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FLOODS OF THE PUYALLUP AND CHEHALIS RIVER BASINS WASHINGTON

BY
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CONTENTS

ILLUSTRATIONS

TABLES

FLOODS OF THE PUYALLUP AND CHEHALIS RIVER BASINS, WASHINGTON

By Irving E. Anderson

ABSTRACT

The Puyallup and Chehalis River Basins are situated in the southern half of western Washington. The two basins are comparable in size and shape but are unlike in other characteristics. The Puyallup River rises in the glaciers of Mount Rainier and flows through mountainous, foothill, and delta topography. Its basin ranges in altitude from sea level to 14,408 feet, and the average annual precipitation ranges from 40 inches in the delta to more than 100 inches on the slopes of Mount Rainier. The Chehalis River rises in the Willapa Hills and the western foothills of the Cascades. Its basin ranges in altitude from sea level to a maximum of about 4,000 feet. The greatest annual precipitation in the Chehalis Basin has not been measured because of lack of gages, but it probably does not exceed that of the Puyallup.

For purposes of this study the Puyallup Basin was divided into two parts, mountainous and valley. Although a close comparison was not possible because of the lack of precipitation gages, the study indicated that runoff characteristics for floods from the Chehalis River and the valley part of the Puyallup River are not greatly different.

Consistency between rainfall and run-off in the upper Puyallup, Carbon, and White Rivers, tributaries from the mountainous part of the Puyallup River, indicated that a computation of mean precipitation based on relation between precipitation and altitude gives reasonable results.

The investigation indicated that differences in physical characteristics between the mountainous and valley parts of the Puyallup River do not greatly affect the discharge.

INTRODUCTION

Location and extent of region.—The region considered in this report is that part of the State of Washington west of the Cascade Range. (See fig. 27.) It has an area of about 24,500 square miles and a population of about 1,200,000 persons, according to the 1940 census.

Acknowledgments.—The preparation of this report, which was made possible by an allocation of funds by the Federal Emergency Administration of Public Works for a "survey of floods and droughts," was under the direction of G. L. Parker, district engineer, whose deep interest and constructive criticism added much of value. D. J. F. Calkins, office engineer, helped materially with constructive suggestions, advice, and criticism. Preliminary computations were made

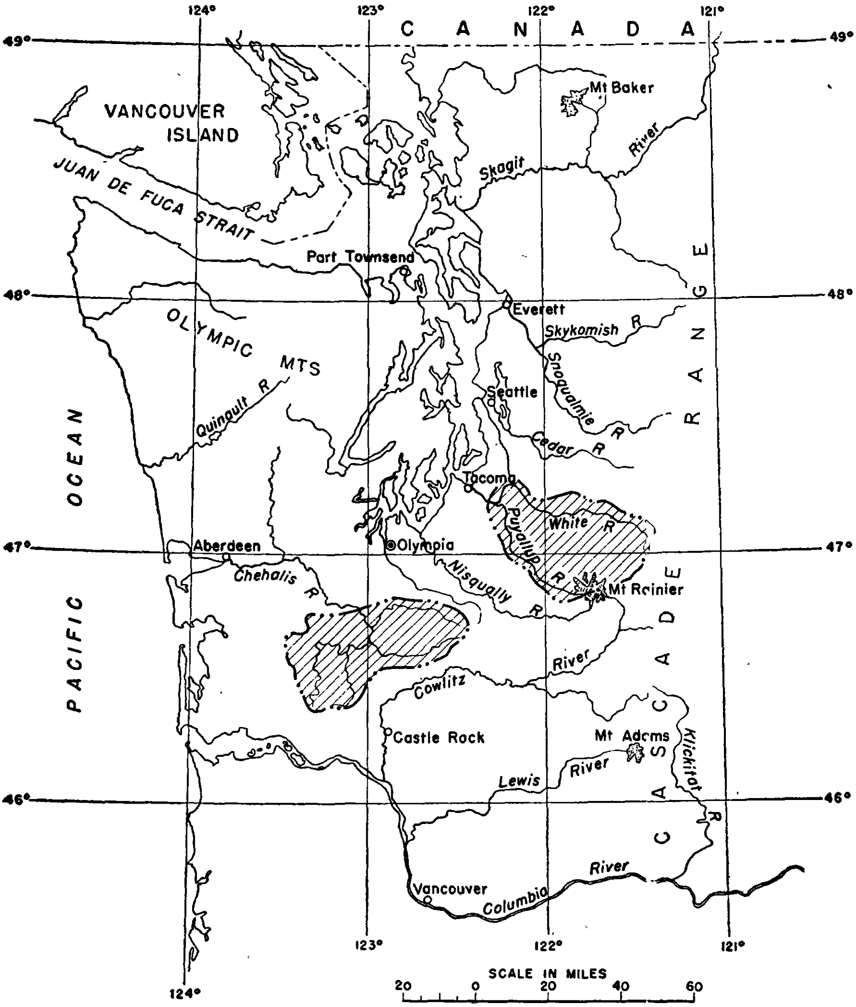

FIGURE 27.—Map of western Washington showing basins investigated and cities, streams, and other physical features mentioned in the text.

and several figures prepared by J. W. Allan. Acknowledgments are also due the Weather Bureau for weather records and the Puget Sound Power & Light Co. for furnishing hourly readings of Lake Tapps. The manuscript was reviewed and prepared for publication by the Division of Water Utilization, R. W. Davenport, chief.

GEOGRAPHIC AND HYDROLOGIC CHARACTERISTICS OF THE REGION

SURFACE FEATURES

The Cascade Range, extending north and south, forms the eastern boundary of the region. Crest elevations along the range vary from

6,000 to 8,000 feet. Many extinct volcanoes protrude through the western slopes of the Cascades and extend into the zone of eternal snow. Among these volcanoes are Mount Baker (elevation, 10,703 feet), Mount Rainier (elevation, 14,408 feet), Mount Adams (elevation, 12,307 feet), and Mount St. Helens (elevation, 9,697 feet). The Olympic Range, with its axis extending northwest to southeast, lies between the Strait of Juan de Fuca on the north and the Chehalis River on the south. Its highest elevations are comparable to those of the Cascades. The Willapa Hills, much lower than either the Cascades or the Olympics, lie in the southwestern part of the region between the Chehalis and Columbia Rivers.

CLIMATE

Western Washington is subject to the moderating effects of prevailing winds from the Pacific Ocean. The Cascades on the east and the mountains of British Columbia on the north act as barriers that protect the region from the climatic extremes characteristic of the interior. Temperature variations at several points in the region are shown in table 1.

TABLE 1.—*Temperature, in degrees Fahrenheit, at selected points in western Washington*

Station	Approximate altitude (feet)	Mean temperature for period of record (° F.)	Length of record (years)	1938	
				Maximum (° F.)	Minimum (° F.)
Aberdeen	105	50.4	47	92	23
Centralia	182	52.8	44	102	20
Tacoma	109	52.4	52	87	25
Seattle	14	53.8	49	92	28
Bellingham	159	50.9	29	84	22

The principal source of precipitation in the region is the water vapor from the Pacific Ocean carried inland by prevailing southwesterly winds. Moisture-laden air enters the interior either through the gaps occupied by the Columbia and Chehalis Rivers and the Strait of Juan de Fuca or over the Olympics and Willapa Hills. As this air is forced upward over the mountains, it is cooled by expansion and produces precipitation to the extent of cooling below the dew point. In summer this cooling is partly offset by the temperature of the land areas, which is higher than that of the ocean; in winter the lower temperature of the land areas augments the cooling of the air, which results in high precipitation in an irregular belt along the Pacific coast. After passing over the mountains to lower levels these air masses are warmed by compression and higher land temperature at those levels. Hence, the tendency is for them to yield

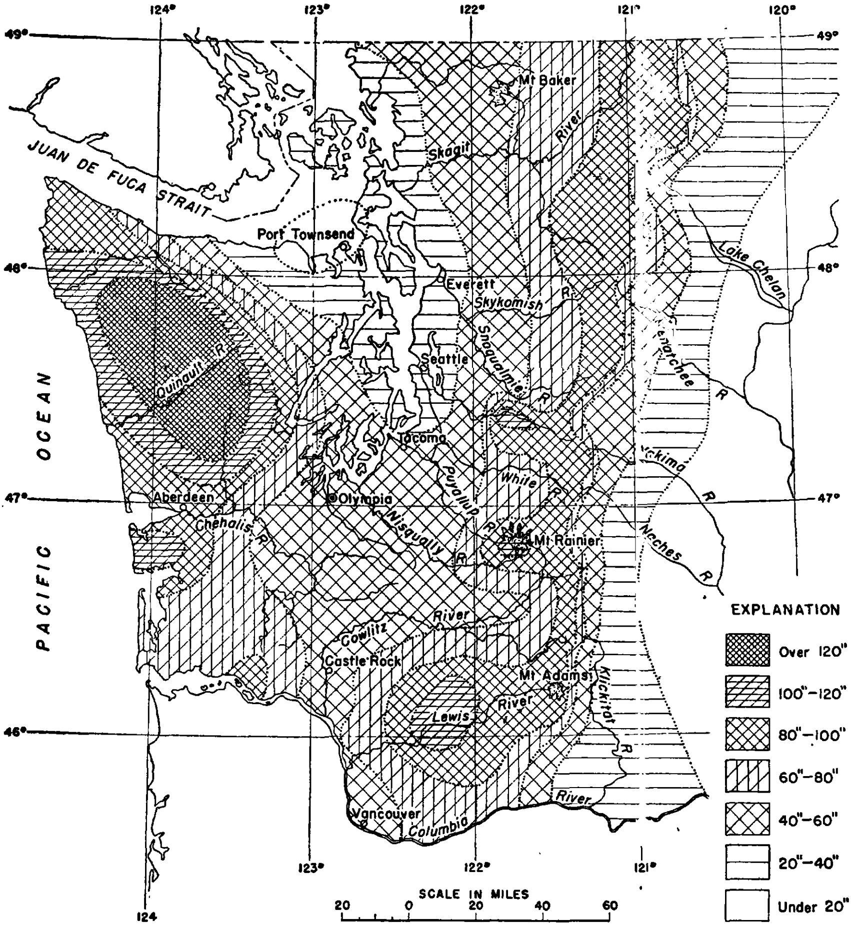

FIGURE 28.—Map of western Washington showing mean annual precipitation, in inches.

only a relatively small amount of precipitation at lower altitudes. The process of expansion and cooling is repeated as the winds ascend to cross the Cascades. Prevailing winds from the west and southwest enter the interior through gaps of the Columbia and Chehalis Rivers and through the Strait of Juan de Fuca, unobstructed by mountains, and produce belts of high precipitation that extend some distance inland along the Columbia and Chehalis Rivers and in that part of the region east of the Strait of Juan de Fuca. The combined effect of topography and prevailing winds results in a wide variation in precipitation throughout the region, and, as shown on figure 28, the annual averages range from less than 20 inches at places in the rain shadow of the Olympics to more than 100 inches on the western slopes of the Olympics and Cascades.

RUNOFF

In general, the principal streams of the region rise in the Olympic or Cascade Mountains, the most notable exception being the Chehalis River, which has its source in the Willapa Hills. Streams rising in the mountains are characterized by two high-water periods each year, the first period from October to January, when precipitation is heaviest, and the second in the spring, when rising temperature causes the snow to melt. Such streams, many of them glacial, are further characterized by well-sustained low-water flow during months of little or no precipitation from June through September. The Chehalis and North Rivers and other streams draining the Willapa Hills have little natural storage in snow and none in glaciers. Hence, their flow in summer is very low. Variations in natural storage, combined with variations in precipitation, topography, soil, and exposure, produce a variable runoff throughout the region. In many localities changes in runoff are abrupt. For example, during 1937–38 the Dungeness River in the northeastern part of the Olympic Peninsula had a runoff of only 36 inches while the Dosewallips, an adjoining basin, had 75 inches. Runoff characteristics for some streams in the region for which records are available for 10 years or more are shown in table 2.

Greater floods than those listed in table 2 have occurred, as disclosed by investigations of the history of floods in the Skagit River Basin. In 1921 James E. Stewart, then hydraulic engineer with the Geological Survey, determined, as explained below, that a greater flood in the Skagit River Basin occurred between 1804 and 1825 (probably about 1815) and another in 1856. He computed the discharge for these floods as 500,000 and 350,000 second-feet, respectively, below the Baker River near Concrete. The height of the earlier flood was marked by deposition of flood sands in protected caves and gulches and in crevices in canyon walls and by faint high-water marks on canyon walls. The date can be placed no closer than 1804 to 1825, which dates Mr. Stewart determined from his conversation with early white settlers who had been told of the flood by the Indians. The flood of 1856 was marked by tree staining, which, however, had disappeared by the time of Mr. Stewart's investigations. Early white settlers saw the stains and made dependable observations as to their height above later floods. Mr. Stewart found mud and flood sand embedded in deep crevices of cedar bark, which verified heights established by the early settlers. The date of this flood is definitely fixed as having occurred between 1854 and 1857 by examination of a group of trees on a sand bar at The Dalles. These trees were of uniform growth and were much younger than those nearby at higher levels, which indicates that the sand bar probably was cleared

TABLE 2.—*Annual precipitation and runoff characteristics of streams in western Washington*

Stream and point of measurement	Period of record	Drainage area (square miles)	Mean annual precipitation (inches)[1]	Average annual runoff: Second-feet per square mile	Average annual runoff: Depth (inches)	Maximum discharge of record: Date	Maximum discharge of record: Second-feet	Maximum discharge of record: Second-feet per square mile
Lewis River near Cougar	1924–38	483	115	5.84	79.27	Dec. 21, 1933	54,400	113
Cowlitz River at Packwood	1911–19, 1929–38	287	73	5.69	77.24	do	36,600	128
Cowlitz River at Castle Rock	1926–38	2,210	73	4.05	54.98	Dec. 23, 1933	139,000	62.9
Clear Fork of Cowlitz River near Packwood	1907–12, 1930–38	56	52.59	4.54	61.63	Dec. 22, 1933	8,030	143
Toutle River near Silver Lake	1909–11, 1919–21, 1922–23, 1929–38	472	60.01	4.38	59.46	Mar. 2, 1910	35,600	75.4
North River near Raymond	1927–38		68	2.95	40.04	Dec. 10, 1933	35,000	
Chehalis River near Grand Mound	1928–38	928				Dec. 29, 1937	48,400	52.2
Wynoochee River at Oxbow, near Aberdeen	1925–38	[2] 65	129.45	10.3	139.82	Jan. 22, 1935	18,000	277
Quinault River at Quinault Lake	1911–38	264	122.88	10.2	138.47	Dec. 12, 1921	37,000	140
Hoh River near Spruce	1926–38	193				Nov. 5, 1934	40,000	207
Elwha River at McDonald Bridge near Port Angeles	1897–1901, 1918–38	262	27.36	5.63	76.42	Dec. 21, 1933	26,700	102
North Fork of Skokomish River below Staircase Rapids, near Hoodsport	1924–38	60	98.97	7.73	104.93	Nov. 5, 1934	23,300	388
Little Nisqually River near Alder	1920–38	27.2	49.72	4.52	61.36	Dec. 20 and 21, 1933	2,430	89.3
Puyallup River at Puyallup	1914–38	948	100.05	3.47	47.10	Dec. 10, 1933	57,000	60.1
South Fork of Skykomish River near Index	1902–5, 1911–38	355	61.57	6.65	90.27	Dec. 18, 1917	57,000	161
North Fork of Skykomish River at Index	1910–22, 1929–38	149	61.57	8.08	109.68	Feb. 26, 1932	21,000	141
North Fork of Snoqualmie River near North Bend	1907–26, 1929–38	105	92.69	6.63	90.00	Oct. 24 or 25, 1934	11,500	110
South Fork of Snoqualmie River at North Bend	1907–26, 1929–38	84	92.69	6.42	87.15	Oct. 25, 1934	7,620	90.7
South Fork of Stillaguamish River near Granite Falls	1928–38	119	80.37	8.66	117.55	Feb. 26, 1932	26,700	224
North Fork of Stillaguamish River near Arlington	1928–38	269	80.37	6.29	85.38	do	27,700	103
Skagit River at Newhalem	1908–38	1,160	74.20	3.80	51.58	Dec. 12, 1921	60,000	51.7
Skagit River near Concrete	1924–38	2,700	74.20	5.35	72.62	Feb. 27, 1932	147,000	54.4
[illegible]	1928–38	180	74.20	5.44	73.84	Feb. 26, 1932	12,900	71.7
[illegible]	1917–22, 1928–38	152	80.37	7.37	100.04	Dec. 12, 1921	23,000	151
[illegible]	1928–38	714	80.37	5.86	79.55	Feb. 26, 1932	68,500	95.9

of all trees by heavy drift during an unusually high flood. Mr. Stewart assumed that new growth started the year after the flood. The approximate age of the trees was computed by counting the tree rings. The year 1856 was confirmed by study of precipitation records, which are available at Vancouver, Wash., for the years since 1853.

DEFICIENCIES IN PRECIPITATION DATA

The maximum annual precipitation recorded within the region west of the Cascade Mountains is about 130 inches, yet the average annual run-off from at least two streams, the Hoh and Quinault Rivers, exceeds that amount by nearly 10 percent, indicating that the actual precipitation is much higher than that recorded. Joseph Jacobs,[1] consulting engineer of Seattle, Wash., describes studies which led him to conclude that annual precipitation on the south and west slopes of Mount Olympus (altitude, 8,150 feet) might exceed 270 inches.

Stevens [2] writes:

> It is a common practice among engineers, when stream-flow data are not available—and sometimes even when they are—to make estimates of stream discharge from precipitation records. Such attempts are usually futile in this State [Washington], first, because such scattered rainfall stations as are being maintained are located in the valleys or in river canyons in situations which do not afford records representative of large areas, second, because practically no records of precipitation have been kept on the higher portions of the drainage basins, the portions that supply most of the water.

Although the number of precipitation stations has increased from about 40 in 1909 to about 100 in 1938, there are still only about 14 stations at elevations above 1,000 feet, which indicates that Mr. Stevens' statement is almost as true today as when he wrote it. Roughly, half the entire region is at elevations in excess of 1,000 feet, yet it is served by only 14 stations, only two of which are above an elevation of 4,000 feet. Figure 29 shows the effect of elevation on precipitation on the southern and western slopes of Mount Rainier in the Puyallup River Basin and on the southern slope of the Olympic Mountains in the Wynoochee River Basin.

The higher elevations in the region are subject to large accumulations of snow, exceeding 20 feet at Paradise Inn on the south slope of Mount Rainier. The depth of the snow is measured daily, but no regular measurements had been made of water content of the snow during the period covered by this report. Under such circumstances, it is impossible to segregate accurately runoff caused by melting snow from that caused by rain.

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[1] Some random notes on rainfall and runoff in the State of Washington, unpublished report to Water Resources Division, Washington State Planning Council.

[2] Stevens, J. C., Water powers of the Cascade Range: U. S. Geol. Survey Water-Supply Paper 253, pt. 1, pp. 14–15, 1910.

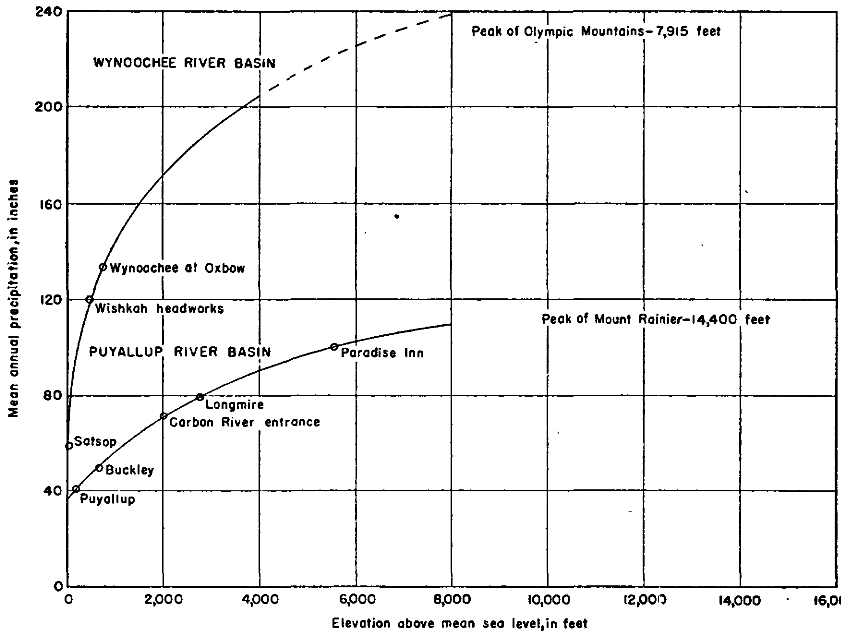


FIGURE 29.—Mean annual altitude-precipitation relation for the southern slope of the Olympic Mountains and for the southern and western slopes of Mount Rainier.

OBJECTIVES AND SELECTION OF AREAS

Practically every stream in the region flows through areas of two distinct types of topography—the upper mountainous area and the lower valley area—in which the physical and climatic characteristics are very different. The present study was undertaken to determine, if possible, the effect of this difference in characteristics on the behavior of flood runoff.

The Puyallup River, whose basin comprises both mountainous, foothill, and delta topography, lends itself fairly well to such a study. Stream-flow records are available on both the upper and the lower river and on three of its tributaries, so it is possible to segregate the runoff of the valley part from that of the mountainous part of the basin. Although the average annual runoff from the Puyallup River is not so great as for most streams in the region, the flood menace is of considerable consequence because of the relatively dense population and the highly developed areas in the lower part of the basin.

A comparison between valley runoff of the Puyallup River and that of a nearby stream seemed desirable. The Green and Nisqually Rivers, in adjacent basins, flow through areas somewhat similar to that of the Puyallup River but available records are not sufficient to make possible the segregation of the valley runoff. The Chehalis River, to the south, flows through rolling lowlands, somewhat similar to those of the Puyallup River Valley. That river was, therefore, chosen for study along with the Puyallup River. The location of the Puyallup and Chehalis River Basins is shown on figure 27.

PUYALLUP RIVER BASIN

DESCRIPTION OF AREA

The Puyallup River rises in the Puyallup and Tacoma Glaciers on the western slopes of Mount Rainier, flows 46 miles in a generally northwesterly direction to Commencement Bay, into which it empties at Tacoma. For a distance of 20 miles from its source the river traverses a comparatively high mountainous area with a very steep gradient. In this stretch the channel occupies a narrow canyon for a distance of 9 miles. Below this 20-mile stretch the valley widens, the gradient decreases abruptly, and the river flows through rolling lowlands to its mouth. The Carbon and White Rivers are the principal tributaries.

The Carbon River rises in the Carbon and Russell Glaciers on the northwestern slopes of Mount Rainier and flows northwestward to the Puyallup River, which it enters about 2½ miles below Orting. The Carbon River also flows through rugged, mountainous country and occupies narrow, precipitous canyons.

The White River is formed by the junction of its east and west forks on the northern slope of Mount Rainier. It has its source in Emmons, Frying Pan, and Winthrop Glaciers. From the junction of the forks, the White River flows almost due west to Buckley and thence northwestward to the Puyallup River, which it joins a mile east of the city of Puyallup. Originally, the flow of the White River near its mouth was divided, one part flowing through the Stuck and Puyallup Rivers to Commencement Bay, and the other through the Duwamish River to Elliot Bay. In 1914, Pierce and King Counties entered into an agreement to dam the outlet into the Duwamish River and to divert the entire flow through the Stuck River into the Puyallup River. The Greenwater River, which drains the western slope of the Cascades from Pyramid Peak on the north to Castle Mountain on the south, is the principal tributary of the White River. The White River drains a high, rugged, steep area on the northern slope of Mount Rainier but, unlike the Carbon and Puyallup Rivers, it does not flow through narrow canyons. Below the forks, the river meanders back and forth across a rather wide valley flanked on both sides with benches that slope upward to the basin boundaries and downward toward Pudget Sound.

Drainage areas for the Puyallup River and its principal tributaries are listed below:

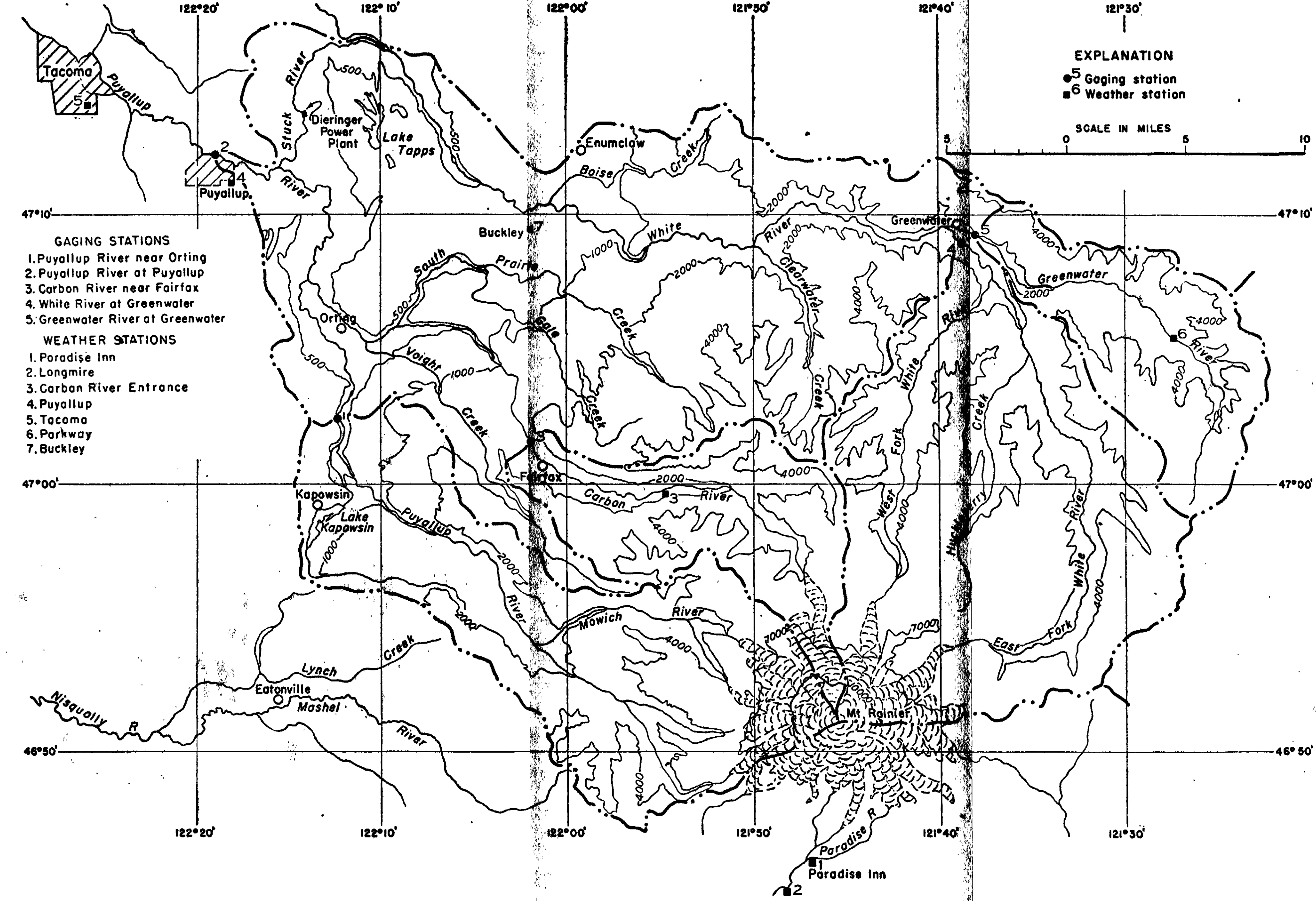
Stream and point of measurement	*Square miles*
Puyallup River at mouth	977
Puyallup River just above mouth of White River	440
Puyallup River just above mouth of Carbon River	188
White River at mouth	500
White River just above mouth of Greenwater River	217
White River above the Forks	212
Greenwater River at mouth	77
East Fork of White River at mouth	146
West Fork of White River at mouth	66
Carbon River at mouth	224

Elevations within the Puyallup Basin range from sea level at Tacoma to 14,408 feet at the summit of Mount Rainier. The lower ends of the glaciers are between elevations of 4,000 and 5,000 feet.

Above an elevation of 6,000 feet the soil cover is scanty, most of the weathered rock particles having been washed down the slopes into the valleys. Vegetation is sparse, owing to lack of soil, steep slopes, and low temperatures. At lower elevations the soil cover is plentiful, and conditions are favorable for the dense growth of timber and underbrush. Originally the area below an elevation of 6,000 feet was covered with heavy forests of fir, cedar, and hemlock, but much of the timber has been depleted by logging operations and fire. The low-lying plains adjoining the lower Puyallup River are composed of glacial outwash, from which the fine material has been eroded. The resulting deposit of coarse sand and gravel permits considerable underground seepage, with a consequent decrease in surface runoff.

Average annual precipitation, as shown in figure 28, ranges from about 40 inches in the vicinity of Puget Sound to more than 100 inches on the upper slopes of Mount Rainier and on the summit of the Cascades. At the higher elevations much of the precipitation is snow, which reaches a depth of nearly 40 feet in drifts and averages nearly 20 feet. A summary of climatic data within the area is shown in table 3.

The upper Puyallup and Carbon River Basins are in the direct path of the moisture-laden prevailing winds. The White River Basin, on the north and east slopes of Mount Rainier, is shaded from them. The effect of Mount Rainier in intercepting and deflecting prevailing winds is well illustrated in table 3 by comparing the precipitation at Parkway on the leeward side with that of Longmire on the windward side, both stations having about the same altitude. The average temperature gradient is 2.2° F. per 1,000 feet increase in altitude.



CONTOUR MAP OF THE PUYALLUP RIVER BASIN SHOWING RIVER-MEASUREMENT AND CLIMATOLOGIC STATIONS

TABLE 3.—*Precipitation, average temperature, and snowfall for year ending Dec. 31, 1938, at stations in the Puyallup River Basin and vicinity*

No. on plate 1	Station	Altitude (feet)	Average temperature (° F.)	Precipitation (inches)	Snow	
					Total (inches)	Maximum accumulated depth (inches)
1	Paradise Inn	5,550	39.6	76.23	484.5	139
2	Longmire	2,761	46.5	63.77	163.0	27
3	Carbon River Entrance	2,026		[1] 57.99		
4	Puyallup	100	51.2	28.94	1.0	0
5	Tacoma	109	52.4	27.12	3.5	0
6	Parkway	2,628	44.1	40.85	151.2	29
7	Buckley	685	51.1	36.92	5.0	0

[1] No record for January, February, or March; total for year computed on basis of record at Longmire.

DIVISION OF AREA

Rainfall and runoff have been analyzed for the mountainous and valley parts of the Puyallup Basin. The mountainous part, as considered in this report, is the part above the gaging stations of the upper Puyallup, Carbon, White, and Greenwater Rivers, which are listed in table 4 and are shown in relation to topography on plate 1; this part has an area of 541 square miles. The valley part is between the upper gaging stations (nos. 1, 3–5 on pl. 1) and the station on the lower Puyallup River at Puyallup (no. 2); it has a drainage area of 407 square miles.

TABLE 4.—*Gaging stations on streams draining mountainous areas in the Puyallup River Basin*

No. on plate 1	Gaging station	Drainage area (square miles)
1	Puyallup River near Orting	170
3	Carbon River near Fairfax	81
4	White River at Greenwater	216
5	Greenwater River at Greenwater	74
	Total mountainous part	541

The mountainous part is predominantly above an altitude of 2,000 feet, the average being about 3,900 feet; the valley part is predominantly below 2,000 feet, average 1,500 feet. Accurate segregation of the two parts with respect to altitude is not practicable; the mountainous part as outlined on plate 1 includes relatively small areas below 2,000 feet, whereas Voight Creek and Clearwater River, in the valley part, receive the drainage from relatively small areas as high as 6,000 feet. These slight nonconformities tend to lessen somewhat the significance of differences in flow from the two parts. Table 5 shows the classification of the areas with respect to altitude.

TABLE 5.—*Distribution of area in the Puyallup River Basin with respect to altitude (in percent)*

Altitude (feet)	Mountainous part				Valley part (407 square miles)
	White River plus Green-water River (290 square miles)	Upper Puyallup River (170 square miles)	Carbon River (81 square miles)	Total (541 square miles)	
0–1,000	0	5	0	2	45
1,000–2,000	2	32	12	15	21
2,000–3,000	12	19	21	17	18
3,000–4,000	24	19	21	21	11
4,000–5,000	28	10	27	22	[1] 5
5,000–7,000	31	8	14	18	
7,000–9,000	2	5	3	3	
Above 9,000	1	2	2	2	
Total	100	100	100	100	100

[1] Total area above 4,000 feet.

SELECTION OF FLOODS

In addition to the rainfall and runoff studies for the two parts of the Puyallup River Basin, comparisons were made between the Chehalis River and the valley part of the Puyallup River. Floods were selected, therefore, for two purposes—to show differences in flood behavior between the mountainous and valley parts of the Puyallup River and between the valley part of the Puyallup River and the Chehalis River.

During December 1933 and January 1934 three floods occurred on the Puyallup River; the crest of the first was on December 10, that of the second was on December 22, and the third on January 23. The two December floods greatly exceeded any previous floods of record, overtopping and breaking levees and causing great damage. The January flood, though much lower, was included because it followed so soon after the two in December. In December 1937, a minor flood occurred on the Puyallup River that would be of little interest were it not for the fact that the Chehalis River was at that time experiencing its maximum flood of record, which indicated that the flood was caused by rain at the lower altitudes. In April 1938 the reverse occurred, for a high flood on the Puyallup River and a low one on the Chehalis River indicated that a major contributing factor to the Puyallup River flood was snow melt at the higher altitudes.

OTHER FLOODS

Prior to December 1933 the maximum recorded flood on the Puyallup River was that of December 1917, which reached a crest discharge of 40,500 second-feet, about 6,000 second-feet less than the smaller of the two 1933 floods. Other major floods occurred in 1919 and 1921. However, as only scanty runoff records are available for the upper Puyallup and Carbon Rivers prior to 1931, a detailed investigation of these earlier floods cannot be made.

RECORDS OF DISCHARGE

On the following pages are presented the records of discharge at five stations in the Puyallup River Basin for the selected floods that were investigated. These records consist of a station description, a table of daily discharge for the entire flood periods, and a table of discharge at indicated time for the days when the discharge was varying rapidly. The discharges at indicated times are given in sufficient number for a reasonably reliable delineation of the hydrographs for the flood periods.

Also included are records of discharge for the Chehalis River near Grand Mound for the floods that were studied. These have been included in this section of the report so that all the records of discharge will be available in one place in the report.

PUYALLUP RIVER NEAR ORTING, WASH.

LOCATION.—Lat. 47°02'30'', long. 122°12'20'', in SW¼ sec. 17, T. 18 N., R. 5 E., 4 miles south of Orting and 7½ miles upstream from Carbon River.

DRAINAGE AREA.—170 square miles.

GAGE-HEIGHT RECORD.—Water-stage recorder graph.

STAGE-DISCHARGE RELATION.—Changes often; defined by frequent current-meter measurements; extended above 8,000 second-feet.

MAXIMA.—Dec. 5–16, 1933: Discharge, 12,700 second-feet (estimated), Dec. 10.

Dec. 17–31, 1933: Discharge, 11,300 second-feet 10:30 p. m., Dec. 21, (gage height, 9.57 feet).

January 1934: Discharge, 5,360 second feet 2:30 p. m., Jan. 22 (gage height, 8.64 feet).

December–January 1937–38: Discharge, 4,420 second-feet 4:50 p. m., Dec. 28 (gage height, 7.63 feet).

April 1938: Discharge, 8,680 second-feet 3:55 a. m., Apr. 18 (gage height, 9.14 feet).

REMARKS.—Records fair. Discharge for period Dec. 5–15, 1933, estimated by comparison with records for other stations in Puyallup River Basin. Slight regulation by Puget Sound Power & Light Co.'s plant at Electron.

Discharge, in second-feet, for flood period

1933				1934		1937-38		1938	
Dec. 5	590	Dec. 19	2,800	Jan. 17	2,420	Dec. 25	576	Apr. 15	430
6	3,000	20	4,290	18	2,140	26	762	16	513
7	2,700	21	7,490	19	3,000	27	1,050	17	2,010
8	1,900	22	[1] 4,790	20	3,240	28	3,780	18	4,420
9	[1] 6,600	23	2,610	21	3,100	29	2,650	19	2,320
10	12,000	24	1,300	22	3,980	30	1,940	20	1,790
11	7,900	25	1,480	23	2,230	31	1,390	21	1,330
12	3,800	26	2,500	24	1,670	Jan. 1	1,160	22	1,160
13	2,600	27	2,340	25	2,300	2	994	23	994
14	2,300	28	2,470	26	2,360	3	895	24	895
15	1,700	29	2,800	27	1,840	4	721	25	804
16	1,210	30	2,740	28	1,550				
17	1,990	31	2,360	29	1,420				
18	3,450			30	1,420				

Period	Second-foot-days	Runoff	
		Inches	Acre-feet
Dec. 5-16, 1933	46,300	10.13	91,830
Dec. 17-31, 1933	45,410	9.93	90,070
Jan. 17-30, 1934	32,670	7.13	64,800
Dec. 25, 1937, to Jan. 4, 1938	15,918	3.48	31,570
Apr. 15-25, 1938	16,666	3.65	33,060

[1] Revised.

Discharge, in second-feet, at indicated time

Hour	1933		1934	1937	1938
	Dec. 9	*Dec. 20*	*Jan 21*	*Dec. 27*	*Apr. 17*
12 m	5,250	3,300	3,560	840	1,820
2 p. m	6,930	3,690			2,220
4	8,090	4,100	3,300	1,130	2,550
6	9,730	5,190			2,820
8	10,300	7,400	3,040	1,660	2,460
10	11,300	9,200			5,580
12	11,900	9,020	2,980	2,860	4,070
	Dec. 10	*Dec. 21*	*Jan. 22*	*Dec. 28*	*Apr. 18*
2 a. m	12,400	7,400	2,980	3,740	4,310
4	12,600	7,230	3,040	3,840	8,650
6	12,700	6,380	3,430	3,500	8,040
8	12,600	6,380	3,820	3,360	6,210
10	12,400	6,210	4,100	3,170	4,800
12 m	12,200	6,040	4,400	3,190	4,240
2 p. m	12,100	6,040	5,030	3,660	3,500
4	12,000	6,040	5,030	4,200	3,000
6	12,000	6,890	4,550	4,380	3,110
8	11,800	9,760	3,960	4,100	2,820
10	10,700	11,300	3,960	3,990	2,530
12	9,950	10,300	3,690	3,560	2,460
	Dec. 11	*Dec. 22*	*Jan. 23*	*Dec. 29*	*Apr. 19*
2 a. m	9,810	8,120	3,560	3,270	2,460
4	8,800	5,530	3,300	3,100	2,530
6	8,390	4,550	2,740	3,000	2,420
8	7,780	4,870	2,470	2,890	2,370
10		4,250	2,140	2,430	2,290
12 m	8,250	4,870	1,890	2,400	2,190
2 p. m		5,190	1,690	2,220	2,220
4	7,520	3,820	1,460	2,160	2,220
6		3,300	1,600	2,180	2,140
8	6,790	2,740	1,550	2,270	2,160
10		3,430	1,600	2,270	2,100
12	6,120	3,430	1,500	2,180	2,130

PUYALLUP RIVER AT PUYALLUP, WASH.

Location.—Lat. 47°12′20″, long. 122°19′30″, in NE¼ sec. 20, T. 20 N., R. 4 E., 1 mile northwest of Puyallup, 3½ miles downstream from Stuck River, and 7 miles upstream from mouth. Datum of gage is mean sea level (general adjustment of 1929).

Drainage area.—948 square miles.

Gage-height record.—Water-stage recorder graph.

Stage-discharge relation.—Well defined by current-meter measurements; extended above 40,000 second-feet.

Maxima.—Dec. 5–16, 1933: Discharge, about 57,000 second-feet 2:30 a. m., Dec. 10 (gage height, 31.0 feet, present datum).

Dec. 17–31, 1933: Discharge, 46,000 second-feet 5:30 a. m., Dec. 22 (gage height, 27.5 feet, present datum).

January 1934: Discharge, 28,900 second-feet 9 a. m., Jan. 23 (gage height, 21.9 feet, present datum).

December–January 1937–38: Discharge, 19,000 second-feet 12:05 a. m., Dec. 29 (gage height, 18.6 feet).

April 1938: Discharge, 33,900 second-feet 11:05 a. m., Apr. 18 (gage height, 23.6 feet).

Remarks.—Records good. Large part of flow of White River diverted into Lake Tapps above station. All diverted water returned to river above gage.

Discharge, in second-feet, for flood periods

1933				1934		1937–38		1938	
Dec. 5	2,820	Dec. 19	16,800	Jan. 17	6,010	Dec. 25	2,530	Apr. 15	2,640
6	15,200	20	16,300	18	5,290	26	3,990	16	2,990
7	14,400	21	35,200	19	8,120	27	4,740	17	8,620
8	8,960	22	44,400	20	12,500	28	14,400	18	27,900
9	26,400	23	35,500	21	11,200	29	15,400	19	16,600
10	53,400	24	17,900	22	16,800	30	13,900	20	10,200
11	32,400	25	13,400	23	25,700	31	9,100	21	7,510
12	18,700	26	15,400	24	14,500	Jan. 1	6,110	22	5,640
13	13,600	27	12,900	25	10,500	2	4,520	23	4,960
14	10,900	28	9,900	26	10,000	3	3,780	24	4,080
15	8,250	29	9,130	27	8,730	4	3,080	25	4,240
16	6,000	30	7,900	28	7,310				
17	6,920	31	7,120	29	6,930				
18	21,300			30	6,190				

Period	Observed		Change in contents[1] (acre-feet)	Adjusted for change in contents	
	Second-foot-days	Runoff (acre-feet)		Runoff in acre-feet	Runoff in inches
Dec. 5–16, 1933	211,030	418,600	−4,830	413,800	8.17
Dec. 17–31, 1933	270,070	535,700	−4,920	530,800	10.49
Jan. 17–30, 1934	149,780	297,100	−8,960	288,100	5.68
Dec. 25, 1937, to Jan. 4, 1938	81,550	161,800	−44	161,800	3.20
Apr. 15–25, 1938	95,380	189,200	−4,770	184,400	3.65

[1] Gain or loss in storage in Lake Tapps.

Discharge, in second-feet, at indicated time

Hour	1933		1934	1937	1938
	Dec. 9	*Dec. 21*	*Jan. 22*	*Dec. 27*	*Apr. 17*
12 m.	24,800	36,100	14,700	4,640	7,540
2 p. m.	31,600	34,600	16,700		9,080
4	38,000	33,400	19,000	4,540	10,200
6	42,800	33,100	21,800		11,900
8	47,600	33,700	24,700	5,500	14,100
10	50,700	35,500	26,500		16,400
12	53,300	39,200	27,100	8,190	18,400
	Dec. 10	*Dec. 22*	*Jan. 23*	*Dec. 28*	*Apr. 18*
2 a. m.	56,800	42,900	27,100	9,770	21,800
4	56,800	45,500	27,400	11,400	24,900
6	56,200	45,700	28,000	12,600	27,600
8	55,200	45,400	28,600	13,100	30,600
10	54,200	44,800	28,300	13,800	33,300
12 m.	53,900	44,400	28,000	14,400	33,900
2 p. m.	53,300	44,100	26,200	14,800	33,000
4	53,000	44,400	24,700	15,400	30,600
6	52,000	45,100	23,500	16,700	28,500
8	51,000	44,800	21,800	18,100	26,400
10	48,500	44,400	20,400	18,700	24,900
12	46,100	44,100	19,000	19,000	22,600
	Dec. 11	*Dec. 23*	*Jan. 24*	*Dec. 29*	*Apr. 19*
2 a. m.	43,700	42,300	17,700	18,100	20,600
4	40,800	41,000	16,700	17,600	19,300
6	37,800	39,500	15,700	16,400	18,200
8	34,700	38,200	15,000	15,900	17,400
10	32,700	37,600	15,200	15,600	17,200
12 m.	30,800	36,700	14,400	15,100	16,700
2 p. m.	29,700	35,800	13,700	14,600	15,700
4	28,000	32,800	13,400	14,100	15,200
6	26,700	30,700	12,700	14,100	14,200
8	25,600	29,200	12,500	13,800	13,400
10	24,000	27,100	11,800	13,400	13,400
12	22,900	25,000	10,900	13,100	12,200

CARBON RIVER NEAR FAIRFAX, WASH.

LOCATION.—Lat. 47°01′30″, long. 122°02′00″, in SW¼ sec. 2[illegible], T. 18 N., R. 6 E., 1¼ miles northwest of Fairfax and 12 miles upstream from Voight Creek.

DRAINAGE AREA.—81 square miles.

GAGE-HEIGHT RECORD.—Water-stage recorder graph.

STAGE-DISCHARGE RELATION.—Fairly well defined by current-meter measurements; extended above 1,300 second-feet.

MAXIMA.—Dec. 5–16, 1933: Discharge, about 8,030 second-feet 6:30 p. m., Dec. 9 (gage height, 10.2 feet).

Dec. 17–31, 1933: Discharge, about 5,480 second-feet 10:30 p. m., Dec. 21 (gage height, 8.08 feet).

January 1934: Discharge, about 3,380 second-feet 6 a. m., Jan. 23 (gage height, 6.20 feet).

December–January 1937–38: Discharge, 1,460 second-feet 6 p. m., Dec. 28 (gage height, 3.83 feet).

April 1938: Discharge, 5,560 second-feet 4 a. m., Apr. 18 (gage height, 6.98 feet).

REMARKS.—Records good except those above 1,500 second-feet and those for Dec. 24–26, 1933, which were estimated by comparison with records for other stations in Puyallup River Basin, which are poor.

Discharge, in second-feet, for flood periods

1933				1934		1937-38		1938	
Dec. 5	392	Dec. 19	1,620	Jan. 17	815	Dec. 25	268	Apr. 15	256
6	1,710	20	2,060	18	695	26	330	16	336
7	1,080	21	3,720	19	896	27	423	17	2,010
8	820	22	3,980	20	1,480	28	1,150	18	3,660
9	4,810	23	2,580	21	1,420	29	1,250	19	1,460
10	4,300	24	1,800	22	2,040	30	1,150	20	958
11	2,360	25	1,500	23	2,730	31	794	21	739
12	1,790	26	1,400	24	1,440	Jan. 1	610	22	676
13	1,510	27	1,360	25	1,120	2	479	23	606
14	1,420	28	1,180	26	1,080	3	400	24	526
15	1,380	29	1,080	27	935	4	344	25	470
16	1,380	30	995	28	785				
17	1,580	31	875	29	767				
18	2,180			30	737				

Period	Second-foot-days	Runoff	
		Inches	Acre-feet
Dec. 5-16, 1933	22,952	10.53	45,520
Dec. 17-31, 1933	27,910	12.83	55,360
Jan. 17-30, 1934	16,940	7.76	33,600
Dec. 25, 1937, to Jan. 4, 1938	7,198	3.30	14,280
Apr. 15-25, 1938	11,697	5.36	23,200

Discharge, in second-feet, at indicated time

Hour	1933		1934	1937	1938
	Dec. 8	*Dec. 21*	*Jan. 22*	*Dec. 27*	*Apr. 17*
12 m	790	2,740	1,720	353	1,620
2 p. m		2,910	2,000		2,040
4		3,480	2,280	450	2,430
6	760	4,280	2,660		2,850
8		5,260	3,090	633	3,630
10		5,480	3,280		4,020
12	940	5,150	3,180	843	4,440
	Dec. 9	*Dec. 22*	*Jan. 23*	*Dec. 28*	*Apr. 18*
2 a. m	1,200	4,490	3,180	895	4,860
4	1,700	3,980	3,380	930	5,420
6	2,620	3,780	3,380	975	5,000
8	3,580	3,680	3,090	1,000	4,440
10	4,600	3,780	2,910	1,010	4,030
12 m	5,590	3,980	2,820	1,140	3,640
2 p. m	6,360	4,030	2,500	1,300	3,390
4	6,470	4,080	2,280	1,410	2,910
6	6,950	3,880	2,180	1,460	2,800
8	7,910	3,680	2,070	1,360	2,470
10	6,590	3,580	1,960	1,360	2,140
12	5,810	3,480	1,860	1,360	2,250
	Dec. 10	*Dec. 23*	*Jan. 24*	*Dec. 29*	*Apr. 19*
2 a. m	5,480	3,380	1,720	1,360	1,920
4	5,150	3,280	1,540	1,310	1,760
6	5,040	3,000	1,620	1,290	1,610
8	4,710	2,820	1,540	1,260	1,560
10	4,490	2,580	1,480	1,240	1,460
12 m	4,080	2,350	1,440	1,200	1,420
2 p. m	4,280	2,280	1,380	1,170	1,330
4	3,980	2,280	1,360	1,160	1,280
6	3,780	2,240	1,320	1,220	1,240
8	3,680	2,210	1,300	1,270	1,200
10	3,280	2,210	1,260	1,290	1,150
12	3,000	2,210	1,240	1,310	1,110

WHITE RIVER AT GREENWATER, WASH.

LOCATION.—Lat. 47°08'50", long. 121°38'50", in SE¼ sec. 10, T. 19 N.. R. 9 E., three-quarters of a mile southeast of Greenwater, three-quarters of a mile upstream from Greenwater River, and 25 miles upstream from Buckley.

DRAINAGE AREA.—216 square miles.

GAGE-HEIGHT RECORD.—Water-stage recorder graph.

STAGE-DISCHARGE RELATION.—Defined by current-meter measurements; extended above 3,600 second-feet.

MAXIMA.—Dec. 5–16, 1933: Discharge, 10,500 second-feet 8:30 p. m., Dec. 9; gage height, 9.13 feet 5 p. m., Dec. 9.

Dec. 17–31, 1933: Discharge, 12,100 second-feet 9 p. m., Dec. 21 (gage height, 9.38 feet).

January 1934: Discharge, 5,440 second-feet 2:30 a. m., Jan. 23 (gage height, 6.20 feet).

December-January, 1937–38: Discharge, 2,010 second-feet 6 a. m., Dec. 30 (gage height, 3.99 feet).

April 1938: Discharge, 5,440 second-feet 5:45 a. m., Apr. 18 (gage height, 5.66 feet).

REMARKS.—Records good except those over 4,000 second-feet, which are poor.

Discharge, in second-feet, for flood periods

1933				1934		1937–38		1938	
Dec. 5	772	Dec. 19	3,320	Jan. 17	1,270	Dec. 25	661	Apr. 15	601
6	2,920	20	4,090	18	1,160	26	661	16	788
7	1,820	21	7,900	19	1,510	27	691	17	2,210
8	1,380	22	9,220	20	1,800	28	1,390	18	4,640
9	[1] 6,620	23	6,460	21	2,150	29	1,730	19	2,900
10	8,830	24	3,930	22	3,500	30	1,820	20	1,920
11	5,070	25	2,810	23	4,250	31	1,300	21	1,530
12	3,880	26	2,360	24	2,580	Jan. 1	1,050	22	1,420
13	3,100	27	2,150	25	2,010	2	900	23	1,310
14	2,460	28	2,080	26	1,870	3	788	24	1,260
15	2,140	29	2,220	27	[1] 1,650	4	724	25	1,180
16	1,840	30	2,150	28	1,500				
17	2,970	31	1,940	29	1,440				
18	4,340			30	1,440				

Period	Second-foot-days	Runoff	
		Inches	Acre-feet
Dec. 5–16, 1933	40,832	7.05	80,990
Dec. 17–31, 1933	57,940	9.99	114,900
Jan. 17–30, 1934	28,130	4.84	55,800
Dec. 25, 1937, to Jan. 4, 1938	11,715	2.02	23,240
Apr. 15–25, 1938	19,759	3.40	39,190

[1] Revised.

Discharge, in second-feet, at indicated time

Hour	1933		1934	1937	1938
	Dec. 9	*Dec. 21*	*Jan. 21*	*Dec. 28*	*Apr. 17*
12 m	7,470	6,110	2,500	1,300	1,940
2 p. m	9,160	6,830		1,420	2,280
4	9,540	8,270	2,430	1,570	2,500
6	9,730	9,780		1,710	2,900
8	10,500	11,100	2,290	1,760	3,400
10	10,300	11,600		1,750	3,800
12	10,500	11,300	2,220	1,710	4,320
	Dec. 10	*Dec. 22*	*Jan. 22*	*Dec. 29*	*Apr. 18*
2 a. m	10,200	9,600	2,150	1,700	4,860
4	9,780	9,030	2,220	1,680	5,200
6	9,590	8,650	2,360	1,680	5,440
8	9,780	8,650	2,650	1,680	5,320
10	9,590	9,030	2,970	1,680	5,200
12 m	9,020	9,030	3,450	1,680	4,860
2 p. m	8,640	9,410	4,010	1,660	4,420
4	8,450	9,600	4,250	1,660	4,320
6	8,270	9,410	4,590	1,760	4,100
8	7,550	9,030	4,760	1,870	4,000
10	6,830	8,650	4,760	1,960	3,700
12	6,290	8,270	5,100	2,010	3,500
	Dec. 11	*Dec. 23*	*Jan. 23*	*Dec. 30*	*Apr. 19*
2 a. m	5,750	8,080	5,440	2,010	3,400
4	5,580	8,270	5,270	2,010	3,300
6	5,410	7,890	4,760	2,010	3,300
8	5,240	7,340	4,590	1,960	3,100
10	5,070	6,980	4,250	1,990	3,000
12 m	4,730	6,460	4,250	1,830	2,900
2 p. m	4,730	6,120	4,090	1,780	2,700
4	4,560	5,780	3,850	1,710	2,610
6	4,300	5,610	3,610	1,660	2,520
8	4,560	5,440	3,530	1,620	2,520
10	4,560	5,100	3,370	1,580	2,380
12	4,300	4,760	3,130	1,520	2,310

GREENWATER RIVER AT GREENWATER, WASH.

LOCATION.—Lat. 47°09′15″, long. 121°38′00″, in NW¼NW¼ sec. 11, T. 19 N., R. 9 E., 1 mile upstream from mouth, 1 mile east of Greenwater, and 17 miles east of Buckley.

DRAINAGE AREA.—74 square miles.

GAGE-HEIGHT RECORD.—Water-stage recorder graph.

STAGE-DISCHARGE RELATION.—Defined by current-meter measurements; extended above 1,000 second-feet.

MAXIMA.—Dec. 5–16, 1933: Discharge, 4,140 second-feet 11:45 p. m., Dec. 9 (gage height, 9.24 feet, site and datum then in use).

Dec. 17–31, 1933: Discharge, 3,440 second-feet 3:30 a. m., Dec. 23 (gage height, 8.23 feet, site and datum then in use).

January 1934: Discharge, 1,960 second-feet 4:30 a. m. to 6:30 a. m., Jan. 23 (gage height, 6.00 feet, site and datum then in use).

December–January 1937–38: Discharge, 586 second-feet 7 a. m. to 9 a. m., Dec. 30 (gage height, 3.93 feet).

April 1938: Discharge, 1,410 second-feet 9:40 a. m. to 11 a. m., Apr. 18 (gage height, 5.33 feet).

REMARKS.—Records excellent except those above 1,500 second-feet, which are fair.

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Discharge, in second-feet, for flood periods

1933				1934		1937–38		1938	
Dec. 5	190	Dec. 17	691	Jan. 17	389	Dec. 25	241	Apr. 15	189
6	768	18	1,350	18	375	26	238	16	227
7	586	19	1,060	19	428	27	241	17	579
8	443	20	1,150	20	548	28	361	18	1,260
9	2,170	21	2,270	21	705	29	480	19	930
10	3,720	22	3,090	22	1,190	30	565	20	658
11	2,020	23	2,880	23	1,780	31	475	21	530
12	1,310	24	1,610	24	1,080	Jan. 1	400	22	470
13	1,040	25	1,140	25	765	2	335	23	450
14	845	26	885	26	725	3	295	24	450
15	705	27	785	27	685	4	264	25	440
16	585	28	725	28	605				
		29	705	29	585				
		30	665	30	565				
		31	625						

Period	Second-foot-days	Runoff	
		Inches	Acre-feet
Dec. 5–16, 1933	14,382	7.23	28,530
Dec. 17–31, 1933	19,631	9.87	38,940
Jan. 17–30, 1934	10,425	5.26	20,680
Dec. 25, 1937, to Jan. 4, 1938	3,895	1.96	7,730
Apr. 15–25, 1938	6,183	3.10	12,260

Discharge, in second-feet, at indicated time

Hour	1933		1934	1937	1938
	Dec. 9	*Dec. 22*	*Jan. 22*	*Dec. 29*	*Apr. 17*
2 a. m.	524	3,300	825	460	325
4	632	3,230	825	460	370
6	860	3,090	825	465	420
8	1,240	2,950	845	465	470
10	1,600	2,880	905	470	520
12 m.	1,960	2,880	988	470	560
2 p. m.	2,200	2,880	1,160	470	608
4	2,670	2,880	1,360	480	658
6	3,720	3,020	1,560	495	718
8	4,070	3,160	1,660	510	790
10	4,070	3,300	1,780	525	900
12	4,140	3,370	1,840	540	990
	Dec. 10	*Dec. 23*	*Jan. 23*	*Dec. 30*	*Apr. 18*
2 a. m.	4,000	3,440	1,900	555	1,110
4	3,930	3,440	1,960	570	1,200
6	3,930	3,370	1,960	576	1,290
8	4,000	3,230	1,960	586	1,350
10	4,070	3,090	1,900	581	1,410
12 m.	4,000	2,950	1,780	576	1,410
2 p. m.	3,930	2,740	1,720	570	1,350
4	3,720	2,600	1,660	565	1,320
6	3,510	2,460	1,560	560	1,260
8	3,300	2,320	1,510	545	1,230
10	3,090	2,200	1,410	535	1,170
12	2,880	2,140	1,360	525	1,140
	Dec. 11	*Dec. 24*	*Jan. 24*	*Dec. 31*	*Apr. 19*
2 a. m.	2,740	2,020	1,310	520	1,080
4	2,530	1,900	1,240	510	1,050
6	2,320	1,780	1,180	500	1,020
8	2,200	1,720	1,140	490	960
10	2,080	1,660	1,080	480	930
12 m.	2,020	1,610	1,040	475	900

CHEHALIS RIVER NEAR GRAND MOUND, WASH.

LOCATION.—Lat. 46°47′, long. 123°02′, in NE ¼ sec. 22, T. 15 N., R. 3 W., at Meadow, 1½ miles southwest of Grand Mound and about 6 miles downstream from Skookumchuck River. Datum of gage is 123.27 feet above mean sea level (general adjustment of 1929).

DRAINAGE AREA.—928 square miles.

GAGE-HEIGHT RECORD.—Staff gage read once daily Dec. 5–31, 1933, and Jan. 17–30, 1934. Water-stage recorder graph Dec. 25, 1937, to Jan. 4, 1938, and Apr. 15–25, 1938.

STAGE-DISCHARGE RELATION.—Well defined by current-meter measurements; extended above 30,000 second-feet.

MAXIMA.—Dec. 5–16, 1933: Discharge, about 10,000 second-feet Dec. 11.

Dec. 17–31, 1933 Discharge, about 46,000 second-feet Dec. 21 or 22.

January 1934: Discharge about 25,000 second-feet Jan. 23.

December–January 1937–38: Discharge, 48,400 second-feet 11:30 a. m., Dec. 29 (gage height, 18.39 feet).

April 1938: Discharge, 13,000 second-feet 9:30 p. m., Apr. 18 (gage height, 10.70 feet).

REMARKS.—Figures of daily discharge for floods of December 1933 and January 1934, published in Water-Supply Paper 767, were computed from gage reading once daily. For purpose of this investigation, daily discharges for these floods were computed from a graph based on the gage readings made once daily and shape of recorder graph for North River near Raymond. All discharges shown in various tables were derived in this way and vary from those previously published in Water-Supply Paper 677. The records published herein do not supersede the records published in Water-Supply Paper 767 but are intended only for the purpose of this report. These revised records are fair. Records for December 1937, January and April 1938, when water-stage recorder was operating, are good.

Discharge, in second-feet, for flood periods

1933		1933		1934		1937–38		1938	
Dec. 5	3,110	Dec. 19	42,900	Jan. 17	9,620	Dec. 25	3,370	Apr. 15	1,690
6	13,500	20	37,400	18	7,950	26	6,790	16	2,810
7	25,100	21	43,000	19	7,920	27	14,600	17	5,040
8	21,500	22	44,800	20	13,700	28	26,800	18	10,700
9	19,200	23	39,900	21	17,000	29	46,300	19	11,000
10	22,700	24	29,400	22	18,500	30	35,800	20	7,100
11	38,300	25	17,300	23	24,800	31	25,300	21	5,040
12	27,700	26	15,900	24	21,000	Jan. 1	17,600	22	3,860
13	20,400	27	18,000	25	16,000	2	11,400	23	3,370
14	16,300	28	14,000	26	11,100	3	7,860	24	2,810
15	12,800	29	11,900	27	7,950	4	5,840	25	2,530
16	9,840	30	11,900	28	5,970				
17	10,500	31	9,780	29	5,010				
18	22,100			30	4,210				

Period	Second-foot-days	Runoff: Inches	Runoff: Acre-feet
Dec. 5-16, 1933	230,450	9.24	457,100
Dec. 17-31, 1933	368,780	14.78	731,500
Jan. 17-30, 1934	170,730	6.82	338,600
Dec. 25, 1937, to Jan. 4, 1938	201,660	8.10	400,000
Apr. 15-25, 1938	55,950	2.24	111,000

Discharge, in second-feet, at indicated time

1937				1938			
Dec. 28		*Dec. 30*		*Apr. 18*		*Apr. 19*—Con.	
12 m	25,300	2 a. m.	41,400	2 a. m.	7,860	2 p. m.	10,500
2 p. m.	28,000	4	40,000	4	8,450	4	10,300
4	31,000	6	38,800	6	9,260	6	9,890
6	35,200	8	37,600	8	9,890	8	9,470
8	38,200	10	36,400	10	10,500	10	9,050
10	40,700	12 m	35,200	12 m	11,200	12	8,850
12	42,800	2 p. m.	34,600	2 p. m.	11,700		
		4	33,400	4	12,200	*Apr. 20*	
Dec. 29		6	32,800	6	12,700	2 a. m.	8,450
2 a. m.	44,200	8	32,200	8	13,000	4	8,250
4	44,900	10	31,000	10	13,000	6	7,860
6	46,300	12	30,400	12	13,000	8	7,480
8	47,700					10	7,290
10	48,400	*Dec. 31*		*Apr. 19*		12 m	7,100
12 m	48,400	2 a. m.	29,400	2 a. m.	12,700	2 p. m.	6,730
2 p. m.	47,700	4	28,900	4	12,400	4	6,550
4	47,000	6	28,000	6	12,200	6	6,370
6	46,300	8	27,100	8	11,700	8	6,190
8	44,900	10	26,200	10	11,200	10	6,010
10	43,500	12 m	25,800	12 m	11,000	12	5,840
12	42,100						

Mean discharge for 8-hour periods ending 8 a. m., 4 p. m., and 12 p. m. for floods of December 1933 and January 1934

December 1933				January 1934	
Day	*Second-feet*	*Day*	*Second-feet*	*Day*	*Second-feet*
5	2,330	19	41,800	17	9,840
	2,740		44,600		9,740
	4,260		42,400		9,280
6	8,790	20	39,000	18	8,720
	13,100		36,900		7,980
	18,600		36,200		7,150
7	23,000	21	39,600	19	7,050
	26,200		43,800		7,610
	26,200		45,500		9,090
8	23,700	22	45,500	20	11,400
	21,200		45,000		13,600
	19,700		43,800		16,100
9	18,800	23	41,900	21	17,700
	19,000		40,300		17,100
	19,800		37,400		16,300
10	20,800	24	34,200	22	17,000
	21,900		29,000		18,300
	25,500		24,900		20,300
11	37,300	25	20,900	23	23,900
	40,400		16,800		25,500
	37,100		14,100		24,900
12	31,600	26	14,200	24	22,800
	27,200		16,000		21,000
	24,300		17,600		19,200
13	22,100	27	18,500	25	17,600
	20,300		18,300		16,000
	18,700		17,100		14,300
14	17,500	28	15,300	26	12,400
	16,200		14,000		11,000
	15,200		12,700		9,840
15	13,800	29	11,600	27	8,720
	12,800		11,800		7,890
	11,800		12,300		7,240
16	10,600	30	12,300	28	6,500
	9,650		12,000		5,940
	9,280		11,300		5,480
17	9,470	31	10,400	29	5,290
	10,300		9,740		5,010
	11,700		9,190		4,730
18	15,600			30	4,450
	20,400				4,180
	30,400				3,990

Mean discharge, in second-feet, for 6-hour periods ending 6 a. m., 12 m., 6 p. m., and 12 m. for floods of December 1937–January 1938 and April 1938

1937-38				1938			
Dec. 25	3,540	Dec. 31	27,200	Apr. 15	1,740	Apr. 21	5,630
	3,440		26,700		1,690		5,160
	3,300		24,400		1,690		4,740
	3,300		22,200		1,760		4,490
26	3,600	Jan. 1	19,700	16	1,920	22	4,230
	4,670		18,200		2,420		3,980
	7,690		16,800		3,160		3,780
	11,300		15,400		3,710		3,720
27	13,500	2	13,600	17	4,070	23	3,560
	14,400		12,100		4,390		3,430
	14,600		10,800		5,390		3,260
	15,600		9,780		6,540		3,120
28	18,000	3	8,850	18	8,190	24	3,000
	22,300		8,150		10,200		2,880
	29,800		7,420		12,000		2,780
	39,300		6,980		12,900		2,680
29	44,600	4	6,490	19	12,500	25	2,660
	47,700		6,100		11,400		2,590
	47,500		5,730		10,300		2,460
	44,200		5,350		9,230		2,360
30	40,300			20	8,280		
	36,700				7,370		
	33,800				6,610		
	31,400				6,010		

COMPUTATION PROCEDURE

On any river during a given time interval the difference in flow past two points, when adjusted for channel storage, is the contribution from the intervening drainage area. In determining natural yield from the valley part of the Puyallup River, channel storage was computed on the basis of mean rate of change in stage at five gaging stations and the channel area involved. The mean rate of change recorded at the upper four gaging stations listed in table 4 was used to compute the volume of channel storage in the stretch of river between the four gaging stations and the Dieringer power plant on the Stuck River. (See pl. 1 for location.) Rate of change of stage at the station on the Puyallup River at Puyallup was used to determine channel storage in the stretch below Dieringer power plant. These rates of change of stage were applied to areas of river surface in the river reaches as defined above, as determined by multiplying their respective river lengths by the approximate surface widths. The river lengths were obtained from a report by the Corps of Engineers, United States Army,[3] and the river widths were assumed to be the same

[3] Report of Chief of Engineers, U. S. Army, to Chairman of the Senate Committee for Commerce, 74th Cong., 2d sess., Mar. 2, 1936.

as those measured at the gaging stations. The river surface so computed in the respective reaches is as follows:

	Mean surface area (square feet)
Greenwater River, mouth to gaging station at Greenwater	316,800
White River, Dieringer power plant to gaging station at Greenwater	32,472,000
Carbon River, mouth to gaging station near Fairfax	8,448,000
Puyallup River, mouth of Stuck River to upper gaging station near Orting	12,672,000
River-surface area assigned to upper gaging stations	53,908,800
Stuck River, Dieringer power plant to mouth	5,280,000
Puyallup River, mouth of Stuck River to gaging station at Puyallup	5,280,000
River-surface area assigned to gaging station at Puyallup	10,560,000

The storage in Lake Tapps, which is subject to regulation for the generation of electric energy at the Dieringer power plant, was added to the storage tabulated above. The surface level of Lake Tapps is observed hourly by power-plant attendants. The sum of the discharges measured at the gaging stations on the mountain tributaries was deducted from the flow at Puyallup as corrected for channel storage to determine the discharge from the valley part of the Puyallup River Basin, as shown in tables 6, 7, 8, and 9.

A much quicker but possibly less accurate method of determining yield from the valley part is by use of a time interval for synchronizing peaks at upper stations and the lower gaging station at Puyallup. Then by simple subtraction the inflow is ascertained. An average lag interval of 8 hours was used for each station as determined by a study of the time of travel of two floods. This method was used on one flood to check results determined by using channel storage. Flows from the valley part as computed by both methods for the period December 5–14, 1933, are shown in figure 30.

TABLE 6.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of December 1933 for 8-hour periods ending 8 a. m., 4 p. m., and 12 p. m.*

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
Dec. 5	2,421	2,436	330	225	476	138	1,169	1,267	3.11
	2,524	3,028	343	270	566	154	1,333	1,695	4.16
	3,501	6,399	999	688	1,320	284	3,291	3,108	7.64
6	7,682	11,650	2,951	1,810	3,234	726	8,721	2,929	7.20
	18,090	18,770	3,046	1,745	2,980	857	8,628	10,140	24.9
	20,020	19,080	3,083	1,565	2,518	756	7,922	11,160	27.4
7	16,810	16,010	2,940	1,255	2,090	656	6,941	9,069	22.3
	14,020	12,990	2,795	1,090	1,860	581	6,326	6,664	16.4
	11,950	11,070	2,408	950	1,650	524	5,532	5,538	13.6
8	9,752	9,239	2,168	861	1,490	468	4,987	4,252	10.4
	8,916	8,258	1,896	790	1,370	433	4,489	3,769	9.26
	8,236	8,246	1,605	812	1,340	426	4,183	4,063	9.98
9	9,173	14,670	2,689	1,945	2,335	716	7,685	6,985	17.2
	25,100	33,590	5,878	5,394	7,416	1,928	20,616	12,970	31.9
	46,540	49,160	10,530	6,898	10,140	3,791	31,359	17,800	43.7
10	56,010	55,430	12,490	5,232	9,928	3,982	31,632	23,800	58.5
	53,880	52,860	12,250	4,299	9,091	3,965	29,605	23,260	57.1
	50,260	49,110	11,370	3,558	7,530	3,300	25,758	23,350	57.4
11	40,680	37,440	8,966	2,629	5,651	2,532	19,778	17,660	43.4
	31,140	28,700	7,950	2,245	4,858	1,998	17,051	11,650	28.6
	25,430	23,230	6,808	2,140	4,462	1,665	15,075	8,160	20.0
12	21,050	19,660	4,842	1,982	4,198	1,466	12,488	7,170	17.6
	18,820	17,440	3,560	1,800	3,922	1,332	10,614	6,826	16.8
	16,400	15,040	3,090	1,692	3,600	1,213	9,595	5,445	13.4
13	13,960	13,490	2,808	1,600	3,220	1,128	8,756	4,734	11.6
	13,520	12,480	2,524	1,514	3,082	1,060	8,180	4,300	10.6
	12,980	11,540	2,578	1,466	2,980	965	7,789	3,751	9.22
14	11,120	10,520	2,300	1,425	2,722	905	7,352	3,168	7.78
	11,170	10,080	2,300	1,420	2,515	845	7,080	3,000	7.37
	10,390	9,172	2,212	1,390	2,415	805	6,322	2,350	5.77
15	8,675	7,945	1,900	1,380	2,270	760	3,310	1,635	4.02
	8,781	7,850	1,710	1,380	2,140	705	5,935	1,915	4.71
	7,562	6,930	1,540	1,380	2,020	665	5,605	1,325	3.26

TABLE 6.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of December 1933 for 8-hour periods ending 8 a. m., 4 p. m., and 12 p. m.*—Continued

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
Dec. 16	5, 941	6, 355	1, 360	1, 380	1, 880	612	5, 232	1, 123	2. 76
	6, 106	6, 218	1, 210	1, 380	1, 840	585	5, 015	1, 203	2. 96
	5, 988	5, 953	1, 150	1, 380	1, 760	578	4, 868	1, 085	2. 67
17	5, 230	5, 954	1, 100	1, 380	1, 715	548	4, 743	1, 211	2. 98
	5, 974	7, 952	1, 390	1, 360	2, 445	591	5, 786	2, 166	5. 32
	9, 682	14, 640	3, 516	2, 070	4, 754	994	11, 334	3, 306	8. 12
18	19, 400	20, 320	4, 004	2, 508	5, 070	1, 466	13, 048	7, 272	17. 9
	24, 080	23, 050	3, 292	2, 062	4, 189	1, 354	10, 897	12, 150	29. 9
	20, 690	19, 020	3, 002	1, 878	3, 740	1, 216	9, 836	9, 184	22. 6
19	17, 350	16, 580	2, 815	1, 695	3, 520	1, 120	9, 150	7, 430	18. 3
	16, 860	15, 920	2, 860	1, 661	3, 372	1, 061	8, 954	6, 966	17. 1
	15, 800	14, 360	2, 574	1, 531	3, 064	980	8, 149	6, 211	15. 3
20	13, 590	13, 200	2, 491	1, 512	2, 915	902	7, 820	5, 380	13. 2
	15, 010	15, 680	3, 316	1, 690	3, 450	969	9, 425	6, 255	15. 4
	21, 680	25, 110	7, 089	2, 988	6, 029	1, 226	17, 732	7, 378	18. 1
21	35, 420	34, 580	7, 178	3, 275	6, 538	2, 268	19, 259	15, 320	37. 6
	35, 760	35, 040	6, 125	2, 919	6, 538	1, 968	17, 550	17, 490	43. 0
	34, 650	38, 140	9, 030	4, 834	10, 580	2, 608	27, 052	11, 090	27. 2
22	44, 080	42, 650	6, 446	4, 164	9, 314	3, 169	23, 093	19, 560	48. 1
	44, 550	43, 520	4, 614	3, 918	9, 149	2, 889	20, 570	22, 950	56. 4
	44, 640	43, 150	3, 274	3, 730	9, 006	3, 151	19, 161	23, 990	58. 9
23	40, 940	39, 650	3, 341	3, 202	8, 011	3, 388	17, 942	21, 710	53. 3
	36, 450	33, 720	2, 702	2, 440	6, 530	2, 924	14, 596	19, 120	47. 0
	28, 980	26, 220	1, 790	2, 226	5, 355	2, 338	11, 709	14, 510	35. 7
24	21, 220	19, 090	1, 540	2, 094	4, 386	1, 908	9, 928	9, 162	22. 5
	17, 550	15, 880	1, 256	1, 836	3, 885	1, 611	8, 587	7, 293	17. 9
	14, 920	13, 480	1, 066	1, 450	3, 416	1, 410	7, 342	6, 138	15. 1
25	12, 900	12, 800	1, 146	1, 362	2, 985	1, 236	6, 729	6, 071	14. 9
	13, 010	13, 040	1, 451	1, 536	2, 770	1, 115	6, 872	6, 168	15. 2
	14, 240	14, 340	1, 898	1, 616	2, 586	1, 016	7, 116	7, 224	17. 7
26	14, 480	14, 280	2, 512	1, 612	2, 378	932	7, 434	6, 846	16. 8
	15, 800	14, 750	2, 558	1, 330	2, 264	872	7, 024	7, 726	19. 0
	15, 680	14, 510	2, 401	1, 249	2, 378	828	6, 856	7, 654	18. 8

Dec. 27	13,340	13,110	1,999	1,180	2,290	822	6,291	6,819	16.8
	12,990	12,320	2,482	1,500	2,150	792	6,924	5,396	13.3
	11,850	10,690	2,451	1,349	2,080	772	6,652	4,038	9.92
28	9,915	10,160	2,375	1,235	2,045	745	6,400	3,760	9.24
	10,320	8,871	2,430	1,170	2,071	730	6,401	2,470	6.07
	9,748	10,120	2,629	1,132	2,159	720	6,640	3,480	8.55
29	8,625	11,130	2,745	1,120	2,238	705	6,808	4,322	10.6
	9,540	10,040	2,742	1,085	2,238	700	6,765	3,275	8.05
	9,218	9,910	2,830	1,030	2,202	685	6,747	3,163	7.77
30	7,950	12,880	2,770	1,008	2,150	665	6,593	6,287	15.4
	8,102	12,160	2,724	995	2,150	658	6,527	5,633	13.8
	7,826	9,730	2,724	980	2,115	648	6,467	3,263	8.02
31	7,310	11,520	2,604	930	2,039	642	6,215	5,305	13.0
	7,215	11,450	2,350	865	1,940	625	5,780	5,670	13.9
	7,001	9,806	2,172	807	1,846	608	5,433	4,373	10.7

TABLE 7.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin, for the flood of January 1934 for 8-hour periods ending 8 a. m., 4 p. m., and 12 p. m.*

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
Jan. 17									
	6,418	6,690	2,375	845	1,270	389	4,879	1,811	4.45
	6,012	6,042	2,290	800	1,233	387	4,710	1,332	3.27
18	4,975	6,065	2,198	735	1,180	381	4,494	1,571	3.86
	5,515	5,471	2,150	695	1,141	375	4,361	1,110	2.73
	5,402	5,320	2,115	671	1,135	372	4,293	1,027	2.52
19	4,962	6,172	2,220	659	1,220	376	4,475	1,697	4.17
	7,678	9,511	2,948	809	1,440	418	5,615	3,896	9.57
	11,890	12,940	3,658	1,204	1,870	477	7,209	5,731	14.1
20	13,460	13,810	3,658	1,600	1,835	533	7,626	6,184	15.2
	12,850	12,010	3,282	1,515	1,800	548	7,145	4,865	12.0
	11,160	10,460	2,965	1,300	1,835	565	6,665	3,795	9.32
21	9,842	10,120	2,955	1,245	1,883	572	6,655	3,465	8.51
	11,220	11,960	3,398	1,400	2,395	705	7,898	4,062	9.98
	12,740	12,520	3,090	1,632	2,294	835	7,851	4,669	11.5
22	11,600	12,540	3,212	1,495	2,291	828	7,826	4,714	11.6
	15,460	17,820	4,489	1,720	3,470	1,039	10,718	7,102	17.4
	24,010	25,660	4,208	2,940	4,646	1,650	13,444	12,220	30.0
23	27,580	27,140	3,170	3,268	5,078	1,938	13,454	13,690	33.6
	27,290	24,780	1,921	2,729	4,202	1,806	10,658	14,120	34.7
	21,890	19,680	1,558	2,070	3,500	1,504	8,632	11,050	27.1
24	16,780	15,290	1,576	1,645	2,880	1,245	7,346	7,944	19.5
	14,880	12,780	1,541	1,438	2,541	1,055	6,575	6,205	15.2
	11,790	10,930	1,902	1,295	2,281	922	6,400	4,530	11.1
25	10,120	9,379	2,149	1,150	2,150	825	6,274	3,105	7.63
	10,850	8,208	2,268	1,085	2,006	752	6,111	2,097	5.15
	10,650	8,681	2,446	1,075	1,966	718	6,205	2,476	6.08
26	9,788	9,140	2,445	1,070	1,940	705	6,160	2,980	7.32
	10,440	8,625	2,360	1,110	1,870	718	6,058	2,567	6.31
	10,080	8,140	2,[illegible]	1,085	1,800	725	5,832	2,308	5.67
28	8,902	7,841	2,002	1,004	1,670	703	5,379	2,462	6.05
	8,704	6,968	1,852	935	1,670	685	5,142	1,826	4.49
	8,391	6,466	1,765	875	1,610	658	4,908	1,558	3.83
29	7,479	6,375	1,630	825	1,555	632	4,642	1,733	4.26
	7,239	6,205	1,550	785	1,500	605	4,440	1,765	4.34
	7,072	6,002	1,502	779	1,480	599	4,360	1,642	4.03
29	6,598	6,105	1,430	773	1,460	592	4,255	1,850	4.55
	7,334	6,088	1,420	767	1,440	585	4,212	1,876	4.61
	6,979	5,736	1,398	757	1,440	578	4,173	1,563	3.84
30	6,032	5,619	1,300	747	1,440	572	4,059	1,560	3.83
	6,650	5,840	1,375	737	1,440	565	4,117	1,723	4.23

TABLE 8.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of December–January 1937–38 for 6-hour periods ending 6 a. m., 12 m., 6 p. m., and 12 p. m.*

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
1937									
Dec. 25	2,585	2,895	580	270	672	245	1,767	1,128	2.77
	2,440	2,910	587	268	664	241	1,760	1,150	2.83
	2,440	2,910	600	266	658	240	1,764	1,146	2.82
	2,690	3,020	597	264	658	236	1,755	1,265	3.11
26	2,837	3,412	600	299	666	236	1,801	1,611	3.96
	3,515	4,338	778	393	690	244	2,105	2,233	5.49
	4,953	4,805	853	340	666	242	2,101	2,704	6.64
	4,748	4,397	810	296	642	234	1,982	2,415	5.93
27	4,149	4,100	738	279	635	232	1,884	2,216	5.44
	4,227	4,355	794	305	632	232	1,963	2,392	5.88
	4,653	5,058	1,100	435	674	235	2,444	2,614	6.42
	6,317	8,462	2,128	687	760	255	3,830	4,632	11.4
28	10,520	12,620	3,680	911	1,074	299	5,964	6,656	16.4
	13,470	14,020	3,253	1,022	1,240	327	5,842	8,178	20.1
	15,250	16,070	3,990	1,336	1,498	383	7,207	8,863	21.8
	18,220	18,200	3,968	1,376	1,740	440	7,524	10,676	26.2
29	17,830	17,070	3,173	1,332	1,692	461	6,658	10,412	25.6
	15,750	14,870	2,613	1,248	1,680	468	6,009	8,861	21.8
	14,430	13,570	2,237	1,180	1,683	478	5,578	7,992	19.6
	13,600	13,220	2,232	1,275	1,905	517	5,929	7,291	17.9
30	13,910	14,250	2,053	1,327	2,010	561	5,951	8,299	20.4
	15,080	14,030	2,038	1,227	1,957	579	5,801	8,229	20.2
	14,360	13,000	1,793	1,078	1,745	568	5,184	7,816	19.2
	12,580	11,250	1,628	973	1,597	541	4,739	6,511	16.0
31	10,270	9,867	1,517	886	1,463	514	4,380	5,487	13.5
	9,578	9,163	1,418	822	1,347	486	4,073	5,090	12.5
	8,303	7,888	1,350	766	1,255	461	3,832	4,056	9.97
	7,753	7,568	1,297	714	1,185	438	3,634	3,934	9.67

TABLE 8.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of December–January 1937-38 for 6-hour periods ending 6 a. m., 12 m., 6 p. m., and 12 p. m.*—Continued

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
1938									
Jan. 1	6,912	6,863	1,220	667	1,125	423	3,435	3,428	8.42
	6,300	6,303	1,163	621	1,058	403	3,245	3,058	7.51
	5,967	5,983	1,118	587	1,017	384	3,106	2,877	7.07
	5,437	5,430	1,077	555	988	373	2,993	2,437	5.99
2	4,763	4,837	1,039	521	945	357	2,862	1,975	4.85
	4,510	4,660	976	492	903	343	2,714	1,946	4.78
	4,462	4,448	967	468	873	327	2,635	1,813	4.45
	4,395	4,312	941	442	853	317	2,553	1,759	4.32
3	3,793	3,868	890	424	825	308	2,447	1,421	3.49
	3,673	3,540	889	408	800	298	2,395	1,145	2.81
	4,003	3,615	871	393	774	287	2,325	1,290	3.17
	3,798	3,613	831	381	768	281	2,261	1,352	3.32
4	2,988	3,137	723	363	747	275	2,108	1,029	2.53
	2,887	3,083	735	351	726	269	2,081	1,002	2.46
	3,213	3,237	727	339	717	260	2,043	1,194	2.93
	3,237	3,167	698	331	711	253	1,993	1,174	2.88

TABLE 9.—Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of April 1938 for 6-hour periods ending 6 a. m., 12 m., 6 p. m., and 12 p. m.

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
1938									
Apr. 15	2,287	2,282	417	247	587	184	1,435	847	2.08
	2,487	2,652	420	253	588	189	1,450	1,202	2.95
	2,890	2,600	420	265	605	190	1,480	1,120	2.75
	2,928	2,710	428	272	655	198	1,553	1,157	2.84
16	2,372	2,540	450	293	712	210	1,665	875	2.15
	2,488	2,903	500	312	765	222	1,799	1,104	2.71
	3,200	3,050	530	325	794	230	1,879	1,171	2.88
	3,762	3,977	633	422	908	260	2,223	1,754	4.31
17	3,803	5,122	1,293	791	1,215	350	3,649	1,473	3.62
	5,939	7,403	1,607	1,342	1,695	490	5,134	2,269	5.57
	9,667	12,080	2,473	2,235	2,400	635	7,743	4,337	10.7
	15,220	18,210	3,938	3,765	3,603	848	12,154	6,056	14.9
18	23,280	27,280	7,012	5,000	4,913	1,150	18,075	9,205	22.6
	31,550	30,330	5,353	4,263	5,223	1,370	16,209	14,121	34.7
	31,600	28,720	3,253	3,173	4,403	1,335	12,164	16,556	40.7
	25,620	22,820	2,692	2,378	3,833	1,203	10,106	12,714	31.2
19	20,100	18,210	2,480	1,870	3,367	1,070	8,787	9,423	23.2
	17,320	15,160	2,302	1,512	3,067	950	7,831	7,329	18.0
	15,450	13,480	2,203	1,313	2,673	868	7,057	6,423	15.8
	13,330	11,750	2,130	1,175	2,438	802	6,545	5,205	12.8
20	11,070	10,310	2,023	1,073	2,150	727	5,973	4,337	10.7
	10,770	9,540	1,835	985	1,932	672	5,424	4,116	10.1
	9,907	8,648	1,648	907	1,790	625	4,970	3,678	9.04
	9,014	8,028	1,518	840	1,717	589	4,664	3,364	8.27
21	7,765	7,262	1,428	801	1,633	563	4,425	2,837	6.97
	8,085	7,072	1,337	751	1,548	532	4,168	2,904	7.14
	7,695	6,583	1,257	710	1,495	510	3,972	2,611	6.42
	6,702	6,161	1,197	688	1,482	493	3,860	2,301	5.65

TABLE 9.—*Computation of mean discharge, in second-feet, from valley part of Puyallup River Basin for the flood of April 1938 for 6-hour periods ending 6 a. m., 12 m., 6 p. m., and 12 p. m.*—Continued

Date	Puyallup River at Puyallup		Mountain tributaries					Valley part	
	Observed	Corrected for channel storage	Puyallup River near Orting	Carbon River near Fairfax	White River at Greenwater	Greenwater River at Greenwater	Sum of columns 4, 5, 6, and 7	Column 3 minus column 8	Second-feet per square mile
1	2	3	4	5	6	7	8	9	10
Apr. 22	5,407	5,619	1,175	674	1,452	482	3,783	1,836	4.51
	5,838	5,859	1,173	669	1,418	470	3,730	2,129	5.23
	5,900	5,648	1,155	674	1,400	459	3,688	1,960	4.82
	5,633	5,552	1,117	662	1,398	460	3,637	1,915	4.71
23	4,888	5,158	1,065	655	1,360	460	3,540	1,618	3.98
	5,032	5,118	1,017	625	1,312	453	3,407	1,711	4.20
	4,939	4,870	958	586	1,272	443	3,259	1,611	3.96
	4,996	4,973	935	566	1,300	443	3,244	1,729	4.25
24	4,010	4,463	918	555	1,283	447	3,203	1,260	3.10
	3,937	4,584	900	532	1,272	450	3,154	1,430	3.51
	4,175	4,361	864	516	1,233	452	3,065	1,296	3.18
	4,152	4,478	832	501	1,225	443	3,001	1,477	3.63
25	3,808	4,193	812	488	1,205	440	2,945	1,248	3.07
	4,202	4,410	797	473	1,188	440	2,898	1,512	3.71
	4,611	4,082	782	467	1,160	440	2,849	1,233	3.03
	4,540	4,078	761	455	1,163	435	2,814	1,264	3.11

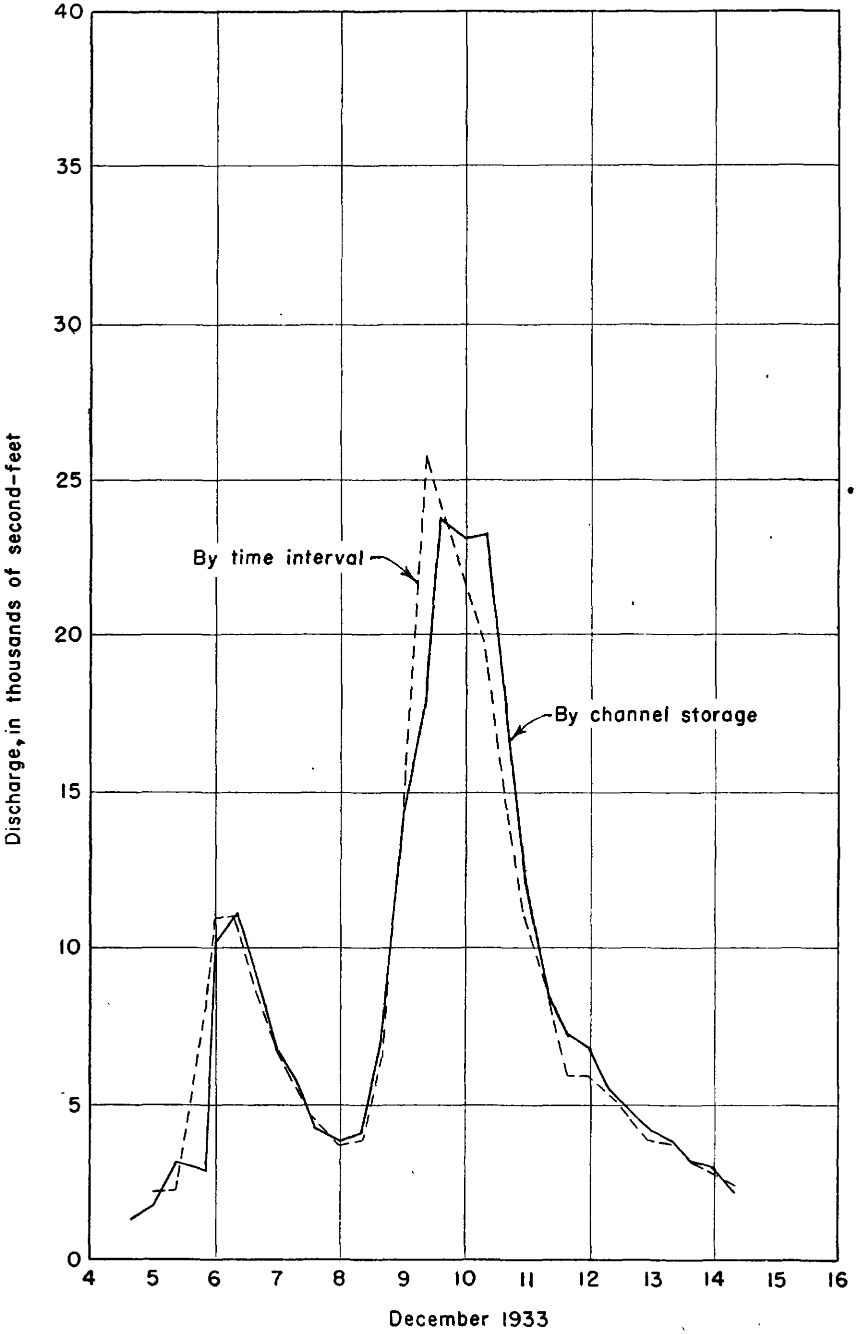

FIGURE 30.—Graphs of discharge for the valley part of the Puyallup River as computed by two methods.

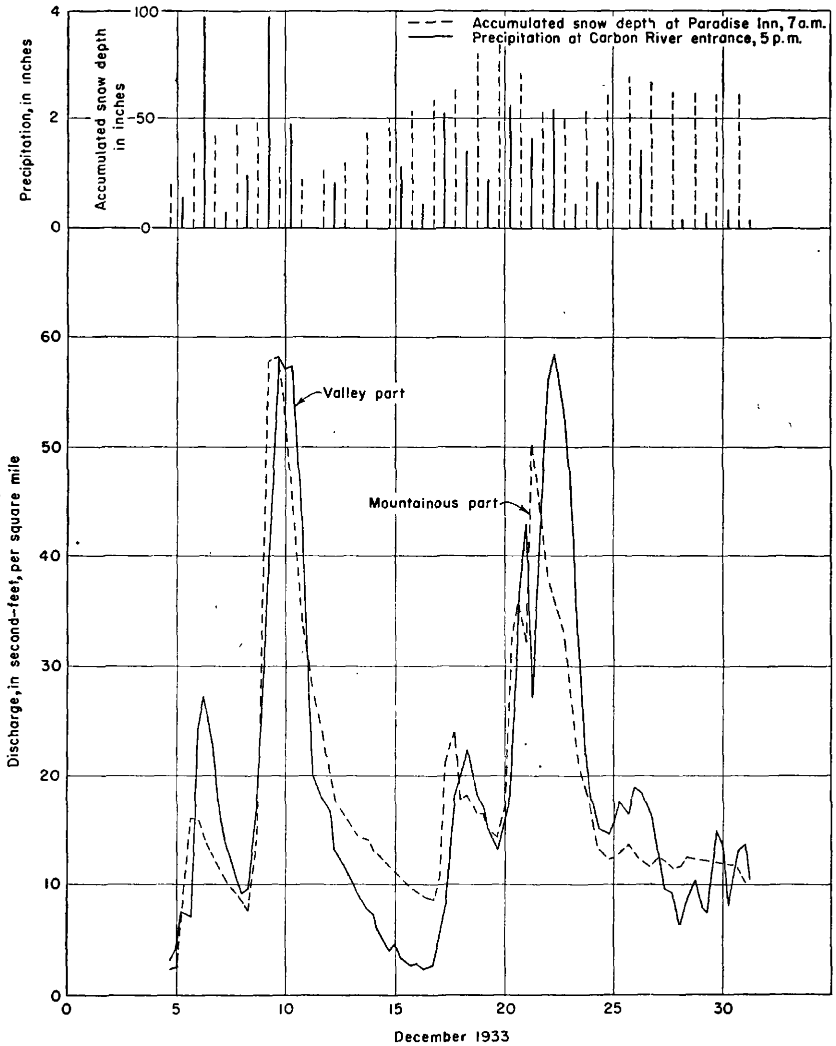

FIGURE 31.—Climatologic and discharge data pertaining to the Puyallup River above Puyallup, Wash., for flood of December 1933.

Records for the Puyallup River near Orting for December 1933 are much less satisfactory than those for other stations. Discharge was estimated December 5–15 on the basis of records at nearby stations. The occurrence during late December of a radical change in the stage-discharge relation and the impossibility of closely determining when the change occurred introduce some uncertainty. For this reason it seemed inadvisable to compute the flow for the floods of December 1933 for intervals of less than 8 hours. During December 1937 and

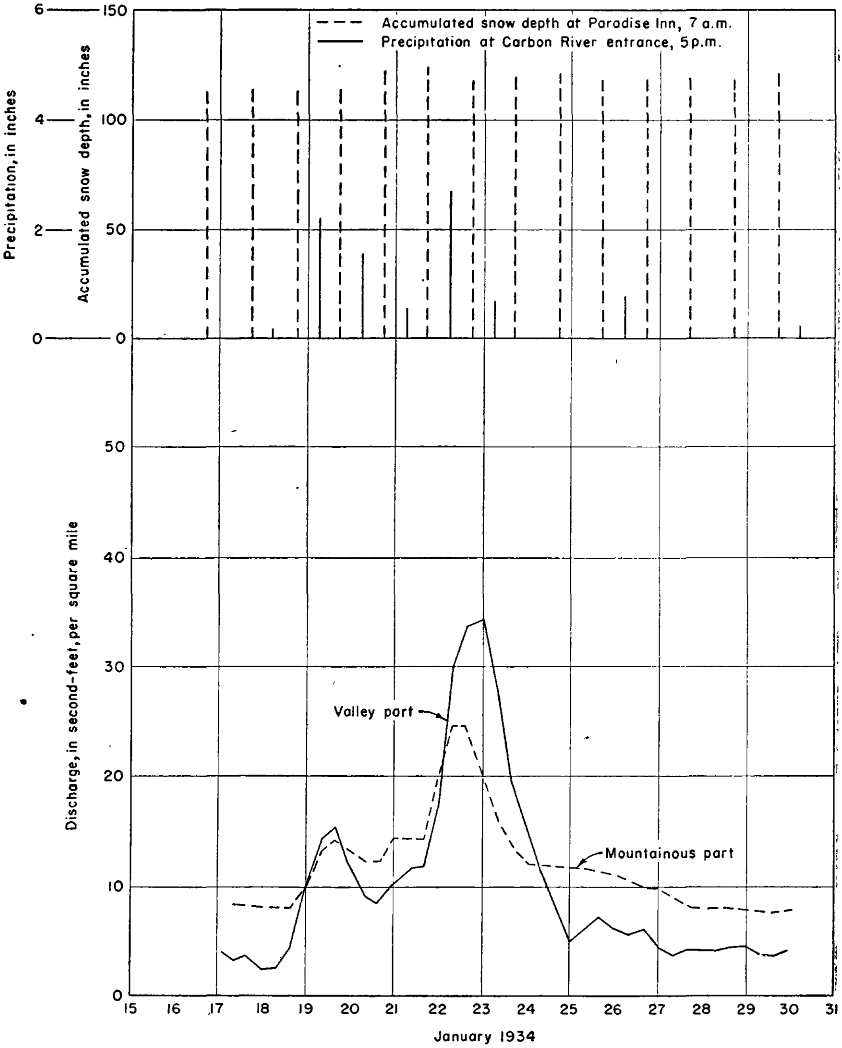

FIGURE 32.—Climatologic and discharge data pertaining to the Puyallup River above Puyallup, Wash., for flood of January 1934.

January and April 1938, when the discharge determinations were more accurate, computations were made on a 6-hour basis. Discharge graphs for the mountainous and valley parts for 6- and 8-hour periods are shown in figures 31–34.

Precipitation records are available only at four places within the Puyallup Basin, namely, Puyallup and Buckley in the valley part and the Carbon River Entrance and Parkway in the mountainous part. (See pl. 1 and table 3.) Paradise Inn, on the south slope of Mount

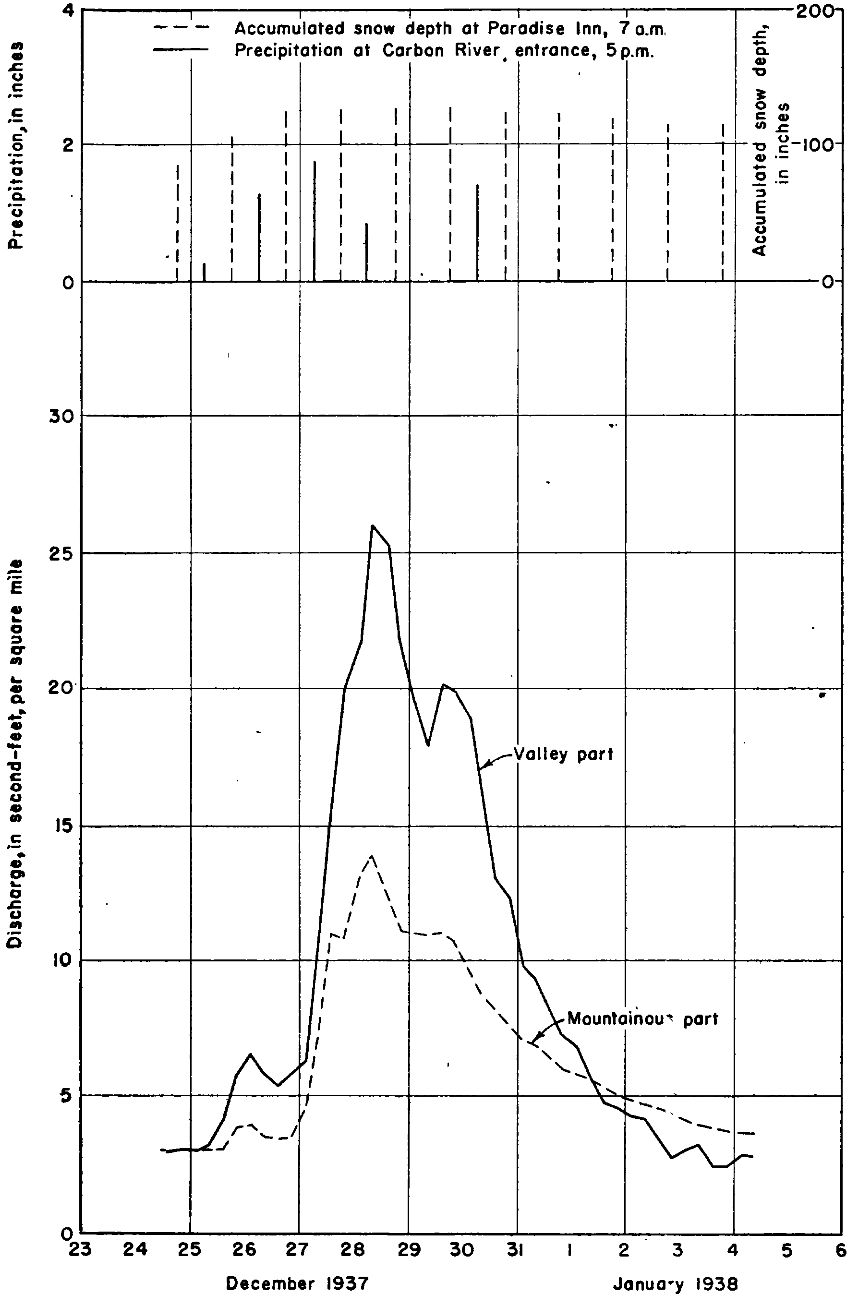

FIGURE 33.—Climatologic and discharge data pertaining to the Puyallup River above Puyallup, Wash., for flood of December–January 1937–38.

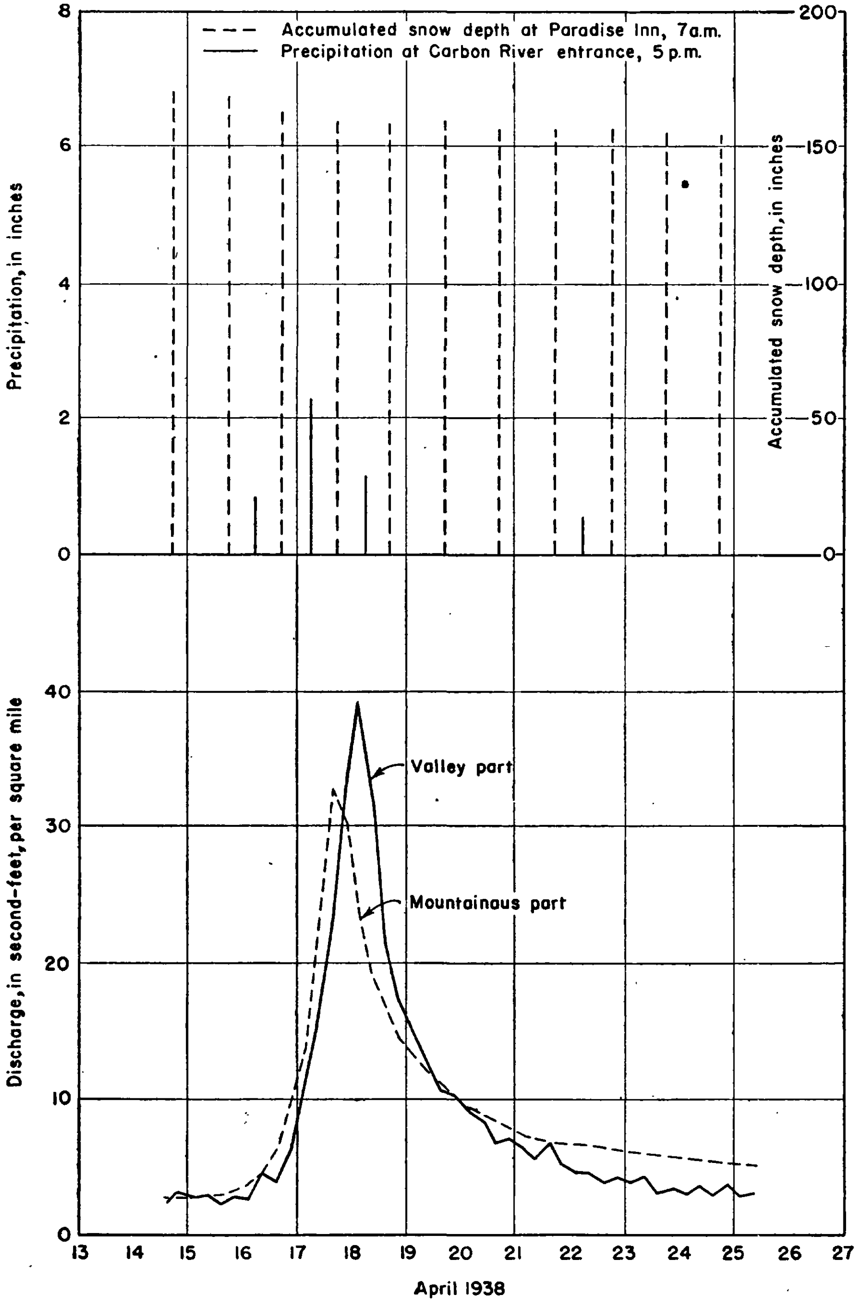

FIGURE 34.—Climatologic and discharge data pertaining to the Puyallup River above Puyallup Wash., for flood of April 1938.

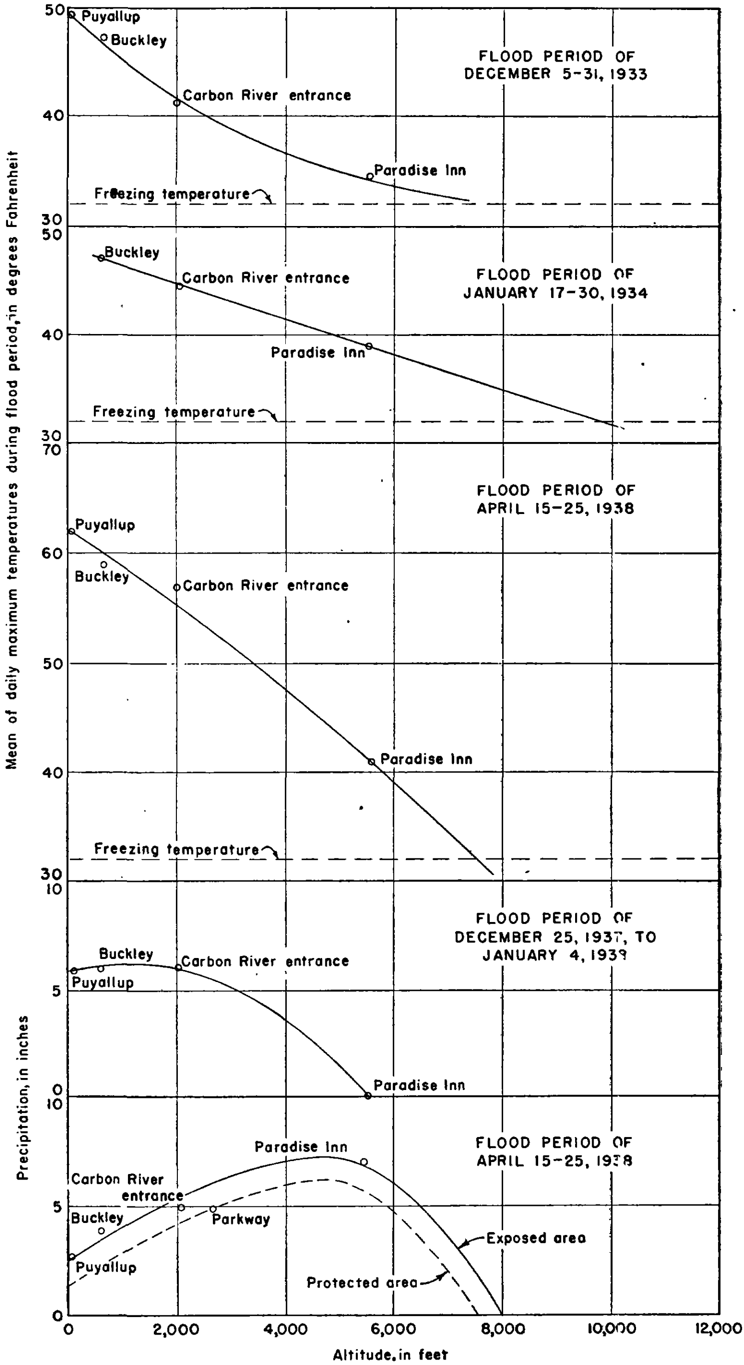

FIGURE 35.—Altitude-precipitation and altitude-maximum temperature relations for the Puyallup River Basin.

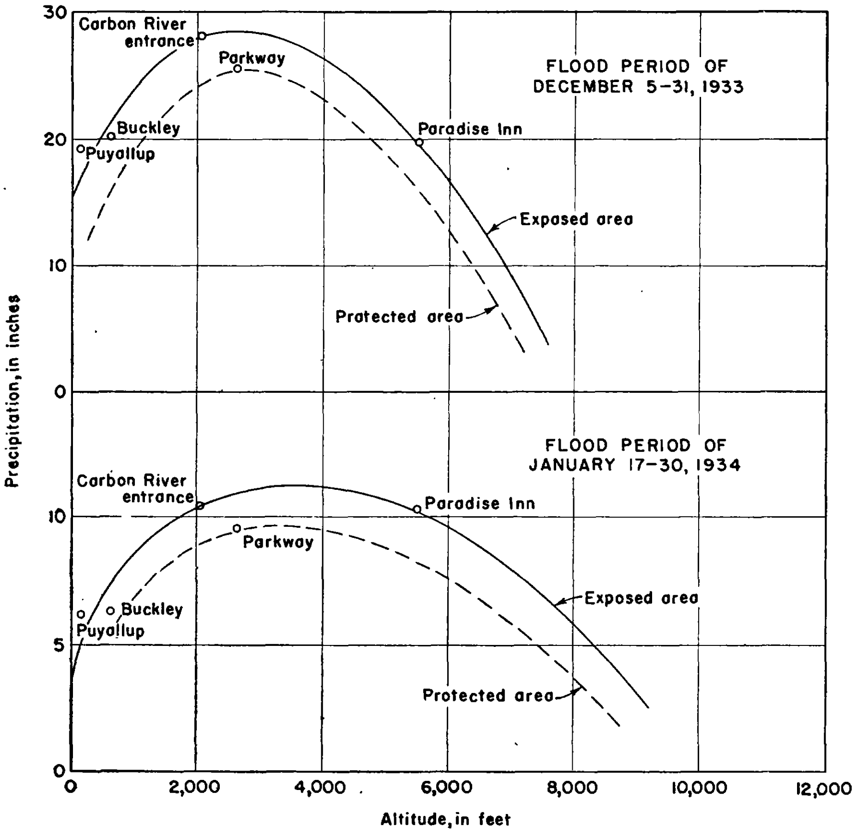

FIGURE 36.—Altitude-precipitation relations for the Puyallup River Basin.

Rainier, is close enough to the basin to be considered representative of the part exposed to the prevailing winds. The computation of mean daily precipitation or even the mean precipitation for the entire flood period by the commonly accepted isohyetal or perpendicular-bisector (Thiessen) method is impossible for several reasons—lack of gages, inability to define accurately the limits of rain-shadow influence of Mount Rainier, and lack of information as to water content of accumulated snow. Computation of mean precipitation for the period as a whole instead of by days was based on altitude. One basic assumption was necessary, that is, water content of snow. Newly fallen snow ordinarily has a water content of about 10 percent. Accumulated snow, or snow that melts partly as it falls, is denser and frequently has a water content of as much as 40 percent. A mean water content of 20 percent was assumed.

For each flood period under investigation a precipitation-elevation relation was defined by use of available records; 20 percent of the increased or decreased snow depth was assumed to represent depth of water to be deducted from or added to rainfall during the period to give the net precipitation available for runoff. The possibility that decreased snow depth might be caused by compaction of the snow, as well as by melting, must be kept constantly in mind. For each period two relations were determined between precipitation and elevation; one for the exposed area and one for the area shaded by Mount Rainier (the White River and Greenwater River Basins above Greenwater). The first relation, which is based on records from four gages, is fairly well defined. The elevation, at and above which precipitation available for runoff was zero, was approximated from a plot of maximum temperature-elevation relations, as shown on figure 35. The elevation at which the curve crossed 32° F. was considered

TABLE 10.—*Precipitation and snow depth, in inches, and temperature, in degrees Fahrenheit, at stations in the Puyallup River Basin for storm of December 1933*

1933	Puyallup (altitude 100 feet)[1]			Buckley[2] (altitude 685 feet)	Carbon River Entrance[1] (altitude 2,026 feet)	Parkway[3] (altitude 2,628 feet)		Paradise Inn[4] (altitude 5,550 feet)			
	Precipitation	Temperature		Precipitation	Precipitation	Precipitation	Snow depth	Precipitation	Snow depth	Temperature	
		Maximum	Minimum							Maximum	Minimum
Dec. 1	------	49	30	------	------	------	------	------	Tr.	47	31
2	0.41	48	33	0.41	0.29	0.49	------	0.21	2.0	49	32
3	Tr.	46	36	.09	.39	.70	1.8	.40	6.0	37	22
4	.01	45	37	------	.21	.80	5.2	.80	14.0	29	19
5	.55	53	41	.79	.59	.89	7.5	.60	20.0	30	19
6	2.22	51	43	2.30	3.84	2.10	9.5	2.23	34.0	34	26
7	.46	47	39	.35	.32	.50	13.5	.93	42.0	35	23
8	.20	47	41	.26	1.01	.30	11.0	.63	48.0	30	23
9	2.87	55	41	3.14	3.89	4.17	6.5	.52	48.0	36	26
10	1.50	55	42	1.91	1.94	2.10	4.0	4.12	28.0	40	33
11	.19	55	43	.16	------	.20	2.1	.93	22.0	40	32
12	.15	55	41	.01	.75	.68	2.0	1.15	26.0	47	31
13	.36	52	36	.40	------	------	1.0	.51	30.0	38	27
14	.40	44	39	.32	------	.20	4.8	1.31	44.0	32	20
15	.13	40	32	.50	1.16	.61	11.7	.44	49.0	28	18
16	Tr.	43	29	------	.40	.20	14.8	.52	54.0	22	15
17	1.90	52	38	1.39	2.11	2.10	11.0	.40	58.0	30	16
18	.68	49	38	.86	1.45	1.50	13.0	.83	64.0	37	27
19	.69	50	38	.52	.92	1.60	15.0	1.59	80.0	31	26
20	1.17	55	40	1.58	2.24	2.25	11.5	.42	84.0	32	25
21	1.46	57	40	1.57	1.67	2.20	7.0	1.73	71.0	36	30
22	1.76	56	48	1.68	2.22	2.21	5.5	2.99	54.0	39	21
23	.05	52	33	.04	.46	------	5.0	1.86	50.0	26	20
24	.14	42	30	.30	.86	.20	8.0	.29	54.0	27	17
25	.87	36	33	1.14	------	.22	12.0	.94	61.0	31	20
26	.64	48	34	.57	1.48	.20	15.0	1.51	70.0	34	27
27	.02	47	40	.04	------	Tr.	14.0	.08	68.0	35	31
28	.23	47	40	.17	.15	Tr.	13.0	.18	62.0	37	30
29	.64	53	44	.37	.28	.91	12.0	.98	62.0	36	31
30	.04	52	43	.14	.35	1.10	11.0	.43	61.0	35	31
31	------	50	39	.01	.13	------	11.0	.26	61.0	33	20

[1] Gage read at 5 p. m.
[2] Gage read at 7 p. m.
[3] Gage read at 4 p. m.
[4] Gage read at 7 a. m.

to be the maximum elevation from which runoff could occur. On this basis, elevation 8,000 feet was considered the upper limit of runoff for the flood periods of December 1933 and April 1938 and 10,000 feet for the flood period of January 1934. During the flood period of December 1937 and January 1938, when records of temperature were incomplete, the increase in snow depth at Paradise Inn indicated that no runoff occurred above elevation 5,500 feet. The precipitation-elevation curve for the rain-shadow area is based on one precipitation gage (at Parkway) and is drawn to conform in shape with that for the exposed area. Only the White and Greenwater River Basins above the gaging stations at Greenwater were considered as being in the shaded area. The curves of relation are shown on figures 35 and 36.

Flood-period precipitation for any basin was computed by scaling from the curve of relation a mean for each zone of thousand-feet range in elevation, multiplying it by the fraction of the total area involved, and adding the products. During the period from December 1937 to January 1938 precipitation for Parkway seems to be especially high. It has, therefore, been neglected and the curve as determined for the exposed area has been used to determine the mean for the White River area. Climatologic data for the periods under investigation are given in tables 10, 11, 12, and 13. The location of the weather stations is shown on plate 1.

TABLE 11.—*Precipitation and snow depth, in inches, and temperature, in degrees Fahrenheit, at stations in the Puyallup River Basin for storm of January 1934*

1934	Puyallup (altitude[1] 100 feet)			Buckley[2] (altitude 685 feet)	Carbon River Entrance[1] (altitude 2,026 feet)	Parkway[3] (altitude 2,628 feet)		Paradise Inn[4] (altitude 5,550 feet)			
	Precipitation	Temperature: Maximum	Temperature: Minimum	Precipitation	Precipitation	Precipitation	Snow depth	Precipitation	Snow depth	Temperature: Maximum	Temperature: Minimum
Jan. 15	0.07	37	26	0.10	-------	-------	11.4	-------	105	31	15
16	.83	56	35	.63	1.53	2.21	10.0	0.62	110	34	26
17	.15	47	34	.17	-------	-------	9.7	.49	114	34	21
18	.06	43	26	.03	.17	-------	9.5	-------	114	28	18
19	2.00	53	36	1.83	2.19	1.57	9.1	.93	113	36	18
20	.10	51	39	.10	1.54	Tr.	9.0	1.26	114	36	18
21	.35	50	43	.39	.57	.86	8.6	1.78	123	32	21
22	1.26	53	42	1.65	2.72	2.92	8.5	1.90	124	43	28
23	.71	53	43	.50	.69	Tr.	7.9	2.56	118	40	18
24	.01	44	30	-------	-------	-------	7.9	.19	120	44	11
25	.39	48	40	.62	-------	.87	9.7	.62	122	33	14
26	.01	56	46	.06	.79	.20	9.1	1.28	118	34	16
27	-------	52	38	-------	-------	-------	9.1	1.37	118	35	17
28	-------	49	37	-------	-------	-------	9.1	-------	118	50	32
29	-------	48	39	-------	-------	-------	9.1	-------	117	52	39
30	.17	52	39	.19	.25	.23	8.1	.42	121	49	27

[1] Gage read at 5 p. m.
[2] Gage read at 7 p. m.
[3] Gage read at 4 p. m.
[4] Gage read at 7:30 a. m.

TABLE 12.—*Precipitation and snow depth, in inches, and temperature, in degrees Fahrenheit, at stations in the Puyallup River Basin for storm of December 1937–January 1938*

[Measured in afternoon]

1937–38	Puyallup (altitude 100 feet)			Buckley (altitude 685 feet)	Carbon River Entrance (altitude 2,026 feet)	Parkway (altitude 2,628 feet)		Paradise Inn (altitude 5,550 feet)			
	Precipitation	Temperature[1] Maximum	Temperature[1] Minimum	Precipitation	Precipitation	Precipitation	Snow depth	Precipitation	Snow depth	Temperature Maximum	Temperature Minimum
Dec. 15	0.10	54	44	0.04	1.16	0.10	0.0		42.0	34	28
16	.43	56	46	.51	1.16	.66		0.80		34	30
17	.27	56	45	.36	.96	.70		.08		34	22
18		46	41					Tr.		34	24
19		48	41							(2)	24
20		42	39							(2)	26
21		44	38							(2)	20
22	.13	43	37		.11	Tr.		.14		(2)	17
23	Tr.	39	29	Tr.	.02	Tr.		.84		(2)	10
24	.42	36	33	.38	.36	2.00		2.10		(2)	8
25	.18	41	31	.14	.27	.90		.96		(2)	10
26	.90	44	32	1.40	1.30	2.50		2.44		(2)	18
27	.82	50	32	1.14	1.73	3.00		2.10		(2)	16
28	2.53	57	46	1.84	.82	2.10		1.39		(2)	30
29	.32	55	47	.36	(3)	.75		1.26		(2)	30
30	.48	45	40	.58	1.40	.60		1.13		(2)	18
31		53	42	.01			15.0	Tr.	125.0	(2)	18
Jan. 1	.02	50	31							(2)	23
2		47	31							(2)	20
3		39	35							(2)	27
4		48	29							(2)	32

[1] Temperatures at Puyallup not available; those shown are for Tacoma.
[2] Record missing.
[3] Included in the following measurement.

TABLE 13.—*Precipitation and snow depth, in inches, and temperature, in degrees Fahrenheit, at stations in the Puyallup River Basin for storm of April 1938*

1938	Puyallup[1] (altitude 100 feet)			Buckley[2] (altitude 685 feet)	Carbon River Entrance[1] (altitude 2,026 feet)	Parkway[3] (altitude 2,628 feet)		Paradise Inn[4] (altitude 5,550 feet)			
	Precipitation	Temperature Maximum	Temperature Minimum	Precipitation	Precipitation	Precipitation	Snow depth	Precipitation	Snow depth	Temperature Maximum	Temperature Minimum
Apr. 10		60	37				18.0	Tr.	171	48	22
11	0.16	58	33	0.10	0.21		17.0		169	35	24
12	.12	60	40	.14	.18	0.07	16.0	Tr.	168	39	19
13		61	33	.01			14.0		167	44	24
14		63	38				13.0	0.29	169	37	28
15	.18	58	38	.20		.04	12.0	.29	169	44	28
16	.40	62	48	.56	.82	.14	10.0	.24	168	41	29
17	1.45	61	51	1.98	2.33	.82	8.0	3.35	163	43	35
18	.30	58	46	.81	1.16	1.02	6.5	Tr.	158	38	24
19		58	51				4.5		158	39	23
20		64	30				3.0		158	47	24
21		66	41						156	41	33
22	.22	63	47	.24	.57	.07			156	37	30
23		62	35			.05		Tr.	156	47	24
24	Tr.	62	41	.02		.20		Tr.	155	42	29
25		62	47	.08		Tr.			154	39	29

[1] Gage read at 5 p. m. [2] Gage read at 7 p. m. [3] Gage read at 4:30 p. m. [4] Gage read at 7:30 a. m.

DISCUSSION OF RESULTS

Precipitation during December 1933 was heavy and practically continuous; a total of 21 inches fell at Buckley, 30 inches at Paradise Inn, 28 inches at Parkway, 20 inches at Puyallup, and 29 inches at the Carbon River entrance. Most of this precipitation fell on December 5, 8–9, 17–23 and caused corresponding rises on December 6, 10, 18, and 22. As the temperature on the upper slopes of Mount Rainier was low December 1–9 much of the precipitation during that period occurred as snow, 48 inches having accumulated at Paradise Inn during the period December 1–8. The first rise, that of December 6, showed a much greater unit runoff from the valley part than from the mountainous part as a result of this accumulation of snow on the upper slopes. (See fig. 31.) In sharp contrast, temperatures were high December 10–12, even on the upper slopes, and during this period precipitation ranged from 4.4 inches at Puyallup to 6.2 inches at Paradise Inn. The unit runoff from the two areas was about the same. In addition, snow depth at Paradise Inn was reduced from 48 inches to 22 inches. On December 13 temperatures on the upper slopes dropped again and stayed low until December 20, so that practically all of the precipitation during that period was snow, the accumulated depth at Paradise Inn increasing from 22 inches to 84 inches. During this period a third rise, that of December 18, occurred. Heavy precipitation occurred again December 20–22, ranging from 4.4 inches at Puyallup to 6.6 inches at Paradise Inn. During this period snow depth at Paradise Inn was reduced from 84 inches to 50 inches. As the temperatures were low, it is possible that this reduction in snow depth was due partly to compacting and partly to melting. The discharge shows that runoff from the mountainous part of the basin was considerably less than from the valley part for this period, which indicates that much of the rain on the upper slopes was probably absorbed by the snow.

Enough precipitation fell during the first 18 days of January 1934 to continue runoff at a fairly high rate. Heavy precipitation January 19–22 ranged from 3.7 inches at Puyallup to 7.5 inches at Paradise Inn. As temperatures were very low on the upper slopes, much of the precipitation during the period was snow, a total of 19 inches falling at Paradise Inn. Snow accumulation at Paradise Inn was reduced from a maximum of 124 inches during the storm to 118 inches by January 23. It is reasonable to suppose that much of the rain on the upper slopes was absorbed by the snow, resulting in very little runoff from the upper slopes. This supposition is substantiated by the discharge graph for the period (fig. 32), which shows a much greater unit runoff from the valley part.

The high water of December 28–29, 1937, was caused primarily by heavy rains on the lower slopes of Mount Rainier and in the valley part. During 3 days, December 26–28, precipitation ranged from 4.2 inches at Puyallup to 5.9 inches at Paradise Inn. During the last half of December, 13.24 inches of precipitation fell at Paradise Inn, and accumulated snow depth increased by 83 inches. The entire period was very cold, reaching a minimum of 8°. The upper slopes of Mount Rainier, at least those above the altitude of Paradise Inn, probably contributed little if any runoff during the period. The discharge graph for the period (fig. 33) shows that the valley part had nearly twice as great a unit runoff as the mountainous part.

During the flood of April 1938 most of the area was contributing runoff. The discharge graph for the period (fig. 34) shows relatively little difference in unit runoff between the valley and mountainous parts. Heavy precipitation April 15–18 caused a peak on the 18th. Precipitation ranged from 2.2 inches at Puyallup to 4.2 inches at Paradise Inn. Whether or not snow melted at the higher altitudes during the period is difficult to determine. At Paradise Inn the depth of snow was reduced by 11 inches, but this reduction may have been due to compacting rather than melting. Some of the rain that fell at Paradise Inn may have been absorbed by the accumulated snow so that actually less than the recorded amount, 4.2 inches, was available for runoff. At Parkway, however, which is at a considerably lower altitude than Paradise Inn, 12 inches of snow that accumulated on April 15 had completely disappeared by April 21. This evidence at Parkway therefore suggests that considerable snow melted at least as high as Paradise Inn and possibly higher.

The bulk of the glaciers on Mount Rainier lie above 6,500 feet altitude and contributed negligible flood runoff. Any glacial runoff that may have been produced by melting of the tongues, which reach down to 5,000 feet, was probably slight and may be considered as part of the seasonal base flow.

The total direct runoff for each basin for each flood period is shown in table 14. Precipitation as given in the table represents the mean for each basin as determined from the altitude-precipitation relations by the methods previously outlined. Precipitation and runoff for the White and Greenwater Rivers have been combined because both are in the shaded area and precipitation for both is based on records obtained at Parkway.

Direct runoff was computed from plotted hydrographs of flood discharge, as shown on figures 31–34, and by drawing on these hydrographs a line estimated to represent the base flow or the flow that would have been maintained irrespective of the storm. The area above the estimated base flow line and within the hydrograph of total discharge is equal to the volume of direct runoff ascribed to the indicated storm periods. This area was planimetered and converted into inches over the tributary areas.

TABLE 14.—*Precipitation and associated direct runoff for selected floods in the Puyallup River Basin*

Flood period	Mountainous part				Valley part (inches)	Approximate altitude of upper limit of runoff (feet)
	Upper Puyallup River (inches)	Carbon River (inches)	White and Greenwater Rivers (inches)	Average (inches)		
Dec. 5–31, 1933						8,000
Precipitation	24.2	24.0	19.3	21.5	23.8	
Direct runoff	15.33	16.29	12.72	14.06	15.26	
Jan. 17–30, 1934						10,000
Precipitation	9.8	10.2	9.3	9.6	8.7	
Direct runoff	2.54	2.86	2.07	2.34	3.38	
Dec. 25, 1937, to Jan. 4, 1938						5,500
Precipitation	4.3	3.5	2.7	3.3	5.4	
Direct runoff	2.05	1.92	.78	1.35	2.89	
Apr. 15–25, 1938						8,000
Precipitation	5.2	5.9	5.2	5.3	4.3	
Direct runoff	2.70	3.72	2.05	2.50	2.71	

Figure 37 shows a plot of total storm precipitation and associated direct runoff for the mountainous and valley parts. The positions of the points indicate generally comparable behavior between valley and mountainous parts. The erratic plotting of the storm of January 17–30, 1934, for the mountainous part may be due to undisclosed

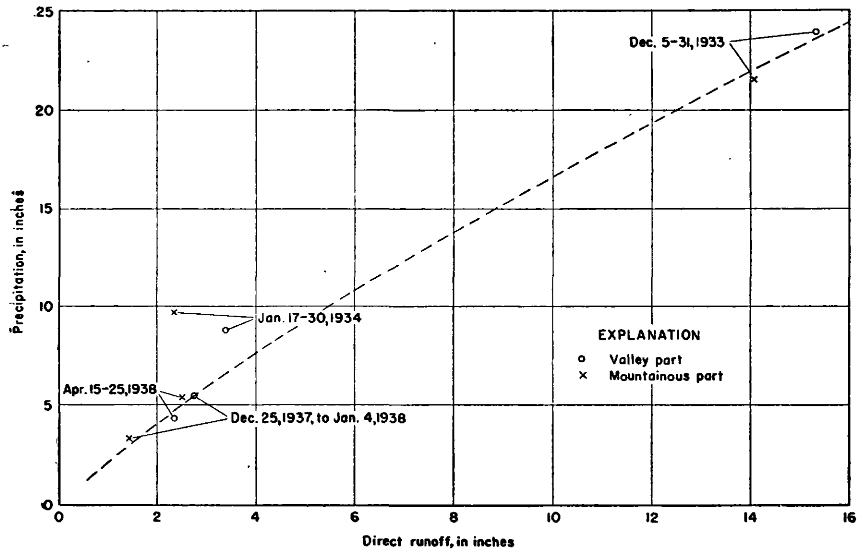

FIGURE 37.—Comparison between precipitation and associated direct runoff in the Puyallup River Basin for selected flood periods.

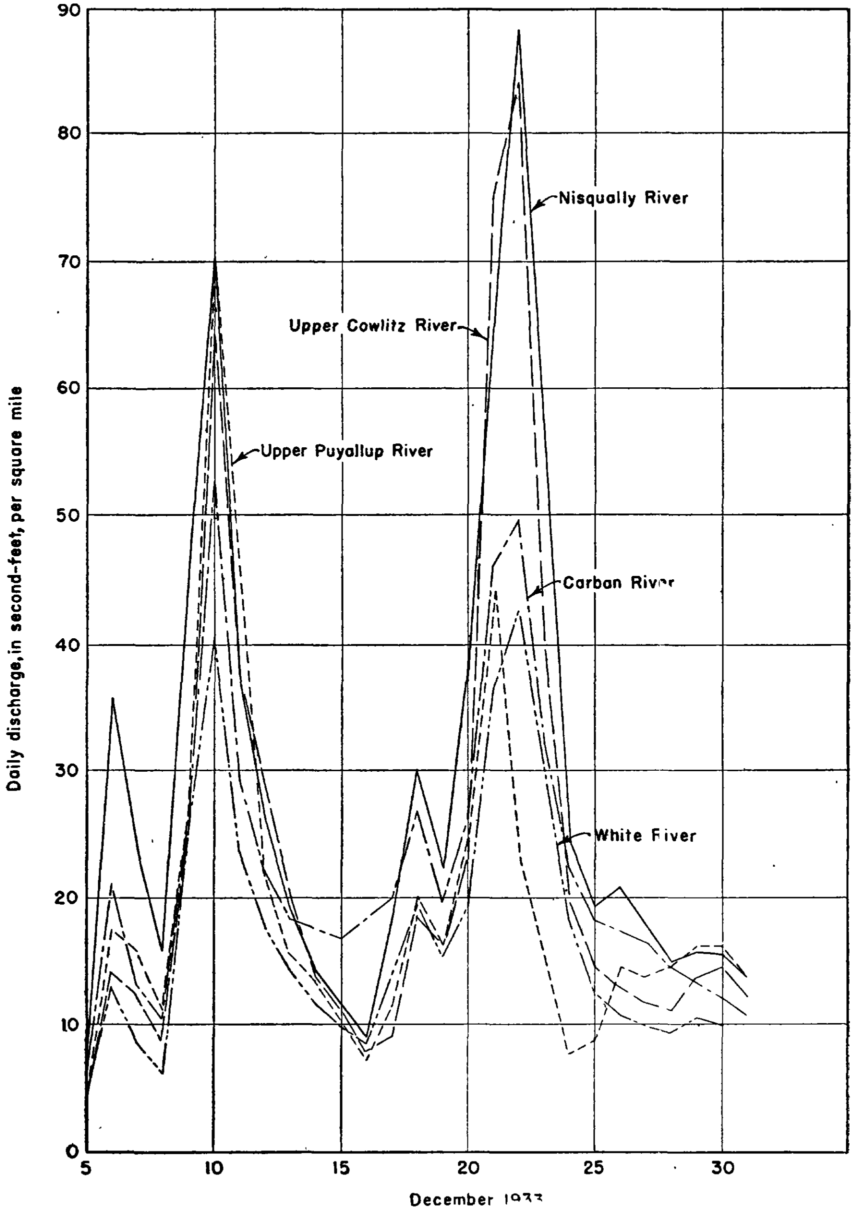

FIGURE 38.—Daily discharge of streams draining Mount Rainier during flood of December 1933.

difference in hydrologic conditions or to deficiency in base data. The general consistency between valley and mountain data, indicated by figure 37, suggests that for the limited examples given the differences in physical or hydrologic characteristics are not reflected in material differences in the rainfall-runoff relation as here displayed.

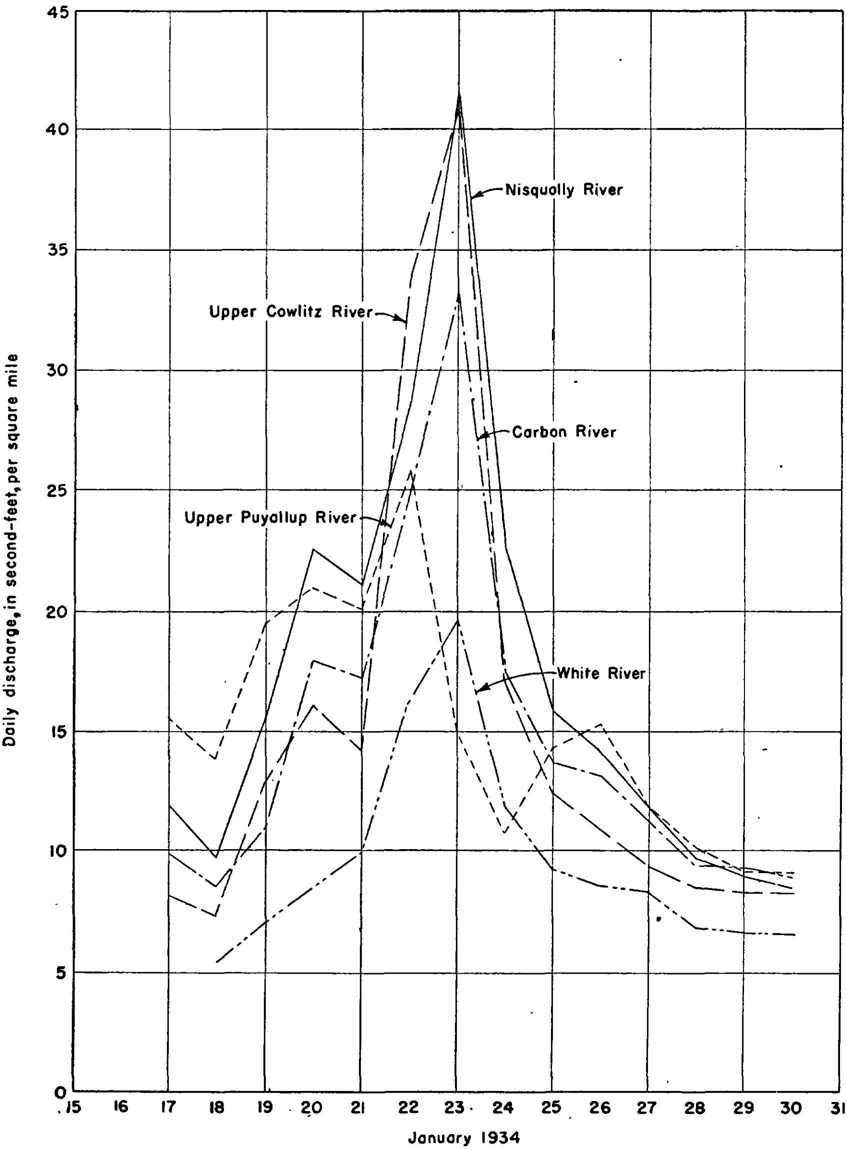

FIGURE 39.—Daily discharge of streams draining Mount Rainier during flood of January 1934.

The volumes of direct runoff from each of the three mountain areas associated with the storms listed in table 14 are consistent with one another if the respective amounts of precipitation are considered. The consistency indicates substantial similarity in hydrologic characteristics and indicates the relatively uniform hydrologic conditions that prevail in this region during the winter rainy period. The White and

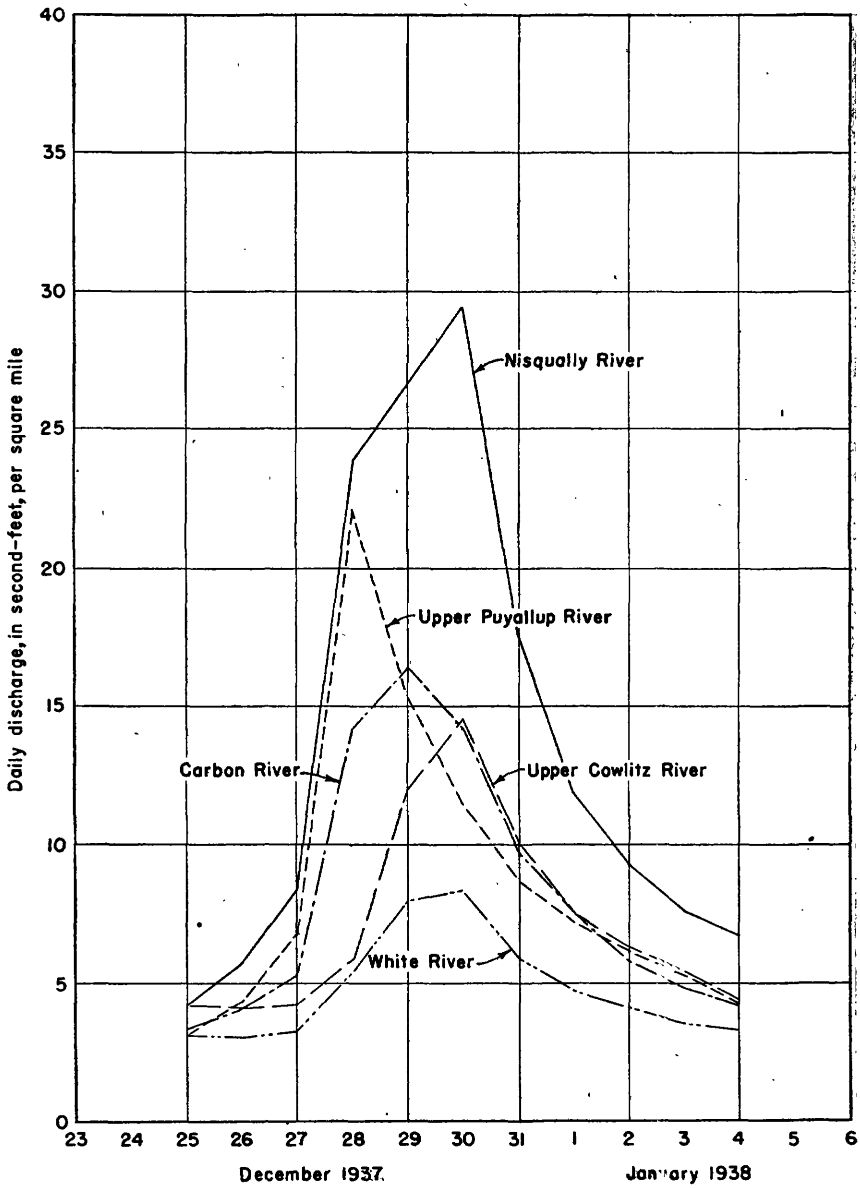

FIGURE 40.—Daily discharge of streams draining Mount Rainier during flood of December-January 1937-38.

Greenwater River Basins in the rain-shadow of Mount Rainier generally had less precipitation than the other two areas.

The effect of Mount Rainier as a moderating influence on the leeward or northeast slope has already been referred to in connection with precipitation where the marked difference between the Parkway

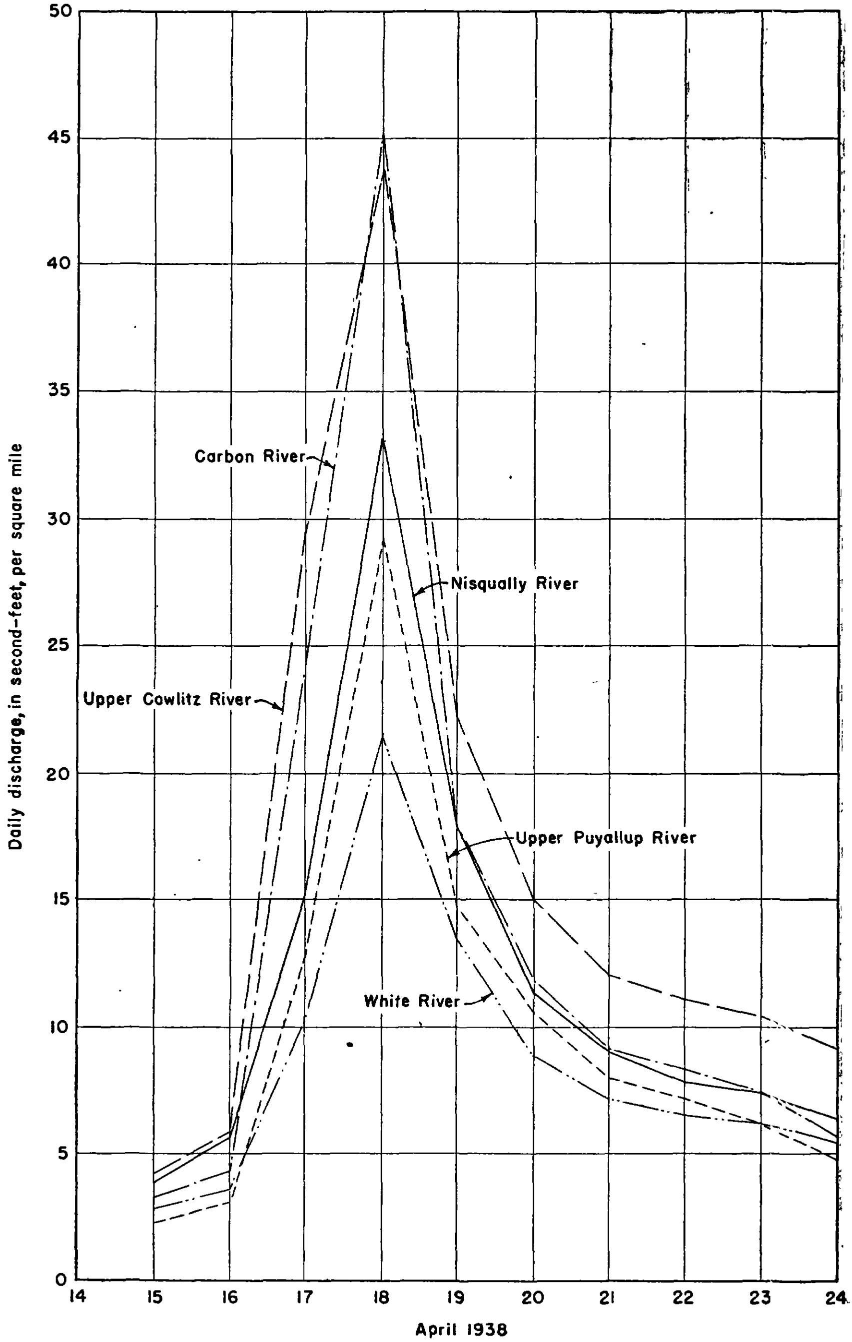

FIGURE 41.—Daily discharge of streams draining Mount Rainier during flood of April 1938.

and Carbon River Entrance records was noted. This effect is more strikingly shown by runoff either, for a flood period or on a yearly basis. Discharge graphs for streams rising in Mount Rainier for each of the flood periods considered are shown in figures 38–41. In tables 15 and 16 are tabulated runoff data by flood periods and by years for all streams rising in the glaciers of Mount Rainier. These tables indicate that the White River, which drains the shaded northeast slope, has a consistently lower unit runoff than the other basins, particularly those of the south slope.

TABLE 15.—*Peak discharge and direct runoff for streams rising in the glaciers of Mount Rainier for floods of December 1933, January 1934, December–January 1937–38, and April 1938*

Flood period	Northeast slope, White River	Northwest slope		Southwest slope, Nisqually River	Southeast slope, Upper Cowlitz River
		Carbon River	Upper Puyallup River		
Dec. 5–31, 1933					
Peak discharge:					
Second-feet	12,100	8,030	12,700	25,000	36,600
Second-feet per square mile	56.0	99.1	74.7	99.2	128
Direct runoff ....inches	12.85	16.29	15.33	21.99	20.34
Jan. 17–30, 1934					
Peak discharge:					
Second-feet	5,440	3,380	5,360	12,300	18,600
Second-feet per square mile	25.2	41.7	31.5	48.8	64.8
Direct runoff ....inches	2.04	2.86	2.54	4.23	3.90
Dec. 25, 1937, to Jan. 4, 1938					
Peak discharge:					
Second-feet	2,010	1,460	4,420	8,850	4,700
Second-feet per square mile	9.31	18.0	26.0	35.1	16.4
Direct runoff ....inches	.85	1.92	2.05	3.89	1.31
Apr. 15–25, 1938					
Peak discharge:					
Second-feet	5,440	5,560	8,680	9,620	15,700
Second-feet per square mile	25.2	68.6	51.1	38.2	54.7
Direct runoff ....inches	2.17	3.72	2.70	3.06	4.74

Tables 14–16 show that the contribution of the White River is far less than that of either the upper Puyallup or the Carbon River. The White River Basin comprises over 25 percent of the entire area of Puyallup River Basin, so that any reduction in its runoff would be strikingly felt in the basin as a whole. Large amounts of snow storage and high precipitation on the upper slopes would seem to indicate that Mount Rainier is a definite flood menace. However, Mount Rainier in protecting the White River Basin from the moisture-laden winds and at high altitudes in reducing the temperature below freezing point so that the precipitation falls as snow, has tended to reduce flood runoff from the mountain areas to such an extent that the lower Puyallup Basin is greatly benefited. Moreover, pre-

TABLE 16.—*Annual mean discharge, in second-feet, and annual runoff, in inches for streams rising in the glaciers of Mount Rainier*

Water year	North-east slope, White River	Northwest slope		South-west slope, Nisqually River	South-east slope, upper Cowlitz River
		Carbon River	Upper Puyallup River		
1931–32:					
Mean discharge .... second-feet..	861	433	715	1,350	1,700
Runoff .... inches..	54.25	[1] 72.74	[1] 57.25	73.69	80.66
1932–33:					
Mean discharge .... second-feet..	1,040	506	866	1,500	2,030
Runoff .... inches..	65.39	[1] 84.80	[1] 69.24	81.53	96.07
1933–34:					
Mean discharge .... second-feet..	1,186	578	977	1,677	2,331
Runoff .... inches..	74.60	[1] 96.75	[1] 78.03	91.00	110.30
1934–35:					
Mean discharge .... second-feet..	922	427	739	1,325	1,862
Runoff .... inches..	57.96	[1] 71.52	[1] 59.02	71.94	88.01
1935–36:					
Mean discharge .... second-feet..	713	389	636	1,114	1,518
Runoff .... inches..	44.92	[1] 65.34	[1] 50.86	60.65	71.99
1936–37:					
Mean discharge .... second-feet..	717	370	607	1,058	1,398
Runoff .... inches..	45.04	62.07	48.50	56.98	66.20
1937–38:					
Mean discharge .... second-feet..	916	435	705	1,277	1,625
Runoff .... inches..	57.53	72.93	56.33	68.75	76.88
1931–38:					
Mean discharge .... second-feet..	908	448	749	1,329	1,781
Runoff .... inches..	57.10	75.16	59.89	72.08	84.30

[1] Based on revised drainage area.

cipitation reaching the slopes of Mount Rainier above elevations of 8,000 feet may be relatively small because the storm clouds usually hang at or below that level. However, an invasion of a deep mass of warm air associated with rainfall may release much snow and ice at higher altitudes. Such conditions existed during the flood of December 1937 [4] in northern California, where a temperature 7° to 8° F. above normal increased the flood-contributing area by about 10,000 to 12,000 square miles.

CHEHALIS RIVER BASIN

DESCRIPTION OF AREA

The Chehalis River rises in the Willapa Hills in southwestern Washington, flows generally northeastward to Chehalis, there turns abruptly to the northwest and flows into Grays Harbor at Aberdeen. (See fig. 27.) The principal tributaries are the Newaukum and Skookumchuck Rivers, which rise in the western foothills of the Cascade Range. The entire basin is low, ranging in altitude from sea level to about 4,000 feet. In this report only that part of the basin above the gaging station near Grand Mound, an area of 928 square miles, is considered. (See fig. 42.)

[4] McGlashan, H. D., and Briggs, R. C., Floods of December 1937 in northern California: U. S. Geol. Survey Water-Supply Paper 843, pp. 56–65, 1939.

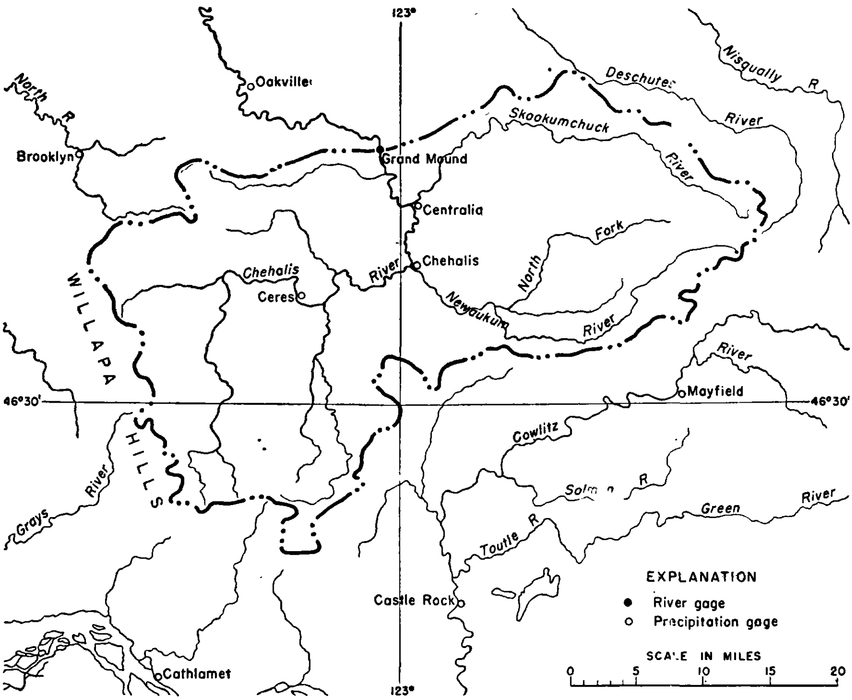

FIGURE 42.—Map of the Chehalis River Basin above Grand Mound.

Rainfall in much of the basin above Grand Mound is affected by the shadow effects of the Willapa Hills. Centralia and Rainbow Falls State Park (Ceres), in the interior, have an annual mean precipitation of 45 inches and 52 inches, respectively. Just outside the area, precipitation is much higher. Oakville and Brooklyn to the west and Mayfield to the southeast have annual mean precipitations of 50 inches, 68 inches, and 62 inches, respectively; these stations lie in the unobstructed path of prevailing southwest winds, which approach the mainland through the Chehalis and Columbia River gaps.

COMPUTATION PROCEDURE

Stream-flow records for the period covered by this report are available from only one gaging station in the Chehalis River Basin, that near Grand Mound. A description of that station and the discharge records are included with the records for the Puyallup River Basin in the section, "Records of discharge." (See pp. 181–83). A water-stage recorder was installed at the Grand Mound station in October

1934; only daily gage readings were available during the floods in December 1933 and January 1934. Daily discharge was computed originally on the assumption that one daily gage reading represented the mean for the day. In this report the discharge was revised on the basis of a gage-height graph defined by the daily gage readings and the shape of the continuously recorded gage-height graph for the gaging station on North River near Raymond. Discharges during the floods of December 1933 and January 1934 were computed for 8-hour periods. During the floods of December–January 1937–38 and April 1938 discharge was computed for 6-hour periods because the water-stage recorder then in operation provided a more dependable gage-height record and thereby justified greater refinement in computing discharge.

TABLE 17.—*Precipitation, in inches, for stations in or near the Chehalis River Basin for storm of December 1933*

[Measured in afternoon]

1933	Centralia [1] (altitude, 182 feet)	Rainbow Falls State Park (Ceres) [2] (altitude, 212 feet)	Cathlamet [2] (altitude, 470 feet)	Castle Rock [2] (altitude, 120 feet)	Headworks [3] (altitude, 985 feet)	Mayfield [4] (altitude, 600 feet)	Oakville [1] (altitude, 85 feet)	Brooklyn [2] (altitude, 180 feet)
Dec. 1					Tr.			
2	0.28	0.35		0.76	0.97	0.36	0.45	0.83
3	.22	.19		.37	.13	.48	.30	.33
4	.13	.15	1.45	.22	.06	.28	.12	.26
5	1.08	1.00	1.59	1.25	1.61	.46	2.06	3.10
6	2.17	2.43	3.70	2.91	2.37	.86	1.86	1.84
7	.40	.52	1.40	.78	.40	1.96	.44	.74
8	.39	.27	.17	.18	.16	1.54	.17	.50
9	3.95	2.57	5.26	5.40	2.84	.23	4.21	5.13
10	1.15	1.17	4.75	1.41	1.35	1.28	1.73	1.53
11	.29	.36	.35	.21	.65	2.26	.56	.97
12	.16	.36	.57	.38	.50	.24	.38	.85
13	.19	.19	.18	.44	.46	.38	.07	.15
14	.39	.45	.16	.39	.39	.36	.70	.83
15	.26	.26	.94	.11	.15	.45	.13	.28
16		.04	.09	2.07	.01	.38	.15	.20
17	2.40	2.53	(5)	1.47	2.87	.73	3.30	3.90
18	1.60	1.89	2.80	.97	1.73	2.26	1.54	1.84
19	.67	.67	1.23	2.12	1.30	1.68	.64	.87
20	1.96	1.87	1.00	2.26	2.34	.98	2.66	2.78
21	1.07	1.41	1.80	1.89	1.55	2.16	1.53	1.98
22	.90	1.04	3.22	.09	.85	2.28	1.64	1.75
23	.01	.07	1.18	.49	.23	.56	.15	.15
24	.15	.31	.67	.21	.33	.38	.21	.24
25	1.14	1.15	.31	1.11	.95	1.12	.90	1.24
26	.58	.69	1.60	.63	.49	.82	.88	.40
27		.03	.01		.01		.02	
28	.18	.14	.06	.13	.17	.14	.19	.32
29	.40	.67	1.06	.31	.42	.36	.80	1.24
30		.06	.04	.03	.04	.28	.08	.15
31	Tr.	.02	.01				.02	.04

[1] Gage read at 6 p. m.
[2] Measured in the afternoon.
[3] Gage read at 5 p. m.
[4] Measured in the morning.
[5] Included in the following measurement.

Precipitation records were available at only two places in the basin, Centralia and Rainbow Falls State Park (Ceres). As previously pointed out they are located in a zone of comparatively light precipitation. Several other rain gages are available outside the basin but within reasonable distances of it. (See fig. 42 and tables 17–20.) All the available gages are at altitudes below 1,500 feet; hence a computed mean cannot be considered representative of the entire area. Run-off depths for the Newaukum and Skookumchuck Rivers, tributaries of the Chehalis River, for 2 years of record greatly exceeded those for the entire Chehalis River Basin above Grand Mound for the same period, which indicates that the eastern part of the basin has a much higher precipitation than the basin as a whole, a difference nor disclosed by the limited number of available precipitation records in the basin. Therefore, neither the method of perpendicular bisectors nor the method developed for computing mean areal precipitation in the Puyallup River Basin can be applied to the Chehalis Basin because of lack of gages at the higher altitudes and lack of contour maps for a part of the basin.

TABLE 18.—*Precipitation, in inches, for stations in or near the Chehalis River Basin for storm of January 1934*

[Measured in afternoon]

1934	Centralia [1] (altitude, 182 feet)	Rainbow falls State Park (Ceres) [2] (altitude, 212 feet)	Cathlamet [2] (altitude, 470 feet)	Castle Rock [2] (altitude, 120 feet)	Headworks [3] (altitude, 985 feet)	Mayfield [4] (altitude, 600 feet)	Oakville [1] (altitude, 85 feet)	Brooklyn [2] (altitude, 180 feet)
Jan. 15	Tr.	Tr.		0.03	0.06		0.50	0.11
16	0.53	0.63	0.75	.91	.81	0.36	.75	1.00
17	.03	.08	.39	.05	.17	.43	.10	.04
18	.08	.05	.09	.12	.01		.16	.12
19	1.15	.90	2.09	1.45	1.28	1.03	1.46	2.65
20	.48	.49	.78	.77	.36	1.38	.60	1.75
21	.82	.66	(5)	1.32	.38	.53	.88	1.32
22	1.27	.80	4.77	1.40	1.19	.84	1.98	2.72
23	.48	.34	.79	1.05	.59	1.15	.37	.04
24	.17					.96		.46
25		.18	.50	.43	.44	.37	.42	.72
26		.02				.43	Tr.	
27								
28								
29								
30	.02	.03	.48	Tr.	.03		.04	.28

[1] Gage read at 6 p. m.
[2] Measured in the afternoon.
[3] Gage read at 5 p. m.
[4] Measured in the morning.
[5] Included in the following measurement.

TABLE 19.—*Precipitation, in inches, for stations in or near the Chehalis River Basin for storm of December 1937–January 1938*

1937–38	Centralia [1] (altitude 182 feet)	Rainbow Falls State Park (Ceres) [2] (altitude 212 feet)	Cathlamet [2] (altitude 470 feet)	Castle Rock [2] (altitude 120 feet)	Headworks [3] (altitude 985 feet)	Oakville [4] (altitude 85 feet)	Brooklyn [2] (altitude 180 feet)	Mineral [5] (altitude 1,440 feet)
Dec. 15	0.13	0.23		0.02	0.15	0.86	0.30	0.26
16	.82	.88		1.39	.68	.75	1.43	1.36
17	.47	.56		.62	.49	.02	1.13	.86
18						.03	.01	
19							.02	
20							Tr.	
21				.02		.14	.02	
22	.27	.13		.07	.51		.23	(6)
23	.03	.06		.13	.90	.43	.10	.41
24	.63	.37		1.01	.45	.32	.73	(6)
25	.35	.58		.34	.27	1.57	.86	(6)
26	2.10	1.40		2.40	2.35	.99	2.34	(6)
27	1.48	1.72		2.17	1.65	3.17	1.43	(6)
28	1.83	2.06		1.56	1.65	1.38	3.14	(6)
29	.24	.31		1.05	.30	.55	.64	(6)
30	.30	.44		.47	.71	.14	.56	(6)
31	Tr.	.04				.16	.17	13.0
Jan. 1							.09	
2				Tr.	.01		.01	
3							.08	
4				.02			.01	

[1] Gage read at 6 p. m.
[2] Measured in the afternoon.
[3] Gage read at 5 p. m.
[4] Gage read at 8 a. m.
[5] Measured in the morning.
[6] Included in the following measurement.

TABLE 20.—*Precipitation, in inches, for stations in or near the Chehalis River Basin for storm of April 1938*

1938	Centralia [1] (altitude 182 feet)	Rainbow Falls State Park (Ceres) [2] (altitude 212 feet)	Cathlamet [2] (altitude 470 feet)	Castle Rock [2] (altitude 120 feet)	Headworks [3] (altitude 985 feet)	Oakville [4] (altitude 85 feet)	Brooklyn [2] (altitude 180 feet)	Mineral [5] (altitude 1,440 feet
Apr. 10						0.07	Tr.	0.01
11	0.31	0.23	0.41	0.25	0.04	.08	0.13	.04
12	.14	.03	.08	.30			.05	.13
13	.01				.03			
14						.27		
15	.13	.60	1.89	.26	.01	.73	1.11	.49
16	.34	.42	.68	.70	.29	1.03	.87	1.25
17	1.11	1.24	(6)	1.83	.72	1.14	2.43	
18	.30	.45	4.21	.29	.53	.02	.61	
19	.01				.05			
20								
21						.17		2.05
22	.22		.16				.13	
23	.01				Tr.		.02	
24	.05	.08		Tr.	.03	.01		
25					Tr.			

[1] Gage read at 6 p. m.
[2] Measured in the afternoon.
[3] Gage read at 5 p. m.
[4] Gage read at 8 a. m.
[5] Measured in the morning.
[6] Included in the following measurement.

COMPARISON OF THE VALLEY PART OF THE PUYALLUP RIVER WITH THE CHEHALIS RIVER

Because of lack of precipitation data in the Chehalis River Basin satisfactory comparisons between it and the valley part of the Puyallup River Basin cannot be made. However, precipitation at one place in each basin at comparable altitudes can be used as an index of the relative amount in each basin. Precipitation as shown in table 21 is that recorded at Puyallup in the valley part of the Puyallup Basin and at Centralia in the Chehalis Basin.

TABLE 21.—*Precipitation, direct runoff, and maximum discharge for the valley part of the Puyallup River Basin and the Chehalis River Basin*

[Precipitation indicated for valley part of Puyallup River Basin was measured at Puyallup; that for Chehalis River Basin was measured at Centralia]

Flood period	Valley part of Puyallup River Basin	Chahelis River Basin
Dec. 5–31, 1933:		
Precipitation..........inches..	19.32	21.49
Runoff..........do....	15.26	19.22
Maximum discharge [1]..........second-feet per square mile..	58.9	49.0
Jan. 17–30, 1934:		
Precipitation..........inches..	6.11	5.03
Runoff..........do....	3.38	3.53
Maximum discharge [1]..........second-feet per square mile..	34.7	27.5
Dec. 25, 1937, to Jan. 4, 1938:		
Precipitation..........inches..	5.67	6.96
Runoff..........do....	2.77	6.60
Maximum discharge [2]..........second-feet per square mile..	26.2	51.4
Apr. 15–25, 1938:		
Precipitation..........inches..	2.55	2.17
Runoff..........do....	2.34	1.56
Maximum discharge [2]..........second-feet per square mile..	39.4	13.9

[1] Maximum for 8-hour period. [2] Maximum for 6-hour period.

As Centralia and Puyallup are at about the same altitude, the precipitation records at those cities for the same storms should be comparable. The fact that Centralia has greater precipitation at times than Puyallup does not necessarily mean that the precipitation of the Chehalis River Basin is greater than that of the valley part of the Puyallup River, which reaches much higher altitudes and probably has a higher mean altitude. It is significant that for each flood analyzed the ratio of the maximum rate of discharge per square mile to the depth of runoff in inches was greater for the valley part of the Puyallup River Basin than for the Chehalis, which indicates that the valley part of the Puyallup River has characteristics favorable for greater concentration of discharge. This probably is due to its smaller area and steeper slopes.

Flood runoff during the period December 5–31, 1933, was somewhat greater in the Chehalis Basin than in the valley part of the Puyallup Basin. The individual records of precipitation in and near the two areas show that precipitation probably was greater in the Chehalis

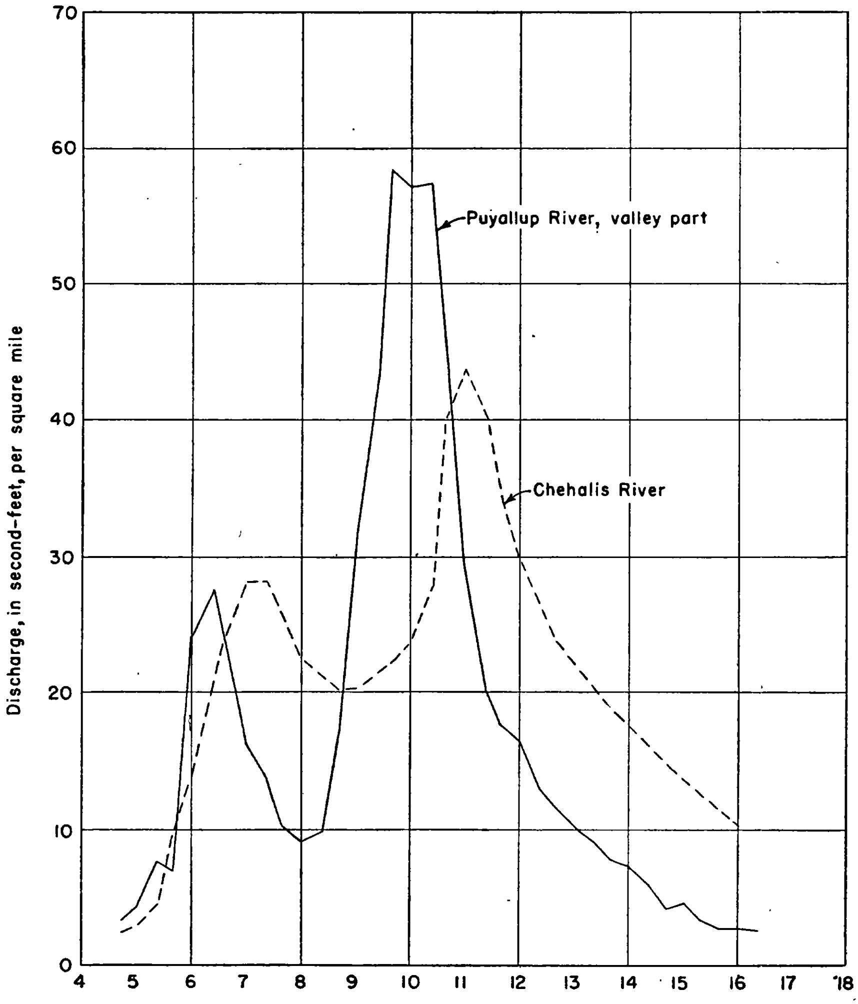

FIGURE 43.—Graph of discharge for the valley part of the Puyallup River Basin and the Chehalis River for flood of December 5–16, 1933.

Basin: Centralia (altitude, 182 feet) had about 10 percent more than Puyallup (altitude, 100 feet); Mayfield, within 10 miles of the Chehalis Basin (altitude, 600 feet), had about 20 percent more than Buckley (altitude, 685 feet). Furthermore, unusually high precipitation during December 1933 at Cougar, Naselle, Wynoochee Oxbow, and Cento, all in the southern part of the region, seems to indicate that the storm center was nearer to Centralia than to Puyallup.

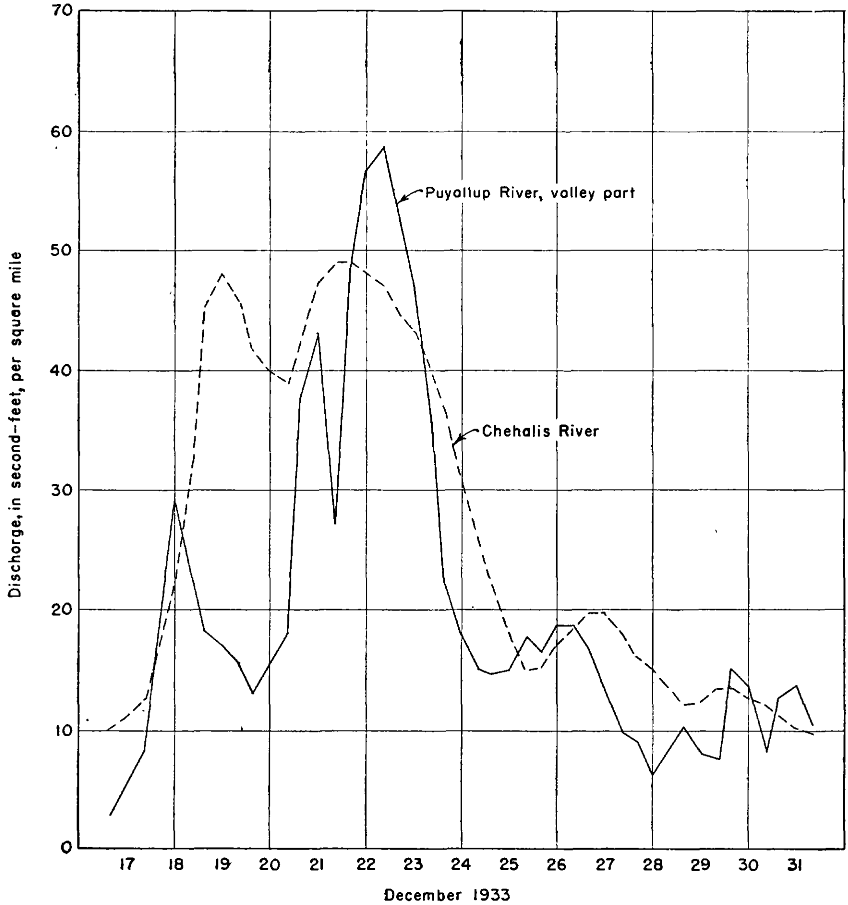

FIGURE 44.—Graph of discharge for the valley part of the Puyallup River Basin and the Chehalis River for flood of December 17–31, 1933.

Flood runoff during the period January 17–30, 1934, again was greater in the Chehalis Basin, but evidence indicating greater precipitation in the Chehalis Basin during this period is not conclusive; Centralia had slightly less that Puyallup, but Mayfield had about 20 percent more than Buckley.

During the period December 25, 1937, to January 4, 1938, precipitation in the Chehalis Basin greatly exceeded that for the valley part of the Puyallup Basin; it was nearly 7 inches at Centralia as compared with less than 6 inches at Puyallup, and more than 13 inches at Mineral, within 15 miles of the eastern watershed of the Chehalis Basin at an altitude of 1,440 feet, as compared with 6 inches at Carbon River Entrance at a much higher altitude. A considerable amount of

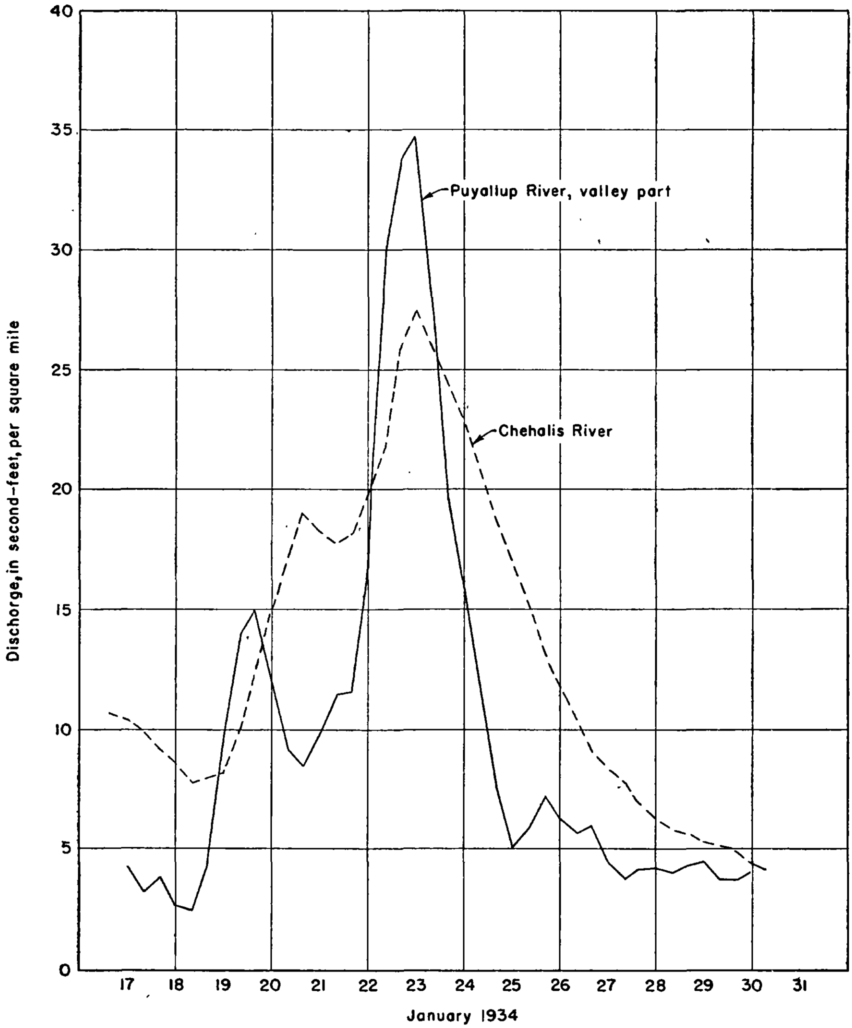

FIGURE 45.—Graph of discharge for the valley part of the Puyallup River Basin and the Chehalis River for flood of January 1934.

snow storage at the higher altitudes of the valley part of the Puyallup River Basin was retained during the flood.

During the period April 15–25, 1938, precipitation in the Chehalis Basin was somewhat less than in the Puyallup Basin; Centralia had about 15 percent less than Puyallup, and Mineral about 25 percent less than Carbon River Entrance. In addition, there was some snow melt in the upper reaches ot the valley part of the Puyallup River.

According to available records, precipitation during January 1934 was about the same in both basins, and the resulting runoff differed

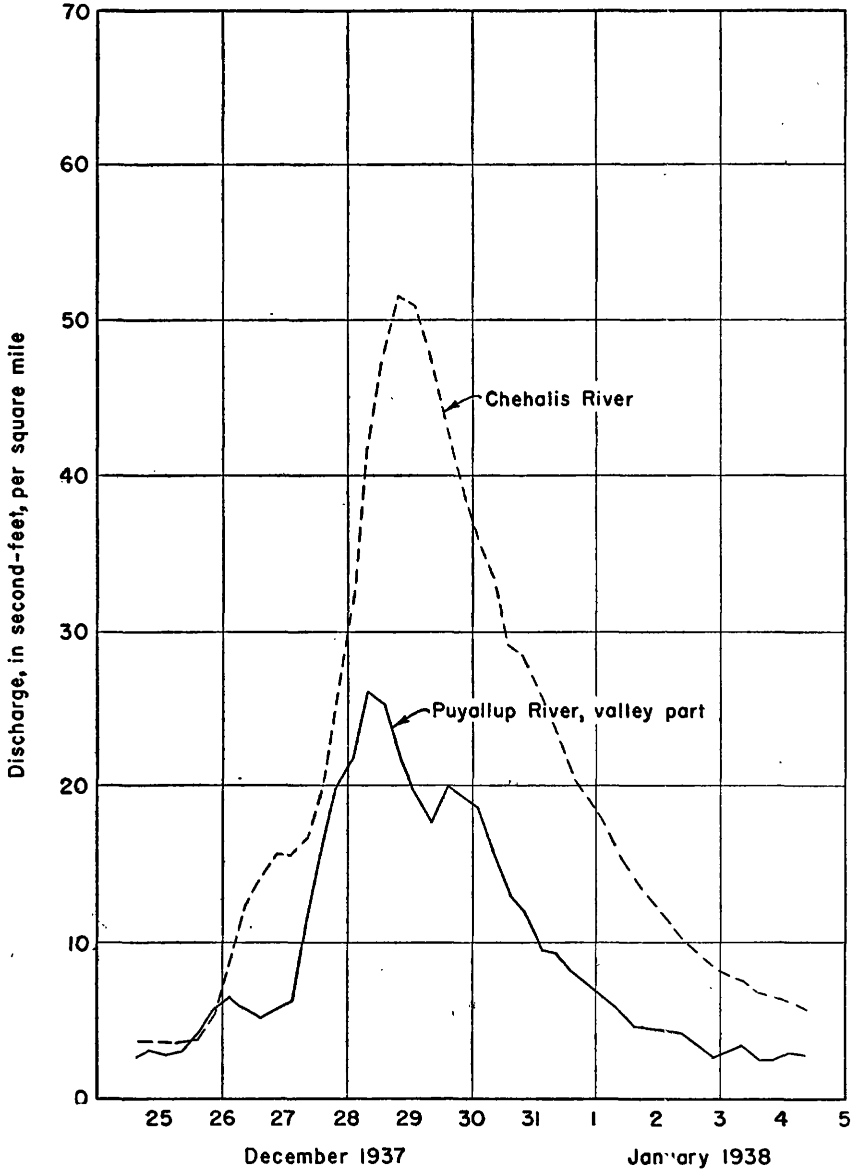

FIGURE 46.—Graph of discharge for the valley part of the Puyallup River Basin and the Chehalis River for flood of December-January 1937-38.

by less than 5 percent, indicating that runoff characteristics in the two basins are about the same. In general the difference in direct runoff between the two areas is not greater than can be explained by indicated differences in precipitation. Discharge graphs for the two basins are shown in figures 43–47.

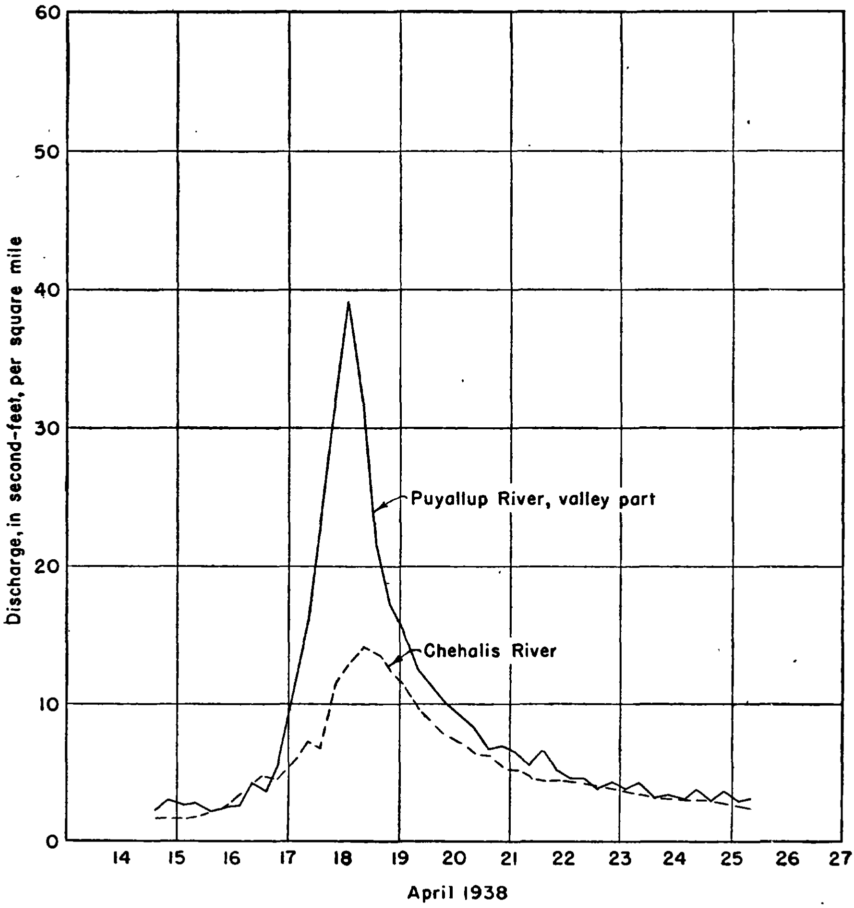

FIGURE 47.—Graph of discharge for the valley part of the Puyallup River Basin and the Chehalis River for flood of April 1938.

CONCLUSION

Precipitation records in western Washington are inadequate both in number and in distribution. Even in the Puyallup River Basin, where the distribution of gages is more adequate than for the region as a whole, this investigation has shown that more gages are desirable. Moreover, there is need for additional measurements of snow cover and its water density.

The computed means of precipitation for the area are probably fairly accurate, as is evidenced by the general consistency between rainfall and associated direct runoff for the upper Puyallup and Carbon Rivers, which drain adjoining areas with similar physical characteristics. Even with inadequate precipitation records, differences in runoff from separate basins can be accounted for by comparison of individual records obtained in those basins under similar conditions, especially in regard to altitude. Sometimes it may be possible to establish comparisons of runoff characteristics between two basins even if fairly satisfactory records of precipitation are available in only one of the areas. Such comparisons are, of course, not definite but they do furnish an index of possible flood behavior. Comparisons of this kind made between the Chehalis River Basin and the valley part of the Puyallup River Basin, indicate that characteristics of the two are not far different.

The comparison of rainfall and associated direct runoff in the Puyallup River Basin indicates that in this region differences in physical characteristics of mountainous and valley areas exert very little influence on resulting flood runoff as compared to differences in precipitation. This result is, of course, affected somewhat by the fact that definite and accurate segregation of the mountainous and valley parts was not possible.

This investigation has shown that the exposure of the drainage areas in western Washington to the prevailing moisture-laden winds tends to cause greater precipitation and consequent runoff. This effect has been shown by comparison of rainfall and runoff for the White River Basin, in the rain shadow of Mount Rainier, with other streams rising on that peak. Contrary to widespread opinion, Mount Rainier frequently acts as an influence tending to reduce flood runoff in the lower Puyallup River Basin.

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