UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

Water-Supply Paper 968

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES 1944

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ILLUSTRATIONS

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FLOOD RUNOFF IN THE WILLAMETTE VALLEY, OREG.

BY
M. D. BRANDS

Contributions to the hydrology of the United States, 1944
(Pages 1-60)

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FLOOD RUNOFF IN THE WILLAMETTE VALLEY, OREGON

By M. D. Brands

ABSTRACT

A study of flood runoff in the Willamette Valley, Oreg., is significant because of the peculiarities of the climate in relation to floods. The Willamette Valley is included within the region extending from northern California to Canada and lying between the Cascade Range and the Pacific Ocean, the only area in the continental United States where the climate is characterized by heavy rains in winter and droughts in summer. Owing to the definite division of the seasons into wet and dry, floods occur only during the period November to April. During these months, discharges of streams are generally high because of the fairly constant rains, and floods may come at any time. Normal soil conditions are conducive to excessive runoff during this period. Because of the lack of rainfall combined with the resulting depletion of soil moisture, the possibility of floods during the summer, June to October, is so remote that it may be disregarded.

In the Willamette Basin the characteristics of the climate cause quite frequent floods. The frequent occurrence of floods enlarges the stream channels sufficiently to carry off the average floods that cause only minor damage to the farms towns, and cities in the river valley. Extraordinary floods, however, may inundate large areas of farm and pasture land as well as many towns and cities. The greatest floods known in the Willamette Valley occurred in 1813, 1844, 1861, 1881, 1890, 1909, and 1923. Of the floods of 1813 and 1844 little information is available except as noted under History of floods prior to 1861 (pp. 10–13). The flood of 1861, the greatest since the Oregon country was settled by white men, was caused by a storm, which centered over the valley at a time when conditions were especially favorable to excessive runoff.

The flood of January 1923, the most recent of the large floods, was caused by rain which fell almost continuously on the Willamette Valley from December 22 to January 19. The average precipitation on the drainage area above Salem (7,280 square miles) totaled 21.1 inches for this period. It has been estimated that there was 14.6 inches of runoff at Salem associated with this storm. Runoff from snow covering the high mountain areas did not materially affect the crest discharge or the total flood runoff.

In western Oregon the greatest recorded runoff associated with a single flood occurred in December 1933 on the Wilson River, the drainage basin of which is adjacent to the Willamette Valley, but which flows directly into the Pacific Ocean. The direct runoff at the gaging station near Tillamook was 26.7 inches for the 11-day flood period, December 17–27, inclusive. Excessive runoff is to be expected in this area where monthly precipitation totals greater than 50 inches have been recorded.

To determine the relative effects of snow and rain on floods in the Willamette Valley the discharge from the entire basin was divided into two parts, one in which rainfall was the sole factor producing flood runoff, the other in which both rain

and snow affected runoff. Unit hydrographs were defined from flood discharges for the part of the basin solely affected by rain. For that part from which runoff from snow is an important factor, various relations between temperature, altitude, and snow runoff were determined. The great variability of these relations prohibited their exact evaluation, but the study of the underlying relations was made to determine the probable effects of given snow conditions on flood runoff

INTRODUCTION

The Willamette River and its tributaries, draining 11,200 square miles, form a part of the Columbia River Basin, joining the Columbia 99 miles above its mouth. In the basin drained by the Willamette River are most of the industries and population of Oregon; in fact, approximately 60 percent of its total population live in only 12 percent of the area of the entire State. The principal city, Portland, is on the Willamette River about 12 miles above its mouth, and many smaller cities are situated close to the river in the upper part of the basin. The Willamette Valley also supports a large farm population and produces many valuable crops.

This study was made primarily because of the interest in the control of floods in the Willamette Valley and the need for general information about flood characteristics on the main river and tributaries. The Corps of Engineers, United States Army, for several years has been investigating a multiple-purpose development of the basin for flood control, navigation, water-power, irrigation, and stream purification. The initial coordinated plan, called the Willamette Valley project, includes seven storage reservoirs in the foothills on the Coast Fork of the Willamette, on the Row, Long Tom, North Santiam, and South Santiam Rivers, on the Middle Fork of the Willamette River, and on the McKenzie River. Construction of the first four of the reservoirs named above was initiated by funds from an appropriation by Congress for the fiscal year 1940. This report presents information relating to the larger known floods and results of detailed analyses of floods of more recent date for which more data, particularly records obtained with water-stage recorders, are available. Information recently obtained on large floods prior to 1861 by the Corps of Engineers, Portland District, has been included to show comparison of these early floods with major floods of record. (See pp. 10–13.)

All available rainfall and runoff data were assembled for a study of their relation, and the influence of snow on this relation was investigated. A study of the runoff of the valley also was made, using the principles of the unit-hydrograph, which led to a study of the volume of storage in the stream channels. Factors affecting precipitation have been discussed to give a fuller understanding of the storm characteristics of the Willamette Valley and western Oregon.

ACKNOWLEDGMENTS

This report was prepared as a part of the surface-water investigations in Oregon under the direction of G. H. Canfield, district engineer, Portland, Oreg., under an allotment to the Geological Survey by the Public Works Administration for surveys of floods and droughts. The assembly of the basic data, and the preparation of this report, was done by M. D. Brands with the assistance of others in the district office of the United States Geological Survey at Portland. The report was reviewed and prepared for publication by the Division of Water Utilization, R. W. Davenport, Chief.

A report [1] on the Willamette River and tributaries by the North Pacific Division of the Corps of Engineers, United States Army, furnished general information on past floods and some detailed information as to areas inundated by these floods. All rainfall and temperature data were furnished by the United States Weather Bureau, Portland, Oreg., and the description of the 1861 flood was largely obtained from unpublished reports in the files of that Bureau. Oregon State College at Corvallis, Oreg., supplied the continuous record of rainfall at Corvallis.

Wherever special data have been used, individual acknowledgments are given at appropriate places in the report.

TOPOGRAPHY

The Willamette River Basin, in the northwestern part of the State of Oregon, is bounded on the west by the Coast Range, on the east by the Cascade Range, and on the south by the Calapooya Mountains. The northern part merges with the Columbia River Valley near Portland. Figure 1 shows the location of the Willamette Valley in relation to adjoining drainage basins.

The Cascade Range is the predominant topographic feature of Oregon, extending across the State and closely following the meridian of 122° W. It is cut only by the Columbia River gorge. On their western slope the Cascade Mountains are dissected by many deep valleys formed by glaciers and streams flowing down the precipitous slopes. Some of the valleys are as much as 1,000 feet deep, and in these the tributaries of the Willamette River flow towards the relatively level valley floor. The summit of the range is generally about 5,000 feet above sea level, with some of the lowest passes about 4,000 feet. At varying intervals along that part of the range forming the divide of the Willamette Basin are many perenially snow-capped peaks. Named in order from north to south, with their altitudes, these peaks are: Mount Hood, 11,253 feet; Mount Jefferson, 10,495 feet; Three

[1] Willamette River, Oreg., 72d Cong., 1st Sess., H. Doc. 263.

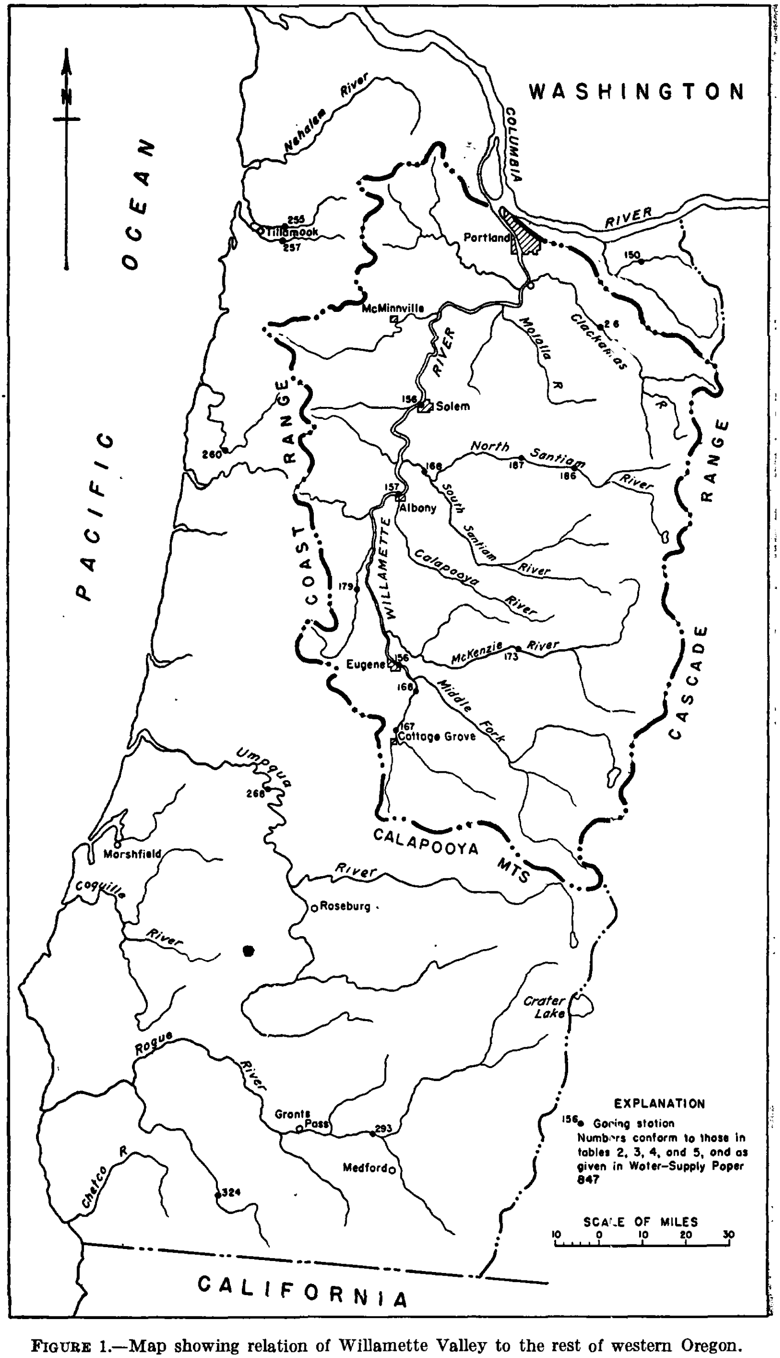

FIGURE 1.—Map showing relation of Willamette Valley to the rest of western Oregon.

Fingered Jack, 7,848 feet; North Sister, 10,094 feet; Middle Sister, 10,053 feet; South Sister, 10,354 feet; Broken Top, 9,165 feet; and Diamond Peak, 8,750 feet. These mountains form a discontinuous alpine zone, the runoff from which materially increases the summer flow of streams rising on their slopes. Between the valley floor and the main ridge of the Cascade Range is a belt of geologically mature foothills. These form a belt, averaging 25 miles wide, through which the streams must pass to reach the main river. The western slope of the Cascade Range, including the foothills, comprises 60 percent of the area of the Willamette Basin.

The Coast Range, the western boundary of the basin, obstructs the moisture-laden winds from the Pacific Ocean, but as the mountains are comparatively low, large quantities of moisture pass over them to the Willamette Basin. The summit of the range, which is generally less than 2,000 feet in altitude, winds northward in a sinuous line, marked here and there with a few peaks, of which the highest is Marys Peak, elevation, 4,100 feet. The slopes of the Coast Range have been deeply eroded by the streams that carry off the heavy precipitation of the region. The valleys are closely spaced, and the mountains approach the valley floor in a succession of ridges.

The Calapooya Mountains, a group of low hills on the southern boundary of the basin, divide the Willamette River drainage from that of the Umpqua River just to the south. Similarly, mountainous regions, interspersed with small valleys, extend southward through Oregon into northern California. The streams rising from the Calapooya Mountains are like those on the east slope of the Coast Range; they discharge a great quantity of water in the winter, but their summer flow is small.

The floor of the Willamette Valley between these mountain ranges is generally flat, sloping gently toward the mouth of the river. On it is the principal agricultural land of the basin. Several hills rise out of the comparatively level floor, but none of these is more than a few hundred feet high. Most of the good agricultural land has been built up as alluvial deposit by the river in its frequent floods. A considerable area adjacent to the river, which has established a temporary base level, caused by the rock ledge at the falls of Oregon City, is subject to inundation every few years. The main channel follows a meandering course along the valley floor, with many ox bows, sloughs, and overflow channels, such as are common to rivers flowing in alluvial valleys. This area, comprising 30 percent of the basin, needs protection from floods.

Figure 2 shows the relative areas of mountains and lowlands in the Willamette Basin.

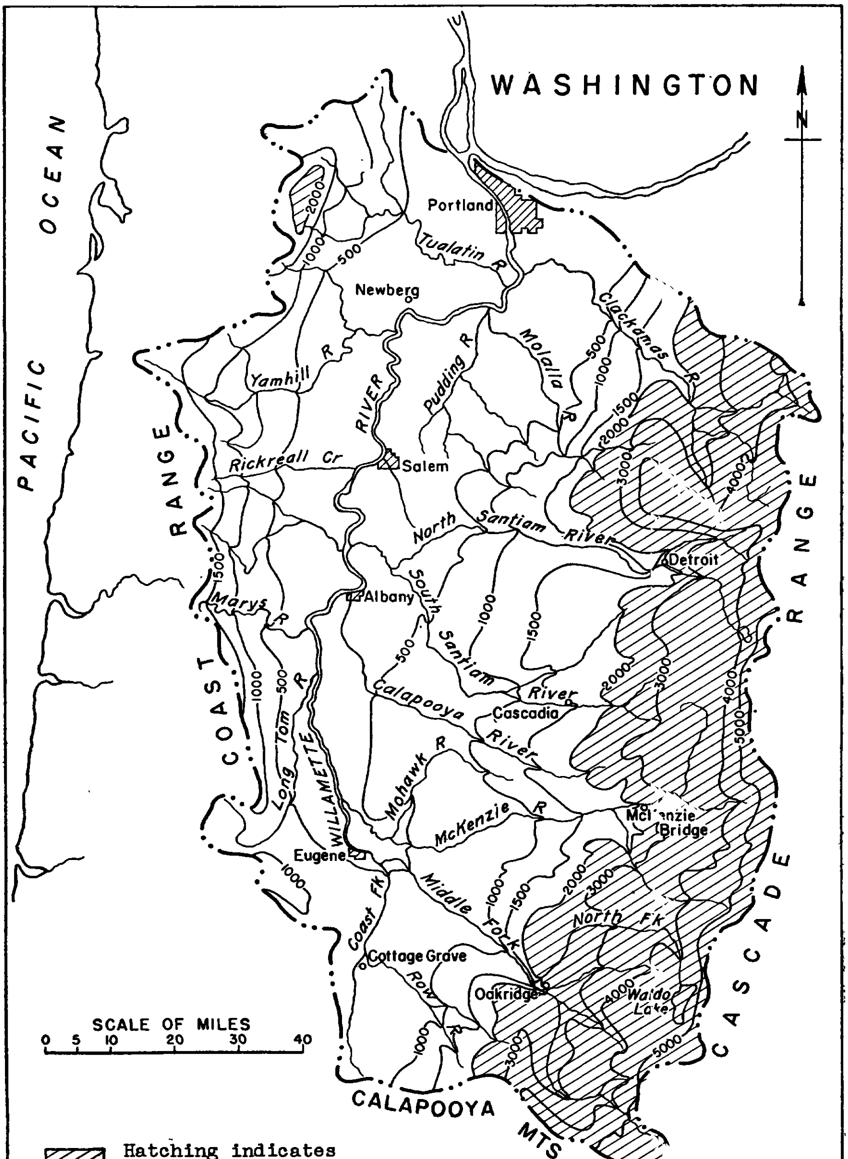

FIGURE 2.—Contour map of Willamette Valley.

Formerly the Willamette Basin was almost entirely forest covered. The only exceptions were open spaces called "prairies," in the lower valley. However, the first settlers cleared the valley floor for farming, and in later years loggers deforested many of the foothills. At present, forest land, most of it in the upper part of the tributary basins, comprises 7,800 square miles of the 11,200 square miles of the basin.

The Middle Fork of the Willamette River rises at an altitude of about 6,000 feet in a small unnamed lake, which is in the southeastern corner of the basin near the summit of the Cascade Range. It flows northwestward, and near Eugene it joins the Coast Fork of the Willamette River to form the main Willamette River, from where it meanders along the valley a distance of 180 miles to its junction with the Columbia River near Portland. The Middle Fork drops 5,600 feet from its source to its junction with the Coast Fork, a distance of about 90 miles. Similarly, steep slopes are characteristic of the principal tributaries rising in the Cascade Range. In the 180 miles from Eugene to the mouth, the Willamette River falls about 400 feet, the drop occurring largely in riffles between long stretches of slack water. The streams rising in the Coast Range and flowing into the main stream from the west are short and discharge large quantities of water only during the rainy season. They flow in winding channels across the valley floor before they reach the main river.

The principal tributaries below the junction of the Middle Fork and Coast Fork are the McKenzie, Santiam, Molalla, and Clackamas Rivers, which rise in the Cascade Range, generally at altitudes around 5,000 feet, flow to the valley floor in a series of rapids and falls, and meander along the valley for a few miles before reaching the main stream. The Long Tom, Marys, Luckiamute, Yamhill, and Tualatin Rivers, which are the tributaries from the east slope of the Coast Range, flow into the Willamette River from the west.

CLIMATE

The Willamette Valley has an equable climate, free from extremes of temperature, with cloudy, wet winters, and clear, dry summers. The Coast Range shelters the valley from the ocean winds, giving it a climate materially different from that of the coastal area. On the valley floor average annual precipitation (most in form of rain) is 40 inches. The annual precipitation along the summit of the Coast Range is about 100 to 150 inches, decreasing rapidly as the valley floor is approached. The foothills of the Cascade Range receive heavy precipitation on some of the south and west slopes, amounting to more than 100 inches per year with a possible maximum of 150 inches on small areas. Large variations in precipitation occur over small areas in the Willamette Valley because of changes in land elevation and exposure to the storms. The heaviest precipitation shown on figure 3 has been estimated partly from stream runoff data, as rainfall stations are not sufficiently numerous to determine all the local areas of intense precipitation. However, along the length of

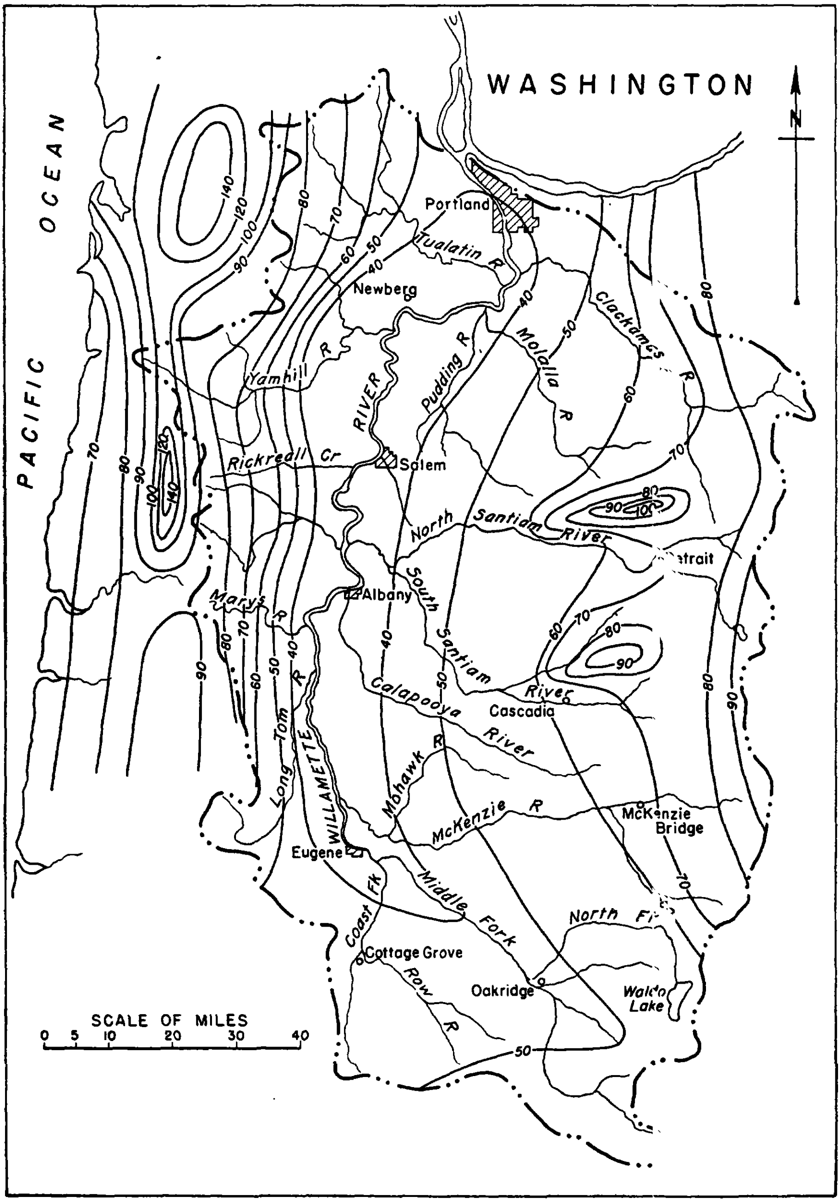

FIGURE 3.—Isohyetal map of the Willamette Valley showing mean annual precipitation, in inches.

the valley the precipitation tends to increase up the slope of the main Cascade Range reaching about 90 inches annually near the summit. A large percentage of precipitation above 2,000 feet altitude is snow, of which some 200 to 300 inches falls every winter. Below 4,000 feet the snowfall may be reduced by winter thaws due to warm "chinook" winds and usually is all melted by May 1; above that altitude, snow accumulates all winter, and its melting, through surface or underground runoff, tends to sustain the flow of tributary streams through the summer.

That part of Oregon west of the Cascade Mountains has a Mediterranean-type climate [2] characterized by dry summers and wet winters. In winter, the season when most of the yearly rainfall occurs, Oregon is in the path of the westerly winds with their rain-bringing cyclones, and during these rainstorms, being on the southern edge of this zone, it has winds that are usually from the southwest. In summer, the more direct incidence of the sun's rays brings Oregon within the effect of the drought-producing, subtropical high-pressure zones, and at this season very little rain falls. Because of the high latitude of this area, approximately 45° N. at Salem, the summers, with a normal July temperature of 65°, are considerably cooler than are those of most Mediterranean-type climates of latitudes between 30° and 40°.

Ordinarily, 95 percent of the total yearly precipitation occurs during fall, winter, and spring. Frequently no rainfall occurs for periods of from 60 to 90 days in summer, when river discharge becomes very low, the lowest flow recorded at Salem being 2,470 second-feet (0.34 second-feet per square mile). The storms producing most precipitation may occur at any time from November to April. Cyclonic storms coming from the west are forced over the Coast Range and then over the Cascade Range, orographically producing heavy rains, which can continue for 1 to 2 or 3 weeks. The steep gradients of their channels to the valley floor cause flashy runoff in most of the tributary streams of the basin. The rainfall usually comes when the ground is well saturated and the humidity high and consequently has a large percent of runoff. Figure 4 illustrates the seasonal characteristics of the rainfall at some typical valley stations. Figure 5 indicates the variation in mean annual runoff of various Oregon rivers both east and west of the Cascade Range.

Variations in temperature during the year are not great; the normal minimum January temperature in the valley generally is between 31° and 34° F. Some freezing weather occurs every winter but does not last long. On the valley floor, in the foothills, and in the Coast Range rarely is it cold enough for snow to last for more than a few days. It is only at the higher altitudes in the Cascade Range that snow accumulates through the winter. In the valley the normal maximum temperature in July ranges from 78° to 84° F., although maximum daily temperatures as high as 100° F. have been recorded at most of

[2] Trewartha, Glenn T., Introduction to Weather and Climate, Appendix A, pl. 2, p. 360, McGraw-Hill Book Co., Inc., 1937.

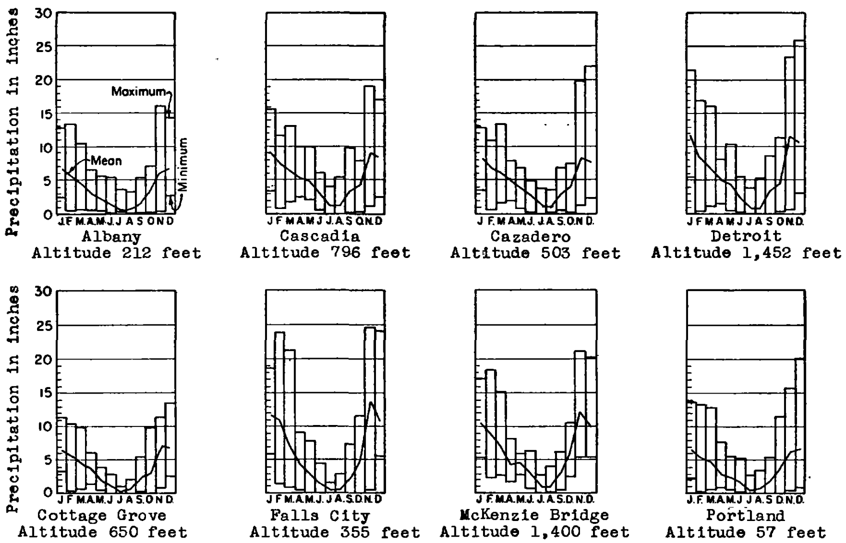

FIGURE 4.—Monthly precipitation, in inches, at representative cities in the Willamette Valley.

the stations there. The highest temperatures are caused by winds from east of the Cascade Range which bring warm air that is further heated by subsidence. The ocean, however, tends to moderate the climate of the valley at all times.

HISTORY OF FLOODS PRIOR TO 1861

The first Americans to visit the Willamette Valley were Lewis and Clark in 1805 on their memorable trip of exploration overland from the Mississippi Valley. They spent the winter of 1805–06 near the mouth of the Columbia River, some 70 to 80 miles to the west of the Willamette River and out of the Willamette Valley proper.

In 1811 the settlement of Astoria was made, fur trappers were sent out from Astoria to cover most of the Oregon country, as it was then known, including the present States of Oregon, Washington, Idaho, and part of the territory of British Columbia, in Canada. Most of the early history of the Willamette Valley has been obtained from the records of those trappers.

A rather complete study of the early history of the Willamette Valley, with special reference to floods has been made by Muldrow,[3] a substantial part of which is quoted as follows:

In December, 1813, Alexander Henry arrived as chief factor for the Northwest Fur Co. From his journal we get the first mention of a flood of Willamette River. On January 24, 1814, he paid a visit to the Henry House above Champoeg to look for a site on higher ground because, as his journal relates, "the present

[3] Muldrow, W. C., Early floods of Willamette River, Oregon (manuscript report in files of Corps of Engineers, U. S. Army.)

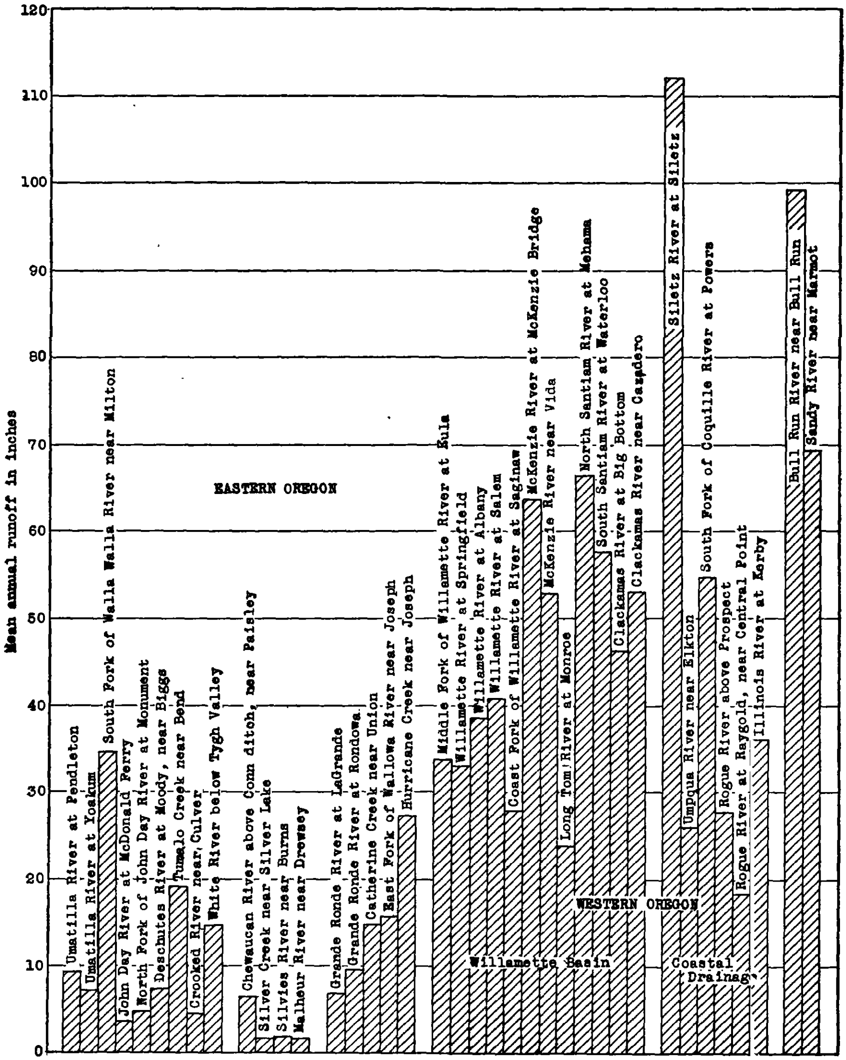

FIGURE 5.—Mean annual runoff, in inches, of selected streams in Oregon.

situation is overflowed at high water, altho' its level above low water is between 30 and 40 feet." His guess was poor; the location of this house is definitely known and it is some 52 feet above low water. The flood of 1861 covered it some 15 feet, but the house stood. It was finally pulled down in 1872. Factor Henry described the site as open grass-covered prairie. We have many accounts proving that a large part of Willamette Valley before settlement was treeless prairie.

William Henry, who built this house, was a Northwest Fur Co. man and a cousin of Factor Alexander Henry. The purpose of Factor Henry's visit indicates that this site was flooded in the fall of 1813, shortly before Factor Henry's visit. Two later references will be cited to strengthen this conclusion. Knowing that

1861 and 1890 were the only recorded floods that did cover this site, we are justified in the conclusion that the flood of 1813 was at least the third flood of the century in order of magnitude. Whether it was second, or even first, will never be known unless the journals of William Henry for 1813 can be found, with some evidence of the depth of water that covered this site. In correspondence with this writer, Oliver Wendell Holmes, Curator of the National Archives in Washington, stated that Henry's journal might be in possession of William Waldorf Astor in London.

Lacking the detailed journals of the men who occupied these Willamette posts from 1813 to the coming of settlers in the 1830's, we have only general references to the Willamette floods. We find that these freshets soon became a familiar phenomenon to the trappers. They complained bitterly of parties isolated; of trap lines disrupted, with loss of traps and catch; of goods and furs lost in crossing the swollen rivers. Jason Lee, with a party, arrived in 1834 and established a Methodist Mission about one mile from the Wheatland Ferry. Already a number of French-Canadians released from the service of the Hudson's Bay Company had settled, with their Indian wives and families, on lands around Champoeg. They raised wheat and cattle, which the Company bought. Beginning about 1838, they were joined each year by a number of American settlers. Thomas McKay had built a flour mill on Champoeg Creek.

Hine's History of Oregon, 1850, contains a detailed account of a flood which occurred February 8–15, 1843. A missionary family of four, travelling by canoe, was swept over Willamette Falls and drowned. The Rev. Hines says, "The river is higher than it has been since 30 years ago." This points to the flood of 1813, substantiating Henry's reference. A miller named Canning was rescued by canoe from the upper floor of McKay's Mill just before the building collapsed. Mr. McKay built a second mill some 2 miles up Champoeg Creek. Even here the flood of 1861 came into his mill, rising 12 sacks deep on his warehoused flour. A. J. McKay, age 96, still lives near Champoeg, and remembers vividly how, as a lad of 13, he helped try to save this flour.

The following year the Rev. Geo. Gary was living at Oregon City. In his journal we find:

> "Nov. 23, 1844. We have very dark and rainy weather; have not seen the sun for a week, in fact, for five weeks we have not had 48 hours without rain. The Willamette River is very high; many sawlogs lost."
>
> "Nov. 28. We have had very high water in Willamette River; considerable damage done. Today the waters recede; fears abate. This Willamette before our window has risen probably 35 feet. Our mission store has had over two feet of water in its cellar."
>
> "Nov. 29. We hear that the river was considerably higher about thirty years ago." [Here he probably refers to the flood of 1813.]
>
> "Dec. 11. We hear that the mission has lost, in the barn at the late mission farm, some 800 bushels of wheat, the water coming in the barn."

An article in the Oregon Statesman, Salem, says that the 1844 flood was 5 feet below the 1861. An issue of the Spectator, published in Oregon City, dated December 27, 1849, says:

> "The recent heavy snows have gone off with torrents of rain and in consequence the Willamette is higher than it has been for five years." [Flood of 1844.]

The issue of January 10, 1850, under title of "The Late Freshet," tells of sawmills and warehouses being washed away at Clackamas, Tualatin and other points. It estimates the damage in Oregon City and upriver points at "but little short of

$300,000." Lang's History on Willamette Valley describes a disastrous flood of Jan. 1, 1853, which did "enormous damage" in Oregon City, Dayton, and Linn County.

So much has been written about the great flood of 1861 that it is unnecessary to go into detail here. Steamboat transportation had been established and gages were in use at all principal river points. From records and newspaper files, it has been possible to compile a fairly complete list of gage heights for all major floods at Eugene, Corvallis, Albany, Salem, and Oregon City. It was highly desirable, however, to find and to tie in enough high-water marks to produce accurate profiles of all major floods at all points along the river. In April–May 1944, a reconnaissance was carried out by the writer, accompanied by R. Jaren, Planning Section, and Henry Stewart, Hydrology Section, with this object in view. The general method was to contact old residents in each community in the flood plain, inquiring for marks of floods they had seen or which had been shown them by those now gone. Naturally the best results were found on places now occupied by descendents of early settlers. Three persons were found who had seen and remembered the flood of 1861; many who witnessed the floods of 1881 and 1890. At many points marks of 2 or more floods were found, and differences were established which permitted extension where gaps were encountered. Eight dependable marks were tied in on the 1861 flood, 5 on 1881, 30 on 1890, and 60 others on the floods of 1907, 1909, 1923, 1927, and 1943. These made possible a set of profiles on all these floods from which the lands inundated by each can be platted with reasonable accuracy for flood-damage studies.

A number of keenly interesting stories developed out of the experiences of these early settlers in those major floods, but they probably have no proper place in an engineering memorandum. Taking all the evidence into consideration, the writer would rank those major floods prior to 1861 as follows:

1813—Just below 1890; estimated about 37 feet at Salem gage.
1843—Estimated about 31 feet at Salem gage.
1844—Estimated about 34 feet at Salem gage.
1849—Estimated about 31 feet at Salem gage.
1853—Estimated about 30 feet at Salem gage.

MAJOR FLOODS OF RECORD

Floods, which in the Willamette Valley are the direct result of winter rains, occur any time from November to April, the maximum floods usually being during December, January, and February. Some minor rises have occurred mainly because of snow melting in the mountains, but these are comparably small. Storms usually come from the southwest, traveling down the valley in the direction of the flood wave, thus contributing to produce an increasing peak discharge per square mile as the flood travels downstream. In the 1861 flood, the highest on record, the estimated peak runoff at Eugene was 51 second-feet per square mile; at Albany, 70 second-feet per square mile; and at Salem, 69 second-feet per square mile. Table 1 lists maximum floods of record and the four recent floods studied in detail later in this report. Pertinent data for these floods have been included for comparison with floods in other parts of the country. Hydrographs of selected floods are shown on figure 6.

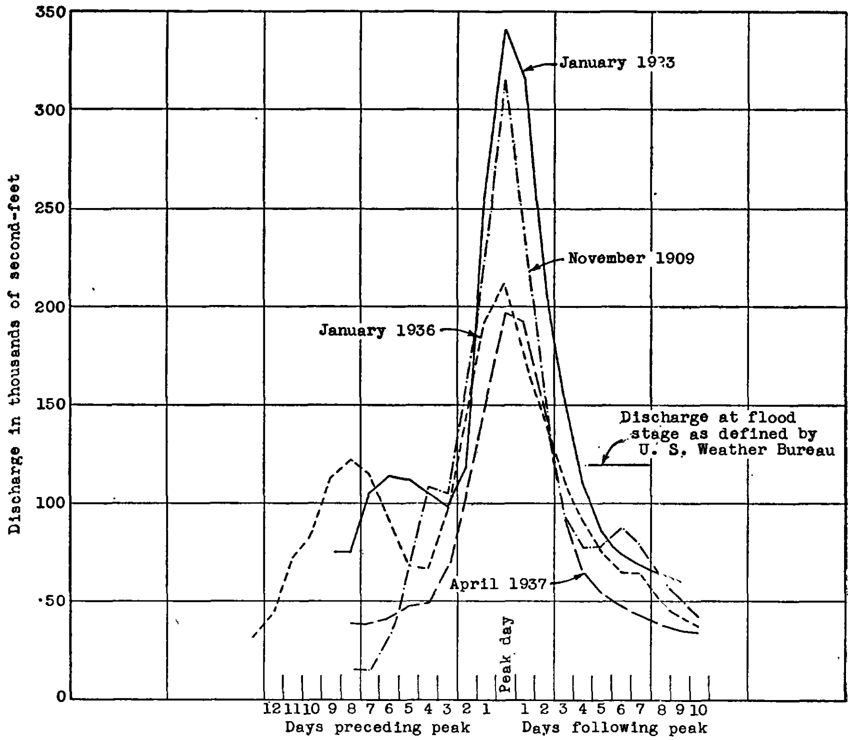

FIGURE 6.—Hydrographs of discharge of selected floods for Willamette River at Salem.

TABLE 1.—*Summary data for selected floods on the Willamette River at Salem*

Maximum floods of record

Date of peak discharge	Duration of flood period (days)	Momentary peak discharge: Second-feet	Momentary peak discharge: Second-feet per square mile	Maximum calendar-day discharge (second-feet)	Entire basin (drainage area, 7,280 sq. mi.): Precipitation (inches)	Entire basin: Direct runoff (inches)	Entire basin: Precipitation minus direct runoff (inches)	Valley floor [1] (drainage area, 4,705 sq. mi.): Precipitation (inches)	Valley floor: Direct runoff (inches)	Valley floor: Precipitation minus direct runoff (inches)
Dec. 4, 1861		[2]500,000	68.7			[2]13.0				
Feb. 4, 1890		[3]450,000	61.8		12.4					
Jan. 16, 1881		428,000	58.8							
Jan. 8, 1923	35	359,000	49.3	342,000	21.1	13.5	7.6			
Nov. 25, 1909	18	[4]315,000	41.5	315,000	10.9	8.3	2.6			
Feb. 23, 1927	19	[4]243,000	33.4	243,000	7.5	5.2	2.3			
Floods studied in this report										
Jan. 14, 1936	17	225,000	30.9	211,000	7.4	5.4	2.0	7.4	6.1	1.3
Apr. 16, 1937	11	201,000	27.6	194,000	5.1	3.6	1.5	5.0	3.8	1.2
Dec. 31, 1937	12	186,000	25.5	173,000	6.7	2.9	3.8	6.1	4.2	1.9
Mar. 20, 1938	18	145,000	19.9	142,000	8.8	4.3	4.5	9.2	6.2	3.0

[1] For definition of the valley-floor area see pp.31-32.
[2] Estimated.
[3] Willamette River and tributaries, Oregon: 75th Cong., 3d sess., H. Doc. 544, p. 49.
[4] Maximum calendar-day discharge, momentary peak discharge not recorded.

Maximum floods in the Willamette Valley are often augmented by snow melting. The southwest storms bring intense warm rains producing heavy runoff on the valley floor causing snow melting in the mountains, and thus adding to the runoff, as happened in both the 1861 and 1890 floods.

The greatest flood known, that in December 1861, came soon after founding by white men of the first settlements and has not left many traces. A report in 1890 by the Chief Signal Officer, United States Signal Service, on "The Climate of Oregon and Washington Territory," gave the following on the 1861 flood: "The November temperature was below normal during most of the month, with an excess of cloudiness which made it seem colder." At Fort Hoskins, in the central part of the basin, rainfall for November and December 1861 was 18.10 and 12.09 inches, respectively. This is 225 percent of normal for November and 140 percent for December.[4]

The above-normal precipitation combined with below-normal temperatures caused the accumulation of large quantities of snow in the mountains and produced conditions favorable for large direct runoff. The flood-producing storm, continuing from the last few days of November into the first days of December, passed over the Willamette Valley, bringing warm south winds and heavy rainfall. No daily values of rainfall are available, but the Oregon City Argus of December 14, 1861, stated "November's long and rather cold rain was succeeded during the closing days of the month by a warm, humid state of the air—rain falling in copious showers almost without intermission." The rain and melting snow produced a discharge of 500,000 second-feet and a stage of 39 feet at Salem, 19 feet above flood stage. The direct runoff from this storm has been estimated to be 13 inches over the basin above Salem. More than 350,000 acres of land were inundated by this flood. Two towns were washed away, and every town along the river was in part submerged.

In 1881 a flood occurred that was slightly lower than that in 1861. At Albany, the gage-height record of this flood was obtained but at Salem only the gage height of the peak was recorded. The peak flow at Albany was 266,000 second-feet compared with 340,000 in 1861 and that at Salem 428,000 second-feet compared with 500,000 second-feet in that year. Above Albany, the runoff directly associated with this storm, eliminating all flow due to antecedent causes, was equivalent to 7.7 inches over the drainage basin. As no precipitation records were obtained, the rainfall-runoff relation could not be studied. This flood caused a great deal of damage. The annual report of the Chief of Engineers, United States Army, for 1881, states that drift accumulated along the river was augmented by

[4] U. S. Weather Bur. Summaries of Climatological Data by Sections, Bulletin W, section 17, p. 4, 1912.

many trees 100 to 200 feet long that had been uprooted in the tornado of January 9, 1880. These formed huge rafts, extending from bank to bank, which swept everything before them as they floated away.

Because the second largest flood known, that of January and February 1890, occurred during a break in the gage-height record at Albany, there is no record of daily discharge. The maximum gage height taken from high-water marks at Albany was 33.9 feet, discharge 291,000 second-feet, and that at Salem, gage height 37.1 feet, discharge 450,000 second-feet. From records of the United States Signal Service for eight stations in the Willamette Valley, the average rainfall in the period January 26 to February 3, was 12.4 inches, probably considerably less than the average for the basin because only one of the eight stations was in the mountain area. A telegram from Eugene on January 29, 1890, as contained in the United States Signal Service report of 1890, stated: "A very heavy rain has been falling all day and evening; a chinook melting the snows in the mountains all around the heads of the valleys. Indications point to very high water." The peak of this flood, at Albany, was sometime on February 4; that at Salem, on the afternoon of the same day, and that at Portland, at 5 p. m. on February 5. At Portland this flood was 28.7 feet above low water and slightly higher than the flood of 1861, although at Salem and Albany it was about 2 feet lower than in 1861.

The flood of January 1923 is the largest of the last 30 years, going above bankfull stage at Salem by 14½ feet with a peak discharge of 359,000 second-feet. A detailed analysis of this flood has been included in a subsequent part of this report. (See pp. 28–31.)

A flood-frequency curve [5] based on the maximum annual peak discharges at Salem for the periods 1895–1916 and 1928–38 is presented on figure 7. Past experience as embodied in this curve shows that a flood of the magnitude of that of 1861 might be equalled or exceeded about once in 500 years, and one the size of the 1923 flood, about once in 50 years. Because of the shortness of the record these results are more suggestive than accurate as indications of the flood frequencies to be expected. At Salem a stage of 20 feet, discharge 162,000 second-feet, can be expected to be equalled or exceeded every 2 years, and at that stage the Corps of Engineers, United States Army, has estimated that 26,900 acres of farm land would be under water.

[5] Jarvis, C. S., and others, Floods in the United States, magnitude and frequency: U. S. Geol. Survey Water-Supply Paper 771, p. 70, 1936.

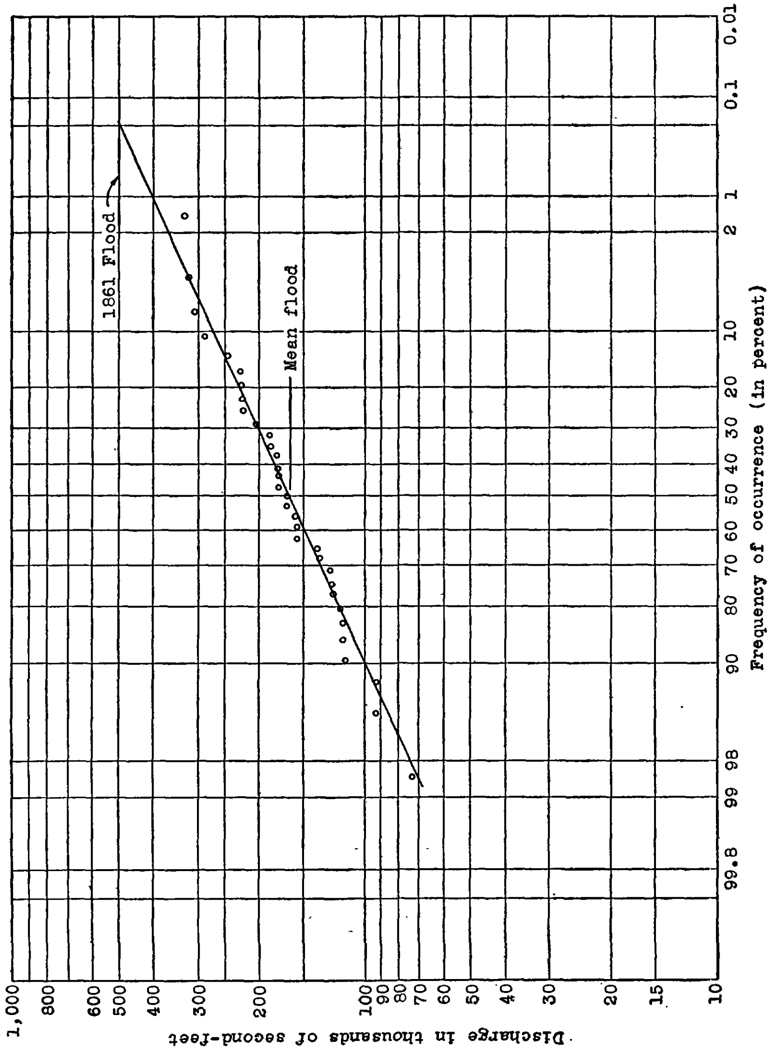

FIGURE 7.—Annual flood-frequency curve for the Willamette River at Salem for period 1895–1916 and 1928–38.

STORMS AND FLOODS OF 1909, 1923, AND 1927

GENERAL ANALYSIS

In analyzing the storms that have produced general floods in western Oregon, one objective has been to determine the approximate relation between rainfall and runoff, and since this must be known accurately, the storms that can be studied are limited to those for which adequate records can be obtained. The great storms in western Oregon for which considerable rainfall and runoff data are available are those of November 1909, January 1923, and February 1927. Greater storms occurred in 1813, 1844, 1861, 1881, and 1890—at least that is indicated by the magnitude of the floods that resulted—but very little rainfall or runoff data are available for those storms.

From Weather Bureau records, the isohyetal maps (figs. 8, 9, and 10) have been prepared to show the total rainfall for the 1909, 1923, and 1927 storms. The isohyetal lines on these maps have been drawn on the basis of daily observations of rainfall at from 38 to 45 places, giving due regard to the influence of altitude and exposure where rainfall observations are lacking. The total rainfall for the respective drainage basins has been determined from these maps. Tables 2, 3, and 4 have been prepared to show pertinent data concerning the storms and resulting floods on various rivers in the Willamette Valley and southern Oregon. The numbers given in the lefthand column refer to figure 1 and conform to those given in Water-Supply Paper 847 [6]. The data on flood period and duration of direct runoff drainage area, momentary peak discharge, momentary peak discharge in second-feet per square mile, and maximum calendar-day discharge have been included in the tables to afford comparisons with various other flood records. The precipitation associated with the flood and the direct runoff, which were computed, furnished a basis for determination of the basin retention.

The daily discharge records have been obtained from Geological Survey records, the only exceptions being the gage heights of the 1923 and 1927 floods on the Willamette River at Salem, which were obtained from the Weather Bureau in the "Daily river stages at river gage stations on the principal rivers of the United States" for the years 1923 and 1927. The mean areal precipitation during the storm was determined from the rainfall maps prepared for that storm (figs. 8–10). The storm runoff was computed as illustrated on figure 11. The daily discharge, A–B–C–D, was plotted and from that the estimated ground-water and antecedent flow was subtracted as shown, A–D. The direct runoff was then determined in inches on the drain-

[6] Williams, G. R., and Crawford, L. C., Maximum discharges at stream-measurement stations through December 31, 1937; U. S. Geol. Survey Water-Supply Paper 847, 272 pp., 1940.

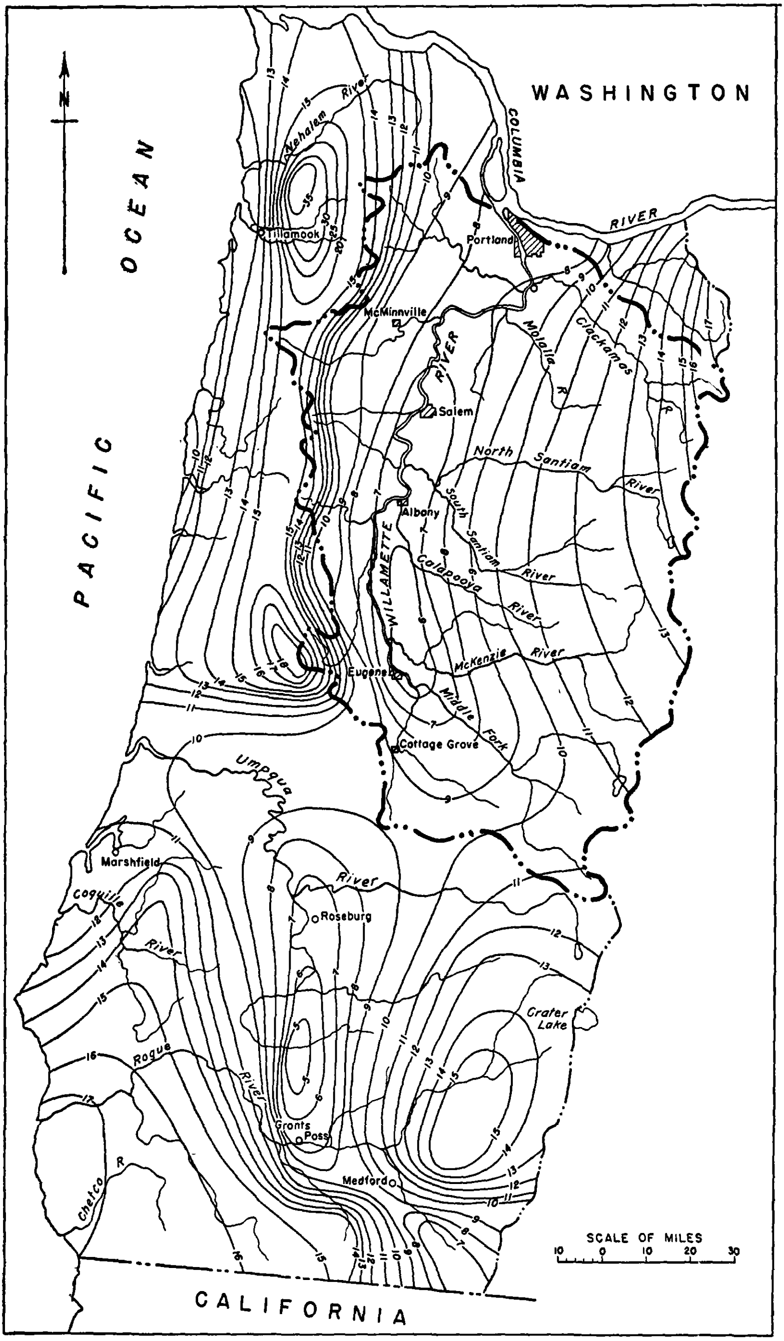

FIGURE 8.—Isohyetal map of western Oregon showing precipitation, in inches, for storm period November 16-30, 1909.

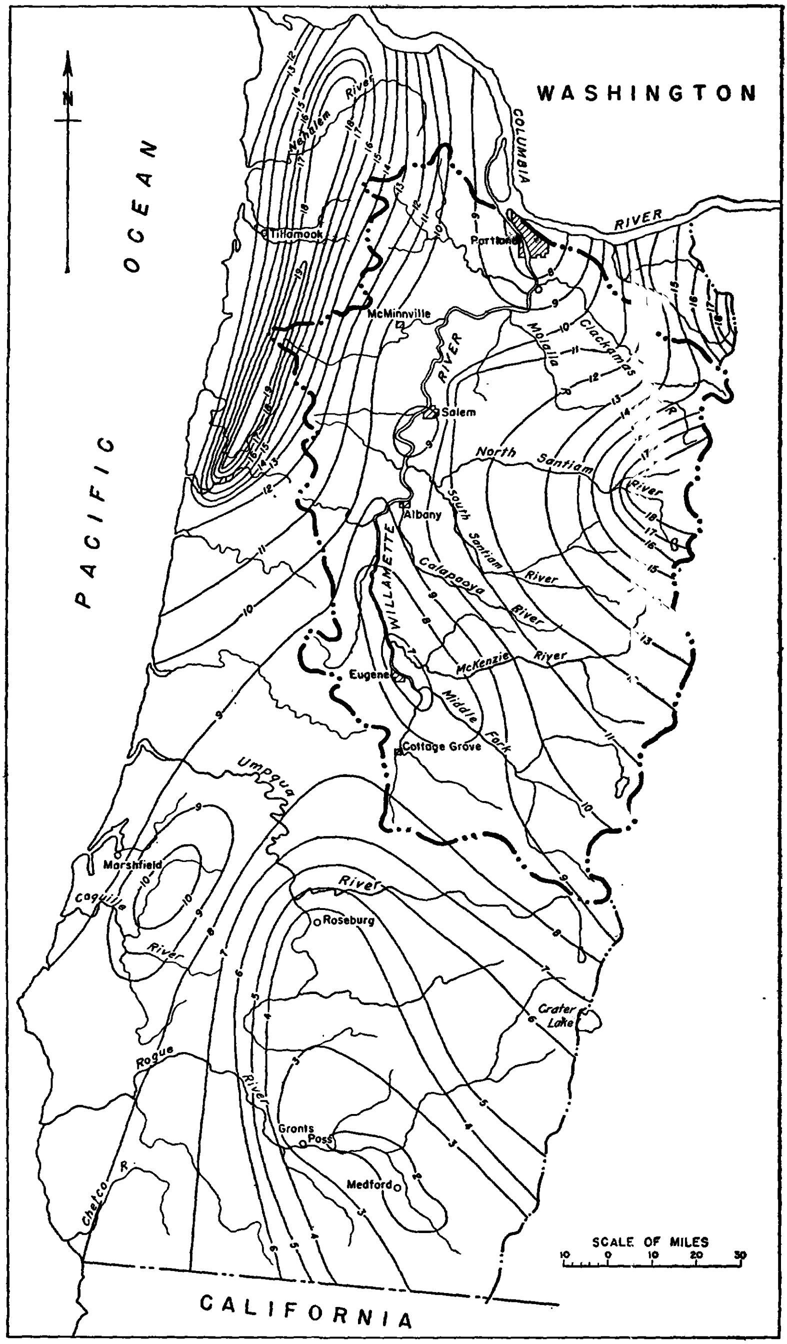

Figure 9.—Isohyetal map of western Oregon showing precipitation, in inches, for storm period December 30, 1922, to January 12, 1923.

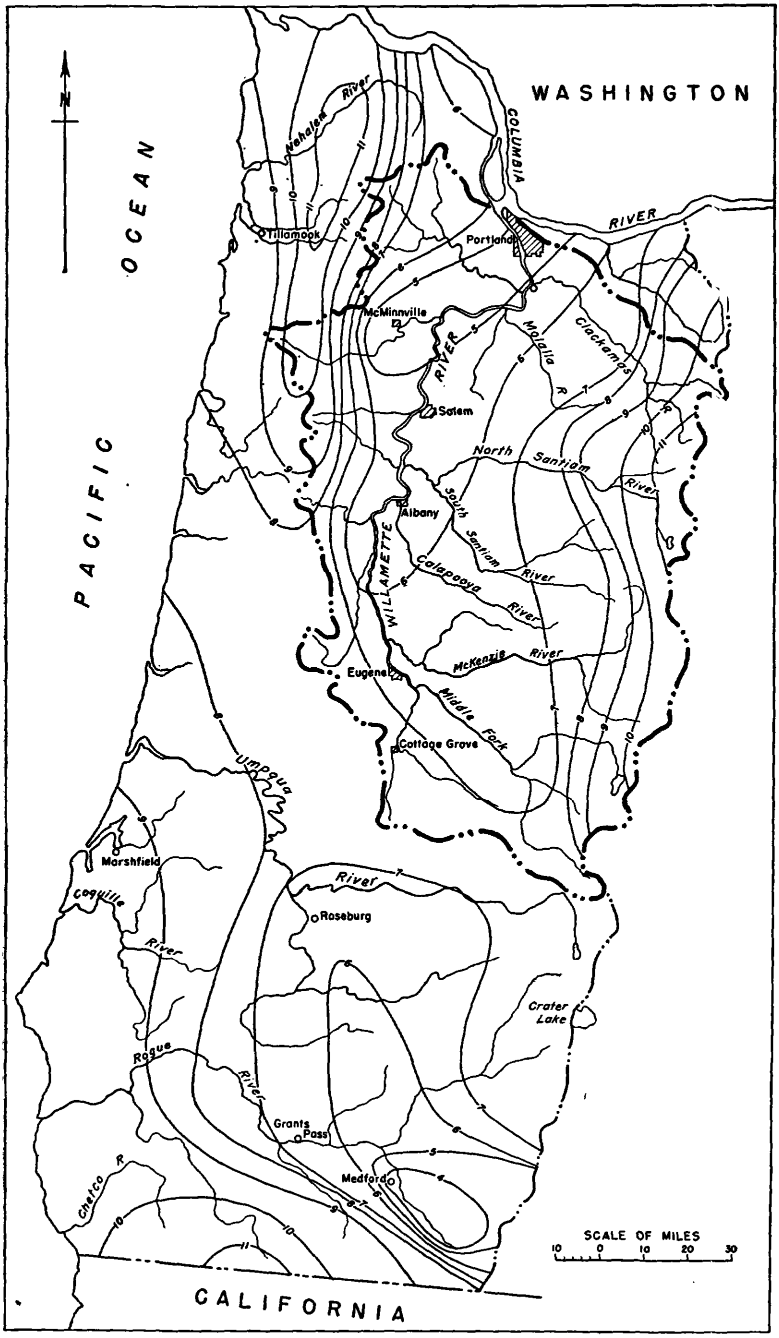

FIGURE 10.—Isohyetal map of western Oregon showing precipitation, in inches, for storm period February 15–28, 1927.

TABLE 2.—*Precipitation and associated hydrologic data for floods during November 1909*

[Discharge data from Water-Supply Paper 370, except as noted]

No. on fig. 1	Stream and point of measurement	Flood period	Duration of direct runoff (days)	Drainage area (square miles)	Momentary peak discharge		Maximum calendar-day discharge (second-feet)	Precipitation during storm associated with flood (inches)	Direct runoff (inches)	Basin retention (inches)	Remarks
					Second-feet	Second-feet per square mile					
150	Bull Run River near Bull Run	Nov. 17 to Dec. 4	18	102	[1] 11,100	109	9,490	13.4	18.0	−4.6	
157	Willamette River at Albany	Nov. 20 to Dec. 6	17	4,840			[2] 193,000	9.8	6.4	3.4	Snow probably fell at high altitudes. Mild temperatures melted some snow at medium altitudes.
158	Willamette River at Salem [3]	Nov. 19 to Dec. 6	18	7,280	[4] 315,000	41.5	315,000	10.9	8.3	2.6	
168	Coast Fork of Willamette River near Goshen.	Nov. 19–30	12	690	[4] 31,300	45.4	31,300	8.9	5.2	3.7	Snow effect small.
186	North Santiam River near Niagara	Nov. 17 to Dec. 6	20	462	[4] 50,200	109	50,200	13.5	18.8	−5.3	Snow effect not determined.
188	Santiam River at Jefferson	Nov. 18 to Dec. 7	20	1,790	[3] 108,000	59.7	93,200	11.4	11.3	.1	
216	Clackamas River near Cazadero	Nov. 18 to Dec. 7	20	665	[3] 46,800	70.4	37,600	14.3	10.6	3.7	Probably snow fell in higher parts of basins.
260	Siletz River at Siletz	Nov. 18–27	10	204	[5] 34,600	170	29,300	14.4	18.7	−4.3	
268	Umpqua River near Elkton	Nov. 17–28	12	3,680	[6] 163,000	44.3	138,000	9.6	3.5	6.1	Most of precipitation on upper part of basin was snow.
293	Rogue River at Raygold, near Central Point.	Nov. 18 to Dec. 5	18	2,020	[7] 67,000	33.2	48,300	12.3	3.7	8.6	

1 Maximum observed; not previously published.
2 From Water-Supply Paper 964.
3 From Water-Supply Paper 414.
4 Maximum calendar-day discharge, momentary peak discharge not determined.
5 From Water-Supply Paper 594.
6 From Water-Supply Paper 444.
7 From Water-Supply Paper 771.

TABLE 3.—*Precipitation and associated hydrologic data for floods during January 1923*

[All discharge data from Water-Supply Paper 574, except as noted]

No. on fig. 1	Stream and point of measurement	Flood period	Duration of direct runoff (days)	Drainage area (square miles)	Momentary peak discharge: Second-feet	Momentary peak discharge: Second-feet per square mile	Maximum calendar-day discharge (second-feet)	Precipitation during storm associated with flood (inches)	Direct runoff (inches)	Basin retention (inches)	Remarks
150	Bull Run River near Bull Run	Jan. 5–13	9	102	18,700	183	17,200	15.9	17.3	−2.4	Probably considerable runoff from melting snow.
156	Willamette River at Eugene (Springfield).	Dec. 31 to Jan. 12	13	2,050	72,500	35.4	62,000	9.0	3.7	5.3	Mean temperature in Willamette Valley was abnormally high during flood period—47° F. on valley floor. This warm weather was preceded by a cold, wet December, and runoff from melting snow increased discharge in Willamette River Basin to some extent.
157	Willamette River at Albany	Dec. 31 to Jan. 16	17	4,840	[1] 206,000	42.6	[1] 199,000	9.6	5.7	3.9	
158	Willamette River at Salem [2]			7,280	359,000	49.3	342,000	(3)	(3)	(3)	
179	Long Tom River at Monroe	Dec. 31 to Jan. 15	16	394	18,600	47.6	15,800	8.4	4.6	3.8	
187	North Santiam River at Mehama	Jan. 3–15	13	665	62,000	93.2	58,000	16.2	9.4	6.8	
216	Clackamas River near Cazadero	Dec. 31 to Jan. 14	15	665	60,000	90.2	49,700	14.9	7.8	7.1	
268	Umpqua River near Elkton	Dec. 29 to Jan. 16	19	3,680	96,000	26.1	93,500	5.9	4.5	1.4	Weather mild and rainfall much less than in Willamette Basin.
293	Rogue River at Raygold, near Central Point.	Dec. 30 to Jan. 13	15	2,020	18,600	9.2	15,600	3.7	1.0	2.7	

[1] From Water-Supply Paper 964.
[2] Gage heights taken from daily river stages at river gage stations on the principal rivers of the United States, U. S. Weather Bur., 1923.
[3] For runoff data see detailed analysis pp. 28–31.

Table 4.—*Precipitation and associated hydrologic data for floods during February 1927*

[Discharge data taken from Water-Supply Paper 654, except for the Willamette River at Salem]

No. on fig. 1	Stream and point of measurement	Flood period	Duration of direct runoff (days)	Drainage area (square miles)	Momentary peak discharge		Maximum calendar-day discharge (second-feet)	Precipitation during storm associated with flood (inches)	Direct runoff (inches)	Basin retention (inches)	Remarks
					Second-feet	Second-feet per square mile					
156	Willamette River at Eugene (Springfield).	Feb. 17 to Mar. 1	13	2,050	73,300	35.8	68,000	7.2	4.0	3.2	Runoff from melted snow was small. Warm rains previous to storm melted most of the snow in the Willamette Basin. Most of precipitation except at high altitude fell as rain because mean temperature during storm period was comparatively high (45° F).
157	Willamette River at Albany	Feb. 17 to Mar. 3	15	4,840	[1] 191,000	39.5	[1] 158,000	7.3	4.3	3.0	
158	Willamette River at Salem [2]	Feb. 17 to Mar. 7	19	7,280	[3] 243,000	33.4	243,000	7.5	5.2	2.3	
167	Coast Fork Willamette River at Saginaw.	Feb. 17–27	11	529	28,600	54.1	24,400	7.6	4.9	2.7	
173	McKenzie River near Vida	Feb. 18–28	11	930	47,200	50.8	31,700	9.0	3.7	5.3	
179	Long Tom River at Monroe	Feb. 17 to Mar. 5	17	394	[3] 10,400	26.4	10,400	7.0	4.2	2.8	
187	North Santiam River at Mehama	Feb. 17–28	12	665	48,000	72.2	33,000	10.0	5.6	4.4	
216	Clackamas River near Cazadero	Feb. 17–27	11	665	28,300	42.6	16,500	9.4	3.0	6.4	
260	Siletz River at Siletz	Feb. 19–28	10	204	[3] 11,500	56.4	11,500	9.3	7.1	2.2	Snow effect negligible.
268	Umpqua River near Elkton	Feb. 18 to Mar. 1	12	3,680	172,000	46.7	157,000	7.0	4.5	2.5	Some snow probably melted at high altitudes; total effect was small.
293	Rogue River at Raygold, near Central Point.	Feb. 17–28	13	2,020	91,500	45.3	48,900	6.3	2.5	3.8	
324	Illinois River at Kerby	Feb. 17–28	12	367	50,000	136.0	30,000	10.7	9.9	.8	

[1] From Water-Supply Paper 964.
[2] Gage heights taken from daily river stages at river gage stations on the principal rivers of the United States, U. S. Weather Bur., 1927.
[3] Maximum calendar-day discharge, momentary peak discharge not determined.

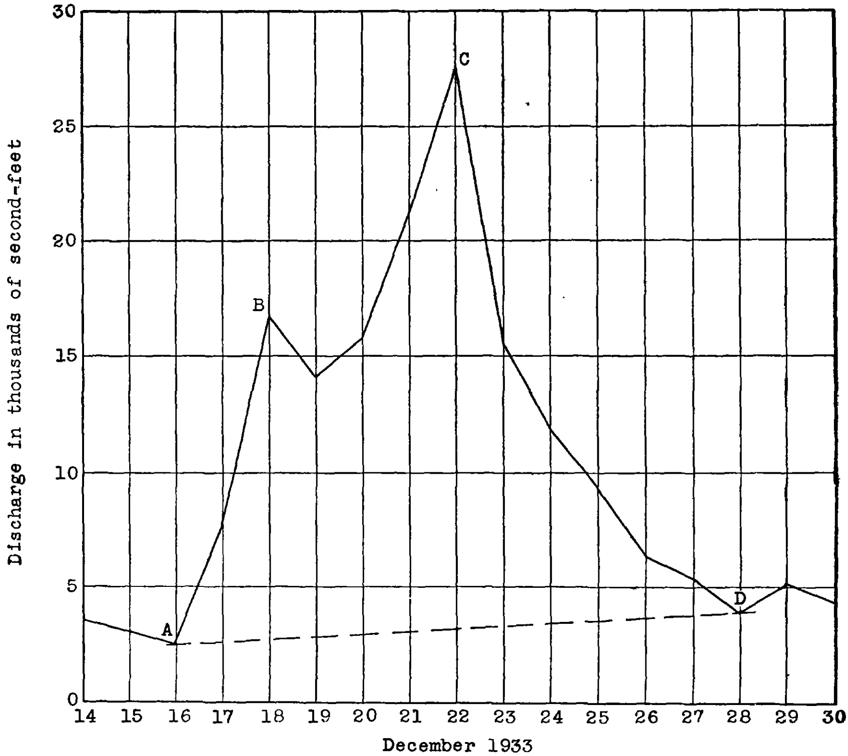

FIGURE 11.—Hydrograph of discharge at gaging station on Wilson River near Tillamook, December 1933.

age area. The basin retention was computed by subtracting the direct runoff in inches from the total precipitation. The total precipitation should be greater than the direct runoff, to account for the loss by evaporation, the infiltration or absorption, and surface interception and storage. In the floods where this result was not obtained, either the computed rainfall was too small or the computed direct runoff too large. This point is taken up in more detail in the discussion of the storm data given below. Table 5 includes data similar to those of the preceding three tables with specific reference to miscellaneous storms, some of which were not general over the western part of the State and resulted in localized floods as reported. Some of these storms were more severe than the general storms for the particular area they covered. Also included in this table are estimates of the direct runoff of the 1861 and 1881 floods.

To determine the factors affecting runoff in this region, it is necessary to understand the areal distribution of rainfall. In examining the rainfall maps of the storms of November 1909, December 1922–January 1923, and February 1927, it may be seen that the northern part

TABLE 5.—*Precipitation and associated hydrologic data for miscellaneous floods*

[Discharge data taken from Water-Supply Papers for part 14 (before 1935, listed as part 12 C) for the year the flood occurred, except as noted]

No. on fig. 1	Stream and point of measurement	Flood period	Duration of direct runoff (days)	Drainage area (square miles)	Monetary peak discharge: Second-feet	Monetary peak discharge: Second-feet per square mile	Maximum calendar-day discharge (second-feet)	Precipitation during storm associated with flood (inches)	Direct runoff (inches)	Basin retention (inches)	Remarks
150	Bull Run River near Bull Run	Nov. 18-25, 1921	8	102	20,300	198	14,500	22.7	14.0	8.7	Runoff from melted snow small.
150	Do	Mar. 29 to Apr. 4, 1931	7	100	20,600	202	16,400	9.4	10.5	−1.1	
157	Willamette River at Albany	Jan. 11-26, 1881	16	4,840	[1] 266,000	47.3	[1] 259,000	----	[2] 7.7	----	Very little precipitation and discharge data available.
158	Willamette River at Salem	Dec. 1-15, 1861	15	7,280	500,000	69	----	----	[3] 13	----	Runoff was estimated from sketchy information. Snow known to have melted at medium altitudes.
187	North Santiam River at Mehama	Nov. 19 to Dec. 9, 1921	21	665	62,000	93.2	50,500	21.0	17.7	3.3	Precipitation data based on record at one station.
216	Clackamas River near Cazadero	Nov. 19 to Dec. 9, 1921	21	665	52,100	78.3	31,700	14.2	10.5	3.7	(Precipitation data based on record at one station.)
255	Wilson River near Tillamook	Dec. 17-27, 1933	11	162	30,000	185	27,500	----	26.7	----	No reliable rainfall data available. Runoff from melted snow negligible.
257	Trask River near Tillamook	Dec. 17-27, 1933	11	152	20,000	132	18,600	----	17.2	----	

[1] From Water-Supply Paper 964.
[2] Gage heights taken from Water-Supply Paper 370; discharge computed from unpublished rating tables.
[3] Daily discharges estimated from a high-water mark and normal shape of flood hydrographs.

of the Coast Mountains receives the largest amount of precipitation, the Willamette Valley considerably less, and the summit of the Cascade Mountains somewhere between these extremes. This was so during each storm and results from the position and influence of the land masses. The 39.0 inches of rain in 15 days, recorded in the Coast Mountains in November 1909, could not have occurred in the Willamette Valley, which is sheltered from the ocean winds by those mountains. Thus, it appears that the controlling topography precludes transposition of storms in this region. Also, by the same reasoning, the centers of greatest precipitation tend to be the same for all storms, so that the greatest runoff is to be expected from certain streams, the Wilson, Trask, and Siletz Rivers in the Coast Mountains, and the Santiam and Bull Run Rivers in the Cascade Mountains. Direct runoff values as great as 26.7 inches have been obtained on the Wilson River in the past 10 years, for which records are available, whereas the estimated value for the Willamette River at Salem for the 1861 flood (greatest in 100 years) was only 13 inches. Thus to study runoff in western Oregon, it is essential to know the location of the mountains and their effect on runoff.

That part of Oregon west of the Cascade Range and south of the Calapooya Mountains is generally mountainous. The two principal rivers, the Umpqua and the Rogue, have comparatively narrow valleys, and although the areas of low rainfall intensity follow the rivers, the precipitation is not subject to so wide a variation as in the Willamette Valley. The rainfall in this region is less than in the Willamette Valley, and the storm runoff from the drainage areas of the Rogue and Umpqua Rivers is generally less than from that of the Willamette River.

The influence of snow during the 1909, 1923, and 1927 storms is uncertain. In general, the headwaters of all streams rising near the summit of the Cascade Mountains received some precipitation in the form of snow. The precipitation withheld as snow was compensated by melting of antecedent snowfall at the lower elevations. The summit of the Coast Mountains, being only 1,000 to 2,000 feet high, receives very little snow at any time. The 26.7-inch runoff on the Wilson River in 1933 was undoubtedly all derived from rainfall. However, the 18.8-inch runoff on the North Santiam River at Niagara in 1909 might have been caused in part by melting snow. The runoff of the Rogue and Umpqua Rivers is affected by snow, but the total snow-affected area is only a small percent of the drainage areas of those streams.

In tables 2, 3, 4, and 5, five floods are recorded in which the runoff exceeded the measured precipitation, and one flood in which the runoff was practically the same as the measured precipitation. This is attributable to small retention in the affected basins as well as the fact that rain gages were located so as not to produce a true average over the basin. This can be illustrated by the fact that, during the 1909 storm one station measured 11.05 inches precipitation and a station 16 miles away, measured 39.0 inches, a difference of approximately 28 inches in 16 miles. In general, values of the retention for the several basins are consistent and appear to be reasonably accurate, especially for the larger basins. The greatest variations pertain to the smaller basins, where there would be less opportunity for eliminating errors in determining precipitation by averaging many records.

FLOOD OF JANUARY 1923

The greatest flood during the period when rainfall and runoff records have been generally available was in January 1923. This flood resulted from a series of storms passing over the Willamette Basin during December 1922 and January 1923. As the pattern of this flood is common to all large floods on the Willamette River and as it presents a condition that is critical in the development of floods, the data have been studied in considerable detail.

During a storm, precipitation may be considered as disposed of by (1) initial abstraction, equivalent to the volume of water intercepted by vegetation, required to wet the ground, and to fill surface depressions; (2) absorption in the ground by infiltration, of which part is subsequently lost by evaporation and by drainage as ground water; (3) evaporation and transpiration; (4) drainage as ground water; and (5) direct runoff, which is the net remainder.

The direct runoff of the Willamette River at Salem during the flood of January 1923 is represented in figure 12 by that portion of the hydrograph above the line *A—B—C—D—E*, and the ground-water discharge or base flow is represented by the portion below that line. In order to determine the portion of runoff attributable to selected periods of rainfall during the storm, the inflow into the channel system of the river was computed by adjusting the hydrograph as observed at Salem for the smoothing effects of channel storage.

Channel storage, as used here, includes water in all the stream channels, however small. This storage [7] is computed by means of recession graphs for various gaging stations in the basin. The dashed line on figure 12 is the sum of the inflow into all the channels of the basin thus computed.

As previously indicated that portion of the hydrograph below *A—B—C—D—E* represents the discharge from ground water, except for the short segment *A—B* which is direct runoff from preceding rainfall.

[7] Langbein, W. B., Some channel-storage studies and their application to the determination of infiltration, Am. Geophys. Union Trans. 19, pp. 435–447, 1938.

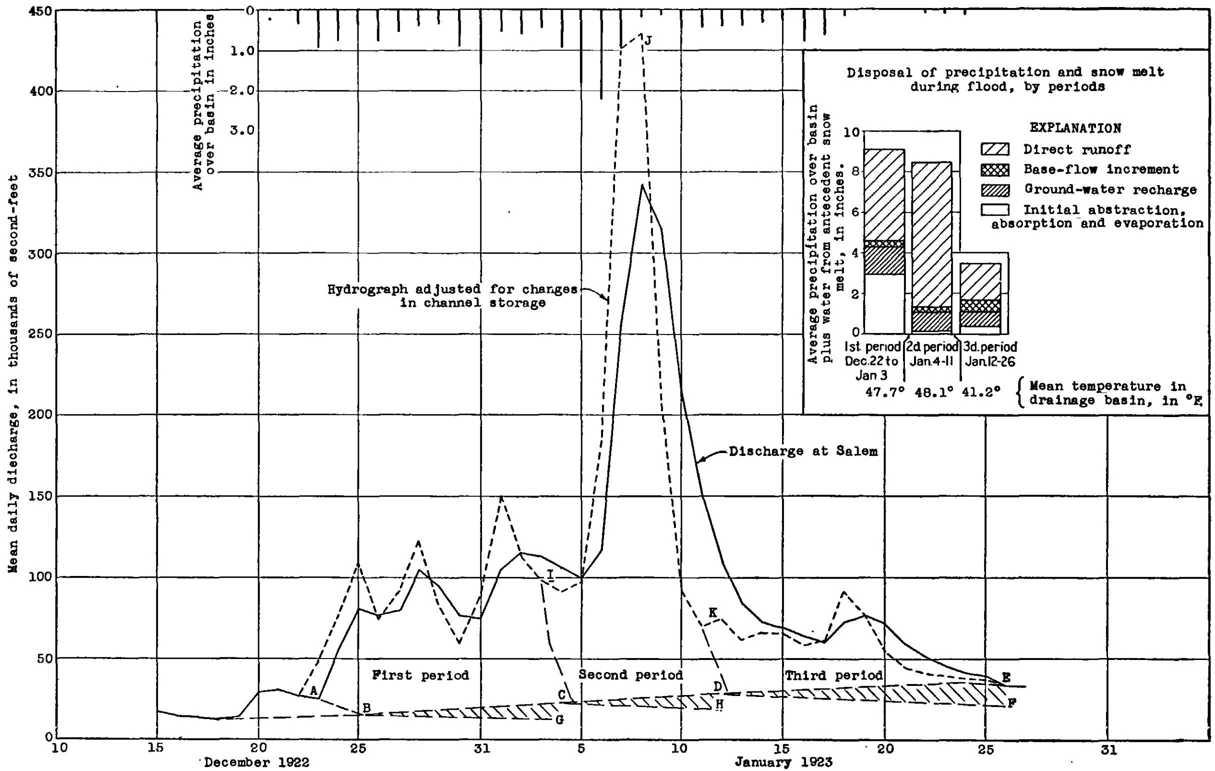

FIGURE 12.—Hydrograph of inflow into the channels of the Willamette River Basin and hydrograph of discharge at Salem for the flood of December 1922 to January 1923.

To compute the relative changes in ground-water storage for the three periods of the storm, a ground-water depletion curve [8] was developed and a ground-water storage curve computed for discharges above 2,500 second-feet. The ground-water storage for this discharge was assumed as zero because it is very close to the lowest recorded (2,470 second-feet) at Salem.

At the beginning of the flood period, December 22, the river was at a fairly low winter stage. There had been a slight rise about the 10th of the month, but most of the effect had disappeared. On December 22 rainfall began, and it continued practically without interruption until January 19. During this 29-day period, there were 14 days when more than 0.5 inch fell, 3 days when more than 1.0 inch fell, and 1 day when more than 2.0 inches fell. There was a total of 21.1 inches of water on the drainage basin during the period December 22, 1922, to January 26, 1923, including an estimated 1.8 inches water equivalent of antecedent snow melted during the period.

The storm period has been divided into three parts. During the first, December 22 to January 3, inclusive, the precipitation was 8.3 inches plus 0.8 inch of water melted from antecedent snow, a total of 9.1 inches, which was disposed of as follows: 4.5 inches was direct runoff, as indicated by area *A—B—C—I* (figure 12); 0.3 inch produced increased base flow, as indicated by area *B—C—G;* and 1.3 inches was increase in ground-water storage, indicated by the rise in base flow from *B* to *C*. Thus, out of a total of 9.1 inches, 6.1 inches appeared as direct and ground-water runoff. The difference of 3.0 inches was substantially the sum of initial abstraction and the volume of water absorbed in the zone of aeration, as the evaporation and transpiration is small during winter storm periods. By comparison with the rainfall and runoff of the second period it is evident that rainfall during the first period raised the water content of the soil to nearly field-moisture capacity.

The second period, January 4–11, includes the time of most intense rainfall and the peak discharge. During this period, there was 7.5 inches of precipitation, and 1.0 inch of water melted from antecedent snow, making a total of 8.5 inches. Of this, 7.2 inches became direct runoff (*I–J–K–D–C*), 0.2 inch increase in ground-water discharge (*C–D–H*), and 1.0 inch increase in ground-water storage represented by the rise in base flow from *C* to *D*. Thus, there was a total of 8.4 inches runoff and ground-water recharge and only 0.1 inch accounted for by absorption and evaporation. Thus it is apparent that the capacity of the soil was practically satisfied during the first period,

[8] Langbein, W. B., and others, Major winter and nonwinter floods in selected basins in New York and Pennsylvania, U. S. Geol. Survey Water-Supply Paper 915.

and that most of the subsequent precipitation was accounted for as runoff or ground-water recharge.

During the third period, January 12–26, there was 3.5 inches of precipitation, of which 1.8 inches may be accounted for as direct runoff, 0.6 inch as increased ground-water runoff, and 0.7 inch as ground-water recharge, making a total of 3.1 inches and leaving 0.4 inch for absorption by the soil and for evaporation.

It is apparent from this study of the January 1923 flood that during winter storms in the Willamette Basin the differences between precipitation and runoff caused by initial abstraction, absorption to the zone of aeration, evaporation, and transpiration are satisfied soon after the beginning of the storm, and thereafter the retention of the basin is based on the rate of infiltration of precipitation to the ground-water table. Because of the frequent rains during this season, the initial losses, such as interception by vegetal cover, surface pondage, and wetting the ground surface, are comparatively small, and the moisture content of the soil in the zone of aeration is near full capacity. Thus the point is soon reached in a storm when the precipitation contributes mainly to direct runoff and ground-water recharge.

The precipitation data for this storm have been based on observed readings at 14 Weather Bureau stations in the Willamette Basin. Isohyetal maps were drawn for each day during the storm period with due regard to elevation and exposure of land masses. The amount of snow melt was estimated from all information available from the United States Weather Bureau. The discharge at Salem was determined from daily Weather Bureau gage readings and unpublished rating tables in the Portland district office of the Geological Survey.

UNIT-HYDROGRAPH ANALYSIS OF FLOODS

GENERAL FEATURES

In studying the characteristics of flood runoff in the Willamette Basin, it was decided that a study of floods by means of the unit hydrograph was the most practical and most useful. The tributaries rising in the Cascade Range are considerably affected by snow runoff, whereas tributaries rising in the Coast and Calapooya Mountains are not. As figure 25 shows, the ratio of peak discharge per square mile of the snow-fed tributaries to peak discharge from the areas not affected by snow, during four floods in 1936–38, varied from 64 to 111 percent, depending on the temperature. This variation is too great to disregard, and as the snow-fed tributaries form a substantial part of the total drainage area, they were eliminated from consideration and the portion of the basin affected by rainfall was studied separately from the snow-fed areas.

To facilitate the separation of snow-fed tributary discharge in the channel-storage computations it was decided to route the flow from the tributaries into the main stem of the Willamette River by groups. The tributary flow divides itself logically into three groups, one for each of the principal tributaries above Salem, namely, the headwater basins tributary to the Middle Fork of the Willamette River, the McKenzie River, and the Santiam River.

The lowest gaging station on the Willamette River is at Salem. Thus the runoff for the rain-fed drainage area of the Willamette River above Salem was determined by subtracting the flow of groups 1, 2, and 3, from the flow at Salem. A map showing the relative areas and location of these gaging stations is shown on figure 13.

Existing gaging stations used to determine the discharge from the snow-affected areas of the Middle Fork of the Willamette River are: Salt Creek near Oakridge (160), Salmon Creek near Oakridge (161), the North Fork of the Middle Fork of the Willamette River near Oakridge (162), and the Middle Fork of the Willamette River above Salt Creek, near Oakridge (153). These streams are designated as group 1.

On the McKenzie River, the gaging station at Vida was used. The flow at this station (173), which is situated at a fairly low altitude, probably is influenced by rain as much as by snow, although the McKenzie River drains to the summit of the mountains. The McKenzie River at Vida is designated as group 2.

Stations used to determine the flow from the snow-affected areas in the Santiam River Basin are: the North Santiam River at Detroit (185), the Breitenbush River above French Creek, near Detroit (193), the Middle Santiam River near Foster (199), and the South Santiam River below Cascadia (197). These four stations are designated as group 3.

All the above gaging stations were equipped with water-stage recorders except that on the North Fork of the Middle Fork of the Willamette River near Oakridge. The discharge of this stream was estimated by using the twice-daily gage readings and drawing a hydrograph based on the water-stage recorder chart at the station on Salmon Creek near Oakridge, which basin is adjacent to that of the North Fork of the Middle Fork of the Willamette River. As some of the stations on the upper tributaries were started as late as 1935, this study has been limited to the floods that have occurred since that time. At Salem the river has gone above bankfull stage four times during the period 1935–39, but no large floods have occurred since then.

Because of the rapid rise and fall of the main river and tributaries, an 8-hour unit of time was used for the unit-hydrograph studies and for the channel-storage adjustments given below.

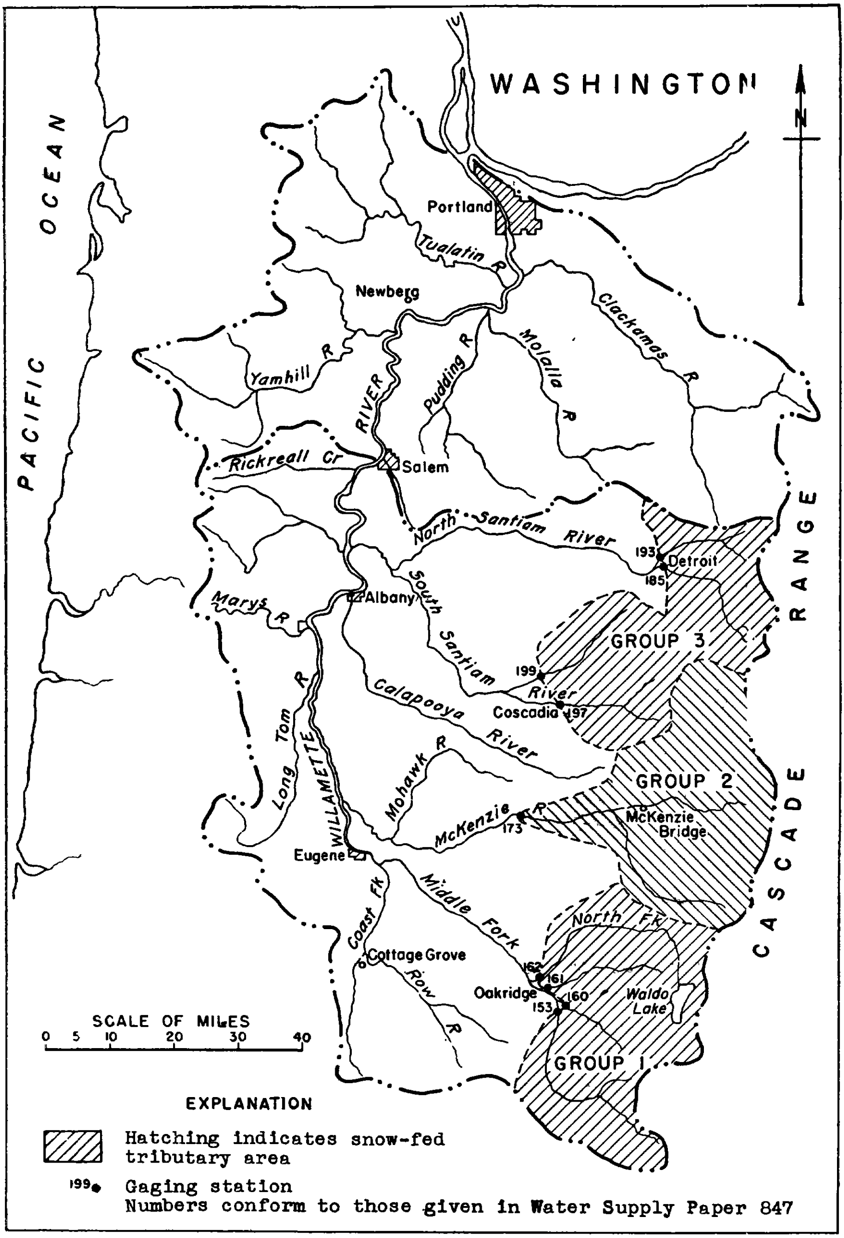

FIGURE 13.—Relative areas of snow-fed tributaries and valley floor in Willamette River Basin above Salem.

Thus the Willamette River Basin above Salem (7,280 square miles) was divided into two parts, one in which snowfall was assumed to have an insignificant effect on floods and which will be called the valley floor (total area, 4,705 square miles), although some foothills areas are necessarily included, and the other in which snowfall has a marked effect and which will be called the snow-fed tributaries (2,575 square miles). As may be seen on the contour map of the basin (fig. 2) the snow-fed tributaries as measured at the gaging stations include some predominantly rain-fed drainage. However, with stations located as they are, it was impracticable to eliminate these areas.

CHANNEL-STORAGE ADJUSTMENTS

After the discharge at the stations on the snow-fed tributaries had been computed for 8-hour periods, it was necessary to adjust their combined flow so that it could be subtracted from the flow at Salem in order to compute the valley-floor discharge. The flow from the tributaries is considerably affected by channel storage along the length of the river, as the Willamette River has a wide flood plain between Springfield and Salem, and consequently water accumulating as storage on a rising stage and flowing out on a falling stage is an important factor in the regimen of the river. The total overbank channel storage in this reach was about 1,500,000 acre-feet in the 1861 flood, which is the highest to date. As this storage was accumulated in 4 or 5 days, it greatly reduced the peak discharge at Salem below what it would have been without such storage.

Storage in the main channel of the river was computed by using stations at Albany and Salem, and the station at Springfield, which is 3 miles above Eugene and 3 miles below the confluence of the Coast Fork of the Willamette River and the Middle Fork of the Willamette River. The storage was computed in two reaches: one from Salem to Albany (35 miles) and the other from Albany to Springfield (66 miles). Some tributaries along these reaches are not gaged and some are equipped only with staff gages and some with recording gages. However, the flow from the ungaged area, which was about 25 percent of the total, could be estimated fairly closely. The flow of the Santiam River into the Salem-Albany reach was determined from an old rating curve for a station on this river at Jefferson, drainage area 1,790 square miles. This station was discontinued in 1916, but the Weather Bureau still reads the staff gage daily except during floods when it is read two or three times a day.[9] The old rating table was applied to Weather Bureau readings to obtain the flow into the reach.

In order to simplify calculations of channel storage, curves were defined showing the relation of the computed mean water-surface

[9] Station reestablished by Geological Survey October 1, 1939.

width of the river to the gage height at the lower end of the reach. The width of the river was computed by obtaining the storage during an 8-hour period from the inflow and outflow records of main stream and tributaries; this volume of storage was then assumed equal to that of a prismoid whose dimensions were the known length of the reach, the mean change in stage as computed from available gage-height records and the computed mean width of the river from bank to bank. A summary of computations is shown on tables 6 and 7. Owing to difficulties in computing accurately the tributary inflow on rising stages, widths were determined on falling stages. The mean widths of the river for the two reaches during one flood are plotted on figures 14 and 15. The storage adjustments for each reach for all the storms studied were then determined by multiplying the mean width as taken from the curve by the length of the reach and the average change in stage.

Much time was saved, perhaps at the expense of some accuracy, by using mean-width curves. However, the mean-width curves were extended and verified by means of field surveys of the flood surface of the floods of 1861 and 1927 made by the Corps of Engineers.[10] The channel storage on the tributaries between the upper gaging stations and the main river could not be readily determined, but it is believed that the omission of this factor did not materially affect the accuracy of the results.

The points determined for the mean width seem more consistent than would be expected from the precision of the data. It was impossible to determine whether the curve followed a loop on the rising and falling stages. As the ungaged tributary inflow was approximately 25 percent of the total flow into the reach its effect was important, and inaccuracy in estimating it would affect the computed storage correspondingly.

The computations of valley-floor discharge for the floods of January 1936, April 1937, December–January 1937–38, and March 1938 are shown on tables 8, 9, 10, and 11. The aggregate discharge of the snow-fed tributaries (groups 1, 2, and 3) was adjusted for the storage estimated as appurtenant to it, as distinguished from that appurtenant to the discharge contributed by the valley-floor area in the Willamette River channel between Springfield and Salem. The total discharge of groups 1, 2, and 3, at the indicated time as recorded, and unadjusted for storage, is shown. In the next column this discharge is shown adjusted for storage; therefore, the valley-floor discharge is the difference between the flow at Salem and the adjusted discharge of groups 1, 2, and 3.

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[10] Willamette River and tributaries, Oreg., 75th Cong., 3d sess., H. Doc. 544, p. 46.

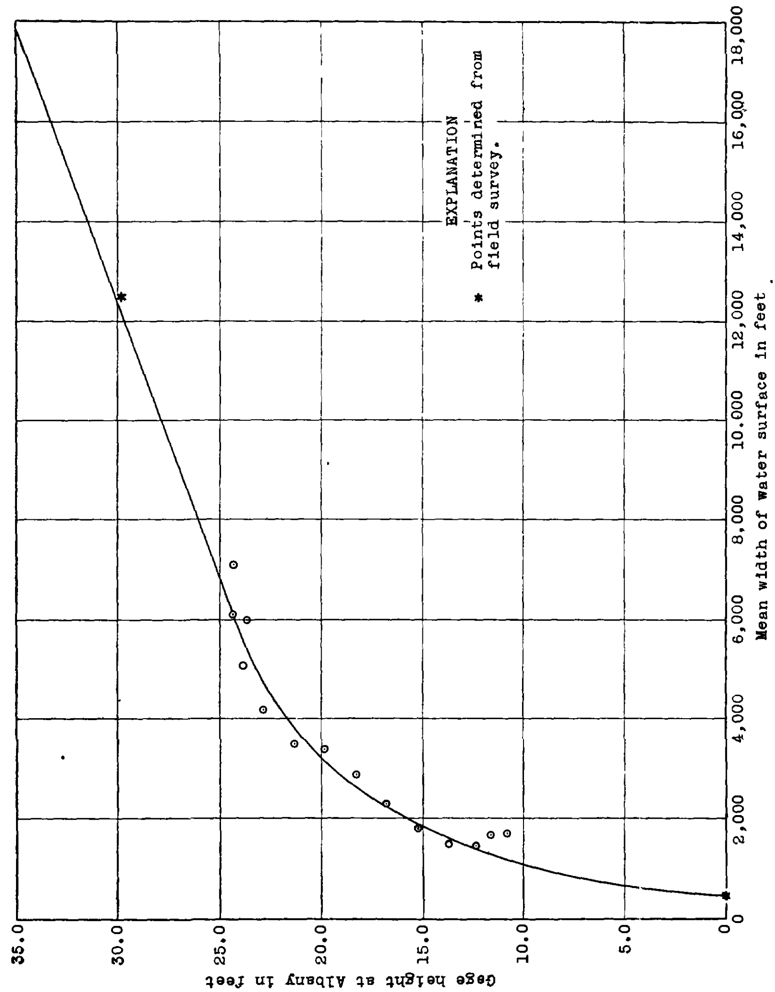


FIGURE 14.—Curve showing mean width of water surface for Springfield-Albany reach.

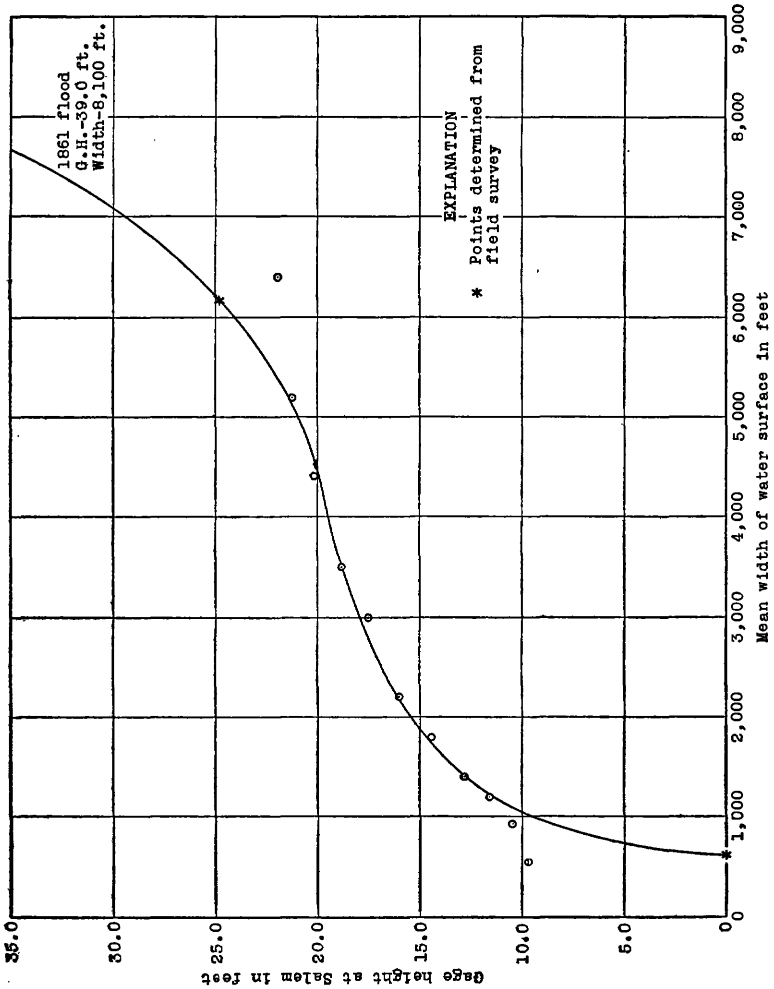


FIGURE 15.—Curve showing mean width of water surface for Albany-Salem reach.

TABLE 6.—*Computations of mean water-surface widths in Springfield-Albany reach, flood of April 1937*

Day	Hour	Gage height		Discharge at Springfield (second-feet)	Measured and estimated tributary inflow (second-feet)	Total inflow (second-feet)	Outflow, discharge at Albany (second-feet)	Inflow less outflow, 8-hour periods (acre-feet)	Change in gage height during 8-hour period		Mean change in gage-height (feet)	Mean width of river (feet)	Mean gage height at Albany (feet)
		Springfield (feet)	Albany (feet)						Springfield (feet)	Albany (feet)			
Apr. 15	12 p. m.	14.50	23.15	46,900	60,100	107,000	114,000						
16	8 a. m.	13.00	24.15	39,500	55,600	95,100	124,000	−11,900	−1.50	+1.00	−0.25	6,000	23.65
	4 p. m.	11.85	24.50	34,000	53,850	87,850	127,000	−22,800	−1.15	+.35	−.40	7,100	24.32
	12 p. m.	10.80	24.35	29,100	46,000	75,100	126,000	−29,500	−1.05	−.15	−.60	6,100	24.42
17	8 a. m.	10.00	23.45	25,500	38,900	64,400	117,000	−34,600	−.80	−.90	−.85	5,100	23.90
	4 p. m.	9.28	22.20	22,300	38,000	60,300	106,000	−32,800	−.72	−1.25	−.98	4,200	22.82
	12 p. m.	8.76	20.70	20,100	33,000	53,100	93,700	−28,500	−.52	−1.50	−1.01	3,500	21.45
18	8 a. m.	8.24	19.15	18,000	29,100	37,100	82,500	−28,500	−.52	−1.55	−1.04	3,400	19.92
	4 p. m.	7.73	17.55	15,900	28,600	44,500	72,300	−24,200	−.51	−1.60	−1.06	2,900	18.35
	12 p. m.	7.38	16.05	14,500	25,400	39,900	63,400	−16,900	−.35	−1.50	−.92	2,300	16.80
19	8 a. m.	7.13	14.40	13,600	22,800	36,400	54,700	−13,800	−.25	−1.65	−.95	1,800	15.22
	4 p. m.	6.90	13.00	12,800	22,600	35,400	47,800	−10,100	−.23	−1.40	−.82	1,500	13.70
	12 p. m.	6.65	11.95	12,000	20,600	32,600	43,000	−7,550	−.25	−1.05	−.65	1,500	12.48
20	8 a. m.	6.48	11.15	11,300	18,700	30,000	39,600	−6,620	−.17	−.80	−.48	1,700	11.55
	4 p. m.	6.33	10.45	10,900	18,600	29,500	36,700	−5,560	−.15	−.70	−.42	1,700	10.80

TABLE 7.—*Computations of mean water-surface widths in Albany-Salem reach, flood of April 1937*

Day	Hour	Gage height		Discharge at Albany (second-feet)	Measured and estimated tributary inflow (second-feet)	Total inflow (second-feet)	Outflow, discharge at Salem (second-feet)	Inflow less outflow 8-hour periods (acre-feet)	Change in gage height during 8-hour period		Mean change in gage height (feet)	Mean width of river (feet)	Mean gage height at Salem (feet)
		Albany (feet)	Salem (feet)						Albany (feet)	Salem (feet)			
Apr. 17	8 a. m.	23.45	22.16	117,000	45,700	162,700	197,000						
	4 p. m.	22.20	21.60	106,000	43,100	149,100	188,000	−24,200	−1.25	−0.56	−0.90	6,300	21.83
	12 p. m.	20.70	20.74	93,700	40,000	133,700	174,000	−26,200	−1.50	−.86	−1.18	5,200	21.17
18	8 a. m.	19.15	19.56	82,500	37,500	120,000	156,000	−25,300	−1.55	−1.18	−1.36	4,400	20.15
	4 p. m.	17.55	18.20	72,300	35,100	107,400	138,000	−22,100	−1.60	−1.36	−1.48	3,500	18.88
	12 p. m.	16.05	16.80	63,400	31,870	95,270	121,000	−18,700	−1.50	−1.40	−1.45	3,000	17.50
19	8 a. m.	14.40	15.20	54,700	29,240	83,940	104,000	−15,200	−1.65	−1.60	−1.62	2,200	16.00
	4 p. m.	13.00	13.55	47,800	27,440	75,240	89,200	−11,300	−1.40	−1.65	−1.52	1,800	14.38
	12 p. m.	11.95	12.07	43,000	25,070	68,070	77,200	−7,640	−1.05	−1.48	−1.26	1,400	12.81
20	8 a. m.	11.15	10.95	39,600	23,400	63,000	69,200	−5,070	−.80	−1.12	−.96	1,200	11.51
	4 p. m.	10.45	10.04	36,700	22,900	59,600	62,800	−3,110	−.70	−.91	−.80	920	10.50
	12 p. m.	9.85	9.30	34,200	21,950	56,150	57,700	−1,570	−.60	−.74	−.67	550	9.67

TABLE 8.—*Discharge, in second-feet, at indicated time for flood of January 1936, showing channel-storage corrections applied to snow-fed tributary discharge*

Day	Hour	Sum of groups 1-3	Column 3 adjusted for channel storage	Discharge at Salem	Valley-floor discharge
Dec. 31	12 p. m.	12,500	10,950	31,100	20,200
Jan. 1	8 a. m.	11,900	10,980	31,500	20,500
	4 p. m.	11,400	11,080	31,600	20,500
	12 p. m.	11,100	10,810	32,600	21,800
2	8 a. m.	10,800	9,750	36,100	26,400
	4 p. m.	20,400	15,870	46,900	31,000
	12 p. m.	43,500	26,960	64,700	37,700
3	8 a. m.	56,800	38,110	71,500	33,400
	4 p. m.	46,500	37,400	73,200	35,800
	12 p. m.	34,500	29,210	75,000	45,800
4	8 a. m.	27,400	24,570	78,900	54,300
	4 p. m.	41,500	38,050	87,600	49,600
	12 p. m.	57,900	47,380	98,000	50,600
5	8 a. m.	74,600	50,240	108,000	57,800
	4 p. m.	77,900	54,900	120,000	65,100
	12 p. m.	63,200	61,900	127,000	65,100
6	8 a. m.	47,500	49,400	125,000	75,600
	4 p. m.	37,400	36,130	120,000	83,900
	12 p. m.	31,600	29,060	117,000	87,900
7	8 a. m.	27,500	28,200	116,000	87,800
	4 p. m.	24,600	30,090	114,000	83,900
	12 p. m.	22,000	30,910	107,000	76,100
8	8 a. m.	20,300	30,090	96,000	65,900
	4 p. m.	19,400	27,240	84,900	57,700
	12 p. m.	18,600	23,830	75,700	51,900
9	8 a. m.	17,900	20,870	70,200	49,300
	4 p. m.	18,200	19,400	67,300	47,900
	12 p. m.	19,700	20,020	65,600	45,600
10	8 a. m.	21,800	21,370	65,600	44,200
	4 p. m.	23,200	21,020	68,500	47,500
	12 p. m.	24,600	20,620	74,100	53,500
11	8 a. m.	36,400	26,940	85,600	58,700
	4 p. m.	56,600	37,730	102,000	64,300
	12 p. m.	65,400	36,150	121,000	84,800
12	8 a. m.	66,400	49,000	137,000	88,000
	4 p. m.	52,800	38,400	150,000	112,000
	12 p. m.	46,200	27,220	162,000	135,000
13	8 a. m.	48,600	27,270	177,000	150,000
	4 p. m.	51,000	26,000	203,000	177,000
	12 p. m.	53,600	43,840	224,000	180,000
14	8 a. m.	48,000	69,100	220,000	151,000
	4 p. m.	41,400	56,100	204,000	148,000
	12 p. m.	37,000	43,900	189,000	145,000
15	8 a. m.	36,300	39,400	180,000	141,000
	4 p. m.	37,100	47,000	172,000	125,000
	12 p. m.	35,300	51,700	161,000	109,000
16	8 a. m.	32,600	48,600	150,000	101,000
	4 p. m.	29,400	40,000	138,000	98,000
	12 p. m.	27,600	33,300	127,000	93,700
17	8 a. m.	26,500	32,970	117,000	84,000
	4 p. m.	24,900	31,790	108,000	76,200
	12 p. m.	23,200	29,970	99,600	69,600
18	8 a. m.	21,300	25,890	92,600	66,700
	4 p. m.	19,700	23,780	87,500	63,700
	12 p. m.	18,300	22,560	82,700	60,100
19	8 a. m.	17,500	22,220	77,600	55,400
	4 p. m.	17,400	21,980	72,200	50,200
	12 p. m.	18,100	21,720	68,700	47,000
20	8 a. m.	18,600	21,170	66,100	44,900
	4 p. m.	19,100	21,110	64,100	43,000
	12 p. m.	18,900	20,540	61,400	40,900
21	8 a. m.	18,100	19,700	58,800	39,100
	4 p. m.	17,200	18,980	56,300	37,300
	12 p. m.	16,500	18,340	53,700	35,400
22	8 a. m.	15,700	17,620	50,900	33,300
	4 p. m.	15,000	16,630	48,200	31,600
	12 p. m.	14,600	16,160	45,400	29,200
23	8 a. m.	14,100	15,540	42,900	27,400
	4 p. m.	13,800	15,070	41,100	26,000
	12 p. m.	13,800	14,800	39,600	24,800

TABLE 9.—*Discharge, in second-feet, at indicated time for flood of April 1937, showing channel-storage corrections applied to snow-fed tributary discharge*

Day	Hour	Sum of groups 1-3	Column 3 adjusted for channel storage	Discharge at Salem	Valley-floor discharge
April 11	12 p. m.	18,400	17,750	49,100	31,400
12	8 a. m.	17,800	18,050	48,600	30,600
	4 p. m.	17,100	17,850	48,100	30,200
	12 p. m.	16,700	16,330	51,000	34,700
13	8 a. m.	16,500	13,860	59,800	45,900
	4 p. m.	22,200	15,900	72,300	56,400
	12 p. m.	43,500	31,390	87,000	55,600
14	8 a. m.	54,200	28,940	102,000	73,100
	4 p. m.	72,100	38,300	115,000	76,700
	12 p. m.	82,200	49,100	129,000	79,900
15	8 a. m.	81,200	60,000	143,000	83,000
	4 p. m.	80,200	44,100	159,000	115,000
	12 p. m.	79,600	42,600	179,000	136,000
16	8 a. m.	67,800	52,600	192,000	139,000
	4 p. m.	57,800	59,000	199,000	140,000
	12 p. m.	50,100	58,100	200,000	142,000
17	8 a. m.	43,100	57,700	197,000	139,000
	4 p. m.	37,900	58,700	188,000	129,000
	12 p. m.	33,600	54,800	174,000	119,000
18	8 a. m.	30,100	48,600	156,000	107,000
	4 p. m.	27,700	46,000	138,000	92,000
	12 p. m.	25,900	40,500	121,000	80,500
19	8 a. m.	24,300	37,100	104,000	66,900
	4 p. m.	22,900	33,100	89,200	56,100
	12 p. m.	21,400	29,980	77,200	47,200
20	8 a. m.	20,200	26,020	69,200	43,200
	4 p. m.	19,400	23,420	62,800	39,400
	12 p. m.	18,900	22,330	57,700	35,400
21	8 a. m.	18,400	21,200	54,200	33,000
	4 p. m.	18,900	20,620	51,700	31,100
	12 p. m.	19,900	21,050	50,400	29,400
22	8 a. m.	20,200	21,200	48,800	27,600
	4 p. m.	19,500	20,460	47,600	27,100
	12 p. m.	18,600	19,550	46,300	26,800
23	8 a. m.	17,800	19,300	44,500	25,200
	4 p. m.	17,100	18,610	42,700	24,100
	12 p. m.	16,500	18,180	40,800	22,600
24	8 a. m.	15,900	17,450	38,800	21,400
	4 p. m.	15,300	16,610	37,300	20,700
	12 p. m.	14,800	15,960	36,000	20,000
25	8 a. m.		15,570	34,800	19,200
	4 p. m.		15,270	33,900	18,600
	12 p. m.		15,400	33,400	18,000

TABLE 10.—*Discharge, in second-feet, at indicated time for flood of December 1937 to January 1938, showing channel-storage corrections applied to snow-fed tributary discharge*

Day	Hour	Sum of groups 1-3	Column 3 adjusted for channel storage	Discharge at Salem	Valley-floor discharge
Dec. 25	12 p. m.	10,400	10,320	34,000	23,700
26	8 a. m.	9,920	10,310	33,700	23,400
	4 p. m.	9,690	9,470	35,200	25,700
	12 p. m.	9,950	8,050	41,000	33,600
27	8 a. m.	11,900	7,890	58,000	50,100
	4 p. m.	15,800	9,430	75,900	66,500
	12 p. m.	25,800	17,680	90,400	72,700
28	8 a. m.	28,700	22,030	99,800	77,800
	4 p. m.	27,000	22,740	106,000	83,300
	12 p. m.	24,200	21,730	111,000	89,300
29	8 a. m.	22,200	20,460	119,000	98,500
	4 p. m.	21,300	19,530	125,000	105,000
	12 p. m.	22,300	18,850	136,000	117,000
30	8 a. m.	30,000	24,750	152,000	127,000
	4 p. m.	42,600	36,370	168,000	132,000
	12 p. m.	43,800	37,440	181,000	144,000
31	8 a. m.	45,100	46,100	183,000	137,000
	4 p. m.	38,300	46,800	168,000	121,000
	12 p. m.	32,500	41,160	149,000	108,000
Jan. 1	8 a. m.	28,200	34,140	132,000	97,900
	4 p. m.	25,200	32,040	119,000	87,000
	12 p. m.	22,900	30,620	107,000	76,400
2	8 a. m.	21,000	28,760	95,300	66,500
	4 p. m.	19,300	26,240	84,000	57,800
	12 p. m.	18,000	23,170	74,500	51,300
3	8 a. m.	16,900	21,330	66,700	45,400
	4 p. m.	16,000	19,500	59,700	40,200
	12 p. m.	15,100	17,820	54,300	36,500
4	8 a. m.	14,400	16,280	49,900	33,600
	4 p. m.	13,800	15,880	46,000	30,100
	12 p. m.	13,200	14,920	43,000	28,100
5	8 a. m.	12,700	14,210	40,200	26,000
	4 p. m.	12,300	13,800	37,900	24,100
	12 p. m.	11,900	13,160	36,100	22,900
6	8 a. m.	11,600	12,800	34,500	21,700
	4 p. m.	11,300	12,250	33,200	21,000
	12 p. m.	11,100	12,010	31,800	19,800

TABLE 11.—*Discharge, in second-feet, at indicated time for flood of March 1938, showing channel-storage corrections applied to snow-fed tributary discharge*

Day	Hour	Sum of groups 1-3	Column 3 adjusted for channel storage	Discharge at Salem	Valley-floor discharge
Mar. 13	12 p. m.	15, 500	13, 250	28, 500	15, 200
14	8 a. m.	16, 900	15, 440	30, 100	14, 700
	4 p. m.	16, 300	14, 910	31, 100	16, 200
	12 p. m.	15, 500	14, 740	32, 400	17, 700
15	8 a. m.	15, 300	14, 020	33, 800	19, 800
	4 p. m.	17, 100	13, 700	37, 800	24, 100
	12 p. m.	18, 600	13, 770	43, 400	29, 600
16	8 a. m.	20, 200	12, 750	53, 000	40, 200
	4 p. m.	25, 300	15, 030	66, 400	51, 400
	12 p. m.	29, 900	20, 430	77, 300	56, 900
17	8 a. m.	31, 800	26, 970	82, 900	55, 900
	4 p. m.	28, 600	25, 540	86, 000	60, 500
	12 p. m.	25, 500	23, 700	87, 900	64, 200
18	8 a. m.	23, 000	21, 730	92, 200	70, 500
	4 p. m.	21, 500	18, 300	100, 000	81, 700
	12 p. m.	24, 700	15, 980	110, 000	94, 000
19	8 a m.	39, 700	24, 830	123, 000	98, 200
	4 p. m.	47, 200	30, 690	136, 000	105, 000
	12 p. m.	47, 100	46, 200	143, 000	96, 800
20	8 a. m.	38, 790	39, 700	143, 000	103, 000
	4 p. m.	32, 100	29, 030	140, 000	111, 000
	12 p. m.	27, 700	25, 090	140, 000	115, 000
21	8 a. m.	24, 500	26, 010	142, 000	116, 000
	4 p. m.	22, 300	30, 190	142, 000	112, 000
	12 p. m.	20, 600	30, 970	136, 000	105, 000
22	8 a. m.	19, 000	30, 510	124, 000	93, 500
	4 p. m.	17, 700	28, 640	109, 000	80, 400
	12 p. m.	16, 700	24, 360	96, 200	71, 800
23	8 a. m.	16, 900	17, 100	87, 900	70, 800
	4 p. m.	18, 400	14, 920	84, 900	70, 000
	12 p. m.	22, 700	22, 790	83, 700	60, 900
24	8 a. m.	22, 300	21, 220	84, 500	63, 300
	4 p. m.	21, 900	19, 690	87, 000	67, 300
	12 p. m.	21, 800	20, 880	88, 800	67, 900
25	8 a. m.	21, 100	21, 610	89, 600	68, 000
	4 p. m.	20, 800	22, 700	88, 300	65, 600
	12 p. m.	20, 500	23, 710	85, 500	61, 800
26	8 a. m.	19, 500	23, 000	81, 700	58, 700
	4 p. m.	18, 600	21, 670	77, 600	55, 900
	12 p. m.	17, 900	21, 380	73, 400	52, 000
27	8 a. m.	17, 000	20, 610	68, 800	48, 200
	4 p. m.	16, 400	19, 350	64, 700	45, 400
	12 p. m.	16, 100	18, 860	60, 600	41, 700
28	8 a. m.	15, 800	17, 980	57, 400	39, 400
	4 p. m.	16, 400	17, 100	56, 000	38, 900
	12 p. m.	17, 200	18, 130	54, 500	36, 400
29	8 a. m.	17, 200	17, 690	53, 400	35, 700
	4 p. m.	16, 500	16, 720	52, 900	36, 200
	12 p. m.	15, 700	16, 560	51, 700	35, 100
30	8 a. m.	15, 000	16, 250	50, 200	34, 000
	4 p. m.	14, 500	15, 910	48, 000	32, 100
	12 p. m.	13, 800	15, 300	45, 500	30, 200
31	8 a. m.	13, 300	14, 710	43, 500	28, 800
	4 p. m.	12, 800	14, 260	41, 300	27, 000
	12 p. m.	12, 400	13, 830	39, 200	25, 400

Similar computations were made for the floods of December 1935 and March 1936, from which the distribution graphs were derived. All hydrographs of valley-floor discharge were computed in the above manner from the measured discharge at the selected gaging stations, and the resulting discharge was treated as discharge from an ordinary river basin.

UNIT-HYDROGRAPH STUDIES

The following unit-hydrograph studies were based on the methods described by Bernard [11] in Water-Supply Paper 772.

The lower part of the Willamette Basin is well supplied with precipitation stations, but the higher areas are not. As shown by the map on figure 16, there are several stations near the summits of the Coast Range and the Calapooya Mountains but only two in the upper Cascade Range. The stations used in studying the valley-floor runoff are evenly distributed. Seventeen stations were used in determining the rainfall in the valley, an average of one station for each 275 square miles of drainage area. A straight arithmetic mean was used, no attempt being made to weight the observations according to areas represented.

The discharge was computed using an 8-hour time unit, and likewise the daily rain-gage readings were divided into corresponding 8-hour periods. Most of the rain gages are read at 8 a. m. but some are read in the evening, usually about 5 o'clock. There was one recording rain gage in the drainage basin at Corvallis. On the basis of the rainfall distribution shown by this continuous record it was possible to distribute the rainfall at the individual stations, as recorded either from 8 a. m. to 8 a. m. or 5 p. m. to 5 p. m., into amounts in the periods, midnight to 8 a. m., 8 a. m. to 4 p. m., and 4 p. m. to midnight. The distribution shown by the record at Corvallis was found to be closely similar to that of the continuous record at Portland. The totals were not the same, but the relative amounts falling during given periods were similar, and this similarity created confidence in the reliability of the results obtained by the above procedure. The computed 8-hour quantities at the several rain gages were averaged to obtain the mean rainfall on the valley floor above Salem.

During the period of record studied, only two storms suitable for derivation of a distribution graph had occurred. In that of December 1935 most of the rain occurred in one 8-hour period, and in that of March 1936 the rain was included almost entirely in two 8-hour periods. It was fortunate to find two such storms with 1.57 inches and 1.71 inches of rain, respectively, confined in the short time period. In the climate of the Willamette Valley, it is seldom that a storm is limited to one or two 8-hour periods. The usual storm comes in from the ocean and causes rain over a period of a week or more. The distribution of the runoff for the two floods was based on an 8-hour unit period, and the average of the two was used for determining the distribution graph. (See figs. 17, 18.) The discharge data for these

[11] Hoyt, W. G., and others. Studies of relations of rainfall and runoff in the United States, U. S. Geol. Survey Water-Supply Paper 772, pages 123–244, 1936.

floods were corrected for snow-fed tributary runoff so that the distribution graphs are for valley-floor runoff only and represent the distribution of direct runoff into the channel of the Willamette River from the valley floor as defined.

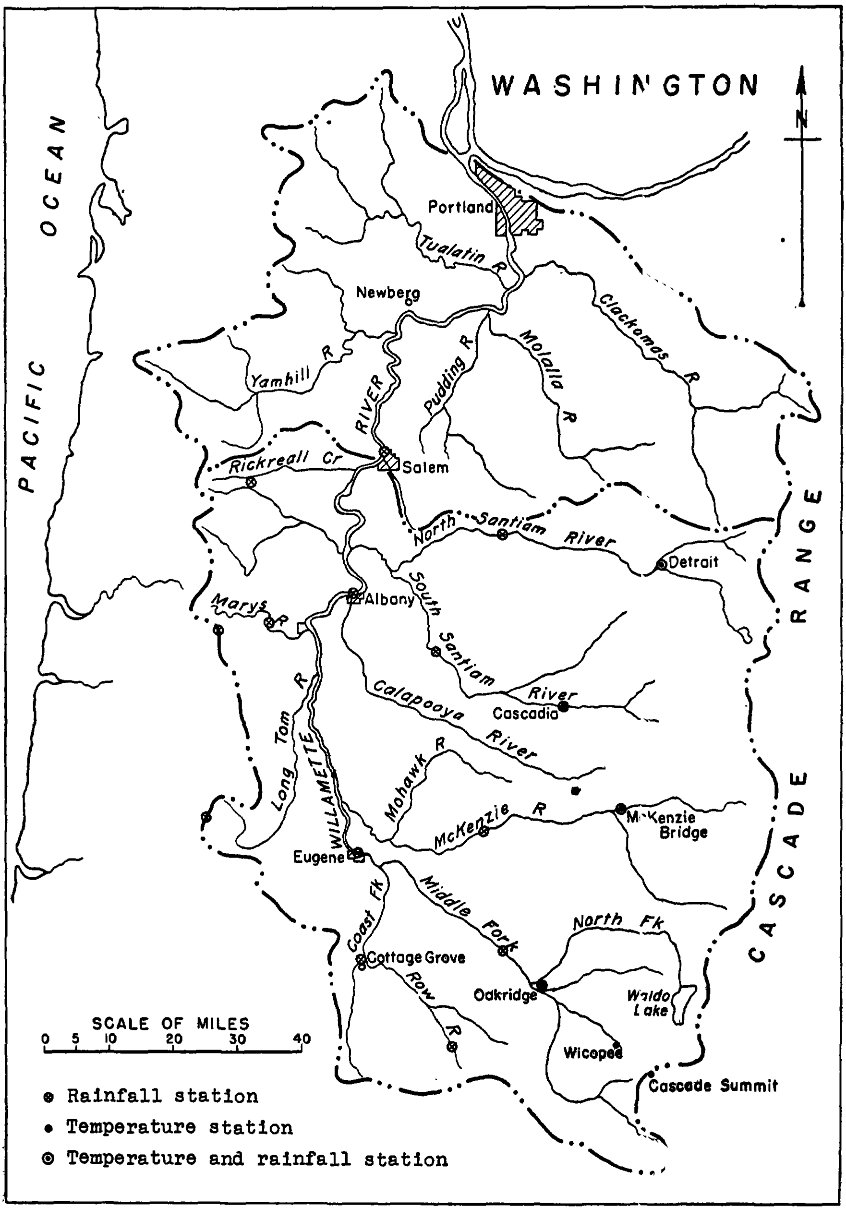


FIGURE 16.—Map showing rainfall and temperature stations used for unit-hydrograph and snow-fed tributary studies.

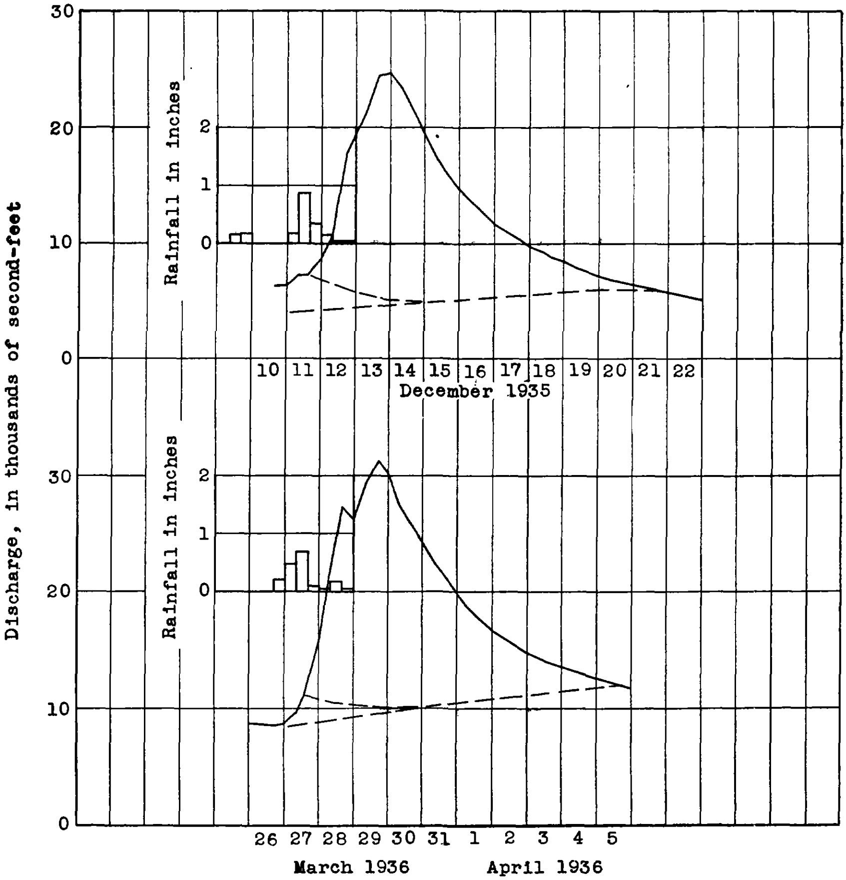
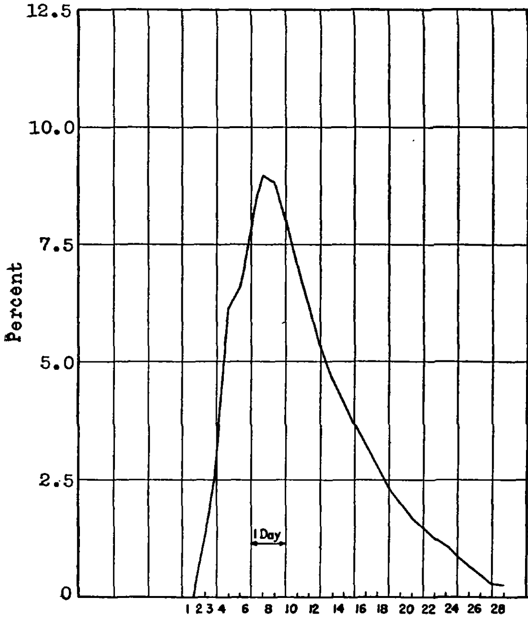


FIGURE 17.—Hydrographs of valley-floor discharge associated with unit storms of December 1935 and March 1936.

When the distribution graph was determined, it was a mechanical process to compute the pluviagraphs [12] for the four storms studied. Figures 19, 20, 21, and 22 show the pluviagraphs, the actual discharge, and the discharge as computed by using the "flood coefficient" for each storm. As explained in Water-Supply Paper 772 [13], the flood coefficient was the ratio of observed peak discharge to the maximum pluviagraph discharge. In all storms the ground water was estimated from the discharge previous and subsequent to the storm, and the runoff from ground water and antecedent rainfall was eliminated.

The basic and computed data for these graphs have been shown in tables 8, 9, 10, and 11.

[12] Hoyt, W. G., op. cit., pp. 123–244.
[13] Hoyt, W. G., op. cit., p. 218.



Distribution of discharge

Period	At end of period
1	0
2	1.4
3	3.4
4	6.2
5	6.6
6	7.8
7	9.0
8	8.8
9	8.0
10	7.1
11	6.2
12	5.4
13	4.8
14	4.1
15	3.6
16	3.2
17	2.7
18	2.3
19	2.0
20	1.6
21	1.4
22	1.2
23	1.0
24	0.8
25	0.6
26	0.4
27	0.2
28	0.2

First period is one in which greatest amount of rain fell.

FIGURE 18.—Distribution graph of valley-floor discharge at Salem based on 8-hour unit time.

The graph for the flood of January 1936 shows the effect of a previous rise. The autumn of 1935 was deficient in precipitation, the western division of Oregon showing about 2 inches less than normal for the month of December. However, the river had one small rise about the middle of the month. When the rains of the first 4 days of January came, the resulting high water had a flood coefficient of 0.63. Then the light rains of January 5–9 were followed by heavy rains for the next 3 days, and the resulting flood coefficient was 1.00. This coefficient, although very high, is believed to be possible because it is only the ratio of discharges at the peak. The runoff is not 100 percent of the rainfall for the duration of the storm, as can be seen on the flood hydrograph. It is believed that very high flood coefficients are possible following 2 or 3 weeks of steady rain. Moreover, the previous rise had filled a great deal of bank storage in the river channels, a condition which was favorable to a high flood coefficient on January 13. This storm also illustrates the progressive increase of the flood coefficient during a flood.

The storm of April 1937 followed a fairly wet winter in the Willamette Basin, the considerable snowfall of January and February having soaked the ground throughout the valley. March was slightly deficient in precipitation, but the ground was kept wet by frequent light rains. During the first 10 days of April there were light rains which were not sufficient to cause a rise in the river at Salem, but when the heavy rains of April 12, 13, and 14 came, the ground was already soaked, and the flood peak of April 16 had a coefficient of 0.87.

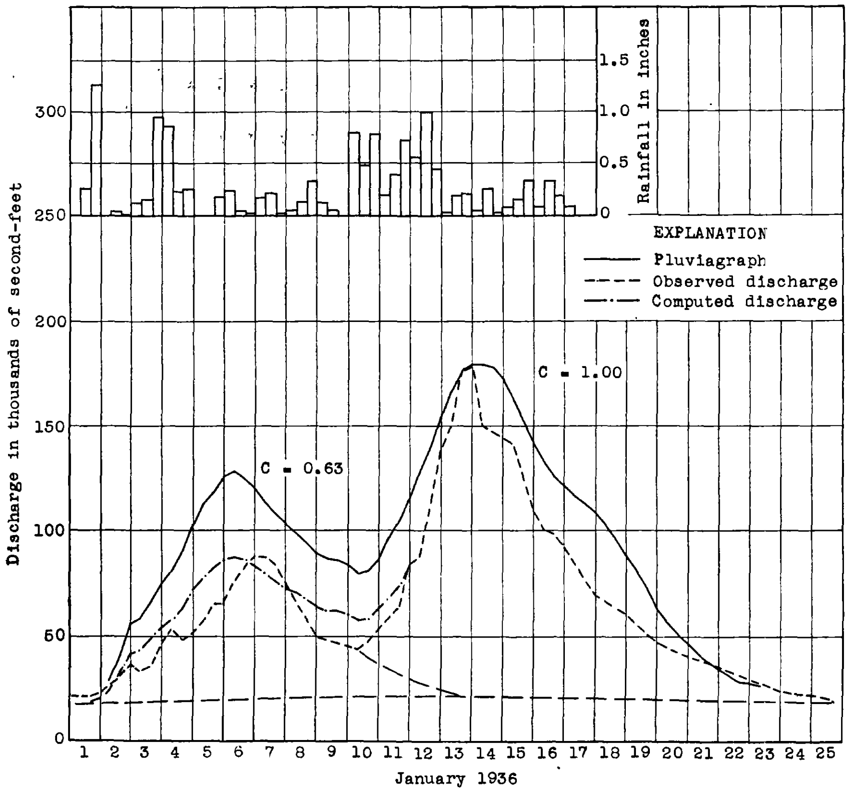


FIGURE 19.—Hydrographs of valley-floor discharge at Salem for flood of January 1936.

The flood of December 1937 to January 1938 was the result of 4 days of rain, 2 days of heavy rain coming in succession, followed by a day of light rain and another day of heavy rain. This was after 2 months of greater than normal precipitation. In the western division of Oregon, November and December 1937 had excesses of 5.82 and 2.81 inches, respectively. In November there was a medium rise of the Willamette River, but early in December the rainfall was scattered with no sharp increases in stage. The steady rains built up the ground water runoff, but apparently did not produce much direct runoff. The concentrated rain of 6.13 inches in 4 days, December 26–29, produced the peak of December 30. This flood had a coefficient of 0.86, which agrees closely with the value obtained during the April 1937 flood.

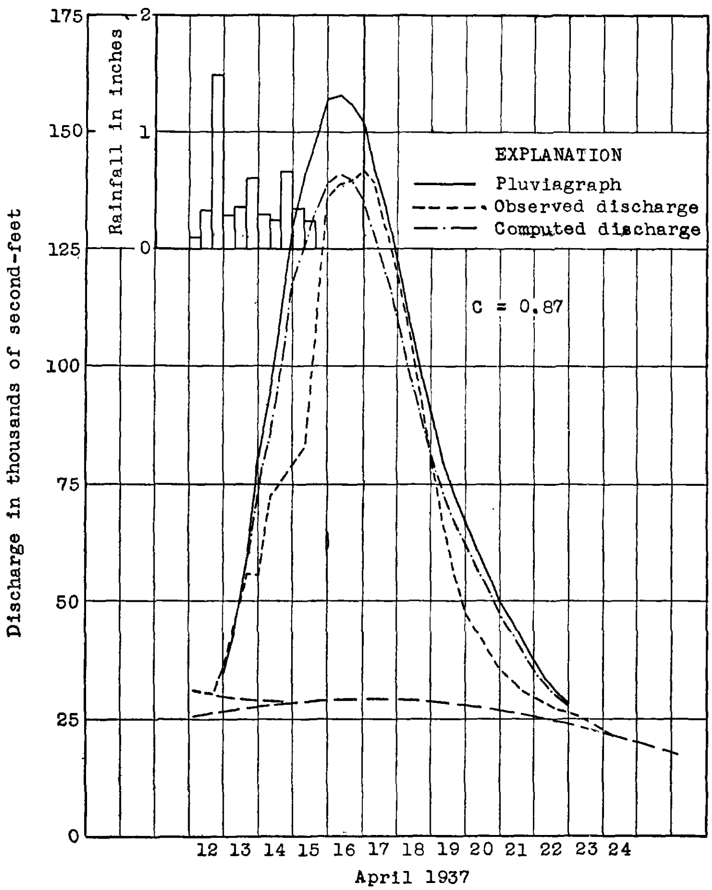


FIGURE 20.—Hydrographs of valley-floor discharge at Salem for flood of April 1937.

In March 1938 a rise occurred that had a peak considerably lower than that of the other floods studied, but it was felt that the flood coefficient obtained from this storm would be of interest because it took place following a drier period than was true of the previous storms. As all winters are wet in the Willamette Valley, the dryness is only comparative. There was a great deal of rain in the first 2 weeks of February, but little during the last 2 weeks of that month and the first 2 weeks of March, thus permitting the surface soil to dry out. Following this short dry period the precipitation of March 14–22 produced a flood that reached a peak on the 21st. This storm was spread out more than the previous storms studied. The combination of these factors resulted in a flood coefficient of 0.69, which is considerably less than the coefficients of the other storms.

A study of the above floods indicates that the rainfall of the preceding 30 days seems to have had a great effect on the flood coefficient. If the main storm is preceded by a week or two of rainy weather, it appears that the flood coefficient will be high, as in the floods of April 1937 and December 1937 to January 1938. However, even if the total winter rainfall is normal or above normal and there are 3 or 4 weeks of dry weather preceding the storm, the coefficient may be about 0.70 as in March 1938.

Preceding the first rise of January 1936 there had been a very dry fall, and evidently the light rains of the first part of December 1935 had not wet the ground to a high degree. Although the coefficient for that rise is only 0.63, the storm soaked the ground to produce the high coefficient for the peak of January 13.

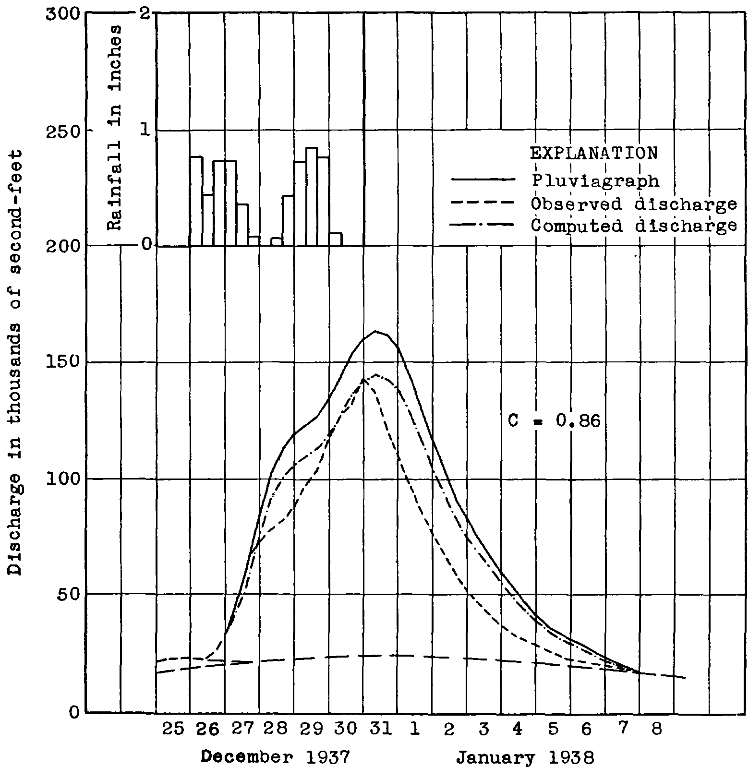


FIGURE 21.—Hydrographs of valley-floor discharge at Salem for flood of December 1937–January 1938.

The magnitude of the rains of the 2 or 3 months preceding a flood do not seem to have so large an effect on the size of the flood coefficient, and similarly the basin retention, unless they occur just previous to the subsequent flood. Soil moisture conditions are the result of the cumulative effect of precipitation, evaporation, and transpiration over a long period, but the 3 or 4 weeks immediately preceding a storm determine to a substantial degree the retention for any given flood.

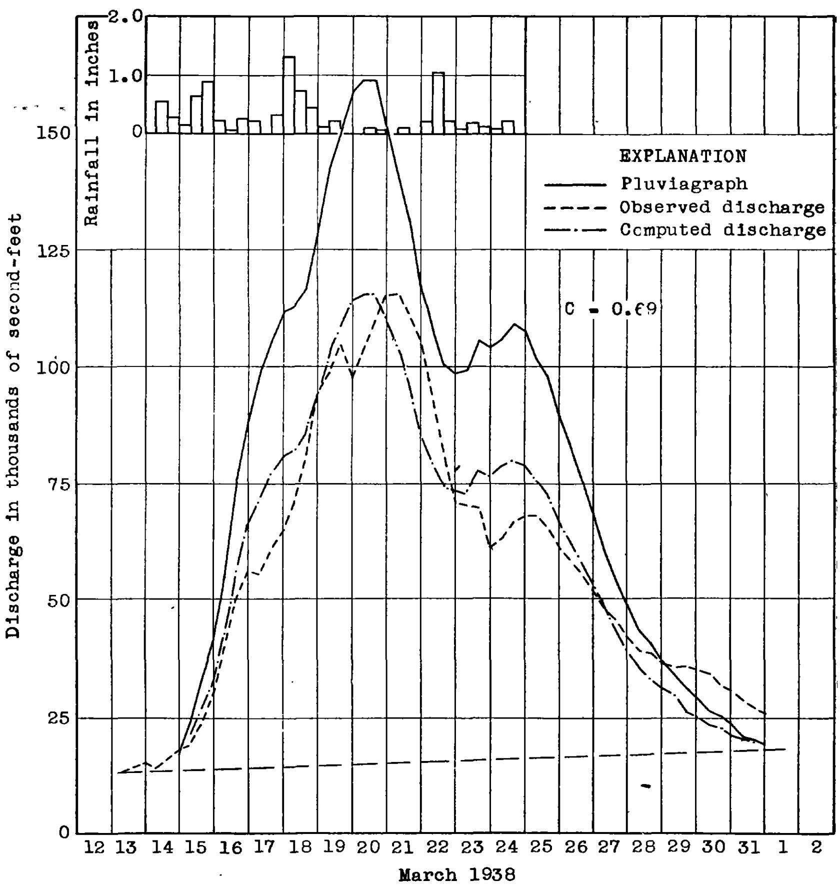


FIGURE 22.—Hydrographs of valley-floor discharge at Salem for flood of March 1938.

In determining retention, the condition of the soil seems to be the controlling factor. The absence of any definite seasonal trend, as noted by Bernard in Water-Supply Paper 772, can be attributed to the fact that storms in the Willamette Valley occur only during the winter.

SNOW-FED TRIBUTARIES

In the snow-fed tributaries, eliminated from the unit-hydrograph studies of discharge of the Willamette River at Salem, no definite relation between precipitation and runoff exists. Different types of winter storms, based on temperature, relative distribution of rain and snow, and presence or absence of snow cover, may produce divergent results, as described in the following two paragraphs. Either condition makes the determination of runoff from precipitation records alone practically impossible.

During one type of storm some of the precipitation may fall as rain and some as snow. The rain if not absorbed by the snow blanket produces immediate runoff in a manner probably similar to that of the valley floor. Snowfall does not cause any appreciable runoff until it melts, except for marginal areas between the rainfall and snowfall where both occur together and melting is instantaneous or where the snow may be carried by the runoff from the rain. Usually the snow accumulates on the ground and remains until melted by a subsequent thaw. Under these conditions only part of the tributary area actively contributes to runoff. Available records are generally inadequate to determine the relative amounts of rainfall and snowfall or the amount of antecedent snow cover and the portion melted; thus comparisons with runoff are impracticable. If the limits of that part of the drainage basin in which only rain is falling were defined, the precipitation could be compared with the runoff by the methods described in the preceding section. The discharge from the area in which only snow occurs could be estimated or neglected if it did not seem appreciable.

During storms accompanied by warm temperatures precipitation in the form of rain occurs at higher altitudes, falling on snow already on the ground. Rapid melting of snow caused by the combination of thawing weather and rain produces runoff in excess of that due solely to rain. Thus the unit-hydrograph flood coefficient, when developed from rainfall alone for this condition, would be more than unity. The situation of rain falling on snow is further complicated by the absorption of rain by the snow. In snow that is more than 3 to 4 feet deep, unless the temperature is high enough to melt the snow, the rain may be absorbed and stored in the snow, and no immediate runoff follow. Shallow snow ordinarily is melted by atmospheric heat and by rain. In the absence of sufficient data for an accurate quantitative analysis of runoff from the snow-fed tributaries of the Willamette River Basin, the present studies were limited to determine if any general relation existed between temperature and runoff that could be used as an aid in studying flood flows.

In order to study runoff in the snow areas the temperatures in these areas were determined, and the six stations shown on the map of precipitation stations (fig. 16) were available for this purpose. Four of the stations, Cascadia, Detroit, McKenzie Bridge, and Oakridge, are at the lower limit of the snow area; the other two, Wicopee (altitude, 2,880 feet) and Cascade Summit (altitude, 4,840 feet), are in the region of prevalent winter snowfall.

During the four storm periods, in order to study the lapse in temperature due to altitude, the mean temperatures at the three stations in the Cascade Mountains, namely, Cascade Summit, Wicopee, and Oakridge, were plotted against altitude as shown on figure 23. The three stations selected are closely grouped and show the decrease in temperature with increase in altitude reasonably well. The daily values varied too much to plot, but the 8- to 11-day averages for the storm periods show a definite trend. Wicopee is 1,600 feet higher and 4° colder than Oakridge; Cascade Summit is 2,000 feet higher and 10° colder than Wicopee. The relationship shown on figure 23 was then used in the computation of mean temperature in the snow-fed tributary basins.

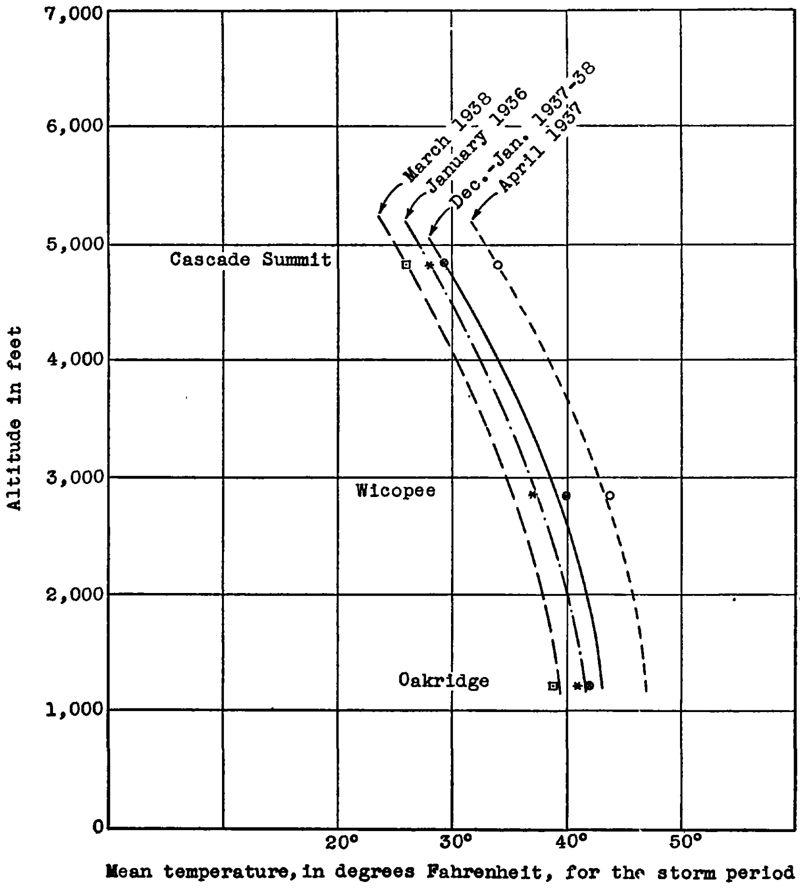


FIGURE 23.—Temperature lapse with altitude at 3 stations in the Cascade Mountains.

The relative discharges in second-feet per square mile of the snow-fed tributaries and the valley floor for the floods previously examined are shown in figure 24. The corresponding temperatures are plotted to show the fluctuation of flow in relation to temperature. In figure 25 the ratio of the valley-floor peak discharge to that of the snow-fed

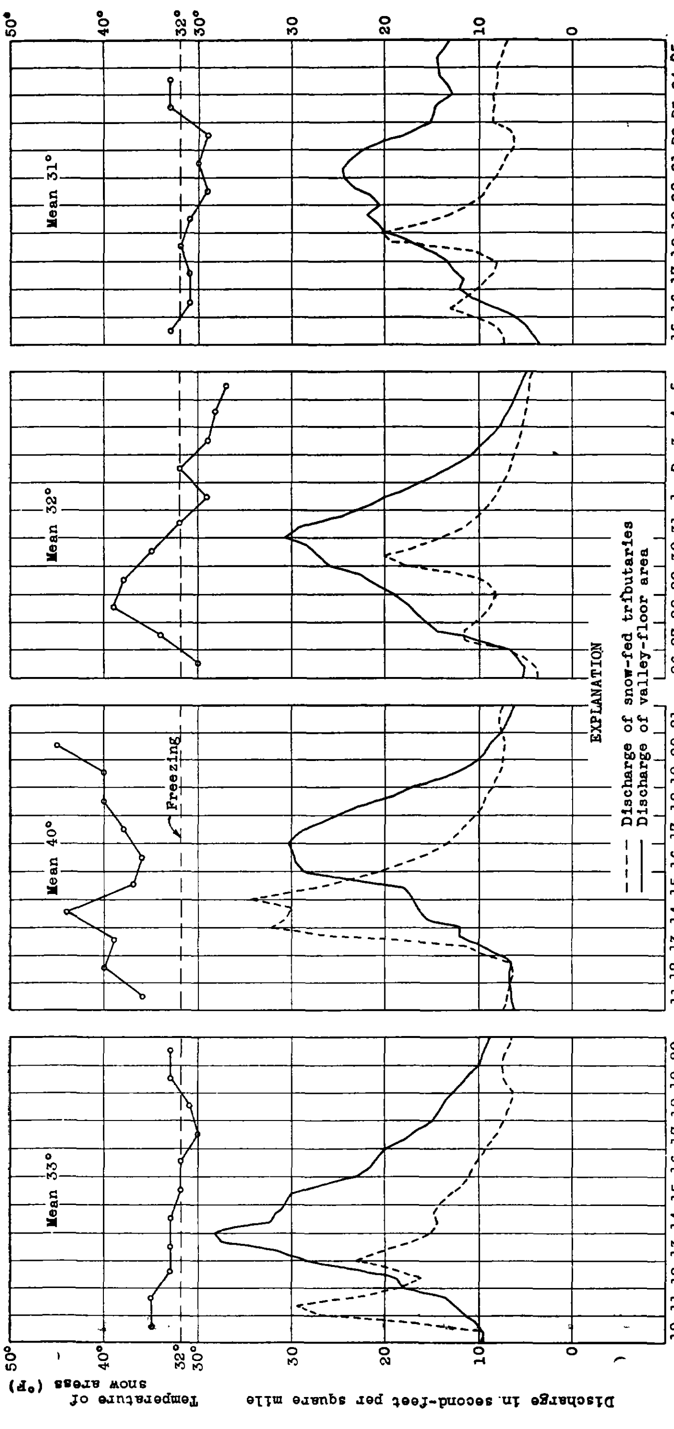


FIGURE 24.—Hydrographs of discharge from valley-floor and snow-fed tributaries with mean temperatures of snow areas.

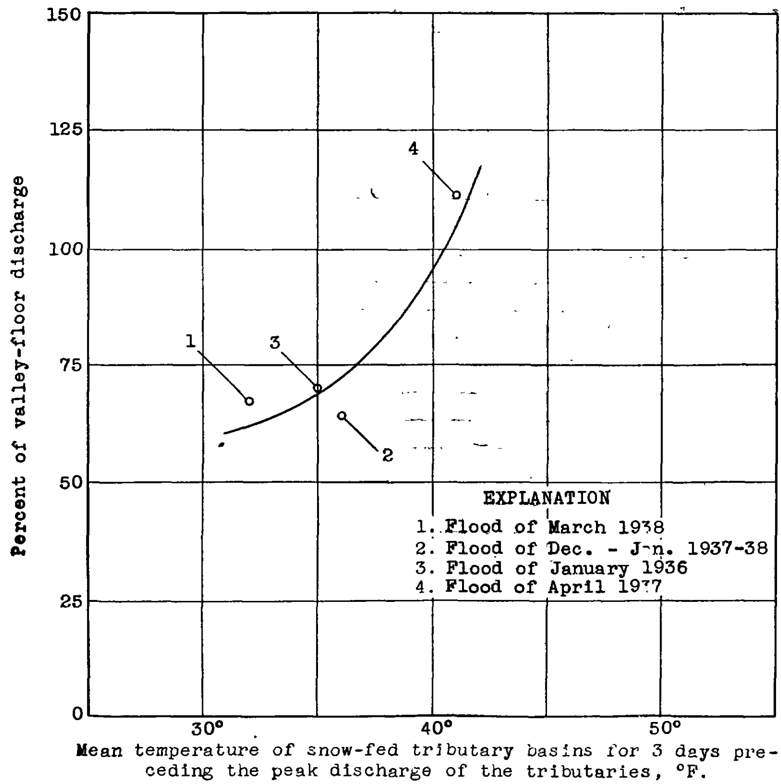


FIGURE 25.—Relation between temperature and maximum discharge from snow-fed tributaries.

tributaries above base flow, both expressed in second-feet per square mile, is plotted against the mean temperature of the 3 days preceding the peak flow of the tributaries. The points merely suggest the trend of temperature effect. More refined data and many more points would be needed to establish a definite relation. However, the curve shows that the higher temperatures prevailing during the flood of April 1937 resulted in relatively greater discharges from the snow areas than occurred during the floods of March 1938 and January 1936 when lower temperatures prevailed. The ratio of maximum discharges of snow-fed tributaries to valley-floor discharge was slightly more than unity in April 1937 and about 70 percent for the cooler periods in March 1938 and January 1936.

The April 1937 flood, with a mean temperature of 40° F. on the snow areas for the storm period and a mean of 41° F. for the 3 days preceding the peak, had a peak discharge in second-feet per square mile from the snow-fed tributaries of 111 percent of that discharge from the valley floor. The March 1938 flood peak discharge in second-feet per square mile from the snow areas was only 66 percent of the valley-floor maximum discharge. The mean temperature of this storm period for the snow areas was 31° F., that of the 3 days preceding the peak flow, 32 degrees.

Figure 26 shows the large differences in the discharges of the three groups of snow-fed tributaries. The discharge in second-feet per square mile of Santiam Basin (group 3) is about twice that of the McKenzie River or Middle Fork of Willamette River Basins (groups 2 and 1, respectively). This excess is caused in part by greater amounts of precipitation. The Middle Fork drainage area is protected from the full force of the storms, and as a result has much less precipitation than the Santiam or the McKenzie areas. The precipitation in the upper McKenzie River drainage basin is very little less than in the Santiam Basin, but lake storage and underground storage provided by the lava beds in the headwaters of the McKenzie reduce flood runoff to a large extent and this is reflected in a well-sustained summer flow. The relative amounts of discharge from the three groups shown on the hydrographs are in the same order as their average annual runoff, which is as follows: Group 1, 39.6 inches; group 2, 55.6 inches; and group 3, 66.4 inches.

CONCLUSIONS

That part of this report dealing with the study of the floods of 1909, 1923, 1927, and the miscellaneous floods has been included to indicate the magnitude of the rare floods that characterize the streams of this area. As may be noted from tables 2, 3, 4, and 5, the rates and volumes of flood discharge for different rivers vary widely. This variation is generally attributable to the location of the basins in relation to mountains and the prevailing wind. Because of the complex situation it seems that any broad generalization as to maximum runoff for western Oregon would be difficult and perhaps misleading. However, values for rare floods can be approximated for specific drainage basins of this region.

In table 5, the flood runoff in inches for the 1861 flood on the Willamette River at Salem has been estimated from the peak discharge, which was determined from a floodmark and the general shape of flood hydrographs. The only information available for determining the shape of the hydrograph for this flood is a general description from the newspaper files. On the basis of this information the total direct runoff was estimated at 13 inches. This flood was the greatest ever known on the Willamette River, exceeding all others by a considerable amount, and therefore, it may be concluded, a single rise only rarely would produce runoff greatly in excess of this amount.

For the streams draining the western slope of the Coast Range the highest measured runoff was from the Wilson River near Tillamook in

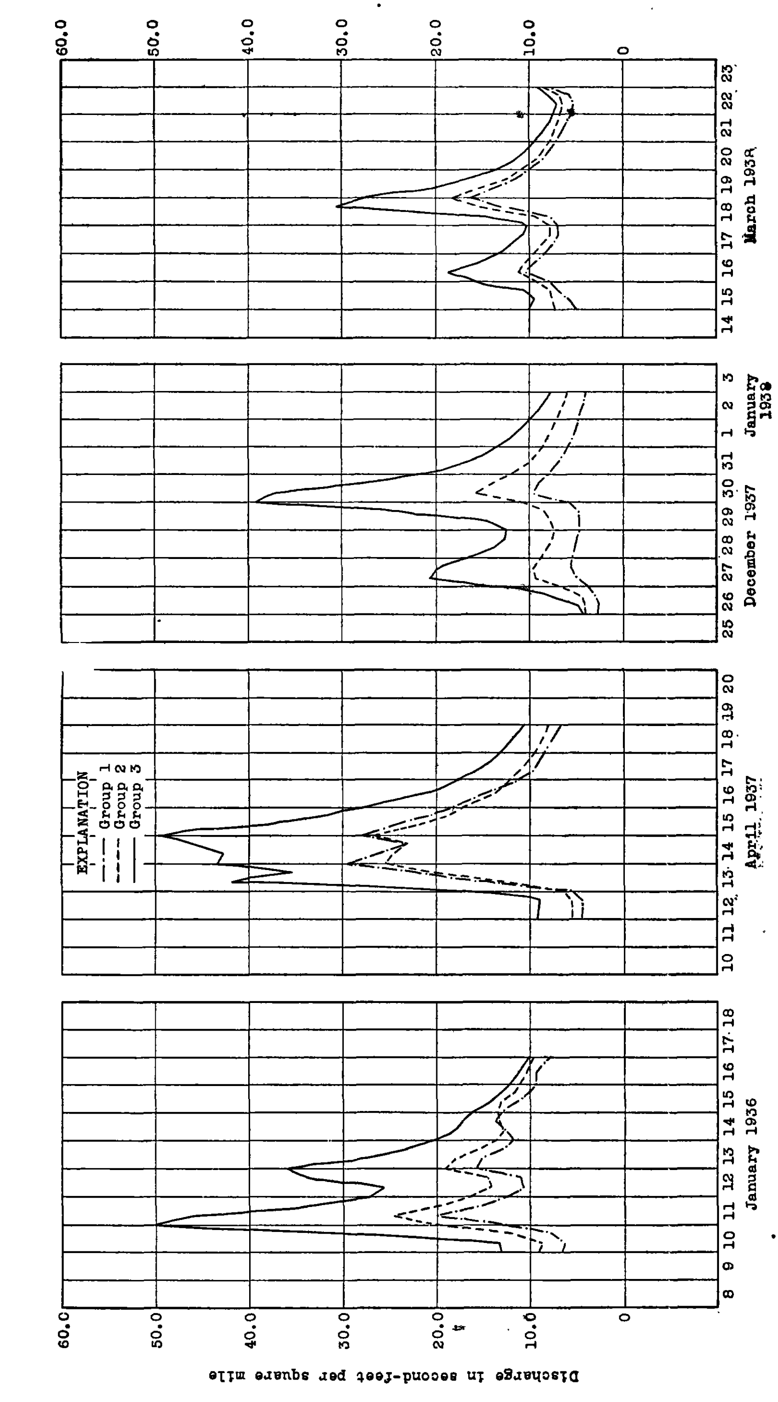


FIGURE 26.—Discharges of the snow-fed tributaries during floods of January 1936, April 1937, December 1937 to January 1938, and March 1938

December 1933, when the river discharged an equivalent of 26.7 inches from the drainage area of 162 square miles. As the basins in that locality are exposed to the full force of southwest storms, the rainfall can be very intense and can continue for a week or two. The runoff records of rivers in the section do not extend back much more than 10 years with the exception of the Siletz River at Siletz, which has a continuous record since 1924 and a record of a few years from 1906 to 1911. In view of the high intensity of these coastal storms, it would seem that a flood runoff of from 30 to 35 inches, solely from rain, might not be impossible for rivers west of the Coast Range and north of the Yaquina River. A flood of this magnitude might have two or three peaks coming quite close together but still could be classed as a single rise, as illustrated by the hydrograph of the Wilson River on figure 8. Runoff from the rivers of southern Oregon is less than that of rivers of the same size in the Willamette Valley. The 1909 and 1927 floods in southwestern Oregon are the largest of record there but were generally exceeded in the Umpqua River Basin by the flood of 1861 and in the Rogue River Basin by the flood of February 1890. The maximum probable flood in this region would undoubtedly be less than in the Willamette Valley or the coastal area.

The detailed study of flood runoff in the Willamette Valley was made as an attempt to determine some of the characteristics of flood flow for this basin. As the flood runoff comes from two sources, snow and rain, it seemed logical to divide the drainage basins into two parts. The line of separation of the two parts was by necessity determined by the location of existing gaging stations.

From the studies made in the Willamette Valley it has been determined that there is little basin retention during the flood season for streams in this area. This is caused by the heavy and relatively continuous rainfall in winter and the resulting saturation of the ground. It must be kept in mind that the floods studied by the unit-hydrograph method in this report are not great but merely moderate floods. The peak discharges at Salem for the floods studied averaged about 200,000 second-feet, as against a maximum flood of record of 500,000 second-feet, and two or three floods of 300,000 to 400,000 second-feet.

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