Estimated value of land: Per acre	Recent annual assessments for diking, per acre: 1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	Total levies to 1931, inclusive: Per acre	Total levies to 1931, inclusive: For district
No. 1	1897	8,268	348	1,392	$1,405,560	$170	$2.53	$1.26	$0.84	$0.84	$0.63	$0.84	$0.51	$0.42	$0.42	-----	$35.60	$294,109
No. 2	1897	2,632	86	344	447,440	170	1.90	1.90	3.04	3.04	2.28	2.28	1.52	1.52	.95	$0.76	71.10	187,079
No. 3	1897	6,366	667	2,668	1,145,880	180	4.49	2.18	1.87	1.87	1.56	1.24	.94	.94	-----	-----	58.40	372,031
No. 4 [1]	-----	1,579	50	200	221,060	140	.64	.51	.32	.19	-----	.32	.22	-----	.38	-----	10.90	17,202
No. 5 [1]	1897	2,828	22	88	395,920	140	3.19	3.19	1.50	1.50	1.50	1.50	.50	1.50	1.50	1.00	54.60	154,478
No. 8 [1]	1897	631	5	20	100,960	160	.79	1.10	.79	.79	.79	-----	-----	.79	.79	.32	12.20	7,716
No. 9 [1]	1897	1,419	15	60	241,230	170	.50	.25	-----	-----	-----	-----	.35	-----	-----	-----	13.80	19,583
No. 12 [1]	1897	13,392	335	1,340	2,276,640	170	.83	.83	.83	.83	.83	1.24	.83	.83	.21	.08	21.70	290,205
No. 13	[2] 1897	1,870	35	140	261,800	140	2.17	2.17	2.94	3.81	3.81	2.72	3.75	1.07	.80	.80	56.30	105,340
No. 15	1903	886	9	36	106,320	120	4.44	4.20	3.37	6.19	2.27	3.93	2.26	1.69	.45	.45	64.90	57,499
No. 16	1904	432	16	64	69,120	160	2.25	2.30	2.29	2.40	2.29	2.24	2.32	2.32	2.31	2.31	58.40	25,208
No. 17	1910	1,263	69	276	214,710	170	4.27	4.29	4.32	4.32	4.31	4.32	4.36	4.36	4.36	3.56	128.40	162,120
No. 18	1918	576	6	24	69,120	120	3.41	4.87	4.86	2.63	1.51	1.26	1.22	1.22	.95	.97	42.30	24,359
No. 19 [1]	1919	1,960	79	316	254,800	130	.98	1.15	1.01	1.00	-----	-----	-----	.51	.15	.03	9.20	17,984
No. 20	1919	537	18	72	53,700	100	1.87	1.87	3.73	2.52	2.52	1.38	1.86	.93	.42	-----	34.30	18,444
No. 21	1922	391	7	28	46,920	120	3.10	1.92	-----	2.11	1.67	2.56	2.05	2.84	1.18	.58	18.00	7,037
Total or average	-----	45,030	1,767	7,068	7,311,180	162	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	39.10	1,760,394

[1] Either wholly or partially outside of Skagit River drainage area, but diking largely occasioned by overflow from the Skagit.
[2] Reorganized 1929.

139. *Drainage and drainage districts.*—Supplementing the protection to the delta lands furnished by the diking districts, drainage districts have been organized for the purpose of providing the necessary drainage for the lower portions of the delta. The principal ditches are shown on plate 3[1] of the maps accompanying this report, and table 45 gives data concerning the districts.

TABLE 45.—*Drainage districts, Skagit County*

District	Date organized	Acres in district (1931)	Recent annual assessments per acre for drainage				
			1922	1923	1924	1925	1926
No. 14	1900	9,453	$0.48	$0.43	$0.53	$0.79	$0.53
No. 15	1906	9,452	.15	.99	.99	.84	.70
No. 16	1906	2,768	.47	.70	.61	.61	.65
No. 17	1909	4,987	1.60	1.40	1.40	1.40	1.30
No. 18	1910	1,575	.32	.32	.38	.45	.45
No. 19	1922	6,508	.91	2.73	2.73	2.66	2.72
No. 20	1920	537	.94	.94	.19	.27	.28
No. 21	1922	547		2.68	4.02	4.02	4.18
No. 22	1928	1,134					
No. 13[2]	1928	1,837					
No. 16[3]	1928	318					
Total or average		39,116					

District	Recent annual assessments per acre for drainage					Total levies to 1931, inclusive	
	1927	1928	1929	1930	1931	Per acre	For district
No. 14	$0.58	$0.58	$0.54	$0.32	$0.42	$21.60	$204,034
No. 15	.84	.85	.53	.38	.31	16.10	151,942
No. 16	.89	.76	.54	.82	.82	15.50	39,141
No. 17	1.30	1.30	1.20	.60	.60	31.90	159,647
No. 18	.45	.44	.51	.76	.51	13.60	21,434
No. 19	2.72	2.73	[1] 6.82	[1] 6.14	[1] 5.51	34.80	227,358
No. 20	.02			.05		6.20	3,313
No. 21	4.18	3.74	4.75	3.64	3.39	34.50	18,865
No. 22			2.65	1.76	1.97	6.38	7,235
No. 13[2]			2.72	1.60	1.20	5.52	10,146
No. 16[3]			2.99	4.72	4.72	12.43	3,957
Total or average						21.60	847,072

[1] Mainly for retirement of bonds
[2] Drainage improvement system within diking district no. 13.
[3] Drainage improvement system within diking district no. 16.

140. Including the amounts spent by individuals, the total expenditures by local interests for the protection and reclamation of the delta lands may be conservatively estimated at nearly $3,000,000. In addition, following the flood of 1921, a levy of 1 mill on the assessed valuation of Skagit County was placed to provide a fund in accordance with State law, known as the "river improvement fund", to be used for the purpose of investigation of the flood problem by competent engineers, the collection of necessary additional hydrographic data, and the preparation of plans for relief. The work done by Mr. Stewart (par. 116) was paid for from this fund. For the purpose of securing accurate stream-flow records, a very complete gaging station has been constructed at The Dalles in collaboration with the United States Geological Survey, which, on account of its excellent location,

[1] Not printed.

will give better records of flood flows than have hitherto been available. Some minor works of improvement have also been carried out. The total expenditures from this special fund to date, plus the available cash balance, amount to over $20,000.

141. *Flood damages.*—The average annual loss by flood damages has probably been between $125,000 and $150,000. Capitalizing this larger amount at 4 percent, it would seem that $3,750,000 represents the maximum amount that might be justified for control of floods. Although the losses are large, their exact determination is difficult, especially in estimating losses due to interruption and disruption of business. During the past 50 years the total loss on account of floods has been considerable. As the valley becomes more highly developed, and without proper flood control, each succeeding flood is likely to be more disastrous than the last. A flood as large as that of 1815, which had nearly double the discharge of the 1909 flood, would cause great suffering and enormous monetary damage.

142. A summary of the known flood losses is given in table 46. The record is incomplete but serves as a guide in establishing the average losses assumed in the preceding paragraph. It will be noted that no floods occurred between 1921 and 1932, these years being recognized as years of low average yield. Additional details of the flood losses are given in the succeeding paragraphs.

TABLE 46.—*Summary of known flood losses*

	Loss
1894	$1, 500, 000
1897	(1)
1906	250, 000
1909	1, 500, 000
1917	500, 000
1921	500, 000
1932	600, 000
Total (incomplete)	4, 850, 000
Average:	
1906–21	183, 000
1894–1921	157, 000
1906–32	129, 000
1894–1932	127, 500

143. The spring flood of 1894, which destroyed crops valued at approximately $1,500,000, prompted the settlers to extend their system of dikes. The flood of 1897 washed out the Great Northern Railway embankment between Burlington and Sedro Woolley, flooded part of Mount Vernon, and caused a heavy loss of stock and property in the district above Concrete. A less disastrous flood in 1906 caused a loss in stock and property of $250,000. The flood of 1909 caused damage conservatively estimated at $1,500,000. It ruined many farms, destroyed several hundred head of horses and sheep, and washed out many dikes and drainage ditches. The Great Northern Railway embankment between Mount Vernon and Burlington was washed out, and serious damage done to the State highway. That part of Mount Vernon west of the river was entirely flooded.

144. The flood of 1917 caused a loss of about $500,000. It destroyed the rights-of-way of the Great Northern Railway and of the Pacific Northwest Traction Co. between Mount Vernon and Burling-

[1] No record.

ton, seriously interrupting the communication of the region for 2 weeks. Extensive damage was also done to the dikes.

145. The 1921 flood caused a tangible loss of more than $500,000, the greatest damage being inflicted upon the land and crops, roads, and bridges, dikes and ditches, and the logging industry.

146. *February 1932 flood damages.*—The tangible damage resulting from the February 1932 flood of the Skagit River is estimated to be about $600,000. This amount does not include such intangible damages as the loss of trade on account of the disruption of business and the crippling of transportation and communication. The chief injuries suffered were, in round numbers: To farm land, improvements, and crops, $500,000; to railways, $46,000; to public roads and bridges, $36,000; and to dikes, $14,000.

147. Farm land and crops: A rough estimate prepared by Mr. Vey J. Valentine, Skagit County agricultural agent, places the flood damage to farm land and crops at more than half a million dollars. Many acres of valuable land were inundated by the flood waters which in numerous cases destroyed harvested and unharvested crops, wrecked farm buildings and fences, and damaged the lands by erosion, and by the deposition of snags, debris, and sand. Those farms which were damaged the most are a total loss for 1 year and a partial loss for several years. In a few cases, particularly above Burlington, where lands were inundated, the river did no great amount of damage, but instead deposited a layer of rich silt of probable greater value than the losses sustained.

148. The following is a summary of the county agricultural agent's estimate of loss to farm land and crops:

Agricultural land	$75, 000
Seed crops	250, 000
Oats	140, 000
Berries	16, 000
Fences and debris	50, 000
Total	531, 000

Although this estimate seems somewhat large, it does not include damages to farm buildings, or intangible losses.

149. Railways: The damage to railways is estimated at approximately $46,000.

Report of extent and cost of damages by Great Northern Ry. Co.:	
Damages to fender pier and rock-filled crib at bridge no. 36 across Skagit River 2 miles south of Burlington	$4, 800
Roadbed washed out for 600 feet ¾ mile north of bridge no. 36	6, 500
Expense of detouring trains, transferring mail, baggage, etc	1, 351
Roadbed of Anacortes to Rockport branch washed out at 14 places	4, 000
Damages to 6 bridges on Anacortes to Rockport branch	1, 697
Total	18, 348
Damages to City of Seattle Lighting Department Ry. above Rockport:	
Destruction of 2 bridges across Bacon Creek and Diobsud Creek	15, 000
Track undermined for 200 feet near Rocky Creek, requiring considerable riprap	3, 000
Total	18, 000
Chief damage to Puget Sound & Cascade Ry., as reported by the Puget Sound Pulp & Timber Co.: 200 feet of track and 600 feet of bank protection washed out about 1½ miles below Hamilton	10, 000
Grand total	46, 348

150. Public roads and bridges: Highway transportation was practically at a standstill for 30 hours, and the estimated damages to roads and bridges is about $36,000. The Pacific Highway was closed south of Burlington, the Avon-Bellingham Road was closed because of a washed-out bridge, the highway was badly flooded between Lyman and Hamilton, the Sedro Woolley-Wickersham Road was closed, about 10,000 cubic yards of fill on the Sedro Woolley-Clear Lake Road was washed out at the north approach to the Skagit River bridge, and a 448-foot county bridge across the Sauk River near Darrington was carried away.

151. The estimated flood damages to public roads and bridges is summarized as follows:

Destruction of bridge and approaches across the Sauk River near Darrington	$15,000
Partial or total destruction of about 20 small bridges	8,000
Damage to roads on account of dike breaks	7,500
Sedro Woolley-Clear Lake Road washout	3,700
Destruction of 60-foot bridge across Diobsud Creek near Marblemount	2,000
Total	36,200

152. Dikes: Four principal breaks occurred in the river dikes, involving a total reconstruction cost of approximately $14,000. (See par. 130.) The following is a summary of estimated damages to dikes:

Location of break	District	Damage
South Fork, near Fir	Diking no. 2	$7,500
Main Skagit, near Great Northern Ry. bridge	Diking no. 12	4,000
North Fork	Diking no. 15	1,500
Deer (Dry) Slough	Diking no. 13	1,200
Total		14,200

153. Miscellaneous: None of the towns along the river suffered any direct loss, except Lyman and Hamilton, which had slight damages to dikes at a total cost of about $400. The city of Seattle lighting department reports a loss of $17,000 not directly attributed to the flood, but principally occasioned by slides along the City of Seattle Railway. These slides killed four workmen. The loss of livestock amounted to a dozen animals.

154. *Interested parties.*—The parties interested in measures for flood relief are:

First, the owners of the lands subject to overflow: Their interest is direct and vital.

Second, the towns along or near the river: Their interest is direct so far as they may be subject to actual flood damage and interruption of business in time of floods; indirect in that their prosperity is largely dependent upon that of the owners of the flooded lands.

Third, the Great Northern Railway Co.: This road has a very direct interest due to the actual damage to its tracks and roadbed, the danger of its bridge being destroyed, and loss of business due to interruption of service.

Fourth, the Pacific Northwest Traction Co.: The bridge of this company would very likely be destroyed if the Great Northern bridge were carried away. Its tracks and roadbed are damaged by floods and its business is interrupted and suffers accordingly.

Fifth, the Puget Sound & Baker River Railroad: A portion of the track of this company lies within the area subject to floods.

Sixth, the Puget Sound & Cascade Railroad: This road closely follows the river bank for considerable distances and might be damaged to some extent in large floods.

Seventh, Skagit County: The direct interest of the county is probably limited to possible damage to county roads and bridges. Indirectly it is vitally interested, since the greater part of its population is located in the delta.

Eighth, the State of Washington: The State has a direct interest insofar as possible damage to its roads and bridge is concerned, and is indirectly interested insofar as its prosperity is dependent upon that of the units of which it is composed.

Ninth, the United States Government: Such interest as the Government has is somewhat remote, but will be referred to later.

IRRIGATION

155. No irrigation works have been constructed in the basin, as the precipitation is abundant for all crops now raised; and it is not likely, therefore, that irrigation will ever be practiced to any great extent.

BANK EROSION

156. *General.*—Bank erosion along the Skagit River is continuous, cutting occurring over nearly the entire length of the stream and at all stages of the water. Geological evidence indicates that the river channel has been shifting so as to occupy the lower valley, at one time or another in the past, for a width of several miles.

157. Generally, the most extensive and consequential cases of erosion occur along the right (north) bank of the Skagit and below the town of Concrete (mile 56). For nearly the entire distance from Concrete to Sedro Woolley, the river hugs the south side of the valley so that the hills along the left bank rise sharply, but the land along the right bank is open and suited to settlement. Above Concrete the effects of erosion are locally confined without danger of serious consequences; whereas, below Concrete, the river affects tracts of developed agricultural land and in some instances there is danger of complete diversion.

158. The erosive work of the Skagit is governed mainly by the soft character of the banks along the lower stretches, and by the transporting power of the river which depends upon its slopes and consequent velocity. From Concrete to the mouth, the material of the river banks changes from gravel to light alluvium, and the transported material varies from coarse sand to fine silt. The stretch of the river from Concrete to Lyman has an average fall of 5 feet in a mile; Lyman to Sedro Woolley, 3 feet in a mile; Sedro Woolley to Avon, less than 1.75 feet in a mile; and Avon to the mouth, less than 0.75 foot in a mile.

159. *Instances of erosion.*—Short descriptions follow for the most prominent cases of bank cutting.

160. A significant but limited case of erosion occurs at a long bend in the river near Rocky Creek (between mile 73 and mile 74). During the February 1932 flood, the stream cut its concave bank for a length of 500 feet and for a depth of about 50 feet, washing out 200 feet of the City of Seattle Railway track and threatening the city of Seattle transmission line. At this location the banks are 20 feet high and composed of heavy gravel.

161. At Cape Horn, about 7 miles below Concrete, the river makes an ox-bow bend and is cutting its concave bank along a length of more than 1,500 feet (between mile 48 and mile 49). The bank has a height of about 40 feet, is composed of gravel, and is subject to the greatest erosion during periods of high water. During the past few decades lateral cutting has taken place over a few hundred feet, making it necessary to move the county road several times. Although this case of bank cutting is an example of rapid erosion, its consequences are not serious as the adjacent land is practically waste and rebuilding of the county road has been a negligible cost.

162. Near the town of Birdsview, on a relatively straight stretch of the river (between mile 45 and mile 46), the right (north) bank has been cut back about 250 feet for a length of 2,000 feet. This cutting was most serious during the 1921 flood, and there has been practically no erosion since then. At this point, the bank, which is composed of sand and gravel, is 25 feet high. The main damage in 1921 was the washing out of 800 feet of county road, which cost about $4,000 to relocate. Because this erosion was principally caused by an obstruction of drift near the opposite bank which deflected the current, extensive cutting in the near future is not probable.

163. About 1 mile above Hamilton (just above mile 41), on a rather straight reach of the river, cutting has occurred during flood periods along the right (north) bank for a length of 1,500 feet. A county road has been washed out several times, and during the 1921 flood the stream cut laterally about 30 feet, destroying 700 feet of road which cost $500 to replace. In this location, the banks are sand and gravel, and about 15 feet high. Erosion takes place chiefly at flood stages when the banks are saturated with water. The 1921 cutting was aggravated by a collection of flood debris which closed a channel near the opposite bank and deflected the current. The adjacent lands are in cultivated farms, but they are not in great danger from the present slight cutting action.

164. At an ox-bow bend (mile 39) just below Hamilton, the water is eating into the concave bank over a length of 3,500 feet. This erosion goes on continuously at all stages of the river, though the effects are greatest during periods of high water and floods. During the past few decades the stream has cut laterally 500 feet or more, destroying farm lands which were divided into small private tracts, and causing the abandonment of nearly 3 miles of county road. Along this stretch, the banks are steep and low, consisting of about 8 feet of sand overlying a layer of gravel. At this location there is danger of a diversion of the river to the northwest in the vicinity of Etach Creek. Such a diversion would cross the Great Northern Railway tracks and the county highway, flow west along the low-lying ground north of the railway tracks, and probably rejoin the main river channel near the town of Lyman.

165. During the February 1932 flood, the river cut the south bank for a length of about 1,000 feet at a bend 1½ miles below Hamilton (between mile 37 and mile 38). The character of the bank at this point is sand and gravel. About 600 feet of bank protection was washed out and 200 feet of track of the Puget Sound & Cascade Railway undermined. It is estimated that the cost of replacement of the protective works and railway grade will be approximately $10,000.

166. At an ox-bow bend (mile 35) immediately above the town of Lyman, the Skagit is cutting its concave bank so as to endanger town property. The bank is affected longitudinally for 1,500 feet and has been cut back laterally about 400 feet in the last 10 years. Sand and gravel compose the bank, which is 15 feet high. Although erosion at this point goes on at all stages of the river, the greatest damage has been done during floods. The 1921 flood destroyed about 4,000 feet of county road. The February 1932 flood cut laterally for 50 to 75 feet into small, privately owned, cultivated tracts. About 15 houses are exposed to loss if the river continues to erode at this point. There is possibility that a diversion may occur between Lyman and Jones Creek. Such a diversion would head to the northwest, cross the Great Northern Railway tracks and the county highway, and thence flow west toward Minkler Lake.

167. Arnold Slough, which is about 3 miles long, is in the nature of a cut-off of the river from near mile 33 to mile 29. At high-water stages the slough carries from one third to one half of the river's discharge. Bank erosion is continuous in both the river and slough. During the February 1932 flood stretches of this slough widened from 150 to 500 feet. Erosion is most marked for 2,000 feet along the concave bank of a long bend in the river at the entrance to the slough, and for about 2,000 feet at ox-bow bends in the slough. The banks are sand and generally about 8 feet high. The chief damage has been the destruction of improved or partially developed farm lands. Near the middle of the slough about 300 feet of county road has been washed out.

168. About 2 miles upstream from Sedro Woolley (between mile 24 and mile 25), the river is cutting the concave bank of a 90° bend for a length of nearly 3,000 feet, and for about a mile below the bend the banks have collapsed after flood waters. The banks are composed of sand, being 15 feet high on the bend and somewhat lower below that point. The chief damage from erosion is to partially cultivated farm lands.

169. At Sterling Bend (between mile 20 and mile 21), about 2 miles below Sedro Woolley, the flood waters of 1921 formed a natural cut-off by breaking across a neck of land that separated two adjoining bends. In creating this new channel, the Skagit scoured an area of land about 2,500 feet long and 1,500 feet wide. Erosion at present is most marked for 2,000 feet along the concave bank of a bend below the cut-off. At this location the banks, which are 20 feet high, are composed of alluvium. The presence of a layer of sand at the level of low water permits the bank to be easily undermined at low stages of the river. The rate of cutting is further increased by hard bars on the opposite side of the stream which deflect the current against the concave bank. During the February 1932 flood the bank was cut back about 40 feet, and it is estimated that during the past 10 years

100 acres of improved farm land have been lost on account of bank erosion.

170. About 1 mile above Burlington (between mile 18 and mile 19), the river is cutting the concave bank of a bend along a length of 3,000 feet. The bank is of alluvium, 20 feet high, and has a layer of quicksand about the level of normal water. Erosion is most rapid at high-water stages, and progresses from 15 to 20 feet laterally per year, destroying cultivated farm lands.

171. On the North Fork, the river is cutting into the right (north) bank of a long bend for a length of nearly 1,000 feet at the county highway bridge (mile 4). This erosion goes on at all stages of the river, and has cut back laterally from 25 to 50 feet, washing out bank revetment. At this point the bank, which is about 10 feet high, is composed of light alluvial material. The north bridge approach and pier are imperiled by this cutting, and the county has spent several thousand dollars in bank protection.

172. *Existing bank-protection works.*—Skagit County, the diking districts, and railroad companies have taken steps to prevent land erosion by the construction of bank revetment, groins, and drift barriers to close secondary channels. Some of these works have given relatively permanent relief, but in many cases the protective works have been either wholly or partially destroyed during flood stages.

173. *Interested parties.*—As the descriptions of cases of bank erosion indicate, the chief loss is sustained by the private riparian owners whose lands are destroyed, and by Skagit County, whose roads have been washed out. The interest of the land owners in bank cutting is direct and vital. The county is interested directly in the damage to its roads and bridges and indirectly in the welfare of its citizens. Of the towns along the Skagit, Lyman is directly interested because it stands immediately in the path of the cutting action of the river. The owners of several railroads which skirt the river have a direct interest where their tracks are subject to probable washouts from erosion. Such interest as the State of Washington has would be direct only in the event of a complete diversion, for such a diversion would affect the State highway and would remove considerable property from the tax rolls. The interest of the United States Government is remote.

Chapter IV. Measures for Improvement

NAVIGATION

174. *Lower river.*—The existing project for improvement of Skagit River has not been a success. This is partially due to the fact that requirements for local cooperation have prevented its completion. The boat line has abandoned the use of South Fork, but its boats are still hampered by shoals at the entrance to North Fork and again near its junction with South Fork. Present or prospective commerce does not warrant any modification or enlargement of the existing project to include either improvement of North Fork or further work on South Fork. Improvement by means of locks is not considered either practicable or advisable on this river. Snagging and a limited amount of emergency dredging has been carried on under the existing project for Puget Sound and tributary waters and will be continued. This work is meeting the needs of navigation in a fairly satisfactory manner.

175. *Upper river.*—Improvements of the river above Sedro Woolley for navigation are not needed except for some small amount of snagging. The commercial use of the river in this section is limited to the towing of logs by light-draft boats with drafts of not over 28 inches. As noted in paragraph 86, during low stages of the river these boats make use of the fluctuations in the river due to the operations of the Baker River power plant of the Puget Sound Power & Light Co. to float the logs over the bars. With ideal regulation of all the storage outlined hereafter for the various power developments, the minimum natural monthly flow at The Dalles for the period from April 1914 to March 1931 would have been more than tripled, and all flows of less than 15,600 second-feet would have been increased. (See fig. 8.) Also, the attendant decrease in flood flows would tend to decrease the number of snags deposited in the lower river.

176. *Federal participation.*—The bulk of the commerce of the river is confined to the tidal section below Mount Vernon. Hence, its movement would not be aided materially, if at all, by an increase in the low-water flow. The increased low-water flow resulting from the regulation of upstream storage would increase navigable depths on the upper river and would thereby aid the towing of logs, to which the commerce of the upper river is limited. However, it will probably be many years before the upstream reservoirs will have been developed and, by that time, the forest resources adjacent to the stream may have been depleted and log towing reduced to the vanishing point unless reforestation is undertaken as outlined in paragraphs 66 and 67. Therefore, participation by the Federal Government in the cost of upstream reservoirs does not appear to be justified on the grounds of benefits to navigation.

POWER

177. *Introduction.*—Undeveloped power sites on the Skagit may be grouped in two general classes, viz, minor and major projects. The scope of the field investigation was limited, as stated in paragraph 7, by the funds allotted for this study. Some 14 so-called "minor projects" are briefly described in the succeeding text and a general plan of development is set up for each. There may be other sites that are as large and as economically feasible as those described herein, but the minor projects include all the principal known sites. The available data for the minor projects are, as a rule, too meager for determination of the best plan of development in each case. The plans are therefore to be considered as tentative only and subject to revision or complete change as additional data become available in each case. The plans are intended merely to indicate in a general way the power possibilities of these sites.

178. The four major power projects discussed herein are classed as major projects principally because of the storage available at each site and because of the possible effect the regulation of this storage might have on navigation in connection with power development and flood control. In general, more data were available for the major projects than for the minor projects, but even so, a large amount of detailed investigation would be required before actual construction could proceed. Some of the projects, both minor and major, show costs that render them economically feasible at the present time; the others may not become economically feasible for many years.

179. All of the large floods that occurred during the 17 years covered by the period selected for particular study, occurred within the 3 winter months from November 1 to January 31. Based on that fact, studies were made of the possibility of combining storage for power and for flood control in the four reservoirs of the major projects. Such a combination of uses appears feasible for the particular 17-year period studied. However, floods have occurred on the Skagit during almost every month of the year. For example, in 1896, there was a flood in January with a gage height at Mount Vernon of 22 feet; one in June of 20 feet, probably not exceeding 100,000 second-feet; and one in November of 24 feet. And in 1932, the next year following the end of the 17-year period, there was a flood on February 27–28. (See par. 126.)

180. In the following descriptions of the four major projects, data are presented showing the possibilities of combining storage for power and flood control for the flows that occurred during the 17-year period. It is shown that top storage in amounts varying with the reservoir could have been reserved in each of the four reservoirs during the 3 winter months, November, December, and January, of the 17-year period and that such a reservation would not have lessened the power output materially. The advisability of limiting this reservation to the 3 winter months is debatable, in view of the fact that floods have occasionally occurred in other months. In consideration of this point, the power available at each of the four sites has been given for the added condition of a full round-the-year reservation for flood storage. It is considered futile to make a definite decision at this time as to the reservations to be made for flood storage, because of the length of time that will probably intervene before these sites are actually developed; because of the indeterminable future value of power to be developed at these sites; and because of the absolute uncertainty as to the extent of the participation by parties to be benefited from such reservations for control of flood waters.

181. The maximum of protection from floods, with the storage hereafter set up, would result from a unified control and a full round-the-year reservation of that storage. It is clear that the cost of such maximum protection is considerably more than the damages avoided. It is, therefore, probable that a full round-the-year reservation of top storage, in the amounts herein set up, will never be effected. Some reservations for storage of flood waters in the reservoirs of the four major projects should be required. Whether those reservations should be for top storage in the amounts herein set up and for the 3 winter months, or for the whole year, or for some greater or lesser amounts, or for other portions of the year, can be determined only when a full knowledge of the extent of participation by interested parties is at hand.

182. For purposes of comparison, the power available at the four major sites is discussed in the following text for three conditions: First, for a development involving use of all the storage for power alone; second, reservation of top storage during the 3 winter months in the interest of flood control; and, third, reservation of top storage all the year around in the interest of flood control.

MINOR POWER PROJECTS

183. *Project no. 1, Thunder Creek*.—The diversion dam for this project would be located on Thunder Creek about 8 miles above its confluence with the Skagit and just below the mouth of Middle Creek (long. 121°02′ and lat. 48°38′). The creek at the site flows through a narrow gorge of granite about 40 feet wide at water surface. The natural low-water elevation is approximately 1,760 feet. A forebay would be created by a concrete arch dam with a normal water elevation of 1,840 feet. Diversion would be made along the left bank by a series of tunnels leading to the power site located on Thunder Creek at the 1,200-foot contour, which is the normal level of Diablo Reservoir. The total head would be 640 feet.

184. The mean monthly stream flow for the creek at its mouth is given in table no. 13 for the 17-year period October 1914 to September 1931, inclusive. The drainage area is given as 111 square miles. The Q 90 natural flow is 162 second-feet. The drainage area at the diversion dam has been estimated as 90 square miles, and the Q 90 flow as 130 second-feet. No regulation was considered, as the stream is highly glacial. The corresponding plant capacity would be 10,000 kilowatts at 70 percent efficiency and 50 percent load factor. The estimated cost per kilowatt of the project is $160, based on the rather meager data available.

185. An alternate plan of development would consist of diversion into the proposed Ruby Reservoir, with the power house located on the 1,700-foot contour. From the available data, this plan does not appear to be economically feasible. Diversion into Ruby Reservoir without development of any power in transit may be feasible and has been mentioned under the Ruby project.

186. *County-line project no. 2*.—The dam site for this project is located on the Skagit River in sec. 10, T. 36 N., R. 11 E., about 7½ miles below the Gorge plant of the city of Seattle. (Long. 121°20′ and lat. 48°37′.) The stream at the site flows through a narrow gorge for half a mile at a fairly high velocity, with a fall of 25 feet to the mile. The width at low stages is about 150 feet. The natural low-water elevation is 375 feet. No test borings have been made at the site. Solid rock is exposed on both banks and the stream bed is composed of boulders, some of which are very large. A dam would be constructed of sufficient height to back the stream up to the existing Gorge plant of the city of Seattle, where the tailwater elevation is 485 feet. The spillway should be of ample capacity and capable of close regulation in order to protect the Gorge plant from undue backwater.

187. Table 8 shows the mean monthly stream flow at the Gorge plant for the period October 1909 to September 1931, inclusive. A stream-flow study for the 17-year period October 1914 to September 1931, with regulation of the Ruby Reservoir between elevations 1,700 and 1,500 feet (2,428,000 acre-feet storage) shows the Q 50, Q 90, and Q 100 flows to be 4,360, 3,920, and 3,810 second-feet, respectively. The power house would be located a quarter mile below the dam, where the natural low-water elevation is about 370 feet. With a head of 115 feet, the corresponding plant capacity for the Q 90 flow would be 61,500 kilowatts at 80 percent efficiency and 50 percent load factor. The available data are not sufficient for a reliable cost estimate.

188. *The Faber project no. 3.*—The urgent need of storage for controlling floods in the lower Skagit Valley, combined with the possibility of developing a large and economical power project, were the factors considered in initiating the investigation of that stretch of the Skagit River immediately below the confluence with the Sauk. (See fig. 7.)[1] The possibility of such a development was first suggested by Mr. G. L. Parker, district engineer of the United States Geological Survey, Tacoma, Wash., about 1925. At his instance, a geological investigation of the suggested dam site was made and an unpublished report rendered in 1927 by Mr. J. T. Pardee, a geologist with the Geological Survey. Mr. Pardee found that—

> The sediments * * * are not only uncemented but contain a maximum of voids or open spaces so that the coarser-textured layers would "leak like a sieve." The silt, however, despite its porosity is so fine-textured that water passes through it slowly and it possibly could be made sufficiently watertight with a reasonable amount of lining.

Notwithstanding this rather adverse report, it seemed desirable to investigate this site still more. Topographic and visible geological conditions indicated 2 probable sites about 3.2 miles apart. Accordingly, 2 drill holes were sunk by this department, 1 at each of the 2 sites; but solid rock was not encountered in either hole. (See fig. 7.)[1]

189. The power development and flood-control possibilities of the two sites are practically the same, hence will be treated as one. Regulation between elevations 400 and 200 feet has been roughly estimated to provide 1,700,000 acre-feet of storage. This would prevent development of the lower Sauk site and would cause some backwater at the county line and Cascade River sites. The mean flow is practically 12,000 second-feet and the Q 90 flow has been roughly estimated at 9,000 second-feet. Assuming an operating head of 180 feet, the permissible plant capacity would be 220,000 kilowatts at 80 percent efficiency and 50 percent load factor. Judging from the study of other Skagit sites, some 400,000 acre-feet flood storage could be reserved in the winter months and half that storage in the early spring run-off at no great detriment to power production.

190. The upstream site, known as the "Upper Faber", is located in sec. 33, T. 35 N., R. 9 E., about a mile downstream from the mouth of the Sauk. (See fig. 7.)[1] The stream at this point is separated into several channels at low flows, the total width at the water surface being 1,500 feet. The natural low-water elevation is 195 feet. The left bank rises on a slope of 1¾, horizontal, to 1, vertical for a height of at least 300 feet above the water surface and is composed of solid rock which has been classified as slate. Apparently it is impervious and could support a dam of any reasonable height. The right bank rises on a 1½, horizontal, to 1, vertical slope for about 300 feet above the water surface and is composed of a glacial silt which has been named Faber silt. This material is fine-grained, contains a large percentage of voids and has a tendency to slump badly. One test hole was drilled on this bank near the water's edge, to a depth of 150 feet (elevation 55 feet). Boulders and gravel were prevalent to a depth of 55 feet, below which the composition was principally silt and fine sand. No bedrock was encountered. The material is considered too porous and unstable to support a dam

[1] Not printed.

of the desired height. B. Thomas, of Seattle, Wash., has applied to the supervisor of hydraulics of the State of Washington for a permit to divert 8,000 second-feet at this site for a power development.

191. The other site, known as the "Lower Faber", is located in secs. 18 and 19, T. 35 N., R. 9 E., about 4 miles downstream from the mouth of the Sauk. (See fig. 7.)[1] The stream is about 600 feet in width and has a natural low-water elevation of 180 feet. The right bank is precipitous and is composed of solid rock classified as argillite. It is apparently sound and impervious. The left bank consists of a low bench extending for more than a quarter of a mile from the river, then rises on a 2 : 1 slope to elevation 600 feet. It is composed principally of Faber silt. A test hole sunk on this bank to a depth of 153 feet (elevation 46 feet) disclosed principally sand and gravel, with some indication of clay in the lower strata. No bedrock was found. The material seems to be more impervious than that at the Upper Faber site, but is not considered suitable for a dam of the desired height.

192. In view of the questionable and very unfavorable foundation conditions of these two sites and the apparent absence of any other sites between the Baker and Sauk Rivers, this project is considered infeasible.

193. *The Dalles project no. 4.*—The dam site for this project is located in sec. 16, T. 35 N., R. 8 E., a mile west of the town of Concrete and 2 miles by river below the mouth of the Baker River. The channel at the site is sinuous and has solid rock walls. (See pl. 2.)[1] At low water it is about 200 feet wide and 45 feet deep. The elevation of natural low water is 143 feet. No test borings have been made. The left bank is composed of slate which rises abruptly to an elevation of 240 feet and on a more gradual slope to an elevation of 1,000 feet or more. The dip of the strata varies from 35° to 90° and the strike runs northwest parallel to the river. The right bank is composed of schist that rises rather abruptly to form a ridge with a maximum elevation of 240 feet, and then recedes. Back of this ridge there is a saddle with a minimum elevation of 180 feet. The depth to bedrock in the saddle is not known.

194. The mean monthly stream flow for the period April 1914 to September 1931 is shown in table 9. The mean flow for this period is 14,400 second-feet, and the minimum is probably less than 2,160 second-feet. Mr. J. E. Stewart in his flood study (see table 35) estimated the peak discharge about 1815 as 480,000 second-feet; about 1856 as 350,000 second-feet; November 19, 1897, as 270,000 second-feet; November 30, 1909, as 260,000 second-feet; December 30, 1917, as 220,000 second-feet; and on December 13, 1921, as 240,000 second-feet. Assuming that this project would not be developed until after construction of upstream flood-retention reservoirs, a spillway capacity of at least 200,000 second-feet would be required.

195. For the above period, the Q 90 natural flow is 5,540 second-feet, and the Q 50 natural flow is 12,000 second-feet. With regulation of Ruby Reservoir to elevation 1,700 feet, Cascade reservoir to 1,100 feet, Lower Sauk to 498 feet, and the upper Baker to 704 feet, all for power only, the Q 100, Q 90, and Q 50 flows are 9,530, 11,000, and 14,300 second-feet, respectively. (See fig. 8.)

[1] Not printed.

196. The forebay elevation for this project would be limited by the backwater effect in the tailrace of the existing Baker River plant owned by the Puget Sound Power & Light Co. With a discharge of 4,000 second-feet through the turbines and no spill over the dam, this tailwater elevation is 175.5 feet. No detailed plan of the project has

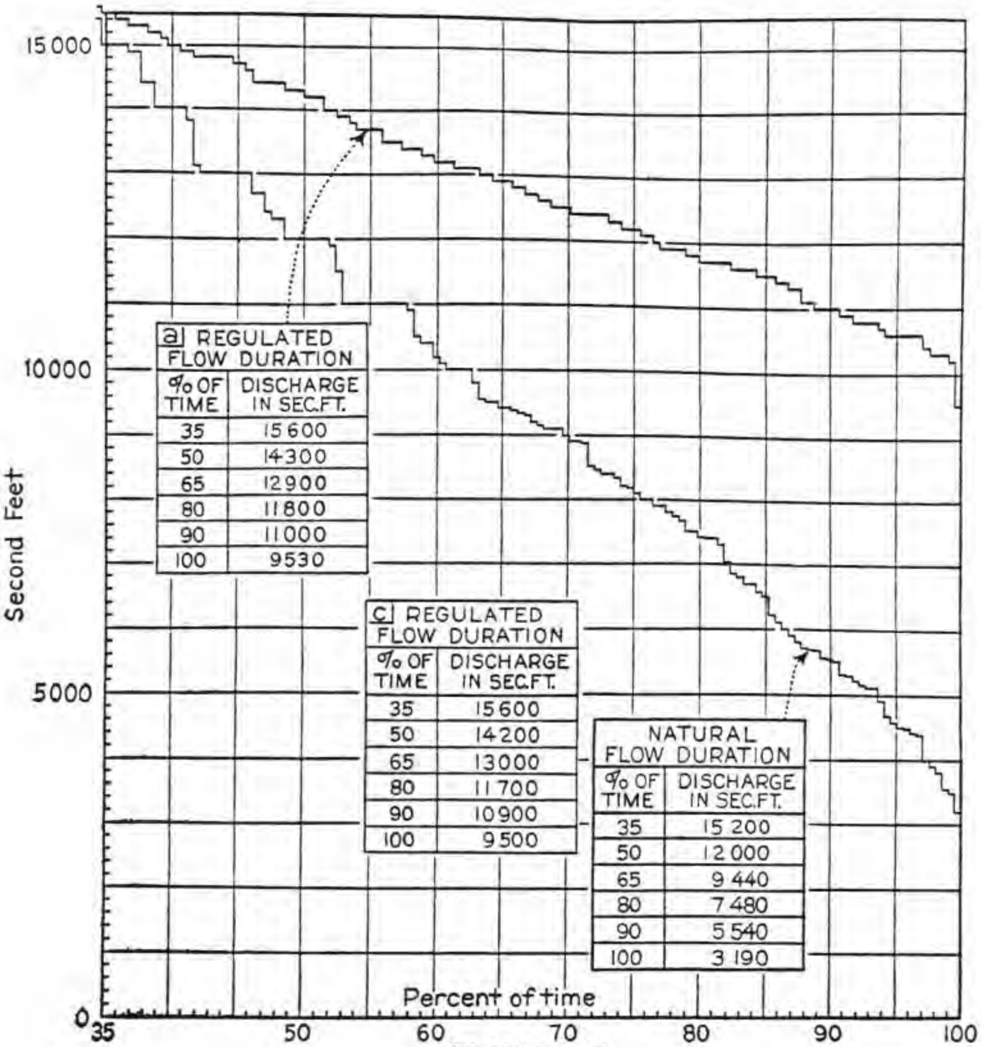


FIGURE 8
SKAGIT RIVER AT THE DALLES
FLOW DURATION–PERIOD APRIL, 1914–MARCH, 1931
U.S. Engineer Office Seattle, Washington

a) Regulation in upstream reservoirs as shown by the a) curves of Figures 9, 11, 12, and 13.
c) Regulation in upstream reservoirs as shown by the c) tables of Figures 9, 11, 12, and 13. (Curve not shown)

been made by this office, but the spillway would be one of the most important and expensive features of the project. The power house would be placed as near to the dam as the spillway conditions would permit. At low flows the tailwater would be at about elevation 144 feet, with an operating head on the plant of about 31 feet. The corresponding plant capacity would be 46,000 kilowatts at 80 percent efficiency and 50 percent load factor. A reliable estimate of cost cannot be made on the data available.

197. *Projects 5 to 13, inclusive.*—These power projects are located on the upper Sauk and on the Suiattle and Whitechuck Rivers, tributary to the Skagit, and are within the Mount Baker and Snoqualmie National Forests in Skagit and Snohomish Counties, Wash. (See pl. 5.) Mr. Robert Howes, a consulting engineer, made a field reconnaissance of many of these sites in October 1914 for the city of Seattle. No definite action looking to the acquisition of any rights in this vicinity was ever taken by the city. The American Nitrogen Products Co., now defunct, made extensive surveys and some test borings in this area in 1916 and 1917. Their plans called for a high utilization of these streams and proposed to concentrate the power at three stations, by rather long conduits. Such a plan would be favorable from the standpoint of economy of operation; but studies by this office indicate that the cost in many cases was not justified. The data for projects 8, 10, and 11 were obtained from the above company and are believed to be reliable. The data for the remaining projects in this area were obtained from the Water Supply Paper 419 (scale, 2 inches to a mile) and from the quadrangle sheets of the area (scale, 1 inch to 2 miles), both of which were prepared and published by the United States Geological Survey. With the exception of a reconnaissance of project 9, none of the projects have been investigated on the ground by this office; hence, the data for those projects are approximate only. Costs were estimated from quantities taken from a paper location of the plants.

198. The stream flow at each of the various points of diversion was computed by assuming the mean monthly discharge per square mile to be the same as the Sauk above the Whitechuck as shown in table 18, which covers the 17-year period, April 1914 to March 1931, inclusive.

199. In the study made by this office of the Stillaguamish River (published in H.Doc. 657, 71st Cong., 3d sess.) it was planned to divert Elliot Creek and the upper South Fork of the Sauk into the Stillaguamish Basin near Barlow Pass, the tunnel to have a capacity of 300 second-feet. Due to this suggested diversion, a project on the South Fork of the Sauk was not considered, although without the diversion an additional installed capacity of about 2,500 kilowatts would be justified for project 6, at a probable cost of $150 per kilowatt.

200. *Project 5.*—The dam and headworks for this project would be located on Sloan Creek about three quarters of a mile above its confluence with the North Fork of the Sauk, on unsurveyed land (long. 121°17½′ and lat. 48° 02½′). It was planned to construct an earth-and-rock-fill dam to store 28,000 acre-feet of water at reservoir elevation 2,350 feet. The North Fork would be diverted into the reservoir by a tunnel about a mile long. The total drainage area of the two streams above points of diversion is 52 square miles. The natural low-water elevation at the dam site is approximately 2,260 feet.

201. Diversion from the reservoir would be made on the left bank by means of a pressure tunnel 2 miles in length leading to the powerhouse site on the North Fork, where the natural low-water elevation is 1,950 feet, which is also the normal reservoir level of project 6. The static head is 400 feet.

202. The estimated flow as regulated by the above storage is 200 second-feet for 90 percent of the time. The corresponding plant

capacity would be 9,600 kilowatts at 70 percent over-all efficiency, using a 50-percent load factor. The estimated cost per kilowatt is $260. The streams are not glacial, hence the reservoir capacity would not be seriously impaired by silting.

203. *Project 6.*—The dam and headworks for this project would be located in unsurveyed land on the North Fork of the Sauk, 2.1 miles above its mouth (long. 121°20′ and lat. 48°05′), where the natural low-water elevation is 1,840 feet. The American Nitrogen Products Co. made a topographic survey of the reservoir site and sunk four test holes at the dam site to depths of 43 to 247 feet. No bedrock was encountered, but wet clay was found at an average elevation of 1,800 feet. As planned, an earth-and-rock-fill dam would be constructed to store water to elevation 1,950 feet with a useful storage of 34,000 acre-feet for a drawdown to 1,870 feet. Benefit would be received from the regulation of project 5. The estimated stream flow 90 percent of the time with above regulation is 317 second-feet. The total drainage area is 78 square miles.

204. Diversion from the reservoir would be made on the right bank by a pressure tunnel 3.7 miles in length leading to a power-house site on the North Fork at natural low-water elevation 1,105 feet, which is the normal reservoir level of project 9. The static head (elevations 1,950 to 1,105 feet) is 845 feet. The corresponding plant capacity would be 33,000 kilowatts at 70 percent over-all efficiency and 50-percent load factor. The estimated cost per kilowatt of a plant of this capacity is $115. As stated for project 5, silting would not be a serious problem.

205. *Project 7.*—The diversion dam for this project would be located on Whitechuck River about 2 miles above Fire Creek, on unsurveyed land of the Snoqualmie National Forest (long. 121°12′ and lat. 48°08′). The natural low-water elevation is 3,100 feet. The stream is glacier fed and heavily laden with silt; hence, storage is not feasible. A concrete-lined canal 5 miles in length, located on the right bank, would cross Fire Creek and run down to a forebay, thence a steel penstock would lead to the power site on the river near the mouth of Camp Creek, at the intake of project 8. The natural low-water surface at the power-house site is 1,900 feet. The total head (elevation 3,100 to 1,900 feet) is 1,200 feet.

206. The drainage area covers 30 square miles. The estimated natural discharge for 90 percent of the time is 69 second-feet, with a corresponding plant capacity of 10,000 kilowatts at 70 percent efficiency and 50 percent load factor. The estimated cost per kilowatt of the project is $115.

207. *Project 8.*—The diversion dam for this project would be located on the Whitechuck River at the mouth of Camp Creek, in unsurveyed land of the Snoqualmie National Forest (long. 121°16′ and lat. 48°09′). The natural low-water elevation is 1,900 feet. As the stream is glacial and a heavy silt bearer, no storage is justifiable. As planned, a concrete-lined canal 8 miles in length would be located on the left bank and extend to the power-house site on the Whitechuck, where the natural low-water elevation is 1,105 feet, which is also the normal reservoir level of project 9. The total head (1,900 to 1,105) would be 795 feet. The drainage area is 50 square miles and includes the entire western slope of Glacier Peak.

208. The estimated natural discharge for 90 percent of the time is 115 second-feet. The corresponding plant capacity is 11,000 kilowatts at 70 percent efficiency and 50 percent load factor. The estimated cost per kilowatt is $130.

209. *Power project 9, Upper Sauk.*—This project involves the construction of an earth-fill dam just below the junction of the Whitechuck and Sauk Rivers, where the natural low-water surface has an elevation of 910 feet. Backing the water up to elevation 1,105 feet would produce a useful storage of 88,000 acre-feet, with a drawdown to elevation 960 feet, as shown by surveys and plans of the American Nitrogen Products Co. On the left bank, solid rock outcrops for a height of several hundred feet and forms a ledge that juts out into the stream. On the right bank the solid rock is exposed for a height of 50 or 60 feet above the water surface. Above this point the bank is composed of glacial till that flattens out on a bench at about elevation 1,080.

210. There is another dam site located on the Sauk about three quarters of a mile above the mouth of the Whitechuck that probably could be constructed at less cost, but the water-tightness of the right bank is questionable. This bank is formed by a ridge of stratified glacial till about 1,000 feet wide adjoining the Whitechuck. Test pits sunk by the American Nitrogen Products Co. show a clay formation for a height of 50 feet above water surface on the right bank, and sand in one pit 110 feet above the water surface. This site would also require the diversion of the Whitechuck into the reservoir by a conduit, with a danger of possible silting up of the reservoir.

211. The useful storage of 88,000 acre-feet as outlined above does not include any storage in the Whitechuck Basin above a point 800 feet from the forks. This upper storage would be available for holding the silt transported by the Whitechuck. After this is filled, the deposit would be near enough to the sluice gates to be periodically sluiced out, thus preventing any silt from the Whitechuck to back up into the Sauk Basin.

212. Diversion would be made by tunnels aggregating 8½ miles in length running through the ridge on the right bank to the power site located on Dan Creek on the 500-foot contour, which is the high-water line of the proposed lower Sauk Reservoir. The total head would be 605 feet. The head lost in the tunnel would approximate 125 feet, leaving a net operating head of 480 feet. The regulated flow 90 percent of the time would be 1,130 second-feet. The corresponding plant capacity would be 74,000 kilowatts at 80 percent efficiency and 50 percent load factor. The estimated cost per kilowatt of the project is $135.

213. *Project 10.*—The diversion dam for this project would be located on the Suiattle River about a mile above Canyon Creek, on unsurveyed land in the Mount Baker National Forest. (Long. 121°04′ and lat. 48°12′.) The natural low-water elevation is 2,575 feet as indicated by the Glacier Peak quadrangle. Canyon Creek would be diverted into the Suiattle above the headworks. The Suiattle is glacier fed and is heavily laden with silt during the summer; hence, storage is not feasible. A concrete-lined canal, 5 miles long, located on the left bank, would conduct the water to the forebay. Thence a steel penstock would run to the power-house site on the Suiattle near the mouth of Milk Creek. The natural low-water elevation at the power-

house site is given as 1,950 feet by the quadrangle sheet, but is given as 1,770 feet on the river profile in Water Supply Paper No. 419. The river profile stopped at this point, so the head was determined from the quadrangle map. It was also planned to divert Milk Creek through an open conduit into the forebay. The total head, as determined from that source, is 625 feet.

214. The drainage area covers 98 square miles. The estimated natural discharge for 90 percent of the time is 225 second-feet, with a corresponding plant capacity of 16,800 kilowatts at 70 percent efficiency and 50 percent load factor. The estimated cost per kilowatt of the project is $100.

215. *Project 11.*—The power house for this project would be located on the left bank of the Suiattle River near the mouth of Downey Creek. (Long. 121°13′ and lat. 48°15′.) The natural low-water surface at the power-house site is 1,385 feet. Water would be diverted from three streams for this plant.

216. One diversion dam would be located on the Suiattle River at the mouth of Milk Creek, at natural low-water elevation 1,770 feet as shown in Water Supply Paper No. 419. A concrete-lined canal 5 miles in length would conduct the water down the left bank to a forebay close to the power house. The total head would be 385 feet. The drainage area, which covers the entire northern and eastern slope of Glacier Peak, is 107 square miles. The estimated natural discharge 90 percent of the time is 245 second-feet and the corresponding machine capacity is 11,300 kilowatts at 70 percent efficiency and 50 percent load factor.

217. Another diversion dam would be located on Sulphur Creek about 3 miles above its mouth, at natural low-water elevation 2,500 feet, and would be connected to the forebay by an open canal about 5½ miles long. The third diversion dam would be located on Downey Creek at the same elevation and would be connected to the same forebay by 6 miles of open conduit. A single steel conduit would conduct the water from the forebay to the power house, crossing the Suiattle en route. The total head from these two streams would be 1,115 feet, and the total drainage area would be 46 square miles. The estimated natural discharge for 90 percent of the time is 105 second-feet. The corresponding machine capacity would be 14,000 kilowatts at 70 percent efficiency and 50 percent load factor.

218. Hence, the total plant capacity derived from the three diversions would be 25,300 kilowatts. The estimated cost per kilowatt is $115.

219. *Project 12.*—The power house for this project would be located on the left bank of the Suiattle River near the mouth of Buck Creek. (Long. 121°20′ and lat. 48°16′.) The natural low-water surface is 1,005 feet. Water would be diverted from two streams for the plant.

220. One diversion dam would be located on the Suiattle River just below the mouth of Downey Creek and below the tailrace of project 11. The natural low-water level at the diversion point is 1,385 feet. An open conduit would be carried down the left bank of the stream 7 miles to the power house. The total head would be 380 feet. The drainage area is 182 square miles. The estimated natural discharge for 90 percent of the time is 420 second-feet, with a corresponding machine capacity of 19,150 kilowatts at 70 percent efficiency and 50 percent load factor.

221. The other diversion dam would be located on Buck Creek about 5 miles above its mouth, where the natural low-water surface is at elevation 2,205 feet. A concrete-lined canal would run down the left bank of Buck Creek a distance of 4½ miles to the forebay. Thence a steel penstock would lead down the hill and across the Suiattle to the power house. The total head would be 1,200 feet. The drainage area is approximately 21 square miles, with an estimated run-off of 48 second-feet 90 percent of the time. The corresponding machine capacity would be 6,900 kilowatts at 70 percent efficiency and 50 percent load factor.

222. The total station capacity would be 26,050 kilowatts. The estimated cost per kilowatt is $100.

223. *Project 13.*—The diversion dam for this project would be located on the Suiattle River just below the mouth of Buck Creek. (Long. 121°21′ and lat. 48°16′.) The natural low-water elevation is 1,005 feet, which is also the tailwater level of project 12. An open conduit 9 miles in length, located along the left bank, and a tunnel 2½ miles long, would lead to the power-house site on the Suiattle River at the 500-foot contour, which is the normal reservoir level of the lower Sauk project. The total head would be 505 feet. The tributary drainage area covers 255 square miles. The estimated natural run-off 90 percent of the time is 350 second-feet. The head loss in the conduit and tunnel totals 105 feet for a hydraulic capacity of 700 second-feet, leaving an operating head of 400 feet. The corresponding plant capacity is 19,000 kilowatts at 80 percent efficiency and 50 percent load factor. The estimated cost per kilowatt is $150.

224. *Project 14.*—This project is located on Illabot Creek, on unsurveyed land of the Mount Baker National Forest. The data used in this report were taken from the Glacier Peak quadrangle, scale, 1 to 125,000, hence is approximate only. It was planned to develop some storage in Illabot Lake, but insufficient data are available to determine the amount. The headworks would be located about 3 miles downstream from the lake, where the natural low-water elevation is 1,500 feet (long. 121°26′ and lat. 48°26′). The stream would be diverted into an open 3-mile long conduit located on the right bank, terminating at the forebay; thence through a steel penstock to the power-house site on the creek, where the natural low-water elevation is 500 feet. The site is situated in the SW¼ sec. 35, T. 35 N., R. 10 E. The total head is 1,000 feet.

225. The area of the drainage basin above the point of diversion is 32 square miles. The estimated natural discharge for 90 percent of the time is 74 second-feet, with a corresponding plant capacity of 8,900 kilowatts. The estimated cost per kilowatt of the project is $90.

Major Power Projects

THE RUBY PROJECT

226. *Detailed description.*—The dam site for this project is located on the Skagit River in unsurveyed land of the Mount Baker National Forest. It is a mile below the mouth of Ruby Creek and approximately at the upstream limit of the backwater effect from the Diablo project, 28 miles upstream from the town of Marblemount, and 106 miles from the mouth of the stream. The general location is shown on plate 5. This project is the upper 1 of 3 being developed by

the city of Seattle. The lowest of these three is the Gorge plant, the middle one, now under construction, being the Diablo plant. Descriptions of these two plants and a general statement regarding the city's plans have been given in paragraph 102 et seq.

RÉSUMÉ

Drainage area .... square miles..	978
Length of pool .... miles..	30
Length of dam .... feet..	1, 200
Height of dam (maximum section foundation to walkway) ... do....	610
Drawdown (elevation 1,700 to 1,500 feet) .... do....	200
Useful storage .... acre-feet..	2, 428, 000
Natural low-water elevation .... feet..	1, 195
Estimated maximum discharge (about 1,815) .... second-feet..	100, 000
River flow (Apr. 1914 to Mar. 1931, inclusive):	
Measured peak discharge .... do....	45, 700
Mean discharge .... do....	3, 150
Minimum discharge, 24 hours .... do....	390
Q 90, natural .... do....	913
Q 90, regulation below elevation 1,700 feet, power only .. do....	2, 450
Mean static head .... feet..	428
Power capacity for regulated flow (Federal Power Commission definition) .... horsepower..	83, 900
Installed capacity tentatively proposed by the city of Seattle kilowatts..	360, 000

227. *Topography and geology.*—The river at the site flows in a southwesterly direction through a rocky gorge, both banks of which are composed of solid granite bedrock. The natural low-water elevation is approximately 1,195 feet, but the upper level of Diablo Reservoir, the city of Seattle project located immediately downstream, is 1,205 feet, hence will affect the tailwater of the Ruby project slightly at maximum water levels. Test borings made by the city of Seattle for a distance of a mile below the mouth of Ruby Creek indicate good foundation rock at depths varying from 25 to 55 feet below the stream bed, with a minimum elevation of approximately 1,100 feet at the site tentatively selected by the city. Above the dam site the valley is fairly straight and narrow, varying in width from 1 to 3 miles, with a length of 30 miles at the 1,700-foot contour, which extends into Canada 6 miles. The reservoir site is heavily timbered. At the Davis ranch, 5 miles downstream from the site, the mean annual precipitation for 13 years was 78 inches, much of which fell in the form of snow. (See table 2.) The mean annual run-off from the tributary drainage basin for the past 17 years was approximately 44 inches. This run-off is low as compared to other portions of the Skagit Basin; for instance, the run-off of the Cascade and Sauk Basins exceed the above by 80 percent. This is due primarily to the fact that the upper Skagit Basin lies in the wind and rain shadow of the high divide to the westward, of which Mounts Baker and Shuksan are a part. The drainage basin covers an area of 978 square miles, of which 390 square miles are in Canada. The entire area within the United States lies within the Mount Baker National Forest.

228. *Power possibilities.*—The mean monthly stream flow is shown in table 6. The mean flow for the 17-year period ended March 1931 amounted to 3,150 second-feet. The unregulated flow-durations for the 17-year period for 35, 50, 90, and 100 percent of the time were, respectively, 2,820, 2,050, 913, and 497 second-feet, computed on the

basis of mean monthly discharges. (See fig. 9.) The minimum 24-hour flow was 390 second-feet, with an instantaneous measured peak, of 45,700 second-feet, during this 17-year period.

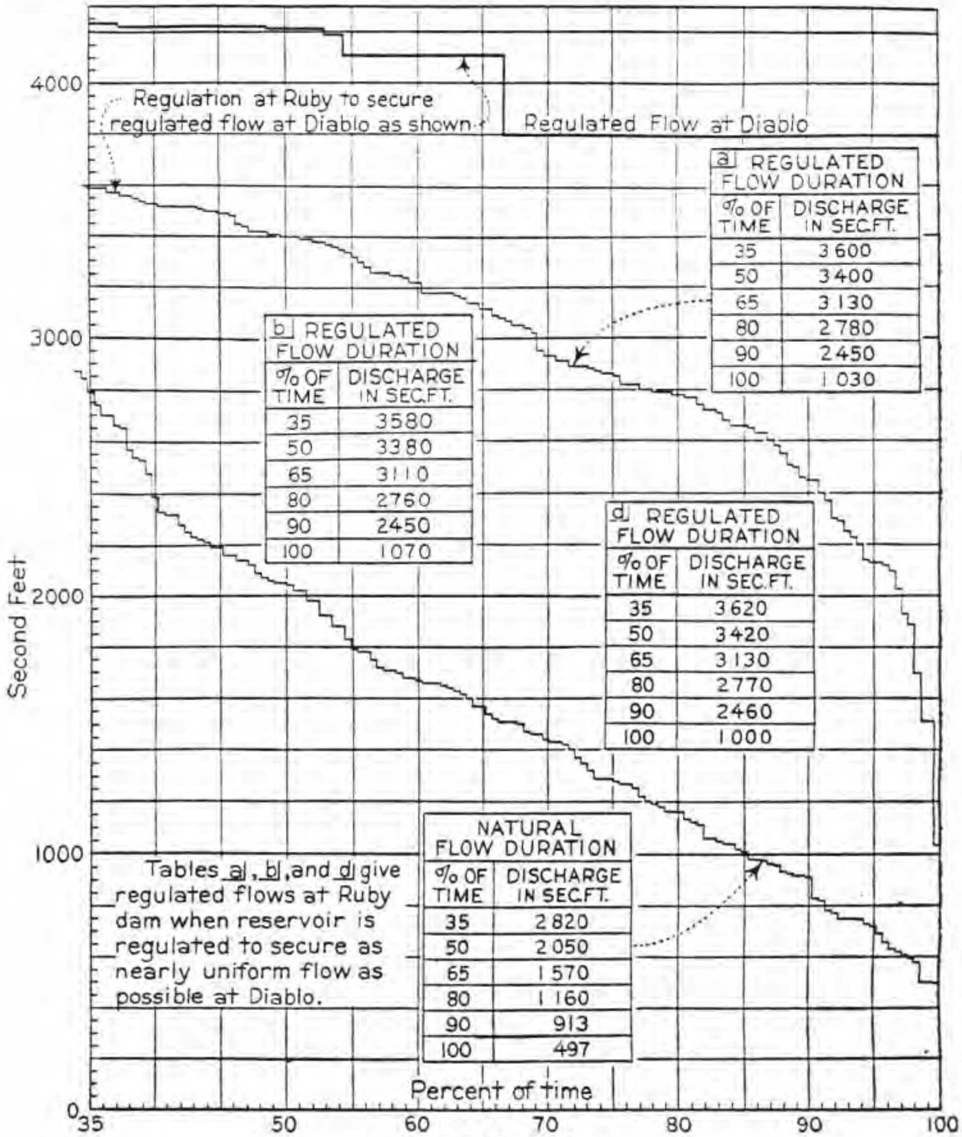


FIGURE 9
SKAGIT RIVER BELOW RUBY CREEK
FLOW DURATION—PERIOD APRIL, 1914–MARCH, 1931
U.S. Engineer Office Seattle, Washington

Lower limit of drawdown elev. 1500:
- a) Regulation below elev. 1700 for power only
- b) Regulation below elev. 1689 for power only (curve not shown)
- c) Regulation below elev. 1700 for power and winter flood control Practically same as a) (table and curve not shown)
- d) Regulation below elev. 1710 for power only (curve not shown)

229. Mr. J. E. Stewart (see par. 116) estimated a peak discharge of 115,000 second-feet about the year 1815, 95,000 second-feet about the year 1856, and of 70,000 second-feet November 1909 at Reflector Bar, 7 miles downstream from the site. The corresponding flows below

Ruby Creek are estimated to have been 100,000, 83,000, and 58,000 second-feet, respectively.

230. As yet, the city of Seattle has no definite or approved plans for the development of this site. Regulation between elevations 1,700 and 1,500 feet is estimated to provide 2,428,000 acre-feet of useful storage. (See fig. 10.)[1] With storage regulated to maintain the greatest possible uniformity of flow at Diablo, which flow includes the run-off of Thunder Creek, the resulting flow-duration for the 17-year period for 35, 50, 90, and 100 percent of the time would be respectively 3,600, 3,400, 2,450, and 1,030 second-feet, with a mean forebay elevation of 1,628 feet. (See fig. 9.) This storage is sufficient to give complete regulation for all years of mean or less than mean run-off, and will be of great benefit to the downstream Diablo and Gorge plants. It is improbable that the reservoir capacity will ever be materially reduced by silting, as the stream carries very little sediment.

231. It is possible to divert the headwaters of Thunder Creek into Ruby Reservoir by means of a tunnel or open conduit. Sufficient data are not now available to determine the feasibility of such a diversion.

232. *Plans for development*.—No designs or estimates have been made for the project by this office. The city of Seattle has made filings on this site with the Federal Power Commission and the State supervisor of hydraulics, and has made preliminary surveys and estimates of cost of the plant. A résumé of the plans for the development of this site as set up in the annual report of the superintendent of the department of lighting for 1930 is quoted herewith:

Ruby development, now being surveyed, clearing to start in 1931 and construction immediately after Diablo plant is in operation, consists of—

Ruby Dam, in Skagit Canyon at the Ripraps site, 1½ miles below the mouth of Ruby Creek. Dam to be of heavy gravity section, arched in plan, with crest at elevation 1,700 feet above sea level, to be 610 feet high and 1,200 feet along the crest to contain approximately 1,750,000 cubic yards of concrete. Spillways to discharge by tunnels through the granite around each end of the dam; no water to flow over the dam.

Ruby Reservoir will be created by Ruby Dam, a lake 30 miles long and 1 to 3 miles wide, with 3,000,000 acre-feet of storage capacity, sufficient to equalize the the entire run-off of the river for power purposes.

Ruby power house, to be placed immediately below the dam with—

Six 60,000-kilowatt vertical generating units, three on each side of the river, operating on 450 feet average head, supplied with water through two tunnels approximately 600 feet long and 30 feet in diameter, through granite around the ends of the dam.

Six 67,500-kilovolt-ampere transformer banks to step up to 220,000 volts for transmission to Seattle by two double-circuit transmission lines on steel towers; conductors of 795,000 circular-mil aluminum cable, steel reinforced, 220,000 volts, 180,000-kilovolt-ampere capacity per circuit. Lines 107.5 miles long to north substation, 127.5 miles to south substation.

* * * Ultimate development of 1,120,000 horsepower (at the Ruby, Diablo, and Gorge plants) is estimated to cost $74,500,000, with transmission lines, or $66.65 per horsepower delivered. * * *

233. *Combined flood control and power*.—A differential mass diagram was prepared for the Skagit at Reflector Bar, just below Diablo, for the 23-year period October 1908 to September 1931, inclusive, using the mean monthly run-off as shown in table 7. A useful storage of 2,428,000 acre-feet was assumed by regulation between elevations

[1] Not printed.

1,700 and 1,500 in Ruby Reservoir. By regulation of this storage to maintain as nearly uniform flow as possible at Diablo, the Q 90 flow at Diablo is 3,800 second-feet. (See fig. 9.) In this study, a regulation of the limited available storage in Diablo Reservoir was used only for the benefit of daily fluctuations of load and for regulation of the natural inflow between Ruby and Diablo Dams. By applying a uniform flow demand of 3,800 second-feet to the mass diagrams, it was found that the Ruby Reservoir would have been filled to capacity in midsummer of the years 1911, 1913, 1914, 1918, 1919, 1921, 1922, 1923, and 1925, or 9 of the 23 seasons. Various amounts of water would have been wasted during each of these seasons. It is worthy of note that the reservoir would not have been full and that no water would have been wasted during the last 6 years of the record.

234. As shown previously in this report, major floods occur only in the winter months. A further study of the mass diagram reveals that 200,000 acre-feet of storage, obtainable between elevations 1,700 and 1,689 feet, may be reserved for this season each year without reducing the Q 90 flow. However, it would reduce the head on the Ruby plant four different seasons by amounts varying from 10 to 14 feet for a total of 26 months, or 9½ percent of the 23-year period. Assuming an average head loss during these 26 months of 12 feet, or 2.8 percent of the total head on the Ruby plant, the mean head would be reduced 0.26 percent for the 23-year period. However, if consideration be given to the yearly peak demand for power, which occurs in December, the power output will be affected even less by this reservation for flood storage.

235. A flood storage capacity of 200,000 acre-feet would be sufficient to retain the assumed maximum 24-hour discharge of 100,000 second-feet. If a free overflow spillway were used, there would also be a temporary retention of water above the spillway crest that would be appreciable, as the area at the 1,700-foot level is approximately 18,000 acres.

236. *Alternate plan.*—If it were desired to retain 200,000 acre-feet for flood storage the year round, the maximum forebay level for power production would be at elevation 1,689 feet, with a useful power storage of 2,228,000 acre-feet above the 1,500-foot contour. The flow-duration as shown in figure 9 indicates that the Q 90 flow would be 2,450 second-feet, the same as the Q 90 flow for the original plan. The mean head would be 423 feet, a reduction of 1.2 percent under that for the original plan. It is, therefore, apparent that the average power output over a period of years for any scheme involving a reservation of 200,000 acre-feet for storage of flood waters would not differ materially from that with no reservation.

CASCADE RIVER PROJECT

237. *Detailed description.*—The dam site for this project is located on the Cascade River in section 7, T. 35 N., R. 12 E., Willamette meridian, 8 miles upstream from the town of Marblemount and the mouth of the river (long. 121°18′ and lat. 48°32′). The powerhouse site is situated on the right bank 4½ miles downstream from the dam site. The general location is shown on plate 5, details regarding the project being shown on plate 6.[1] There are doubtless other power sites on this stream or its tributaries, but because of the very limited

[1] Not printed.

stream flow and pondage available at each site, the capacity in individual cases would be small. No consideration has, therefore, been given in this report to these small sites.

RÉSUMÉ

Drainage area square miles	148
Length of pool miles	6
Length of dam on center line feet	800
Height of dam (maximum section, foundation to walkway) do	365
Drawdown (elevation 1,100 to 1,000 feet) do	100
Useful storage acre-feet	96, 700
Natural low water elevation at dam feet	877
Natural low water elevation at power house do	360
Maximum known 24-hour discharge (Nov. 29, 1909) second-feet	31, 700
River flow (April 1914 to March 1931, inclusive):	
Mean discharge do	870
Estimated minimum discharge do	115
Q 90 natural do	290
Q 90 regulated do	580
Mean static head feet	700
Power capacity for regulated flow (Federal Power Commission definition) horsepower	32, 480
Proposed hydraulic capacity second-feet	1, 160
Proposed installed capacity (in 3 units) kilowatts	54, 000

238. *Topography and geology.*—The river at the dam site flows in a westerly direction through a rocky canyon. (See pl. 6 for topography and cross section.)[1] The stream gradient for a quarter of a mile above the site is very steep. The natural low water elevation at the site is about 877 feet. The bed of the stream and the left bank for a height of about 125 feet are composed of large boulders, with sufficient clay and fines to fill the voids. Above this height, solid rock is exposed on both banks. It is classified as diorite, somewhat schistose in character. Three drill holes sunk at the site all encountered bedrock, the greatest depth found being about 90 feet below the water surface. (See pl. 6.)[1] The formation was similar in all holes and was classified as greenstone schist. It apparently is impervious and capable of supporting a dam of any reasonable height.

239. The drainage basin tributary to the dam site is all located within the Mount Baker National Forest and, excepting limited areas above the timber line near the crest of the Cascade Range, is covered with virgin timber. There are a number of tracts within the national forest that are privately owned, approximately 500 acres of which lie below the flow line of the proposed reservoir. The power-house site and a major portion of the flow line right-of-way are located on private land outside of the national forest.

240. *Power possibilities.*—The mean monthly stream flow is shown in table 15. Flow-durations for natural and regulated conditions for the 17-year period ended March 1931 are shown on figure 11. Dams were designed for the four cases shown in table 47. Case 4 proved to be economically infeasible, so case 3 is proposed as the development that provides the highest utilization of the stream within economic limits of cost. An earth and rock-fill dam was also estimated for cases 1, 2, and 3. The cost for case 1 was practically the same as the cost of the concrete arch for the same forebay level, but was appreciably higher for cases 2 and 3, hence was not investigated further.

[1] Not printed.

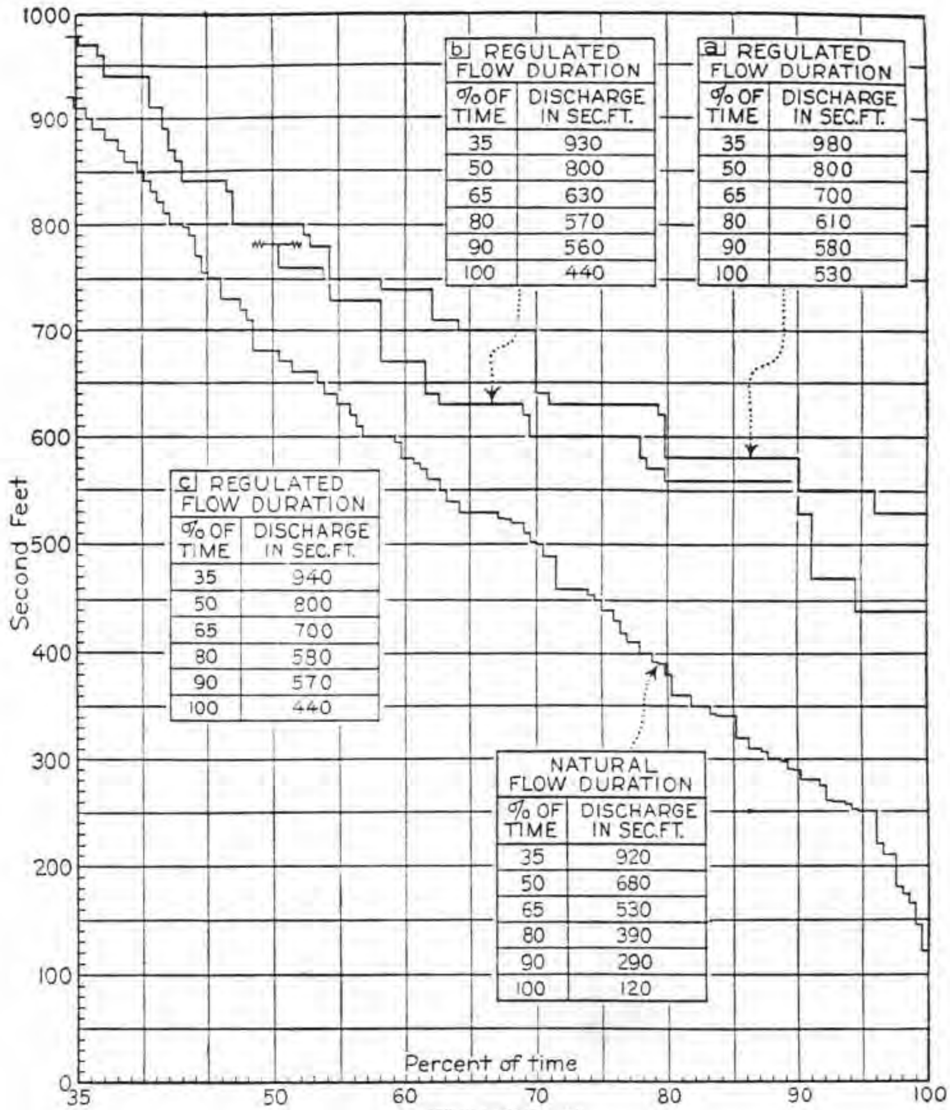


FIGURE 11
CASCADE RIVER BELOW CASCADE RESERVOIR
FLOW DURATION–PERIOD APRIL, 1914 – MARCH, 1931
U.S. Engineer Office Seattle, Washington

Lower limit of drawdown elev. 1000
- a) Regulation below elev. 1100 for power only
- b) Regulation below elev. 1075 for power only
- c) Regulation below elev. 1100 for power and winter flood control (Curve not shown)

TABLE 47.—*Power possibilities, Cascade River*

Item	Case no.— 1	2	3	4
Normal reservoir elevation ... feet	1,060	1,075	1,100	1,125
Limit of drawdown elevation ... do	1,000	1,000	1,000	1,000
Useful storage ... acre-feet	48,000	64,400	96,700	132,900
Flow 90 percent of time ... second-feet	530	560	580	610
Assumed hydraulic capacity ... do	1,060	1,100	1,160	1,220
Assumed friction loss ... feet	44	44	44	44
Natural low-water elevation at power-house site ... do	360	360	360	360
Operating head for normal reservoir ... do	656	671	696	721
Kilowatts available 90 percent of time at 80-percent efficiency and 50-percent load factor	47,400	51,000	54,800	59,200

241. *Plans for development.*—A variable radius arch dam was considered to be the type best adapted to the site. Spillways would be provided by placing a free overflow crest 150 feet in length near each end of the dam. The rock abutments would be protected against scour by a reinforced concrete pavement, which would at all points to be placed in contact with the lower nappe of the free discharge of the weir. Stream-flow records were not of sufficient duration to give reliable flood data. The known maximum 24-hour discharge occurred during the 1909 flood and was 31,700 second-feet. A study of flood flows indicates that this was an exceptionally high flood. The spillway capacity was determined by assuming the maximum 24-hour flow to be 40,000 second-feet without regulation. Under regulation this peak discharge would be reduced to 37,000 second-feet and would produce a head of 10 feet on the overflow crests, with a resulting temporary storage of 15,000 acre-feet.

242. The conduit, as planned, would be a pressure tunnel 4½ miles in length and 12 feet in diameter located on the right bank. It would be possible to drive a tunnel from both ends and in both directions from an adit that could be advantageously located about 1¾ miles from the dam site. The grade of the tunnel would be kept as near the hydraulic gradient as possible with the reservoir level at elevation 1,000 feet. It would terminate in a surge tank located on the side hill back of the power house. Due to lack of subsurface data, the cost estimate provides for lining the tunnel throughout its entire length. If the formation should prove to be hard and impervious, it probably would be economical to increase the size of the tunnel and leave it unlined. Steel penstocks, one for each unit, would extend from the surge tank to the power house.

243. The location of the power house is limited primarily by a suitable location for the surge tank, which would be placed as far downstream as the ridge would permit. The average slope of the river between the dam site and the power-house site is over 100 feet to the mile. The slope flattens down to about 30 feet per mile below this point. It was planned to locate the power house in the southwest corner of sec. 9, T. 35 N., R. 11 E., where the natural low-water elevation is 360 feet. The power house, as planned, would be of sufficient size to accommodate three units. Each unit would consist of a 25,000-horsepower Francis-type turbine direct-connected to a generator of 18,000 kilowatts capacity.

244. Silting is not a serious problem on the Cascade River, due to the limited extent of the glaciers and to the forest cover on practically the entire drainage basin. Some silt is transported during freshets, but it is thought to be of insufficient magnitude to materially affect the storage.

245. Alternate plans: A study of the mass diagram for the 17-year period shows that flood storage may be reserved between elevations 1,075 and 1,100 feet from November 1 to January 31, each season, at no great detriment to power development. The resulting flow duration would be 570 second-feet (instead of 580 second-feet for power only) for 90 percent of the time and 800 second-feet for 50 percent of the time. This reduction in the Q-90 flow is so small that it has been disregarded in the matter of costs and installed capacity. In other words, reservation of the top 25 feet of the reservoir for flood storage from November 1 to January 31 each year does not

materially affect the cost or quantity of the available power. The flood storage thus provided would amount to 32,300 acre-feet in addition to the 15,000 acre-feet temporary storage above the spillway crests, or a total flood storage of 47,300 acre-feet, which is 47.6 percent of the run-off for the three maximum days of the 1909 flood.

246. The development of the project for a normal reservoir level of 1,100 feet but retaining a continuous flood storage capacity of 32,300 acre feet (elevation 1,100 to 1,075 feet) has been briefly covered as case 2 in table 47. The Q-90 flow for this condition would be 560 second-feet and the operating head, 671 feet. The corresponding plant capacity would be 51,000 kilowatts at 80-percent efficiency and 50-percent load factor. The estimated cost would be $8,620,000, or $169 per kilowatt, if the entire cost were charged to power. The estimated increase in the cost of the dam for a normal reservoir level of 1,100 feet over that for a level of 1,075 feet would be $880,000. If this amount were charged to flood control, the cost chargeable to power would be $7,740,000, or $152 per kilowatt of installed capacity, or $12 per kilowatt less than the cost shown in table 47 for case 3.

247. *Economic features.*—The principal items of construction and the estimated capital cost of the project for case 3 of table 47 are shown in table 48. Note that the capital cost for the completed project is $164 per kilowatt. These costs include the cost to the low-tension bus only.

TABLE 48.—*Estimated capital cost of development at Cascade River site for an installed capacity of 54,000 kilowatts*

Preliminary expense	$140, 000
Construction roads	120, 000
Reservoir	50, 000
Dam	3, 170, 000
Headgates and racks	80, 000
Conduit and surge tank	2, 174, 500
Power-house substructure	225, 000
Power-house superstructure	225, 000
Hydraulic equipment	225, 000
Electrical equipment	378, 000
Miscellaneous equipment	30, 000
Permanent buildings	25, 000
Contingencies, 15 percent	1, 026, 500
Total field cost	7, 869, 000
Overhead, 12½ percent	984, 000
Total construction cost	8, 853, 000
Capital cost per kilowatt	164

248. *Earlier plans of development.*—So far as can be ascertained, no comprehensive plans have previously been made for the development of this site. The Skagit Power Co. cooperated with the United States Geological Survey in securing the stream-flow records at the dam site for the period from April 1909 to April 1913, as given in table 15.

LOWER SAUK PROJECT

249. *Detailed description.*—The dam site for this project is located on the Sauk River in section 30, township 34 north, range 10 east, about 7 miles above its confluence with the Skagit. (Long. 121°33′

and lat. 48°24′.) The general location is shown on plate 5. It is about 7 miles south of the town of Rockport and 12 miles north of Darrington.

Résumé

Drainage area (approximately same as at gaging station) square miles	714
Length of pool miles	12
Length of dam feet	1, 600
Height of dam (maximum section, foundation to top) do	250
Drawdown (elevation 498 to 415) do	83
Useful storage acre-feet	541, 900
Natural low-water elevation feet	280
Estimated peak discharge second-feet	146, 000
River flow (April 1914 to March 1931, inclusive):	
Estimated maximum 24 hours (December 1921) do	50, 000
Mean discharge do	4, 200
Probable minimum discharge (Dec. 4, 1929) do	578
Q 90 natural do	1, 500
Q 90 regulated for winter floods do	2, 980
Mean static head feet	175
Power capacity for regulated flow (Federal Power Commission definition) horsepower	41, 700
Proposed installed capacity kilowatts	86, 400

250. *Topography and geology.*—The river in the vicinity flows in a northerly direction as shown on plate 7.[1] The natural low-water surface elevation is 280 feet. On the left bank, a natural abutment is formed by a ridge that extends out into the valley. It is composed of bedrock that outcrops in many places, and has been classified as diorite. It is badly weathered at the surface, but probably sound and impervious at no great depth. The right bank is formed by a glacial bench that levels off at about elevation 525 feet. This bench extends back about a quarter of a mile to the steep face of the foothill.

251. Four test holes were drilled at the site. (See pl. 7 for the location and log.)[1] All encountered bedrock at elevations varying from 189 to 256 feet. The composition of this rock was variable, different strata being classified as basalt, greenstone schist, and slate. All seemed to be reasonably sound and impervious.

252. The economical forebay height is limited to approximately elevation 500 feet by the height of the ridge on the left bank at the dam site and also by the height of the divide between the Sauk and the Stillaguamish Basins at the upper end of the reservoir near Darrington. The elevation of the lowest point on this divide is about 505 feet, which suggests the possibility of diverting a portion of the flood flow into the North Fork of the Stillaguamish. The top of the divide does not vary much from this elevation for a width of nearly 2 miles. No test holes have been sunk into this saddle, but the exposed strata on the banks of the Sauk and the Stillaguamish indicate thick beds of sandy silt and thinner ones of sand and gravel. Although the Stillaguamish is about 30 feet lower than the Sauk at the nearest point, no seepage was visible under natural conditions. As storage to elevation 500 feet will increase the head only 20 feet, the leakage probably would not be serious. The fine glacial silt carried in suspension by the stream during the late summer would tend to retard the seepage. Any plan of development that contemplates storage to this elevation will require a more thorough geological investigation of both this saddle and of the ridge to the left of the dam site.

[1] Not printed.

253. The drainage area tributary to the dam site has been assumed to be 714 square miles, the same as estimated at the gaging station, and lies mostly within the Mount Baker and Snoqualmie National Forests. However, the major portion of the reservoir site is situated outside of the national forests, and is privately owned, probably not more than 200 acres being within the forest area. Practically all of the reservoir site has been logged off.

254. *Flood study.*—Actual stream-flow measurements at or near the site cover the periods March 1911 to July 1912 and July 1928 to March 1931, both inclusive. (See tables 21 and 22.) These records do not include any of the major floods that have occurred in the basin as shown by records at other stations. The peak discharge of the upper Sauk at Darrington in the 1917 and 1921 floods amounted to 122 second-feet per square mile. This drainage area is only 41 percent of that at the dam site. Parallel records for the climatic years 1929 to 1931 show that the three maximum 24-hour run-offs per square mile at the dam site were 80.6 percent of the run-off per square mile for the same days at Darrington. On this basis, the peak flow at the dam site was 70,200 second-feet in the 1921 flood. The peak flow of the Skagit during the 1815 flood at The Dalles, as estimated by J. E. Stewart, was 2.08 times the 1921 peak at the same place. Applying this ratio to the flow at the dam site, shows a peak of 146,000 second-feet for natural flow. Under regulations as effected by the proposed development, the maximum discharge over the spillways would be 108,000 second-feet. The peak discharge during the February 1932 flood was 68,500 second-feet, the maximum 24-hour discharge being 51,400 second-feet on February 26.

255. *Power possibilities.*—The mean monthly stream flow for the 17-year period, April 1914 to March 1931, inclusive, is shown in table 22. The mean discharge for the period amounts to 4,200 second-feet. Flow-durations, both natural and regulated, are shown in figure 12. The results of a study of the power possibilities of the stream for various reservoir levels are shown in table 49. A preliminary study of the site was made to ascertain the most feasible type of structure and limits of regulation. Both concrete and earth-fill dams of various heights were laid out and the costs estimated. Dams of both types were estimated for normal forebay elevations of 450, 475, and 498 feet. Flood and power projects were designed separately and were also combined. The concrete dams, founded on bedrock, proved to be uneconomical, due primarily to the depth of overburden. The estimated cost of earth-fill dams for flood storage alone was also high.

TABLE 49.—*Power possibilities of Lower Sauk site, based on monthly discharges*

Item	Unit	Natural flow	Regulation between elevations—		
			450 and 415	475 and 415	498 and 415
Useful storage	Acre-feet		170,400	341,900	341,900
Q 35	Second-feet	4,900	4,500	4,500	4,510
Q 50	do	3,600	4,000	4,000	4,180
Q 90	do	1,500	2,300	2,700	3,140
Q 100	do	724	1,870	2,400	2,950
Average forebay elevation	Feet		433	445	460
Total head	do		170	195	218
Installed capacity for Q 90 at 80 percent efficiency and 50 percent load factor.	Kilowatts		53,200	71,600	93,400

256. *Plans for development.*—A study of the discharge records for the Skagit and of the mass diagram for the Sauk indicates that all of the major floods have occurred in the winter and that the reservoir would ordinarily be full by July of each year, but would be pulled

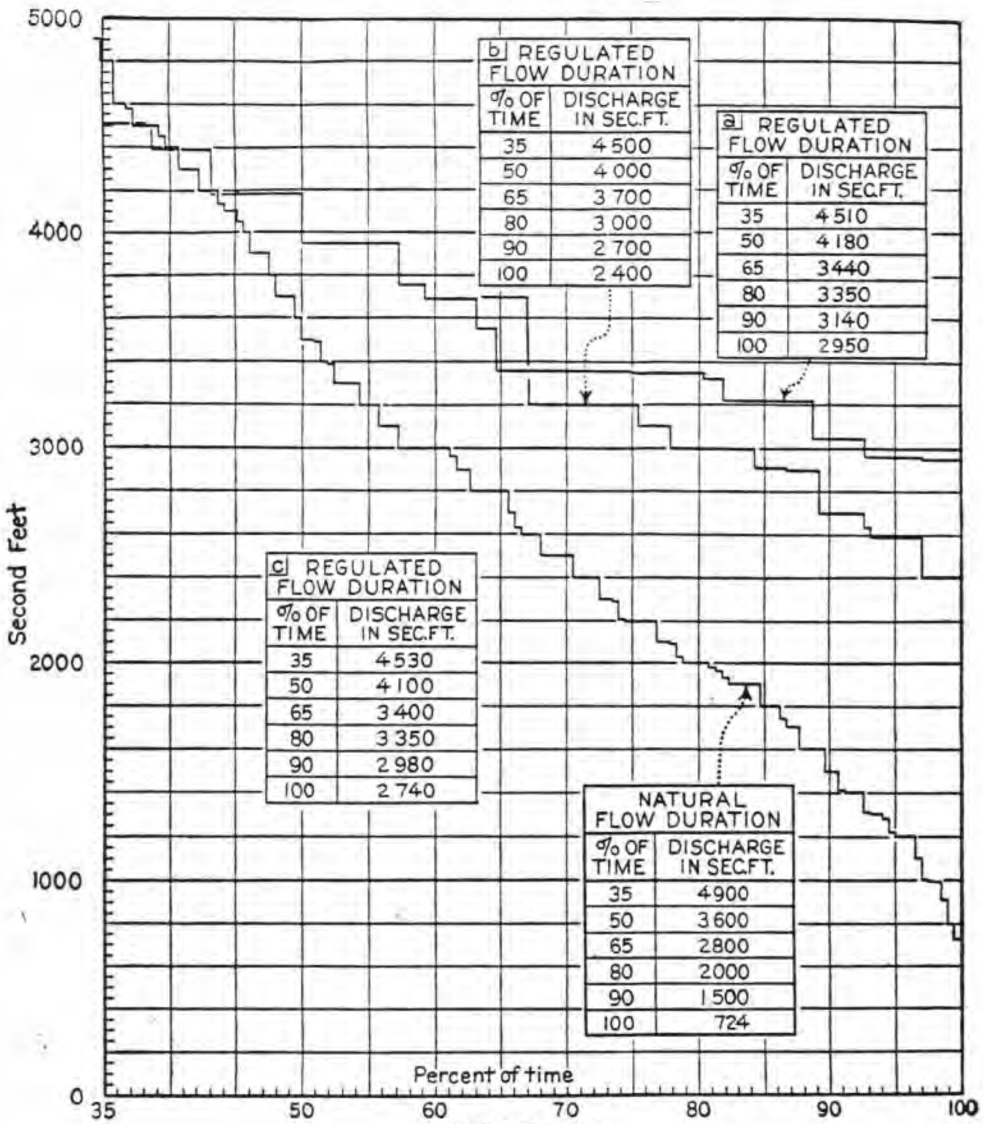


FIGURE 12

SAUK RIVER BELOW SAUK RESERVOIR

FLOW DURATION—PERIOD APRIL, 1914—MARCH, 1931

U.S. Engineer Office Seattle, Washington

Lower limit of drawdown elev. 415 { a) Regulation below elev. 498 for power only
b) Regulation below elev. 475 for power only
c) Regulation below elev. 498 for power and winter flood control (Curve not shown.)

down sufficiently by winter to accommodate considerable flood storage. Taking advantage of this condition, it would be possible to reserve 200,000 acre-feet, obtainable between elevations 498 and 475 feet, for flood storage during the winter months at no great detriment to power production. The Q 90 flow would be reduced from 3,140 to 2,980 second-feet, when this flood storage is provided during November, December, and January of each year. The average forebay elevation would then be 455 feet. The plant capacity would be reduced from 93,400 kilowatts to 86,400 kilowatts at 80-percent efficiency and 50-percent load factor.

257. The plant as planned for this combined power and flood project, involves the construction of an earth-fill dam, a side-channel spillway on the left bank and a power house immediately below the dam. The dam would consist of an earth fill with a 20-foot crest width at elevation 511 feet. A concrete cut-off wall would extend from bedrock up into the earth fill at least 20 feet. The upstream face would be protected by rock pavement.

258. A side-channel spillway would be constructed 1,000 feet long on the left bank with a free overflow crest at elevation 498 feet. The capacity would be about 78,000 second-feet for an 8-foot head, which would give a maximum reservoir elevation of 506 feet and a temporary storage of about 75,000 acre-feet above the spillway crest. A small dike, or even a controlled spillway on the Darrington divide, might be necessary or desirable for proper control during extreme flood conditions. The flood flow at the dam would be carried through the ridge by a concrete-lined tunnel 44 feet in diameter discharging into the tailrace channel. A sluiceway would be placed in the stream bed above the dam and connected to the above tunnel by a concrete-lined tunnel 30 feet in diameter controlled by gates set at the bottom of a gate tower with a capacity of 30,000 second-feet at normal forebay level. This arrangement of tunnels would be used as a diversion conduit during construction, giving a capacity of 16,000 second-feet for the lower head then obtaining.

259. The power house would be placed on the left bank as near to the dam as safe and convenient. It would be connected by a 20-foot lined tunnel to the headworks located in the reservoir. Sufficient space would be provided for three units, each of which would consist of a Francis-type turbine of 40,000-horsepower capacity, direct-connected to a generator of 28,800-kilowatt capacity. A tailrace channel would be constructed of ample size to accommodate the flow from both the power house and the spillway.

260. In operation, the reservoir would be limited to elevation 475 feet to provide 200,000 acre-feet flood storage each fall until February 1, after which storage to elevation 498 feet would be permissible.

261. Alternate plans: The development of the project for power production only, with the normal reservoir level at elevation 498, has been briefly outlined in table 49. For the 17-year period, the Q 90 flow would have been 3,140 second-feet. The total head would have been 218 feet. The corresponding plant capacity would be 93,400 kilowatts at 80 percent efficiency and 50 percent load factor. The estimated cost per kilowatt would be approximately $158.

262. The development of the project for a normal reservoir level to elevation 498 feet but retaining a continuous flood-storage capacity of 200,000 acre-feet (elevations 498 to 475 feet) has also been briefly outlined. In this plan, the Q 90 flow would be 2,700 second-feet and the total head 195 feet. The corresponding plant capacity would be 71,600 kilowatts at 80 percent efficiency and 50 percent load factor. The estimated total cost would be approximately $14,000,000, or $196 per kilowatt, if the entire cost were charged to power. The additional cost of the dam storing to elevation 498 over one storing to elevation

475 would be $3,440,000. If this were charged to flood control, the remaining cost chargeable to power would be $10,560,000, or $148 per kilowatt.

263. *Silt.*—Silting of the reservoir is a very serious problem. The Suiattle and the Whitechuck Rivers are mainly fed from the glaciers on Glacier Peak and are heavily laden with silt in the summer season during the more active glacial movement. The average estimated run-off from these two streams for the period June 1 to September 30 is 575,000 acre-feet. In the absence of definite determinations of the silt content, it is assumed to vary from 1 to 3 percent. On this basis, the reservoir would be entirely filled with silt in from 40 to 120 years.

264. A method of eliminating the major portion of this silt deposit consists in diverting the Suiattle (75 percent of the glacial area is drained by the Suiattle) from its natural channel and emptying it into the reservoir close to the dam during the summer season, thus placing the silt deposit where it could be more readily sluiced out. Diversion would be made by a lined canal of 1,600-second-foot capacity, about 6.7 miles in length, located on the right bank and extending from a point on the Suiattle about 2 miles above the reservoir, crossing the intervening ridge and extending down to the dam, where it would terminate in a chute drop. This canal would be capable of carrying the entire summer run-off of the river after about July 15. The estimated cost is $750,000. This item of cost is not included in table 50.

265. *Economic features.*—The principal items of construction and the estimated capital cost of the project are shown in table 50. The entire cost is $14,612,000. If this were all charged to power the cost per kilowatt would be $169. As previously shown, the available power would be reduced 5.4 percent when the reservoir is regulated for flood control during winter months. On this basis, flood control could properly be charged 5.4 percent of the total cost, or $790,000, and power would pay the remainder, or $13,822,000, which is $160 per kilowatt of installed capacity.

266. The maximum total permissible expenditure for flood control has been set up elsewhere in this report as $3,750,000, based on the mean annual flood losses. Deducting this entire amount from the above capital cost, the least that could be charged to the power development would be $10,862,000, or $126 per kilowatt of installed capacity. For flood control only, a dam with crest at elevation 440 feet would produce a useful storage capacity of 200,000 acre-feet at an estimated cost of $6,100,000, which is decidedly infeasible.

TABLE 50.—*Estimated capital cost of development at the lower Sauk River site for an installed capacity of 86,400 kilowatts*

Preliminary expense	$50, 000	Station equipment	$180, 000
Construction roads	25, 000	Permanent buildings	200, 000
Reservoir	490, 000	Contingencies, 15 percent	1, 694, 150
Dam	5, 690, 400		
Sluiceway and spillway	1, 920, 750	Total field cost	12, 988, 300
Intake	374, 000	Overhead, 12½ percent	1, 623, 700
Power house	960, 000		
Hydraulic equipment	540, 000	Total construction cost	14, 612, 000
Electrical equipment	864, 000	Capital cost per kilowatt	169

267. *Earlier plans of development.*—No comprehensive plans have previously been made to develop this site.

UPPER BAKER PROJECT

268. *Detailed description*.—The dam for this project would be located on the Baker River in the NE¼SW¼ sec. 31, T. 37. N, R. 9 E., Willamette meridian in the Mount Baker National Forest. (Long. 121°41′ and lat. 48°39′.) The power house would be placed about a quarter of a mile downstream. The general location of the project is shown on plate 5.

RÉSUMÉ

Drainage area..........square miles..	[1] 184
Length of pool..........miles..	9
Length of dam..........feet..	1, 100
Height of dam (maximum section foundation to walkway)......do....	280
Drawdown (elevation 704 to 664 feet)..........do....	40
Useful storage..........acre-feet..	115, 800
Natural low-water elevation at dam..........feet..	445
Natural low-water elevation at power house..........do....	435
Maximum known 24-hour discharge [1] (December 1917)..second-feet..	36, 800
River flow [1] (April 1914 to March 1931, inclusive):	
Mean discharge..........do....	1, 970
Minimum discharge..........do....	219
Q 90 natural..........do....	835
Q 90 regulated (power and flood)..........do....	1, 270
Mean static head..........feet..	250
Power capacity for regulated flow (Federal Power Commission definition)..........horsepower..	25, 500

269. *Topography and geology*.—The data presented under this heading were furnished by the Puget Sound Power & Light Co., which has made stadia surveys of the reservoir site and test borings at three different sites all at a stated cost of $100,000.

270. The site first investigated is located near the mouth of Anderson Creek, close to the gaging station. Another site was investigated at Sulphur Creek. Satisfactory foundation conditions were not found at either of these sites. The site now believed to be the best for complete development of the upper stretch is located in the NE¼ of the SW¼ of sec. 31. T. 37 N., R. 9 E., Willamette meridian, just upstream from what is locally known as "Engletrout Canyon." A number of core borings were made at this site and disclosed in general a slate or slate-and-quartz bedrock. Several outcrops of this material occur on the left bank, where apparently very little stripping would be required. A drill hole on the right bank disclosed approximately 150 feet of overburden. However, bedrock outcrops at a point considerably higher up on this bank.

271. The natural low-water surface at the dam site has an elevation of about 445 feet. The bed of the stream lies approximately in the center of the canyon, which is about 1,100 feet wide at the 700-foot contour.

272. *Power possibilities*.—The mean monthly stream flow for each month of the 17-year period from April 1914 to March 1931 inclusive, is shown in table 27. Flow-durations from monthly data for natural and regulated conditions are shown on figure 13. A study of the stream-flow records indicates that the minimum flow generally occurs early in March, with the heaviest run-off in June, followed by a relatively low flow in September, and a fairly heavy flow in November and

[1] At gaging station below Anderson Creek. Stream flow at the dam site considered to be the same, as the drainage area increases less than 2 percent.

December. The mean run-off for the 17-year period is 1,970 second-feet.

273. A study of the discharge records of the Baker River indicates that the major floods occur in the winter and that the maximum reservoir stage generally occurs in midsummer of each year. Taking

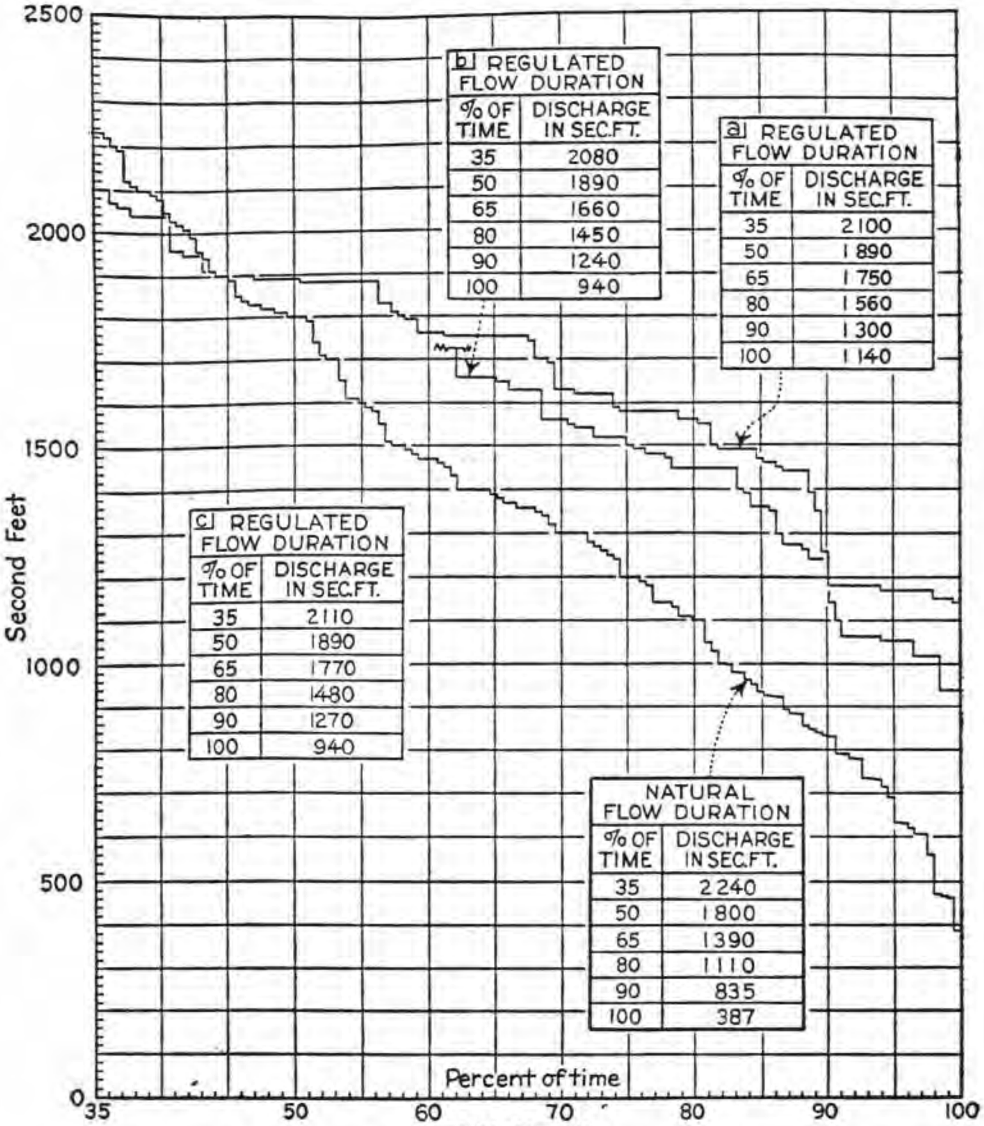


FIGURE 13
BAKER RIVER BELOW ANDERSON CREEK
FLOW DURATION–PERIOD APRIL, 1914–MARCH, 1931
U.S. Engineer Office Seattle, Washington

a) Regulation below elev. 704 for power only
b) Regulation below elev. 694 for power only
c) Regulation below elev. 704 for power and winter flood control. (Curve not shown)
} Lower limit of drawdown elev. 664

advantage of this condition, it would be possible to reserve for flood retention the upper 10 feet of reservoir storage (39,500 acre-feet) until February 1 each winter at no great sacrifice of power. Such reservation would reduce the Q-90 flow from 1,300 to 1,270 second-feet, a reduction of about 2 percent. This amount of flood storage would retain 72 percent of the maximum known 24-hour flow (27,400 second-feet). It is improbable that the reservoir capacity will ever be materially reduced by silting as the tributary streams carry but little sediment.

274. *Plans for development.*—A concrete dam of gravity overflow section seems to be the type best suited to the site. The natural low-

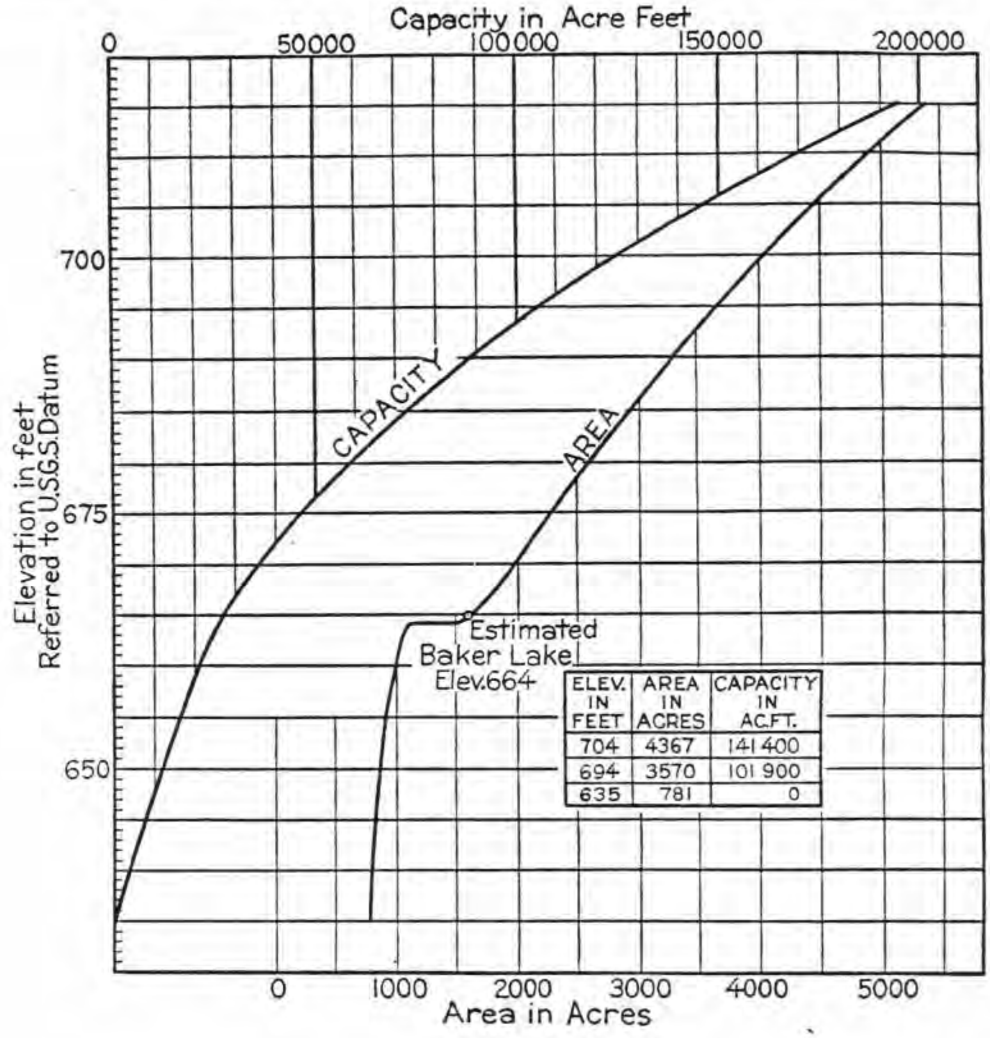


FIGURE 14
BAKER RIVER
UPPER BAKER RESERVOIR
AREA&CAPACITY CURVES&TABLE
(Data furnished by Puget Sound Power & Light Co.)
U.S.Engineer Office, Seattle, Washington

water elevation is 445 feet, which is but slightly above the maximum surface elevation of Shannon Lake, the artificial reservoir that serves the existing Puget Sound Power & Light Co. plant. A useful storage of 115,800 acre-feet would be provided by regulation between elevations 704 and 664 feet. (See fig. 14.) The cost of the dam is estimated at $4,500,000 by Puget Sound Power & Light Co. engineers.

It would be necessary to construct an earth-fill dike in a saddle about three quarters of a mile north of the main dam. As far as known to this office, no subsurface explorations have been made at this saddle.

275. The power house would be located about a quarter of a mile downstream from the dam, where the natural low-water elevation is 435 feet. The installed capacity would be 46,500 kilowatts based on a Q 90 flow of 1,270 second-feet and a head of 269 feet at 80 percent efficiency and 50 percent load factor. The mean static head would then be 250 feet and the maximum head would be 269 feet (from elevation 704 feet to elevation 435 feet).

276. Further study may indicate that the power house could be economically placed farther downstream, to utilize head gained in the draw-down of Shannon Lake. With ideal operation, the level of Shannon Lake would have been higher than elevation 420 feet for about 42 months of the 17-year period. If the power house were placed to utilize head to this elevation, the corresponding installed capacity would be 49,000 kilowatts based on a total head of 284 feet. The mean static head would then have been 263 feet for the 17-year period.

277. Alternate plans: If flood storage in the amount of 39,500 acre-feet were to be reserved the year around, the maximum forebay level for power use alone would be at elevation 694 feet. The useful power storage would then be 76,300 acre-feet and the flow available 90 percent of the time would be 1,240 second-feet and the mean static head would be 247 feet. For a power development with no reservation for flood control, the normal forebay level would be at elevation 704 feet. The useful storage would then be 115,800 acre-feet, the Q 90 flow would be 1,300 second-feet, and the mean head would be 252 feet.

FLOOD CONTROL

278. *Types of flood relief.*—Works for the relief of floods may be divided into three principal classes; flood prevention, flood protection, and flood diversion.

279. *Flood prevention.*—Works for flood prevention include all means of reducing the rate of flood flow. In this class are placed reservoirs or detention basins for the purpose of storing flood flows and feeding the water gradually back to the streams. Detention basins constructed for the sole purpose of storing flood waters are impracticable on the Skagit River because of their great cost in proportion to the benefits. In the preceding discussion of the four major power projects—the Ruby, Cascade, lower Sauk, and upper Baker projects—some consideration was given to using the reservoirs connected with these projects for the joint benefit of power and of flood control.

280. For the Ruby Reservoir, it was suggested that 200,000 acre-feet of storage be reserved for the storage of flood waters. This amount of storage could be obtained in the 11 feet between elevations 1,700 and 1,689 feet, and would be sufficient to hold a 24-hour flow of 100,000 second-feet (the estimated maximum flood). If a free overflow spillway were used there would also be a temporary retention of flow above the spillway crest due to the time required to build up storage to a point that would create the head necessary for discharge of the flood waters. Such temporary retention would be beneficial in the delta area as it would probably delay the time of arrival of the

crest from the upper Skagit sufficiently to insure that the crests from the lower tributaries would have already passed out.

281. Similarly, for the Cascade Reservoir, it was suggested that the 32,300 acre-feet between elevation 1,075 and 1,100 feet be reserved for the storage of flood waters. Here, again, temporary storage amounting to about 15,000 acre-feet additional could be built up above the spillway crest during an estimated maximum flood of 40,000 second-feet. The 32,300 acre-feet represents about 51 percent of the maximum 24-hour run-off of the Cascade during the 1909 flood, the greatest of record, and, including the temporary storage, about 47 percent of the run-off for the 3 maximum days of the 1909 flood. A reservation of very much in excess of the 32,300 acre-feet was considered infeasible as it would reduce the power output of the site rather materially.

282. For the Sauk Reservoir, it was suggested that the 200,000 acre-feet between elevation 498 and 475 feet could be reserved for the storage of flood waters at no great detriment to power production. Actual flood discharge records are almost nil at this site, but the crest discharge of the 1921 flood has been estimated as about 70,000 second-feet. The flood of February 1932 reached a crest discharge of 68,500 second-feet and the maximum 24-hour discharge about 51,400 second-feet. The 200,000 acre-feet would have been sufficient to hold all of the run-off for the maximum day for either of these two floods and could have held 96.2 percent of the run-off for the 3 maximum days of the February 1932 flood. In addition to the 200,000 acre-feet, there would be about 75,000 acre-feet of temporary storage above the spillway crest during a major flood.

283. For the upper Baker Reservoir, it was suggested that the 39,500 acre-feet between elevations 704 and 694 feet could be reserved for the storage of flood waters at no great sacrifice of power. This amount of flood storage would retain over 70 percent of the maximum known 24-hour discharge of the stream.

284. These suggested reservations of reservoir capacity for the storage of flood waters represent different percentages of the total usable storage in the different cases and involve varying amounts of draw-down, but are believed to be the maximum reservation that could be made in each case without unduly restricting the power output or rendering the power element economically infeasible.

285. All of these reservoirs are within national forest areas except the major part of the lower Sauk, and, since regulation of the amount of storage contemplated there would affect navigation on the main stream, it is believed that even this project should be developed under license from the Federal Power Commission. Right to develop the three sites within the national forest could be obtained only through the Federal Power Commission, and, in the case of Ruby Reservoir, the Commission has already made provision for the storage of flood waters in that reservoir. (See par. 104.) Since water rights for all four projects can be obtained only from the State, those rights could be issued subject to proper provision for the storage of flood waters.

286. Data regarding the shape and duration of the flood hydrographs, the rate of propagation of the flood crest down the valley, and the channel storage at different stages are almost entirely lacking thus indicating the need for continuing the operation of the stream gaging stations now established. However, studies of the probable effect of

controlled flood storage in each of the four major power project reservoirs indicate that the 1909 flood could have been reduced from the recorded crest discharge of 220,000 second-feet at Sedro Woolley to a discharge—probably less than 140,000 second-feet—that would not have overtopped the existing dikes.

287. A summary of the suggested reservations at the various reservoirs is given in table 51.

TABLE 51.—*Summary of reservations for storage of flood waters*

Reservoir	Maximum static head	Flood reservation	
		Draw-down from spillway crest	Capacity
	Feet	*Feet*	*Acre-feet*
Ruby	500	11	200,000
Cascade	740	25	32,300
Lower Sauk	218	23	200,000
Upper Baker	284	10	39,500
Total			471,800

288. *Flood protection.*—Works for flood protection do not reduce the flood flows, but protect against them. These works include levees, or dikes, and channel improvements. Channel improvements on the Skagit for the benefit of navigation alone are not justified, except possibly some snagging and minor works; so that the entire cost of such improvements could not be divided between navigation interests and parties benefited by flood-control works, but should be carried entirely by the latter.

289. Study was given to the improvement of Skagit River below Burlington by a coordinated system of dikes and channel betterment as a means of protecting the delta area from floods. The study was limited to such improvements as might be required to safely carry a flood of 220,000 second-feet, this being the discharge of the 1909 flood at Sedro Woolley—the largest of actual record, although a flood of almost double this discharge is believed to have occurred about 1815. (See table 36.)

290. At the beginning of this study it was intended to confine the improvements, excepting for a certain amount of channel excavation at the Great Northern Railway bridge, to a system of dikes. Upon investigation, however, it was found to be impracticable to confine the improvement to a system of dikes. In its natural condition the Skagit River, during flood periods, overflowed its banks and inundated a large portion of the delta. The flood waters reached Puget Sound, not alone through the river channel proper, but also through the many sloughs and small drainage channels and by passing directly across the flats. At the present time the river is partially held in bounds by dikes that have been constructed by local organizations. These dikes have been constructed without a well-developed general plan and are entirely inadequate to handle a major flood. During severe floods the dikes frequently fail by boils before being overtopped.

291. A system of dikes proportioned to carry the entire flood flow at a surface elevation approximating that obtaining under natural conditions, would include so much valuable agricultural land as to be prohibitive. A system of dikes proportioned to carry the entire flood flow within the lateral limits of the natural river channel and at velocities below the point of scour would require high and expensive dikes and would require, in addition, the raising of all bridges in the improved section and the construction of an expensive drop or series of drops at or near tidewater. The latter would also involve the construction of navigation locks. Upon investigation it was found that a compromise between these two extreme systems including some channel improvement would produce the cheapest method of flood protection.

292. This compromise scheme involved the construction of a protection dike on the right bank of the river from the high ground above Burlington (see plate 3)[1] to a point just upstream from the Great Northern Railway bridge. No dike was provided for the left bank along this stretch, as the adjacent Nookachamps area affords considerable storage at the higher river stages. This storage is valuable in that it reduces the flood crests past the Great Northern bridge. The existing diked river system below the Great Northern bridge has an estimated crest flood capacity of 140,000 second-feet. The diked channel would not carry this amount indefinitely as the dike material would soon become water-soaked and fail. To provide for a flow of 220,000 second-feet below this point, it was planned to enlarge the channel and to use the dredged material for the construction of adequate dikes. The cost was worked out down to the head of the forks, about 3 miles below Mount Vernon. The total estimated cost of the improvement from Burlington to the forks is as given in table 52. The total cost there given is about $700,000 more than could be justified. (See par. 141.)

TABLE 52.—*Estimated cost of flood protection by river enlargement and dike construction (to forks only)*

Item	Unit	Quantity	Unit price	Amount
Dikes:				
Embankment	Cubic yards	408, 320	$0. 15	$61, 248
Right-of-way	Acre	80	50. 00	4, 000
Clearing	do	10	150. 00	1, 500
River enlargement:				
Right-of-way [1]	do	1, 575	50–300. 00	287, 500
Excavation	Cubic yards	22, 409, 590	. 12½	2, 801, 199
Bridges:				
Highway		2		427, 580
Railroad		2		466, 520
Incidentals, engineering, legal, etc	Percent	(2)		404, 963
Total				4, 454, 510

[1] Includes buildings involved minus salvage value.
[2] About 10.

293. Since the estimated cost of the improvements from Burlington down to the forks, about 10 miles, exceeded the justifiable expenditures, no estimate was made of continuing the improvements on to the mouths of the river, a farther distance of about 8 miles.

[1] Not printed.

This continuation on to the mouths would probably be more expensive than the works just outlined for the stretch between Burlington and the forks, including, as it would, a drop and navigation lock in each fork.

294. *Flood diversion*.—Occasionally flood flows can be diverted from the places where harm is done to other places where the flood is less objectionable. The desirability of diverting a portion of the flood flows of the Skagit River is apparent. If a diversion could be effected upstream from Burlington at a reasonable cost, the danger and loss occasioned by floods in the delta area could be eliminated or reduced. No opportunity of diverting the flood flows exists above Sedro Woolley. Two possible alternative diversion channels have been suggested below Sedro Woolley—one, to divert just above Burlington, and the other to divert at Avon, below Burlington. The first of these would utilize the low land now occupied by Joe Leary Slough, and will be called the Joe Leary by-pass. The second will be called the Avon by-pass. (See pl. 3.)[1]

295. In designing both of these by-passes, locations and types of construction were proposed that required the absolute minimum of expenditure. The details of location and design might be questioned, but at least they represent the works having the minimum cost. If, as was expected, the cost of either or both of these plans proved to be more than warranted by the benefits, then it would be unnecessary to work out improved or more satisfactory plans calling for a greater cost.

296. Because of inadequate data, certain assumptions were necessary, but it is believed that the assumptions that were made produced the minimum cost estimates. The maximum discharge of actual record was 220,000 second-feet in 1909. Of this amount, it was assumed that 100,000 second-feet could be safely carried by the natural river channel and the existing diking system, leaving 120,000 second-feet to be carried by the by-pass. A river elevation of 35 feet at the point of diversion into the Joe Leary by-pass was assumed. The corresponding figure for the Avon by-pass was 26.5 feet.

297. The principal dimensions and hydraulic data common to both diversions were:

Capacity ... second-feet	120, 000
Velocity ... feet per second	5
Area ... square feet	24, 000
Depth of water ... feet	15
Freeboard ... do	6
Side slopes:	
Horizontal	2
Vertical	1
n	0. 0225
s	0. 000282

298. The Joe Leary by-pass would be 9.6 miles long, and the Avon by-pass 5.6 miles. No intake structure was included in the cost estimate for either route. Under the preceding assumptions, the elevation of the water in the by-pass at tidewater would be 20.62 feet for the Joe Leary by-pass, and 18.04 feet for the Avon by-pass. The tides vary at the end of the spillways in Padilla

[1] Not printed.

Bay from +6.22 feet to −9.28 feet (mean sea level datum). A concrete drop was provided at tidewater for each by-pass to limit currents to less than destructive velocities.

299. The estimated cost of the Joe Leary by-pass is as given in table 53, and that of the Avon by-pass in table 54. The Avon by-pass is the cheaper of the two routes, but even so, the cost of that route is about $780,000 greater than could be justified.

TABLE 53.—*Estimated cost of Joe Leary by-pass*

Item	Unit	Quantity	Unit price	Amount
Channel:				
Right-of-way	Acre	2,500	$50.00–$250.00	$375,000
Excavation	Cubic yards	16,303,880	.12½	2,037,985
Riprap	do	100,000	1.10	110,000
Drop at tidewater:				
Excavation	do	110,000	.30	33,000
Concrete	do	24,500	12.50–16.00	308,716
Steel	Pound	170,240	.07	11,916
Piling (30-foot)	Each	2,440	12.00	29,280
Timber crib	Foot, board measure	961,700	0.05	48,085
Rock fill in crib	Cubic yards	6,513	1.10	7,164
Back fill	do	14,130	.15	2,120
Riprap	do	1,000	2.00	2,000
Coffer dam and pumping	Job			25,000
Bridges:				
Highway		2		911,230
Railroad		3		1,517,354
Incidentals, engineering, legal, etc.	Percent	10		564,260
Total				5,983,110

TABLE 54.—*Estimated cost of Avon bypass*

Item	Unit	Quantity	Unit price	Amount
Channel:				
Right-of-way [1]	Acre	1,828	$50.00–$300.00	$345,900
Excavation	Cubic yards	13,936,440	.12½	1,742,055
Riprap	do	50,000	1.10	55,000
Drop at tidewater:				
Excavation	do	110,000	.30	33,000
Concrete	do	22,540	12.50–16.00	284,216
Steel	Pounds	170,240	.07	11,916
Piling (30-foot)	Each	2,440	12.00	29,280
Timber crib	Feet, board measure	961,700	0.05	48,085
Rock fill in crib	Cubic yards	6,513	1.10	7,164
Riprap	do	1,000	2.00	2,000
Back fill	do	14,130	.15	2,120
Cofferdam and pumping	Job			25,000
Bridges:				
Highway		2		560,040
Railroad		3		916,230
Dike reinforcement:				
Embankment	Cubic yards	126,720	.15	19,010
Right-of-way				1,000
Incidentals: Engineering, legal, etc.	Percent	10–15		447,594
Total				4,529,610

[1] Includes buildings involved minus salvage value.

IRRIGATION

300. *Irrigation.*—As previously stated (par. 155), the precipitation over the basin is abundant for all crops now raised, and it is not likely, therefore, that irrigation will ever be practiced to any great extent. As a consequence, no special provision has been made herein for irrigation withdrawals or works.

BANK EROSION

301. *Measures for erosion relief.*—At most places the cost of protecting banks from erosion would exceed the damages avoided. Relief work should be done only when the reverse is true.

302. Extensive damages, due to erosion, are probable at Lyman, just below Hamilton and along Arnold Slough, and may prove sufficient to justify the cost of bank protection. At Lyman the Skagit flows through two channels, the northerly channel carrying the main discharge and making a reverse curve at the town. Erosion could be prevented by bank protection along the concave side of the bend in this northerly channel, or by opening up the southerly channel at some sacrifice of navigable depths in the northerly channel. In addition, further protection would result from building a closing dike at the head of the high-water slough just below Lyman. Stopping erosion at the ox-bow bend below Hamilton involves constructing bank protection along the bend and placing a closing dike at the head of Etach Creek, which is a slough at high water. A feasible plan to prevent erosion along Arnold Slough would be the construction of a closing dike at the head of the slough and the placing of bank protection along the concave bank of the river at the entrance to the slough.

303. Where erosion particularly threatens the safety of improvements of railway companies, the county, or public corporations, these parties should and probably will take proper measures to protect their interests. Where erosion is a purely local problem, as is most often the case, the cost of protection should be directly charged to the property benefited.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

304. This investigation as to the possibilities of improving the Skagit River in the interest of navigation in combination with power development, the control of floods, and the needs of irrigation leads to the following conclusions.

305. Except for the movement of logs on the upper river, navigation is almost entirely limited to the tidal stretch between Mount Vernon and the mouth. Improvement by means of locks is considered neither practicable nor advisable. Snagging and a limited amount of dredging are meeting the present and reasonably prospective needs of navigation in a satisfactory manner. Operation of upstream reservoirs for the benefit of power will increase the low-water flow of the main stream and thus aid the transportation of logs on the upper river during low-water periods. These same reservoirs could be operated to reduce the crest discharge of floods and the attendant evils of cutting banks and deposition of snags in the navigable channels. Although it is believed that the benefits to navigation from the construction and operation of upstream power projects and reservoirs would not be sufficient to justify the United States in sharing in the cost thereof, the effect on navigation of such regulation of storage is believed to be sufficient under the law to require the Federal Power Commission to exercise jurisdiction over the construction and operation of the major plants as designated in this report.

306. Power can be developed at many sites on the upper river and on the tributaries. It is believed that ultimately many of these sites

will be developed, the market for their output being found in the growing Puget Sound region and in the requirements of individual industrial enterprises. The reservoirs of the various power projects could, with unified control, be operated for the joint benefit of power production and of flood control, the curtailment in power production depending upon the proportion of the capacity of each reservoir reserved for flood control.

307. Floods on the Skagit are a menace to both life and property. Four floods of considerable severity have occurred within the past 23 years, the largest being the flood of 1909. Floods of almost double the magnitude of the 1909 flood are believed to have occurred within the past 120 years and probably will occur again in the future—possibly next year, but improvements for adequate protection against such floods are considered infeasible. Reservoirs of sufficient capacity to prevent such a major flood or even a flood comparable to those of the past 23 years are not economically feasible for flood-control purposes alone. Protection from floods comparable to that of 1909 is infeasible either by the construction of dikes combined with river enlargement or by diversion of such portion of the flood discharge as cannot be safely carried by the existing diked channels. It does appear feasible, however, to reserve for flood prevention purposes a portion of all reservoirs to be constructed primarily for use with power projects. Such a reservation for the four major power projects discussed in the report could probably have reduced the 1909 flood discharge at Sedro Woolley from the recorded crest of 220,000 second-feet to an amount that could have been carried by the existing diked channel. When it becomes expedient to develop storage for power in this basin, local beneficiaries of flood storage should be permitted to secure protection at least to the extent that they are willing to participate in the cost. Pending such development, those interested in flood protection in the delta area should improve the river channel and diking system below Burlington so that it will carry for an indefinite period a discharge of at least 140,000 second-feet. Such improvements would carry the smaller floods without damage, and when upstream storage is provided and properly regulated, potential floods up to 220,000 second-feet would cause no damage. These improvements should include enlargement of the channel at all constricted sections especially at the Great Northern Railway bridge, the strengthening of dikes, and the revetting of banks. The scope of the present study has not permitted a determination of the details of this general plan—such a determination requiring a considerable expenditure of time and money.

308. The damage done by erosion is local in character and is not of sufficient general importance to justify Federal participation in its prevention.

309. Flood history on all other rivers shows that major floods reoccur. It is, therefore, to be expected that the peculiar climatic conditions causing major floods will again obtain in this watershed, that the major flood will occur and that any work done in providing for storage of flood waters, or in channel improvement or diking, will not prevent this flood, nor will it avoid the loss of life and property damages resulting from a major flood. Provision for some flood storage and protection should not lead to a feeling of security on the part of the residents of the valley. Arrangements should be made for a system of flood warnings in addition to the protective measures.

310. Irrigation in the Skagit Valley is not necessary for any crops now grown.

311. This investigation has disclosed the inadequacy of basic stream-flow data and the desirability of obtaining additional long-time records of discharges. The War Department provided funds for the establishment and maintenance, during the period of the investigation, by the United States Geological Survey of six gages. All of these gages, with the exception of the one on the Sauk near Darrington, should be continued in operation.

RECOMMENDATIONS

312. It is therefore recommended:

First. That development of the lower Sauk power site should be governed by the provisions of the Federal Water Power Act;

Second. That local beneficiaries of flood storage be given an opportunity to secure protection at least to the extent that they are willing to participate in the cost of storage to be developed primarily for power purposes, and that regulation of both flood and power storage be accomplished in accordance with such rules as may be prescribed by the Federal Power Commission;

Third. That the river channel and dike below Burlington be improved by those directly interested to carry for an indefinite period a discharge of at least 140,000 second-feet;

Fourth. That no reservations of water or of storage capacity be made for the benefit of irrigation;

Fifth. That stream gaging be continued by those directly interested to the end that adequate long-time basic data be made available for future studies and construction;

Sixth. That no change be made in the existing navigation projects;

Seventh. That the Federal Government contribute neither to the cost of power developments as an aid to navigation and/or flood control, nor to the cost of bank protection, because the resulting national benefits would not be sufficient to justify such participation.

313. The following recommendations, originally made by J. E. Stewart (see par. 116), are concurred in by the district engineer:

First. Install a flood-warning system. This system should include at least three, and preferably more, fully equipped United States Weather Bureau stations. The principal locations for these stations, in the order of their importance, are, Diablo Dam, Gorge power plant, Darrington, upper Baker River, and Sedro Woolley. Preceding an impending flood, hourly radio or telephone reports from these stations and from the various river gaging stations should be collected and studied by the proper agency, and, when conditions dictate such action, warnings should be sent immediately by radio and telephone to the danger points along the river. For a maximum flood the main effort should be to save human life, and to that end the following places should be abandoned as soon as possible after the knowledge of such an impending flood has been received: All of Hamilton, Lyman, and Burlington, and the low-lying portions of Concrete, Sedro Woolley, and Mount Vernon.

Second. Delay or prohibit entirely diking off the Nookachamps Creek district, as this section acts as a storage reservoir and thus reduces the flood height in the surrounding and lower districts.

C. L. Sturtevant,
Lt. Col., Corps of Engineers, District Engineer.

Illustrations Submitted With Report

[Only figures 4, 6, 8, 9, 11, 12, 13, and 14, and plates 1, 4, and 5, printed in this document. Copies of unpublished illustrations may be procured from the District Engineer, U.S. Engineer Office, Seattle, Wash., at cost of reproduction.]

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