Quality of Surface Waters in the Lower Columbia River Basin

By J. F. SANTOS

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1784

A discussion of the chemical quality of streams tributary to the lower Columbia River basin and of the physical and sanitary quality of many of the streams; includes data on radioactivity of the main stem

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QUALITY OF SURFACE WATERS IN THE LOWER COLUMBIA RIVER BASIN

By J. F. SANTOS

ABSTRACT

This report, made during 1959–60, provides reconnaissance data on the quality of waters in the lower Columbia River basin; information on present and future water problems in the basin; and data that can be employed both in water-use studies and in planning future industrial, municipal, and agricultural expansion within this area.

The lower Columbia River basin consists of approximately 46,000 square miles downstream from the confluence of the Snake and Columbia Rivers The region can be divided into three geographic areas. The first is the heavily forested, sparsely populated mountain regions in which quality of water in general is related to geologic and climatological factors. The second is a semiarid plateau east of the Cascade Mountains; there differences in geology and precipitation, together with more intensive use of available water for irrigation, bring about marked differences in water quality. The third is the Willamette-Puget trough area in which are concentrated most of the industry and population and in which water quality is influenced by sewage and industrial waste disposal.

The majority of the streams in the lower Columbia River basin are calcium magnesium bicarbonate waters. In general, the rivers rising in the Coast Range and on the west slope of the Cascade Range contain less than 100 parts per million of dissolved solids, and hardness of the water is less than 50 parts per million. Headwater reaches of the streams on the east slope of the Cascade Range are similar to those on the west slope; but, downstream, irrigation return flows cause the dissolved-solids content and hardness to increase. Most of the waters, however, remain calcium magnesium bicarbonate in type. The highest observed dissolved-solids concentrations and also some changes in chemical composition occur in the streams draining the more arid parts of the area. In these parts, irrigation is chiefly responsible for increasing the dissolved-solids concentration and altering the chemical composition of the streams. The maximum dissolved-solids concentration and hardness of water observed in major irrigation areas were 507 and 262 parts per million, respectively, for the Walla Walla River near Touchet, Wash.

In terms of the U.S. Salinity Laboratory Staff classification (1954, p. 80), water in most streams in the basin has low salinity and sodium hazards and is suitable for irrigation. A salt-balance problem does exist in the Hermiston-Stanfield, Oreg., area of the Umatilla River basin, and because of poor drainage, improper irrigation practices could cause salt-balance problems in the Willamette River Valley, Oreg., in which irrigation is rapidly increasing.

Pollution by sewage disposal has reached undesirable levels in the Walla Walla River, in the Willamette River from Eugene to Portland, Oreg., and in the Columbia River from Portland to Puget Island. In the lower reaches of the Willamette River, the pollution load from sewage and industrial-waste disposal at times depletes the dissolved oxygen in the water to concentrations below what is considered necessary for aquatic life.

Water in most of the tributaries to the lower Columbia River is of excellent quality and after some treatment could be used for industrial and municipal supplies. The principal treatment required would be disinfection and turbidity removal.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

This investigation, made during 1959–60, provides reconnaissance data on the quality of waters in the lower Columbia River basin. These data show the general quality as it now exists, and they form the basis for more intensive local studies on problems that exist or that may arise in the future. In addition, the data can be employed both in water-use studies and as a guide in planning future industrial, municipal, and agricultural expansion in the basin.

The lower Columbia River basin is the drainage area downstream from the confluence of the Columbia and Snake Rivers, about 342 miles from the ocean. Figure 1 is a map of the region showing the location and frequency of quality-of-water sampling. The basin, for quality-of-water studies, can be divided into three areas. One is the heavily forested, sparsely populated mountain regions in which quality of water in general is related to geologic and climatological factors. The second is the semiarid plateau east of the Cascade Mountains; there differences in geology and precipitation, together with more intensive use of the available water for irrigation, bring about marked differences in water quality. The third is the Willamette-Puget trough area, in which are concentrated most of the industry and population and in which water quality is influenced by sewage and industrial-waste disposal.

PREVIOUS INVESTIGATIONS

The earliest investigation of chemical quality of water in the lower Columbia River basin was made by Van Winkle (1914 a, b), during the years 1910–12. Chemical-quality data for 15 of the major tributaries were reported. The following period of relative inactivity lasted until 1929, at which time a study of pollution in the Willamette River was made by Rogers and others (1930). Their report included sources and types of pollution and also included measurements of dissolved oxygen, biochemical oxygen demand (BOD), B coli index,

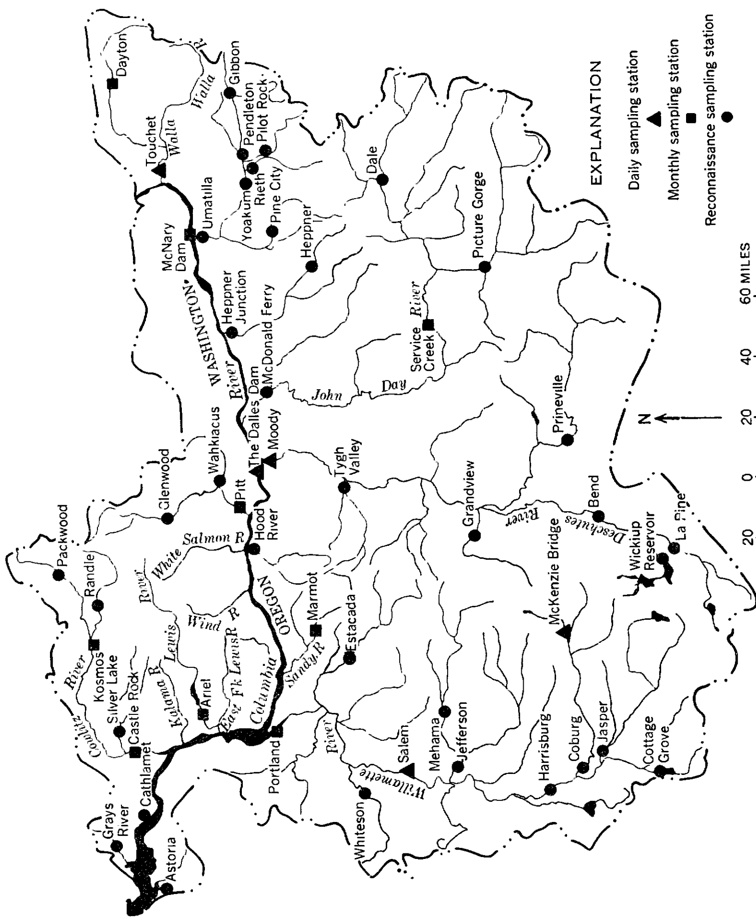

FIGURE 1.—Map of lower Columbia River basin showing the location of sampling stations.

and total and dissolved solids. From 1929 to the present (1961), several studies were made of pollution in the Willamette River basin. These studies included those by Gleeson (1936), Dimick and Merryfield (1945), Merryfield and others (1947), Portland Department of Public Works (1949), and Oregon State Sanitary Authority (1950–53). Lincoln and Foster (1943) reported on pollution in the lower Columbia River from Bonneville to Puget Island. Jones and others (1951) also reported on an investigation of pollution in the lower Columbia River. In the summer of 1952 the U.S. Public Health Service (1953) made a water-quality study of Bonneville Reservoir. This study included radiological measurements of the water, of aquatic plants and animals, and of the bottom muds. In 1952 Robeck and others (1954) made a rather comprehensive study of water quality in the Columbia River from Hanford to Paterson. The principal purpose was to evaluate the effects of the low-level radioactive-waste disposal by the Atomic Energy Commission installation at Hanford. Burt (1956) summarized salinity data for the Columbia River estuary from 1935–55. Sylvester (1958) studied the water quality of the Columbia River and of many of its tributaries during the period 1954–56. His report presented a method for predicting future chemical quality of water in relation to irrigation, population, and industrial expansion. The latest reported work in the basin was the salinity study on the Columbia River made during 1959 by the U.S. Army Corps of Engineers (1960). Salinity, velocity, tide stage, flow predominance, and composition of bed materials were determined.

ACKNOWLEDGMENTS

Data for the Walla Walla, Lewis, and Cowlitz Rivers and for the Columbia River at McNary Dam were collected in cooperation with the Department of Conservation and the Pollution Control Commission of the State of Washington. The Oregon State Sanitary Authority provided data on the Deschutes and Willamette Rivers. The Spokane office of the Bureau of Reclamation furnished additional data for the Walla Walla River basin. Data for 11 sampling points on the Columbia River were supplied by the Washington Pollution Control Commission from a program undertaken in cooperation with the Oregon State Sanitary Authority, Crown Zellerbach Corp., Columbia River Paper Co., Longview Fibre Co., and Weyerhaeuser Co.

The author is grateful for the helpful suggestions provided by Prof. Robert O. Sylvester, University of Washington, and Kenneth H. Spies, Deputy State Sanitary Engineer, Oregon State Sanitary Authority.

DESCRIPTION OF LOWER COLUMBIA RIVER BASIN

The lower Columbia River basin, lying wholly within the States of Oregon and Washington, has a drainage area of approximately 46,000 square miles (fig. 1). This region had an estimated population of 1,560,000 people in 1960 or 13 percent more than the population reported in the 1950 census. The major cities in the basin in Oregon are Portland, Salem, and Eugene; in Washington they are Walla Walla, Longview, and Vancouver. The lower Columbia River is navigable from its mouth to Pasco, Wash. The U.S. Army Corps of Engineers maintains a channel of 35 feet from the mouth to Portland, Oreg. Portland is the normal terminus for ocean-going vessels, and goods are carried by barge from Portland to Pasco.

The principal industries in the basin are lumber, agriculture, tourist trade, aluminum reduction, food processing, and pulp and paper. Economically, the basin can be divided into three regions The semiarid high plateau in the east is sparsely populated, and irrigated farming and cattle raising are the chief occupations. The Cascade Range region is heavily forested and provides much of the timber for the lumber industry; also, extensive recreational use is made of this area. The third region is the Pacific border, in which most of the population is concentrated in the Willamette and Cowlitz River plains. This region contains the major part of industry, shipping, aluminum reduction, and food processing found in the basin.

PRECIPITATION AND RUNOFF

From 1931 to 1955 the average precipitation in the lower Columbia River basin ranged from less than 8 inches in the region around Umatilla, Oreg., to more than 120 inches at many places on the west slope of the Cascade Range. The normal movement of air masses in the basin is from west to east, and the Pacific Ocean provides the moisture. The warm moist air releases some of its moisture in passing over the mountains. Astoria, near the mouth of the Columbia River, has an average annual precipitation of 80 inches. After moving across the Coast Range, precipitation diminishes on the Cowlitz-Willamette River plains to a low of 35 inches at the Portland, Oreg., airport. The air masses rise again in crossing the Cascade Range, and large amounts of precipitation fall on the western slopes and summit areas of the range. East of the summit areas, precipitation diminishes rapidly and a "rain shadow" is formed behind the Cascades. This eastern area is a semiarid plateau. Along the eastern border of the basin, the Blue Mountains exert an orographic influence, and precipitation increases to more than 32 inches, most of which falls as snow during the winter months. Most of the precipitation that falls on the Coast Range and on the Cowlitz-Willamette River plains is in the form of rain, but snow is the predominate form at the higher elevations of the Cascade Range and on isolated volcanic peaks. Some of the heaviest snowfalls in the United States have been recorded in these mountains. On Mount Rainier, a years' snowfall of 1,000 inches was recorded at an elevation of 5,500 feet. Within the basin, elevations range from sea level to 14,408 feet above sea level on Mount Rainier. Many of the higher peaks have permanent glaciers that supplement streamflow during the dry summer months. Most of the Cascade Range is composed of permeable or partly permeable rock; so some of the snowmelt percolates into the ground and appears at lower elevations as springs.

The annual discharge of the Columbia River to the Pacific Ocean averages 197 million acre-feet (1943–57). Almost one-third of this amount is from the lower Columbia River basin (fig. 2). The Willamette, Cowlitz, Deschutes, and Lewis Rivers are the largest streams in the lower Columbia River basin. Figure 3 shows the

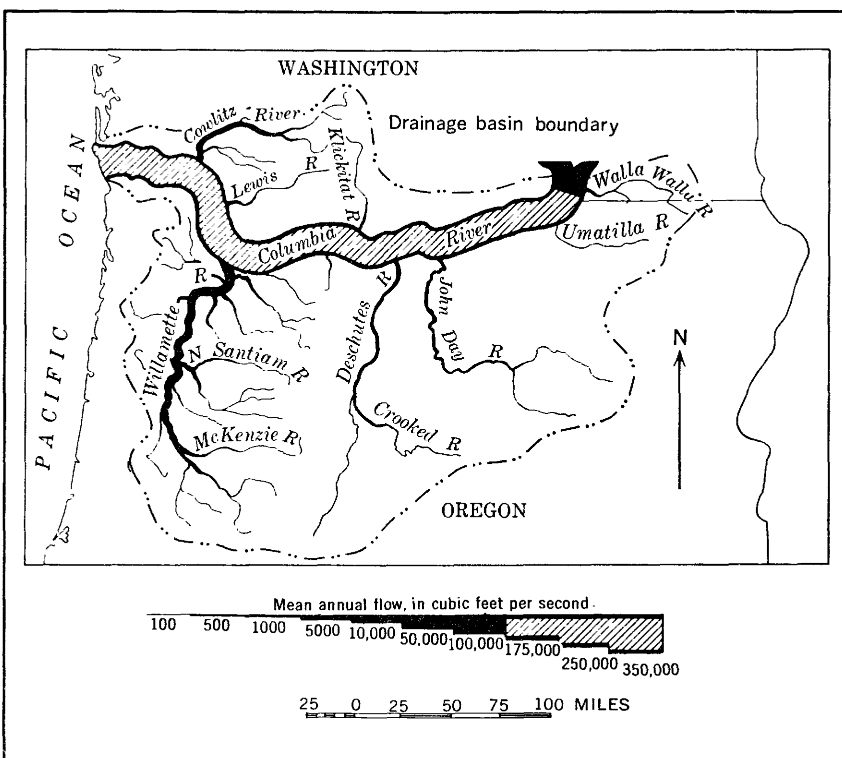

FIGURE 2.—Water discharge of major streams in the lower Columbia River basin.

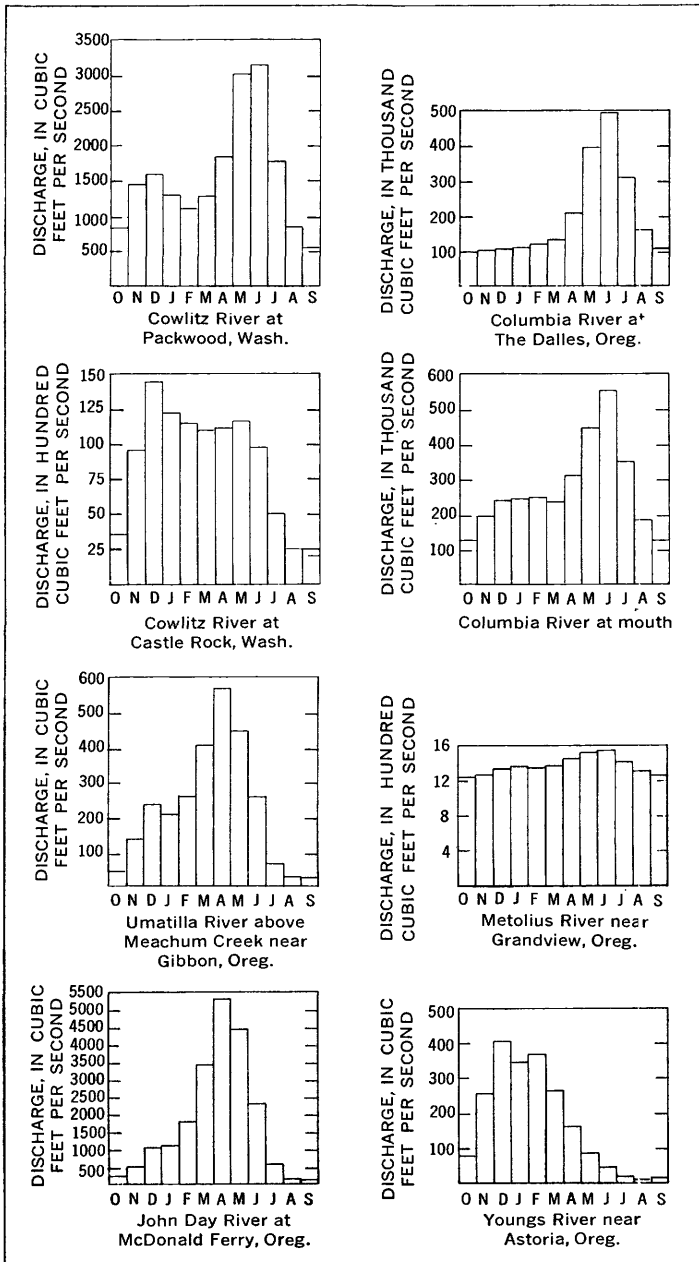

FIGURE 3.—Mean annual discharge characteristics of selected streams in the lower Columbia River basin, 1943–57.

discharge characteristics of selected streams in the basin. The Umatilla and John Day Rivers show the discharge characteristics typical of streams in the eastern part of the basin; periods of highest flow occur in the spring. The Metolius River exhibits a very uniform discharge pattern because the flow is largely from springs. Maximum monthly flows of the Columbia River at The Dalles, Oreg., occur during June owing to melting snow from the Rocky Mountains. At the mouth, the Columbia River has its maximum discharge in May or June. The flow pattern at the mouth is similar to that at The Dalles, except during the winter months. During the period November through March the diagram for the Columbia River at the mouth reveals the influence of the heavy rains during the winter in the basin west of the Cascade Range. The two graphs of the Cowlitz River show the difference in runoff that can take place in the same river basin. The elevation at Packwood, Wash., is 1,048 feet above mean sea level, and peak flows occur during May and June from melting snow in the Cascade Range. The diagram for the Cowlitz River downstream at Castle Rock, showing an elevation of 20 feet above mean sea level, indicates a leveling effect where the winter rains, together with spring snowmelt, produce an 8 month period of high discharge. Youngs River near Astoria, Oreg., is about 12 miles upstream from the mouth of the Columbia River, and it has its headwaters in the Coast Range where heavy winter rains produce high discharge from November to May. Periods of low flow throughout the lower Columbia River basin occur during the months of July to October.

EXPRESSION OF RESULTS

Concentrations of dissolved chemical constituents in water are commonly reported in units of parts per million (ppm). One part per million represents 1 milligram of solute in 1 kilogram of solution. Parts per million do not relate combining weights of ions in solution, so at times it is more convenient to express chemical analyses in terms of chemical equivalence or equivalents per million (epm). This value is obtained by multiplying parts per million by the reciprocals of combining weights of the appropriate ions. For example, the sulfate anion SO_4^{-2} has a molecular weight of 96.0616 and a valence of 2; therefore, since

$$\frac{96.0616}{2} = 48.0308$$

and

$$\frac{1}{48.0308} = 0.02082$$

the equivalents per million of sulfate can be obtained by multiplying parts per million of sulfate by the factor 0.02082.

STREAMS TRIBUTARY TO THE LOWER COLUMBIA RIVER

WALLA WALLA RIVER

The Walla Walla River and its principal tributary, the Touchet River, have their headwaters in the northern Blue Moutains in northeastern Oregon and southeastern Washington. The Blue Mountains in the Walla Walla River basin are composed mainly of the Columbia River Basalt of Miocene and Pliocene(?) age whereas the lower reaches of these streams drain sedimentary material of Pliocene and Pleistocene age. The basin has a drainage area of 1,660 square miles at Touchet and a 7-year average discharge of 440,900 acre-feet (1952–59). Mean annual precipitation ranges from more than 40 inches in the mountains to less than 10 inches at the mouth. The rolling hill country north of the Touchet River is dry-farmed for wheat, whereas the relatively flat area, roughly bounded by Milton-Freewater to the south and Walla Walla to the north, is irrigated. The irrigated lands produce peas, beans, beets, and various forage crops.

One daily chemical-quality sampling station was operated until 1962 on the Walla Walla River near Touchet in addition to a monthly station on the Touchet River at Dayton. For daily stations, daily samples are collected and specific conductance is determined on the individual samples. It is not economically feasible to run a chemical analysis on daily samples, so they are composited on an equal-volume basis, chronologically, according to the similarity of their specific conductance. The chemical analysis is then made on the composite sample. For monthly samples, a 4-liter sample is collected and analyzed. In relating discharge to chemical quality of a daily sample, the average discharge for the composite period is used; for a monthly sample, the average discharge of the day of collection is used.

The Walla Walla River near Milton-Freewater was sampled on a monthly basis 3 miles downstream from the confluence of the North and South Forks. The water is a dilute calcium magnesium bicarbonate type. The analyses of water from the Walla Walla River near Milton-Freewater show that the water to that point has a low dissolved-solids content. However, the dissolved-solids concentration increases downstream from Milton-Freewater because of return flows of irrigation water in the basin and because of the addition of spring flow in the alluvial fan of the Walla Walla River.

Fourteen chemical analyses of water from five springs in the alluvial fan showed that the spring water contains larger concentrations of dissolved solids than the water of the Walla Walla River near Milton-Freewater (U.S. Bur. Reclamation unpublished records). The specific conductance of the spring water ranged from 91 to 558 micromhos, and the hardness of the water ranged from 32 to 205 ppm. The chemical composition of water from the five springs was largely calcium magnesium bicarbonate. From May to September 1950 the three springs in the inner spring zone (the area near the apex of the alluvial fan) showed an increase in calcium and magnesium and little change in sodium and potassium; the two springs in the outer spring zone showed a decrease in calcium and magnesium and a corresponding increase in sodium and potassium during the same period. The explanation for this difference may be that in May all the spring water represents the characteristics of the natural recharge water received near the apex of the alluvial fan. Thus the inner and outer spring water is similar in chemical quality to the recharge water, but the outer spring water contains more dissolved solids because of longer contact time with the sedimentary material of the fan. However, owing to irrigation on the inner part of the alluvial fan during June to September, the outer springs represent the chemical characteristics of irrigation water that has percolated into the inner alluvial fan. The above explanation is based on a small amount of chemical-quality data from a few springs and it assumes that the alluvial fan has the classic geologic stratigraphy.

The greatest variation in dissolved-solids concentration in the basin was observed at the daily sampling station on the Walla Walla River near Touchet. Dissolved solids ranged from 94 to 507 ppm, and hardness of water from 34 to 262 ppm; the discharge weighted averages were 119 ppm and 52 ppm, respectively. The Walla Walla River transported 49,000 tons of dissolved solids past the sampling point near Touchet during the 1960 water year. The chemical composition of the water near Touchet remains reasonably uniform during periods of high and medium stages of discharge. At low flow, during the irrigation season, the chemical composition does change: there is a decrease in bicarbonate and an increase in sulfate and chloride. The cations are rather uniform during periods of varying discharge. Figure 4 is a trilinear plot of three selected samples to show the change in chemical composition for different discharges. The increased use of ground water to supplement surface supplies for irrigation may be the reason for the change in the anion composition of the water. Although the chemical composition of the water does not change appreciably, the dissolved-solids concentration does vary for different water discharges. Figure 5 is a plot of the relation of salinity (dissolved solids) to discharge.

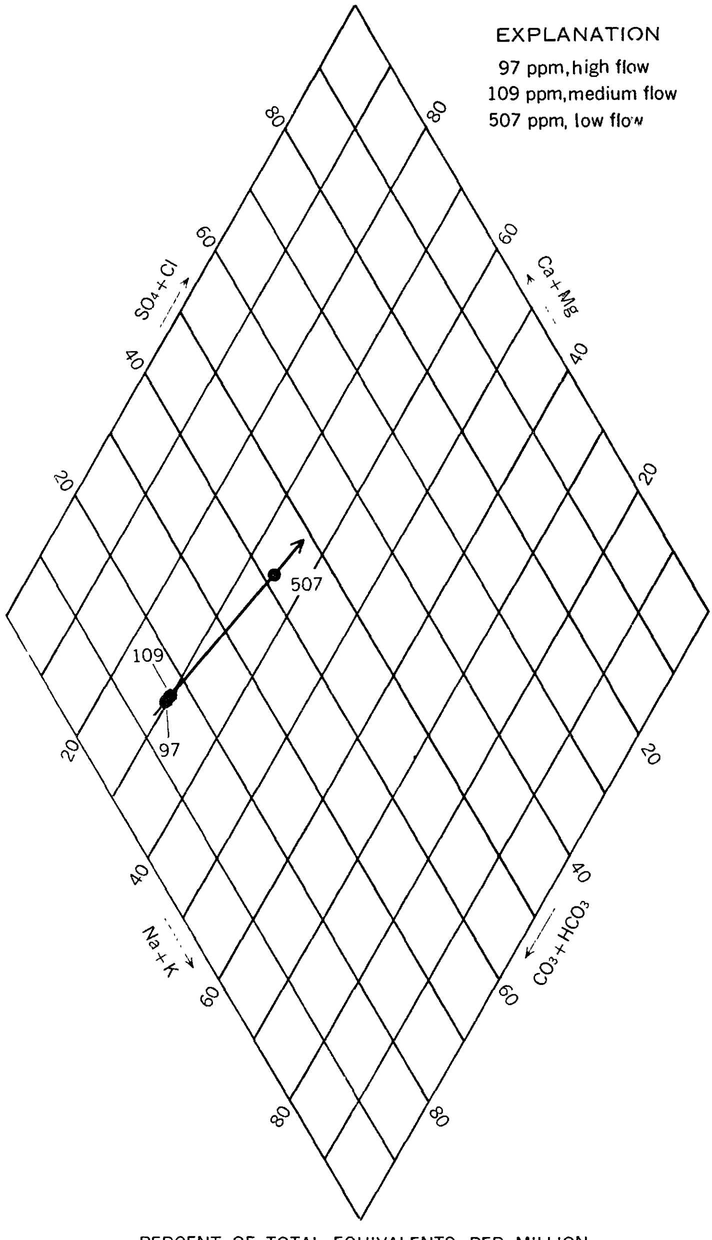

FIGURE 4.—Chemical quality of dissolved-solids content of the Walla Walla River near Touchet, Wash., at high, medium, and low flows. Dissolved solids, in parts per million, shown for points plotted.

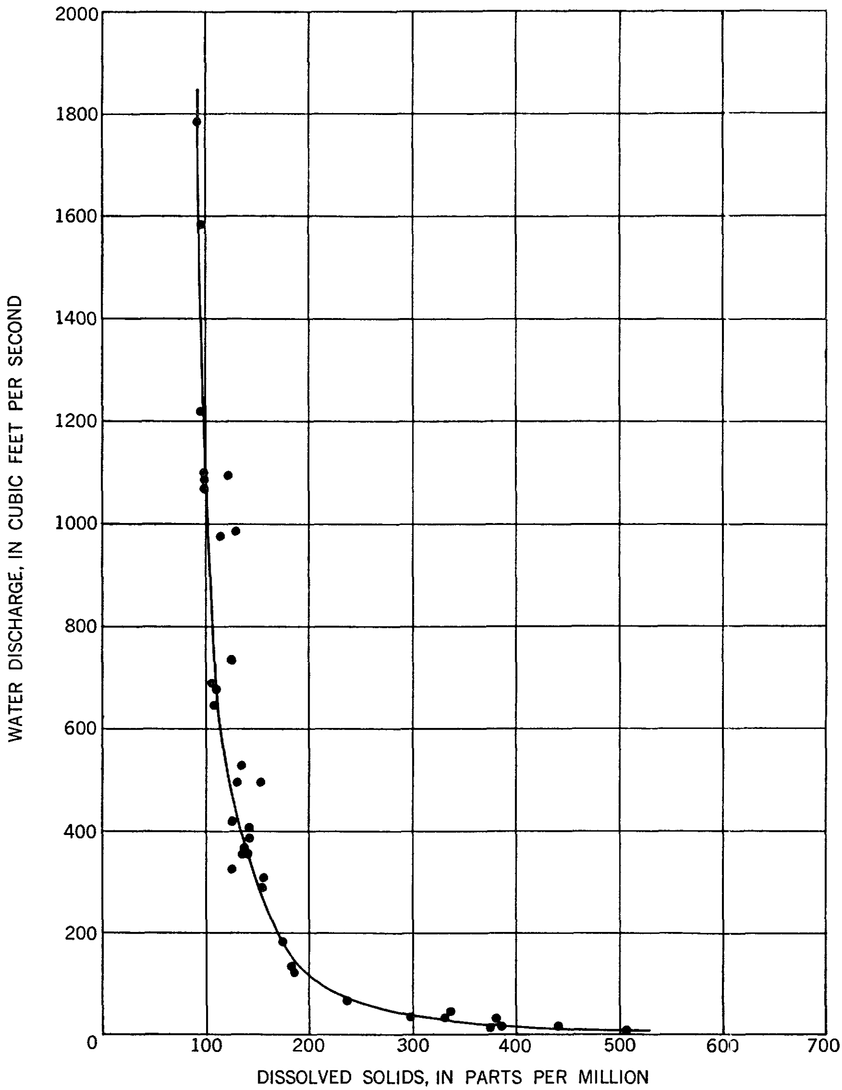

FIGURE 5.—Relation of salinity to water discharge, Walla Walla River near Touchet, Wash., 1960.

The headwaters of the Touchet River are very dilute. Hardness ranged from 20 to 52 ppm during the year (1951) of monthly sampling on the East Fork near Dayton. The Touchet River becomes more concentrated as it flows downstream to the Walla Walla River, but the water remains mainly calcium magnesium bicarbonate in type. Monthly samples of the Touchet River that were collected at Dayton ranged in dissolved-solids content from 66 to 86 ppm. Dissolved-solids data are not available for the East Fork Touchet River or for the Touchet River near Touchet. The chemical constituents that make up the dissolved solids vary somewhat during the year; thus, a correlation between specific conductance and dissolved solids was not definite enough to project the data for the Touchet River at Dayton to the East Fork and Touchet River near Touchet.

The cities of Walla Walla and Dayton divert surface water for municipal use from Mill Creek and from the East Fork Touchet River; however, the largest water use in the Walla Walla River basin is irrigation. About 37,000 acres is irrigated, and the net consumption was estimated by Simons (1953, p. 109) as 1.9 acre-feet per acre. This means that approximately 70,000 acre-feet of water is consumed in the Walla Walla Valley during a year. The area is short of irrigation water in some years, and surface storage or ground-water sources will have to be developed to fill the additional demand. The surface water of the basin is suitable for irrigation. According to the standards of the U.S. Salinity Laboratory Staff (1954, p. 80), the water may cause salt-balance problems where drainage is poor and leaching of residual salts is not consistently practiced; however, no salt-balance problem currently exists.

The problem of pollution differs in intensity throughout the Walla Walla River basin. Bacterial pollution of the Walla Walla River near Touchet is variable but often reaches serious levels. For 11 samples collected near Touchet at approximately monthly intervals beginning in July 1959, the most probable number of coliform bacteria per 100 milliliters (MPN) ranged from 430 to more than 150,000. These values exceed the limit for safe swimming, and the higher values represent a potential health hazard to fishermen. The Pollution Control Council of the Pacific Northwest Area (Bowering and others, 1961, p. 19) recommends that water used for swimming should not exceed an MPN value of 240 and that water used for boating and fishing should not contain more than 1,000 MPN coliform organisms. The Touchet River at Dayton contains coliform organisms exceeding the acceptable limits for recreational use. The MPN of 10 of the 11 monthly samples collected at Dayton exceeded 300; the maximum MPN was 46,000. For both the Walla Walla and Touchet Rivers, the minimum dissolved-oxygen content observed was 7.4 ppm, which is sufficient to maintain aquatic life. The higher levels of bacterial pollution in these streams makes the water unsuitable for many uses. Pollution may be a particular problem in Wallula Lake, which was formed on the lower Walla Walla River by the pool behind McNary Dam. This lake is a widely used recreational facility, and high levels of pollution may lead to undesirable effects.

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Return flows of irrigation water are a form of pollution because of their dissolved-solids contribution to the streams. Of specific interest is the unusually large range in concentrations of orthophosphate (0.00 to 28 ppm) in the water of the Walla Walla River. No exact breakdown can be made as to what amount of orthophosphate is contributed by sewage and what amount is contributed by irrigation return flow.

Concentrations of inorganic industrial wastes in streams of the Walla Walla River basin probably are very low. Semiannual water samples collected at Walla Walla River near Touchet and at Touchet River near Dayton contained 0.00 ppm of arsenic and had maximum concentrations of 0.02 ppm and 0.05 ppm for hexavalent chromium and copper, respectively.

Surface water in the Walla Walla River basin is generally suitable for most industrial purposes. In some areas, however, the water requires treatment for bacterial pollution and turbidity. Silica, color, hardness, and dissolved solids all exceed, at some time of the year, the recommended limits for these constituents. The Touchet River is of better quality than the Walla Walla River and is more suitable for industry. Its water is soft and contains dissolved solids in concentrations of less than 100 ppm. Silica content of the water generally exceeds 25 ppm. At times there is not enough water to satisfy existing water rights for irrigation; therefore, any industry that consumes water in manufacturing a product would have to obtain an existing water right in the Walla Walla River basin.

UMATILLA RIVER AND WILLOW CREEK

The Umatilla River rises on the western slope of the Blue Mountains in northeastern Oregon and flows in a westerly direction to Pendleton, where it makes a gentle curve toward the north before discharging into the Columbia River at Umatilla. Precipitation in the basin ranges from less than 8 inches near the mouth to more than 30 inches in the mountains. The Umatilla area is the most arid part of the lower Columbia River basin, and the Umatilla River and its tributaries supply the irrigation water necessary for growing crops. The upper reaches of the basin are underlain by a series of basalt flows of Miocene age, and the tops of some of the flows are fairly permeable. Snowmelt and rain percolate into these permeable zones and emerge as springs where the flows have been dissected by streams. The springs (ground-water inflow) are responsible for most of the dry-season flow in the Umatilla River. The lower reach of the Umatilla River is principally in glacio-fluviatile deposits of Pleistocene age. Willow Creek is included with the Umatilla River basin because the geology and climate of the basins are similar.

Nine sites were sampled in the Umatilla River and Willow Creek basins during periods of high, medium, and low flow. Analyses for samples collected at seven points in the Umatilla River basin during high-, medium-, and low-flow periods are given in table 1. These samples show that during high and medium flows the dissolved-solids content and hardness are small and that the water is a calcium magnesium bicarbonate type. The maximum observed dissolved-solids content and hardness of water in samples collected from the Umatilla River at Umatilla for these flow periods were 112 and 51 ppm, respectively. During low flows in the summer and fall months, the concentration and character of the water change because of two factors—spring flow and irrigation return flow. Most of the low-water flow is diverted for irrigation, and the small amount of "natural" flow in the streams stems from spring flow, which is more highly mineralized than normal surface runoff. This spring flow to the stream channels is supplemented by irrigation return flow, which often contains appreciable amounts of dissolved minerals. Thus, these two sources of low water flow produce increased mineralization and a change in chemical character of the surface water; although calcium bicarbonate usually still predominates, sodium and magnesium are increased and their combined concentrations often are almost equivalent to the calcium concentration. The increase in dissolved-solids content is not excessive. The maximum dissolved-solids content observed for the Umatilla River was 281 ppm at Umatilla; the maximum observed for a tributary stream was 304 ppm for Birch Creek at Rieth.

Surface water in the Willow Creek basin has a larger dissolved-solids concentration than does surface water in the Umatilla River basin, but the samples of water collected in both basins were primarily a calcium magnesium bicarbonate type. Figure 6 shows a plot of the samples taken in the Willow Creek basin. Samples 129, 155, and 389 were taken at Heppner, and only about 500 acres is irrigated above this point; samples 129 and 155, the high- and medium-flow samples, plot in the same area in figure 6, whereas number 389 is the low-flow sample and shows a decided increase in percent sodium and salinity. Samples 205, 265, and 479 are high-, medium-, and low-flow samples, respectively, that were collected downstream at Heppner Junction which is beyond the irrigated lands. These samples show a further increase in percent sodium. The low-flow samples show a small deviation in equivalents of anions, and they show a 15 percent increase in equivalents per million of sodium and a corresponding decrease in equivalents of calcium and magnesium. The character of the water thus changes from a calcium magnesium bicarbonate type to one in which sodium and bicarbonate are the principal constituents. Even the high- and

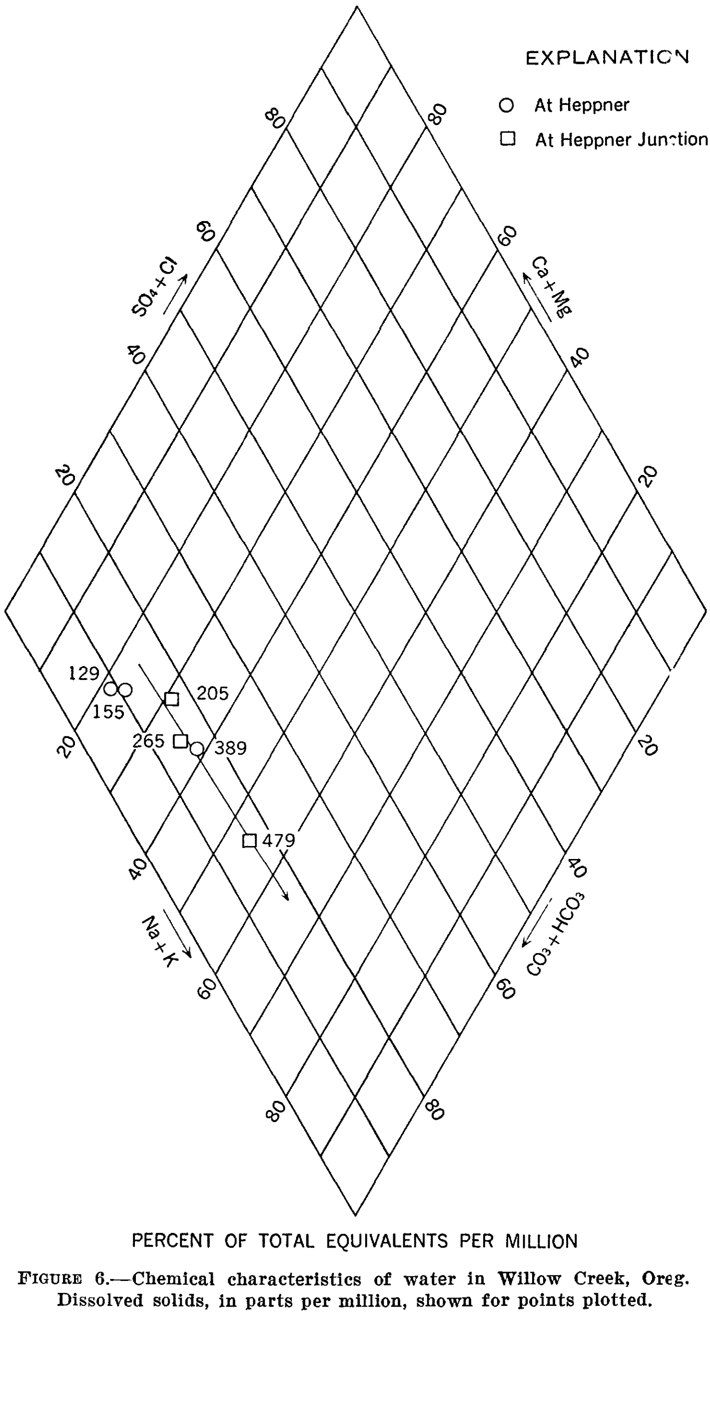


FIGURE 6.—Chemical characteristics of water in Willow Creek, Oreg. Dissolved solids, in parts per million, shown for points plotted.

medium-flow samples show this trend; although the character of water in the upper part of the Willow Creek basin is similar to that in the Umatilla River basin, the character of water in the lower area of the Willow Creek basin below Heppner is different. The trilinear diagram of the high- and medium-flow samples for the Umatilla River and Willow Creek basins (fig. 7) illustrates the similarity of these waters during the season of no irrigation.

Irrigation is the largest consumptive use of water in the Umatilla River basin. Simons (1953, p. 110) estimated that during the period 1921–45 about 23.2 percent of the average annual basin yield was consumed in applications to the 45,000 acres under irrigation in the basin. Water for irrigation is provided by McKay Reservoir on McKay Creek near Pendleton and by Cold Springs Reservoir east of Hermiston; their capacities are 73,830 acre-feet and 44,668 acre-feet, respectively. The Cold Springs Reservoir is not in the Umatilla River basin, but water from the Umatilla River is diverted during the high runoff period to fill the reservoir. Most of this water is used to irrigate lands in the lower Umatilla River basin, but a small amount is diverted to irrigate the benchlands of the Columbia River to the east.

The quality of water for irrigation in the Umatilla River basin can be classified as good. In terms of the standards of the U.S. Salinity Laboratory Staff (1954, p. 80), water of Birch Creek near Rieth has a low sodium hazard and a medium salinity hazard during summer flows. The water at the other six sampling points has both low sodium and low salinity hazards. Even though the water in the basin is of good quality for irrigation, high ground-water levels caused salt-balance problems in the Hermiston-Stanfield area. A detailed study of the hydrology, geology, drainage network, soils, and irrigation practices should be made to find a solution to this problem.

In terms of the classification of the U.S. Salinity Laboratory Staff (1954, p. 80), the water at the mouth of Willow Creek is a low-sodium, high-salinity water that can be used where drainage is good and the soil is not tight. The soils in the Umatilla area are generally permeable, but any increase in upstream irrigation would probably increase salinity and thereby increase the hazard to the downstream user. At present (1961), the stream is used to irrigate less than 4,000 acres, which is about 60 percent of the water rights existing in the basin. During the summer months, the flow in Willow Creek is often less than 0.5 cfs (cubic feet per second), and upstream storage would be necessary to provide more water for this period of low flow. A dam has been proposed for the Willow Creek basin to provide adequate amounts of water for present water rights and to provide some flood control.

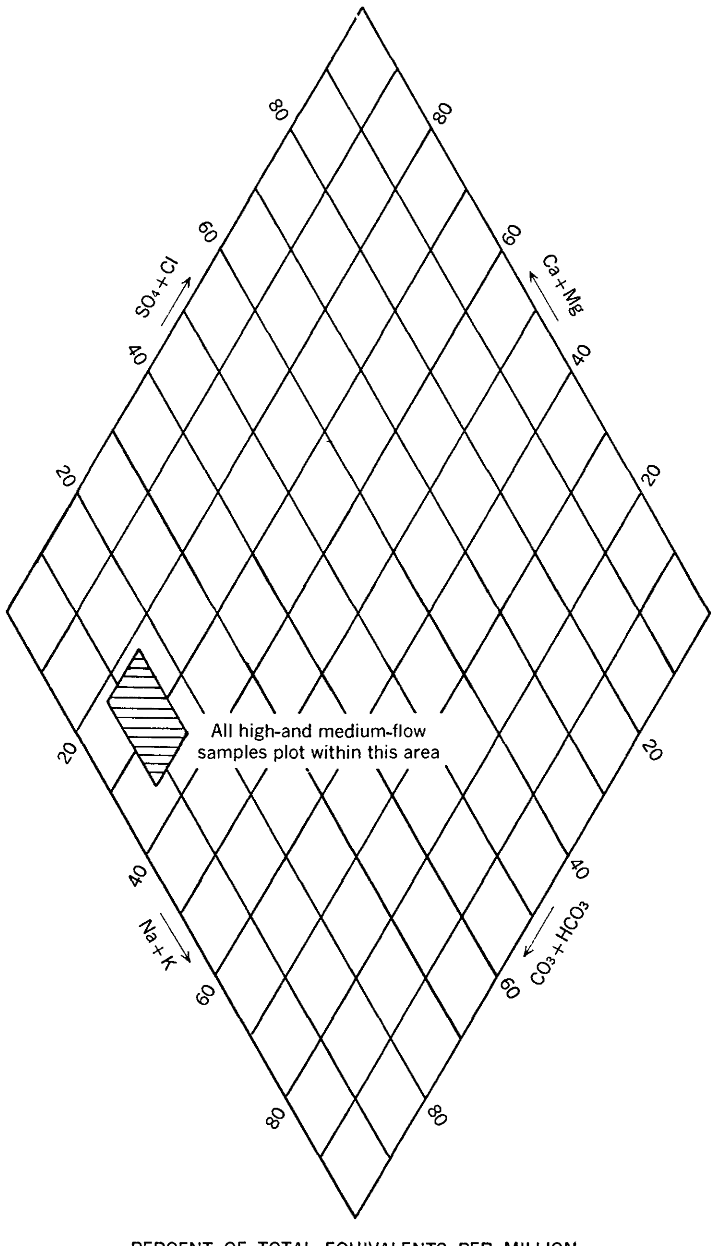


FIGURE 7.—Chemical characteristics of water in the Umatilla River and Willow Creek, Oreg., during high and medium flow.

Many of the tributaries are used for trout fishing, and the lake impoundments are areas of boating activity. The lower reaches of the Umatilla River and Willow Creek do not support game fish because of low flow and high temperatures during the summer months.

JOHN DAY RIVER

The John Day River heads in the Blue Mountains, whose maximum elevations exceed 8,000 feet, and flows in a westerly direction to the western edge of Wheeler County; it then changes its course to almost due north and finally discharges into the Columbia River about 6 miles northeast of Rufus, Oreg. The drainage area at McDonald Ferry is approximately 7,580 square miles and it has a 54-year average discharge (1905–59) of 1,463,000 acre-feet per year (fig. 2).

The John Day River drainage is geologically one of the most complex areas in the lower Columbia River basin. The main stem heads in younger volcanic rocks and interbedded tuffaceous deposits of Pliocene age, intrusive granitic rocks of Late Jurassic or Early Cretaceous age, and low-grade metamorphic rocks of Carboniferous age. It then traverses the Columbia River Basalt of Miocene and possibly early Pliocene age. In places, it has cut through this formation to expose tuffs and other pyroclastic deposits of Oligocene age. The South Fork heads in lime silicate rocks of Jurassic and Triassic age and then flows over the Columbia River Basalt. Tributaries to the South Fork drain the lavas and tuffs of Eocene age and younger lavas of Pliocene age. The lower John Day River drains some limestone shale and conglomerate of Cretaceous age, lavas and tuffs of Eocene age, tuffs of Oligocene age, Columbia River Basalt, and alluvium of Recent age.

Table 1 lists chemical analyses of samples collected for high, low, and medium flows at three reconnaissance locations and also lists an analysis of a spot sample from Rock Creek. In addition, a monthly sampling station was located on the John Day River near Service Creek, Oreg. Examination of the 13 analyses for the John Day basin shows that the waters are a calcium magnesium bicarbonate type. The combined equivalents per million of calcium and magnesium ranged from 68 to 83 percent of the total equivalents per million of cations; the equivalents per million of bicarbonate only varied 10 percent—from a low of 84 percent to a high of 94 percent. The ratio of calcium to magnesium is not consistant but varies with discharge.

The North Fork of the John Day River above Dale, Oreg., drains an area of 525 square miles. Although this area is only about 7 percent of the John Day River basin, it contributes about 20 percent of the total basin discharge. The analyses in table 1 show that the water of the North Fork is a dilute calcium magnesium bicarbonate type which results from the geology of the drainage basin, for man's influence on the quality of water in the upper basin is negligible. The North Fork drains older metamorphosed rocks that contain some limestone and argillite, which would account for the calcium magnesium bicarbonate water. However, the maximum hardness of the three samples collected at varying flows near Dale was only 48 ppm, and the maximum dissolved-solids content was 73 ppm.

The quality of water in samples collected from the John Day River at Picture Gorge near Dayville is similar to the quality of that in the upper John Day and the South Fork John Day Rivers. The water is principally a calcium magnesium type whose sodium content is higher during the summer and fall months than during the winter; the dissolved-solids content of the John Day River is about four times that of the North Fork. Most of this increase in dissolved solids can be attributed to the irrigation return flows from the large irrigated area immediately above the sampling station. The area adjacent to the river contains the largest part of the irrigated acreage in the John Day basin. The irrigation flows largely return to the river by infiltration and percolation to the ground water table and by subsequent flow into the stream from the alluvium. The observed extremes in dissolved-solids content at this sampling point were 165 and 286 ppm.

At Service Creek, Oreg., about 20 miles downstream from the confluence of the North Fork and the Upper John Day Rivers, the drainage area is 67 percent of the total area but produces more than 90 percent of the runoff in the basin. The analyses for the John Day River at Service Creek show the water to have a smaller dissolved-solids content than the water at Picture Gorge. This dilution is brought about by the entry of the North Fork, which has a low dissolved-solids content, between the two sampling points; also, the average flow of the North Fork is almost three times the average flow of the John Day River at their confluence. Figure 8 shows the variation in hardness of water for the John Day River at Service Creek by a plot of hardness, as parts per million of calcium carbonate, versus discharge, as cubic feet per second, for the day the sample was collected. Hardness of water of 13 samples taken at approximately monthly intervals ranged from 49 to 124 ppm. The dissolved-solids content of these samples ranged from 49 to 183 ppm. Streamflow at Service Creek during the 1959 water year was only 82 percent of the 54-year average; thus, the maximum and minimum data are higher than normally would be expected.

At McDonald Ferry, approximately 20 miles upstream from the mouth of John Day River, reconnaissance samples of water indicated

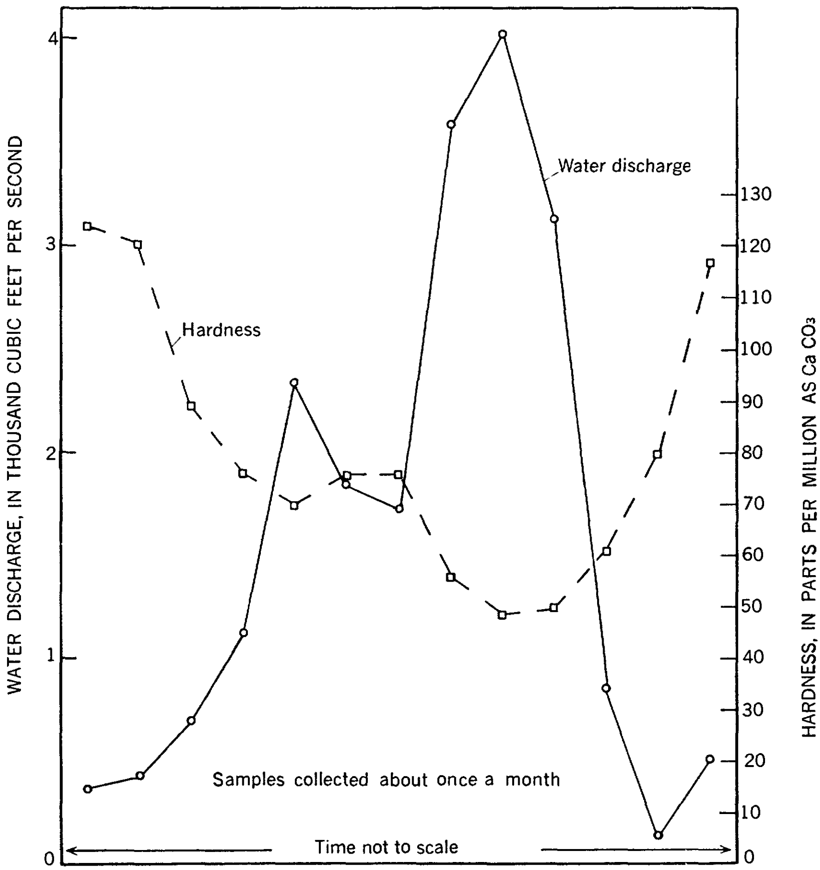


FIGURE 8.—Relation of hardness to water discharge, John Day River at Service Creek, Oreg., water year 1959.

that except for a small increase in dissolved-solids content, the quality of the water is not appreciably different from the quality of water at Service Creek. The water in the basin is principally a calcium magnesium bicarbonate type, that shows an increase in its sodium content during the summer and fall months. Figure 9 shows the chemical composition of the basin waters during the low-flow period.

Increased use of water in the John Day River basin would probably depend on construction of dams in the higher elevations of the headwater forks. The basin has no major dams at the present time (1961). Some timber in the Blue Mountains is suitable for manufacture of pulp, paper, and fiberboard; however, utilization is mainly as saw timber. Chemical analyses of water in the North Fork of the John Day River near Dale indicate that the water would probably be suitable

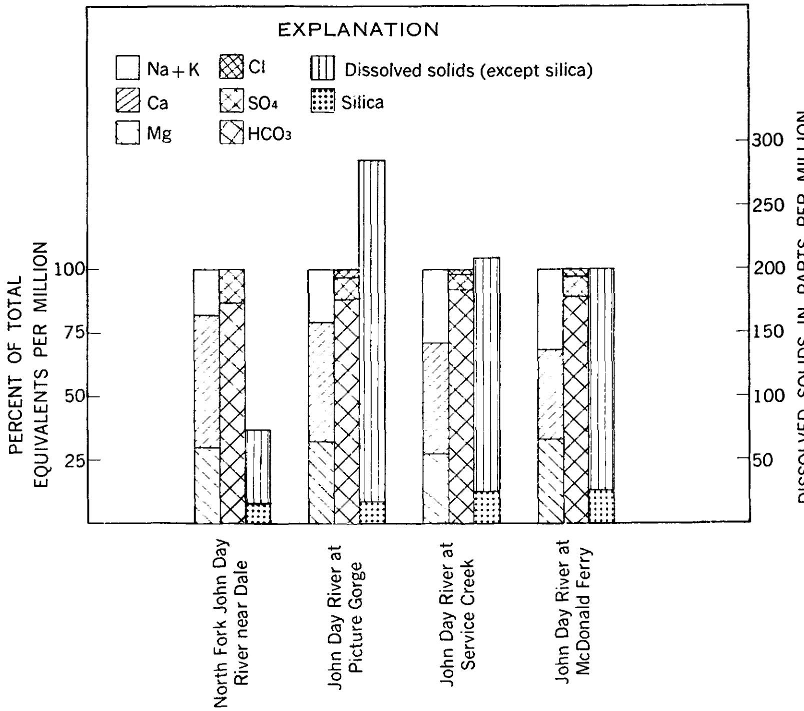


FIGURE 9.—Chemical composition of water in the John Day River basin, Oregon, during period of low flow.

for most paper industries, except the manufacture of fine paper. The water would require turbidity and color removal to meet the standards for this process. The balance of the examined waters in this basin would require additional treatment before use by any of the above industries.

John Day River water in general is suitable for irrigation of most crops and soils. The salinity hazard of the water ranges from low to medium (U.S. Salinity Laboratory Staff, 1954, p. 80), and the water in general can be used without special practices for controlling salinity and the low-sodium hazard. Simons (1953, p. 114) estimated that 6 percent of the basin yield is consumed by irrigation.

Recreational use of the John Day River is chiefly fishing, and it is confined principally to the upper reaches of the various tributaries.

Cities in the basin obtained their water supplies from springs and (or) wells. If developed for public consumption, many of the surface-water supplies in the basin would require softening and, at times, removal of turbidity.

DESCHUTES RIVER

The Deschutes River and the majority of its tributaries rise on the eastern slopes of the Cascade Range. The major tributary from the east is the Crooked River, which has its headwaters in the Ochoco Mountains. Precipitation ranges from 9 inches in the Redmond area to more than 70 inches in the summit area of the Cascades. The Deschutes River at Moody drains about 10,500 square miles and has a 55-year (1897, 1906–59) average discharge of 4,248,000 acre-feet.

The Cascade Range consists mainly of volcanic rocks of Miocene to Recent age. Continental deposits and associated volcanic rocks of Eocene, Oligocene, and Pliocene age constitute a part of the western part of the Deschutes River basin and much of the Crooked River basin. Cretaceous marine deposits also are exposed in the upper Crooked River basin.

Table 1 gives the chemical analyses of the reconnaissance samples of water taken in the Deschutes River basin. The dissolved-solids content is small in streams originating in the Cascade Range because hard, slightly soluble volcanic rocks compose the range. Downstream from Wickiup Reservoir in the upper basin, the maximum observed dissolved-solids content of the Deschutes River water was 53 ppm. The Cascade Range streams have calcium magnesium bicarbonate water. There is a moderate increase in salinity from the headwaters to a point below Bend, Oreg. At Tumalo, for 12 monthly samples, the average dissolved-solids content was 78 ppm; the maximum was 146 ppm. This increase probably was caused by irrigation return flow from the large irrigation project upstream and downstream from Bend. The maximum observed concentration of dissolved solids at Tumalo occurred during the winter months; this delay indicates that part of the irrigation return flow may be via ground-water "channels." Downstream from Tumalo, the dissolved-solids content of the water decreases somewhat; at Cline Falls, for 12 monthly samples, the average was 68 ppm and the maximum was 95 ppm. The decrease may be due to the inflow of ground water above Cline Falls.

The volcanic formations in the Bend-Tumalo area are generally very permeable, and the basalt flows in many places contain subterranean tunnels and caverns. A sizeable volume of ground water moves through these materials. Just above Cline Falls the John Day Formation forms a barrier to the movement of ground water. This formation is composed principally of bentonitic tuffs that are late Oligocene and early Miocene in age. The ground-water inflow to the river at this point is presumed to be partly Deschutes River water that infiltrates the very permeable volcanic materials in the Lava Butte region about 20 miles upstream. Downstream, at Lower

Bridge, the Deschutes River increases slightly in salinity to the sampling point near Culver. The average dissolved-solids content of 12 monthly samples collected near Culver was 108 ppm, and the maximum was 164 ppm.

The Crooked River joins the Deschutes River 2½ miles downstream from the sampling point at the Cove State Park. Most of the streams in the Crooked River basin have a much higher dissolved-solids content than do the streams in the Deschutes River basin. The difference can be attributed to the generally semiarid nature of much of the Crooked River basin and the more soluble metamorphic rocks and sedimentary materials in the basin. Samples were collected at high, medium, and low flows from the Crooked River above Prineville (above the Crooked River damsite). The dissolved-solids content of these samples ranged from 119 to 322 ppm. The medium- and low-flow samples were principally sodium bicarbonate type water. At high flows calcium exceeds the sodium concentration. However, the Crooked River's dissolved-solids content is greatly diluted by inflow from springs in the 15-mile reach above the river's mouth. This ground-water inflow amounts to almost two-thirds of the average flow of the river. The springs flow from the basalt formations, into which the Crooked River has cut a deep canyon. Part of the spring flow, at least, is produced by the damming effect of the John Day Formation on the ground-water flow; this occurrence is similar to that in the Deschutes River above Cline Falls (p. 23).

The Bureau of Reclamation has constructed a dam on the Crooked River, and irrigation agriculture will greatly increase in the Prineville area. Drainage water from this project will probably increase the mineralization in the Crooked River.

The Crooked River transports large quantities of suspended sediments, especially during periods of high runoff. During such periods these sediments and associated turbidity are evident in the Deschutes River from its confluence with the Crooked River to its mouth. However, the Portland General Electric Co. has obtained a license to build a dam on the Deschutes River at the Round Butte site, just downstream from the mouth of the Metolius River. The reservoir behind this dam would impound water above the mouth of the Crooked River. This proposed dam on the Deschutes River and the Prineville Dam on the Crooked River, together with the existing Pelton Dam on the Deschutes River, probably would trap most of the suspended sediment and remove much of the turbidity of the three rivers.

The chemical quality of the Metolius River at Camp Sherman is representative of the dilute calcium bicarbonate type water that issues from the many springs that form this river. The dissolved-solids content normally ranges from 65 to 85 ppm. However, during some summer months it has exceeded 160 ppm; the major increase has been in the calcium and bicarbonate concentrations. The reason for this increase has not been clearly determined; it may be attributable to the small amount of irrigation in this headwaters area, the summer homes and recreational usage of the area, the natural variations, or a combination of all three.

The Deschutes River from its confluence with the Metolius River to its mouth receives surface inflow of low salinity from streams draining eastward from the Cascade Range. In addition to the rivers and creeks, numerous springs contribute water to the Deschutes River. Chemical-quality data for much of this inflow are not available, but because there is a progressive reduction in dissolved-solids content of the river water from the confluence with the Metolius River to the mouth of the Deschutes River near Moody, Oreg., the dissolved-solids content of this inflow must be less than that of the receiving stream.

From December 1952 to February 1954, samples were collected daily from the Deschutes River 0.9 mile upstream from its mouth. The dissolved-solids content of the river for this period ranged from 86 to 105 ppm. Figure 10 is a frequency distribution graph of dissolved solids for the Deschutes River at Moody, Oreg. This graph is based on 38 composite samples for the above period. Some caution is necessary in making use of the graph because the discharge of the Deschutes River for this period ranged from 131 to 133 percent of the 54-year average. The relationship between dissolved-solids content and discharge is not well defined for this stream. Although periods of low flow show both high and low dissolved-solids contents, periods of above-average discharge show the highest content. The relationship between specific conductance and discharge was less uniform than that between dissolved-solids content and discharge. The reason may be that tributaries from the Cascade Range are usually spring flow and snowmelt runoff that are low in dissolved-solids content because they are from areas of slightly soluble rocks. Fluctuation in the dissolved-solids content of the Deschutes River is a function of the discharge of the Crooked River; in general, the Crooked River carries a more highly mineralized water than streams in the rest of the basin.

Pollution is not a serious problem in the Deschutes River basin. The maximum coliform value observed at nine monthly sampling stations on the Deschutes River during 1958–59 was 700 MPN. This concentration occurred in a sample taken immediately downstream from Bend, Oreg. The median value for 12 monthly samples taken

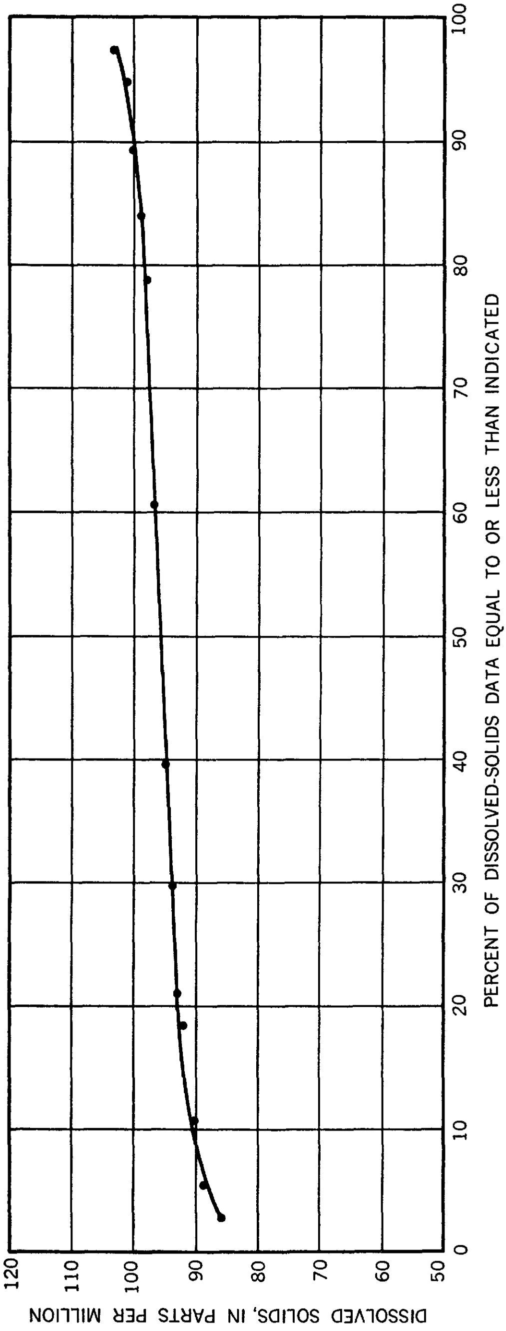


FIGURE 10.—Frequency distribution of dissolved solids, Deschutes River at Moody, Oreg., 1952–54.

at this sampling station was 62 MPN. Most of the higher MPN values observed in the Deschutes River were for the sampling station downstream from Bend. However, water pollution throughout the Deschutes River basin, as indicated by MPN coliform values, is generally low. Dissolved-oxygen content at the above stations ranged from 8.6 to 13.3 ppm, which is well above the minimum level considered necessary for aquatic life. Five-day biological oxygen demand was less than 4 ppm.

Low levels of pollution are of special significance in the Redmond-Bend-Sisters area, in which water with little or no treatment is diverted from irrigation canals for domestic use. Water diversion is a year-round practice because of the high cost of developing wells in the area. The many streams, lakes, and reservoirs in the Deschutes River basin provide great opportunity for water-based recreation. The almost uniform low level of pollution is a great asset for water sports, and recreational activities are a major economic benefit in the basin.

At the present time (1961), there are no large industries in the Deschutes River basin, and the problems of industrial waste disposal are practically nil. However, timber suitable for industrial processing is available on the eastern slopes of the Cascade Range; and the water in the basin, through some treatment, could be made suitable for pulp and paper manufacture. At many of the sampling points, silica content exceeds the specified limit for water used in making soda pulp and fine paper. Minor treatment probably would make the water suitable for unbleached kraft (sulfate) paper manufacture, however.

In any industrial utilization of the surface water, treatment may be required to remove algae that are present in the water of some streams in the Deschutes River basin. In August 1960 the author observed large concentrations of algae in the Little Deschutes River near Lapine and in the Deschutes River from Wickiup Reservoir downstream to Bend. The quantity and identity of the algae were not determined. Additional information about their relationship to a particular industry would be needed to determine the suitability of the water.

More than 140,000 acres of land is irrigated in the Deschutes River basin; and, according to Simons (1953, p. 116), the basin yield of water is reduced a little more than 5 percent by irrigation. The land suitable for irrigation is composed of permeable soils, and no salt-balance problem is known to exist in the basin. The high permeability of the lava and pumice that underlie the soil at shallow depths requires lined irrigation canals where the canals cross such soils; where these canals are not lined, conveyance losses are high.

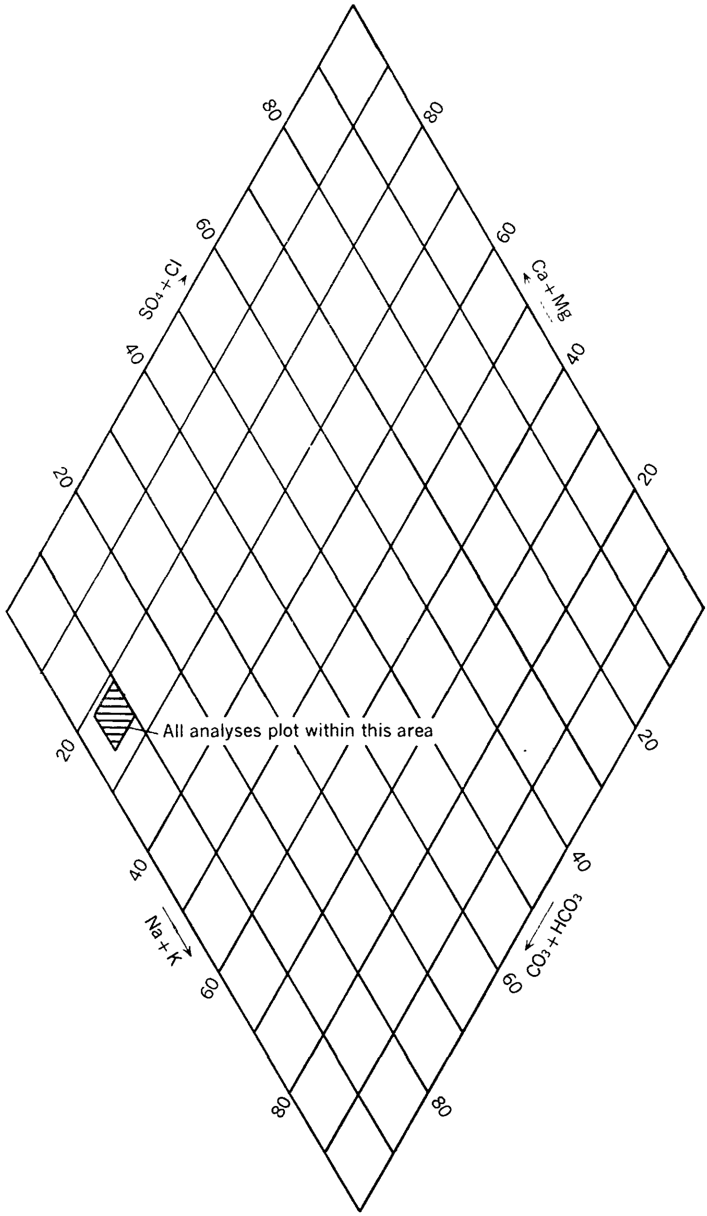
Surface water in the basin generally is suitable for irrigation. In terms of the U.S. Salinity Laboratory Staff (1954, p. 80) rating system, the water has a medium salinity hazard and a low sodium hazard.

KLICKITAT RIVER

The Klickitat River rises on the eastern slope of the Cascade Range, and it has major tributaries on Mount Adams. White Creek and the Little Klickitat River are the major tributaries from the east. The drainage area at Pitt, 7 miles upstream from the mouth of the river, is 1,290 square miles and has a 33-year (1909–11, 1928–59) average runoff of 1,155,000 acre-feet.

Water from the Klickitat River basin is a dilute calcium magnesium bicarbonate type (table 1). In general, the water contains a greater percentage of these constituents than the nearby Cowlitz and Lewis Rivers.

The Klickitat River drains primarily volcanic rocks of Miocene, Pliocene, Pleistocene, and Recent age. These rocks are resistant to solution. At Pitt the dissolved-solids content of 14 samples collected at monthly intervals ranged from 50 to 85 ppm, and the hardness ranged from 20 to 32 ppm. Samples collected at high, low, and medium flow of the Klickitat River at Glenwood show the chemical quality of the water emerging from the forested mountains, on which the only activity of man is logging. The water is low in dissolved-solids content and is soft; therefore, it is suitable for most purposes. Water from Hellroaring Creek, a tributary above Glenwood, is diverted to irrigate about 7,000 acres in a broad valley below Glenwood. Comparison of the samples of water from the Klickitat River at Glenwood with the samples collected at Pitt show no significant alteration in chemical quality that could be attributed to irrigation return flows. The samples collected from the Little Klickitat River near Wahkiacus during high, low, and medium flow had higher dissolved-solids contents than did samples from the other two sampling stations in the Klickitat River basin. Dissolved-solids content ranged from 68 to 98 ppm. Continental sedimentary materials of Pleistocene age in this subbasin could be responsible for the higher dissolved-solids contents. Small diversions are made in the Little Klickitat River above Wahkiacus for irrigating forage crops, but irrigation in this part of the basin is not extensive enough to cause large seasonal variations in chemical quality. Figure 11 is a trilinear plot of the chemical characteristics of the 19 samples collected in the Klickitat River basin; the figure shows the small amount of chemical-composition variation observed in the basin. A study of both Van Winkle's (1914a, p. 79) data for this stream and the present data was made to see if some



PERCENT OF TOTAL EQUIVALENTS PER MILLION

FIGURE 11.—Chemical characteristics of water in the Klickitat River basin, Washington.

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significant change in quality had occurred during this long period of time. Comparison of the two sets of data was not feasible because the earlier study composited time-weighted samples and the recent samples were collected once monthly.

The Klickitat River and most of its tributaries flow through rugged, steep-walled canyons that are unsuitable as industrial sites. Powersites are present in the Klickitat River basin; however, no dams have been constructed or are proposed for construction at this time (1961). Water use in the basin will remain about the same as it is now unless there is industrial development and (or) significant population increase in the valley downstream from Glenwood. Klickitat River water near Glenwood, being low in dissolved-solids content and soft, is suitable for most industrial purposes although removal of turbidity would be required at some times. Industries such as soda and sulfate pulping and fine-paper making, which require water having small silica concentrations and low color values, would have to treat the water prior to use.

The Glenwood valley has an additional 13,000 acres that could be irrigated. A project of lengthening the present canal and also extending it to intercept the West Fork Klickitat River has been proposed to provide water for this acreage. Another proposal would divert water from the Klickitat River into another basin to the east. Water of the Klickitat River is suitable for irrigation and, as rated by the U.S. Salinity Laboratory Staff (1954, p. 80), has low salinity and sodium hazards.

A large proportion of the Klickitat River is inaccessible to man; consequently, recreational use is confined to small areas.

The extent and degree of pollution in the basin probably is small because accessibility is limited and because little water in the basin is used.

MOUNT HOOD STREAMS

Mount Hood, elevation 11,245 feet, is the highest point in Oregon. It is composed of lavas and tuffs extruded during Pleistocene time and its base rests on volcanic rocks of Miocene and possibly Eocene age which form the Cascade Range in this area. The mountain peak is snow covered the year round and precipitation exceeds 80 inches at Government Camp, Oreg., whose elevation is 4,000 feet.

The largest streams originating on Mount Hood are the Sandy and Hood Rivers, and a smaller stream, the White River, is a tributary to the Deschutes River. Runoff characteristics are similar to the Cowlitz River at Packwood (fig. 3).

The chemical quality of the Sandy and Hood Rivers (table 1) is similar to the streams heading in the volcanic peaks in the lower

Columbia River basin. In both streams the water is soft and is a dilute calcium magnesium bicarbonate type that shows little variation in quality during the year. The monthly samples from the Sandy River near Marmot showed only a 5 percent variation in percent sodium, and dissolved-solids content ranged from 29 to 61 ppm. The Hood River reconnaissance samples ranged from 24 to 26 percent sodium as compared with 28 to 32 percent for the Sandy River. The chemical quality of the White River is discussed in the section of this report dealing with the Deschutes River basin, and the water of the White River is similar to that of the Sandy and Hood Rivers. The percent-sodium values for the White River samples were between those given above. Water of the Bull Run River, a tributary of the Sandy River, is a calcium magnesium bicarbonate type that is lower in dissolved-solids content than is the water in other streams discussed above. The maximum dissolved-solids content of the four samples from the Bull Run River was 24 ppm, and the minimum was 16 ppm.

Water from Mount Hood streams is used for municipal water supply, irrigation, and power generation. The largest user of this water supply is the city of Portland, which has developed the Bull Run River for a public supply. Bull Run River, whose headwaters are near the summit of the Cascade Range, has a drainage area of 102 square miles and a 52-year average runoff (1907–59) of 545,100 acre-feet per year. The headwaters of the Bull Run River are separated from Mount Hood summit by the deeply incised canyons of the West Fork Hood and Sandy Rivers. The flow is mainly from springs fed by rain and melting snow. At present (1961), the system serves an estimated population of 600,000 people; however, if fully developed, the watershed could serve 1,500,000 people. Treatment of the water consists only of chlorination and ammoniation. The water is excellent in quality, very soft, and suitable for almost any industrial use. The city of Portland diverts a little more than 95,000 acre-feet per year to serve the city and 55 water districts in the area. Some electric power is generated on the Bull Run River by a private utility, and the city of Portland is constructing an additional storage dam which will also generate electricity. The Bull Run River watershed is a restricted access area, and pollution is not a problem. The degree of pollution in the rest of the Sandy River basin is not known, but the numerous summer homes fronting on the main stem and on tributaries have privies or septic tanks which may be a source of bacterial pollution. Irrigation is not a factor in the chemical quality of water in the Sandy River basin. Neither is it practiced extensively now nor are any future projects proposed for the basin.

Water use in the Hood River basin is mainly the irrigation of the upper and lower valleys although some water is diverted from this basin into the Mill Creek basin for municipal use by The Dalles. Some 13,000 acres of land in the Hood River basin is irrigated to raise apples, pears, and cherries. No figures are available for net consumption of water in the basin. The reconnaissance samples of the Hood River water that were taken near the city of Hood River are representative of nearly all the return flow from upstream irrigation, though some water diverted from the Hood River returns to Indian Creek, which discharges directly to the Columbia River. Chemical analyses of the Hood River samples reveal no detectable alteration of chemical quality. According to the rating of the U.S. Salinity Laboratory Staff (1954, p. 80), the water has low salinity and sodium hazards. Irrigable land in the Hood River valley has been developed to nearly a maximum.

WILLAMETTE RIVER

The Willamette River is the largest tributary in the lower Columbia River basin; it flows north and discharges into the Columbia River in the vicinity of Portland. The major part of the population, industry, and agriculture of the lower Columbia River basin is in the Willamette River valley. The drainage area at the mouth of the Willamette River is 11,200 square miles, and the average runoff (1943–59) is about 27,500,000 acre-feet per year. The Cascade Range forms the eastern flank of the Willamette River basin, and the Oregon Coast Range forms the western flank. The Calapooya Mountains, a transverse spur, connects the Coast Range with the Cascades and forms the southern boundary. Upstream from Oregon City, the Willamette River is a sluggish stream that has numerous oxbow lakes. The sedimentary materials that constitute the present valley floor were deposited mainly during a stage in the Pleistocene Epoch when sea level was higher than it is at present. Deposition of older underlying material began during middle Tertiary time as a result of uplift and subsequent erosion of areas to the east and west. As sea level declined, the river eroded its present channel. The bed of the river at present (1961) has reached the gravelly materials that underlie the silts that were deposited during the Pleistocene Epoch.

The Oregon Coast Range consists principally of sedimentary rocks of Tertiary age that have been deformed by folding and are intercalated with basalts. The sedimentary rocks are chiefly shale and sandstone of Tertiary age. The basalts are chiefly of Miocene age and some are of Eocene age. The general elevation is less than 2,500 feet although isolated peaks exceed this. The Oregon Coast Range is maturely dissected; the stream valleys are deeply incised and closely spaced, and their headwater areas are close to the streams draining to the west.

In contrast to the Oregon Coast Range, the Middle Cascade Range is topographically young; it has V-shaped valleys and steep-gradient streams. Its general elevation ranges from 4,000 to 6,000 feet, but many isolated volcanic peaks rise to altitudes of 10,000 feet and higher. The Middle Cascade Range is composed primarily of volcanic rocks that are mainly basalts and andesites ranging in age from Oligocene(?) to Recent. Lesser amounts of pyroclastic rocks of Eocene to Oligocene age, marine sediments of Oligocene age, and continental sediments of Miocene to Pliocene age are also present.

The geology of the Calapooya Mountains in the southern part of the Willamette River basin is fairly unknown.

The main stem of the Willamette River north of Eugene flows through older alluvium of Pleistocene age and through younger alluvium of Recent age. This is also true of the tributaries to the main stem in their lower reaches. South of Eugene, poorly sorted terrace deposits of Pleistocene age are exposed by many of the tributaries.

One daily-sampling station was operated (1959) in the headwaters of the McKenzie River to obtain data on quality fluctuation throughout the year for a stream whose water quality reflects natural environment. Another daily-sampling station on the Willamette River at Salem has been operated continuously since February 1951. A monthly-sampling station was operated (1960) on the Willamette River at Portland to provide data on the chemical quality of water discharged to the Columbia River. In addition, samples were collected at high, low, and medium flow at eight reconnaissance sampling points (1959–60) throughout the basin. Table 1 lists chemical analyses of the reconnaissance and miscellaneous samples from the Willamette River basin.

The analyses of the high-, medium-, and low-flow samples taken on the Coast Fork and on the Middle Fork of the Willamette River show striking similarity in chemical composition. Sodium content for the Coast Fork was 25, 27, and 22 percent. For the Middle Fork it was 25, 28, and 22 percent. The McKenzie River contains more sodium; during the 1959 water year, the sodium content of the river ranged from 28 to 36 percent. However, water in all three streams is low in dissolved-solids content and is predominately a calcium magnesium bicarbonate type. Perhaps the Recent volcanics in the upper McKenzie River account for that river's higher sodium content; some of those volcanics are only a few thousand years old. The chemical quality of the upper McKenzie River water is similar to that of the Deschutes River at Wickiup Reservoir and to that of the Metolius River near Grandview, both of which have their headwaters on the east slope of the Cascades near the headwaters of the McKenzie River.

The dissolved-solids content of the McKenzie River at McKenzie Bridge is a function of water discharge. Figure 12 shows the relationship between dissolved-solids content and discharge. This is a well-defined, natural relationship, for the activities of man upstream from the sampling point can be disregarded. The factors controlling this relationship are the quantity of water discharge, the amount of time the water is in contact with the rocks of the basin, and the surficial area of rock exposed to the water during the contact time. During periods of high rainfall or snowmelt, the water discharge is high and contact time with the rocks is small. These conditions produce low dissolved-solids content during high runoff. During the dry summer, flow derived from springs predominates and the longer contact time between the rocks and water produces slightly increased dissolved-solids concentrations during low runoff. The dissolved-solids content of the McKenzie River at McKenzie Bridge ranged from 40 to 56 ppm. Maximum hardness of water for the year was only 18 ppm. Downstream near Coburg, the McKenzie River still shows no appreciable change either in chemical composition or in dissolved-solids content.

Willamette River water at Harrisburg is a mixture of the dilute flows from the Coast Fork and Middle Fork Willamette Rivers and the McKenzie River. This mixture has a low dissolved-solids content, and it is a calcium bicarbonate type water. A sample collected during a low-flow period had a dissolved-solids content of 54 ppm and a hardness of 19 ppm.

The Santiam River is the largest tributary of the Willamette River. Analyses of the North Fork Santiam River at Mehama and the main stem at Jefferson show that the water is a dilute calcium magnesium bicarbonate type similar to the water of the Coast Fork and Middle Fork Willamette Rivers. The maximum dissolved-solids content observed was 38 ppm, and the maximum hardness was 20 ppm.

The sampling station at Salem represents a long-term record of the chemical quality of the Willamette River. The collection of samples was begun in February 1951 and is still being continued (1961). Review of the analytical data for the Willamette River at Salem reveals no discernible change in either chemical composition or dissolved-solids content for the period of record. The minor variations that occur from year to year can be largely attributed to variation in discharge. A plot of dissolved-solids content versus discharge did not produce a definite analogy between them, and a plot of dissolved-solids content versus specific conductance also revealed no

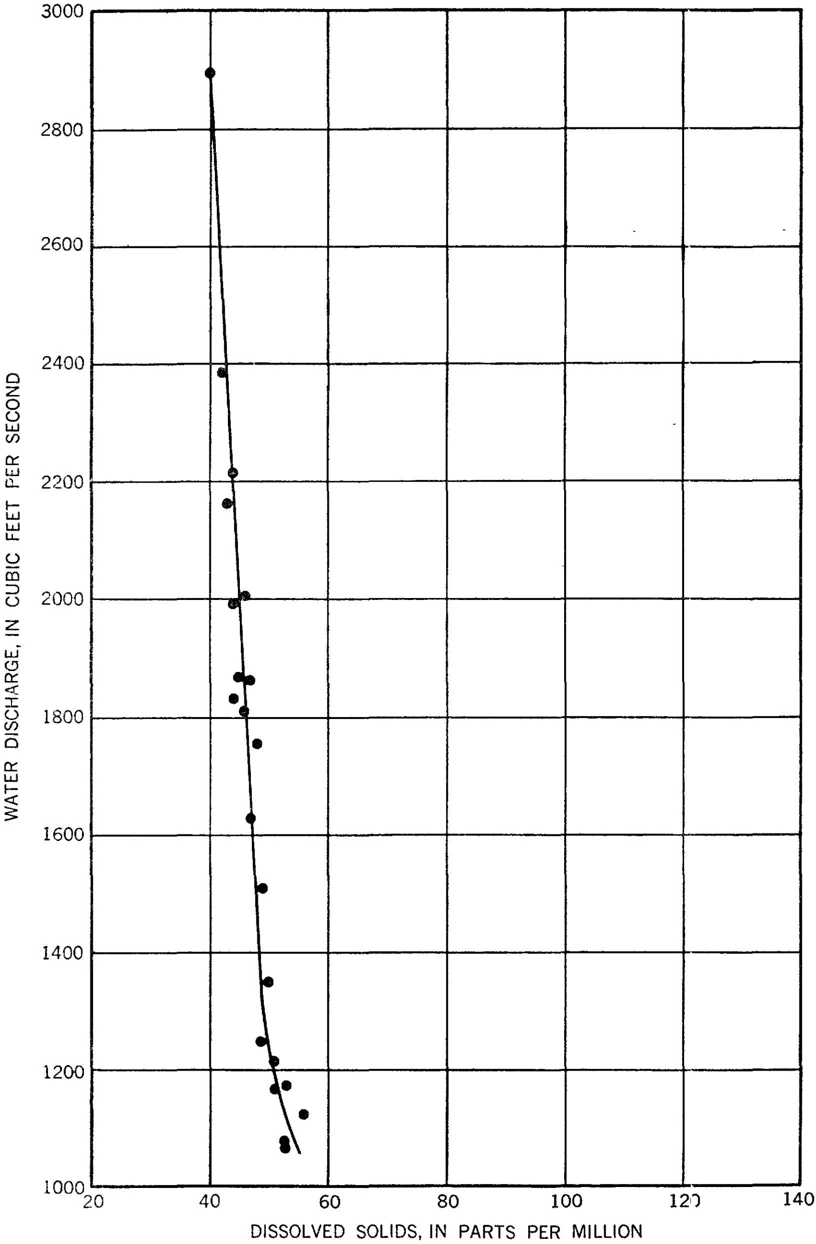

FIGURE 12.—Relation of salinity to water discharge, McKenzie River at McKenzie Bridge, Oreg., 1959.

discernible relationship. For the many users of water, a more satisfactory method of presenting the various data is in the form of cumulative frequency-distribution curves. Figure 13 is such a curve for dissolved solids. This curve is based on 245 determinations that were made on composite samples (p. 9). Ninety-five percent of the values for dissolved-solids content were between 42 and 64 ppm. Figure 14 is a cumulative frequency-distribution curve of temperature readings obtained once daily. Ninety percent of the 2,715 once-daily readings of temperature were below 70° F. The water of the Willamette River at Salem is very soft; the maximum hardness of water observed for the period of record was only 28 ppm. Figure 15 is a cumulative frequency-distribution curve of hardness. Ninety-nine percent of the hardness values were less than 27 ppm.

Although the Willamette River water at Salem is low in dissolved-solids content, the annual dissolved-solids load (salt load) transported by the river is large because of the high discharge. The annual rate of salt transport ranged from a low of 1,220,000 tons to a high of 1,650,000 tons. The 8-year average (1952–59) was 1,287,000 tons per year (fig. 16). The Yamhill and Tualatin Rivers head in the Oregon Coast Range. They are slightly higher in dissolved-solids content than other streams in the Willamette River basin, but they have nearly the same chemical composition. The maximum observed

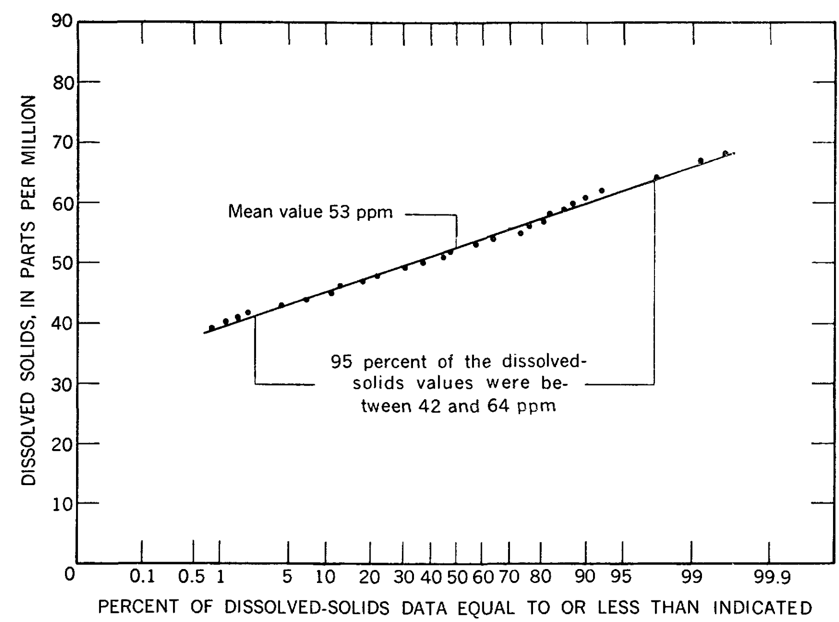

FIGURE 13.—Frequency distribution of dissolved solids, Willamette River at Salem, Oreg., 1952–59.

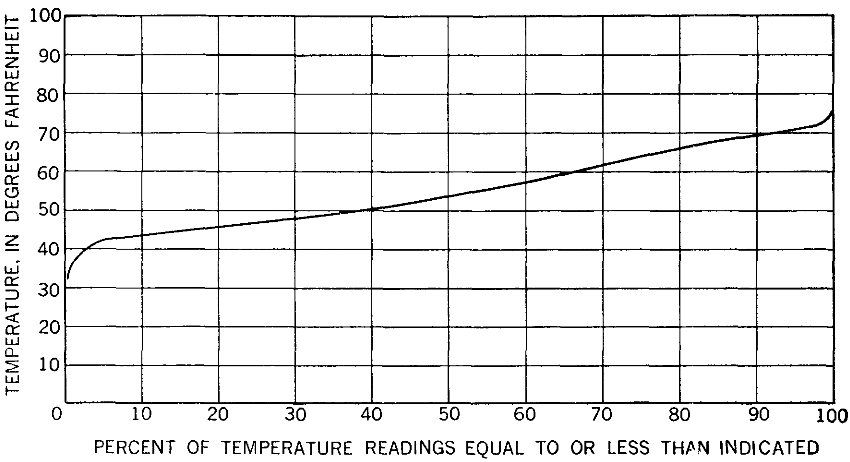

Figure 14.—Frequency distribution of temperature readings, Willamette River at Salem, Oreg., 1952–59.

dissolved-solids content for a sample from the South Yamhill River near Whiteson during low flow in August was 82 ppm.

Griffin and others (1956) reported on the chemical quality of streams in the Portland area, but their study did not include the chemical quality of the Willamette River at Portland. Where it enters Portland (Sellwood Bridge), the Willamette River is virtually homogeneous in cross-sectional chemical quality, but effluents from industries and sewer outfalls alter the cross-sectional chemical quality of the river as it flows through the city. Figure 17 is a plot of specific conductance of the Willamette River at two cross sections: at the Sellwood Bridge near the south edge of Portland and at the Spokane, Portland and Seattle Railway Bridge near the north edge of Portland.

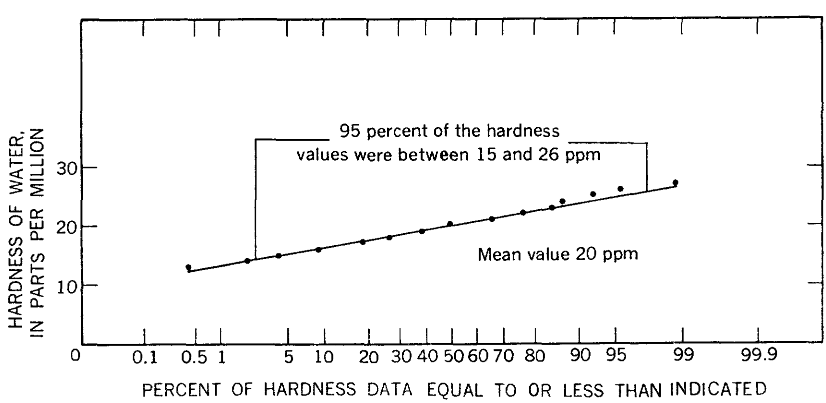

Figure 15.—Frequency distribution of hardness, Willamette River at Salem, Oreg., 1952–59.

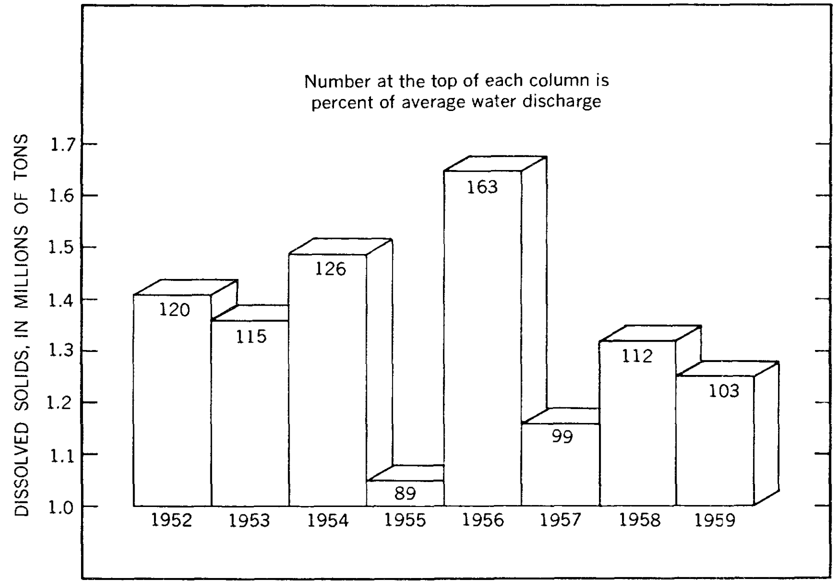

Figure 16.—Annual salt load of the Willamette River at Salem, Oreg., 1952–59.

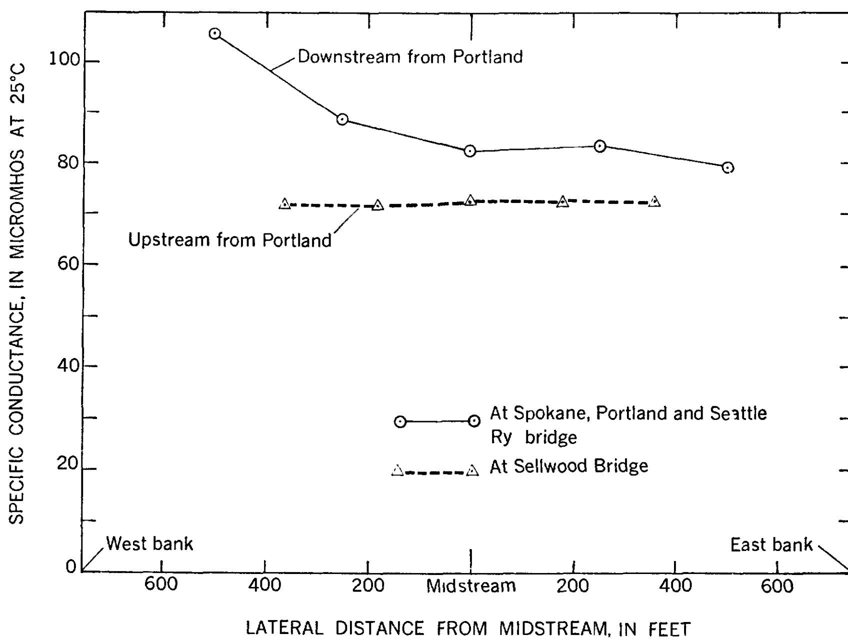

Figure 17.—Comparison of cross-sectional variations in specific conductance in the Willamette River upstream and downstream from Portland, Oreg., 1960.

The magnitude of this cross-sectional variation depends on the discharge. Figure 18 is a plot of specific conductance of three cross sections of the Willamette River at the Spokane, Portland and Seattle Railway Bridge for periods of different discharge. This same variation was detected in temperature and in chloride and alkalinity content. Samples of the cross sections were taken 1 foot below the surface of the river, and the extent of nonuniformity in depth was not determined. No specific data for daily discharge of the Willamette River are available for this reach, and the approximate stage is based on estimated average monthly flow at Portland correlated with the discharge of the Willamette River at the gaging station at Wilsonville.

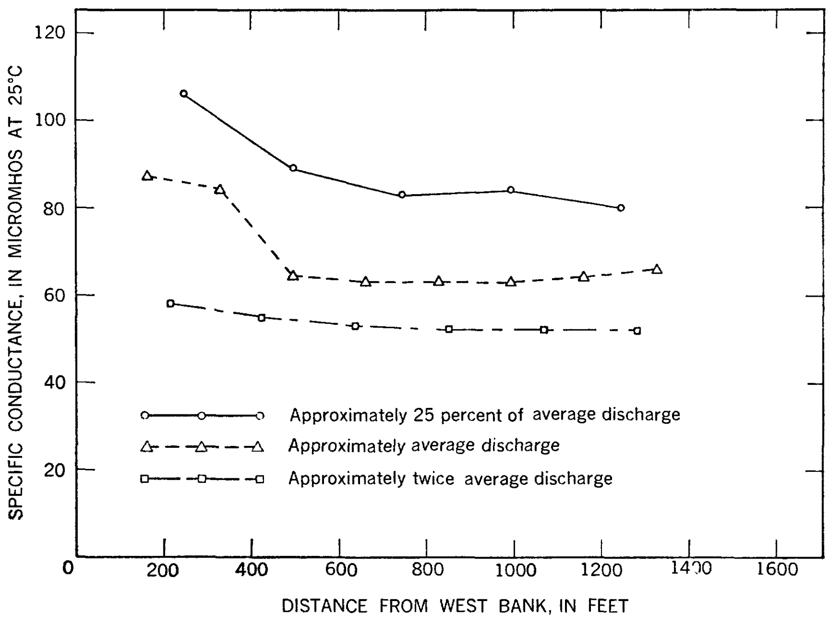

FIGURE 18.—Cross-sectional variation in specific conductance in the Willamette River at the Spokane, Portland and Seattle Railway Bridge, Portland, Oreg., 1960.

Analyses of samples collected at monthly intervals at the Spokane, Portland and Seattle Railway Bridge in Portland show that the water is the same type as that at Salem and is slightly higher in dissolved-solids content. The maximum observed dissolved-solids content at Salem was 57 ppm; at Portland for the same water year (1960), it was 65 ppm. The hardness of water in the Willamette River at Portland ranged from 18 to 30 ppm, and at Salem it ranged from 15 to 24 ppm.

Surface water in the Willamette River basin is fairly uniform in chemical composition. Figure 19 shows the composition of water in the basin.

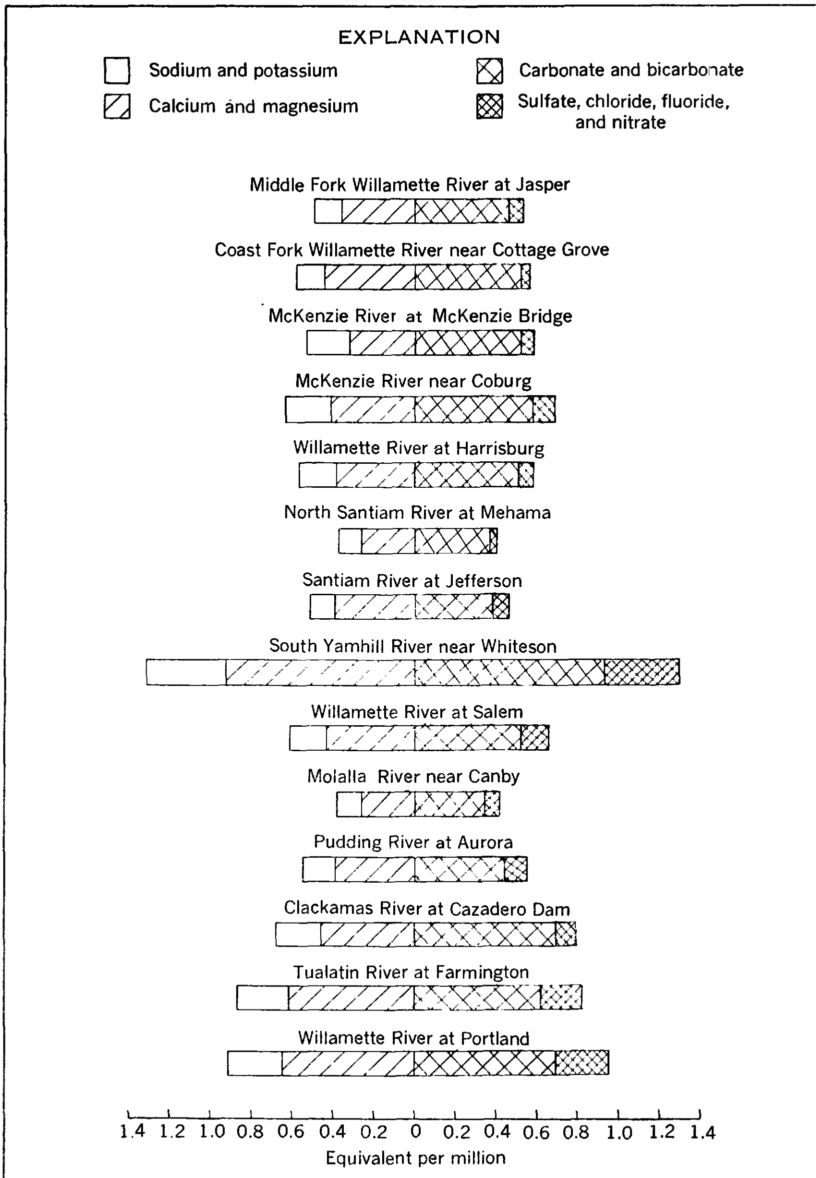

FIGURE 19.—Chemical composition of water in the Willamette River basin, Oregon, during period of low water discharge.

Water uses in the Willamette River basin include recreation, power generation, public supply, industry, irrigation, and waste disposal.

Many communities within the basin divert water from tributaries of the Willamette River for their municipal supplies. Because of the increase in per-capita use of water and the increase in population, many cities in the valley have had to augment their summer supply either by building storage facilities or—as the city of Corvallis had to do—by building a treatment plant to utilize the Willamette River water. Future increases in population and per-capita consumption will aggravate the problem of insufficient water during the summer months. All of the streams examined in the Willamette River basin have water suitable for municipal use, but the required water treatment would range from chlorination alone to complete treatment including flocculation, filtration, and disinfection before the water could be used as a public supply.

Industrial use of Willamette River water is largely confined to cooling and waste disposal. Principal industries in the basin are saw mills, plywood and hardboard plants, pulp-and paper-manufacturing companies, and food processing companies. Most of these industries either obtain their water for product manufacture from municipalities or use ground-water sources; however, four pulp mills in the basin use Willamette River water. The largest users of water in the basin are those industries connected with the timber resources in the basin. Although water of the Willamette River basin is suitable for most industrial purposes, for some uses it would require treatment for turbidity, iron, and color.

The Willamette River from Eugene to Oregon City is subject to flooding. The U.S. Army Corps of Engineers has constructed 12 flood-control dams in the basin and has proposed 3 more to further reduce peak discharges throughout the basin. Power generation and recreation are secondary benefits of these structures. In addition to the Federal structures, private and municipal dams either exist, are under construction, or are proposed. Ultimate upstream storage facilities in the basin will permit a greater degree of flood control and will further increase the base flow of the Willamette River by release of stored water during low-flow periods.

Surface water of the Willamette River basin is suitable for irrigation; according to the rating method of the U.S. Salinity Laboratory Staff (1954, p. 80), the water has low salinity and sodium hazards. The use of surface water for irrigation in the Willamette River basin is generally confined to the areas immediately adjacent to the streams. These areas are along the tributaries to the main stem and are not very extensive. The Willamette River basin has an estimated 650,000 acres of irrigable land; about 200,000 acres is under irrigation. The level land on either side of the Willamette River from Eugene northward has the biggest potential for irrigation. The Bureau of Reclamation studied 21 areas and named 14 as suitable to receive water stored for flood control. There are a few non-Federal and no Federal projects in the basin now; however, many individual farmers in the valley have developed wells for irrigation. Two areas, one east of Albany and the other north of Salem, have wells that produce about 800 to 1,000 gallons per minute. The area north of Salem is undergoing rapid ground-water development for irrigation, and, according to Price (1961, p. 1), "about 500 wells were used for irrigation in 1960 as compared to about 150 in 1950 and less than 50 in 1940." The return flows to the Willamette River basin may alter the chemical quality of the water downstream, for available chemical-quality data on the ground water in the area shows it to be more mineralized than the surface water. The Willamette Valley contains some 850,000 acres of land having poor or impeded drainage, and improper irrigation practices could produce a salt-balance problem.

The Willamette Valley contains some of the most productive farm land in the State of Oregon, and the Oregon State University estimates that irrigation could increase production of the farm crops by 65 percent in addition to increasing the market value of the crops. The economic pressure on the farmer has made him search for a means to increase the value of his crops and the yield per acre. Irrigation in the Willamette Valley probably will increase. Hydrologic data should be obtained now to delineate possible problem areas of water supply, drainage, water quality, and salt balance. These data would help to solve some of the water-supply management problems of the Willamette River basin.

Pollution has been a problem in the Willamette River for more than 30 years. Effluents from industries and cities provide nutrients for excessive slime and algae growths. Solid material from wastes coat the river bed and prevent certain biota from using it as a habitat. Floating solids destroy the aesthetic value of the stream. Surveys by the Oregon State Sanitary Authority (1959, p. 30), of the Willamette River from Springfield to Portland—a distance of about 179 river miles—show that bacterial pollution is excessive for recreational use for this entire reach of the river; coliform values ranged from 240 MPN to more than 70,000 MPN for the period July–September 1959. Figure 20 is a diagram of median MPN found at various river-mile distances. Dissolved-oxygen content is depleted by the effluents to values below what is considered necessary for aquatic biota. The total 5-day BOD of five pulp mills in the basin averaged 107,760 pounds per day during the low-flow period (1959). Minimum dissolved-oxygen values occur during the summer months, and a minimum of 1.5 ppm was observed for the Willamette River at Portland

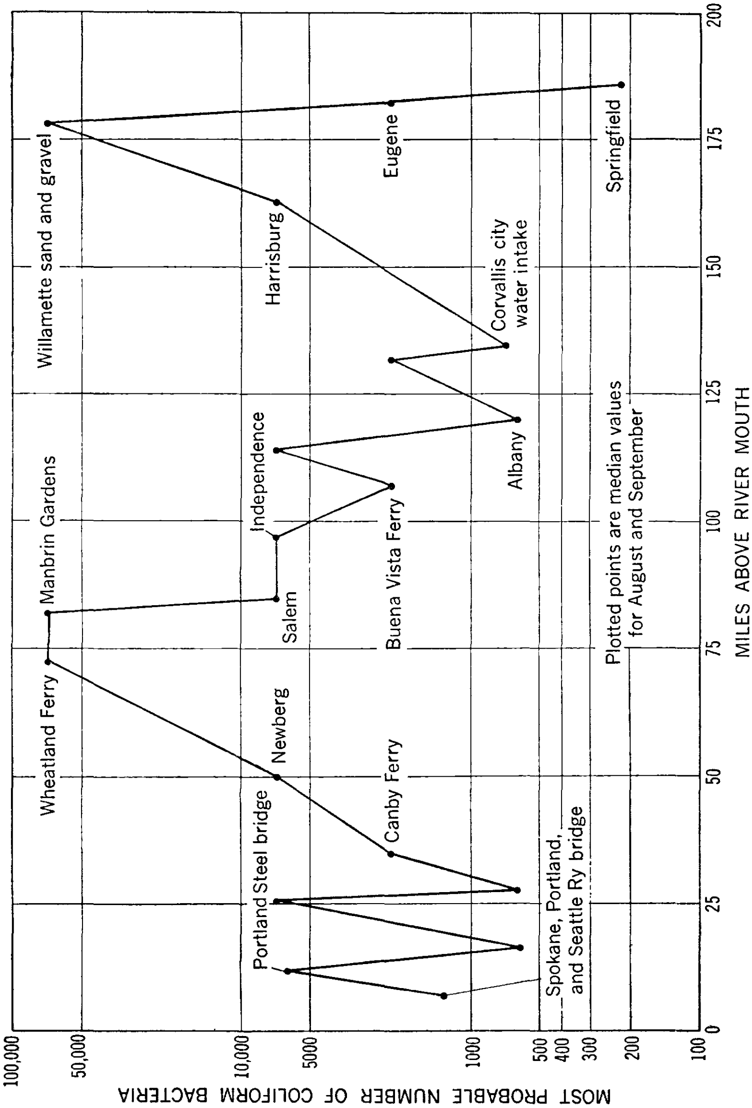

FIGURE 20.—Bacterial contamination in the main stem of the Willamette River, Oreg., July–September 1959.

in July 1959; in a few previous years the dissolved-oxygen values declined to 0.0 ppm. Since those years, stream conditions have improved; and in 1960, according to the Oregon State Sanitary Authority, a minimum dissolved-oxygen content of 3 ppm was maintained in the Willamette River at Portland. This improvement in stream conditions was largely due to reduced waste discharges to the Willamette River from pulp mills and to increased flows from releases in upstream reservoirs during low-flow periods. Additional improvement of stream pollution will depend largely on three factors: (1) reduction of municipal sewage loads by new treatment facilities and by repair or expansion of present ones, (2) utilization and treatment of industrial wastes before disposal, and (3) increased upstream storage to supplement low flow during the summer.

The Willamette River basin provides numerous areas for recreational activities. Impoundments created by dams have provided additional areas for recreational use. Federal and State agencies and private industries have built shoreline facilities on these impoundments for picnicking, boating, swimming, fishing, water skiing, and overnight camping. Many people use these facilities during the summer. Principal species fished for are trout and salmon, but warmwater fishes such as bass and panfish are also taken. The use of the waters for recreation presents a potential health hazard at times. The reservoirs and upper reaches of the tributaries can be regarded as generally safe, but the main stem and certain parts of the lower reaches of some tributaries contain coliform bacteria in concentrations above the level considered safe for swimming.

LEWIS RIVER

The Lewis River rises on the western slope of Mount Adams. It flows in a southwesterly direction and discharges into the Columbia River north of Ridgefield, Wash. The East Fork Lewis River, draining lower elevations, joins the main stem 3.6 miles upstream from the mouth. Precipitation in the basin ranges from less than 40 inches at the mouth to more than 100 inches in the mountainous headwaters. Runoff characteristics are typical of a stream in the western Cascades; peak discharge is reached in January during the winter rainy season and low flows are prevalent during the summer months.

At a monthly chemical-quality sampling station at Ariel, Wash., about 500 feet downstream from Merwin Dam, the 36-year (1923–59) average runoff for the Lewis River is 3,427,000 acre-feet. Chemical analyses show that the water is a calcium magnesium bicarbonate type similar to that of many streams that drain the region. The dissolved-solids content shows little variation, ranging from 29 to

38 ppm; maximum hardness of water tested was 12 ppm. Three dams exist above the sampling point and another is under construction. These reservoirs decrease the seasonal variation in chemical quality. Even during variations in discharge of 15–240 percent of average flow, the dissolved-solids content varied little (fig. 21). The semiannual samples for trace metals in Lewis River water at Ariel contained a maximum of 0.01 ppm of total chromium, 0.22 ppm of copper, 0.00 ppm of arsenic, and 0.00 ppm of hexavalent chromium.

Two analyses obtained in 1954 offer a basis for comparing the East Fork of the Lewis River at Heisson with the Lewis River at Ariel. They show that although both are calcium magnesium bicarbonate waters, the East Fork water contains more sulfate, more dissolved solids, and a larger percentage of silica than does the Lewis River at Ariel. These differences probably are due to the difference in rocks. The East Fork rises in volcanic rocks mainly of Miocene age, and the lower part of the basin is predominately continental sedimentary rocks. The main stem upstream from Ariel drains essentially Miocene and some Pleistocene to Recent volcanics.

Upstream from Ariel Dam, activities of man are mainly logging

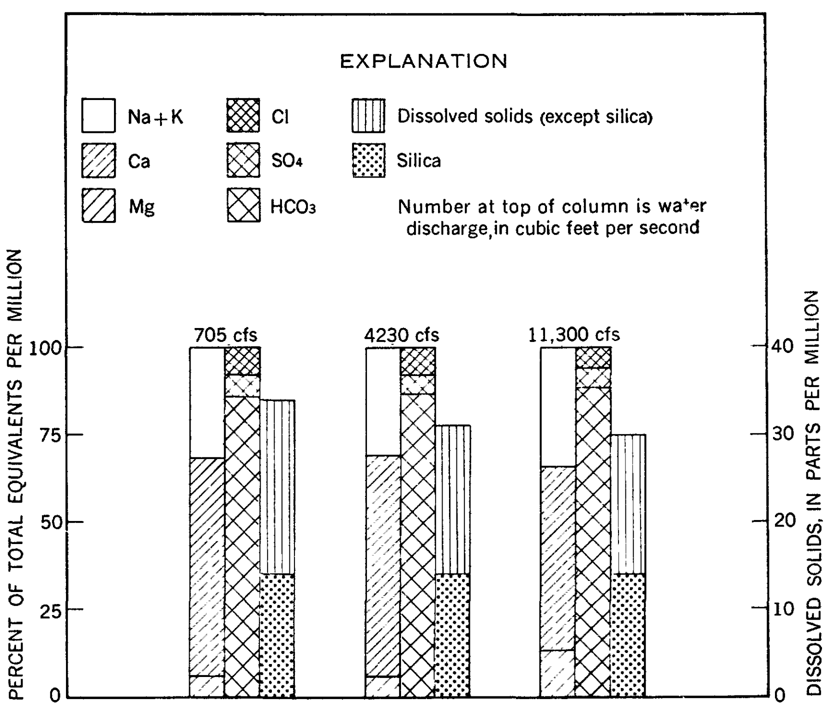

FIGURE 21.—Chemical composition of water during periods of different discharge, Lewis River at Ariel, Wash.

and recreation. Samples collected downstream from Ariel Dam showed a maximum coliform value of 36 MPN, which is well below the limit for safe swimming. Minimum dissolved-oxygen content observed was 8.3 ppm. Apparently, the bacterial pollution of the Lewis River above Ariel Dam is very low; however, recreation is a significant water use in the basin, and the growing recreational use of the Lewis River above this point could alter the bacteriological quality, especially during the low-flow period in the summer.

Surface water in the Lewis River basin is generally of excellent quality. The low dissolved-solids content, hardness of water, and bacterial content make this water highly suitable for public and industrial supplies and for irrigation. Iron contents were less than 0.1 ppm, and maximum color was 5 units. No quantitative determinations of turbidity were made; however, the upstream reservoirs remove most of the turbidity except during periods of high flow.

No known industrial or municipal use is made of the streams in the Lewis River basin at this time (1961). The water is also little used for irrigation. Some small areas along the lower reaches can be utilized for irrigation; however, irrigation probably never will be a major factor in the chemical quality of the Lewis River. The principal use of the water in this area is power generation. The basin contains many excellent hydroelectric power sites, four of which have been developed.

COWLITZ RIVER

The Cowlitz River and its main tributaries, the Toutle and Cispus Rivers, have their headwaters in the Cascade Range in an area bounded on the north by Mount Rainier, whose elevation is 14,408 feet; on the south by Mount St. Helens, whose elevation is 9,671 feet; and on the southeast by Mount Adams, whose elevation is 12,307 feet. The Cowlitz River upstream from the confluence with the Tilton River drains predominately volcanic rocks of Miocene to Recent age; the rocks include the so-called Mount Rainier lavas and the Columbia River Basalt; some Mesozoic marine rocks and Eocene continental strata are also present in this part of the basin. The lower reaches of the Cowlitz River drain the Eocene continental strata and continental sediments of Pleistocene age. Much of the upper part of the basin is heavily timbered, and logging is the principal industry.

The Cowlitz River at Castle Rock, Wash., has a 32-year (1927–59) average runoff of 6,542,000 acre-feet; it is second to the Willamette River in runoff in the lower Columbia River basin. In addition to ground-water inflow, Mounts Rainier, St. Helens, and Adams support glaciers that supplement streamflow during the dry summers. The peak discharge of the Cowlitz River usually occurs during the month of December, and a secondary peak occurs during April, May, or June when the snow melts (fig. 3).

Table 1 gives the results of the analyses for the reconnaissance and miscellaneous samples collected in the basin. In general, water in the basin has a dissolved-solids content of less than 100 ppm and a hardness of less than 50 ppm. The water is predominately calcium magnesium bicarbonate in type. Figure 22 shows the chemical-quality patterns for the low-flow samples in downstream order. The chemical composition of low-flow samples for the Cowlitz River at Packwood and for the Cispus River near Randle correlate very well. The Toutle River near Silver Lake, although it drains geologic terrane similar to that of the Cowlitz River, contains more sodium. This trend is further magnified downstream near Castle Rock where the Toutle River drains the continental sediments. The difference in

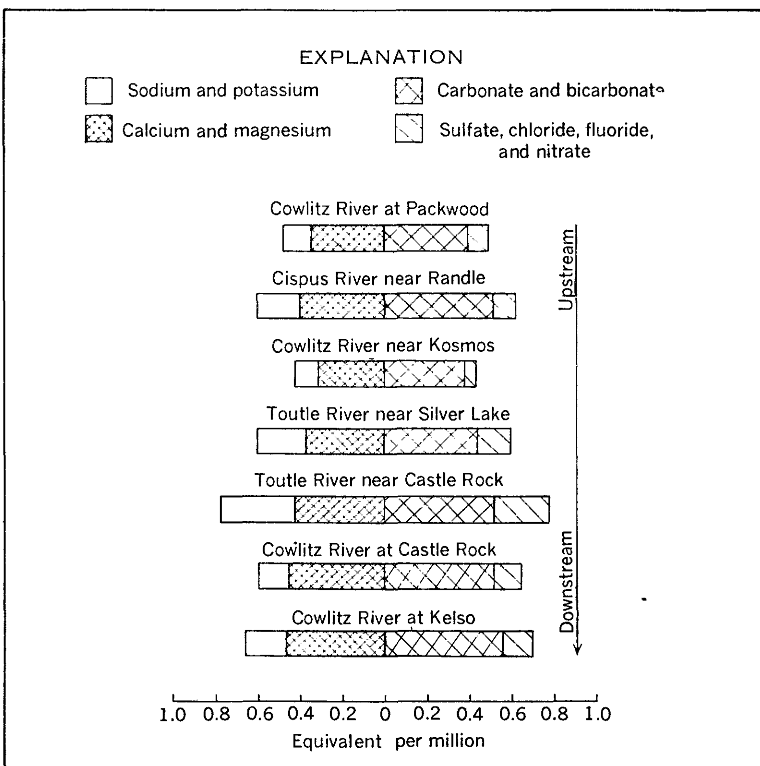

FIGURE 22.—Chemical composition of water in the Cowlitz River basin, Washington, during period of low water discharge.

chemical quality of the upper Toutle River as compared to the headwater reaches of the Cowlitz and Cispus Rivers may result from the continental sediments in the Toutle River basin significantly altering the composition of the water from what could be expected of a stream draining predominately volcanic rocks.

Although the composition of water in the basin may vary from subbasin to subbasin, the available data show that the basic geologic terrane is one of only slightly soluble rocks, and the water is very low in dissolved-solids content. Dissolved-solids content of monthly samples of the Cowlitz River at Castle Rock ranged from 33 to 56 ppm, only. Although the water in the basin is low in dissolved-solids content, the salt load carried by a stream is also a function of discharge, and the total load of salt removal in the basin can be appreciable. Figure 23 shows the salt load carried by the Cowlitz River at Castle Rock on the basis of monthly samples.

Water use in the Cowlitz River basin is confined mainly to municipal supplies and recreation. The streams support trout, and salmon use the streams for spawning. The basin has many excellent powersites, particularly on the Cispus and Ohanopecosh Rivers. At present (1961) the city of Tacoma is constructing a dam on the Cowlitz River at Mayfield for power generation and has proposed another on this stream at Mossyrock. Small diversions in the basin are made for domestic use and irrigation but, as yet, no large-scale irrigation works exist. The small amount of irrigation being done is sprinkler type, and more farmers in the lower part of the basin are starting to increase the yield from their lands by irrigating during the dry summer months. Large areas of the lower Cowlitz River basin could be irrigated by gravity, as is done from streams east of the Cascade Range. The waters in the basin, although not being used extensively for irrigation at present, are rated as to their suitability for irrigation on the assumption that irrigation will increase in the basin. According to the rating of the U.S. Salinity Laboratory Staff (1954, p. 80), the water has low salinity and sodium hazards.

Water in the basin is chiefly used for domestic purposes, and the cities of Kelso and Longview both obtain their supplies from the Cowlitz River. Most industrial use of the Cowlitz River would require some treatment of the water, for although its chemical quality is excellent, the river often contains appreciable amounts of turbidity in the form of glacial flour and suspended sediment. Most aluminum, lumber, pulp, and paper industries in this area use ground water; however, one pulp and paper company uses the Cowlitz River water. At this one plant, the water is used untreated. The company found that shutting down their writing-paper unit whenever turbidity of the river water reduces the paper quality below acceptable limits was

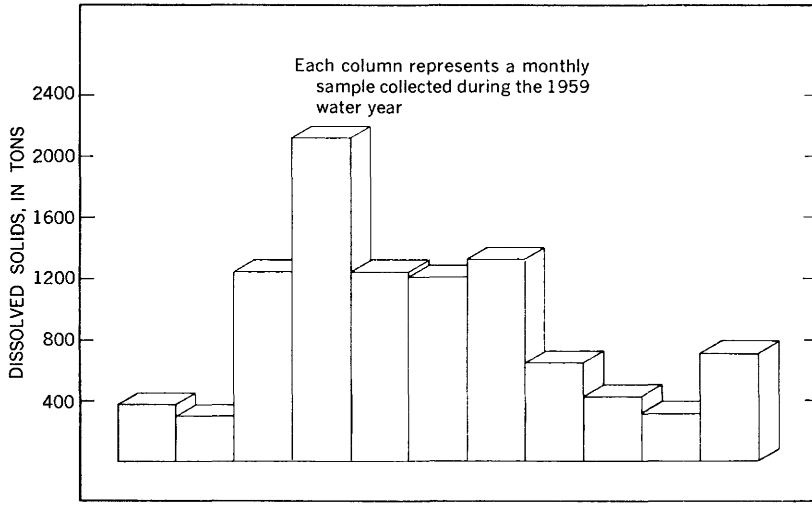

FIGURE 23.—Dissolved solids transported by the Cowlitz River at Castle Rock, Wash., 1959.

more economical than water treatment. The kraft and cardboard units operate the year round.

Pollution of the Cowlitz River is from industries and domestic sewage. At times the Cowlitz River near Kosmos contains bacterial contamination above the limits recommended for safe swimming. The coliform values for monthly samples ranged from less than 23 to 430 MPN. The higher MPN values occur in the summer when streamflow is low. Dissolved-oxygen determinations show that the river near Kosmos contains sufficient oxygen for aquatic life. The minimum dissolved-oxygen content for the 12 samples was 9.0 ppm. Inorganic pollution of the river is low. Samples taken semiannually from the Cowlitz River below Kosmo had arsenic, hexavalent chromium, and total-chromium concentrations of 0.00 ppm. The maximum value observed for copper was 0.15 ppm.

TRIBUTARIES TO THE COLUMBIA RIVER BELOW THE COWLITZ RIVER

Downstream from the Cowlitz River, the Columbia River tributaries are minor streams from the standpoint of flow and use. At the present time (1961), little use is made of them, but they may become valuable if this part of the basin undergoes industrial and municipal expansion.

These tributaries head in the north and south faces of the Coast Range where the Columbia River cuts through this range. The Coast Range is a broad uplift composed of Tertiary marine sedimentary rocks and intercalated basaltic lavas. The streams have drainage areas of less than 100 square miles, and their discharge is very closely related to precipitation. Low flow in the dry summer is from ground-water sources (see Youngs River near Astoria, fig. 3).

Six samples from three streams were taken during medium and low flow (see table 1). The chemical analyses show that the water is a dilute calcium magnesium bicarbonate type. There is no marked change in composition between the medium- and low-flow samples, and only minor variations occur from basin to basin. This part of the Columbia River basin often receives more than 90 inches of precipitation in a year, and most of it is rain; therefore, the soils in the basin are well leached, and little easily soluble materials is available for streams to transport. The highest dissolved-solids contents probably occur when the first rain falls after the exposed rocks have weathered during the dry summer. The maximum observed concentration of dissolved solids was 54 ppm in the August sample from the Elochoman River near Cathlamet. The maximum hardness for the same sample was 22 ppm.

Some small diversions are made in almost all these streams for domestic use, and a tributary of the Youngs River is used for a public supply for the Lewis and Clark Water District that serves Astoria, Oreg. Irrigation is not practicable for most of the region because of the steep topography. Principal future use of these surface-water supplies would probably be industrial. The few analyses available for study indicate that the water is suitable for the pulp and paper industry; however, further study is needed to confirm this evaluation, for no data have been collected on iron, manganese, free carbon dioxide contents and turbidity. Field observations made by the author indicate that turbidity in excess of the limits specified by most industries exists in many of these streams, and some treatment would be necessary before use either for industrial or public supply. Recreational use is mainly fishing for trout, salmon, and steelhead.

COLUMBIA RIVER MAIN STEM

The Columbia River at its confluence with the Snake River is about 300 feet above sea level; from there to Cascade Locks, Oreg., it has eroded almost to its base level. West of Cascade Locks the Columbia River is drowned as a result of subsidence during Recent time. The Columbia River from the mouth of the Snake River to the Cascade Range has eroded its channel in Columbia River Basalt of Miocene and Pliocene(?) age, and in many areas it has deposited sedimentary material. A large amount of these sediments were deposited during the Spokane Flood, which occurred in late Pleistocene time. In the vicinity of The Dalles, the river traverses the Dalles Syncline, Ortley Anticline, Moiser Syncline, and Bingen Anticline, thereby exposing part of a series of basalt flows whose thickness totals at least 2,000 feet. On the north side of the river, the Columbia River Basalt rests upon older Miocene mud flows and tuffs of the Eagle Creek Formation, as it does on the south side from Lindsay Creek to Rooster Rock. The geology of the Columbia River west of the Cascade Range is described in the sections on the Sandy and Willamette River basins and the tributaries west of the Cowlitz River.

CHEMICAL QUALITY

The chemical analyses of monthly samples from the Columbia River at McNary Dam show that the water is a calcium magnesium bicarbonate type and generally is softer and lower in dissolved-solids content than water from the Walla Walla River, which enters McNary Lake near Wallula. The dissolved-solids content ranged from 84 to 128 ppm, and the maximum hardness was 90 ppm. Comparison of the analytical data at McNary Dam with the data of Robeck and others (1954, p. 33) for the Columbia River above the Walla Walla River shows no apparent alteration of chemical quality by the Walla Walla River. The present data show little change in chemical quality as compared with the data collected by Sylvester (1958, p. 121) in 1954–56. The Columbia River at McNary Dam has an average (1950–59) runoff of 139,500,000 acre-feet per year, so a major change in quality-of-water patterns in the upper basin would be necessary to alter the chemical quality of the Columbia River at this point. The hexavalent chromium concentration of samples collected semi-annually was 0.00 ppm. Maximum concentrations for arsenic, copper, and total chromium were 0.01 ppm, 0.02 ppm, and 0.02 ppm, respectively.

For water downstream near The Dalles, a long-term record of chemical quality is available. The records from December 1950 to September 1958 were collected at a station about 22 miles upstream from The Dalles Dam. The samples for the 1959 water year were collected at The Dalles Dam. The data for both stations probably are comparable, and study of the record reveals no short-term trend of chemical-quality change that cannot be attributed to variation in discharge.

In 1910, Van Winkle (1914 a, b) studied the chemical quality of the Columbia River at Cascade Locks, which is about 60 miles downstream from The Dalles. From August 11, 1911, to August 14, 1912, the Columbia River transported 17 million tons of dissolved solids; and from August 11, 1957, to August 13, 1958, the Columbia River at The Dalles transported 18,190,000 tons of disolved solids. The data at Cascade Locks represent a discharge that is 5–6 percent greater than the average at the Dalles. The discharge at The Dalles for the 1957–58 period was 2 percent greater than the discharge for the 1911–12 period; however, the salt load increased 7 percent above the 1911–12 salt load. A study of the data collected at The Dalles for the 8 water years, 1952 through 1959, showed that the discharge–salt-load relationship can vary, but not as it does in the above instance. The following tabluation gives the manner of variation.

Water Year	*Percent difference in discharge*	*Percent difference in salt load*
1952	−6	+2
1953	−9	+4
1954	+6	+6
1955	−10	−10
1956	+23	+23
1957	−2	+2
1958	−9	−9
1959	+7	−1

The percentage difference in discharge was based on the average for the 1952–59 period, and the percentage difference in salt load was calculated in the same way. Although part of the increase in salt load may be due to natural variation or experimental error, much of the increase probably is due to increased water use by man. The maximum and minimum dissolved-solids contents for the station near The Dalles were 163 and 72 ppm, respectively; whereas during Van Winkle's study they were 129 and 62 ppm. The minimum dissolved-solids content has never been observed to be as low as it was during the Van Winkle study, even during the 1956 water year when discharge was 25 percent above the 81-year average. The dissolved-solids load for the Columbia River near The Dalles has ranged from 18,140,000 tons per year to 24,740,000 tons per year for the 8-year period 1952–59 (fig. 24). Figure 25 is a cumulative frequency-distribution curve of dissolved solids of the Columbia River near The Dalles. Temperature of the water has ranged from 32° to 79° F. Figure 26, a cumulative frequency-distribution curve of temperature, shows that 95 percent of the temperature readings were equal to or less than 70° F. Compare this curve with the frequency-distribution curve of temperature for the Willamette River at Salem (fig. 14). The curves are very similar to each other. The major difference is that the Columbia River is slightly colder during the winter months. Figure 27, a cumulative frequency-distribution curve of hardness, shows that 97 percent of the hardness data were less than 100 ppm.

In August 1959 the Washington Pollution Control Commission and the Oregon State Sanitary Authority, cooperating with four pulp and paper manufacturing companies, began a study of the quality of water from Bonneville Dam to Puget Island, some 102 river

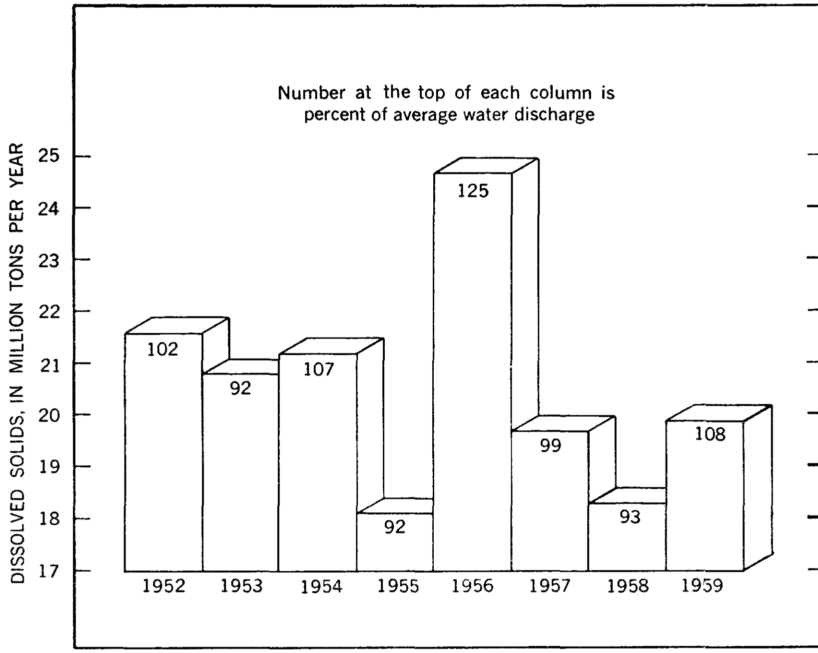

Figure 24.—Annual salt load of the Columbia River near The Dalles, Oreg., 1952–59.

miles downstream. Forty-five sampling points at 11 stations were used to study cross-sectional and downstream variations in quality of water (fig. 28).

The greatest variations, both in cross section and station to station, occur during the winter months when flow of the main river is low and

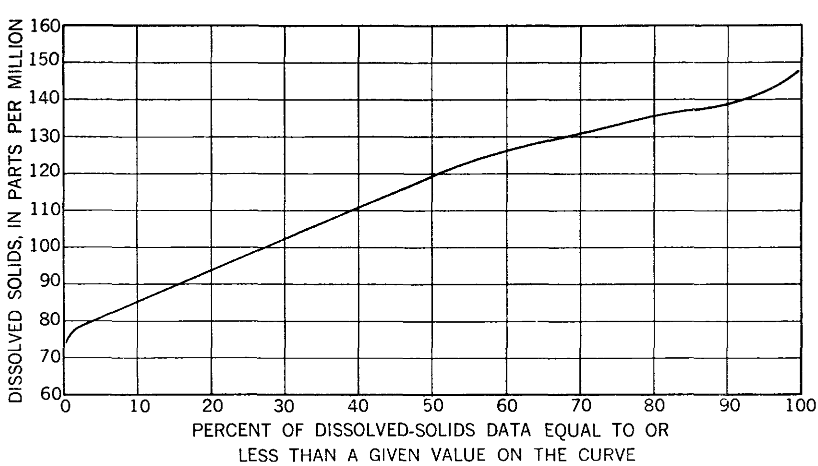

Figure 25.—Frequency distribution of dissolved solids, Columbia River near The Dalles, Oreg., 1952–59.

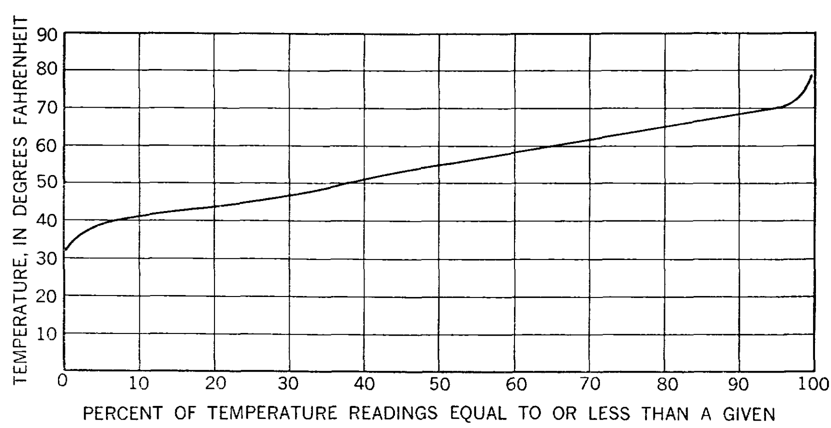

Figure 26.—Frequency distribution of temperature readings, Columbia River near The Dalles, Oreg., 1952–59.

inflow from local tributaries is high. The February 1960 samples ranged in hardness from 13 to 72 ppm. The minimum hardness was observed at Coffin Rock station for the sample collected 900 feet from the Washington shore; it shows the effect of the Kalama River in lowering the dissolved-solids content. The maximum hardness occurred at the Washougal and Hewlitt Point stations.

From Bonneville Dam to the Portland-Vancouver Interstate Bridge, there was no large variation in cross-sectional chemical quality. From Mathews Point to Caplis, the trend is for dilute water to be found

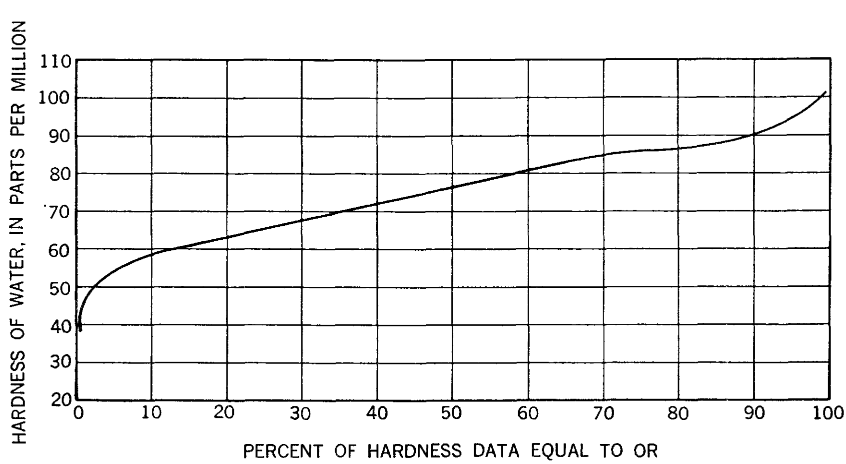

Figure 27.—Frequency distribution of hardness, Columbia River near The Dalles, Oreg., 1952–59.

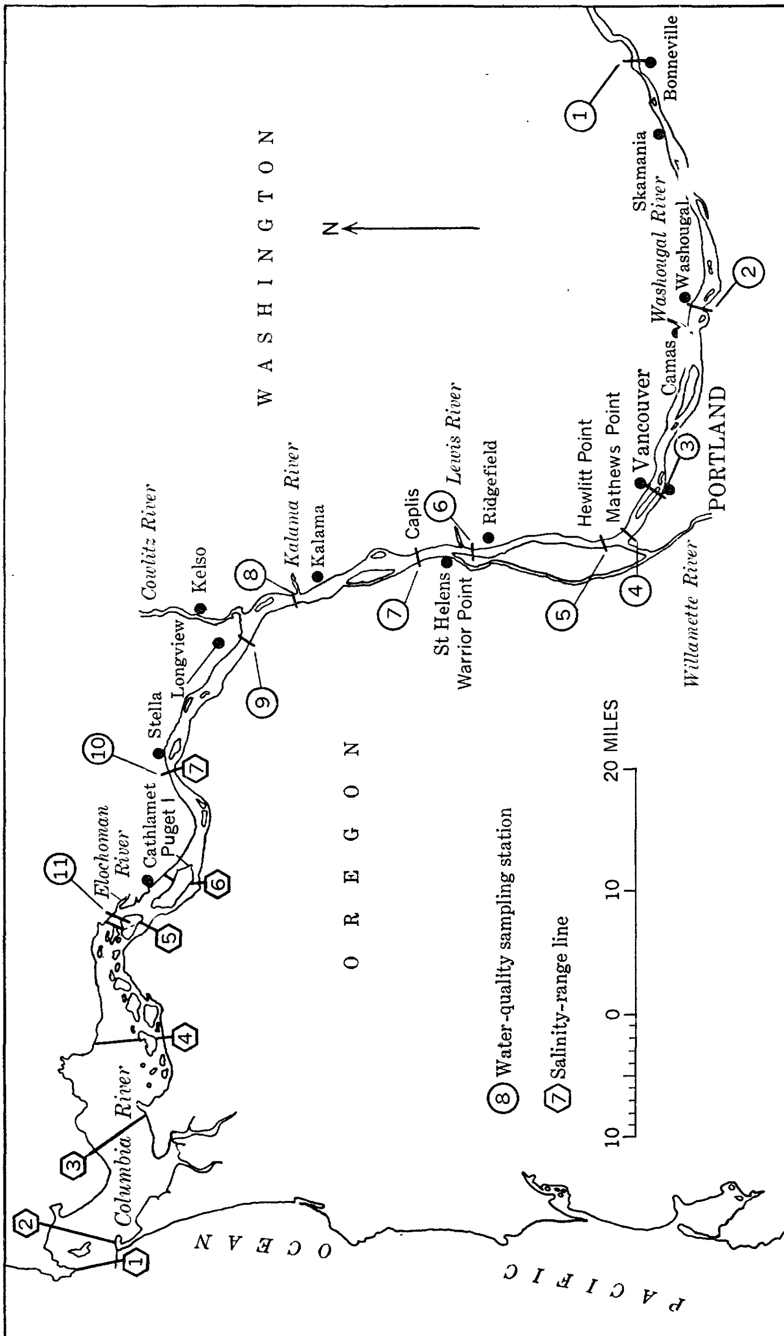

FIGURE 28.—Location of quality-of-water sampling points on the lower Columbia River.

on the Oregon side of the Columbia River. This trend reverses at Coffin Rock, the more dilute water occurring on the Washington side, and this is observable in a lesser degree, at Longview Bridge. The two other stations farther downstream do not show an appreciable cross-sectional variation in chemical quality. In the spring, the high flow from streams above Bonneville Dam have a leveling-out effect on the Columbia River downstream from the dam. This reduces the cross-sectional variation in chemical quality; nevertheless, it is still noticeable at some stations. The most uniform cross sections were observed during August when the discharge is low.

SALINITY OF THE TIDAL PORTION OF THE COLUMBIA RIVER

In 1959, the U.S. Army Corps of Engineers (1960) made a study of salinity, temperature, and velocity of the 52-mile reach of the Columbia River from Beaver Army Terminal to the mouth (fig. 28). The data were collected at seven ranges during 9-day periods of high, medium, and low flow of the Columbia River. Measurements were made at the surface, at one-quarter, one-half, and three-quarters depths, and at the bottom. As used in this section, a water with a dissolved-solids content of 1,000 ppm or more is called a saline water and is referred to as salinity. Salinity was not found at range 4, which is about 24 miles from the mouth. At range 3, approximately 16 miles from the mouth, no salinity was recorded at three of the five stations during the high-flow period; for the station nearest the Washington State shore, however, salinity of more than 6,000 ppm was measured at the one-quarter depth and increased to more than 21,000 ppm at the bottom. For the low-flow period, salinity is present in at least four of the five stations of range 3; no data were given for the fifth station. The degree of salinity varies with the tide; at range 3, station A, in the main channel, it varied from less than 1,000 ppm to more than 7,000 ppm at the surface, and at the bottom it was in excess of 24,000 ppm. At the other two ranges downstream from range 3, salinity increases, and at times the surface salinity approaches that of pure sea water.

The estimated discharge of the Columbia River at the mouth was 5 percent above average during the study period, and it can be assumed that salt-water intrusion may extend up the river beyond range 3 during years of below-average dicharge. At range 7, 52 miles upstream from the mouth, the river is about half a mile wide and flow predominance is downstream during 99 percent of the tidal cycle; therefore, the possibility of salt-water intrusion up to this point is very small.

POLLUTION

Principal types of pollution in the main stem of the Columbia River are wastes from industries and municipalities and low-level radioactive wastes from the Atomic Energy Commission installation at Hanford, Wash. Other pollutants enter the river from pleasure and commercial boats and from irrigation return flows from sub-basins.

The Oregon State Sanitary Authority and the Washington Pollution Control Commission have carried on active programs to control pollution. During 1958 the largest city in the lower Columbia River basin, Portland, Oreg., contributed 97 percent of the bacterial pollution in the lower Columbia River. The electorate of Portland voted in 1961 for an increase in sewer-users service charge; this charge increase should enable the city to construct adequate treatment facilities. The smaller communities along the Columbia River have improved their existing facilities or have new ones under construction. When all treatment facilities are in operation, the bacterial load of the Columbia River should be materially reduced. Some problems of storm-water separation and of interceptor systems in need of replacement still remain; however, the State agencies are making progress in having the municipalities reduce their bacterial load to the river. Coliform counts for the reach from Portland to Puget Island ranged from 0 to 240,000 MPN during August 1959 to August 1960. Most of the coliform values greater than 200 occurred during periods of low flow. During this same period, the minimum dissolved-oxygen content was 7.8 ppm, which indicates the pollution load was not sufficient to deplete the dissolved-oxygen content below that considered necessary for survival of aquatic life.

The release of wastes from pulp and paper mills has long been a problem in the lower reaches of the Columbia River. The principal waste from this source is sulfite waste liquors. These liquors contain lignin, pectin, hemicelluloses, sulfur dioxide, sulfites, polythionates, organic acids, calcium or magnesium, and numerous other organic and inorganic substances. The principal objections to sulfite waste liquors are that the sugars cause high BOD and allegedly provide nutrients that allow sphaerotilus slime growths to flourish. The sulfite waste liquor values ranged from 1 to 320 ppm, and the majority of the values were below 100 ppm. For the sample containing 320 ppm of sulfite waste liquor, the BOD was 1.1 ppm. The highest BOD observed was 3.0 ppm, and most of the values were below 2.0 ppm. The pulp and paper industries on the banks of the Columbia River are trying to solve the problems of the sulfite waste liquor discharge and the slime growth.

RADIOACTIVITY

In 1944, the Hanford Engineering Works began operations. This facility, now under the direction of the Atomic Energy Commission as the Hanford (Wash.) Atomic Plant operations, is adjacent to the Columbia River 38 miles upstream from its confluence with the Snake River. The plant uses Columbia River water for cooling. The water returned to the river contains a very small amount of radionuclides. These radionuclides are short-half-lived beta-particle emitters and have been identified as copper-64, manganese-56, sodium-24, arsenic-76, silicon-31, and phosphorus-32 by Robeck and others (1954, p. 3). Alpha activity is negligible. The study by Robeck and others (1954) showed that phosphorus-32 is the principal element accumulated by plankton, which absorb the nutrients directly from the water. The food chain from plankton to adult resident fish shows a progressive decline in radionuclide accumulation. Ninety percent or more of the radioactivity in adult fish is due to phosphorus-32 whereas only 2 percent of the gross radioactivity in the water is due to this radionuclide. The bones of suckers contained an average gross beta activity of 5,000 pc (pico curies) per gram; on the other end of the food chain, plankton contained an average gross beta activity of 80,000 pc per gram. The average gross beta activity of the Columbia River where these organisms were taken was 19 pc per milliliter. Average background activities for the water were 1×10^{-2} pc per milliliter, and for aquatic organisms they were 1 pc per gram. Migratory species of fishes do not accumulate large amounts of radionuclides. A maximum gross beta activity of 18.6 pc per gram was found in the liver of a steelhead. Many of the fishes in the Columbia River are used for food, and health authorities are concerned about the potential health hazard. However, the greatest concentrations of radioactivity in the fish are in the scale, bone, and viscera, which are not edible; and phosphorus-32, the principal radionuclide ingested by fishes in the Columbia River, has a half life of only 14.3 days. According to Robeck and others (1954), there is no appreciable buildup or carryover of the radionuclides from year to year.

The radioactivity level in the Columbia River shows a progressive decline in the downstream direction. At Paterson it is about one-tenth of that just below Hanford. This decrease is due to natural radioactive decay, to activity being sorbed on sediments, and to incorporation of activity into the physiology of aquatic biota. A comparison of the levels of radioactivity during the 1951–53 study to data obtained during 1957–59 shows a decrease in extremes. The maximum gross beta activity observed in the early study at Pasco was

480×10^{-2} pc per milliliter whereas the more recent data show a maximum of $2{,}863 \times 10^{-3}$ pc per milliliter. Minimum gross beta activities for the 1951–53 study and the 1957–59 study were 46×10^{-2} pc per milliliter and 59×10^{-3} pc per milliliter, respectively.

The maximum total beta activity found downstream at Bonneville, Oreg., for the 1957–59 period was 614×10^{-3} pc per milliliter. Farther downstream at Clatskanie, Oreg., the maximum total beta activity for the same period was 463×10^{-3} pc per milliliter. Total beta activity as reported by the U.S. Public Health Service for the 1957–59 data is the sum of the activity in suspension and activity in solution. Figure 29 shows the seasonal variation of total beta activity at Bonneville and Clatskanie. Inspection of the graph reveals several anomalies. The January 5 and May 11 samples at Clatskanie show a greater activity than the upstream samples at Bonneville. In the January 5 sample the increase in total activity was due principally to increases in the dissolved activity whereas in the May 11 sample the increase was due to almost equal increases in both dissolved and suspended activities. This anomaly also is shown, to a minor extent, by samples taken on December 1, 1958, and May 4 and 26, June 1 and 8, July 6, and August 9, 1959. The principal reason for these anomalies is that the samples for total beta activity are taken near the surface of the Columbia River; consequently, only the finer particles of fluvial sediment include the beta activity attributed to suspended solids. The larger particles, which also have sorbed radionuclides, are near the bottom of the river and are not measured in the present sampling method except when river currents bring them near the surface. Sediments contributed by the tributaries between Bonneville and Clatskanie may have sorption characteristics that affect the ratio of suspended to dissolved activity. A comparison of the discharge of the Columbia River at The Dalles with graphs of the total beta activity (fig. 29) indicates that the anomaly usually can be correlated with discharge. The month of May is a particularly good example. The lack of knowledge concerning the interrelationships between fluvial sediments, discharge, bed movement, radioactivity, and ion exchange in the Columbia River points out the need for additional work that should be done in the near future. Such further studies may well uncover basic hydrologic concepts applicable to many other areas. In addition, more reliable methods of determining low-level radioactivity are needed, as some of the above anomalies may well be attributable to discrepancies in analytical techniques.

There is some background radiation in the lower Columbia River tributaries. The nine miscellaneous measurements made by the U.S.

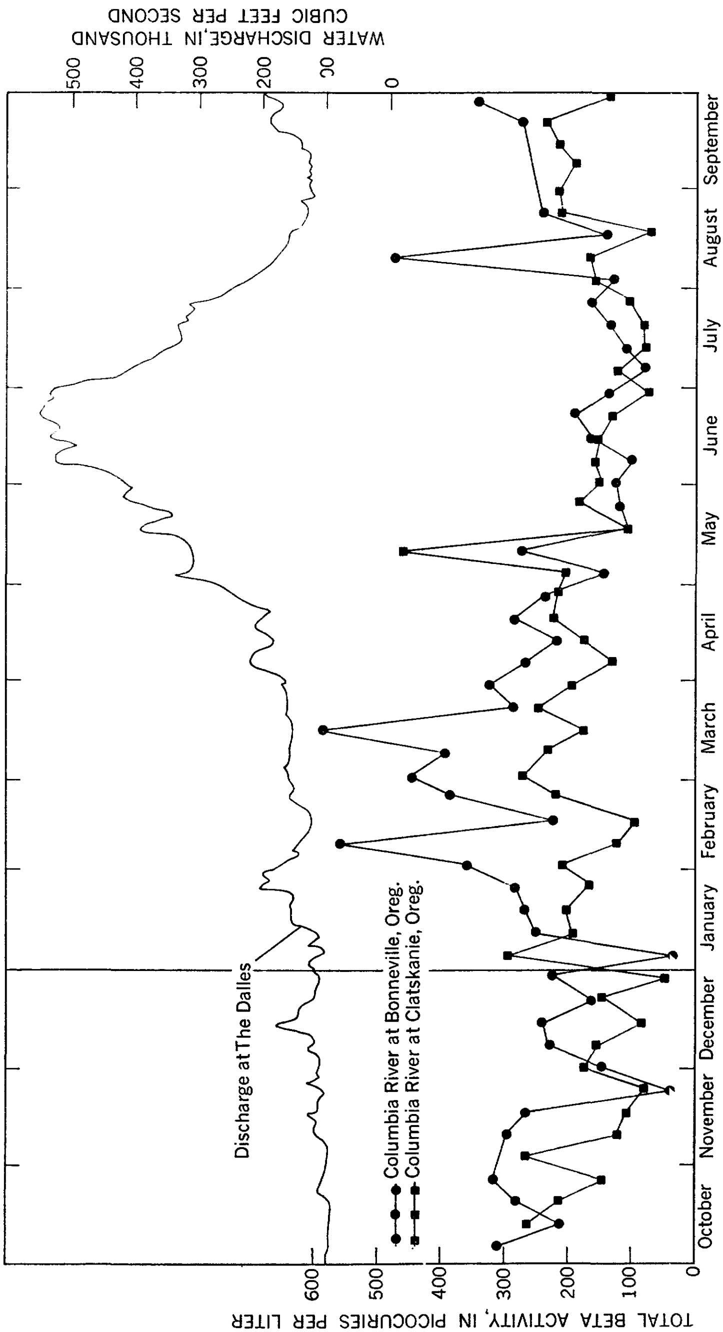

FIGURE 29.—Variation of radioactivity in the Columbia River. Source of radioactivity data: U.S. Public Health Service, October 1958–September 1959.

Geological Survey for tributaries showed values that were less than 23×10^{-5} pc per milliliter of beta gamma activity.

A study made at Pasco in 1951 by the General Electric Co. (Robeck and others 1954, p. 83), prime contractor at the Hanford facilities of the Atomic Energy Commission, showed that the conventional water-plant treatment of the Columbia River water removes 50–95 percent of the radionuclides. The largest amount is removed in the coagulation process and is concentrated on the sand filter. Backwash water from the filter had a gross beta activity of 1,300 pc per gram. Influent water had a gross beta activity of $700–800 \times 10^{-2}$ pc per milliliter whereas the effluent activity was reduced to 50×10^{-2} pc per milliliter. The U.S. Public Health Service Drinking Water Standards (1962, p. 9) limits gross beta activity in drinking water to 1,000 pc per liter in the absence of strontium-90 and alpha emitters.

The increasing use of radionuclides by government, industry, and educational institutions will probably increase the level of radioactivity in the streams of the lower Columbia River basin. Present efforts are directed to the determination of the radioactive quality of water for streams that have radioactive facilities near them. However, very little has been done in gathering radiological data for the many streams that may have such facilities in the future. The radioactive levels in these streams should be determined now. These radioactive data should be implemented with data of other water-quality parameters and could serve as a guide for locating plant sites and for determining the permissible amount of waste disposal, the size, and the design of a facility using radioactive materials.

WATER USE

Water use of the Columbia River main stem is diverse, and often one use conflicts with another. The river is used for transportation, cooling, recreation, power generation, irrigation, and waste disposal. Increases in population, irrigated acreage, and industry will have a great impact on water quality because of the increased reuse of water.

Sylvester (1960, p. 47) devised a water-usage factor to compare the past with the present and to predict future chemical quality of water in the Columbia River basin. Predictions were made on the broad assumption that a constituent change between the present (1960) and the year 2000 would be proportional to the change in usage factors and constituent values between 1912 and the present. This factor, which takes into consideration population (including industrial waste

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equivalent), irrigated acreage, discharge, and drainage area, is expressed as follows:

$$\frac{\text{Population+irrigated acreage}}{\text{Discharge in cubic feet per second+drainage area in square miles}}$$

In applying this factor to the quality of the Columbia River near The Dalles, Sylvester used the average discharge and estimated the numerator factors. His predictions on quality for the year of 2000 were compared with the weighted averages for the 1957 water year when discharge was within 6 percent of average. Sylvester (1960, p. 49) predicted that the weighted average dissolved-solids content of the Columbia River near The Dalles would increase to 153 ppm, which is about a 50-percent increase compared to the 1957 water year. In the 1957 water year, the Columbia River near The Dalles transported 19,670,000 tons of dissolved salts. Calculations using the discharge figure for the 1957 water year and Sylvester's figure for dissolved solids indicate that the total salt removal will have increased to 29,000,000 tons by the year 2000.

Irrigation in the main stem of the lower Columbia River is confined to the adjacent low-lying areas, and the quantity of water taken out of the river for this purpose is unknown; it can be assumed, however, to be small because the acreage suitable for irrigation is small. The net consumption of water by irrigation in the subbasins above The Dalles was estimated by Simons (1953, p. 121) as 5.3 percent of the yield for 1946. Since 1946 irrigation above The Dalles has been increasing, particularly in the Columbia Basin Project area in Washington. This and future increases will increase the amount of water consumed by irrigation and, in turn, will result in further chemical-quality deterioration at The Dalles.

The Columbia River main-stem water is generally suitable for irrigation. Using the maximum values for the 1950–59 record made at The Dalles, the water is rated, according to the standards of the U.S. Salinity Laboratory Staff (1954, p. 80), as having a low to medium salinity hazard and a low sodium hazard.

The estimated industrial use of surface water in the lower Columbia River basin is in excess of 826,000 acre-feet per year. Not included in the above estimate is the unknown amount of water used for cooling purposes by industries in the basin. The largest single use made of the Columbia River by industry is waste disposal. In certain reaches of the river, this practice has caused problems that are discussed in the section on pollution.

From Portland upstream, the water of the Columbia River is suitable for most industrial uses. The dissolved-solids content of the water generally is less than 175 ppm, and hardness of water ranges from soft to moderately hard (fig. 27). The water may require some treatment for removal of turbidity and iron. Downstream from Portland, the quality of the water in the Columbia River is variable and complex. The effluents from cities and industries on both sides of the river alter the quality of the water cross-sectionally for considerable distances downstream from their point of discharge. The chemical quality is not seriously altered; however, if bacterial quality or organic wastes are particular criteria in a proposed usage, an "on site" study of water quality may be necessary to establish suitability.

The Columbia River is used by many people for boating, fishing, water skiing, and swimming. Upstream from Portland the river is generally suitable for all recreational uses although at times the coliform count has exceeded the limits recommended as being safe for swimming. Downstream from Portland the coliform count at all seven stations (fig. 28) exceeded the limits for safe swimming and water skiing at some time during August 1959–August 1960. At some places below Portland, the coliform count is 100 times the level considered safe for swimming. Even during periods of high discharge, the Columbia's flow is not large enough to dilute coliform counts to safe levels at some of these stations. The high coliform counts also are a possible health hazard to fishermen when handling fish caught in these areas. At certain times of the year, the combination of nutrients from organic wastes, temperature, and steamflow are beneficial to the growth of slime, which fouls the lines of sport fishermen and the nets of commercial fishermen. The slime that grows in large quantities below Camas, Vancouver, and Longview, Wash., has been identified as sphaerotilus. It grows attached to objects in the stream, breaks off, and drifts down the river.

The water in the Columbia River above Portland is, in general, suitable for public supply, but some treatment would be necessary. Principal treatment required would be disinfection and removal of turbidity and suspended sediment. The water is moderately hard to soft and the maximum hardness on record is 104 ppm for a sample collected at The Dalles (fig. 27). Downstream from Portland the suitability of the water is questionable. Studies have shown that the usual methods for treating water can cause the finished water to have a bad taste when the raw water contains organic wastes or certain species of algae. Organic wastes from paper industries and cities are present in the river in addition to the slime growth. A study covering selected periods throughout the year would be needed to determine if the raw Columbia River water could be economically treated to produce finished water without objectionable taste and odor. Furthermore, the variations in concentrations of the organic waste and the growth of slime may introduce operational problems for a water-treatment plant using water from this reach of the Columbia River.

CONCLUSIONS

The majority of the streams in the lower Columbia River basin contain calcium magnesium bicarbonate type water. In general, the rivers rising in the Coast Range and west slope of the Cascade Range contained less than 100 ppm dissolved solids and less than 50 ppm hardness. Headwater reaches of streams on the east slope of the Cascade Range are very similar to those on the west slope; although irrigation downstream increases dissolved-solids content and hardness, most of the waters remain calcium magnesium bicarbonate in type. The maximum dissolved-solids content and some changes in chemical composition occur in the streams draining the more arid part of the area. Irrigation in these more arid regions is chiefly responsible for increasing the dissolved-solids content and altering the chemical composition of the streams. The maximum dissolved-solids content and hardness observed in major irrigation areas were 507 and 262 ppm, respectively, for the Walla Walla River near Touchet, Wash.

A salt-balance problem exists in the Hermiston-Stanfield, Oreg., area of the Umatilla River basin, and because of poor drainage, improper irrigation practices could cause salt-balance problems in the Willamette River Valley, Oreg., where irrigation is rapidly increasing. According to the classification of the U.S. Salinity Laboratory Staff (1954, p. 80), most of the stream waters in the basin have low salinity and sodium hazards, and such waters are very suitable for irrigation applications.

Most of the tributary waters to the lower Columbia River are of excellent quality and could be used for a municipal supply after some treatment. Principal treatment required would be disinfection and turbidity removal. The waters also could be used by most industries without extensive treatment.

Pollution by sewage disposal has reached undesirable levels in the Walla Walla River, the Willamette River from Eugene to Portand, Oreg. and the Columbia River from Portland to Puget Island. In the lower reaches of the Willamette River, the pollution load from sewage and industrial-waste disposal at times depletes the dissolved oxygen of the water to a concentration less than that considered necessary for aquatic life.

In reviewing previous quality-of-water studies of the lower Columbia River basin, the author has noted that one parameter of water quality has received very little study—that of fluvial sediment transport. The small amount of work done on sediment transport has been for specific local problems such as gravel-washing operations or road construction. No comprehensive quantitative studies have been made to evaluate sediment production and transport in the lower Columbia River and the majority of its tributaries. A program should be undertaken to determine the rate and quantity of sediment being contributed to the lower Columbia River. This program should include mineralogic identification and particle-size-distribution determination, and it should consider ion-exchange processes and their effect on other water-quality parameters. The results of a study such as this would aid in planning, developing, and managing the water resources of the lower Columbia River basin.

TABLE 1.—*Representative chemical analyses of water*

[Results in parts per million except as indicated. Analyses by U.S. Geol. Survey]

Location	Type of flow	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids, residue on evaporation at 180° C		Hardness as $CaCO_3$ (Calcium, magnesium)	Percent sodium	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot				
Umatilla River basin, Oregon																		
Umatilla River:																		
Near Gibbon	Low	June 17, 1958	37	6.4	1.0	3.6	1.8	31	4.5	1.0	0.1	0.0	52	------	20	26	60	7.3
Do	Medium	Jan. 22, 1959	30	4.0	1.6	2.2	1.3	25	1.4	.8	.3	.2	57	0.08	16	22	43	6.9
Do	High	Apr. 7, 1959	29	4.0	.8	2.2	1.6	23	1.0	.5	.2	.2	54	.07	14	24	43	7.1
Do	Low	Sept. 9, 1959	35	8.0	2.0	7.7	2.3	49	1.6	5.5	.2	.1	97	.12	28	35	97	7.5
At Pendleton	do	Aug. 28, 1956	30	7.9	2.6	5.2	2.4	48	------	3.0	------	1.2	80	.11	30	------	92	7.1
Do	Medium	Jan. 21, 1959	31	5.5	1.6	3.1	1.6	31	2.1	1.2	.3	.7	69	.09	20	23	59	7.4
Do	High	Apr. 7, 1959	30	7.5	1.2	3.4	1.6	33	2.6	1.0	.4	1.2	70	.10	24	23	68	7.2
Do	Low	Sept. 9, 1959	32	10	5.1	9.9	2.8	69	4.9	8.0	.2	.3	107	.15	46	30	143	7.5
McKay Creek near Pilot Rock	do	June 18, 1958	43	8.0	3.9	4.2	2.4	51	4.9	1.0	.1	.0	69	------	36	19	96	7.5
Do	Medium	Jan. 22, 1959	33	6.5	2.9	3.9	1.7	38	2.6	1.0	.4	1.2	82	.11	28	22	76	7.4
Do	High	Apr. 7, 1959	34	6.0	2.2	3.4	1.7	36	2.1	.5	.2	.8	80	.11	24	22	69	7.2
Do	Low	Sept. 9, 1959	37	15	3.8	7.4	2.8	78	2.8	2.5	.2	.4	111	.15	53	22	143	7.2
Birch Creek at Rieth	Medium	Jan. 21, 1959	38	14	5.6	10	2.6	81	6.4	4.0	.5	1.1	130	.18	58	26	156	7.0
Do	High	Apr. 7, 1959	36	11	4.2	6.8	2.3	62	4.2	2.5	.5	1.6	110	.15	44	24	118	7.2
Do	Low	Sept. 8, 1959	39	40	15	38	6.5	222	35	26	.3	.6	304	.41	161	33	485	7.7
Umatilla River at Yoakum	High	Mar. 26, 1951	------	------	------	------	------	39	4.0	2.0	------	------	------	------	32	------	79	7.0
Do	Medium	Jan. 21, 1959	33	7.5	2.7	4.8	2.1	43	3.4	2.0	.3	.9	85	.12	30	24	85	6.9
Do	High	Apr. 7, 1959	31	8.0	1.8	4.0	1.7	38	2.8	1.8	.3	1.5	78	.11	27	23	76	7.1
Do	Low	Sept. 8, 1959	35	12	3.8	7.7	3.0	70	3.9	3.5	.3	1.2	115	.16	46	25	133	7.7
Butter Creek:																		
At Vinson	do	June 28, 1957	------	36	12	22	4.2	[1] 201	------	------	------	------	------	------	139	26	354	8.4
Near Vinson	do	June 16, 1958	44	29	9.7	16	3.8	164	7.0	5.0	.3	.0	191	------	112	23	279	8.2
Near Pine City	High	Mar. 26, 1951	------	------	------	------	------	84	7.0	3.6	------	------	------	------	58	------	154	7.2
Do	Medium	Jan. 21, 1959	36	20	5.9	11	2.7	103	6.7	5.0	.5	1.9	153	.21	74	24	193	7.9
Do	High	Apr. 7, 1959	32	21	1.2	7.5	2.1	79	3.6	2.2	.5	1.3	124	.17	58	22	143	7.5
Do	Low	Sept. 8, 1959	34	45	14	36	5.3	242	22	18	.6	1.2	294	.40	168	32	475	7.7
Near Hermiston	do	Aug. 28, 1956	34	44	14	48	4.4	285	------	9.0	------	4.4	326	.44	168	38	500	8.2
S. F. Butter Creek near Heppner	do	June 16, 1958	52	32	11	32	4.0	216	9.1	7.0	.5	.4	251	------	125	35	373	7.9

Umatilla River near Umatilla	Medium	Nov. 25, 1950	39	20	8.0			122	8.0	7.5		1.7			83		218	
Do	High	Mar. 26, 1951						57	5.0	2.7					38		111	7.2
Do	Medium	Jan. 21, 1959	34	13	4.5	8.3	2.5	73	5.0	3.0	0.3	1.4	112	0.15	51	25	139	7.5
Do	High	Apr. 7, 1959	32	12	2.7	6.6	2.2	57	3.7	2.5	.4	2.0	100	.14	41	25	112	7.3
Do	Low	Sept. 8, 1959	42	48	12	25	6.2	[2] 254	12	6.5	.4	3.9	281	.38	169	24	414	8.4
Willow Creek basin, Oregon																		
Willow Creek:																		
At Heppner	Low	June 16, 1958	46	37	13	28	3.6	[3] 220	14	8.0	0.3	2.5	229		146	29	377	8.6
Do	Medium	Jan. 21, 1959	36	21	7.5	11	2.2	114	5.9	4.0	.3	2.6	155	0.21	83	22	206	7.7
Do	High	Apr. 7, 1959	31	19	4.7	7.6	1.8	89	3.7	2.2	.5	1.8	129	.18	67	19	157	7.5
Do	Low	Sept. 8, 1959	39	50	20	56	9.4	338	26	18	.6	2.8	389	.53	207	36	603	8.3
At Heppner Junction	Medium	Jan. 21, 1959	38	26	10	20	3.2	147	11	7.8	.3	4.9	205	.28	106	28	281	7.9
Do	High	Apr. 7, 1959	40	35	13	33	4.2	211	14	9.2	.6	9.2	265	.36	140	33	393	7.9
Do	Low	Sept. 8, 1959	33	50	18	100	5.9	433	34	22	.5	7.2	479	.65	199	51	758	7.9
John Day River basin, Oregon																		
North Fork John Day River near Dale	High	Apr. 18, 1960	23	7.0	2.0	2.7	1.0	38	2.8	0.0	0.0	0.2	61	0.08	26	18	67	7.2
Do	Medium	June 13, 1960	17	6.0	1.9	2.2	.9	33	2.8	.2	.0	.1	51	.07	22	18	57	7.6
Do	Low	Aug. 17, 1960	15	12	4.2	3.9	1.5	60	7.2	.0	.1	.0	73	.10	48	15	113	8.1
John Day River at Picture Gorge near Dayville	High	Apr. 6, 1951						132	12	2.3					108		230	7.4
Do	Medium	Jan. 22, 1959	30	26	13	9.8	1.9	148	11	2.0	.2	.5	165	.22	118	15	246	8.0
Do	Low	Sept. 9, 1959	32	50	18	22	4.0	274	23	4.5	.2	.2	280	.38	200	19	455	8.1
Do	do	Aug. 17, 1960	17	50	20	24	3.2	280	23	4.8	.1	.2	286	.39	208	20	460	7.9
Rock Creek near Condon		June 28, 1957		25	8.8	18	3.9	150							99	27	262	7.8
John Day River at McDonald Ferry	Medium	Mar. 14, 1951						142	10	3.4					107		249	7.3
Do	Low	Aug. 28, 1959	26	24	14	23	3.3	[4] 178	13	4.0	.3	.1	200	.27	117	29	306	8.4
Do	High	Apr. 18, 1960	28	14	5.5	6.3	1.2	82	4.8	1.0	.1	.2	104	.14	58	19	140	7.5
Do	Medium	June 13, 1960	25	14	6.3	7.4	1.2	89	4.8	.8	.1	.2	110	.15	61	20	148	8.1
Do	Low	Aug. 17, 1960	9.9	22	6.9	9.6	1.7	106	13	2.2	.3	.1	118	.16	84	20	199	8.2
Deschutes River basin, Oregon																		
Deschutes River at Wickiup Reservoir	Medium	Apr. 19, 1960	23	3.5	1.7	4.0	1.4	34	0.2	0.5	0.1	0.1	50	0.07	16	33	55	7.0
Do	High	June 14, 1960	21	4.0	1.5	4.0	1.2	32	.4	1.0	.0	.0	53	.07	16	33	53	7.6
Do	do	Aug. 16, 1960	18	4.0	1.6	4.5	1.5	35	.0	.0	.0	.1	46	.06	16	35	57	7.8
Fall River near Lapine	Medium	Apr. 3, 1951						40	2.5	1.2					18		67	7.0

See footnotes at end of table.

TABLE 1.—*Representative chemical analyses of water*—Continued

Location	Type of flow	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids, residue on evaporation at 180° C		Hardness as $CaCO_3$ (Calcium, magnesium)	Percent sodium	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot				
Deschutes River basin, Oregon—Continued																		
Little Deschutes River near Lapine	High	Apr. 3, 1951						25	2.6	0.9					14		44	6.7
Do	Medium	May 11, 1956	26	3.2	0.9	2.6	1.0	22	.7	1.0		0.5	48	0.07	12	30	39	6.8
Do	do	Apr. 19, 1960		3.0	1.0			22							12		41	7.1
Do	High	June 14, 1960						23							12		44	7.0
Do	Medium	Aug. 16, 1960						24							12		42	7.6
Deschutes River near Bend	do	Apr. 19, 1960	26	4.0	1.8	5.1	1.2	36	.4	.8	.1	.1	58	.08	18	37	61	7.7
Do	High	June 14, 1960	22	4.0	1.6	4.9	1.2	33	.4	1.0	.0	.1	56	.08	16	37	56	7.5
Do	do	Aug. 16, 1960	20	4.0	1.9	5.2	1.4	36	.0	.2	.1	.0	50	.07	18	37	66	7.5
Crooked River:																		
Near Post	Medium	May 3, 1961	32	16	6.6	13	1.9	109	4.8	3.8	.2	.3	134		67		183	8.2
Near Prineville	do	Feb. 27, 1951	38	26	11			158	12	5.0		.8		.26	110		278	7.8
Do	High	Apr. 15, 1958	27	16	5.1	7.3	1.9	87	2.8	1.0	.1	.7	119	.16	61	20	145	7.7
Do	Medium	Apr. 19, 1960	32	16	5.6	13	2.0	102	5.4	3.0	.1	.2	128	.17	63	30	176	7.8
Do	Low	June 14, 1960	27	26	14	35	3.6	[5] 226	10	6.5	.2	.2	241	.33	124	37	373	8.7
Do	do	Aug. 17, 1960	31	26	18	59	6.0	[3] 280	24	13	.4	.2	322	.44	138	47	485	8.6
Suttle Lake near Sisters		Mar. 31, 1958	20	5.2	2.4	3.6	.8	33	1.6	.6	.0	.0			23		54	7.4
Metolius River near Grandview	Medium	Mar. 3, 1959	30	5.5	2.6	5.6	1.3	44	1.1	1.5	.1	.0	69	.09	24	32	76	7.0
Do	do	May 19, 1959	29	5.0	2.8	5.4	1.3	44	1.1	1.0	.1	.2	65	.09	24	31	73	7.5
Shitike Creek near Warm Springs		Dec. 2, 1955	19	3.6	.7	3.3	.9	23	.6	1.2	.1	.2	43	.06	12		41	7.3
White River near Tygh Valley	High	Jan. 23, 1959	21	4.5	1.4	2.9	.9	26	1.7	1.5	.2	.2	46	.06	16	27	47	7.4
Do	Medium	May 20, 1959	21	5.0	1.6	3.3	.8	31	1.6	1.0	.2	.2	47	.06	19	26	55	6.9
Do	Low	Aug. 27, 1959	25	3.5	2.9	5.4	1.3	44	3.1	1.3	.2	.3	60	.10	28	28	84	7.5
Deschutes River near Moody	High	Apr. 18, 1960	30	8.0	3.6	8.2	1.6	62	2.0	1.8	.1	.2	87	.12	34	33	109	7.6
Do	Medium	June 13, 1960	29	7.0	4.1	9.4	1.8	64	.8	3.0	.1	.0	88	.12	34	36	111	7.8
Do	Low	Aug. 17, 1960	31	7.0	4.9	10	1.8	[6] 70	2.4	1.5	.1	.0	90	.12	38	35	118	8.6

Klickitat River basin, Washington

Klickitat River near Glenwood	Medium	Jan. 13, 1959	24	4.5	2.3	2.6	1.1	32	0.9	0.5	0.2	0.2	58	0.08	20	20	53	7.2
Do	High	June 2, 1959	20	5.0	.9	2.0	.9	26	1.6	.2	.3	.2	42	.06	16	21	45	7.0
Do	Low	Aug. 27, 1959	30	7.0	2.2	3.5	1.9	44	1.4	.8	.1	.2	71	.10	26	21	74	7.5
Little Klickitat River near Wahkiacus	High	Jan. 13, 1959	28	8.0	2.5	3.4	1.4	41	1.5	1.2	.3	2.2	68	.13	30	19	76	7.3
Do	Low	June 2, 1959	28	8.5	4.7	4.2	1.3	58	.8	.8	.3	.6	75	.10	40	18	96	7.2
Do	do	Aug. 28, 1959	30	12	5.0	5.8	2.0	79	.5	1.5	.2	.3	98	.13	50	19	127	8.2

Hood River basin, Oregon

Green Point Creek below North Fork near Dee		May 12, 1956	13	3.2	1.1	1.7	0.3	20		1.0	0.1	0.2	30	0.04	12		36	6.9
Hood River near city of Hood River	High	Nov. 26, 1950	21					26	1.3	2.5		.2			18		45	
Do	Medium	Mar. 13, 1951						33	4.4	2.5					27		66	7.0
Do	High	Jan. 13, 1959	18	3.5	1.2	2.4	.7	22	1.2	1.0	.2	.3	40	.05	14	26	39	7.0
Do	Medium	June 2, 1959	22	5.0	1.2	2.8	.9	27	1.7	1.0	.1	.3	49	.07	18	24	48	6.9
Do	Low	Aug. 26, 1959	28	7.0	2.5	4.5	1.5	42	3.0	1.5	.3	.3	76	.10	28	25	80	7.7

Willamette River basin, Oregon

Middle Fork Willamette River at Jasper	High	Jan. 14, 1959	17	4.5	0.9	2.3	0.5	24	1.2	1.2	0.3	0.2	45	0.06	14	25	40	7.0
Do	Medium	May 12, 1959	18	5.5	.7	3.1	.5	26	1.2	2.2	.2	.2	42	.06	16	28	46	7.0
Do	Low	Sept. 4, 1959	18	5.0	1.3	2.5	.9	28	1.4	1.0	.1	.3	45	.06	18	22	51	6.9
Coast Fork Willamette River near Cottage Grove	High	Apr. 21, 1960	15	5.0	.8	2.6	.8	24	1.2	2.0	.1	.0	43	.06	16	25	46	7.2
Do	Low	June 15, 1960	14	5.0	1.1	2.9	.4	27	1.6	1.5	.0	.1	49	.07	17	27	47	7.1
Do	do	Aug. 16, 1960	14	6.0	1.7	3.1	.4	32	.6	1.2	.0	.2	43	.06	22	22	59	7.1
McKenzie River near Coberg	High	Jan. 14, 1959	16	3.5	1.3	2.3	.5	22	1.1	1.2	.1	.3	38	.05	14	26	39	7.0
Do	Medium	May 12, 1959	18	4.5	1.1	2.9	.7	25	1.6	1.8	.2	.2	38	.05	16	28	45	7.1
Do	Low	Sept. 4, 1959	23	5.0	1.9	4.4	1.2	35	2.3	1.8	.2	.1	55	.07	20	31	64	7.1
Willamette River at Harrisburg	High	Apr. 21, 1960	16	4.5	.8	2.2	.7	23	1.2	.8	.1	.1	40	.05	14	25	43	7.3
Do	Medium	June 15, 1960	17	5.0	1.1	3.1	.7	28	.6	1.0	.1	.1	44	.06	17	27	50	7.3
Do	Low	Aug. 16, 1960	18	5.0	1.6	3.6	.8	31	1.0	1.5	.1	.0	54	.07	19	29	56	7.0
North Santiam River at Mehama	High	Jan. 14, 1959	9.6	3.0	.3	1.6	.1	14	1.1	.8	.1	.1	22	.03	9	28	24	6.9
Do	Medium	May 12, 1959	11	3.5	.4	1.6	.3	16	1.4	.5	.2	.2	27	.03	10	25	30	6.6
Do	Low	Sept. 4, 1959	16	4.0	.7	2.1	.6	22	1.2	.5	.1	.0	32	.04	13	24	38	7.3

See footnotes at end of table.

TABLE 1.—*Representative chemical analyses of water*—Continued

Location	Type of flow	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids, residue on evaporation at 180° C		Hardness as $CaCO_3$ (Calcium, magnesium)	Percent sodium	Specific conductance (micromhos at 25° C)	pH
													Parts per million	Tons per acre-foot				
Willamette River basin, Oregon—Continued																		
Santiam River at Jefferson	Low	Apr. 21, 1960	12	4.0	0.2	1.8	0.4	18	1.0	0.5	0.0	0.2	33	0.04	11	26	36	7.1
Do	Medium	June 15, 1960	13	4.0	.8	2.3	.5	22	1.2	1.0	.0	.1	37	.05	13	27	39	7.2
Do	Low	Aug. 16, 1960	14	4.0	2.3	2.5	.5	23	3.2	.5	.0	.2	38	.05	20	22	48	7.2
South Yamhill River near Whiteson	Medium	Apr. 21, 1960	13	6.0	.8	4.0	.8	23	4.0	3.8	.1	.1	53	.07	18	30	65	7.2
Do	Low	June 15, 1960	15	8.0	2.6	6.0	.5	40	4.0	5.5	.1	.2	63	.09	31	29	95	7.2
Do	do	Aug. 16, 1960	15	12	3.8	8.4	.7	57	4.2	9.2	.1	.0	82	.11	46	28	130	7.3
Clackamas River near Estacada	High	Jan. 29, 1959	14	3.0	.9	1.8	.5	19	.3	.5	.2	.2	35	.05	12	25	33	7.3
Do	Low	Sept. 2, 1959	19	6.5	1.6	4.3	1.0	36	1.2	2.5	.1	.2	54	.07	23	28	71	7.3
Cowlitz River basin, Washington																		
Cowlitz River at Packwood	High	June 22, 1960	9.1	4.0	0.9	2.0	0.2	20	1.4	1.2	0.1	0.1	32	0.04	14	24	38	7.2
Do	Low	Aug. 24, 1960	10	5.5	.8	2.8	.3	24	2.2	1.8	.0	.1	38	.05	17	26	48	7.3
Cispus River near Randle	Medium	June 22, 1960	15	4.0	1.7	2.3	.5	23	2.2	1.0	.1	.0	39	.05	17	22	43	7.7
Do	Low	Aug. 24, 1960	20	6.0	1.2	3.7	1.4	31	2.8	1.5	.1	.1	53	.07	20	27	59	7.4
Cowlitz River near Mayfield	do	Oct. 10, 1956	13	7.5	1.4	3.4	.5	34	------	2.0	------	.5	50	.07	24	23	68	6.9
South Fork Toutle River at Toutle	do	Oct. 10, 1956	15	5.2	.9	3.7	.6	26	------	2.2	------	.4	52	.07	17	32	54	6.4
Do	do	Aug. 24, 1960	------	4.0	1.4	------	------	24	------	------	------	------	------	------	16	------	46	7.3
Toutle River near Silver Lake	Low	Oct. 10, 1956	19	6.4	1.6	6.7	.7	31	------	5.0	------	.2	56	.08	23	38	75	6.6
Do	Medium	June 22, 1960	16	4.0	1.1	4.1	.4	23	2.6	2.8	.1	.1	44	.06	14	38	50	7.4
Do	do	Aug. 24, 1960	17	5.0	1.3	5.0	.7	27	2.2	3.5	.1	.2	60	.08	18	37	58	7.3

Cowlitz River at Castle Rock	Low	Sept. 30, 1947	19	6.8	1.8			45	4.4	3.7		0.4			24		76	
Do	High	Jan. 7, 1948	15	4.8	.9			20	4.4	1.9	0.1	1.0			16		38	
Do	Low	Oct. 10, 1956	16	7.9	.5	4.4	0.7	34		2.8		.2	52	0.07	22	30	75	6.6
Elochoman River basin, Washington																		
Elochoman River near Cathlamet	Low	June 22, 1960	14	5.5	0.9	4.1	0.4	24	2.2	4.0	0.1	0.2	47	0.06	17	34	58	7.4
Do	do	Aug. 23, 1960	14	6.5	1.3	4.6	.6	25	2.2	6.8	.1	.2	54	.07	[7] 22	31	67	7.2
Grays River basin, Washington																		
Grays River near city of Grays River	Low	June 22, 1960	11	5.0	0.3	3.5	0.1	22	2.0	2.5	0.1	0.1	37	0.05	14	35	47	7.2
Do	do	Aug. 23, 1960	11	6.0	1.2	4.4	.4	25	4.2	3.5	.1	.3	48	.07	20	32	60	7.2
Youngs River basin, Oregon																		
Youngs River near Astoria		June 23, 1960	13	3.0	0.9	5.6	0.4	16	2.6	6.0	0.1	0.3	45	0.06	11	51	53	7.1
Do		Aug. 23, 1960	13	3.0	1.7	6.5	.7	20	2.6	7.0	.1	.2	57	.08	14	47	59	7.0

1 Contains the equivalent of 4 ppm carbonate.
2 Contains the equivalent of 10 ppm carbonate.
3 Contains the equivalent of 14 ppm carbonate.
4 Contains the equivalent of 6 ppm carbonate.
5 Contains the equivalent of 12 ppm carbonate.
6 Contains the equivalent of 3 ppm carbonate.
7 Sample also contains noncarbonate hardness of 1 ppm.

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