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WATER RESOURCES OF THE PORTLAND, OREGON, AND VANCOUVER, WASHINGTON AREA

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WATER RESOURCES OF THE PORTLAND, OREGON, AND VANCOUVER WASHINGTON, AREA

By W. C. Griffin, F. A. Watkins, Jr., and H. A. Swenson

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PREFACE

This report is one of a series concerning the water resources and present water utilization of selected industrial areas of national importance. The reports have been prepared at the request of and in consultation with the Water and Sewerage Industry and Utilities Division of the Business and Defense Services Administration of the Department of Commerce. The series is designed to serve the dual purpose of providing basic information for national defense planning and at the same time to render a valuable service to business and industry in their development of water resources for present and future use. These reports are prepared in the Water Resources Division. This report was prepared by W. C. Griffin, under the supervision of K. N. Phillips and F. M. Veatch, district engineers (Surface Water); F. A. Watkins, Jr., under the supervision of R. C. Newcomb, district geologist (Ground Water); and H. A. Swenson, district chemist (Quality of Water).

Most of the data summarized in this report were collected over a period of many years by the U. S. Geological Survey in cooperation with Federal, State, and local agencies. In Oregon the surface-water investigations in the area considered in this report are conducted by the U. S. Geological Survey in cooperation with the State Engineer, the State Highway Department, the State Fish Commission, the city of Portland, the U. S. Bureau of Reclamation, and the Corps of Engineers, Department of the Army. In Washington such investigations are conducted in cooperation with the Division of Water Resources of the State Department of Conservation and Development, and the respective State Departments of Highways, Fisheries, and Game. Most ground-water studies in Oregon are made in cooperation with the State Engineer, and in Washington in cooperation with the Division of Water Resources of the State Department of Conservation and Development. Other studies have been made on behalf of the U. S. Bureau of Reclamation. In recent years several important investigations have been made as part of the nationwide Federal program of the Geological Survey. Part of the geologic information used herein was derived from an investigation of the Portland metropolitan area now underway by the U. S. Geological Survey.

Chemical data were obtained largely from records of the Geological Survey, and for the period 1910–12, from cooperative investigations with the Oregon State Engineer. The Charlton Laboratories, Portland, Oreg., furnished considerable analytical data on water supplies in the area. Information on river water temperatures and river stages for Columbia River at Vancouver and Willamette River at Portland was obtained from the United States Weather Bureau and from the Portland district, Corps of Engineers.

Most information on water used by industry is from recent reports of the United States Public Health Service, prepared in cooperation with the Oregon State Sanitary Authority and the Washington State Pollution Control Commission.

Many individuals furnished detailed information on the water supply within the areas they serve. Special acknowledgment is due C. M. Everts, Jr., Oregon State Sanitary Authority; Ben S. Morrow, city of Portland Bureau of Water Works; E. S. Ellison, U. S. Weather Bureau; F. M. Lewis, Corps of Engineers; Prof. Fred Merryfield, Oregon State College; E. C. Jensen, Washington State Department of Public Health; and R. R. Harris, U. S. Public Health Service.

CONTENTS

ILLUSTRATIONS

TABLES

WATER RESOURCES OF THE PORTLAND, OREGON, AND VANCOUVER WASHINGTON, AREA

By W. C. Griffin, F. A. Watkins, Jr., and H. A. Swenson

ABSTRACT

The water supply available to the Portland-Vancouver area exceeds requirements for any foreseeable industrial expansion. Surface water is used for the municipal supply of Portland, Oreg., and is distributed by this city to many water districts and smaller communities in the metropolitan area. Vancouver, Wash., is the largest user of ground water in the area. Some cities in the area use surface water for the main supply and water from wells to supplement the main supply during periods of peak demand. The combined daily requirements of surface and ground water for municipal, industrial, and irrigational uses in the Portland-Vancouver area in 1953 is estimated as 375 million gallons. About 75 mgd (million gallons per day) is used for municipal supplies. Industrial requirements are computed as 255 mgd, of which more than 170 mgd is used by paper and pulp manufacturers. The use of water for irrigation is about 45 mgd, averaged for a 12-month period, of which two-thirds is estimated to be surface water.

Surface water flows through the report area at an average rate in excess of 150,000 mgd, and the minimum rate, under present conditions of reservoir regulation, is estimated to be at least half the average. The estimate of the minimum is conservative as it is based on the assumption that low flows would occur simultaneously on all streams in the area, whereas the flow regimen of the Columbia River at The Dalles is such that minimum flows are most likely to occur during the winter, a time when flows in the smaller streams in the report area are high.

Less than 15 percent of the average flow of Bull Run River at the water-system headworks is used. The supply is adequate for considerable future expansion provided development of additional reservoir storage within the basin is feasible.

Both surface and ground sources, with few exceptions, yield water of satisfactory quality for most uses. Water from the Columbia River contains dilute concentrations of dissolved solids and is moderately hard. Waters from tributary streams in this area contain much smaller concentrations of mineral solids and are very soft. The maximum dissolved solids concentration of waters from 12 tributary streams was 61 ppm (parts per million), and the maximum hardness, 25 ppm. The Bull Run River, heading in the western slopes of the Cascade Range and the major source of municipal supply, furnishes a water of excellent quality. In a few streams turbidity and color cause some seasonal difficulty in operation of treatment plants.

Ground-water supplies are generally of good quality. Several cities pump water from the Columbia River basalt or from sand and gravel deposits. Ground water in the Portland-Vancouver region is generally harder and more mineralized than the surface water, and some of it contains objectionable quantities of iron. The Troutdale formation and Boring lava yield soft to slightly hard water having moderate mineral content and good quality. Ground water from the marine sedimentary rocks of Tertiary age is brackish and unsatisfactory for domestic and industrial use. Raw water from wells is used extensively for cooling and condensing. The advantage of ground water for cooling is its uniformly cool temperature.

The municipalities listed in this report supply water of better quality than the minimum drinking-water standards prescribed by the U. S. Public Health Service for water used by commercial carriers in interstate commerce.

INTRODUCTION

Purpose

The purpose of this report is to summarize the available information on water for the Portland-Vancouver area in a form useful for initial guidance in the planning of additional industrial and municipal supplies and defense needs in the event of national emergency. To accomplish this end, this report summarizes the available streamflow data in the area including information on the magnitude and frequency of floods. The quantity and quality of ground-water supplies are evaluated so far as these are disclosed by available information, and chemical quality and other data on public water supplies are given. No attempt has been made to present the complete record of the hydrology of the area.

Description of the Area

The area considered in this report includes all of Clark County, Wash., practically all of Washington and Multnomah Counties, Oreg., and parts of Clackamas, Columbia, and Yamhill Counties, Oreg., and a small part of Cowlitz County, Wash. It comprises an area of 2,600 square miles and is roughly the shape of an inverted T with the maximum north-south distance being about 52 miles and the maximum east-west distance being about 60 miles. (See pl. 1.) Portland, Oreg., and Vancouver, Wash., are the largest cities in the area.

Topography and Drainage

The area is characterized by three main types of topography: the Cascade Range on the eastern edge of the area, the major river valleys and the adjacent low-lying land in the central part, and the Coast Ranges at the western edge. The lower slopes of the Cascade Range at the eastern edge of the area rise to an altitude of about 4,500 feet, and flood plains of the Columbia River in the central part of the area have a minimum altitude of about 20 feet. The foothills of the Coast Ranges at the western edge of the area reach a maximum altitude of about 2,000 feet. Maximum relief, therefore, is nearly 4,500 feet.

The major rivers of the area are the Columbia and Willamette. The Columbia River enters the area in the gorge near the center of the eastern boundary and flows westward through the lowlands to the bedrock ridges of the Portland Hills, where it turns northward, and flows out of the area near the center of the northern edge. The Willamette River enters near the southwest corner of the area, where it flows eastward along the northern edge of the French Prairie. It turns north, passes through the bedrock ridges, forming spectacular falls at Oregon City, and flows northwestward through Portland to the Columbia River. The Columbia River is tidal throughout the report area, and the Willamette is tidal upstream as far as the falls at Oregon City.

Geologic Character of the Area

The general basic structure of the rock units of the Portland area is a large synclinorium. Consequently, the oldest rocks crop out in the flanks of the anticlinal areas to the east and west.

Volcanic rocks of Eocene age, known as the Tillamook volcanic series and the Siletz River volcanic series crop out in the Coast Ranges at the west edge of the area. In the Cascade Range at the northeast margin of the area, the older volcanics are a part of the extensive Keechelus andesitic series of Oligocene and Miocene age as well as part of the Eagle Creek formation of Miocene age. Both of these oldest flanking rock units dip inward toward the valley, pass beneath younger formations, and, as shown by cuttings from the deepest oil-test drillings, underlie the valley. The rocks are partly altered and generally nonpermeable lavas and tuffs that afford only small yields of water to wells.

The successively younger formations on the Coast Ranges side comprise the volcanic rocks of Eocene age (included with the older volcanic rocks on pl. 1), sedimentary rocks of Eocene age and of Tertiary age (inclusively shown as undifferentiated sedimentary rocks on pl. 2), and the Columbia River basalt of Miocene and Pliocene(?) age in this area. The Columbia River basalt is the only rock sequence that is recognized on both the eastern (south of the Columbia River) and the western side of the Portland-Vancouver lowland. (See pl. 1.)

Overlying the Columbia River basalt is an extensive stratum of semiconsolidated continental clastic sediments of the alluvial-fan types. It is called the Troutdale formation. It dips westward off the lower slopes of the Cascade Range. Farther west it lies more nearly horizontal and forms the main sedimentary fill beneath the Portland-Vancouver lowland. Recently the deposit has been mapped to the north, south, and west, disclosing considerably greater extent than was known heretofore; it appears to be part of a widespread coalesced system of alluvial fans that were deposited along the lower western slope of the Cascade Range during Pliocene time. The lower half, or more, of these deposits contains much clay and silt, but the upper part includes many sand and gravel layers. The deposit, or its local counterpart, extends through the gaps in the interior anticlinal ridges that extend northward from Oregon City, and there it fills much of the Tualatin Valley section of the synclinorium. (See pl. 1.) The coarse-grained beds of the Troutdale formation lie at shallow depths and form the most widespread aquifers of the Portland-Vancouver area.

Following a period of mild warping and subsequent erosion during which an erosional surface developed across the strata of the Troutdale, a late period of volcanic activity occurred. Basaltic lava, known as the Boring lava, welled up from fissures, some of which were integrated along linear structural lines and some dispersed as local pipes and necks. The Boring lava spread out locally on the eroded surface of the Troutdale formation and on the Columbia River basalt but, for the most part, was of sufficient viscosity that it remained on the upper levels without reaching the stream channels in many places. Some of the important mountains of the Portland-Vancouver area, such as Mount Sylvania and Mount Scott as well as the less spectacular lava rock plateaus, like those east of Oregon City and around Boring, originated from this volcanic activity.

During the latter part of the Pleistocene or Ice Age of Quaternary time, several deposits of coarse outwash debris, mainly from the Columbia River, were strewn over the terraces of the Portland lowland. Some local mountain glaciers and their melt-water deposits reached the valley lands along the foothills of the Cascade Range. The glacial outwash and alluvium of that time were strewn widely and accompanied the erosional reexcavation of the stream channels, so that fluviatile deposits of that epoch remain over the Portland and Vancouver terraces in a vertical range that extends from above the 300-foot altitude down to the level of the Recent flood plains. Much of the deposits of this Pleistocene epoch have been referred to, and are shown on plate 1, as older alluvium.

The graded streams, mainly the Columbia and Willamette Rivers and their principal tributaries—the Clackamas, Tualatin, and Lewis Rivers—have developed flood plains underlain by deposits of Recent age. These deposits include some of the most productive aquifers and underlie some of the most valuable agricultural and industrial land of the Portland-Vancouver area.

Population

The population of the Portland-Vancouver area in 1950 was about 718,000. The gain during the 1940–50 period was approximately 35 percent. The population of the study area is expected to be nearly 800,000 by 1960.

Transportation

The area is served by 5 railroads, 7 airlines, 13 buslines, 30 companies operating river boats, 57 steamshiplines, about 100 trucklines, a network of Federal, State, and county highways. Portland is the only large fresh-water port on the Pacific coast and handles about 12 million tons of cargo annually. Over a million tons of this cargo is inland-waterways commerce.

Industry

In the Portland-Vancouver area industry is diversified. The 1947 Census of Manufacturers lists 1,297 separate manufacturing firms with a total employment of about 51,700 workers. The present estimate is 1,400 manufacturing plants employing 60,000 workers. Annual production is valued at more than $500 million. Paper mills, meatpacking plants, basic aluminum plants, chemical plants, and dairies use large amounts of water daily.

The Columbia and Willamette Rivers afford cheap transportation and provide large amounts of raw water to many industries in the area. Hydroelectric power also is supplied to the area from dams on the Columbia River and its tributaries.

Natural Resources

Water in this area is used for public water supply, generation of hydroelectric power, manufacturing, cooling, irrigation, recreation, waste disposal, and navigation. Other natural resources in the area are the soils, fish and timber.

Climate

Portland's climate is a mixture of that of the nearby coastal areas and that common to the continental lands of eastern Oregon. Portland is shielded on the west by the Coast Ranges and on the east by the Cascade Range. The prevailing winds are from the west, off the Pacific Ocean, and this tends to moderate both the winter and summer temperatures.

Weather data have been collected at Portland by the U. S. Weather Bureau since January 1871. The highest temperature of record at Portland was 107°F in July 1942, and the lowest recorded temperature was -2°F in January 1888. (See fig. 1.) The average temperature for the period 1871–1952 was 53°F. Temperatures above 100°F are reached only once in about 4 years, while below-zero temperature has been reached only once during the period of record. The average growing season is 257 days, with killing frosts recorded as late as May 2 and as early as October 13.

The average annual precipitation at Portland during the period 1871–1952 was 42.04 inches. Precipitation at Portland is definitely seasonal; almost 80 percent falls in the 6-month period between October 1 and March 31. Annual precipitation for the 82 years of record ranges from 26.11 inches in 1929 to 67.24 inches in 1882. The village of Timber, just west of

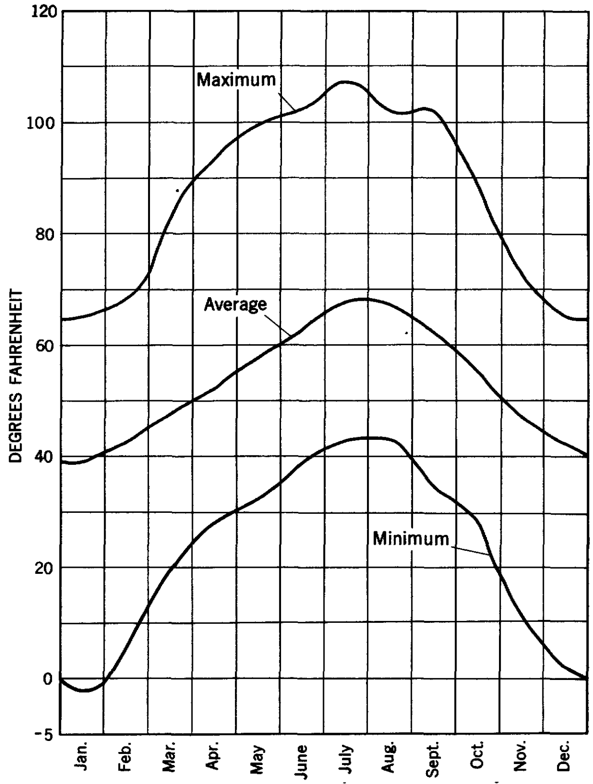


Figure 1.—Air temperatures at Portland, 1871–1952.

the study area, has a 20-year-average rainfall of 61.73 inches, and the headworks of the Portland water system in the eastern part of the area has an average of 85.91 inches during the same period. Figure 2 shows the annual precipitation and monthly distribution of precipitation at the Portland station.

The relative humidity during the winter is fairly high. The monthly average relative humidity is 80 percent and ranges about 5 to 8 percent above and below this figure. In the summer the range is much larger, the monthly averages ranging from about 85 percent to about 50 percent.

In Portland 48 percent of the days in the year are sunny. Heavy fog occurs on 15 to 20 days of the year and is most common during October and November. Winds greater than 25 miles per hour occur infrequently, 57 miles per hour being the highest of record. The yearly average is 6.8 miles per hour with little difference during the seasons of the year.

Definition of Terms

Quantities of water, as presented in this report, are in units of million gallons per day (mgd), gallons per day (gpd), gallons per minute (gpm), cubic feet per second (cfs), and acre-feet. Second-feet was formerly used in U. S. Geological Survey reports as an abbreviation of cubic feet per second.

A cubic foot per second (cfs) is the rate of discharge equivalent to that through a channel 1 square foot in cross-sectional area at an average velocity of 1 foot

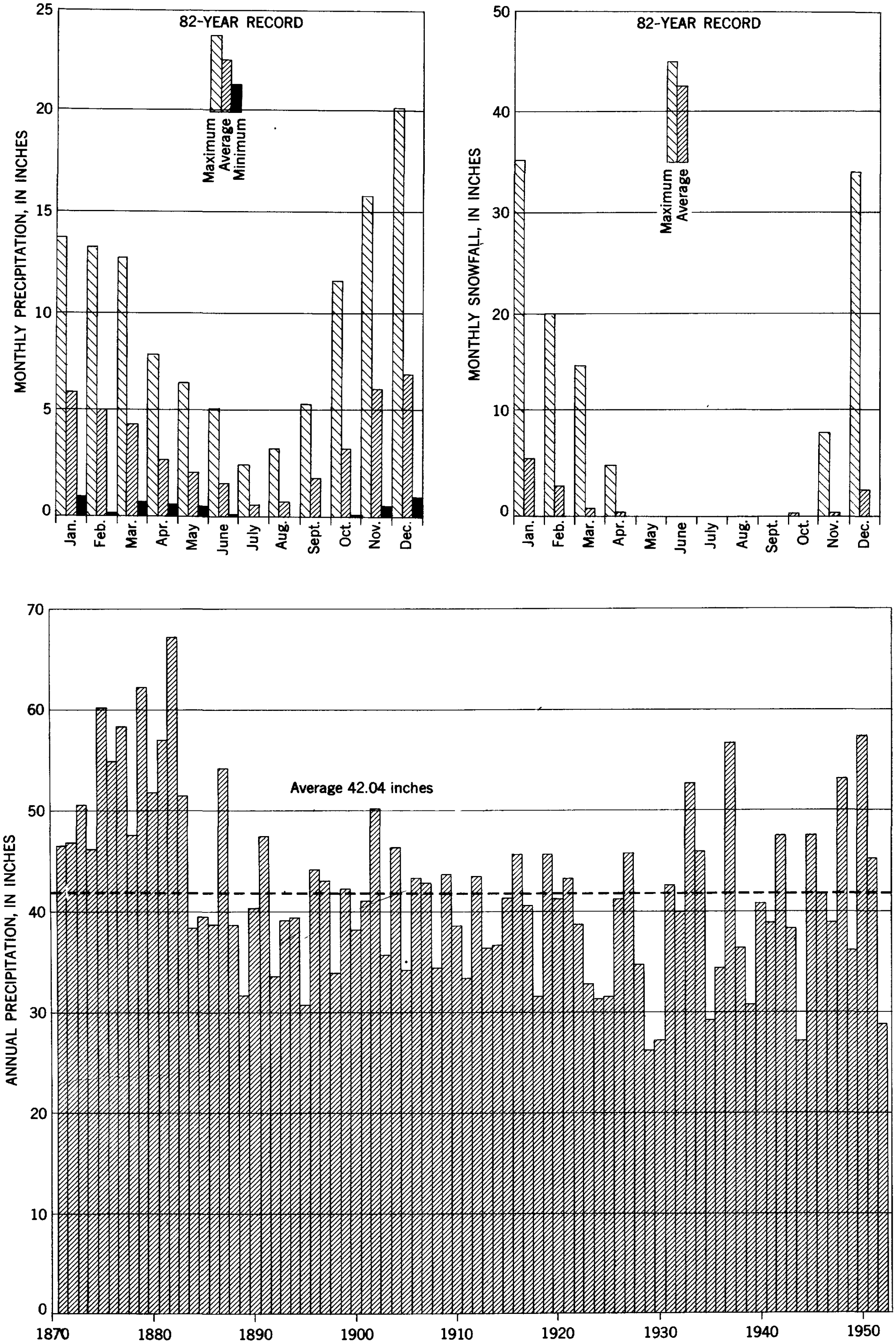


Figure 2.—Precipitation at Portland, 1871–1952.

per second. Cubic feet per second per square mile is the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the runoff is distributed uniformly as regards time and area. An acre-foot is equivalent to 43,560 cubic feet and is the quantity required to cover an acre to a depth of 1 foot. The relationship between those units is given in the following tabulation.

1 cfs	= 449 gallons per minute
1 cfs	= 646,317 gallons per day
1 mgd	= 694 gallons per minute
1 mgd	= 1.55 cfs
1 acre-foot	= 0.504 cfs for 1 day.

The water year begins October 1 and ends September 30 and is the year for which most streamflow data are reported. The water year is used in analysis and presentation of streamflow information in this report.

Throughout this report chemical concentrations are expressed either as parts per million or as equivalents per million. Parts per million (ppm) is the number of unit weights of the constituent in 1 million unit weights of the solution. For example, 20 ppm of chloride is equal to 20 milligrams of chloride in 1 million milligrams of the solution. Equivalents per million (epm) expresses concentration in terms of reacting capacity and is the number of unit equivalent reacting weights of an ion in 1 million unit weights of the water. An equivalent weight of a substance is the weight that is exactly equal in reacting capacity to one atomic weight (1.0080 grams) of hydrogen. The equivalents per million for each constituent are calculated by dividing its concentration in parts per million by its equivalent weight. For example, 100.16 ppm of calcium divided by its equivalent weight (20.04) amounts to 5 epm of calcium. Equivalents per million are useful in expressing chemical combinations as well as in expressing analyses graphically, because 1 equivalent of a cation, such as calcium, will combine exactly with 1 equivalent of an anion, such as chloride, to form 1 equivalent of a compound, such as calcium chloride.

Specific conductance is a measure of the capacity of water to conduct an electrical current. Conductance varies with the quantities of dissolved mineral constituents and the degree of ionization of these constituents, as well as with the temperature of the water. It is useful in indicating the degree of concentration of mineral matter in water.

OCCURRENCE OF WATER

Precipitation is the source of our fresh-water supplies. Only part of the water that falls as rain or snow reaches the ground surface; the remainder is intercepted by vegetation and evaporated. The rain that reaches the ground seeps into the soil, except when the rainfall rate exceeds the rate at which the water can seep into the soil and the surplus flows into the streams. Part of the water which infiltrates the soil is returned to the atmosphere by transpiration and evaporation and part percolates downward to the water table to replenish the ground-water supply. The water that reaches the water table may be withdrawn by wells or may flow to discharge areas such as seeps or springs, where it appears as streamflow. The interchange of water involving its movement from the atmosphere to the earth and return to the atmosphere is called the hydrologic cycle. The cycle is complicated and is affected by such factors as precipitation, temperature, topography, and geology. Storage influences some phases of the cycle; for example, precipitation as snow in the higher altitudes may not melt until several months after it falls. In the area considered in this report, evaporation and transpiration are greatest during the summer when precipitation is at a minimum.

The Coast Ranges and the Cascade Range strongly affect the hydrologic cycle in the area. Moisture-laden winds from the Pacific precipitate much of their moisture as they move inland and rise over the mountains. Precipitation is heaviest along the western slopes and in some places along the Cascade Range amounts to considerably more than 100 inches yearly. This effect results in high runoff in streams in the area which have their origins on the slopes of the Cascade Range.

Local precipitation replenishes the ground-water reservoirs and local streams. The more important streams are Sandy, Bull Run, Tualatin, and Clackamas Rivers, in Oregon; and Washougal, Lewis, and East Fork Lewis Rivers, in Washington. The greatest single source of supply is the Columbia River, and the second greatest, the Willamette River. Both of these streams discharge large quantities of water and are fed by precipitation upstream from and outside the Portland-Vancouver area.

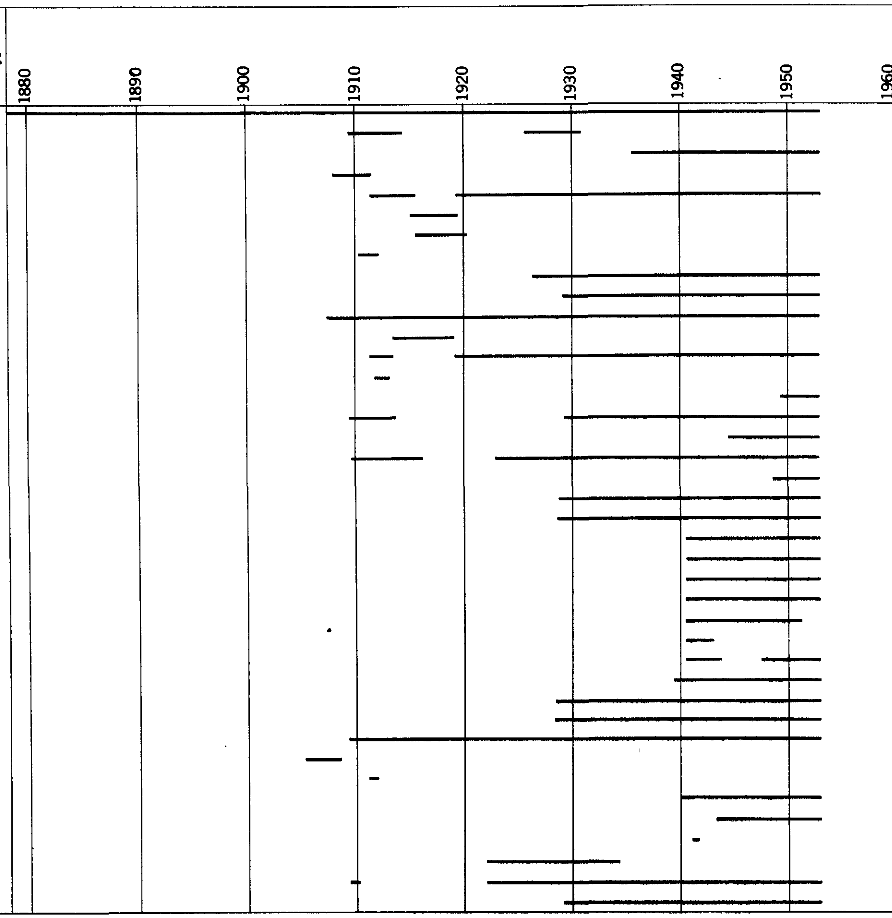
SURFACE WATER

Many streams referred to in this report have undergone developments which may have caused changes in the flow regimen. However, tests for changes in flow characteristics show that there have been no appreciable changes since the collection of discharge records began. Therefore, the tables and curves in this report show the supply available at the present degree of development. If the diversions and regulations remain about as they are now, the streamflow data given in this report can be used to forecast the flow that may be expected.

Columbia River

The drainage area of Columbia River basin above Vancouver is 238,500 square miles. The average annual precipitation in the basin ranges from about 6 inches in parts of the semiarid Columbia Plateau region to considerably more than 100 inches in regions of high elevation along the western slopes of the Cascade Range. The average annual runoff ranges from about 0.5 inch in parts of the Columbia Plateau to about 100 inches on the western slopes of the Cascade Range.

The Columbia River normally has high flow during the summer and low flow during the winter. (See figs. 4 and 9.) At the farthest downstream gaging station near The Dalles, 95 miles east of Portland, yearly maximum flow has occurred during May, June, or July in each year of record. Stage records at Vancouver show a variation from this pattern to the extent that high stages may also occur anytime during November through April because of backwater from the



INDEX NUMBER (PL. 1)	DRAINAGE AREA (SQ MI)	GAGING STATION
1	237,000	Columbia River near The Dalles, Oreg.
2	117	Sandy River above Salmon River, at Brightwood, Oreg.
3	106	Salmon River above Boulder Creek, near Brightwood, Oreg.
4	242	Sandy River below Salmon River, near Brightwood, Oreg.
5	262	Sandy River near Marmot, Oreg,
6	264	Sandy River below dam, near Marmot, Oreg.
7		Sandy River Canal near Marmot, Oreg.
8	291	Sandy River above Bull Run River, near Bull Run,Oreg.
9	74	Lake Ben Morrow near Bull Run, Oreg.
10	74	Bull Run River below Lake Ben Morrow, Oreg.
11	102	Bull Run River near Bull Run, Oreg.
12	17.9	Little Sandy River near Marmot, Oreg.
13	22.3	Little Sandy River near Bull Run, Oreg.
14		Little Sandy Flume near Bull Run, Oreg.
15	136	Bull Run River at Bull Run,Oreg.
16	440	Sandy River below Bull Run River, near Bull Run, Oreg.
17	108	Washougal River near Washougal, Wash.
18	7,280	Willamette River at Salem, Oreg.
19	8,400	Willamette River at Wilsonville, Oreg.
20	323	Molalla River near Canby, Oreg.
21	479	Pudding River at Aurora, Oreg.
22	51	Tualatin River at Gaston, Oreg.
23	44.0	Scoggin Creek near Gaston, Oreg.
24	133	Tualatin River near Dilley, Oreg.
25	66.0	Gales Creek near Forest Grove, Oreg.
26	49.2	West Fork Dairy Creek at Banks, Oreg.
27	43.0	East Fork Dairy Creek at Mountaindale, Oreg.
28	27.6	McKay Creek near North Plains, Oreg.
29	566	Tualatin River at Farmington, Oreg.
30		Oswego Canal near Oswego, Oreg.
31	710	Tualatin River near Willamette, Oreg.
32	657	Clackamas River near Cazadero, Oreg.
33	829	Clackamas River near Barton, Oreg.
34	930	Clackamas River of Park Place, Oreg.
35	28.2	Johnson Creek of Sycamore, Oreg.
36	18.3	Salmon Creek near Battleground, Wash.
37	63	Salmon Creek near Brush Prairie, Wash.
38	64	Canyon Creek near Amboy, Wash.
39	731	Lewis River at Ariel, Wash.
40	125	East Fork Lewis River near Heisson, Wash.

Figure 3.—Duration of records at gaging stations in the Portland-Vancouver area.

Willamette River. Most tributaries below The Dalles have a different yearly pattern, with low flows in summer and high flows in winter. Winter floods seldom produce stages at Vancouver as high as those resulting from snowmelt in the spring and early summer.

The upstream storage reservoirs reduce peak flows and increase minimum flows. The largest controllable volume of storage is at Roosevelt Lake, which is formed by Grand Coulee Dam and has a usable capacity of more than 5 million acre-feet.

Navigation.—The planned depth of the Columbia River project is 35 feet from the mouth to Willamette River, 30 feet from Willamette River to Vancouver, Wash., and 27 feet from Vancouver to The Dalles, Oreg. Upstream from The Dalles, channel depths of at least 5 feet are maintained to Pasco, Wash. After completion of The Dalles and John Day Dams, navigable depths between The Dalles and Pasco will be increased considerably and slack-water navigation will be possible on the Columbia River to a point about 35 miles upstream from Pasco and on the Snake River to a point about 10 miles upstream from the mouth. The Dalles Dam is under construction and the John Day Dam is in the planning stage (1954).

Discharge.—The average discharge of the Columbia River at The Dalles during the 75 years 1879–1953, is 125,800 mgd. The maximum, minimum, and average monthly and annual discharges are shown in figure 4. The minimum discharge during this period was 22,600 mgd on Jan. 12, 1937. With present regulation the minimum flow will be 2 or 3 times as much.

Floods.—Records of floods on the Columbia River near The Dalles, Oreg., are continuous since 1858. The gaging station near The Dalles is upstream from the Portland-Vancouver area. Because Bonneville Dam and a series of rapids are within the intervening reach, flood elevations near The Dalles are not representative of those within the Portland-Vancouver area. The Weather Bureau has published records of stage at Vancouver for the periods 1902–4, 1907–53. These records do not include the highest known flood stage, which occurred in June 1894, but according to

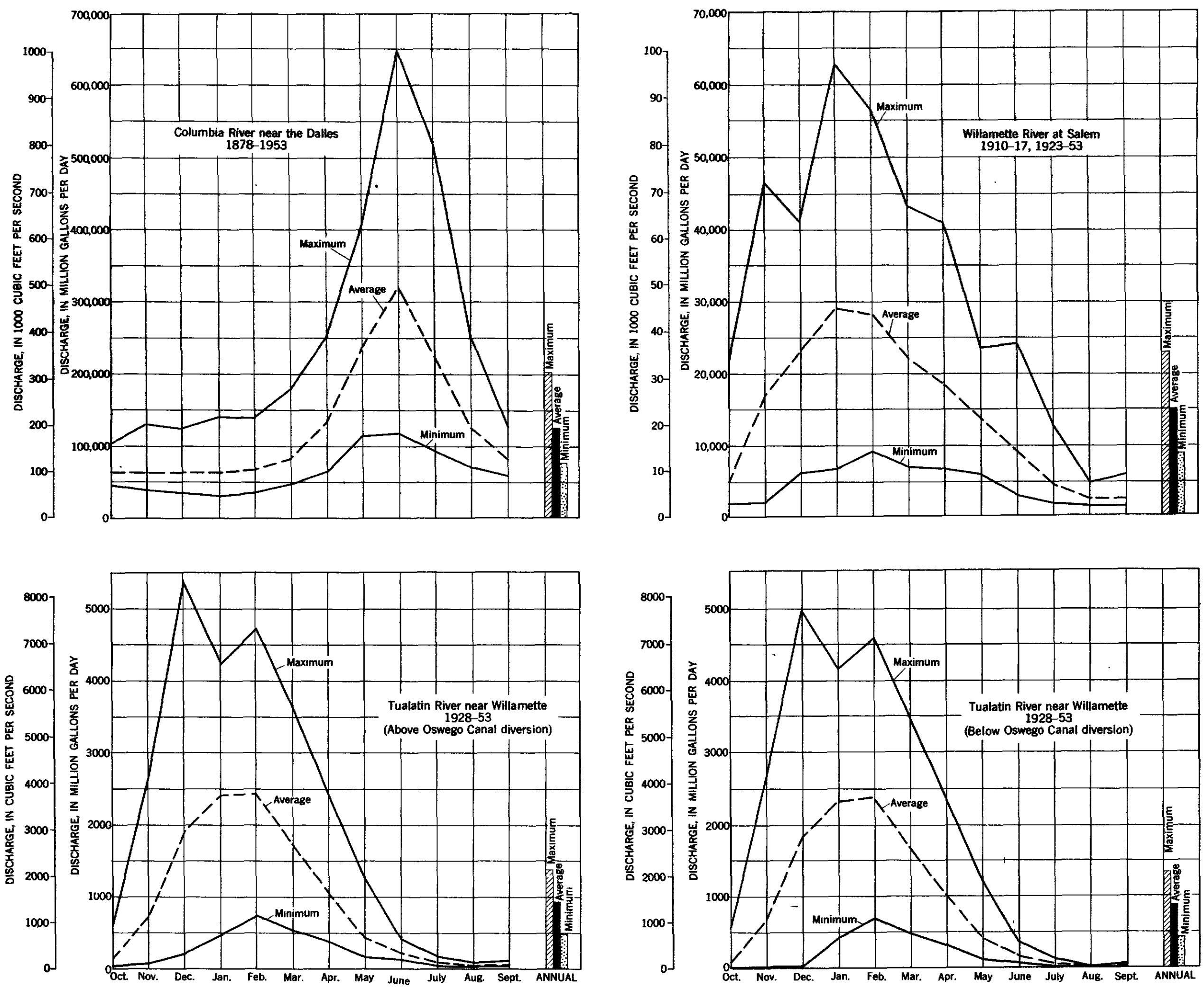


Figure 4.—Maximum, minimum, and average monthly and annual discharge of selected streams.

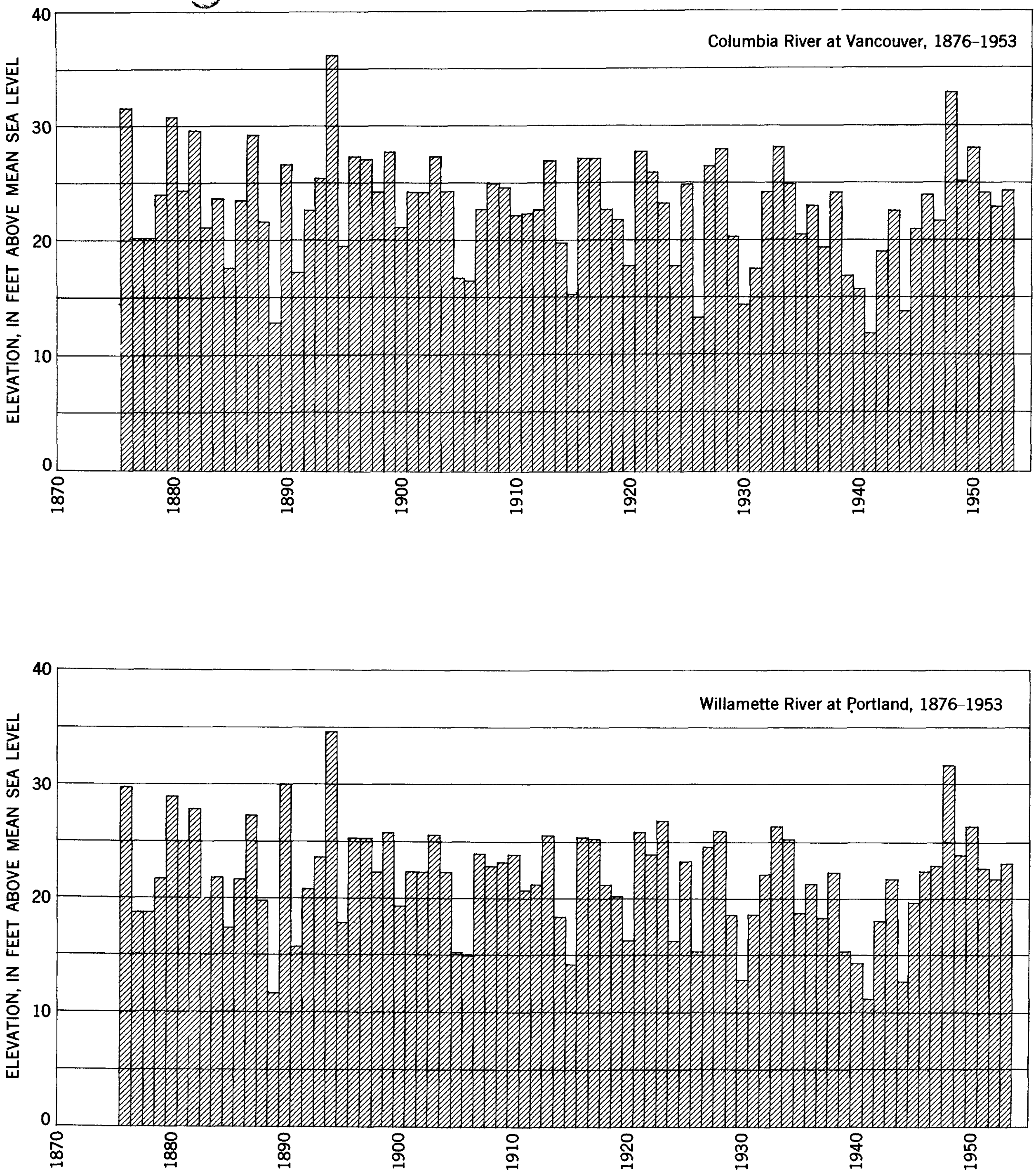


Figure 5.—Highest flood in each year, Willamette River at Portland and Columbia River at Vancouver.

information furnished by the Corps of Engineers the 1894 flood reached an elevation of about 36.5 feet.

The highest elevation reached by the Columbia River at Vancouver, Wash., during each year of record is shown in figure 5. The highest floods in the vicinity of Vancouver originate in the Columbia River basin above the Willamette River and occur during the late spring season when the flow of the Willamette River is relatively low. Some of the lesser floods at Vancouver occur during the winter as a result of heavy inflow from lower Columbia River tributaries and backwater from the Willamette River.

The flood of 1894 discharged 1,240,000 cfs, but the flood of 1948, with a flow of 1,010,000 cfs, caused greater financial losses, owing to the development of the area.

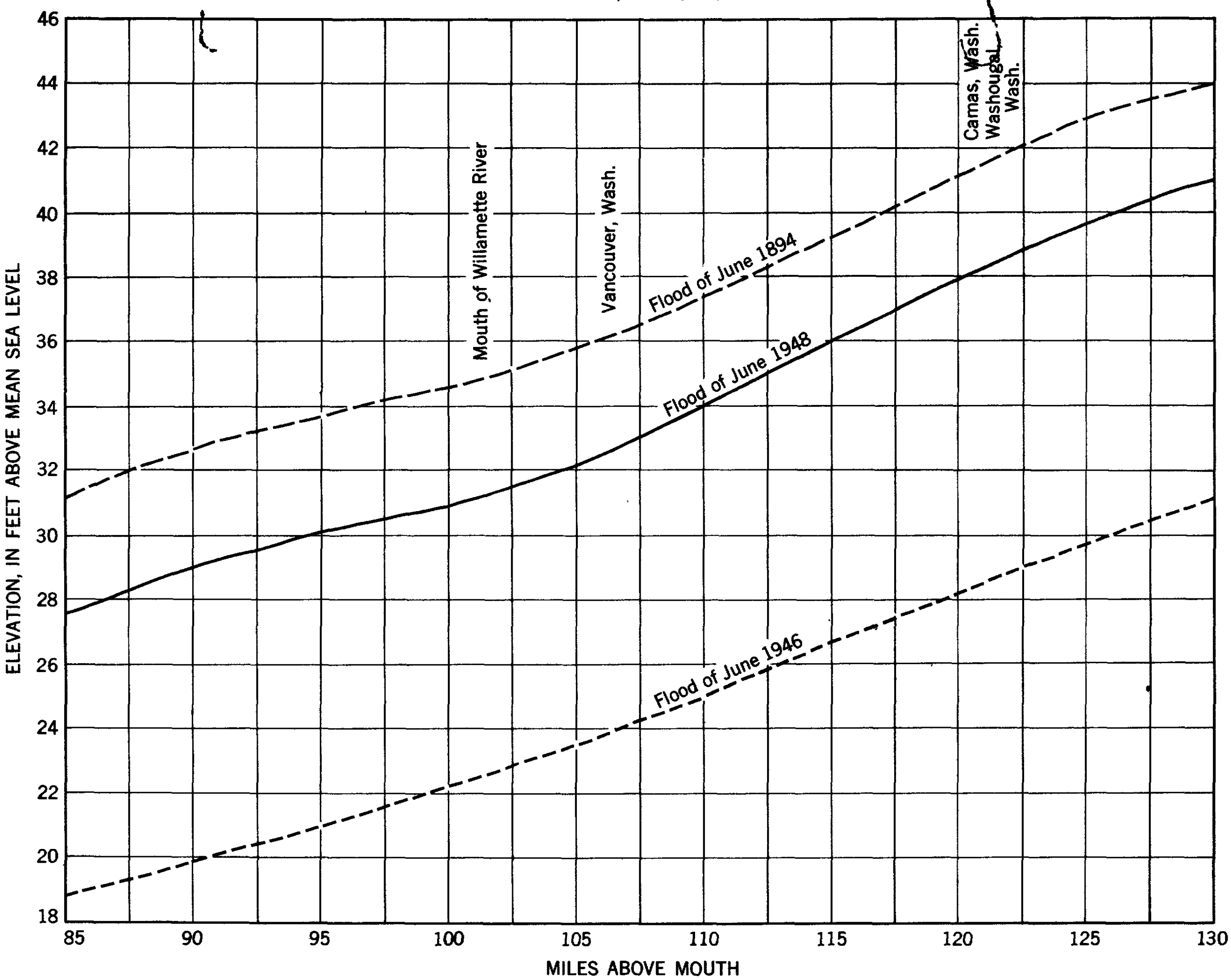


Figure 6.—Water-surface profile for selected floods on the Columbia River, mile 85 to mile 130.

A water-surface profile of the reach past Vancouver, Wash., from mile 85 to mile 130 for the 1948 flood is shown in figure 6.

The probable frequency of floods is an important factor in the design and location of structures in areas susceptible to flooding. A flood-frequency graph for the Columbia River at Vancouver shows the probable average interval in years between floods of several magnitudes (fig. 7). This curve is based on records of past floods, some prior to and some following construction of reservoirs in the basin. It is estimated by the Corp of Engineers that, with the present degree of river development, peak discharges on the lower Columbia River from headwater (snowmelt) floods may be reduced by about 50,000 cfs. A reduction of 50,000 cfs in flood flow would reduce the stage in Portland harbor by 1 to 2 feet.

Quality.—The water of the Columbia River is a composite of many types of water from many tributaries of diversified origin. Averages of chemical analyses of the river water near The Dalles and at Cascade Locks, Oreg., are reported in table 1.

A cumulative-frequency curve of dissolved solids in Columbia River water near The Dalles, 1951–53, is shown in figure 8. The curve shows that the dissolved solids may be expected to exceed 150 ppm about 5 percent of the time. The hardness of the river water at this station varies seasonally in response to changes in runoff and normally is less in May and June (fig. 8) than at other times.

In late spring and early summer, when streamflow is increased by snowmelt in the upper basin the river water contains less dissolved solids than at other times. The water is more mineralized during periods of low discharge (fig. 9).

Water-pollution control on the main stem is necessary to maintain a water of a quality suitable for municipal and industrial use, to protect health, and to safeguard the fishery resources.

Extended records of sediment discharge of the lower Columbia River are not available. However, selected reaches of the river have been sampled for short periods. In 1910–12 the U. S. Geological Survey included measurements of suspended sediment at Cascade Locks in a report on quality of surface waters of Oregon.

Cumulative-frequency curves of river-water temperature at Bonneville, Oreg., and Vancouver, Wash., are shown in figure 10. Maximum water temperatures at Vancouver occur during July and August, and

Table 1.—Chemical quality of selected surface waters in the Portland-Vancouver area

[Parts per million except as indicated]

Source	Date of collection	Discharge (cfs)	Temperature (°F)	pH	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness: Total	Hardness: Noncarbonate
Columbia River main stem																			
Columbia River near The Dalles	[a]1950-51	257,100	...	...	164	13	0.06	19	5.5	6.0	3.3	80	14	3.3	0.3	1.0	105	70	4
Do.	[a]1951-52	208,300	...	...	177	13	.06	20	6.0	6.9	1.9	85	15	3.9	.3	1.1	111	75	5
Do.	[a]1952-53	179,300	...	...	188	10	...	21	5.9	9.2	1.7	89	17	3.8	...	.7	116	77	4
Columbia River at Cascade Locks	[a]1910-11	251,500	...	...	...	13	.04	16	4.2	7.1		67	13	2.0	...	.4	89	57	2
Do.	[a]1911-12	171,300	...	...	...	14	.06	17	3.9	7.5	1.8	69	12	3.2	...	.5	97	58	1
Sandy River basin																			
Sandy River near Brightwood	[a]1911-12	933	...	...	...	16	0.07	4.6	1.3	4.2	0.8	18	7.2	1.7	...	0.2	49	17	2
Sandy River near Marmot	Dec. 7, 1953	3,400	40	6.3	36.3	12	.00	3.4	.6	2.5	.9	16	2.3	.5	0.1	.6	33	11	0
Sandy River near Bull Run	Mar. 6, 1951	1,840	...	...	39.9	17	...	...	...	...	...	21	2.5	2.0	...	.1	...	14	0
Lake Ben Morrow	Dec. 8, 1953	...	41	6.2	19.1	6.7	.00	1.8	.2	1.5	.6	9	.7	1.0	.1	.3	16	5	0
Bull Run River near Bull Run	[a]1911-12	796	...	...	...	9.0	.03	2.7	.5	3.1	.5	12	3.1	1.3	...	.3	30	9	0
Do.	Mar. 6, 1951	330	...	...	21.3	8.5	...	...	...	...	...	13	.3	1.2	...	.0	...	8	0
Do.	Dec. 8, 1953	5,600	41	6.3	19.0	7.5	.00	1.6	.3	1.4	.5	10	.5	.5	.1	.5	16	5	0
Bull Run River at Bull Run	Dec. 7, 1953	3,400	43	6.2	25.9	10	.10	2.6	.2	1.8	.8	11	.5	1.0	.0	.6	24	7	0
Little Sandy River near Bull Run	Dec. 7, 1953	460	40	6.2	22.2	8.5	.00	1.8	.5	1.6	.7	10	.3	.8	.0	.7	20	7	0
Washougal River basin																			
Washougal River near Washougal	Apr. 21, 1954	560	51	7.2	23.2	11	0.00	2.4	0.2	1.8	0.7	12	1.4	1.5	0.2	0.7	26	7	0
Willamette River basin																			
Willamette River at Salem	[a]1910	...	...	...	...	15	0.07	6.5	2.2	6.4		33	5.7	4.0	...	1.6	61	25	0
Do.	[a]1911-12	23,980	...	...	...	15	.10	5.3	1.4	3.8	.8	26	3.7	1.9	...	.4	51	19	0
Do.	[a]1951	...	...	...	60.5	18	.08	5.2	2.1	3.6	2.4	31	2.4	2.6	0.2	.6	56	22	0
Do.	[a]1951-52	24,740	...	...	54.0	16	.08	4.9	1.9	3.7	1.1	27	2.8	2.5	.3	.7	52	20	0
Do.	[a]1952-53	26,770	...	...	51.5	15	...	5.0	2.0	3.2	1.0	26	3.2	2.6	...	.6	52	21	0
Willamette River at Oregon City	Nov. 27, 1950	...	48	...	51.2	16	...	4.2	2.5	5.0		25	5.6	3.2	...	.9	50	21	0
Molalla River near Canby	Apr. 21, 1954	1,050	48	7.3	40.4	13	.00	4.8	.2	2.4	.8	21	1.2	1.0	.2	.6	37	13	0
Pudding River at Aurora	Feb. 20, 1951	2,500	44	...	57.7	17	...	...	...	...	...	28	4.0	2.9	...	2.1	...	21	0
Do.	Apr. 21, 1954	1,200	52	7.4	55.5	16	.06	6.6	.7	3.2	.8	27	1.5	1.8	.2	1.2	52	19	0
Tualatin River at Farmington	Apr. 21, 1954	1,020	52	7.0	87.0	18	.03	10	1.3	5.1	1.2	38	3.0	4.0	.2	1.1	76	30	0
Tualatin River near Willamette	Dec. 11, 1953	6,015	47	6.6	71.0	11	.41	6.0	1.8	4.0	1.7	29	4.1	6.0	.0	.9	57	22	0
Clackamas River above Three Lynx Creek	Feb. 7, 1951	1,990	...	...	52.5	19	...	...	...	...	...	23	1.0	1.5	...	.1	...	18	0
Clackamas River at Cazadero	[a]1911-1912	2,660	...	...	...	17	.05	5.3	1.4	4.2	.8	26	3.9	1.7	...	.2	50	19	0
Clackamas River near Cazadero	Feb. 27, 1951	2,580	...	...	50.4	19	...	...	...	...	...	32	1.8	1.8	...	.1	...	25	0
Do.	Dec. 6, 1953	10,800	41	6.5	40.6	9.4	.00	4.0	.8	2.5	.9	21	.7	1.0	.0	.5	36	13	0
Clackamas River at Gladstone	Nov. 27, 1950	...	45	...	38.0	14	...	...	...	...	...	22	2.6	3.0	...	1.1	...	14	0
Johnson Creek at Sycamore	Dec. 8, 1953	380	43	6.3	70.3	6.7	.09	5.4	1.5	3.5	1.8	16	4.9	4.0	.1	5.2	46	20	7
Lewis River basin																			
Lewis River at Ariel	Apr. 1, 1954	7,750	42	7.0	39.5	19	0.30	3.0	0.7	2.5	0.8	18	0.9	1.8	0.2	0.2	34	10	0
East Fork Lewis River, near Heisson	Apr. 1, 1954	434	43	7.2	31.5	12	.07	3.0	.6	2.0	.6	14	1.9	1.5	.2	.2	26	10	0

[a]Mean or weighted averages for period of sampling only. Data for the station Columbia River near The Dalles are for water year, whereas for station Columbia River at Cascade locks data are for calendar year.

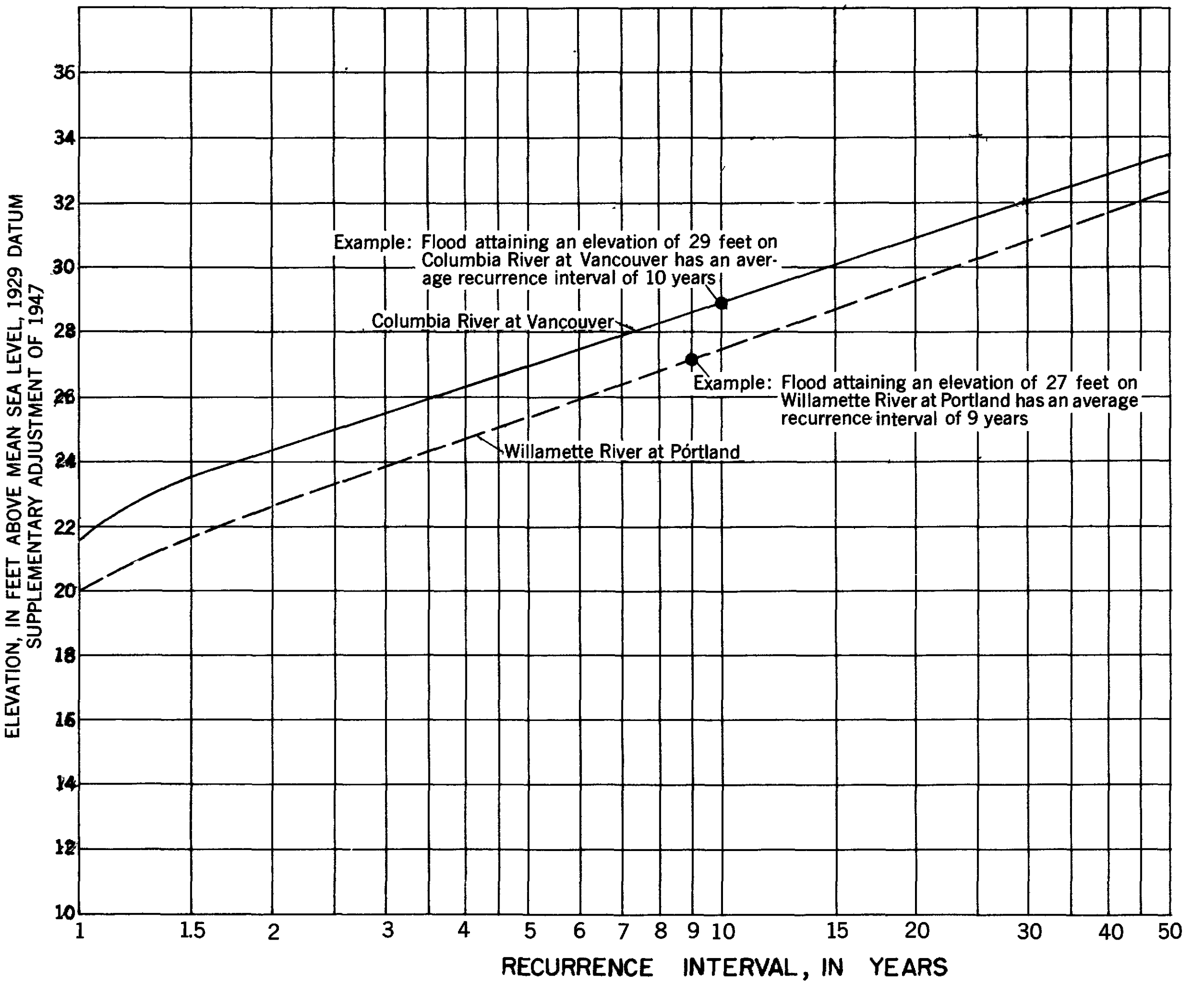


Figure 7.—Flood-stage recurrence intervals, Columbia River at Vancouver and Willamette River at Portland.

minimum temperatures, in January and February. The temperature of Columbia River water has economic significance to industries that use this supply for cooling.

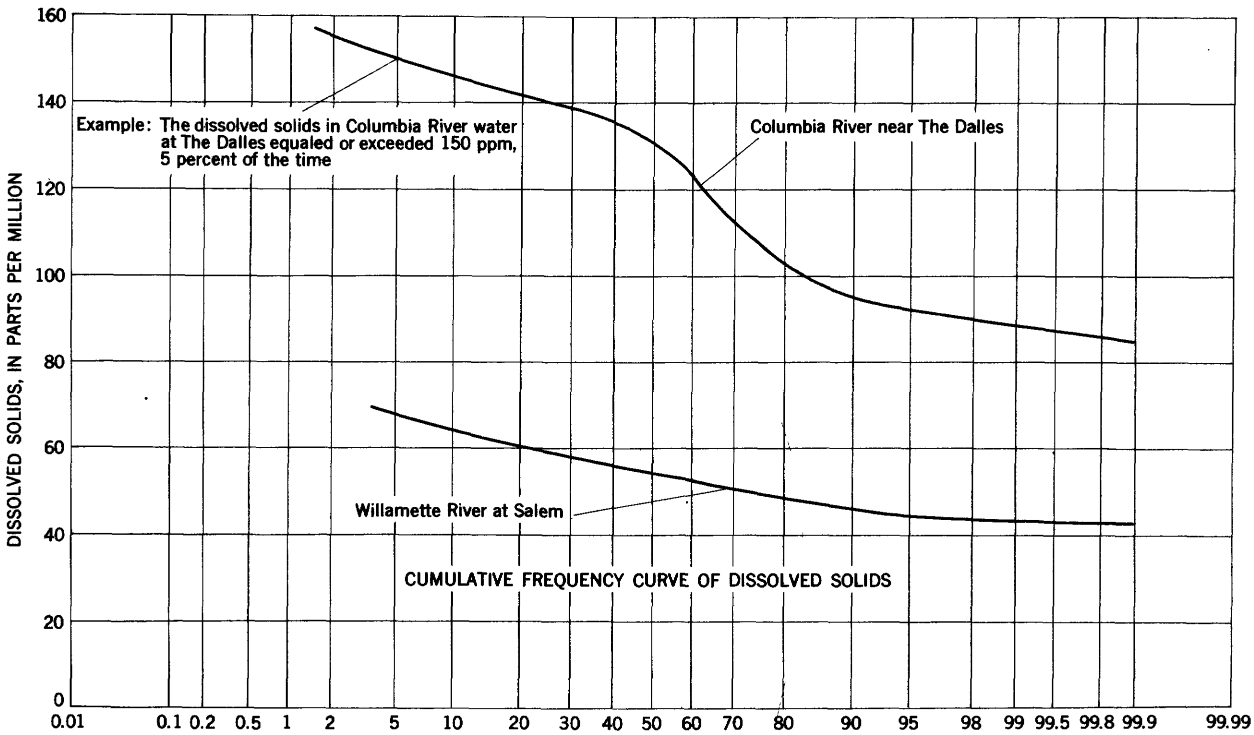
Sandy River

Sandy River, a typical mountain stream, enters the Columbia River near Troutdale, and falls about 7,000 feet from its source to its mouth. The upper part of the basin is heavily timbered and practically uninhabited.

Discharge.—Continuous records of discharge have been collected for Sandy River near Marmot since August 1911. The gaging station is upstream from all effects of diversion or regulation. The drainage area above the station is 262 square miles, which is about half the total drainage area of 510 square miles above the mouth. The average discharge of Sandy River near Marmot for the 42 years (1912–53) of Geological Survey record is 860 mgd. The minimum discharge of record was 132 mgd on Sept. 21–24, 1940. The runoff characteristics of Sandy River are indicated by a flow-duration curve (fig. 11). The curve shows the percentage of time that the daily flow of the Sandy River near Marmot equaled or exceeded values between 150 and 10,000 mgd. The shape of the curve is an indication of the flow characteristics of the stream. If a basin were entirely impervious, runoff after each rain would be rapid. A short period of decreasing runoff would follow, and all of the water soon would drain out of the basin. Thereafter there would be no flow until the next rain. For this extreme condition the slope of the duration curve would be very steep. The more gently sloping duration curves of most streams result from the release of water stored in the ground or in lakes or swamps. Storage reduces flood runoff, and release from storage increases flow during low-water periods.

The maximum discharge since August 1911 is 18,900 mgd on Jan. 6, 1923. Most of the flood damage in the basin occurs near the mouth but is minor. A flood-control project, consisting principally of strengthening the existing levee, has been authorized for construction by the Corps of Engineers. No work has been done on this project to date (1954).

About $1\frac{1}{2}$ miles downstream from the Marmot gaging station a part of the flow of Sandy River is diverted to a hydroelectric plant on Bull Run River at Bull Run. Consumptive use of the water above the point of diversion would conflict with the power use. Another factor to be considered is the fishery resource. As part of



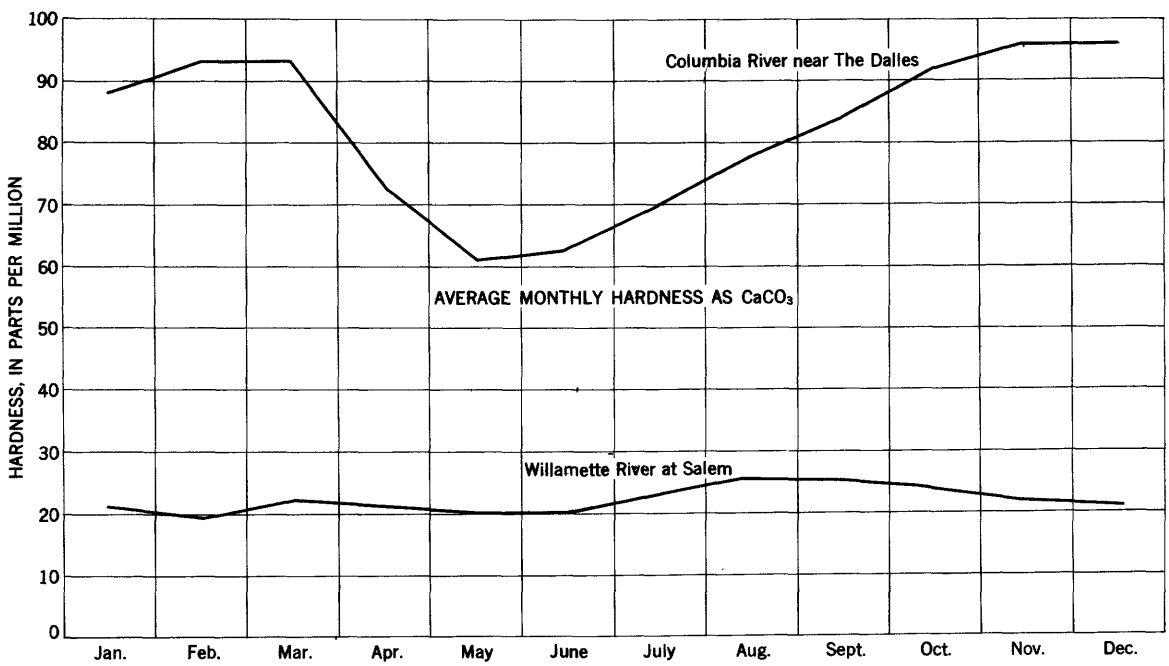


Figure 8.—Hardness and dissolved solids in Columbia River and Willamette River waters, 1951–53.

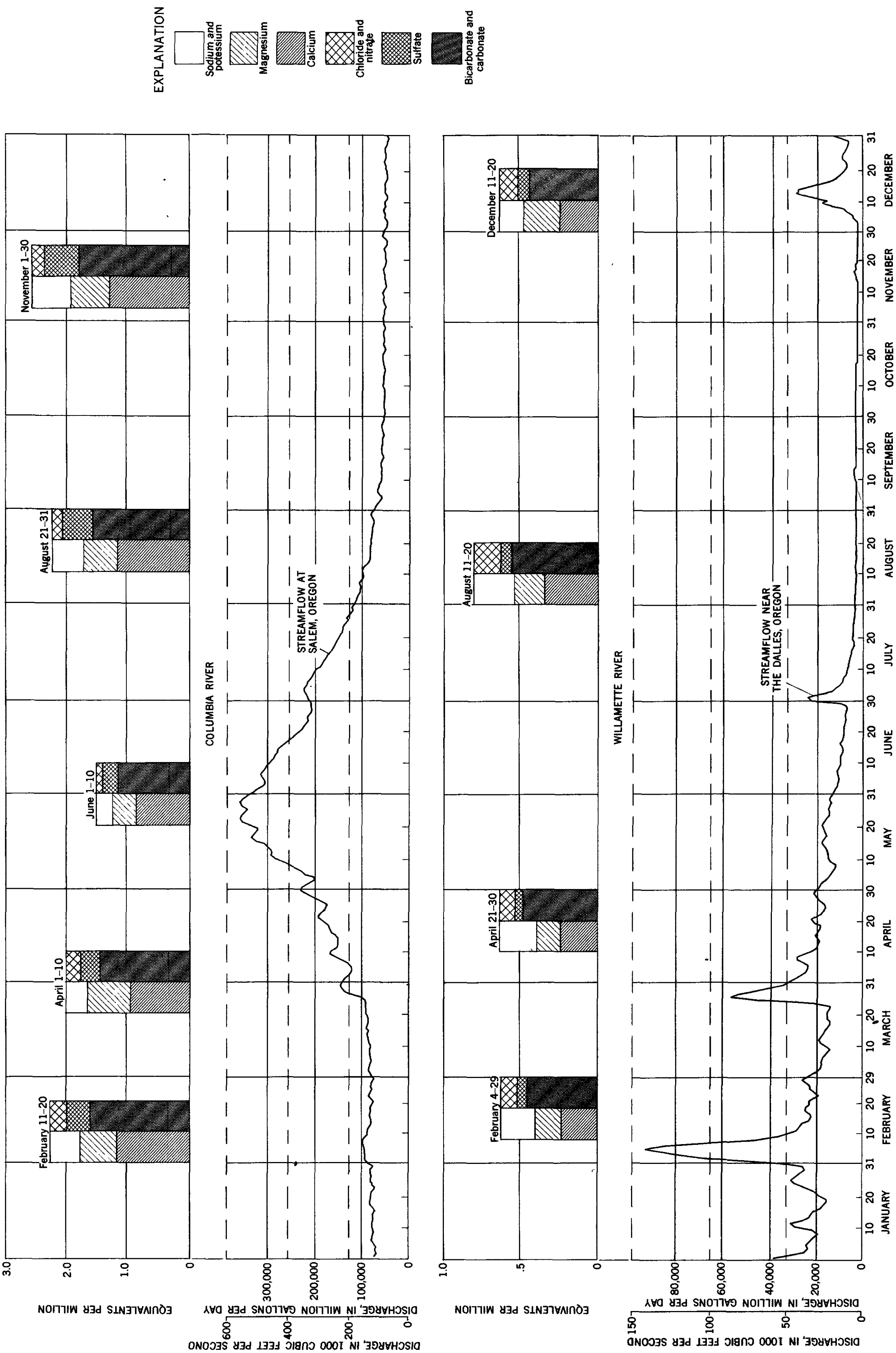


Figure 9.—Relation between streamflow and chemical composition of the water, Columbia and Willamette Rivers, 1952.

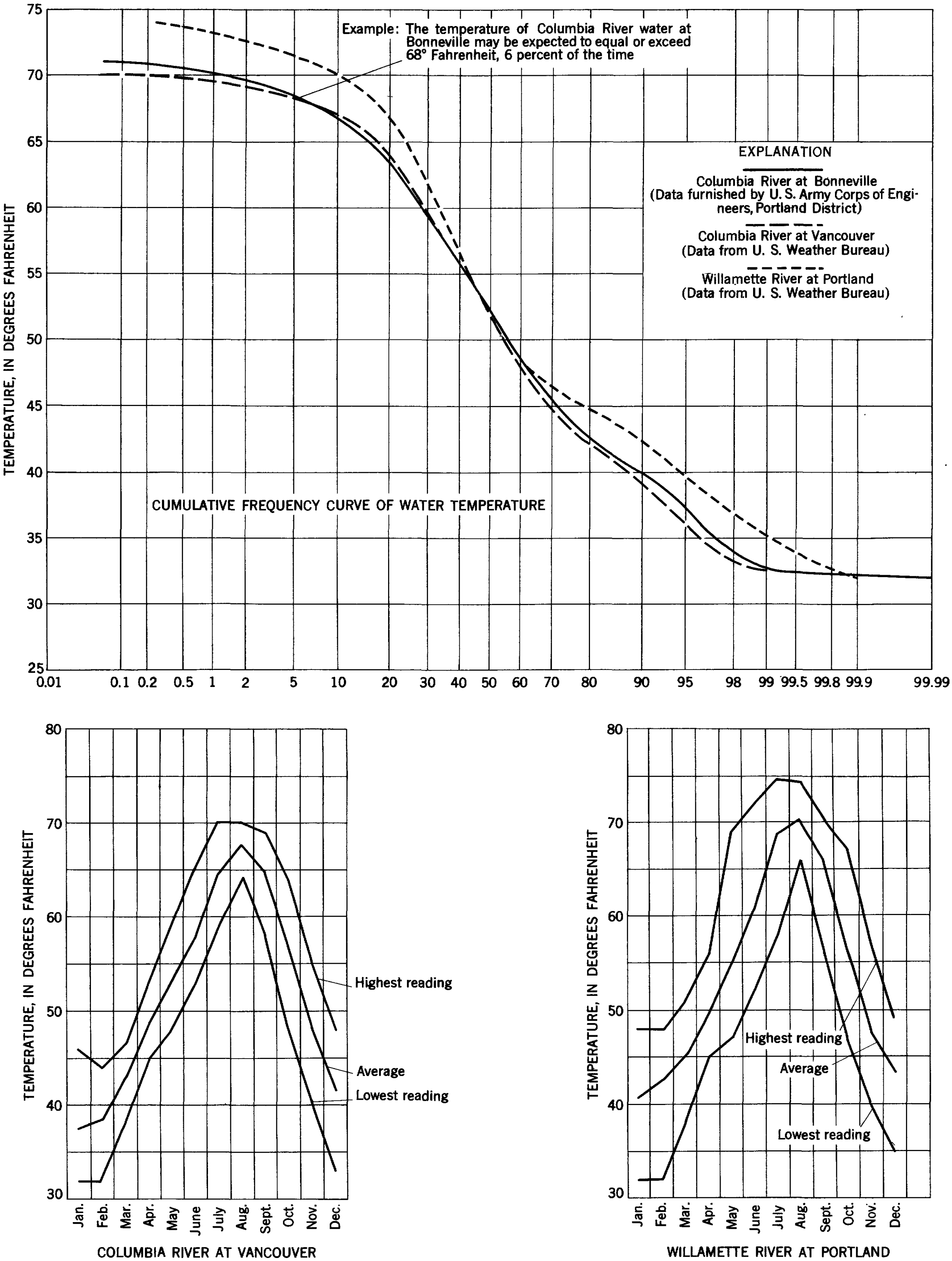


Figure 10.—Temperature of Columbia River and Willamette River waters, 1945–53.

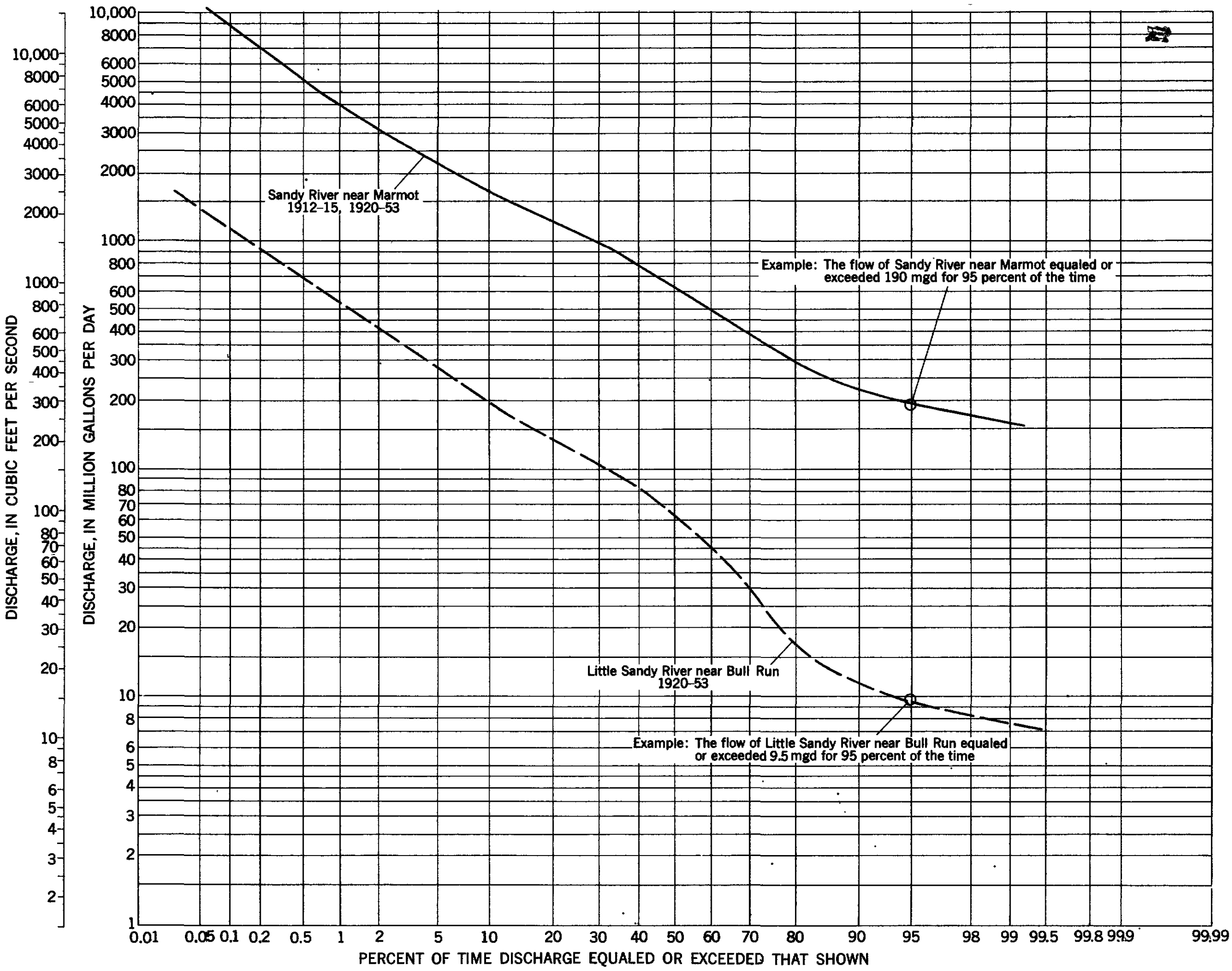


Figure 11.—Duration of daily flow, Sandy River near Marmot and Little Sandy River near Bull Run.

the lower-tributary fishery plan for the Columbia River, the Oregon State Fish Commission tentatively plans to improve Sandy River as a spawning and rearing area for fish.

Quality.—The chemical quality of water from the Sandy River was determined from samples collected near Brightwood, Marmot, and Bull Run (table 1). Detailed examination of the river water near Brightwood in 1911–12 showed that the water was soft and low in mineral content. Sandy River, a glacier-fed stream, transports some suspended and bed-load sediment from June to September. The river water is normally clear during the winter and spring.

Bull Run River

Bull Run River is a tributary of Sandy River. It rises near the summit of the Cascade Range about 7 miles northwest of Mount Hood.

Discharge.—The longest streamflow record for Bull Run River is that made during the water years 1908–53 near Bull Run (drainage area, 102 square miles). The station is between Lake Ben Morrow and the diversion dam for the Portland water-supply system. The average discharge during the period is 479 mgd.

The Bull Run River gaging station below Lake Ben Morrow (drainage area, 74 square miles) has recorded an average adjusted flow of 374 mgd since October 1929.

Figure 12 is a draft-storage curve for Bull Run River below Lake Ben Morrow. A draft-storage curve, a variation of a mass-curve analysis, is one means of studying the flow characteristics of a stream. Maximum deficiencies in flow volumes below specified outflow rates are computed. Thus, the diagrams show the net storage, disregarding dead storage and storage to provide for water losses such as evaporation and seepage, required to maintain specified outflow rates. Computations for these storage-requirement curves were made from critical low periods since operation of the gaging station began.

Quality.—The quality of water in Bull Run River is important because the city of Portland obtains its municipal supply from this source. Analyses of the water (table 1) show it to be very soft and exceptionally low in mineral content. The water is clear, largely because of lake storage and underground flow. The

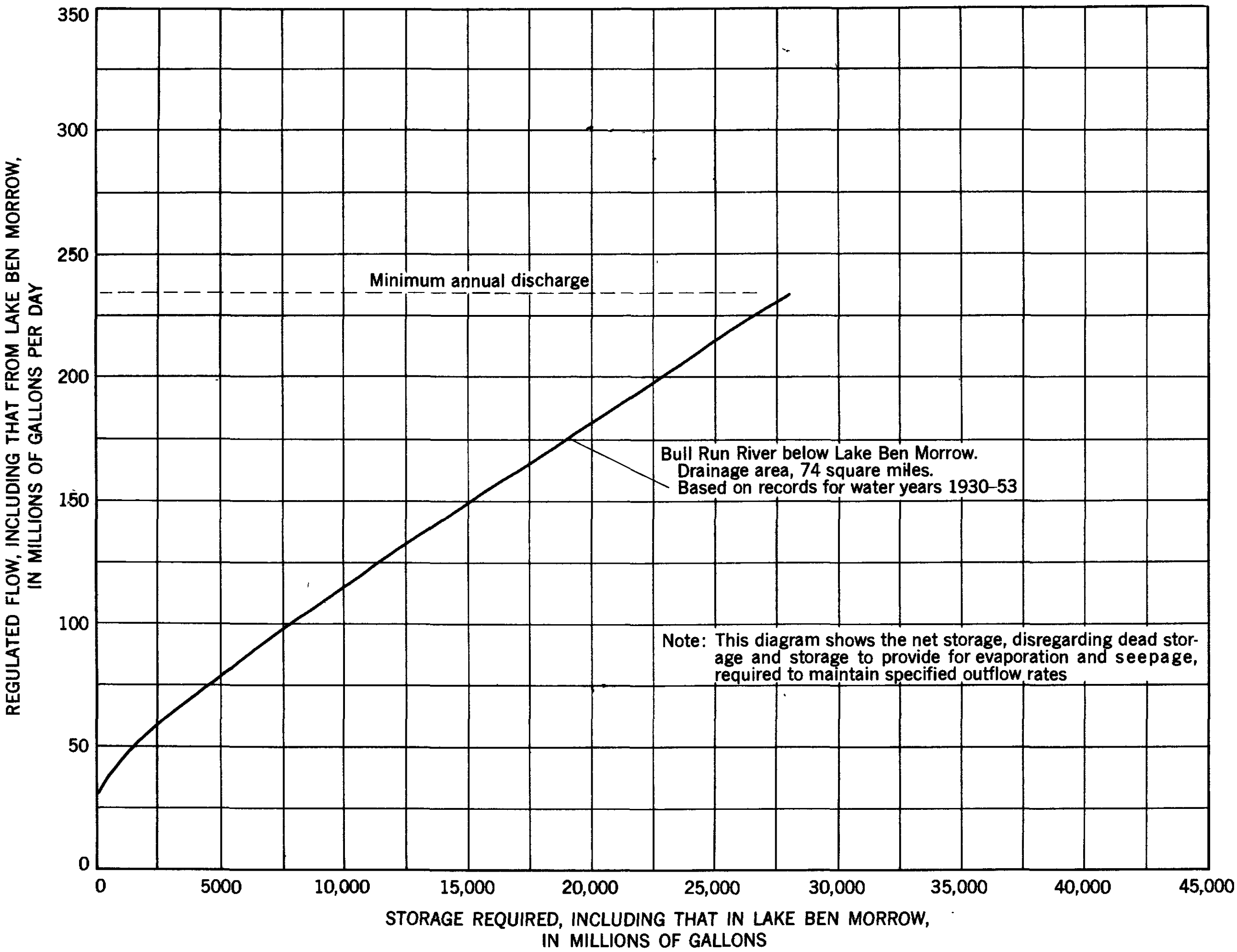


Figure 12.—Draft-storage curve, Bull Run River below Lake Ben Morrow, based on adjusted monthly discharge.

drainage area above the intake is protected from trespass and stock grazing by an act of Congress. Efficient patrol of the area assures a water supply free from sources of pollution.

Little Sandy River

The Little Sandy River flows through a rugged, heavily timbered area and empties into Bull Run River about 2 miles east of the town of Bull Run.

Discharge.—Records have been collected on Little Sandy River by the U. S. Geological Survey at a site about 3 miles east of Bull Run for the periods May 1911 to April 1913 (fragmentary) and since July 1919. The drainage area above this site is 22.3 square miles. The average discharge during 34 years, 1920–53, is 90.5 mgd. The minimum discharge was 5 mgd on August 20, Sept. 16, 17, 1940. The maximum discharge was 3,440 mgd (5,320 cfs) on Nov. 20, 1921. The flow characteristics of Little Sandy River are shown by a flow-duration curve (fig. 11) and a storage-requirement curve (fig. 13).

Quality.—The analysis of a water sample from the Little Sandy River near Bull Run River is reported in table 1. The water is very soft and generally low in mineral content, except for 8.5 ppm of silica.

Washougal River

The Washougal River drains an area of about 240 square miles in Skamania and Clark Counties, Wash., and enters the Columbia River at Camas.

Discharge.—Continuous streamflow records have been collected of Washougal River near Washougal (drainage area, 108 square miles) since September 1944. The flow-duration characteristics of the river at that gaging station are shown in table 2. The average discharge for the 9 years, 1945–53, is 578 mgd. The minimum observed discharge was 29 mgd on Oct. 7, 1952, and the maximum discharge was 11,400 mgd (17,600 cfs) on Feb. 17, 1949, and Feb. 24, 1950. The natural regimen of flow is undisturbed and there are no developments above the gaging station that regulate or divert the flow of the river.

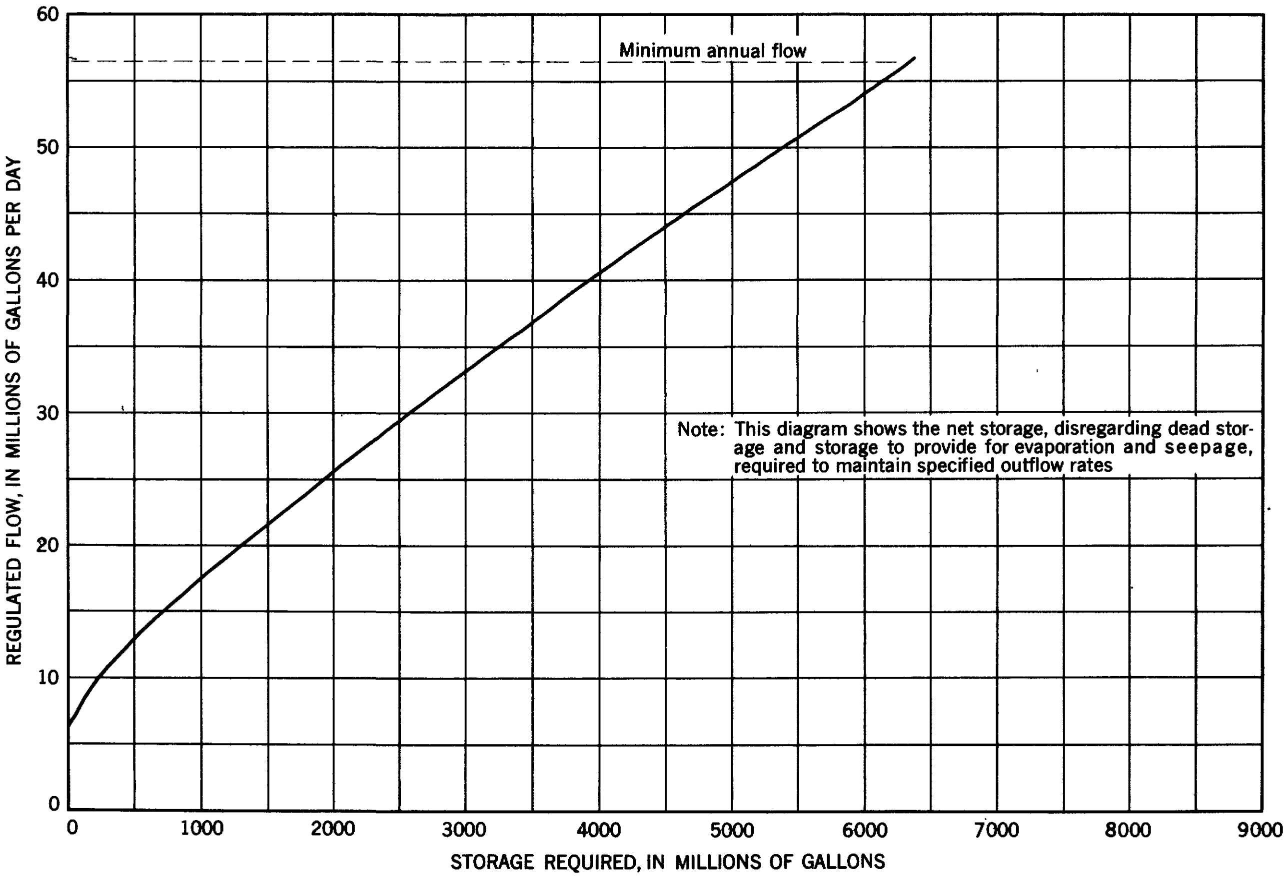


Figure 13.—Draft-storage curve, Little Sandy River near Bull Run, 1930–53.

Quality.—An analysis of water from the Washougal River near Washougal is included in table 1. This water is very soft, low in mineral content, and free of suspended sediment.

Willamette River

The normal regimen of the Willamette River and its tributaries, like that of most streams west of the

Table 2.—Duration of daily flow at several gaging stations in the Portland-Vancouver area

Percent of time indicated discharge was equaled or exceeded	Washougal River near Washougal, Wash. (water years 1945–53)		Molalla River near Canby, Oreg. (water years 1929–53)		Pudding River at Aurora, Oreg. (water years 1929–53)		Clackamas River near Cazadero, Oreg. (water years 1910–53)	
	mgd	cfs	mgd	cfs	mgd	cfs	mgd	cfs
1	4,000	6,190	4,400	6,810	4,200	6,500	7,900	12,200
5	2,000	3,090	2,300	3,560	2,900	4,490	4,200	6,500
10	1,400	2,170	1,600	2,480	2,100	3,250	3,200	4,950
20	820	1,270	1,000	1,550	1,200	1,860	2,400	3,710
30	600	928	770	1,190	820	1,270	1,900	2,940
40	440	681	570	882	570	882	1,500	2,320
50	310	480	410	634	390	603	1,200	1,860
60	200	309	260	402	230	356	980	1,520
70	120	186	145	224	101	156	770	1,190
80	73	113	76	118	63	97	630	975
90	49	76	50	77	45	70	530	820
95	43	67	42	65	38	59	480	743
99	34	53	33	51	31	48	430	665

Cascade Range, is high flow during the winter and low flow during the late summer and fall. (See figs. 4 and 9.) Storage reservoirs regulate the flow somewhat. Five storage and power projects have been completed on the Willamette River forks and tributaries, and 12 other projects are planned. The completed dam and reservoir projects and their years of completion are Cottage Grove (1942), Fern Ridge (1941), Dorena (1949), Detroit (1953), and Lookout Point (1954). Their principal effect is to increase the low flows and decrease flood flows.

Navigation.—The Willamette River has authorized project depths (channel improvements together with streamflow regulation) as follows:

Reach	Depth (in feet)
Mouth to Broadway Bridge, Portland	35
Broadway Bridge to Ross Island Bridge	30
Ross Island Bridge to Oregon City	8
Oregon City to Santiam River	6
Santiam River to Albany	5
Albany to Corvallis	2.5–3.5

Release of stored water during periods of low flow has already benefited navigation. An improvement authorized by Congress provides for construction of a single-lift lock at Oregon City with a depth of 9½ feet above the sills.

Discharge.—The drainage area of Willamette River at Salem is 7,280 square miles, and continuous discharge records have been collected at the station from October 1909 to December 1916 and since January 1923. The average discharge for these periods is 14,850 mgd. The maximum, minimum, and average monthly and annual discharges are shown in figure 4. The minimum discharge during the period was 1,600 mgd on Aug. 27, 1940. The maximum discharge observed was 225,000 mgd (348,000 cfs) on Jan. 8, 1923. The maximum discharge known was 323,000 mgd (500,000 cfs) on Dec. 4, 1861.

Floods.—Records of floods of the Willamette River at Salem are not representative of flood elevations reached in the Portland-Vancouver area, because of the distance and the intervening Willamette Falls at Oregon City. The Weather Bureau has published records of stage at Portland since 1876. The highest elevation attained by the Willamette River at Portland during each year of record is shown in figure 5. Floods at Portland are caused by heavy rains in the Willamette River basin and by backwater from the Columbia River. Headwater floods usually occur in winter, and those caused by backwater, in summer.

Quality.—The chemical and physical properties of water from the Willamette River at Salem have been measured intermittently for many years (table 1). Recent analyses show little change since 1910–12. An analysis of the river water at Oregon City in 1950 shows it to be similar to that at Salem.

A cumulative-frequency curve for dissolved solids in the river water at Salem, 1951–53, is given in figure 8. The range in dissolved solids is small, 43 to 69 ppm; about 10 percent of the time the concentration exceeds 64 ppm. The river water is soft and does not vary much in hardness throughout the year (fig. 8). Even peak stages following heavy rains in the upper Willamette River basin do not modify appreciably the chemical composition or mineral content of the river water (fig. 9).

Pollution in the lower reaches of the Willamette River is a problem of serious concern to health agencies and civic groups. Major causes of pollution are sewage from municipalities, waste from food-processing plants and pulp and paper mills, and logging operations. The city of Portland has nearly completed (1954) a 17-million-dollar pollution-abatement program. Raw sewage now being discharged into the Willamette River will be treated and the effluent will be discharged into the Columbia River. Several industries, notably those manufacturing pulp and paper, have taken steps to treat these industrial wastes before discharge to the river.

The sediment concentration in the river water at Salem was measured in 1910–12. The present rate of sediment movement in the Willamette River at Portland is not accurately known. Sufficient sediment is deposited in Portland harbor, however, to require dredging of navigational channels every 4 or 5 years.

The average monthly temperature of the river water at Portland during 1945–53 ranged from 40.5°F in January to 70°F in August (fig. 10). The highest reading in the 9 years was 74.5°F, observed during July 1945; the lowest reading was 32°F, observed during January 1949 and February 1950. About 10 percent of the time the temperature exceeds 70°F (fig. 10).

Molalla River

The Molalla River enters the Willamette River from the southeast near the southern edge of the report area.

Discharge.—Continuous discharge records have been collected at a gaging station near Canby since August 1928. The drainage area above this site is 323 square miles. The average discharge for the 25 years 1929–53 is 704 mgd. The minimum discharge was 16 mgd on Sept. 14, 1938. The maximum discharge was 16,200 mgd (25,100 cfs) on Jan. 7, 1948. The flow-duration characteristics of Molalla River are shown in table 2. A few small diversions are made above the station for irrigation.

Quality.—The chemical character of Molalla River water (table 1) was determined from a sample collected near Canby, Oreg., in April 1954. The river water is soft and low in dissolved-solids content, but at times is reported to be turbid. Untreated sewage has been discharged into tributaries of the middle reaches of the river; however, measures have been taken to correct this condition.

Pudding River

The Pudding River flows generally northward, entering the Molalla River about 2 miles upstream from the mouth of Molalla River.

Discharge.—Continuous discharge records have been collected on the Pudding River at a gaging station at Aurora, Oreg., since October 1928. The drainage area above this site is 479 square miles. The average discharge during the 25 years 1929–53 is 759 mgd. The minimum discharge was 24 mgd on Sept. 9, 12, 1935. The maximum discharge during the period of record was 16,400 mgd (25,400 cfs) on Dec. 30, 1937. The maximum discharge known was 18,000 mgd (27,900 cfs) on Jan. 7, 1923. The flow-duration characteristics of Pudding River are shown in table 2. Small diversions are made at times above the station, and there is slight regulation by small mills on tributaries at times during the summer.

Quality.—Analyses of water from the Pudding River at Aurora (table 1) indicate a soft water, low in dissolved-solids content. The river water is turbid at times during the year. Inadequately treated industrial sewage is discharged into the lower reaches of the river.

Tualatin River

The Tualatin River flows eastward, entering the Willamette River about 3 miles upstream from Oregon City.

Discharge.—Discharge records have been collected at the gaging station on Tualatin River at Farmington (drainage area, 568 square miles) since October 1939. The average discharge for the 14 years (1940–53) is 845 mgd. The minimum discharge of record was 4.4 mgd on Aug. 26, 1951. A flow-duration curve for Tualatin River at Farmington is shown in figure 14.

Floods.—The highest flood at Farmington since October 1939 reached an elevation of 134.9 feet on Feb. 18, 1949. The maximum known flood, which occurred on Dec. 22 or 23, 1933, reached an elevation of about 137 feet. The greatest flood of each water year from 1940 to 1953 is listed in table 3. The flood-

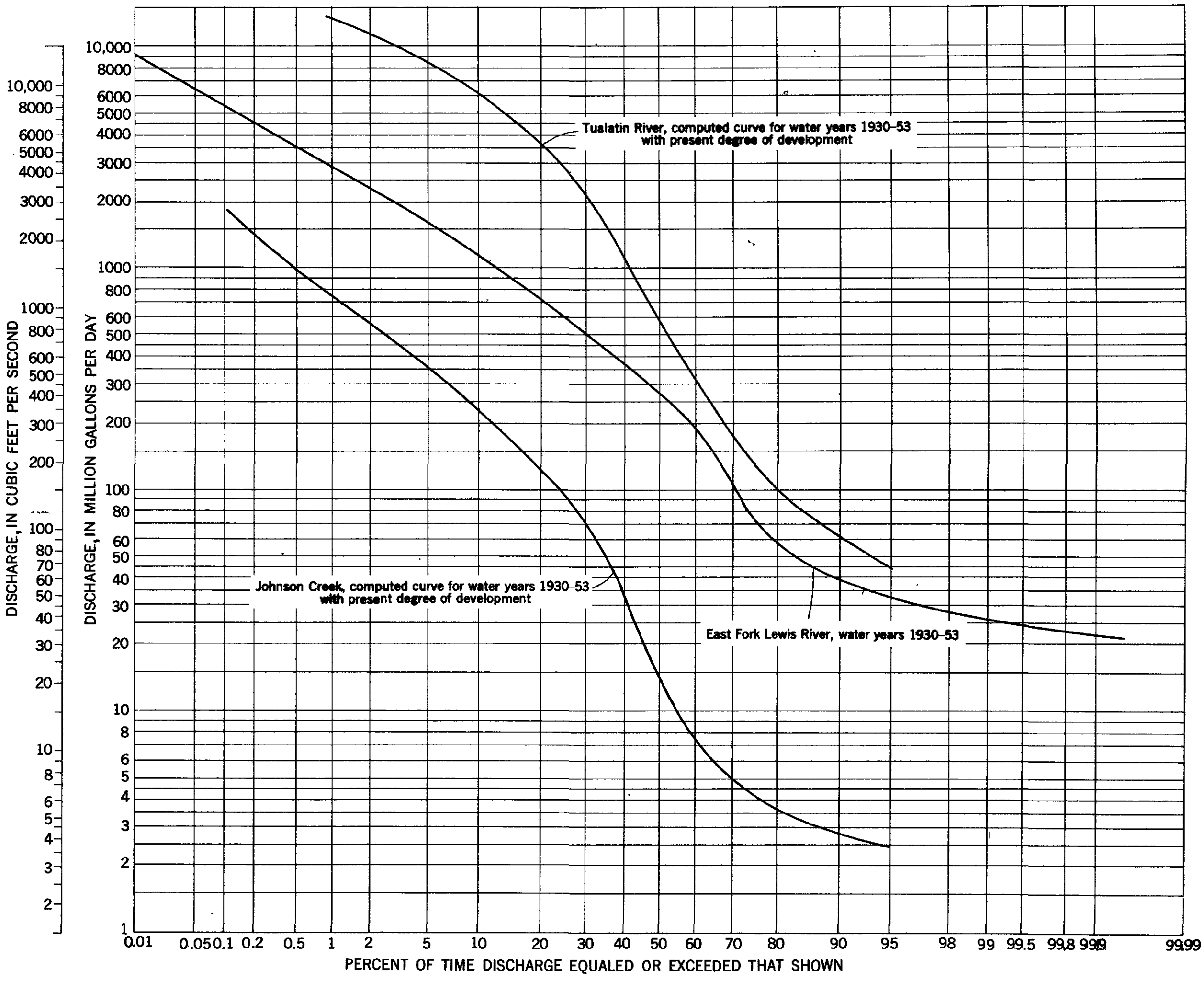


Figure 14.—Duration curve of daily flow, East Fork Lewis River near Heisson, Wash., Johnson Creek at Sycamore, Oreg., and Tualatin River at Farmington, Oreg.

Table 3.—Greatest flood in each water year, Tualatin River at Farmington, 1940–53

[Gage height plus 100.42 ft equals elevation above mean sea level, datum of 1929]

Water year	Date	Gage height (feet)	Elevation above mean sea level (feet)	Discharge (cfs)
1940	Feb. 8, 1940	29.2	129.6	8,890
1941	Jan. 21, 1941	28.38	128.80	6,960
1942	Dec. 20, 1941	33.45	133.87	14,500
1943	Apr. 2, 1943	33.04	133.46	12,100
1944	Feb. 8, 1944	19.18	119.60	3,520
1945	Mar. 22, 1945	30.30	130.72	8,180
1946	Feb. 8, 1946	32.81	133.23	12,300
1947	Dec. 16, 1946	32.58	133.00	11,000
1948	Jan. 9, 1948	32.76	133.18	11,800
1949	Feb. 18, 1949	34.5	134.9	17,400
1950	Feb. 26, 1950	33.5	133.9	13,500
1951	Jan. 23, 1951	33.0	133.4	11,100
1952	Dec. 6, 1951	33.4	133.8	12,700
1953	Jan. 21, 1953	33.30	133.72	11,900

frequency graph shows the recurrence interval of flood elevations and approximate discharges (fig. 15). At this gaging station the relation between river stage and discharge is only approximate because the variable slope of the water surface affects the discharge. An auxiliary gage, 6½ miles downstream, is used to ascertain the slope of the water surface and make it possible to compute discharge. The flood hazard is aggravated by a meandering debris-choked channel extending several miles upstream and downstream from the gage.

Continuous records of discharge have been collected by the U. S. Geological Survey on the Tualatin River near Willamette (drainage area, 710 square miles) since July 1928. Oswego Canal diverts water from the Tualatin River, at a point 4½ miles upstream from the Willamette gage, for recreational use in Oswego Lake and for a small power plant between the lake outlet and the Willamette River. The tail water is discharged to Willamette River. A gaging station has been maintained on Oswego Canal near Oswego since October 1928. Figure 4 shows the average, maximum, and minimum monthly and annual discharges of the river above and below the point of diversion.

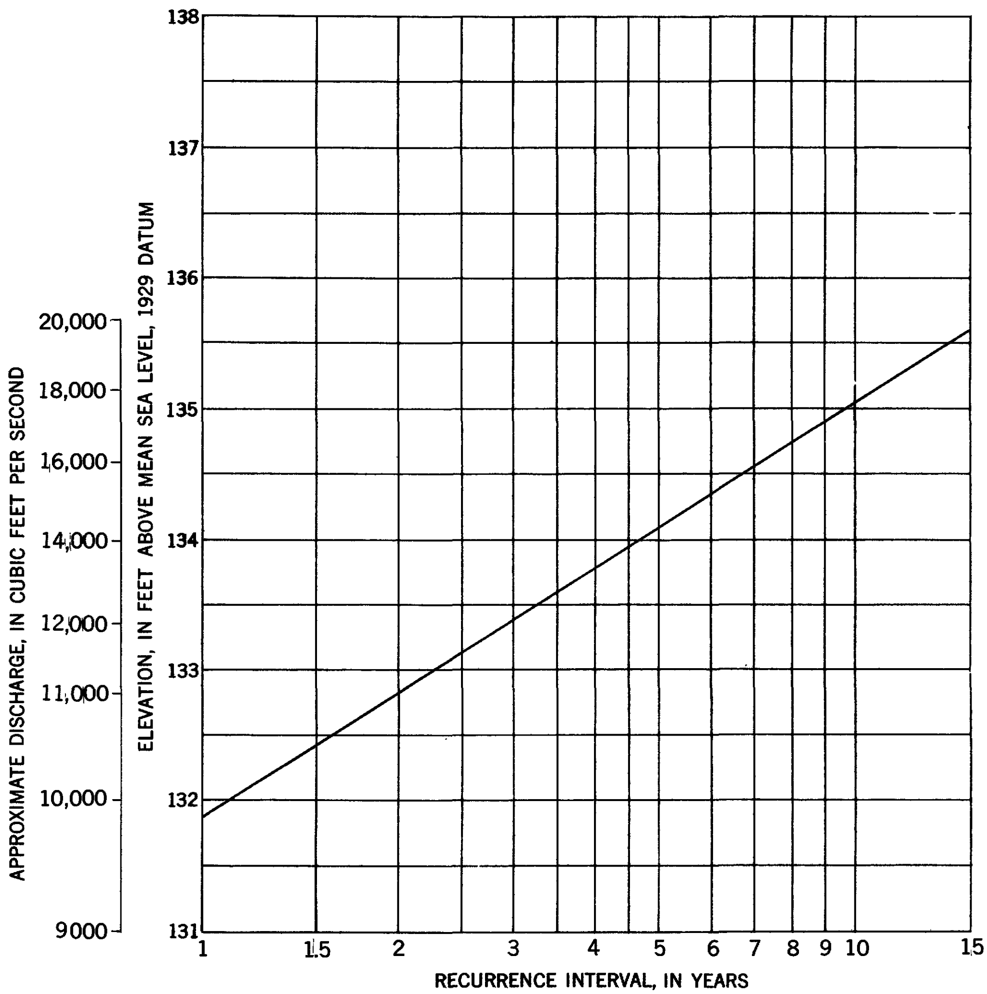


Figure 15.—Flood-stage recurrence intervals, Tualatin River at Farmington, Oreg., 1940–53.

Quality.—Tualatin River water was sampled at Farmington and at Willamette, Oreg., and analytical data are listed in table 1. The river water is soft and contains moderate amounts of dissolved solids. After heavy rains the river water is turbid and transports considerable sediment in suspension. Some inadequately treated sewage from unincorporated areas is discharged into the lower reaches of the river.

Clackamas River

The Clackamas River empties into the Willamette River just downstream from Oregon City. Three hydroelectric plants on the river use part of the great amount of fall between the river's source and mouth. Operation of those plants causes diurnal fluctuations in flow but otherwise has little regulating effect. A storage reservoir is under construction on Oak Grove Fork at Timothy Meadows, in T. 5 S., R. 8 E. Occasional flood damage along the lower reaches of the river is caused by headwater floods or by backwater from the Willamette River.

Discharge.—Continuous records of discharge have been collected on the Clackamas River near Cazadero since January 1909. The drainage area above this site is 657 square miles, which is 71 percent of the total drainage area of the basin.

The average discharge for the 45 years 1910–53 is 1,710 mgd. The minimum discharge of record was 265 mgd on Oct. 20, 1925, and September 28, 1930, but this was caused by a shut-down of the power plant at Three Lynx. The minimum daily flow was 379 mgd, Aug. 17, 1930. The maximum flood known reached an elevation of 556.5 feet on Mar. 31, 1931, discharge, 39,300 mgd (60,800 cfs). The flow-duration characteristics of Clackamas River are shown in table 2.

Quality.—A study of the quality of Clackamas River water at Cazadero was based on analyses of 37 samples of river water obtained during a 12-month period in 1911–12. The mean of these analyses and more recent data collected above and below Cazadero are reported in table 1. The supply is a soft, calcium bicarbonate water having low mineral content. Except for occasional turbidity, resulting largely from logging operations in the upper basin, the water is suitable for general use. Low concentrations of suspended sediment were reported in the 1911–12 investigation.

Johnson Creek

Johnson Creek enters the Willamette River at Milwaukie. The creek has a drainage area of about 54 square miles at its mouth. The drainage area above the gaging station at Sycamore is 28.2 square miles.

Discharge.—The average discharge of Johnson Creek at Sycamore for the 13 years of Geological Survey record (1941–53) is 33.7 mgd. The minimum discharge of record was 0.13, mgd Aug. 14–16, 18–22, 1940, and Aug. 2, 21, 22, 1941. The flow characteristics of Johnson Creek are shown by the flow-duration curve (fig. 14). The low-flow regimen may have been affected by changes in use for irrigation throughout the period of record.

Floods.—The maximum stage since the station was established was 13.77 feet above gage datum or 241.80 feet above mean sea level on Feb. 10, 1949, discharge, 2,110 cfs. The highest flood in each water year is given in table 4, and a flood-frequency graph is shown in figure 16.

Table 4.—Greatest flood in each water year, Johnson Creek at Sycamore, 1941–53

[Gage height plus 228.47 ft equals elevation above mean sea level, datum of 1929, supplementary adjustment of 1947]

Water year	Date	Gage height (feet)	Elevation above mean sea level (feet)	Discharge (cfs)
1941	Jan. 18, 1941	5.90	234.37	499
1942	Dec. 19, 1941	8.51	236.98	937
1943	Nov. 23, 1942	11.76	240.23	1,770
1944	Feb. 6, 1944	4.79	233.26	260
1945	Feb. 7, 1945	6.33	234.80	529
1946	Nov. 27, 1945	8.70	237.17	888
1947	Dec. 12, 1946	11.25	239.72	1,420
1948	Jan. 7, 1948	13.06	241.53	1,900
1949	Feb. 10, 1949	13.77	242.24	2,110
1950	Jan. 10, 1950	8.99	237.46	839
1951	Nov. 17, 1950	10.62	239.09	1,160
1952	Dec. 1, 1951	8.39	236.86	714
1953	Jan. 18, 1953	10.0	238.47	1,020

Damaging floods occur practically every year, because the carrying capacity of the meandering channel is low. In places the channel is choked by debris, and the carrying capacity is further reduced by trees along the banks. A flood-control project consisting of channel improvements and bank protection has been authorized. This project will offer protection against most floods in the reach from a little above Gresham to the mouth. Some channel improvements were made between Sycamore and Milwaukie by the Works Progress Administration in the 1930's.

Quality.—Chemical data for water from Johnson Creek near Sycamore are reported in table 1. The water is soft and low in dissolved-solids content. In the past, untreated food-processing wastes were fed into Johnson Creek. This practice polluted the stream and led to completion in 1955 of a primary treatment plant near the Columbia River. Cannery wastes are pumped to this treatment plant, and the effluent after treatment is discharged into the Columbia River.

Lewis River

The Lewis River enters the Columbia River from the northeast. The river falls nearly 8,000 feet between its source and its mouth and has many potential power sites, but only two hydroelectric plants are in operation.

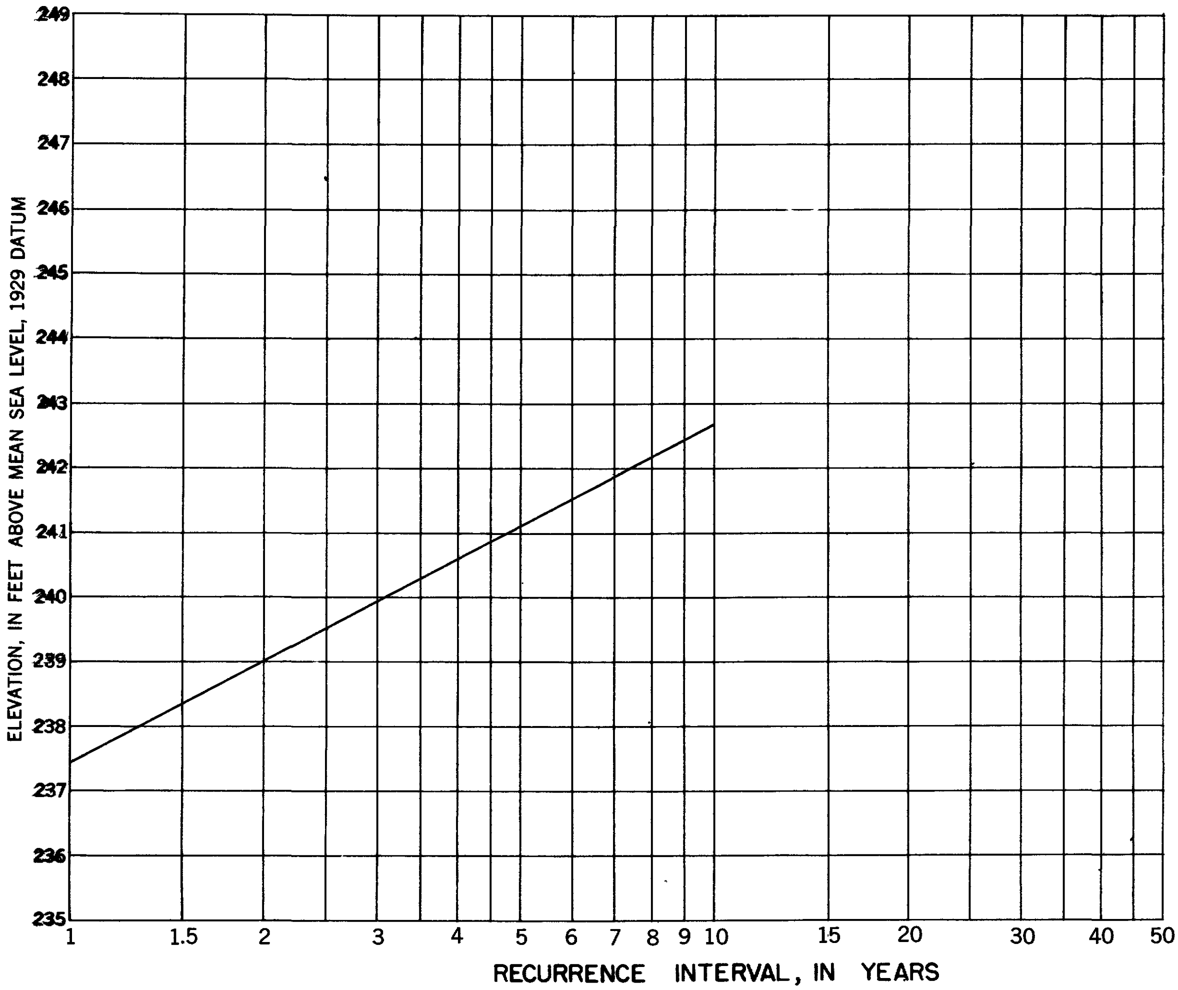


Figure 16.—Flood-stage recurrence intervals, Johnson Creek at Sycamore, Oreg., 1941–53.

Discharge.—The river has a total drainage area of 1,050 square miles, of which 731 square miles is above the gaging station at Ariel. Discharge records have been collected at Ariel since July 1922. Lake Merwin is impounded by Ariel Dam, which was completed in 1931, and Yale Reservoir is impounded by Yale Dam, which was completed in 1952. Ariel Dam is in the SW¼ sec. 34, T. 6 N., R. 2 E., half a mile upstream from the gaging station at Ariel. Yale Dam is in the NE¼ sec. 32, T. 6 N., R. 4 E., 3½ miles southeast of Yale. These reservoirs regulate the discharge past the gaging station. The average discharge, adjusted for storage, for the 30 years of record (water years 1924–53) is 2,970 mgd. There was no flow past the gage at times during the construction of Ariel Dam. The maximum discharge of record was 83,400 mgd (129,000 cfs) on Dec. 22, 1933. Figure 4 shows average, maximum, and minimum monthly and annual discharge for the water-years 1932–53, after completion of Ariel Dam. Figure 4 shows discharge past the gaging station, unadjusted for storage.

Quality.—An analysis of water from Lewis River is given in table 1. This typical mountain stream yields clear, soft water of low mineral content.

East Fork Lewis River

East Fork Lewis River is t·ibutary to Lewis River, which it enters about 3½ miles upstream from the Columbia River. The river stage is affected by tides for about 3 miles upstream.

Discharge.—Discharge records have been collected at the gaging station East Fork Lewis River near Heisson, Wash., (drainage area, 125 square miles) for 24 years, 1930–53. The average discharge at this site is 472 mgd, and the minimum discharge of record was 19 mgd on Nov. 3, 1935. The flow characteristics of East Fork Lewis River are shown by the flow-duration curve (fig. 14), low-flow frequency curve (fig. 17), and storage-requirement curve (fig. 18). The low-flow frequency curve shows the average interval in years at which various rates of flow will occur as the lowest flow during the year. The recurrence interval does not imply any regularity of occurrence; instead it is the probable average interval at which a selected rate of flow will be the lowest during the year. For example, the daily flow receded to about 30 mgd in about half of the years and to about 22 mgd once in 10 years. Daily flows as low as 22 mgd could occur in

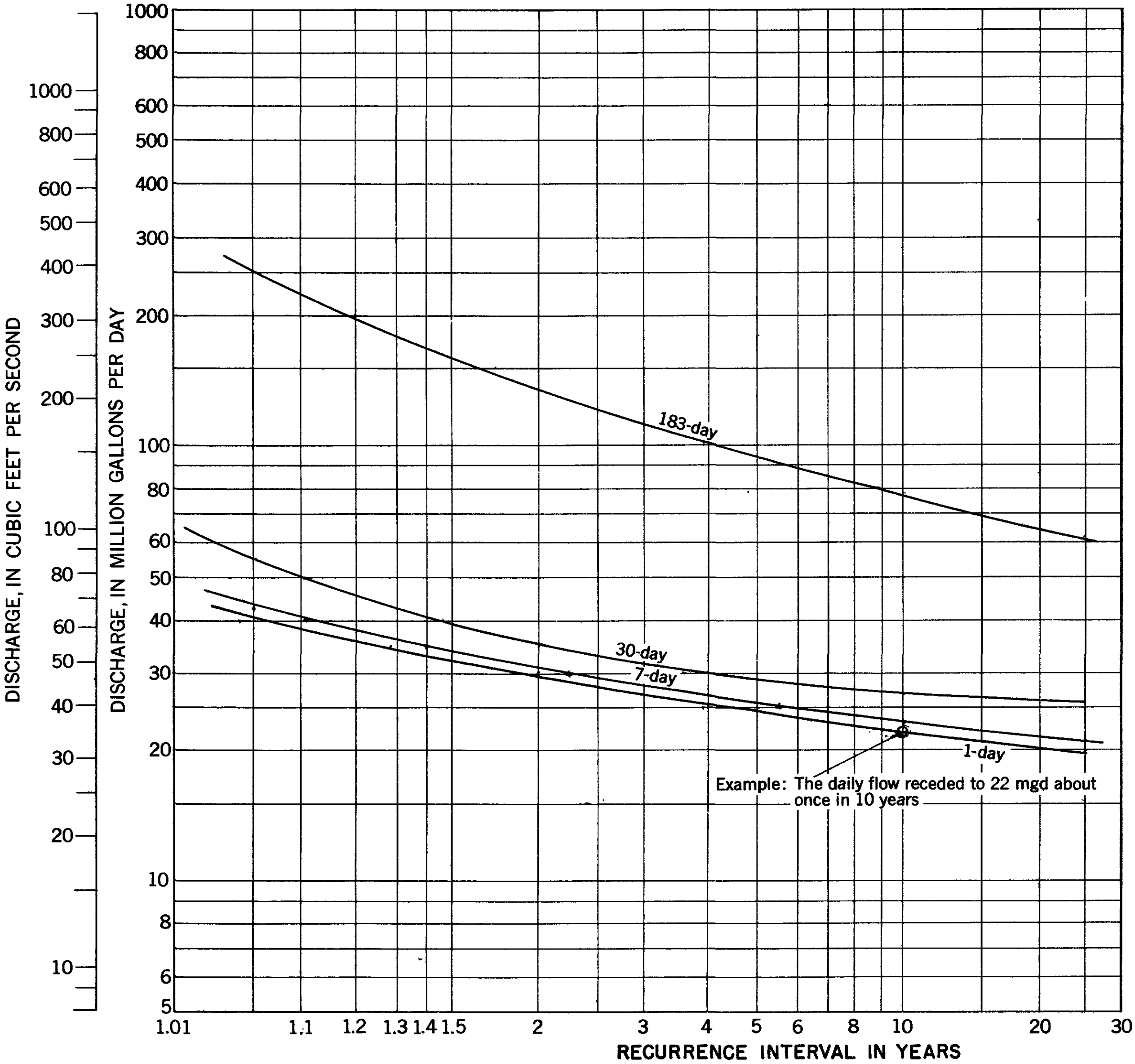


Figure 17.—Low-flow recurrence intervals, East Fork Lewis River near Heisson, Wash., 1930–53.

consecutive years, but during a long period the flow would recede to about 22 mgd in 10 years out of 100.

Floods.—The maximum discharge since the station was established was 10,100 mgd (15,600 cfs) on Dec. 22, 1933. The maximum stage was 12.3 feet, which was 379.1 feet above mean sea level. Selected major floods are given in table 5, and a flood-frequency graph is shown in figure 19. Some flood damage occurs at La Center near the mouth of the river.

Special Conditions.—A potential reservoir site about 5½ miles upstream from the gaging station near Heisson could store more than 100,000 acre-feet of water according to studies made by the Corps of Engineers. Water could be diverted through a tunnel to another potential reservoir site on Salmon Creek, which is in a separate basin. A usable storage capacity of nearly 300,000 acre-feet could be developed on Salmon Creek about a mile west of Venersborg. Thus, water diverted from 100 square miles on East Fork Lewis River and 19 square miles on Salmon Creek could be stored to irrigate about 50,000 acres, and some incidental power and flood-control benefits could be obtained.

East Fork Lewis River is included in the lower tributary fishery plan for the Columbia River and proposals for works on the river should consider the effect upon the fisheries.

Quality.—Results of an analysis of water from East Fork Lewis River are given in table 1. The water is clear, soft, and low in mineral content.

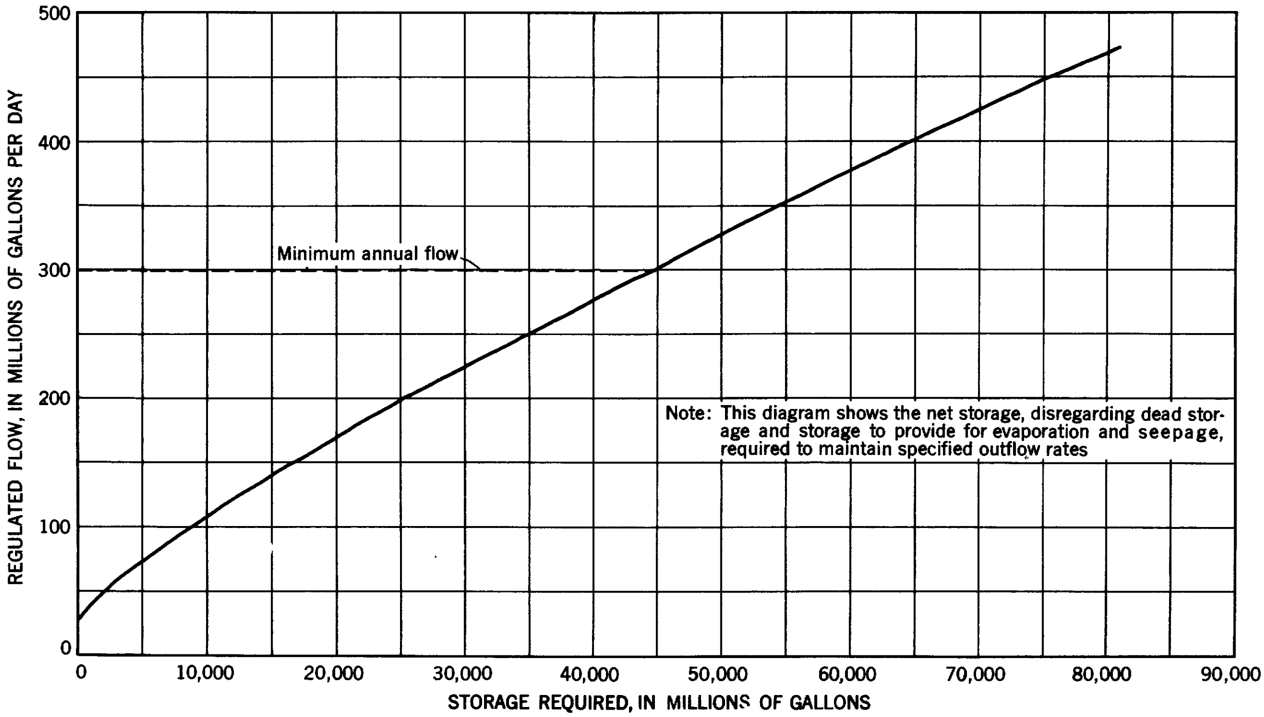


Figure 18.—Draft-storage curve, East Fork Lewis River near Heisson, Wash., 1930–53.

Table 5.—Major floods on East Fork Lewis River near Heisson, for period of record 1929–53

[Gage height plus 366.8 ft equals elevation above mean sea level, from river-profile surveys]

Date	Gage height (feet)	Elevation above mean sea level (feet)	Discharge (cfs)
Mar. 31, 1931	12.2	379.0	15,500
Dec. 6, 1933	11.54	348.3	13,600
Dec. 22, 1933	12.3	379.1	15,600
Dec. 21, 1934	10.18	376.98	10,500
Dec. 29, 1937	10.60	377.40	11,400
Nov. 23, 1942	11.17	377.97	12,800
Nov. 18, 1946	10.02	376.82	10,100
Dec. 11, 1946	10.84	377.64	11,900
Feb. 17, 1949	11.72	378.52	14,000

GROUND WATER

Occurrence

Ground water is water within the earth in the zone of saturation. Openings in earth material range in size from the minute pores in clay and shale to larger openings between grains of sand, pebbles, gravel, or boulders, and to open fractures and solution channels in some rocks. Any water-bearing material whose openings are large enough to discharge water freely to a well or spring is called an aquifer.

Ground water occurs under two principal conditions: water-table or unconfined, and artesian or confined. Water-table conditions occur where the upper surface of the zone of saturation is open to atmospheric pressure; the water levels in wells then coincide approximately with the level of the water table. When the water table lowers, some formerly saturated material is dewatered; and, when the water-table rises, some of the material previously unsaturated becomes saturated. Artesian or confined conditions occur where a saturated aquifer is overlain by an impermeable stratum and water is under sufficient pressure to rise above the zone of saturation when the zone is penetrated. Where an aquifer of this type is penetrated in drilling a well, the water rises in the well to a height corresponding to the hydraulic pressure on the water in the aquifer. The surface to which the confined water will rise under its full head is called the piezometric or pressure surface.

Ground water occurs under both unconfined and confined conditions in the Portland-Vancouver area. Unconfined conditions are common in the upper part of the alluvial valley-fill materials, and confined conditions occur generally in the lower strata of those materials and in the bedrock below.

Ground water also occurs as perched water beneath the higher terraces and the hills around the margins of the area. In some places, the main zone of saturation is overlain by unsaturated material that contains an impervious formation above which the material is locally saturated. Water in these local isolated zones of saturation is perched water. Perched water is obtained for many farmsteads and suburban homes at

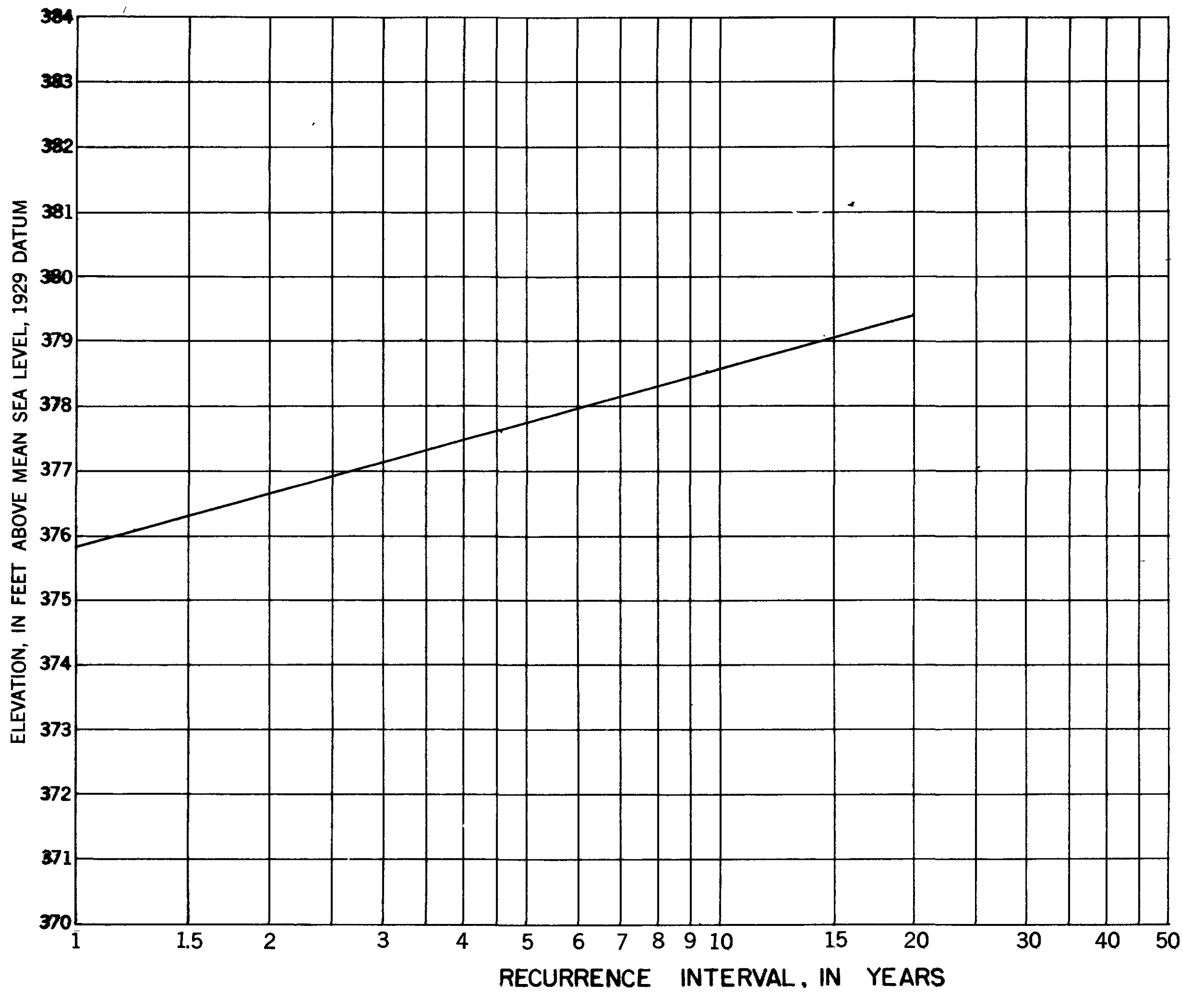


Figure 19.—Flood stage recurrence intervals, East Fork Lewis River near Heisson, 1930–53.

less expense than would be possible from the deeper main zone of saturation. Perched water supplies only a relatively small part of all ground water that is used.

The Water-Bearing Character of the Rock Units

Formations older than the Columbia River basalt are mostly nonpermeable and do not transmit much fresh water. (See table 6.) Water from these formations is mineralized and commonly is high in calcium and sodium chloride.

The Columbia River basalt contains moderate amounts of ground water, mostly in permeable rubble along interflow contacts. Ground water from this rock is tapped around the edges of the valley plains. At some places yields of 500–1,000 gpm are obtained by 12-inch wells drilled through several hundred feet of the basalt.

Recoverable ground water occurs in some of the gravel and sand beds in the Troutdale formation. These gravel and sand beds are more abundant in the upper few hundred feet than in the lower part of the normal Troutdale section. Near the large rivers the Troutdale formation yields water to 12-inch wells at rates as high as 1,000 gpm, but elsewhere few wells yield more than 900 gpm. In the western part of the Portland and Vancouver areas, especially in the Tualatin Valley, strata believed to be of Troutdale age are consistently clayey or fine-grained and yield only small amounts of water.

The Boring lava in the plateaulike areas contains ground water in fractures, joints, and porous flow structures, but at many places the water drains away because of the elevated position at which much of the lava rock occurs.

Large quantities of recoverable ground water are contained in the older alluvial materials. At most places the water is perched, but at a few it is part of the unconfined main water body and is continuous with that in the underlying Troutdale formation. An extensive body of ground water in these materials extends southward from Salmon Creek to the Columbia River bluff where the water is discharged along the prominent spring line at an altitude of 125 to 175 feet. The

Table 6.—Water-bearing properties of geologic formations in the Portland-Vancouver area

AGE		Deposit or formation	Thickness (feet)	Lithologic character	Water-bearing characteristics
Period	Epoch				
QUATERNARY.	Recent.	Alluvium.	0-130	Sand, gravel, silt, mud and clay.	Yields water from sand and gravel beds that are below water table.
	Pleistocene.	Alluvium.	0-300	Sand, gravel, and clay; includes some glaciofluviatile deposits.	Do.
		Glacial outwash and till.	0-50	Sand and gravel; silt, clay, and till; gray to buff.	Unimportant as an aquifer. Occurs only in a small area; water mostly perched.
TERTIARY or QUATERNARY.	Pleistocene or Pliocene.	Boring lava.	0-230	Gray volcanic rock.	Yields small amounts of perched water by wells at some places from base of the flow rock.
		Undifferentiated sedimentary rocks.	0-1,480	Clay with a few beds and lenses of fine-grained sand.	Some water obtained from sand zones in the Tualatin Valley fill.
		Volcanic rocks of the High Cascades.	0-1,000+	Andesitic flows and pyroclastic rocks.	Unimportant as a source for wells but supplies important storage of water which helps maintain base flow of streams.
TERTIARY.	Pliocene.	Troutdale formation.	0-1,000	Sand, gravel, and clay with some sandstone; gravel is partly indurated.	Water-bearing capacity varies with degree of induration; gravelly upper part more permeable than lower clayey part.
	Pliocene(?) and Miocene.	Columbia River basalt.	0-1,000	Layered dense black basalt with well-developed joints.	Important but variable aquifer; yields water from interflow zones, crevices, joints, and fractures.
	Oligocene.	Silver Star granodiorite of Felts, 1939.	?	Granodiorite intrusive.	Unimportant as an aquifer; occurs in a small mountainous area.
	Oligocene and Eocene.	Undifferentiated sedimentary rocks.	0-2,000+	Marine sediments; largely tuffaceous shale and sandstone.	Yields mostly saline water.
	Eocene.	Older volcanic rocks.	?	Basaltic and andesitic flows, pyroclastic rocks, and associated sediments.	Mostly low in permeability; yield little water.

spring line extends eastward from Vancouver to Prune Hill, a distance of 10 miles. The materials beneath the higher levels of the Portland terraces contain ground water, perched at places, and the materials beneath the lower terraces near the river contain water at a level near that of the river. The water in the lower terraces is continuous with the ground water in the Troutdale formation. Wells producing 50 to 300 gallons per minute are characteristic of the perched water zones. In some places greater amounts are obtained from wells that tap the coarse-grained units of the Troutdale formation.

The younger alluvial sand and gravel in places beneath the flood plains of the larger rivers yields large amounts of water. Some of the alluvium is fine grained and of lower permeability, as in the valleys of many of the smaller streams and beneath the Recent alluvial plains in parts of the Tualatin Valley.

The undifferentiated valley-fill deposits of the Tualatin Valley are largely non-water-yielding clays and silts, but contain some fine-grained sand zones, especially in the Forest Grove and Hillsboro districts; and these yield small amounts of ground water to properly constructed wells.

Principal Ground-Water Districts

Portland-Vancouver Lowland

The location and extent of the Portland-Vancouver lowland are shown on plate 1. The land is mainly flood plains and terraces. It is relatively level with a maximum relief of about 500 feet. The outer limit of the lowland is about at the 500-foot contour. Geologic sections (pl. 2), together with the following drillers' logs, show the sequence of the strata.

Well owned by the Aluminum Company of America, NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 19, T. 2 N., R. 1 E., altitude about 30 feet

[Representative of wells on the flood plain north of the Columbia River. Static water level 26 ft below land surface Sept. 16, 1940. Pumped 1,100 gpm with 3 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Recent alluvium:		
Sand (dredged)	10	10
Soil	3	13
Clay, yellow	24	37
Clay, blue, and silt	21	58
Pleistocene deposits:		
Sand, packed	34	92
Sand	5	97
Silt, blue	13	110
Troutdale formation:		
Gravel and sand, tight	10	120
Gravel, loose, water-bearing	8	128
Gravel, tight	8	136

Well owned by the Federal Housing Authority, NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 30, T. 2 N., R. 2 E., altitude about 193 feet

[Representative of wells on the terrace plains east of Vancouver. Static water level 108 ft below land surface. Pumped 275 gpm with 82 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Pleistocene deposits:		
Soil	5	5
Sand	64	69
Troutdale formation:		
Gravel, cemented, with some water in upper 3 ft	131	200
Gravel, cemented, and clay	32	232
Gravel, loose, water-bearing	13	245
Gravel, loose	13	258
Gravel, cemented	42	300

"Ladd" well, in the eastern part of Portland in SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 36, T. 1 N., R. 1 E., about 350 feet north and 250 feet east of the intersection of the center lines of NE. 39th Avenue and Glisan Street, altitude 210 feet

[Drilled about 1885 and abandoned long ago. Static water level reported as 340 ft below land surface. No pumping test]

Materials	Thickness (feet)	Depth (feet)
Pleistocene deposits:		
Earth, clayey sand, and "drift" sand	100	100
Sand, clay, and gravel	20	120
Sand with boulders of basalt and "granite"	20	140
Troutdale formation(?):		
Boulders and gravel with layers of sand, water-bearing	40	180
Gravel and sand	20	200
Boulders, cobbles, and pebbles	20	220
Gravel and coarse sand with layers of sand and "conglomerate"	110	330
Sand and fine basaltic gravel	26	356
Sand, coarse and fine	4	360
Clay, sand, and "granite" boulders in alternate layers	45	405
"Marl" and compact clay in part sandy, fossil wood and plants	315	720
Sand, fine and coarse, with gravel	10	730
"Marl" and compact shale, with gravel and layers of soft fine "sandstone"	120	850
Clayey shale with layers of fine sand and plentiful fossil wood and plants	150	1,000
Fine micaceous sand, white and compact, coarse basaltic sand and fine gravel	80	1,080

"Ladd" well, in the eastern part of Portland in SE¼NE¼ sec. 36, T. 1 N., R. 1 E., about 350 feet north and 250 feet east of the intersection of the center lines of NE. 39th Avenue and Glisan Street, altitude 210 feet—Continued

Materials	Thickness (feet)	Depth (feet)
Troutdale formation(?)—Continued		
Conglomerate, shale, and "marl" with iron-stained sand and fossil plants	120	1,200
Coarse sand and gravel, basaltic	50	1,250
"Marl," fine and sandy, soft shale with iron-stained gravel and fossil plants	50	1,300
Columbia River basalt(?):		
"Granite"	400	1,700

Well owned by Ray Shiiki, south of Gresham, Oreg., in NE¼ SE¼ sec. 22, T. 1 S., R. 3 E., altitude about 600 feet

[Static water level 183 ft below land surface. Pumped 600 gpm with 75 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Pleistocene deposits(?):		
Clay, yellow	64	64
Boring lava:		
Rock	90	154
Rock and clay, yellow	24	178
Rock	16	194
Troutdale formation:		
Clay, yellow	6	200
Gravel, cemented	15	215
Clay, yellow	4	219
Gravel, cemented	46	265
Gravel, water-bearing	5	270
Gravel, cemented	61	331
Gravel, water-bearing	10	341
Gravel, cemented	19	360
Clay, blue, and rock	34	394
Clay, blue	66	460
Clay, green	10	470
Columbia River basalt:		
Rock	29	499
Rock, soft, water-bearing	9	508
Rock, hard	2	510

Most wells in the Portland-Vancouver lowland obtain water from the alluvium or from the semiconsolidated strata in the Troutdale formation. A few wells along the western and southern edges of the area extend through the unconsolidated materials and tap water in the underlying Columbia River basalt. The wells in this area drawing water from the unconsolidated materials produce from 2 or 3 gpm to more than 3,000 gpm. The quantity of water a well produces depends largely on the type and thickness of the saturated material tapped, and the diameter and type of construction of the well. Yields from the Columbia River basalt range from a few gallons per minute to 800 gpm, depending upon the number of interflow zones tapped and the type of construction and diameter of the well. A few of the wells that tap the basalt along the foot of the Portland ridges from north Portland to just south of St. Helens yield saline water of a type characteristically found in the sedimentary rocks of Tertiary age that underlie the basalt.

The depth to the water table ranges from about 10 feet below the surface of the flood plains of the Columbia and Willamette Rivers to 300 feet or more below the surface of the higher land along some of the boundaries of the area. The piezometric surface of the water in the artesian aquifers at most places is only slightly above the level of the water table, but some wells in the area flow. Figure 20 shows water level and volume of water pumped from the Weisfield and Goldberg well at Washington and Broadway Streets in Portland and the stage of the Willamette River at Portland, 1945–54. The well is 155 feet deep and is 2,300 feet from the Willamette River.

Tualatin Valley

The Tualatin Valley (see pl. 1) is a large, relatively flat alluvial valley, the floor of which is about 150 to 300 feet in altitude. In the south-central part of the valley several bedrock hills rise to an altitude greater than 500 feet. As with the Portland-Vancouver lowland, the boundaries of the Tualatin Valley plain are defined approximately by the location of the 500-foot contour. A geologic section (pl. 2) and drillers' well logs show the sequence of the underlying earth materials.

Texas-Cooper Mountain no. 1 oil test well. Drilled by The Texas Oil Company on Cooper Mountain in the NE¼SE¼ sec. 25, T. 1 S., R. 2 W., altitude about 765 feet

Materials	Thickness (feet)	Depth (feet)
Soil and mantle (undifferentiated):		
Clay and weathered basalt	100	100
Columbia River basalt:		
Basalt	939	1,039
Sedimentary and volcanic rocks of Tertiary age:		
Sand and shale, fossiliferous	1,801	2,840
"Volcanic" sand, agglomerate, shale	1,430	4,270
Shale, sandstone, and agglomerate	4,936	9,206
"Volcanics," agglomerates, and flows	57	9,263

Well owned by Commonwealth, Inc., SE¼SW¼ sec. 2, T. 1 S., R. 1 W., altitude about 420 feet

[Static water level 235 ft below land surface Nov. 12, 1953. Pumped 175 gpm with 68 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Soil and mantle (undifferentiated):		
Clay and soil	9	9
Boring lava (basalt):		
Rock, broken	18	27
Rock, gray, medium-hard	9	36

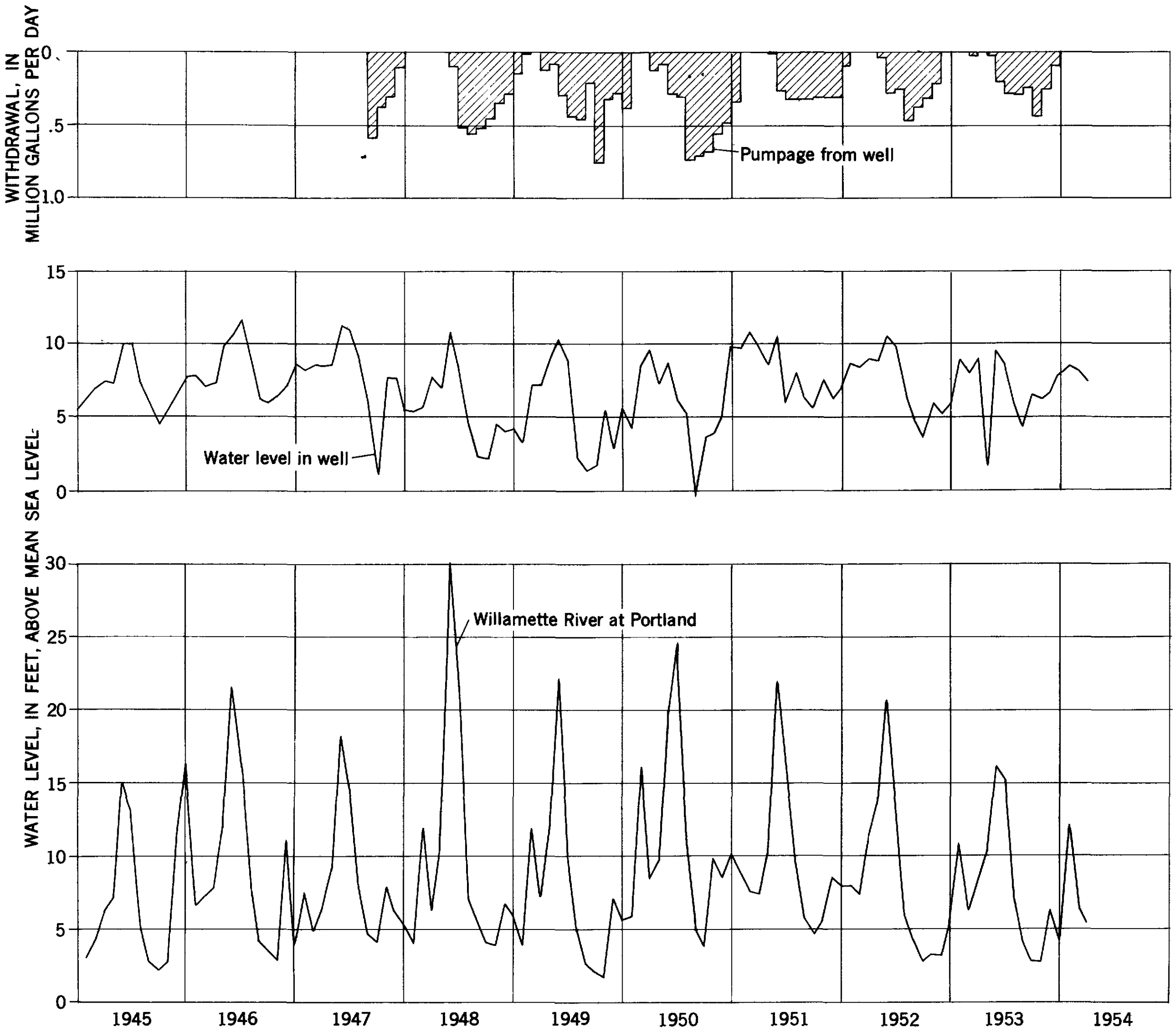


Figure 20.—Stage of Willamette River at Portland, and water level and pumpage at Weisfield and Goldberg wells in Portland, 1945–54.

Well owned by Commonwealth, Inc.—Continued

Materials	Thickness (feet)	Depth (feet)
Boring lava (basalt)—Continued		
Rock, gray, hard	73	109
Rock, gray, hard (some broken crevices with brown seams)	42	151
Rock, gray, crevices	7	158
Rock, gray, hard	56	214
Rock, gray, very hard	17	231
Rock, brown	8	239
Troutdale formation:		
Conglomerate	14	253
Clay, yellow	44	297
Clay, blue	7	304
Clay, yellow	12	316
Clay, blue	13	329
Clay, yellow	35	364
Clay, blue	129	493

Well owned by Commonwealth, Inc.—Continued

Materials	Thickness (feet)	Depth (feet)
Troutdale formation—Continued		
Clay, red	34	527
Clay, blue	66	593
Clay, red	27	620
Clay, yellow	7	627
Conglomerate	46	673
Columbia River basalt:		
Rock, decomposed	44	717
Rock, brown, hard	12	729
Rock, gray, hard	41	770
Rock, brown, hard, broken	7	777
Rock, gray	57	834
Rock, black	20	854
Rock, black, water-bearing	18	872
Rock, gray, hard	3	875

Well at the Tigard Senior High School, NE¼NE¼ sec. 14, T. 2 S., R. 1 W., altitude about 190 feet

[Static water level 7 feet below land surface Sept. 1, 1953. Pumped 30 gpm with 224 feet of drawdown]

Materials	Thickness (feet)	Depth (feet)
Valley fill (undifferentiated):		
Clay and sand	18	18
Clay, yellow, blue	48	66
Clay, blue, and yellow sand	50	116
Clay, blue, gray	34	150
Clay and "quicksand"	40	190
Clay, blue	52	242
Sand and gravel	2	244
Clay, blue-gray	16	260
Sand, water-bearing	1	261
Clay, blue-gray	63	324
Clay, yellow	17	341
Clay, blue	9	350
Clay, brown	10	360
Clay, blue	18	378
"Shale," blue-gray	6	384
Clay, blue	46	430
Clay, brown (1 gpm with rotten wood in water)	7	437
Clay and weathered gravel	8	445
Clay, blue-gray	32	477
Clay, brown, "gritty"	2	479
Clay, gray	33	512
Clay, chocolate-brown	16	528
Clay, blue, sandy	5	533
"Shale," hard, brown	5	538
Clay, red	21	559

Well at the Tigard Senior High School—Continued

Materials	Thickness (feet)	Depth (feet)
Columbia River basalt:		
Rock, soft, and red clay	31	590
Rock, soft, and yellow clay	37	627
Rock, soft, brown, yellow (5 gpm at 615 ft)	23	650
"Shale," blue	7	657
Rock, brown	8	665
"Shale," hard, blue	2	667
Rock, black	13	680

Most wells in the Tualatin Valley obtain water from sand and, in a few places, gravel in the upper 300 or 400 feet of the valley fill. Most wells that tap the water in the underlying Columbia River basalt are around the margin of the valley and on the flanks of the interior hills, where bedrock is at depths of less than 500 feet. Wells in the sand and gravel of the valley fill produce from 1 or 2 gpm to 200 gpm depending upon the thickness of the permeable beds and the diameter and method of construction of the well. Wells in the Columbia River basalt produce up to 800 gpm, depending upon the number of interflow zones tapped in the basalt and the diameter and method of construction of the well. The Tertiary sedimentary rocks below the basalt contain saline water and in some places, along the fault zones, in the axes of synclines, and near the shale, the basalt contains saline water of a type characteristic of the underlying sedimentary rocks of Tertiary age.

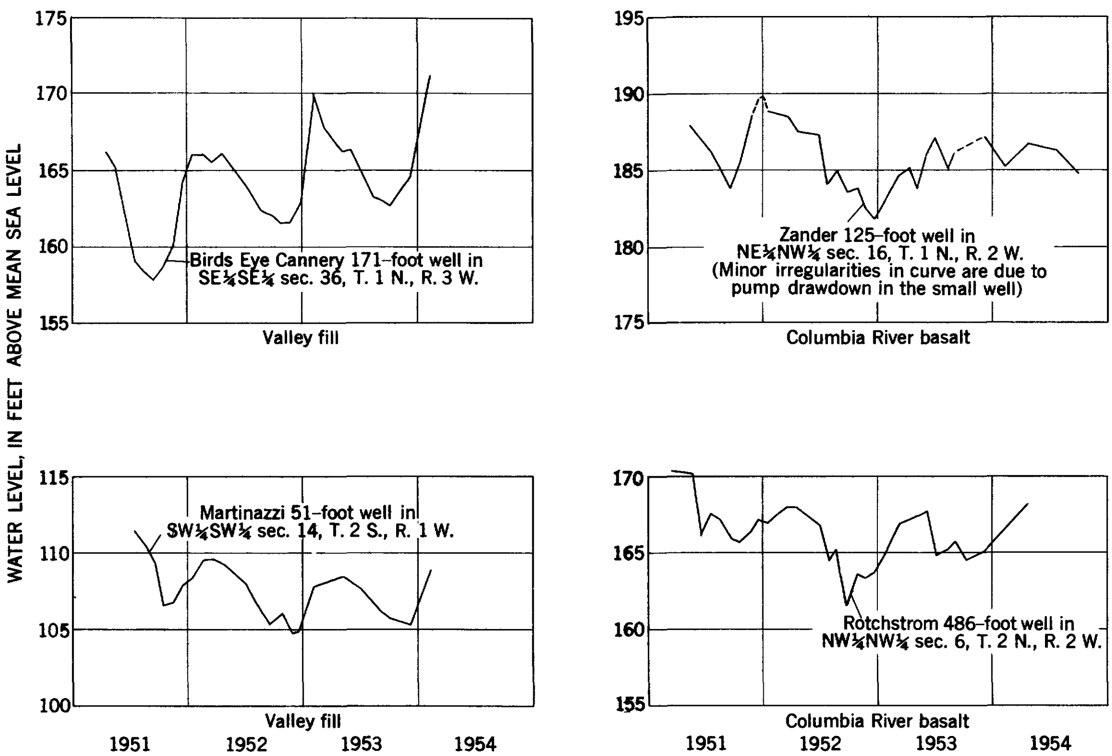


Figure 21.—Water levels in representative wells in the Tualatin and Willamette River valleys.

The water table beneath the floor of the valley is within a few feet of the surface. The water in most wells that tap the deeper artesian aquifers rises about to the level of the water table, although some wells flow at the surface. Figure 21 shows water levels observed in four wells in the Tualatin Valley. The water-level graphs show fluctuations of the water table. In general, the ground-water supply is being replenished when the water level is rising and being depleted when the level is falling.

Willamette Valley Plain

The small part of the Willamette Valley plain (see pl. 1) discussed in this report is along the northern edge of the plain. The sequence of the strata underlying the plain is shown by a geologic section (pl. 2) and the following drillers' well logs.

Well owned by the city of Newberg, SE¼NW¼ sec. 29, T. 3 S., R. 2 W., altitude about 80 feet

[Static water level 32 ft below land surface Dec. 10, 1951. Pumped 1,000 gpm with 30 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Recent alluvium:		
Clay	3	3
Clay, sandy	20	23
Sand, brown	17	40
Gravel, pea-sized	2	42
Sand and gravel	4	46
Older alluvium(?):		
Gravel, loose	14	60
Gravel, blue	18	78
Clay	22	100

Well owned by the city of Canby, NW¼SW¼ sec. 33, T. 3 S., R. 1 E., altitude about 160 feet

[Static water level 52 ft below land surface in 1928. Pumped 100 gpm with 22 ft of drawdown]

Materials	Thickness (feet)	Depth (feet)
Older alluvium:		
Gravel and boulders in large part	87	87
Clay	20	107
Gravel and coarse sand, water-bearing	1.5	108.5
Clay, blue	171.5	280
Sand, fine and clean	1	281
Troutdale formation(?):		
Clay, red	229	510
"Asphalt"	9	519
Sand, black	5	524
Sand, fine, gray, and blue clay in alternate beds several feet thick, water-bearing	127	651
Sandstone, gray, non-water-bearing	1	652

Wells in the Willamette Valley plain obtain water mainly from the alluvial deposits. The wells in the younger alluvium beneath the Willamette River flood plain produce from 2 to 1,000 gpm, and those in the older alluvium beneath the terraces produce as much as 100 gpm. Some wells have been drilled into the Columbia River basalt below the alluvium. Most of these wells in basalt obtain only small amounts of water; the highest reported yield is 100 gpm. Most of these wells were drilled into the basalt for only a few feet. Probably some wells would have larger yields if the drilling had penetrated deeper in the basalt.

The water table beneath the low-lying land along the streams usually stands slightly higher than the level of the adjacent streams. Figure 22 shows the record of the water level for two wells in the Willamette Valley plain area.

Source of Ground-Water Recharge

Ground-water recharge can come from several sources: (1) absorbed rainfall penetrating the alluvial deposits and the intake areas of the bedrock aquifers, (2) infiltration from the streams, especially from the Columbia and Willamette Rivers, through their banks or beds, and (3) artificial recharge.

Recharge from rainfall on the alluvial deposits is estimated to average about 500,000 gpd per square mile. Practically all this recharge occurs during the 6-month period October 1 to March 31—during the nongrowing season. (See fig. 22.)

Infiltration from streams can be induced by drawing heavily on wells in alluvial deposits that are hydraulically connected to the river. Water will flow from the streams to the well, if the water level surrounding the well is maintained lower than the adjacent stream long enough. Induced infiltration is practical in only certain places along most of the rivers but could be practiced along much of the Columbia and Willamette Rivers in the Portland area by the use of properly constructed wells.

Artificial recharge is practiced only on a small scale in the area. Two places where artifical recharge has been practiced on a small scale are in the reverse-cycle heating and air-conditioning systems of the Equitable and Oregonian buildings in Portland. Cooling water is pumped out of one well, and the heated water is returned to another well. The interwell transfer is later reversed for heating. In St. Helens excess water from springs has been recharged down a town well in the winter and pumped out the following summer.

Quality

Ground water in the Portland-Vancouver area is generally of good quality. Water from the Troutdale formation and Boring lava is generally softer, contains less dissolved solids, and is more uniform in concentration than water from the Columbia River basalt and

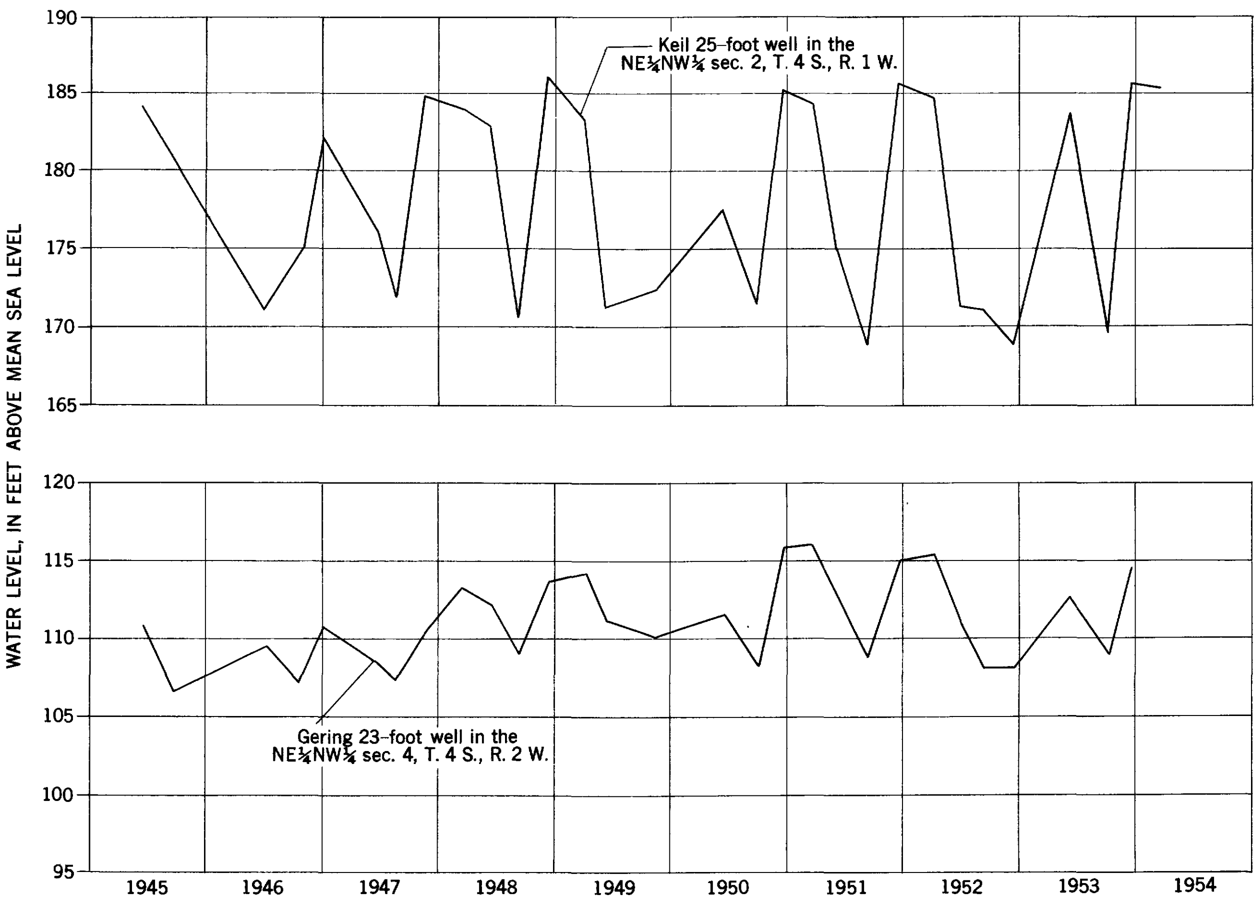


Figure 22.—Water levels in representative wells tapping the older alluvium in the Willamette River Valley.

the unconsolidated deposits (fig. 23). Analyses of water from 40 wells and springs are given in table 7.

The Columbia River basalt yields water generally of good quality. This aquifer is the source of public water supply for several communities in the Tualatin Valley. Dissolved solids and hardness of 15 water samples averaged 300 ppm and 121 ppm respectively (table 8). Water from this formation is of the calcium bicarbonate type and may contain significant concentrations of silica, or troublesome amounts of iron. Some deep wells drilled through the basalt tap the underlying Tertiary marine sedimentary rocks, which yield a brackish, highly mineralized water of entirely different character.

The Troutdale formation supplies a soft or slightly hard water of moderate mineral content (table 8). Several wells supplying water to the city of Vancouver and to metal-processing plants along the Columbia River probably tap the Troutdale formation.

Water from the Boring lava has about the same chemical and physical properties as supplies from the Troutdale formation (table 8). The range in concentration of dissolved solids in four samples from lava rock was 134 to 162 ppm; hardness ranged from 47 to 69 ppm. In places treatment for removal of iron may be necessary.

Many wells and springs in the Portland-Vancouver area derive water from alluvium, terrace sands and gravels, and other unconsolidated deposits. Water from these materials generally is satisfactory in chemical quality. In 15 water samples analyzed the average concentration of dissolved solids was 268

Table 7.—Chemical quality of water from selected wells and springs in the Portland-Vancouver area

[Parts per million except as indicated]

Water-bearing material and location	Depth (feet)	Date	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Ca, Mg	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH
Portland-Vancouver lowland																			
Columbia River basalt:																			
SE¼NW¼ sec. 20, T. 2 S., R. 2 E[1]	685	2-28-50	...	53	...	42	...	...	...	142	...	144	...	...	452	106	0	...	7.6
Do[1]	685	7-26-50	...	53	0.07	35	6.2	87		149	0.3	149	0.6	...	480	114	0	...	7.8
Do[1]	685	6-23-53	...	49	.40	37	12	63		139	4.0	137	.4	...	409	144	30	...	...
NW¼SE¼ sec. 20, T. 2 S., R. 2 E[1]	250±	3-17-52	...	24	.13	34	5.3	82		142	.4	136	.4	...	418	107	0	...	7.7
Do	250±	6-9-53	...	49	.43	54	14	95		142	4.6	225	.4	...	589	195	79	...	7.7
Troutdale formation and comparable sedimentary rocks:																			
SW¼NW¼ sec. 11, T. 2 N., R. 1 E[1]	198	10-7-50	...	...	.06	...	...	...	...	183	18	9.2	.6	...	192	96	0	...	7.6
NE¼NE¼ sec. 20, T. 2 N., R. 2 E	221	5-17-49	50	36	4.8	10	5.7	3.5	4.4	56	7.4	4.0	.0	0.3	104	48	2	111	8.0
NW¼NW¼ sec. 2, T. 3 N., R. 2 E	140	5-17-49	51	44	.02	22	8.4	9.3	3.6	126	2.7	4.0	.2	1.0	157	89	0	206	7.7
Troutdale formation and unconsolidated deposits:																			
NW¼NE¼ sec. 19, T. 2 N., R. 1 E[2]	111-136	4-16-41	...	45	1.4	35	17	11		212	4.6	1.9	.4	...	238	159	0	...	...
Do	111-136	10-13-43	...	44	.35	37	8.4	13		202	9.3	7.6	...	...	215	127	0	...	...
Boring lava:																			
NW¼NE¼ sec. 8, T. 1 N., R. 3 E	390	5-17-49	...	49	.04	13	9.0	6.6	2.8	88	4.9	6.9	.1	8.4	144	69	0	181	7.7
NW¼SE¼ sec. 6, T. 2 N., R. 3 E	97	5-17-49	...	58	.01	14	7.5	5.7	4.0	78	.8	3.0	.2	5.4	137	66	2	151	7.0
Unconsolidated deposits:																			
SW¼NW¼ sec. 4, T. 1 N., R. 1 E[1]	125	5-10-43	...	50	.05	33	4.8	13		109	25	12	.1	...	274	112	23	...	...
SE¼NW¼ sec. 4, T. 1 N., R. 1 E[1]	137	5-10-43	...	55	.15	33	14	9.8		112	16	13	.2	...	264	128	36	...	...
NW¼SE¼ sec. 4, T. 1 N., R. 1 E[1]	148	5-10-43	...	43	.05	34	12	11		117	15	14	.3	...	272	135	39	...	...
NW¼SW¼ sec. 28, T. 1 N., R. 1 E[3]	...	9-10-46	...	50	.00	23	2.2	...	...	157	30	173	...	...	496	67	0	...	7.9
SW¼SE¼ sec. 35, T. 2 N., R. 1 W[1]	118	4-23-43	...	48	.10	41	4.3	...	...	237	12	5.3	.1	...	284	119	0	...	6.4
Do[1]	118	2-8-44	...	61	.03	22	8.6	...	...	110	7.8	5.0	.1	...	193	92	2	...	7.2
NE¼SW¼ sec. 33, T. 2 N., R. 2 E	Spring	5-17-49	50	50	.02	15	5.2	4.2	5.6	64	11	2.9	.2	7.2	133	59	6	140	7.6
SW¼SE¼ sec. 33, T. 3 N., R. 1 E	48	5-23-49	...	64	.10	37	17	8.1	4.0	96	41	16	.4	44	279	162	84	376	6.3
Willamette Valley plain																			
Troutdale formation and comparable sedimentary rocks:																			
NW¼SW¼ sec. 33, T. 3 S., R. 1 E	652	10-10-28	60	45	0.21	11	5.5	93	2.9	258	4.1	29	...	1.0	326	50	0	...	...
Unconsolidated deposits:																			
NW¼SW¼ sec. 30, T. 3 S., R. 1 E	57	10-10-28	52	60	.56	8.7	7.0	4.1	1.1	62	5.4	1.8	...	.05	112	50	0	...	...
NW¼SW¼ sec. 33, T. 3 S., R. 1 E	107	10-10-28	53	41	.19	24	11	7.4	1.8	132	5.0	4.0	...	2.4	163	105	0	...	...
Tualatin Valley																			
Pre-Miocene Tertiary sediments:																			
NE¼SE¼ sec. 25, T. 1 S., R. 2 W[1]	9,203	5-9-46	...	...	...	15,400	31	8,980	608	196	16	43,700	...	...	68,800	38,500	38,300	...	...
SW¼SW¼ sec. 23, T. 2 S., R. 4 W	93	4-19-51	...	19	1.7	1,980	113	824	12	51	30	5,010	0.2	...	8,010	5,400	5,360	13,300	7.0
Pre-Miocene Tertiary sediments and Columbia River basalt:																			
NE¼NE¼ sec. 17, T. 1 S., R. 1 W	1,374	11-19-53	...	45	.33	222	45	290	40	63	2.7	960	.1	0.3	1,640	739	687	3,140	8.2
NE¼NW¼ sec. 27, T. 1 S., R. 1 W[1]	314	3-17-52	55	...	...	587	...	510		...	...	1,840	...	...	3,640	1,480	...	...	...
SE¼NE¼ sec. 21, T. 1 S., R. 2 W[1]	780	2-16-38	...	...	6.0	...	...	...	...	54	0	2,000	...	...	3,940	540	496	...	6.9
Columbia River basalt:																			
SE¼NE¼ sec. 20, T. 1 N., R. 1 W	480	5-17-51	57	52	.13	37	2.7	68	11	174	6.6	83	.2	.1	346	104	0	541	7.6
NW¼SE¼ sec. 1, T. 1 N., R. 3 W	710	4-3-51	59	49	.03	15	7.9	31	9.0	136	2.1	23	.2	.1	204	70	0	283	7.6
SE¼SE¼ sec. 23, T. 1 N., R. 4 W	300	6-19-51	...	42	.12	8.4	4.1	7.7	1.8	62	1.4	2.3	.1	.1	99	38	0	...	7.4
SE¼SW¼ sec. 21, T. 1 S., R. 1 W[1]	800	1-2-46	...	32	.20	39	2.9	35		183	25	41	.1	1.5	326	146	0	...	6.9
SW¼NW¼ sec. 26, T. 1 S., R. 1 W[1]	162	12-21-51	...	51	.78	34	15	9.3		167	2.3	22	...	...	293	151	0	...	6.7
NE¼NW¼ sec. 31, T. 1 S., R. 2 W	715	5-15-51	...	50	.43	24	15	12	5.3	156	1.6	15	.2	.1	200	122	0	427	7.7
NE¼NW¼ sec. 10, T. 2 S., R. 1 W[1]	...	4-30-49	...	...	.10	...	...	...	...	162	...	3.6	...	...	206	50	0	...	6.8
NW¼NW¼ sec. 32, T. 2 S., R. 1 W[1]	...	12-20-46	...	26	.10	8.9	2.6	20		112	1.0	1.5	.1	.3	159	34	0	...	7.0
SE¼SE¼ sec. 8, T. 2 S., R. 1 E[1]	...	11-6-45	...	55	.52	92	30	76		168	.6	285	.9	...	807	355	217	...	7.4
NW¼NW¼ sec. 9, T. 2 S., R. 1 E[1]	...	5-14-46	...	49	.50	21	7.8	172		132	.7	4.3	.0	.1	175	85	0	...	7.5

Table 7.—Chemical quality of water from selected wells and springs in the Portland-Vancouver area—Continued

Water-bearing material and location	Depth (feet)	Date	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Ca, Mg	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH
Tualatin Valley—Continued																			
Boring lava:																			
SW¼NW¼ sec. 3, T. 1 S., R. 1 W.[1]	Spring	4-23-45	......	55	1.3	11	5.4	8.1		59	2.6	12	......	......	134	47	0	......	6.7
SE¼NE¼ sec. 10, T. 1 S., R. 1 W.[1]	Spring	9-20-41	......	57	.04	14	6.9	11		77	3.4	4.8	0.2	......	162	64	0	......	......
Unconsolidated deposits:																			
SE¼SW¼ sec. 21, T. 1 N., R. 2 W.	40	5-15-51	......	46	2.3	44	15	8.9	9.5	241	.6	2.9	.4	0.3	247	172	0	383	7.2
SE¼SW¼ sec. 32, T. 1 N., R. 3 W.[1]	285	10-17-40	......	30	3.5	20	8.2	81		277	.7	2.1	......	......	303	117	0	......	......
NW¼SE¼ sec. 15, T. 1 S., R. 1 W.[1]	390	11-18-41	......	25	.16	13	6.6	98	.9	285	.6	29	.1	......	348	66	0	......	......
SE¼NE¼ sec. 21, T. 1 S., R. 2 W.[1]	26	1-11-38	......	......	.10	......	......	......	......	104	0	7.8	......	......	215	36	0	......	6.6
SE¼NW¼ sec. 5, T. 1 S., R. 3 W.	112	9-15-51	......	44	2.2	68	30	30	1.9	428	.1	2.4	.3	.1	389	293	0	595	7.4

[1] Analysis by the Charlton Laboratories, Portland, Oreg.
[2] Analysis by Alcoa, Vancouver, Wash.
[3] Analysis by the Flox Company, Inc., Portland, Oreg.

Table 8.—Range in chemical characteristics of ground water in the Portland-Vancouver area

[Parts per million, except pH]

Characteristic	Columbia River basalt			Unconsolidated deposits			Troutdale formation		Boring lava	
	Number of samples	Range	Average	Number of samples	Range	Average	Number of samples	Range	Number of samples	Range
pH	12	6.7–7.8	7.3	7	6.3–7.9	....	3	7.6–8.0	3	6.7–7.7
Silica (SiO_2)	11	26–55	46	13	25–64	48	3	36–45	4	49–58
Iron (Fe)	12	.03–.52	.31	14	.00–3.5	.72	4	.02–4.8	4	.01–1.3
Bicarbonate (HCO_3)	12	62–183	144	14	62–428	164	4	56–258	4	59–88
Sulfate (SO_4)	11	.6–25	4.5	14	0–41	11	4	2.7–18	4	.8–4.9
Chloride (Cl)	12	1.5–285	70	14	1.8–173	20	4	4.0–29	4	3.0–12
Fluoride (F)	10	.0–.9	.3	9	.1–.4	....	3	.0–.6	3	.1–.2
Nitrate (NO_3)	7	.1–1.5	....	6	.05–44	....	3	.3–1.0	2	5.4–8.4
Dissolved solids	12	99–807	318	14	112–496	263	4	104–326	4	134–162
Hardness ($CaCO_3$)	12	34–355	124	14	36–293	114	4	48–96	4	47–69

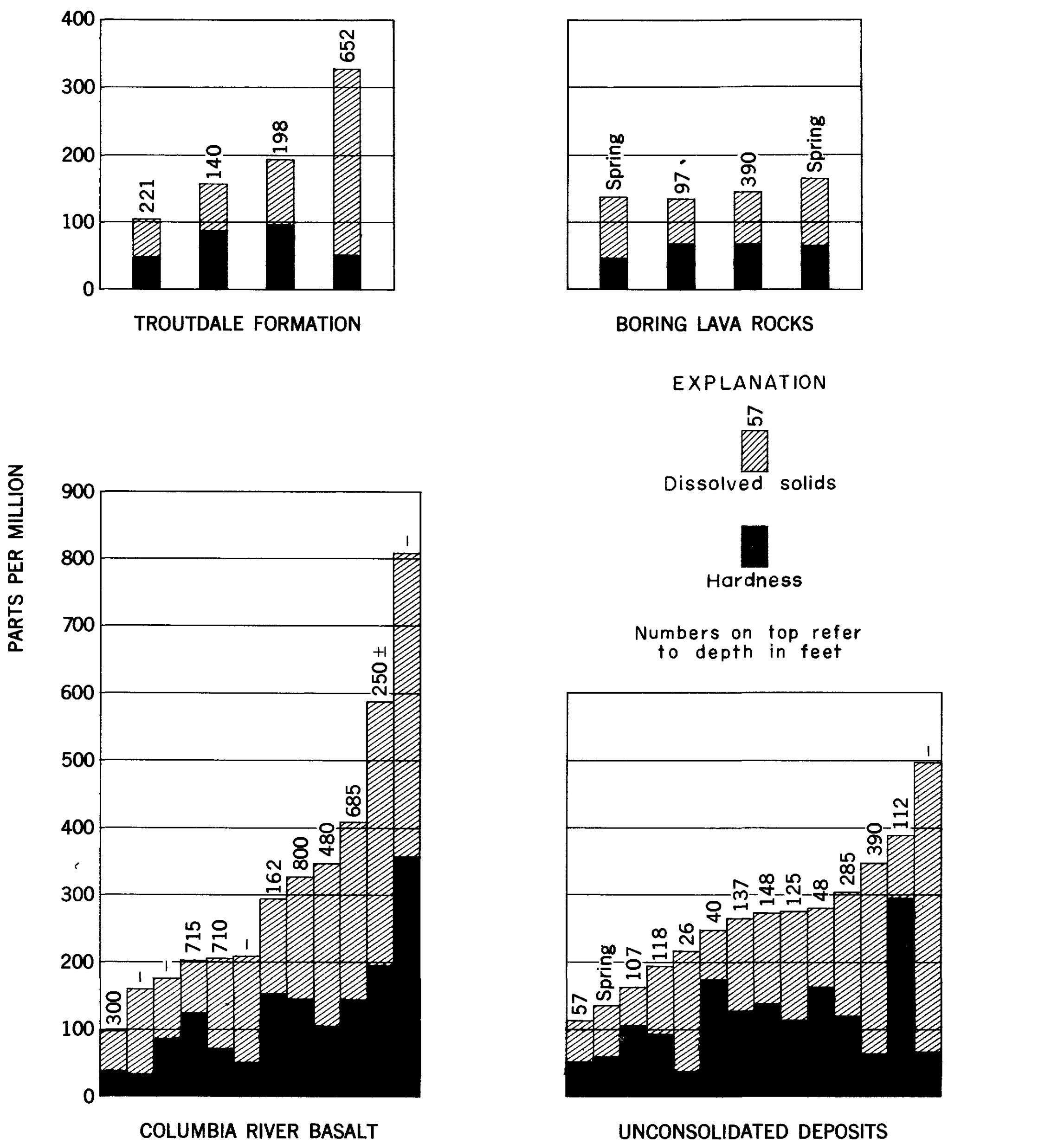


Figure 23.—Hardness and dissolved solids in ground water in the Portland-Vancouver area.

Table 9.—Summary data for municipal water systems, 1953

Municipality	Population 1950 census	Primary source of water	Secondary source of water	Total consumers served by supply 1953 (estimated)	Water used 1953 (million gallons)
Portland, Oreg.	373,628	River	....	1/524,500	1/21,670
Vancouver, Wash.	41,664	Springs and wells	....	50,500	1,971
Oregon City, Oreg.	7,682	River and creek	....	10,600	913
Milwaukie, Oreg.	5,253	Wells	....	6,800	245
Hillsboro, Oreg.	5,142	River and creek	....	16,000	555
Camas, Wash.	4,725	Creeks	Wells	5,600	639
St. Helens, Oreg.	4,711	Springs and creek	Wells	5,000	274
Forest Grove, Oreg.	4,343	Creeks	....	6,000	391
Newberg, Oreg.	3,946	Springs	Wells	5,000	201
Oswego, Oreg.	3,316	Wells	....	4,000	133
Beaverton, Oreg.	2,512	Wells	....	4,500	217
Tigard, Oreg.	600	Wells	....	1,900	41

1/ Fiscal year 1953; other figures are for calendar year 1953.

ppm, and the range was from 112 to 496 ppm (table 8). Hardness averaged 110 ppm and ranged from 36 to 293 ppm. The amount of iron in the ground water differs from place to place. Because of the objectionable unsanitary quality and occasional turbidity of Willamette River water, many industries, especially food-processing plants in Portland, pump ground water from the alluvium or underlying strata.

The chemical composition of water from repesentative wells that tap bedrock or unconsolidated deposits in the Portland-Vancouver area is shown in figure 24.

PUBLIC WATER SUPPLIES

Public water-supply systems in the Portland-Vancouver area furnished water to about 640,000 people in 1953. The Portland supply, from Bull Run River, served 82 percent of this population. The estimated population served and the sources of water are shown in table 9.

The hardness and dissolved solids content of water served in the area ranges widely. (See fig. 25.)

Portland, Oreg.

The city of Portland is unusually fortunate in having an ample supply of pure, soft water from a source not subject to pollution. The present supply is believed by city authorities to be ample for a population of 1 million.

The water supply of Portland is diverted from the Bull Run River 30 miles east of the city. The drainage area above the diversion is 102 square miles, and the altitude ranges from 750 to 4,700 feet above mean sea level. The watershed is part of the Bull Run division of the Mount Hood National Forest, a heavily timbered uninhabited area of 218 square miles set aside as a public reservation by proclamation of President Harrison in 1892. In 1904 the Congress passed an act which protects the Reserve from trespass or stock grazing.

Bull Run River stems from Bull Run Lake, which lies close to the summit of the Cascade Range about 7 miles northwest of Mount Hood. The lake is $1\frac{3}{4}$ miles long and $\frac{3}{4}$ of a mile wide and has a storage capacity of about 3,000 million gallons. Both the lake and the river are fed by springs and small creeks which derive their water from melting snow and from rainfall. Contrary to popular belief, Bull Run River water does not originate in the glaciers of Mount Hood. Deep canyons of the West Fork of Hood River and the Sandy River lie between Bull Run River and the mountain. Water from Bull Run Lake seeps underground through basaltic strata and emerges in a series of large springs about a mile downstream from the lake at an altitude 175 feet below lake level. Bull Run River heads in these springs.

Because peak demand on the water supply occurs during the summer, when natural river flows are at a minimum, storage additional to that in Bull Run Lake has been provided by a concrete gravity dam on Bull Run River, completed by the city in 1929. The reservoir created by this dam extends $3\frac{1}{2}$ miles upstream and impounds 11,000 million gallons of water.

At the headworks, 5 miles below the storage dam, a small gravity dam diverts river water into 3 steel conduits which transport the water 24 miles to distribution reservoirs on Mount Tabor in east Portland. The 3 conduits have a combined capacity of 225 mgd. The supply for the west side of Portland is piped across the Willamette River in 2 submerged lines, 24 inches and 30 inches in diameter, and in 2 lines on the Ross Island bridge each 24 inches in diameter. Four distribution reservoirs are located on Mount Tabor and two in Washington Park; their combined storage capacity is 192 million gallons. Supplementing these reservoirs are 29 tanks and standpipes, mainly on the hillside areas of the West Side, which have capacities that range from 50,000 gallons to 1 million gallons. The total storage capacity within the city is about 200 million gallons. Distribution of water within the city is mostly by gravity, the total pumpage being less than 8 percent of the water delivered.

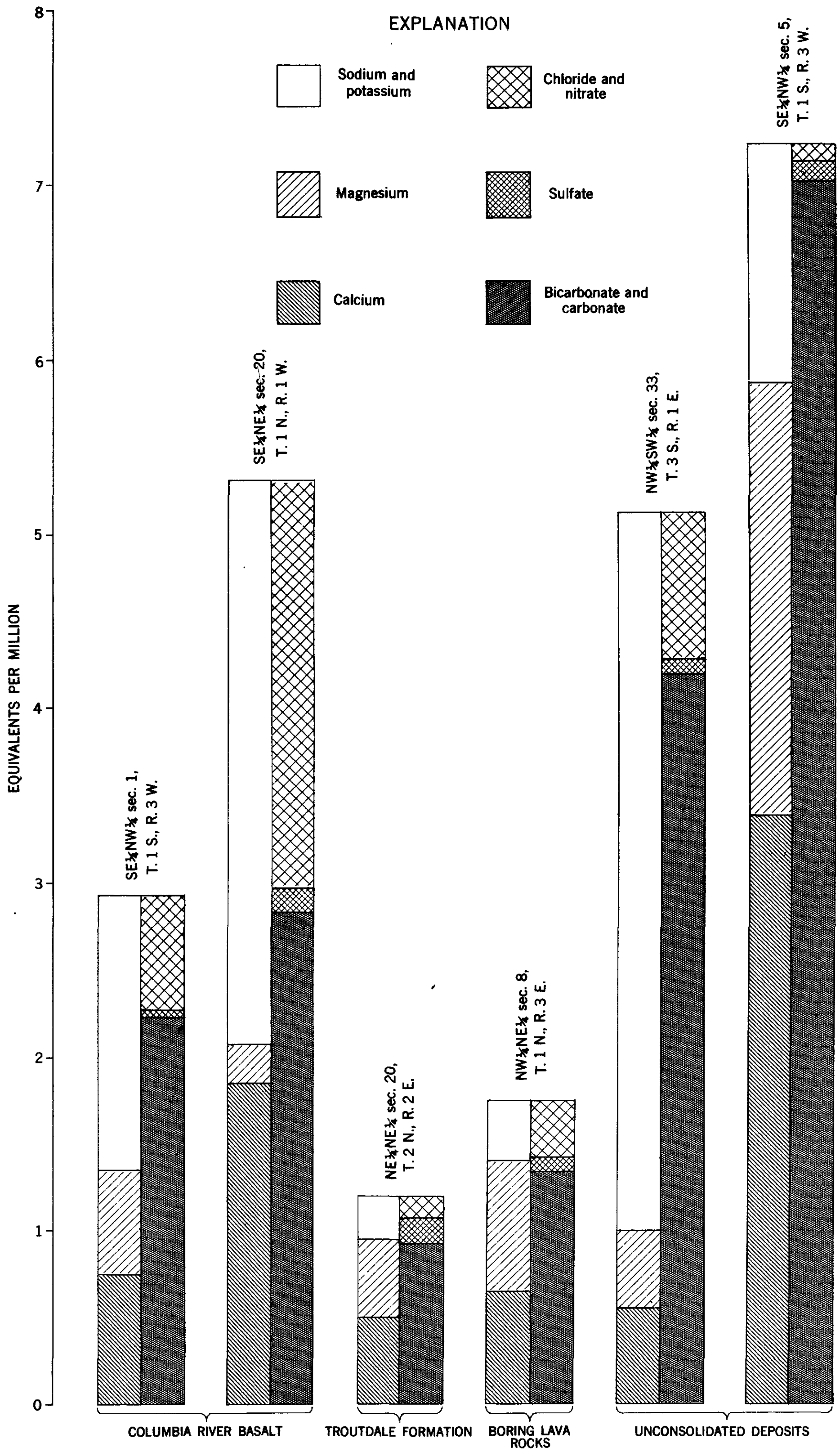


Figure 24.—Chemical composition of representative ground waters.

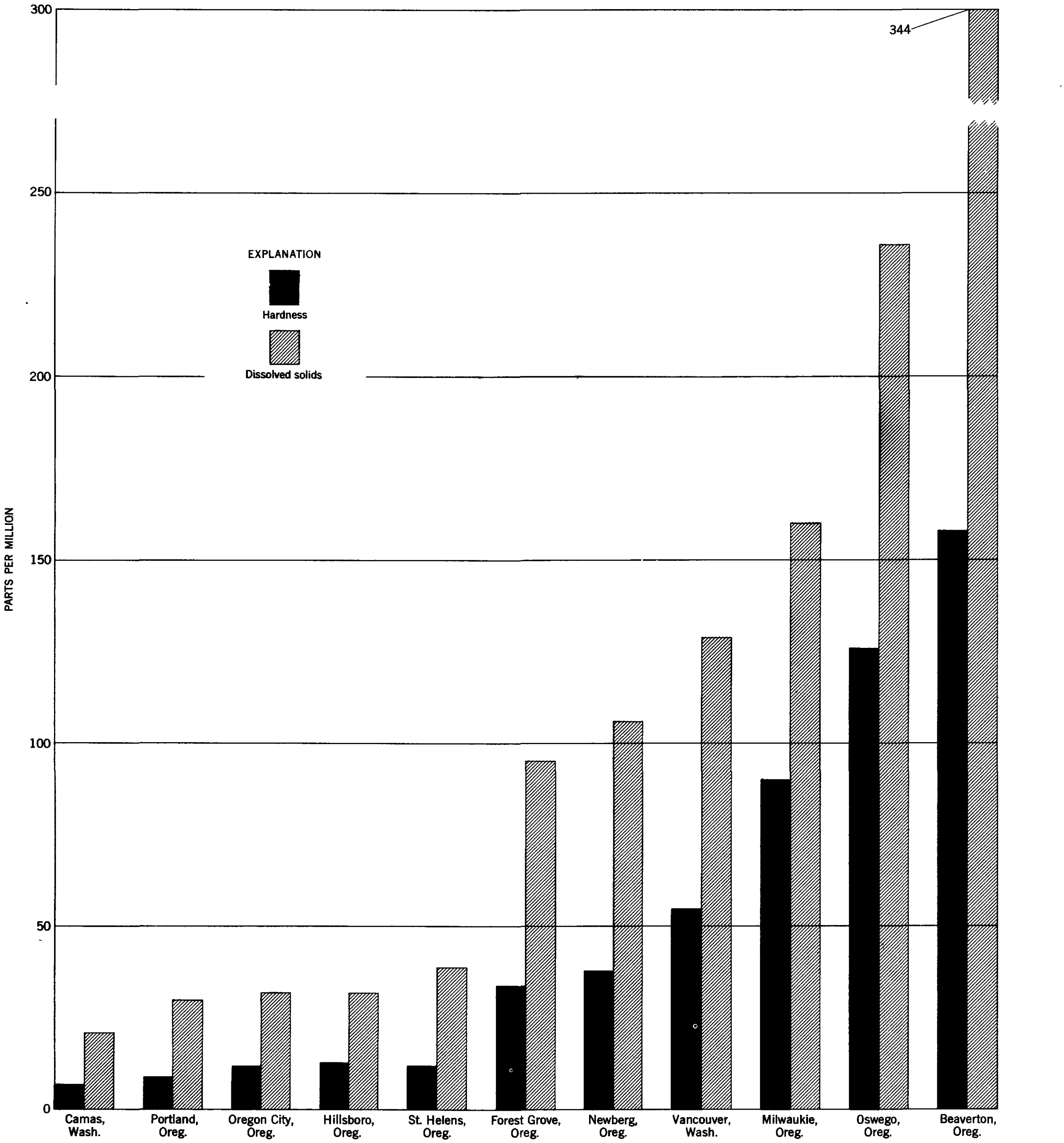


Figure 25.—Hardness and dissolved solids in public water supplies.

Table 10.—Water used by the Portland Bureau of Water Works, 1953

	Municipal system	Water districts	Total
Estimated population supplied	414,200	110,300	524,500
Water used:			
For year.....million gallons..	18,230	3,440	21,670
Average daily.....million gallons..	49.95	9.42	59.37
Per capita per day.....gallons..	121	85	113
Maximum day, July 15.....million gallons..	118.90	.....	.....
Minimum day, December 17.....million gallons..	42.16	.....	.....
Maximum month, July.....million gallons..	3,020	.....	.....
Minimum month, February.....million gallons..	1,260	.....	.....

The municipal Bureau of Water Works supplies water not only to the city of Portland but also, in 1953, to 55 water districts and companies in areas adjacent to Portland. Data on use of water during the fiscal year ending June 30, 1953, are summarized in table 10.

From 1949 to 1953 the total use of water averaged 20,470 million gallons annually.

Water from the Portland public supply was used as follows during the 5-year period 1949–53. Quantities are expressed in millions of gallons per year.

Use of Portland water supply, 1949–53

[Millions of gallons]

Calendar year	Dwellings	Commercial	Water companies	Total
1949	8,960	7,550	2,750	19,260
1950	9,240	7,760	2,990	19,990
1951	10,020	8,100	3,070	21,190
1952	10,200	8,260	3,420	21,880
1953	9,010	7,860	3,140	20,010
5-year average	9,490	7,910	3,070	20,470

The quality of the city water is excellent. The variation in chemical character is very small, and the only treatment is the addition of chlorine and ammonia at the headworks. The mean of 36 analyses of Bull Run River water during a 12-month period in 1911–12 (table 1) defines a very soft dilute water having 9 ppm hardness and 30 ppm dissolved solids. Analysis of a sample of city water in 1947 gave results for hardness and dissolved solids practically identical to concentrations reported for the river water (table 11).

Temperature of water in reservoir no. 5, Mount Tabor, during the 12-month period ending June 1953 is given in the following tabulation.

Temperature of water in reservoir no. 5

[Degrees Fahrenheit]

Date	Low	High	Mean
1952			
July	48	64	53.9
August	50	54	51.4
1952—Continued			
September	51	57	53.6
October	52	56	54.6
November	40	48	44.1
December	38	43	40.2
1953			
January	37	44	41.5
February	36	42	40.0
March	39	42	40.3
April	40	46	42.3
May	43	48	46.1
June	46	51	47.9

Vancouver, Wash.

Vancouver derives its water supply from 3 springs and 17 wells. The springs issue from sand and gravel terrace deposits of Pleistocene age at their contact with the underlying Troutdale formation. On October 15, 1945, the combined flow of the springs, which have been used continuously since 1869 as a source of supply, was 2,085 gpm. The 17 wells, ranging in depth from 122 to 280 feet, obtain water mainly from Pleistocene terrace deposits. Some of the wells probably tap the Troutdale formation. Shortly after being drilled, most of the wells had test capacities of 1,000 to 2,000 gpm with drawdowns of a few feet. Present capacity of the pumps installed in the 17 wells totals about 39,200 gpm.

In 1953 the average daily consumption of water was 5.4 million gallons, and the estimated population served was 50,500. During peak demands in the summer the average daily use is about 7.1 million gallons, and the maximum in a single day may be 15 million gallons. The combined yield of the two sources of supply is computed as 59.5 mgd, of which 2.5 mgd is obtainable from the springs and the remainder from wells.

Ground-level storage in 1954 was 9.6 million gallons, and elevated storage was 2.4 million gallons. It is planned to increase this storage of 12.0 million gallons by 4.5 million gallons in 1955; the total storage capacity will then be about 16.5 million gallons. Six separate pressure levels are used in the transmission of water, and the service pumping capacity of the Vancouver water supply system is 12,150 gpm.

The city water is soft and of moderate mineral content, as shown by an analysis of a sample collected

Table 11.—Chemical quality of finished water from public supplies in the Portland-Vancouver area

[Parts per million except as indicated]

Public supply	Date of collection	Temperature (°F)	pH	Specific conductance (micromhos at 25°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	
																	Ca, Mg	Noncarbonate
Beaverton, Oreg.	Dec. 8, 1953	50	7.7	571	46	0.09	37	16	47	7.0	170	4.1	88	0.4	0.4	344	158	19
Camas, Wash.	Apr. 1, 1954	....	6.8	22.9	11	.08	2.0	.5	1.8	.6	11	.5	2.0	.2	.3	21	7	0
Forest Grove, Oreg.	Apr. 20, 1954	....	7.3	100	46	.14	12	1.1	5.2	1.0	47	2.0	3.0	1.2	.7	95	34	0
Hillsboro, Oreg.	Dec. 8, 1953	62	6.5	40.0	9.4	.10	3.6	.9	2.5	.8	16	1.3	2.5	.0	.5	32	13	0
Milwaukie, Oreg.[1]	Dec. 6, 1951	....	7.2	....	42	.04	17	11	....	....	124	3.9	3.9	....	....	160	90	0
Newberg, Oreg.	Dec. 7, 1953	51	6.7	115	35	.12	9.1	3.8	6.0	2.6	56	2.0	1.0	.1	2.9	106	38	0
Oregon City, Oreg.	Mar. 30, 1954	48	7.3	38.9	14	.00	4.0	.6	2.6	1.0	20	.7	2.2	.0	.6	32	12	0
Oswego, Oreg.	Dec. 7, 1953	....	7.5	342	52	.09	37	8.1	18	2.9	174	3.7	16	.2	.5	236	126	0
Portland, Oreg.[1]	Sept. 19, 1947	59	7.0	....	7.2	.20	2.3	.7	2.1	.2	15	.9	2.4	.0	.3	30	9	0
St. Helens, Oreg.	Feb. 18, 1954	....	6.9	43.2	16	.10	3.2	1.1	2.9	1.2	18	1.6	2.8	.1	1.3	39	12	0
Vancouver, Wash.[1]	Apr. 18, 1949	....	6.9	....	44	.30	14	4.8	4.4		73	5.7	3.2	.0	....	129	55	0

[1]Analysis by Charlton Laboratories, Portland, Oreg.

in 1949 (table 11). Chlorination of the spring water is the only treatment applied. An analysis of a water sample from a city-owned spring in the Portland-Vancouver lowland (NE¼SW¼ sec. 33, T. 2 N., R. 2 E.) appears in table 7.

Oregon City, Oreg.

Oregon City obtains water, which it chlorinates, from the South Fork Clackamas River and its tributary Memaloose Creek. This supply serves an estimated population of 10,600, which includes the nearby community of West Linn. Average daily use is about 2.5 million gallons. This daily average increases during the summer to about 3.4 million gallons, and on days of maximum use, to about 3.5 million gallons. Impounded storage capacity is 12 million gallons. The dependable yield of the supply from the two rivers is 7.0 mgd, and the maximum transmission capacity, 3.5 mgd. Elevated storage, mainly for pressure regulation, is provided for 0.5 million gallons. It is estimated that 84 percent of the average output is for domestic use and 16 percent is used by industry and commerce. One paper-manufacturing plant supplements its supply by using about 0.5 mgd of city water.

The city water supply is very soft, low in mineral content, and similar in character to the Portland supply. A sample of the Oregon City supply, collected in March 1954, contained 32 ppm of dissolved solids and 12 ppm hardness (table 11). After heavy rains and at times during logging operations the water may be turbid.

Plans for the use and treatment of water from the main stem of the Clackamas River are under consideration. An alternate proposal is to develop a groundwater supply from wells tapping alluvial sand and gravel along the river.

Milwaukie, Oreg.

Three wells ranging in depth from 250 to 290 feet are the source of water supply for Milwaukie. An estimated 6,800 consumers use a daily average of 670,000 gallons of water. Peak summer demand averages 1.05 mgd. The installed capacity of pumps on the 3 wells totals 1.9 mgd. Service pumping capacity is about 1.7 mgd from 2 pumps rated at 600 gpm each. Distribution is from ground-level storage (1.5 million gallons) and from elevated storage (0.165 million gallons). About 90 percent of the daily output is used for domestic purposes and the remainder for industrial and commercial purposes. The city has a standby connection to the Portland system.

A representative sample of the Milwaukie supply, taken in December 1951, contained 160 ppm of dissolved solids and 90 ppm hardness (table 11) and is, therefore, water with moderate mineral content and hardness.

Hillsboro, Oreg.

The Tualatin River and Seine Creek are the sources of water for Hillsboro and the smaller communities of Gaston, Cornelius, Aloha, and Huber, having an estimated combined population of 16,000. The average daily use of water in 1953 was 1.52 million gallons, and the maximum daily use was 4.0 million gallons. The dependable yield of the source is computed as 4.5 mgd, of which the Tualatin River supplies 3.5 mgd, and Seine Creek, 1.0 mgd. Maximum capacity of the transmission system is 4.0 mgd.

Ground-level storage capacity at Hillsboro is 1 million gallons, and elevated storage 0.15 million gallons. The Aloha-Huber district has elevated storage of 0.50 million gallons. Neither Gaston nor Cornelius has storage facilities. About 70 percent of the total city water output is used domestically, and 30 percent industrially. The water is treated with chlorine and ammonia at the intake.

The Hillsboro supply is very soft water with low mineral content and is very similar chemically to the Portland supply. An analysis of the Hillsboro water showed a concentration of dissolved solids of 32 ppm and a hardness of 13 ppm (table 11).

Camas, Wash.

Camas obtains water both from creeks and from wells. During about 8 months of the year the supply is exclusively from Boulder and Jones Creeks on which the impounded storage capacity is 1.8 million gallons. During periods of low flow the surface-water supply is supplemented by water from 3 wells. The use of city water averages 1.75 mgd and ranges from 1.1 mgd, in the winter to 4.15 mgd, in the summer. Water is furnished to a population of about 5,600. Treatment of the supply consists of chlorination of the creek water. About 85 percent of the supply is distributed for domestic use, and the remainder, for industry. The system has a capacity of 4.5 mgd.

The 3 city wells range in depth from 78 to 80 feet and obtain water from unconsolidated sand and gravel deposits of Pleistocene age. Each well produces between 1,200 and 1,800 gpm, and drawdown is a few feet. The dependable combined capacity of the 3 pumps is 3,000 gpm, or about 4.3 mgd.

A water sample collected in April 1954 indicates that the Camas supply is a very soft water of very low mineral content (table 11). The analysis showed a hardness of 7 ppm and dissolved solids of 21 ppm. The city water may be slightly harder when wells are the primary source of supply.

St. Helens, Oreg.

St. Helens' primary source of water is five springs and Salmonberry Creek, a branch of Milton Creek. Impounded storage is 2.5 million gallons. A well, 411 feet deep in the basalt and having a capacity of 250 gpm, supplements the primary supply during peak demands. The average daily use of city water is 0.75 million gallons, and the estimated population served is 5,000. Maximum daily demand is about 1.4 million gallons, and use during a period of peak demand averages about 1.1 mgd. The safe yield of the surface supply is computed as 0.76 mgd, and the dependable production of the well tapping the basalt is 0.36 mgd. Raw-water storage capacity is 27 million gallons. The rated capacity of the water-treatment plant is

1.5 mgd, and treatment consists of the addition of chlorine and ammonia. Finished-water storage is 2.5 million gallons. About 85 percent of city water is delivered for domestic use, and 15 percent, for industrial use.

The city water is very soft and contains a low concentration of dissolved solids and in these respects is very similar to the Portland supply. A sample of water from the St. Helens supply contained 12 ppm hardness and 39 ppm of dissolved solids (table 11). In the fall the water has a color which is objectionable to some consumers.

The public water system of St. Helens is currently being changed, 1955, to include a collector-type well on the bank of the Columbia River, to provide a minimum supply of 3 mgd. It has been reported that the well and Milton Creek will be abandoned as the primary source of public supply upon operation of the collector. The springs will be used as a supplemental source of water.

Forest Grove, Oreg.

The water supply of the city of Forest Grove is derived from tributaries and the main stem of Gales Creek. In 1953 the average daily consumption was 1.07 million gallons, and the population served was about 6,000. The principal source of water is Clear Creek. To augment this supply about 1.5 mgd is pumped from Gales Creek in the approximate period June 15 to October 1. During August 1953, the month of maximum demand, the average daily use was 1.46 million gallons, and the maximum daily use was 2.4 million gallons.

Treatment consists of filtration, chlorination, and fluoridation; the treatment plant has a rated capacity of 1.5 mgd and a maximum capacity of 2.6 mgd. Storage capacity for raw water is 5.0 million gallons, and for treated water, 2.0 million gallons. Of total output, it is estimated that 75 percent is delivered for domestic use; and 25 percent, for industrial and commercial uses.

The Forest Grove supply is a soft, moderately mineralized water and is satisfactory for domestic and many industrial uses (table 11). The city fluoridates its water to obtain an average concentration of 1.0 ppm fluoride.

Newberg, Oreg.

The city of Newberg supplies water from springs and wells to about 5,000 people. Five springs—Oliver, Snyder, Otis, Gordon, and Skelton— are the main source of supply. Two wells, 90 feet deep, supplement this supply during peak demands in the summer. The springs are believed to issue along the contact between the Columbia River basalt and underlying Tertiary sedimentary rocks. The wells tap alluvial gravels along the Willamette River.

The daily use of water averages 0.55 million gallons and during peak demands may exceed 1 million gallons. The summer flow of the 5 springs is about 0.94 mgd, and each of the 2 wells can supply 1.08 mgd. Ground-level storage capacity is 0.75 million gallons. Transmission facilities are adequate for peak flows of the 5 springs, estimated as 0.965 mgd.

The spring water is a soft, bicarbonate water of moderate mineral content and meets ordinary requirements for domestic and general use. An analysis of the city supply is reported in table 11. To improve the quality of the water from the city wells, a treatment plant for iron removal was completed during 1954. Water from some springs and both wells is chlorinated.

Oswego, Oreg.

Oswego obtains water from 4 wells that range in depth from 209 to 1,040 feet. Pumps on these wells, tapping the Columbia River basalt, have a combined installed capacity of 750 gpm or 1.08 mgd. In 1953 the daily average use of water was 0.364 million gallons, and the estimated population served was 4,000. During peak demands the average daily use of water is 0.7 million gallons. Elevated storage for distribution has a capacity for 1.2 million gallons. About 98 percent of the supply is pumped for domestic use, and the remainder, for industry and commerce. Oswego has a standby connection to the Portland system, and obtained about 1.6 million gallons of Bull Run River water during the fiscal year ending June 30, 1953.

The Oswego supply is a calcium bicarbonate water of moderate mineral content; the water has hardness of 126 ppm (table 11). No treatment of the city water is provided.

Beaverton, Oreg.

Beaverton obtains its water supply from 2 wells that have pumps capable of delivering 800 gpm or 1.15 mgd. These wells, 735 feet and 800 feet deep, tapping the Columbia River basalt, furnished about 0.594 mgd in 1953 to an estimated population of 4,500.

During August 1953, the month of maximum demand, the average daily use was 0.792 million gallons. Storage capacity of 1 million gallons for treated water is provided by two 0.5-million-gallon tanks, elevated 8 feet above ground. Treatment consists of the addition of chlorine at each well. It is estimated that 98 percent of the city supply is used domestically.

The quality of the city water is good, though moderately hard (table 11).

Tigard, Oreg.

Two wells tapping the Columbia River basalt supply water to Tigard. In 1953 the community used 40.73 million gallons of water, a daily average use of 0.111 million gallons. The supply serves an estimated population of 1,900. About 96 percent of the supply is used domestically. No treatment of the supply is provided.

USE OF WATER

The total water used in the Portland-Vancouver area in 1953 was about 375 mgd exclusive of water for cooling at steam-powered electric generating plants. About two-thirds of the water was from surface sources and one-third from ground sources.

Public Supplies

Public water-supply systems required on the average about 75 mgd during 1953. Of that quantity about 67 mgd was from streams, and 8 mgd was from wells and springs.

Private Industrial Supplies

The major industries in the Portland-Vancouver area using private water supplies have total water requirements of about 255 mgd. Approximately 62 percent of the water is from surface supplies, and the remainder is from private wells. More than half the total use of water in industry is in the manufacture of pulp and paper products, and a substantial amount is used in the aluminum industry.

Industry used an average of about 100 mgd of ground water from private supplies in 1953. Pumping was concentrated in lowlands—mainly from the alluvium and the Troutdale formation along the Columbia and Willamette Rivers.

Industrial pumping of ground water has increased in recent years because of new industries moving into the area, expansion of existing industries, and new water-using processes and methods. The increase in the number of plants using ground water and the ground-water pumpage between 1943 and 1953 is shown in the following table.

Ground-Water Pumpage in Portland, 1943 and 1953

[From data by the Portland Department of Public Works]

Industrial use	1943		1953	
	Number of private supplies	Average daily pumpage (mgd)	Number of private supplies	Average daily pumpage (mgd)
Food products.....	8	0.85	17	1.70
Cold storage and ice manufacturers............	6	1.01	6	1.01
Air conditioning..	14	.45	27	.96
Miscellaneous.....	2	.09	4	.62
Total...........	30	2.40	54	4.29

Rural Supplies

Nearly all rural water supplies in the Portland-Vancouver area are from wells. Exact figures for pumpage are not available, but using a per capita consumption of 30 gallons per day, rural domestic use is estimated as about 1.8 mgd. Many suburban areas, especially along the east and west margins of Portland, obtain water from extensions of the city mains.

Irrigation pumpage from ground water, averaged over the 12-month period, is estimated to be 15 mgd. About 30 mgd from surface sources is used for irrigation.

POTENTIAL SUPPLY

Ground Water

The potential ground-water supply of the area is roughly estimated to be about 500 mgd, and the present use is about 125 mgd. The distribution of this undeveloped supply is estimated to be 60 percent in the Portland-Vancouver lowland, 26 percent in the Tualatin Valley, and 14 percent in the small part of the Willamette Valley plain in this area. The above figures do not include any supply which might be added by artificial recharge or induced infiltration.

Surface Water

The largest and most important source of surface water in the area is the Columbia River. The quantity of water flowing in the Columbia River past The Dalles, 95 miles east of the area, has ranged from a minimum of 22,600 mgd to a maximum of 801,000 mgd. The average flow is 125,800 mgd. Under present conditions of regulation, minimum flows in the future should not be less than 2 to 3 times the previous minimum of record.

The Willamette River is a secondary large source of surface water. The minimum discharge of record past the gaging station at Salem was 1,600 mgd, and the average is 14,700 mgd. Minimum flows will be higher in the future as a result of the operation of storage reservoirs in the basin.

The difference in flow regimen of the Columbia River on one hand and the Willamette River and lower Columbia tributaries on the other has a compensating effect on low flows. Low flows in the Columbia River normally occur during the winter, while the Willamette River and other streams west of the Cascade Range have their highest flows during the late fall and winter seasons.

The municipal water supply of Portland is adequate for a considerable expansion in use. Less than 15 percent of the average flow of Bull Run River at the water system headworks is used. Bull Run Lake, which is upstream from Lake Ben Morrow Reservoir, has a capacity of about 3,000 million gallons and is not artificially regulated. In the event of future need, consideration may be given to enlarging the capacity and providing means for artificially regulating the outflow during periods of low flow. The lake is not easily accessible, and the feasibility of its development is uncertain. There is considerable underground outflow from the lake. Crest gates 8 feet high were added to the outlet of Lake Ben Morrow Dam during the summer of 1954 to increase the storage capacity of the reservoir from 8,800 million gallons to 9,800 million gallons. The year 1952 was the most critical for the Portland water supply. In that year storage in Lake Ben Morrow Reservoir was drawn down from 8,800 million gallons to 3,300 million gallons over a period lasting 5 months.

WATER LAW

Water laws applicable to the Portland-Vancouver area are the Federal regulations relating to navigation, flood control, and hydroelectric development and the laws of the respective States. The Portland District, Corps of Engineers, U. S. Army have jurisdiction over navigation and flood control. The Columbia and Willamette Rivers are navigable streams. Deposit of refuse matter in a navigable stream other than that flowing from streets and sewers and passing therefrom in a liquid state is prohibited if navigation is affected. This prohibition extends to the nonnavigable tributaries if the refuse may be washed into the navigable stream.

The State laws of Oregon and Washington are based on the doctrine of appropriation for beneficial use, subject to vested rights. A vested water right is the right to continue a beneficial use of water that began before passage of the act establishing the State water code.

Oregon Law

The use of surface water in Oregon is controlled by the State water code, which was adopted February 24, 1909. Responsibility for administration of most provisions of the water code is vested in the State Engineer. The Hydroelectric Commission of Oregon has jurisdiction over all developments for the generation of electricity, and any person, firm,or corporation (except municipalities) desiring to use water for the generation of electricity must make application to that Commission. The Oregon State Sanitary Commission has responsibility for enforcement of State statutes relating to stream pollution. That Commission has done much in recent years toward improving cleanliness, especially in the Willamette River. The State Fish Commission and State Game Commission require that, when obstructions are placed in streams, properly designed fishways or fish ladders shall be provided and that artificial diversions be provided with properly designed screens.

Exclusive rights to the waters of Bull Run River and Little Sandy River have been granted to the city of Portland, and the State Engineer has authority to reject applications for the use of water in these streams if the appropriation could impair the municipal supply.

The State Engineer is charged with control of ground-water withdrawals.

Washington Law

Supervision over the allocation of surface and ground water in Washington is exercised by the supervisor of water resources acting under the Director of the Department of Conservation and Development. The State water code was established June 6, 1917, and has been amended from time to time.

Other State agencies that control the use of water are the Department of Health, the Pollution Control Commission, and the Departments of Fisheries and Game.

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