DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 339

QUALITY OF THE SURFACE WATERS OF WASHINGTON

BY

WALTON VAN WINKLE

Prepared in cooperation with the State Board of Health of Washington

WASHINGTON
GOVERNMENT PRINTING OFFICE
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QUALITY OF THE SURFACE WATERS OF WASHINGTON.

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OUTLINE OF INVESTIGATION.

The value of water for any particular use is determined by the nature and amount of the material it holds in suspension and solution—that is, its quality. Water for drinking must be free from poisonous chemicals or disease-producing organisms and from excessive amounts of dissolved materials; preferably it should be clear, odorless, colorless, and palatable. Water for cleansing should be soft and should be free from large amounts of iron in order not to cause waste of soap or spots and stains on clothing. Water for steam generation should not contain materials that form excessive deposits of scale or that corrode the boilers. Water for industrial processes should not contain substances which will combine with the raw material or with the bleaches or dyes to the injury of the finished product or the waste of materials of manufacture.

Analyses of "spot samples" of water are often misleading, especially of samples collected in regions of slight rainfall or marked seasonal variations in precipitation. The data obtained by study of many samples systematically collected over long periods, however, are not only locally important, affording essential information to municipalities and manufacturers, but they are also scientifically valuable, as they illuminate many problems of physiography, chemical denudation, and geochemistry.

Late in 1909 the United States Geological Survey and the State Board of Health of Washington began a cooperative study of the quality of the surface waters of the State of Washington, including their seasonal variation in composition and in physical characteristics, and the pollution to which they are subject.

No systematic study of the quality of the surface waters of Washington had previously been made, though miscellaneous analyses of water from a few lakes and rivers have been published in periodicals or in special reports to municipalities, and analyses of serial samples of water from Salmon and Palouse rivers were made by the United States Reclamation Service in 1905.[1]

[1] Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, pp. 80, 111, 1911.

The bacteriologic work of the investigation was done by the State Board of Health, the chemical work by the United States Geological Survey, and the field expenses were shared by both organizations. The writer was detailed to perform the chemical and field work under the direction of R. B. Dole, chemist of the water-resources branch of the Geological Survey.

The chemical determinations were made at the city hall at Seattle in a room procured through the courtesy of Mr. Thompson, the city engineer, until March, 1910, when, in response to an invitation from the University of Washington, the laboratory was moved into quarters in the chemistry building of that university.

In the chemical work the writer was assisted during the greater part of the time by Mr. McClintock Taylor.

Sampling stations were established at certain points, from which daily samples of water were forwarded to the laboratory during the periods indicated by the dates. Each of the stations, except that at Okanogan and that near Montesano, was inspected from time to time by the writer. The stations are listed below and their locations are shown on Plate II.

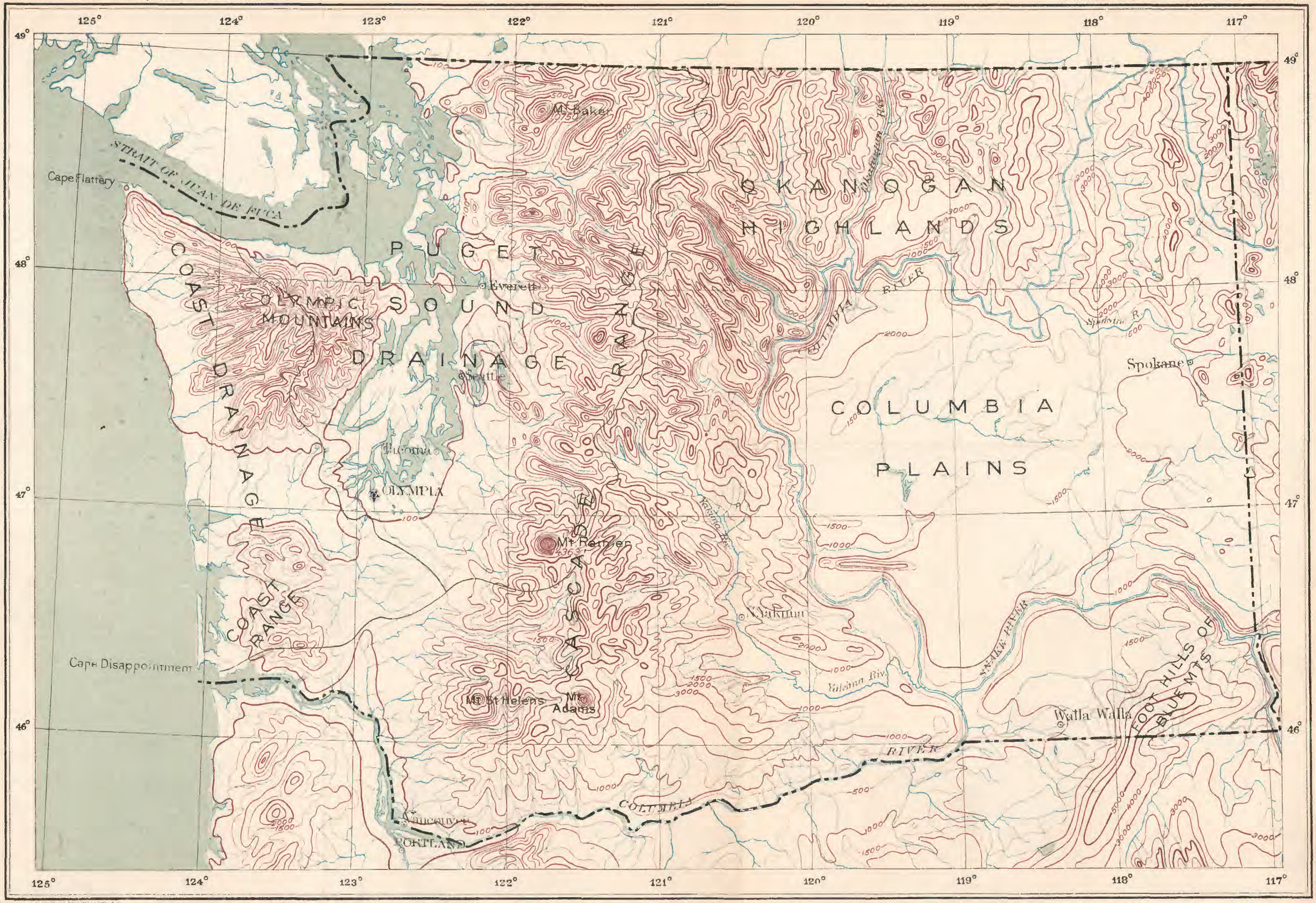
Instructions in collecting and plating bacteriologic samples were given the collectors at all places except Okanogan, but the results of the bacteriologic investigations, which were conducted by Dr. E. P. Fick, bacteriologist of the State Board of Health, have not been included in this report.

Sampling stations on streams in Washington.

Stream.	Sampling point.	Collections.	
		Begun.	Discontinued
Cedar River	Gaging station at Seattle intake near Ravensdale	Feb. 1, 1910	Jan. 31, 1911
Chehalis River	Bridge above Centralia	do	Do.
Columbia River	Ferry, Northport	Jan. 22, 1910	Do.
Do	Waterworks intake, Pasco	Feb. 2, 1910 May 2, 1910	Apr. 21, 1910 Jan. 31, 1911
Do	Above rapids at Cascade Locks	Mar. 13, 1910 Aug. 1, 1910	Dec. 31, 1910 Aug. 14, 1912
Green River	Bridge near hotel, Hot Springs	Feb. 1, 1910	Aug. 18, 1910
Klickitat River	Gaging station near railroad station, Klickitat	do	Jan. 31, 1911
Naches River	Power house near Naches	do	June 30, 1910
Okanogan River	Near Okanogan	Mar. 31, 1910	Jan. 16, 1911
Skagit River	North Pacific Ry. bridge near Sedro Woolley	Feb. 1, 1911	Jan. 31, 1911
Snake River	North Pacific Ry. bridge near Burbank	Mar. 13, 1910	Do.
Spokane River	Bridge above Spokane	Feb. 1, 1910	Do.
Wenatchee River	Bend between gaging station and Cashmere	do	Do.
Wood Creek	Inlet into city reservoir, Everett	Mar. 13, 1910	Do.
Wynoochee River	Fry's camp, 20 miles above Montesano	July 17, 1910	Aug. 19, 1910
Yakima River	100 yards below wagon bridge at Clealum	Feb. 1, 1910	Jan. 31, 1911
Do	Flouring mill above Prosser	Aug. 20, 1910	Do.

ACKNOWLEDGMENTS.

Thanks are due especially to the officials of the University of Washington, particularly to Dr. Thomas H. Kane, president of the university, and to Dr. H. G. Byers, director of the chemical laboratories, for



MAP OF WASHINGTON SHOWING PRINCIPAL NATURAL FEATURES

Scale $\frac{1}{2,500,000}$

25 0 25 50 75 100 Miles

25 0 25 50 75 100 Kilometers

1914

Drawn from U.S. Land Office map

MAP OF WASHINGTON SHOWING SAMPLING STATIONS AND DRAINAGE BASINS

—— Boundary of drainage basins • Sampling station

Scale $\frac{1}{1,500,000}$

10 0 10 20 30 40 50 60 70 Miles

1914

furnishing laboratory space, fuel, light, and water; and to Mr. Thomp, son, city engineer of Seattle, and to the engineer in charge of tests- Mr. C. Moore. The hearty cooperation of Dr. A. P. Duryee, of Everett; Mr. A. B. Youngs, of Seattle; Dr. B. M. Grieve, of Spokane; and Mr. Charles Ewarts, of Aberdeen, rendered possible the collection of samples from Wood Creek, Cedar River, Spokane River, and Wynoochee River. The serial samples at Okanogan were collected by an employee of the United States Reclamation Service, through the kindness of Christian Anderson, project engineer.

The writer has drawn freely on the geologic reports of the Washington Geological Survey and the United States Geological Survey for information regarding the geology of the State, and on the publications of the United States Weather Bureau for information regarding climate and precipitation. He wishes to extend special thanks to Mr. Henry Landes, State geologist, for valuable personal assistance in matters pertaining to local geology, and to Messrs. J. C. Stevens and F. F. Henshaw, of the district office of the United States Geological Survey in Portland, Oreg., for assistance in obtaining records of stream discharge.

NATURAL FEATURES OF WASHINGTON.

LOCATION AND EXTENT.

The State of Washington, occupying the extreme northwest corner of the continental United States, exclusive of Alaska, extends from latitude 46° to 49° north (see Pl. I) and longitude 40° to 47° 30′ west from Washington meridian and comprises an area of 69,127 square miles, of which 2,291 square miles is water.[1] Its land surface is therefore greater than the combined areas of the New England States and nearly as great as that of the New England States and New Jersey or of Missouri. The water surface includes much of Puget Sound and a number of small lakes.

TOPOGRAPHY.

The most prominent feature of relief in Washington is the Cascade Range, which crosses the State from north to south and divides it into two regions of dissimilar climate—to the west a region of abundant rainfall, cool summers, and mild winters, and to the east a region of moderate or scanty rainfall, hot summers, and cold though not severe winters. Viewed from a point below the 6,000-foot level, the Cascade Range appears to form a series of jagged peaks, but a view from a summit reveals the fact that all the peaks are remnants of a long plateau, perhaps 50 miles wide, and that the valleys have resulted from stream and glacial erosion. Probably every observer

[1] Gannett, Henry, The areas of the United States, the States, and the Territories: U. S. Geol. Survey Bull. 302, p. 8, 1906.

who has crossed these mountains has noticed this fact and many have recorded it in their published descriptions. Most of the mountain tops are 5,500 to 6,000 feet above sea level, although isolated peaks rise to much greater heights. Mount Rainier, the highest in the State (altitude 14,364 feet), is not one of the peaks of the Cascades but is an extinct volcano resting on the western slope of the range. Mount Baker, Mount St. Helens, and Mount Adams are also flanking volcanic peaks and are not integral parts of the range.

West of the Cascade Range and at its base is a long troughlike valley the northern part of which is submerged and forms Puget Sound. This valley is separated from the coastal plain on the southwest by a low divide called the Coast Range, which is one of the minor topographic features of the State.

The Olympic Mountains, their peaks capped by perpetual snow, rise abruptly from the western edge of Puget Sound. These mountains, like those of the Cascade Range, are remnants of a high plateau, now deeply dissected and eroded; and, like the Cascades, they reveal their original form only from their summits. Their average elevation above sea level is more than 6,500 feet, but individual peaks attain altitudes of 9,000 feet and more. Their slopes are steep and in many places precipitous, and the short, steep valleys leading from their uplands contain torrential streams of considerable size.

The eastern slopes of the Cascade Mountains merge at their base into the Columbia River plains, which occupy the eastern part of the State. These plains appear practically level to the casual observer, but in reality they rise gently eastward and southeastward until they merge into the foothills of the Blue Mountains of Oregon. The eastern and southern parts of the plains are rolling prairie land and constitute the wheat belt of Washington. The plains are cut in all directions by canyons of living or ancient streams. Snake River traverses the whole width of the plains in Washington in a canyon whose walls are in most places nearly perpendicular cliffs and whose average depth is 2,000 feet. Between upper Columbia River and the Cascade Range are the Okanogan highlands.

DRAINAGE.

RIVERS.

The drainage of the State passes to the Pacific through Columbia River, streams tributary to Puget Sound, and minor coastal streams.

Columbia River, the principal river of Washington, receives the drainage of the entire State east of the Cascade Range and of a narrow strip in the southwestern part. The area of its basin in Washington comprises 48,000 square miles, or 18.5 per cent of the total area drained by the river, the rest of which is in Oregon, Idaho, Montana, and Canada. It includes within its boundaries all varieties of topography. The rugged, eroded slopes of the Cascades border it on the west; the lower ranges of the Okanogan highlands, with their deeply gouged glacial troughs, form its northern border; the rolling prairies of the eastern Washington "Palouse country" and the level Columbia plains comprise its eastern portion; and the short, narrow valleys of the Klickitat region and the gently sloping, mature valleys of the Cowlitz and Kalama region characterize its southern portion. The territory between Cascade Mountains and Columbia River contains wide, fertile, mountain-girt valleys that form the chief apple-growing section of the State. The climate of the basin is as diversified as its topography. The plains are hot in summer, but not very cold in winter; but the rolling uplands skirting them are subjected to both hot summers and cold winters. The valleys bordering the Cascades are characterized by warm summers and cold winters and on the higher elevations of the Cascades the climate is extremely rigorous. Rainfall is copious in the summit region of the Cascades, but decreases eastward until it amounts to only 5 or 6 inches a year in the lower portions of the Columbia plains. It is greater in the eastern section and in the Okanogan highlands and Blue Mountain region, but is still inadequate for full agricultural development. Much of the drainage area is treeless and forests are confined to the mountainous portions. The principal tributaries of the Columbia River in Washington are Snake River, the largest, and Colville, Spokane, Okanogan, Methow, Chelan, Wenatchee, Yakima, Klickitat, Lewis, Kalama, and Cowlitz rivers.

Most of the rivers rising on the western slopes of the Cascades flow into Puget Sound. Many of these are short and relatively unimportant, but some, such as Skagit River, are of considerable magnitude. The streams draining the eastern and northern slopes of the Olympic Mountains also flow into Puget Sound. These are all short and swift and afford many power sites. Precipitation is abundant throughout the area draining to Puget Sound except along the northern shore of the sound itself, which receives an exceedingly low rainfall. The climate is moderate, the summers being cool and the winters mild. Sunshine is not abundant; the sky in summer is often obscured by haze or by smoke from forest fires and in winter is overcast by clouds. Forests cover most of the uplands of the basin.

The minor coastal streams drain a narrow strip of country extending from the Straits of Juan de Fuca to the mouth of the Columbia. The only large stream in this area is Chehalis River. Other rivers of the region are the Soleduck, Hoh, Queets, and Queniult, draining the western slopes of the Olympic Mountains, and Willapa River, draining the Coast Range. Rainfall in this strip is copious and the climate is mild. Much of the area is forested.

Two periods of high water are usual, one in spring or early summer and the other in late autumn or early winter. The floods in spring usually last longer, but those in winter are commonly more violent. When rain and melting snow are concomitant, freshets are sure to be severe. A southerly chinook wind on the Cascades, especially if it is accompanied by a rainstorm and follows a period of heavy snowfall, causes destructive floods that at times have paralyzed traffic across the Cascade Mountains for days. The landslides that sometimes accompany sudden thaws on the slopes of the Cascades have caused great loss of life and property.

LAKES.

Lake Chelan occupies a glacial trough 48 miles long and about 1 mile wide, extending southeastward from the Cascade Range in the northern part of the State. Its water surface is 1,080 feet above sea level. This lake is perhaps one of the most picturesque in America. Other lakes, mostly small, lie in the Okanogan highlands. The water of many of them is brackish, and that of some, according to available information, contains large amounts of sodium sulphate.

The beds of the coulees in the Big Bend region contain several small and a few large lakes. Many of these "lakes" are really playas or intermittent shallow pools; some are fresh and fill widenings of the channels of the small streams flowing through the coulees; others are alkaline sinks or residual lakes with no outlet. Moses, Alkali, and Freshwater lakes in Grand Coulee, and Tule, Sylvan, Pacific, and Crab lakes in Crab Creek coulee are the best known. All contain carbonate water.

Rock Lake and Colville Lake are situated in the eastern part of the State. The Olympic Mountains contain two principal lakes, Queniult and Crescent. The latter is growing in popularity as a summer resort for residents of the cities around Puget Sound. Silver Lake, in Cowlitz Basin, is the only important lake in the southern part of the State. The region of glacial drift around Puget Sound contains many fresh-water lakes. Lake Washington and Lake Union, the former bordering and the latter within the city of Seattle, may be mentioned.

GEOLOGY.

ROCKS.

The geology of Washington in general has been studied by several writers, and selected areas have been investigated in considerable detail. The following statements have been drawn from the published writings of many authors, to whom credit is hereby given: Paleozoic gneisses and schists with some limestones and granites are abundant in the Okanogan highlands and give place southward to the basalt of Miocene age. The formations of the Olympic Mountains include metamorphic rocks of Jurassic age encircled by Upper Cretaceous sediments that along the coast are covered by late Tertiary sediments. The core of the mountain mass is granitic.

The Cascade Range is a huge uplifted mass of great length and width. The core, at least in the northern portion, is composed of granites and granodiorites, in large areas flanked by Paleozoic and later metamorphic rocks—schists, gneisses, and serpentines. In the middle section of the range andesitic and basaltic formations are found in contact with the Miocene basalt of Columbia River and with various Tertiary sediments and metamorphic rocks. The rocks of the southern section are largely basaltic.

The plains of Columbia and Snake rivers and the Blue Mountain uplift are covered with the Miocene basalt, overlain in part by the later Miocene sediments of the Ellensburg formation.

The Puget Sound trough is filled to a depth of several hundred feet with Quaternary glacial deposits, but in the eastern borders Eocene and Miocene sedimentary formations are exposed.

SOILS.

The soils of eastern Washington are eolian, or wind borne, and residual, derived by decay from underlying rocks. They are extremely fertile and produce excellent crops under cultivation. According to Calkins[1] the eolian soils, which predominate and are very thick, are light colored, very friable silty loams of fine, open texture. The residual soils from basalt are darker, and in many places angular pieces of basalt are mingled with the fine loam.

The soils of the intermountain valleys are sands, sandy loams, or clays in the southern and central sections and stony, gravelly, or sandy soils in the northern, glaciated sections.

The soils of the western region are largely glacial detritus—gravels or sandy loams. The southern part of the coastal region is overlain by silty clay loams and silty loams derived from the Tertiary sandstones and shales. Many of the glacial soils are poor in nitrogen, and their enrichment through the growth of leguminous plants greatly aids production of crops. The deficiency of plant food and organic matter is due both to the origin of the soils and to the excessive leaching they have undergone.

CLIMATE.[2]

Of the two unequal areas into which the Cascade Range divides the State, the western is a region of abundant rainfall, cool summers, and mild winters, and is for the most part covered by forests of

[1] Calkins, F. C., Geology and water resources of a portion of east-central Washington: U. S. Geol. Survey Water-Supply Paper 118, p. 45, 1905.

[2] Abstracted from Climatology of the United States, by A. J. Henry: U. S. Weather Bur. Bull. Q, p. 926, 1906.

gigantic evergreens; the eastern is a region of moderate or scanty rainfall, hot summers, and cold but not severe winters, and the greater part of it is treeless.

To say that the normal annual temperature of the State is 49.3° F. and the normal annual precipitation 37.1 inches is to give information that, though correctly deduced, is almost wholly valueless for any particular locality. Only one broad generalization can safely be made: The area west of the Cascade Range is wet and that east of it is dry. Greater accuracy requires the subdivision of the wet section into a moist and a very wet area, and the dry section into semiarid and arid. The wet section lies between the ocean and the summits of the Coast Range and Olympic Mountains. Its annual rainfall is 60 to 120 inches, and 75 per cent of this occurs during the so-called "wet season," from November to April. In the semiarid area, comprising the eastern and northern portions of the State, the annual precipitation as rain and snow is 12 to 25 inches. The very dry or arid area, in the central portion of the State east of the Cascades, receives annually less than 12 inches of rain and snow.

The climate of the coastal strip is almost marine, except occasionally when winds blow from inland at the time cold waves of great intensity are overspreading Alberta, British Columbia, and Montana. The mean annual temperature is 47° to 51°. The normal temperature in January is 36° to 42°, in April 46° to 49°, in July 57° to 63°, and in October 48° to 55°. The temperature has never been lower than 10° above zero at Aberdeen. It almost never exceeds 90°, and is below freezing only about 40 times a year.

The climate in the Puget Sound basin is somewhat similar to that of the coastal strip in mean annual and monthly range of temperature, but it is greatly modified by cold and warm winds coming across the Cascade Mountains. The rainstorms that are so frequent in winter have about the temperature of the sea in this latitude, and hence the rainy days in winter are very mild. During dry spells in winter the air is sharp and frosty, as it either is coming from the region east of the Cascade Mountains or is a descensional current from an anticyclonic area which is central over Puget Sound. The extremes of temperature recorded for the region are 102° (at Centralia) and 6° below zero (at Blaine).

The climate east of the Cascades is essentially continental, although it is undoubtedly modified by storms and by air currents from the sea. There is a great diversity and range of temperature as well as rainfall. Stevens and Douglas counties, the former in extreme northeastern and the latter in central Washington, are the coldest. The annual average temperature in Stevens County is 44° to 46°, ranging from 20° in January to 68° in July. In the country around Spokane the temperature ranges from about 24° in January to 68°

in July. At Spokane 30° below zero and 104° above zero have been recorded. Winters in the settled part of Kittitas County are cold but not severe except for an occasional cold snap lasting a few days. The summers are short and sometimes hot. In all the southeast counties the summers are hot and the winters are mild, with little snowfall except in the mountains and only short periods of moderately cold weather. In the region about Lake Chelan and in the valley of Okanogan River the winters are phenomenally mild.

The dominant wind for the year over the Puget Sound basin is southerly; along the coast it is south to west; these are the rain-producing winds. The northerly and easterly winds are, for the most part, dry. In summer the winds are very moderate. The prevailing winds east of the Cascades are from the southwest, though local topography in Wenatchee and Yakima valleys make the direction northwest. Occasionally during summer hot desiccating winds, injurious to crops, blow from the north and east over the plains of the eastern division. Hailstorms sometimes occur, but they are almost invariably light and do little damage except to fruit. "Dust storms," so-called, occasionally occur in the Walla Walla, Snake River, and Yakima valleys, but they are more disagreeable than injurious.

ECONOMIC FEATURES.

POPULATION.

The United States census of 1910 gave the population of Washington as 1,141,990, the increase since 1900 having been 120.4 per cent. That more than half the inhabitants now dwell in only 27 cities indicates the wonderful industrial and commercial growth of the State in recent years. More than one-fifth of the people reside in two counties bordering on Puget Sound and comprising only 5.7 per cent of the total area of the State. Increase in rural population has been marked and well distributed. Spokane, Walla Walla, and North Yakima, three of the seven largest cities of the State, are primarily agricultural centers, and the density of rural population in the counties in which they lie is from 5.5 to 18.1 persons per square mile of land. Future development will probably result in a generally increased rural population, but in a much more largely increased urban population, for manufacturing and commerce will undoubtedly lead agriculture.

AGRICULTURE.[1]

Washington is divided by differences in rainfall, temperature, and soils into three great agricultural provinces. The western part of the State, from the Cascade Range to the ocean, produces vegetables

[1] All figures from the Thirteenth Census of the United States, 1910.

and other crops that require much moisture. The intermountain country, the valleys of the Okanogan highlands, and the uplands of the Spokane country form the apple belt, in which prunes, cherries, and other fruits also are raised. The Columbia plains and the foothills of the Blue Mountains are the wheat and cattle regions. Lincoln, Whitman, Adams, Walla Walla, Douglas, Grant, Franklin, and Spokane counties produce seven-eighths of the entire wheat crop, which in 1911 was 50,000,000 bushels. Stevens, Spokane, and Whitman counties produce one-fifth of all the hay and forage. Barley is grown principally in Columbia, Garfield, Walla Walla, Whitman, and Lincoln counties. Spokane County produces the most potatoes, but each county produces good crops of this vegetable. Corn growing is confined to the counties east of the Cascades, and hop raising is practiced almost exclusively in Yakima County. Yakima and Wenatchee valleys and the extreme eastern part of the State produce most of the orchard fruits.

Much of the orchard and farm land must be irrigated; indeed, irrigation is practiced on 13.6 per cent of all the farms in the State, and the acreage is rapidly being increased. The United States Reclamation Service has placed under irrigation 55,690 acres, the Indian Service 35,000 acres, and corporate, cooperative, or individual enterprises 243,688 acres. Several large irrigation projects are in course of construction and others are contemplated, so that large additions to these acreages will soon be made.

MANUFACTURES AND COMMERCIAL INDUSTRIES.[1]

Washington is the chief lumber-producing State in the Union, and making or handling wood or its products constitutes nearly half of the commercial activity of the State. The total amount sawed in 1910 was 4,097,492 thousand feet board measure.[2] This lumber was used rough, dressed, or as boards, posts, cordwood, and shingles. The amount of standing timber is, however, at the present time less than in Oregon, whose production is only slightly more than half that of Washington. The standing timber in Washington is chiefly in private ownership, as is shown by the following table:

Ownership of standing timber in Washington.

[Billion feet board measure.]

Private	294.6
National forests	81.6
All other	14.8

Flour and grist milling, slaughtering and meat packing, canning and preserving, and printing and publishing are other leading indus-

[1] All figures from Thirteenth Census of the United States, 1910, unless otherwise noted.
[2] Statistical abstract of the United States, Dept. Commerce and Labor, Bureau of Statistics, p. 167, 1911.

tries. Minor industries of the State include the production of malt liquors, leather goods, food preparations, and ice. The fisheries employ nearly 5,000 men, 190 vessels, and 2,800 small boats. Salmon and oysters are the chief products.

The lumber industry, by its sawdust waste and the soda refuse of its pulp mills; the leather industry, through its waste liquors; and the wool industry, through its scouring and dye liquors, affect the quality of the stream waters and thereby alter their economic value for municipal and industrial use. Proper protective legislation should regulate the disposal of the wastes of these industries.

NATURAL WATERS.

CONSTITUENTS.

Even rain, the purest natural water, contains appreciable amounts of organic and inorganic material, both in solution and in suspension. Rain falling near the seacoast contains more or less dissolved salt that is drawn up from the ocean with the water vapor—a fact that has been utilized in the study of pollution of surface waters near coasts by determining the quantity of chlorine carried by normal unpolluted waters.[1] Charts indicating the amount of chlorine brought down in rain can then be prepared by plotting the results of such determinations and connecting points at which equal amounts are found, thus establishing lines of equal chlorine (isochlors). Abnormalities resulting from human pollution can be discovered by comparing analyses of other surface waters with these charts.

But isochlors are useful only near the coast in humid regions not containing chloride-bearing rocks, and they are of doubtful value in regions of great seasonal variation of rainfall. Streams flowing through arid regions contain relatively large amounts of chlorides left after incomplete leaching of the sedimentary rocks, and though the amount of native chlorine may be slight where the rocks are mostly volcanic or plutonic unpolluted waters may be high in chlorine because of concentration of "cyclic" or wind-borne chlorine by evaporation.

Carbon dioxide and oxygen, the important gases dissolved in rain-water, are powerful agents of solution and oxidation, and the water containing them, having reached the earth, begins at once to acquire a further charge of dissolved matter. The carbon dioxide already present is augmented by that produced by the decay of vegetable matter on the surface of the ground or in the soil. Silica and the rock silicates are practically insoluble in pure water, but hydrated silicates are easily decomposed in weak solutions of carbonic acid, and

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[1] Jackson, D. D., The normal distribution of chlorine in the natural waters of New York and New England: U. S. Geol. Survey Water-Supply Paper 144, 1905.

"quartz is attacked and dissolved by prolonged digestion in even dilute alkaline carbonate solutions."[1] Silicate rocks are thus broken down by the action of water bearing carbon dioxide, and silica and alkalies are dissolved. The dissolved carbonic acid also attacks any limestone with which it comes into contact, for although calcium carbonate is only slightly soluble in pure water it goes readily into solution in the presence of carbonic acid, probably as calcium bicarbonate.

Direct solution, hydrolysis, and double decomposition all aid in bringing other materials into solution. Many secondary rocks, such as gypsum, enter directly into solution, and limestone may be dissolved by interaction with alkali sulphates.

All elements are soluble in water to some extent, but relatively few are found in appreciable amounts in natural waters. The important materials usually found are silica, iron, alumina, calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulphates, chlorides, nitrates, and organic matter.

USES OF WATER.

VARIETIES OF USE.

Water is of general and diversified use in the industries. It is used directly to furnish power, to transport heat or materials, or to perform an essential part in some processes of production, and indirectly to produce power through steam or electricity. Some idea of the magnitude of the indirect use, which during recent years has been the greater, may be gained by considering that a stationary boiler requires approximately 10 pounds of water an hour to furnish 1 horsepower to a triple-expansion condensing engine, and a boiler for a noncondensing engine, such as a locomotive, requires almost twice that amount. Few engines, however, are operated with so little water; the more modern and larger condensing engines waste an insignificant amount, but the older and smaller engines use many times the amount theoretically necessary.

DOMESTIC USE.

Drinking water must be free from suspended or dissolved matter which may endanger health or which may render it unpalatable. Even a small amount of iron gives a disagreeable taste to water and injures the quality of tea and coffee by combining with the steep liquors of the beverages to produce inks. The presence of sodium chloride in water in amounts greater than 400 parts per million can be detected by taste by most persons, and water containing more than

[1] Lunge and Millberg, Zeitschr. angew. Chemie, 1897, pp. 390, 425. Cited by Chase Palmer in The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, p. 23, 1911.

1,000 parts per million would be palatable to few. The use of water containing large amounts of sulphates tends to produce unpleasant laxative effects. The esthetic quality of water used for drinking is also important, and for this reason it should be clear, colorless, and odorless. Suspended matter not only renders water esthetically unattractive but clogs pipes and valves, reduces the capacity of reservoirs, stains clothes, and produces sludge in boilers. For domestic uses other than cooking and drinking water should be soft, as hard water increases the consumption of soap by forming insoluble compounds that react with the alkaline earths it contains. Hard water and water containing iron also spot and "rust" clothing washed in it.

BOILER WATER.

Water used for generating steam should be examined for the purpose of forecasting and preventing corrosion, which seriously shortens the life of a boiler, and the deposition of scale, which lowers materially the economy of heat transference. The prevention of foaming in the boiler, important in some places, need not be considered in using most of the surface waters of the Pacific Northwest.

CORROSION.

The corrosion or slow solution of a metal manifests itself in boilers as pitting or grooving. As no metal is absolutely insoluble in water, a small, perhaps inappreciable, amount will be dissolved even under ideal conditions. Severe corrosion is caused by the action of acids or, if the boiler metal is nonhomogeneous, by the electrolytic action due to the effect of salt solutions. Severe corrosion due to the presence of organic matter or dissolved gases capable of producing acids, or to the depolarizing effect of dissolved oxygen, may occur even with waters of low mineral content. The substances that cause corrosion are: (1) Dissolved carbon dioxide, hydrogen sulphide, or similar gases; (2) dissolved oxygen; (3) organic matters—particularly organic oils—that produce organic acids by decomposition; (4) dissolved mineral acids; (5) dissolved salts of acid reaction or dissolved salts that are decomposed by heat freeing an acid, such as calcium nitrate, aluminum or copper sulphate, magnesium chloride, and more rarely calcium chloride or magnesium sulphate; and (6) dissolved alkali or other salts that undergo hydrolysis.

Corrosion may be inhibited by allowing a thin film of scale to be deposited in the boiler, by increasing the alkalinity of the water—particularly by means of soda ash—by preheating to remove dissolved gases, by generating an electric current to keep the iron of the boiler electropositive, and by making the boiler shell of absolutely pure homogeneous metal. Each method is effective under proper conditions, but the means to be employed should be adopted after a study of the causes and the resultant economy. Thus far, however, it has been impracticable to make boilers of pure homogeneous metal.

Stabler's formula[1] is useful for ascertaining the approximate tendency of the dissolved solids in a water to produce corrosion. This formula can not be applied haphazard to the soft waters of Washington, as corrosion with them is less likely to be caused by dissolved solid material than by dissolved gases or by acids produced by decomposition of organic matter. The computed corrosion factor for such waters as those of Cedar River is misleading, unless it be understood that it refers only to preheated water and that sufficient soda ash may have to be introduced to counteract the effect of organic acids. The amount of carbonate in solution in many surface waters of Washington is probably sufficient to prevent corrosion from such cause.

FORMATION OF SCALE.

Formation of scale is the deposition of material within the boiler, either by sedimentation of suspended matter or by precipitation of dissolved matter. The scale may vary from soft muck to hard, crystalline, closely adhering incrustations. Any material that is neither corrosive nor volatile will, when present in sufficiently large quantity, form scale, but as the more soluble substances, such as salts of the alkalies, for example, do not become sufficiently concentrated to be deposited, scale usually comprises only compounds of the alkaline earths, suspended matter, and colloidal matter.

The mineral matter in the surface waters of Washington is composed largely of silica, clay, and organic detritus, which is deposited as more or less adherent crust. The colloidal material includes silica, iron, aluminum, and organic materials. Silicon may be present as a silicate radicle in some waters, but it is usually considered to be entirely colloidal silica (SiO_2). Deposits of it from most waters are insignificant, but where it forms a large proportion of the scale-forming material as in the waters of Washington it produces a hard, strongly adherent incrustation, very troublesome and dangerous, and removable only with great difficulty. Iron and aluminum are deposited mostly as hydrates which are converted by heat into oxides, although they may be precipitated as basic salts. They are usually unimportant, but where aluminum sulphate is used as a coagulant in water purification an excess of the reagent hydrolyzing in the boiler may cause precipitation of the hydrate and the formation of a strongly corrosive sulphuric acid. Organic matter, especially that of an oily nature, is dangerous, as it either hydrolyzes and corrodes the metal of the boiler or is deposited as a hard varnish-like coating that renders the boiler walls liable to overheating.

[1] Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, p. 173, 1911.

The chief scale-forming ingredient of most boiler waters is calcium, which is deposited as the carbonate or the sulphate. Few of its compounds undergo hydrolysis, so it can seldom be considered a cause of corrosion. The amount of calcium which can be present without causing serious trouble from scaling depends largely on the relative abundance of the acid radicles present; much more calcium can be present in a carbonate than in a sulphate water, because preheating a calcium-carbonate water precipitates most of the calcium as soft, easily removable sludge, while preheating a calcium-sulphate water removes little scale-forming matter and leaves the water more likely to yield a hard, resistant, and troublesome scale. Magnesium is analogous to calcium in its action in a boiler, except that its salts, hydrolyzing under high pressure, deposit the oxide and set free corrosive mineral acids. Magnesium carbonate may be formed, but even that salt is decomposed under the conditions in most boilers.

Alkaline salts have been stated to form no permanent precipitates, but to undergo hydrolysis and cause corrosion when they are sufficiently concentrated. As addition of soda ash or other alkaline salt in water softening increases the amount of alkalies in the softened water and therefore its tendency to foam, it is necessary to determine whether the chemical treatment is likely to remove one objectionable feature by introducing another.

Bicarbonates are converted by heat into carbonates, which are precipitated in combination with the alkaline earths. Many natural waters contain enough bicarbonate in solution to precipitate thus the greater part of the alkaline earths and the addition of reagents for softening is then unnecessary. The carbonate scale from such water is soft sludge easily removable from the heating system by blowing off or by similar means. Carbonate scale is the least harmful to boilers and the object of chemical treatment is to remove as much as possible of the scale-forming material as carbonates.

Sulphates form hard, compact scale with the alkaline earths. As it is not economical to remove the sulphate radicle from most waters, it is customary to add sufficient alkaline carbonate to precipitate the alkaline earths and to leave the sulphates in equilibrium with the alkalies. The quantities of nitrates and chlorides in most waters of Washington are not great enough to make them important in boiler-room practice, though they may act as powerful corrosives under some conditions in highly concentrated waters.

FOAMING.

Foaming in boilers is the formation of bubbles in the steam space above the surface of the water. If foaming proceeds to such extent that water is forced from the boiler with the steam, "priming" is said to occur. The causes of foaming and priming are somewhat obscure, but it seems probable that they may be due to the presence of the hydroxide radicle, as it appears that foaming results when a solution containing a weak acid in balance with a strong base is heated, unless it is prevented by outside agencies. As the amount of alkaline bases in a water is an index of its hydroxyl-producing power, it seems reasonable to adopt the measure of the total alkali bases as the index of foaming propensity, and that is the common custom. Suspended matter, not only that normally in the feed water but also that composed of precipitated sludge, and small particles of scale loosened from the deposits in the boiler may, however, cause foaming, and it is well recognized that with some waters foaming and priming depend much on the design of the boiler and the manner of its operation.

FACTORY WATERS.

CHIEF INDUSTRIES AFFECTED.

The factories of Washington in which quality of water has direct bearing on economy of operation or quality of output or both comprise breweries, dye works, ice plants, laundries, meat-packing houses, paper and pulp mills, soap factories, tanneries, woolen mills, and wool-scouring works. The largest establishments are the paper mills, breweries, woolen mills, and laundries. A brief discussion of the use of water and the harmful effects of certain constituents in each of these industries is presented in the following paragraphs. The reader is referred to any of the standard works on industrial chemistry or the use of water in special industries for more complete discussions of the operations and reactions that are involved.

BREWERIES.

The water used for brewing must be of great bacterial purity and must contain suitable mineral matter in solution, for it is not only a solvent and a reaction medium throughout the whole process, but forms a part of the finished product. Decomposable organic substances or bacteria are especially harmful, as they mold the barley, lessen the activity of the yeast, and destroy the keeping qualities of the beer by producing offensive putrefaction products.[1] Iron forms dark-colored precipitates with the diastase, thus disturbing the conversion of the barley. As it also forms inks with the tannin of the hops, the beer acquires a dark color, a disagreeable odor, and an unpleasant taste.

Calcium-sulphate water is desirable for making light-colored beers free from resinous taste, because the calcium sulphate, by reacting with the soft resins ("bitter principle") dissolved from the hops, produces insoluble resins and thus removes them from the beer.

[1] Palmer, Chase, Quality of the waters [of the Blue Grass region of Kentucky]: U. S. Geol. Survey Water-Supply Paper 233, p. 195, 1909.

Water high in alkaline carbonates makes a dark beer, on the other hand, as the carbonates promote the solution of these resins. Light beers are said to have a hop flavor and dark beers a malt flavor, but there is more hop material dissolved in dark than in light beers, the difference in flavor being due to the greater amount of resins in the dark beer and to the slighter solubility of both hop resins and malt in the sulphate water of the light beers. Waters moderately high in chlorides aid the fermentation; but if they are too high in chlorides, development of the yeast, and therefore fermentation, is retarded. Sulphur dioxide for sterilizing the barrels in which beer is shipped is used to some extent; but if other means of disinfection were employed and the keeping qualities of the beer were insured by proper care of the water supply, the general quality of the beer would be higher.

PAPER MILLS.

Water is used in immense quantities in the manufacture of paper, many mills requiring almost 400,000 gallons of water per ton of product. The water serves as a solvent and a carrier for chemicals, as in digesters and cookers; it conveys the pulp through the various processes; it is the medium in which the wastes are removed; and large amounts are used in the boilers and heaters. The water is usually treated to remove suspended and organic matter, particularly living organisms. Much suspended matter may cause irregularities in texture and appearance of the finer grades of paper, and organic matter may promote algal growths that streak and spot the paper and choke screens and pipes. Organic matter also wastes bleach and bisulphite liquors. Iron is especially undesirable in the water as it deposits from alkaline solutions and spots or streaks the paper. Cross and Bevan [1] state that very soft water is undesirable for loading papers with any form of calcium sulphates, because of the solubility and consequent waste of these materials in such waters. Dole [2] mentions the probable undesirability of strong chloride waters for the same reason. But very hard water is at least equally objectionable in the chemical process and is much more so for use in making the large amounts of steam that are required in most mills. Hard water deposits calcium carbonate on the screens used to separate the pulp from the liquors; it also interferes with sizing and dyeing, precipitating the resins of the size, and wasting the dyes or changing their actions. The presence of alkali chlorides, on the other hand, is helpful in separating the thick sludge from the size liquor in preparing size.

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[1] Cross, C. F., and Bevan, E. J., A textbook of paper making, New York, p. 294, 1900, cited by Dole, R. B., in The underground waters of north-central Indiana: U. S. Geol. Survey Water-Supply Paper 254, p. 247, 1910.

[2] Capps, S. R., and Dole, R. B., The underground waters of north-central Indiana: U. S. Geol. Survey Water-Supply Paper 254, p. 247, 1910.

WOOL-SCOURING, BLEACHING, AND DYEING WORKS.

Water in which wool is scoured should be soft, as hard water forms with the grease of the wool insoluble soaps that cling to the fiber and interfere with subsequent processes, thus causing the wool to be of inferior grade, hard "feel," poor luster, and uneven color. Very little wool is now bleached, as the natural cream-colored stock is more salable. Wherever wool is bleached, however, it is customary to use sulphur dioxide, which is less injurious to the fiber than hypochlorite powder. Sodium peroxide is an effective bleaching agent for wool,[1] but hypochlorites can not be used because they would combine with the fiber without destroying the color.

Though hard water is required in some processes, soft water is generally essential in economical and successful dyeing of wool. This textile combines with dyes much more readily than does cotton or linen, owing to the nitrogen in the wool, and dyeing it is therefore somewhat simpler. The dyes may be of acid, basic, or mordant type. As the reactions involved are delicate and easily disturbed, and as large quantities of water are used, it is very important to avoid irregularities in its quality that may cause variations in the color of the finished product. In some processes the dye may be precipitated on the fiber by reaction with alkaline earths and thus produce irregular spots. Iron is especially objectionable because it may alter the colors in white and madder dyeing. Chlorides in large amounts are also objectionable, as they may react with the dyes.

LAUNDRIES.

Hard water causes waste of soap in laundries because the calcium and magnesium in the water form insoluble compounds with the fatty acids of the soap and thus destroy its cleansing value. The alkaline-earth soaps thus formed are deposited on the fabrics and partly decomposed by heat and thus produce spots on the cloth. Iron is objectionable because it gives rise to rusty spots, and suspended matter because it soils fabrics.

Whipple,[2] who has determined by means of nine makes of soap the soap-consuming power of waters of different hardness, concludes that for each part per million increase in hardness about 200 pounds more of soap is required to soften 1,000,000 gallons of water. At 5 cents a pound this represents a loss of $10 per million gallons for each part per million increase in hardness. If his figures are applicable to softer waters than those he mentioned, it would require almost 2,000 pounds of soap to give cleansing properties to 1,000,000 gallons of soft water. Any soap consumption greater than 1 ton per million gallons of water therefore represents waste.

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[1] Matthews, J. M., Textiles, in Rogers and Aubert's Industrial chemistry, p. 733, New York, 1912.
[2] Whipple, G. C., The value of pure water, p. 26, New York, 1907.

OTHER INDUSTRIES.

Hides to be tanned are unhaired by solutions of quicklime. If very hard water is used in that process, calcium carbonate that is deposited on the skins prevents thorough action of the tannin and thus causes spots in the leather. The tannin of the tan bark is not thoroughly extracted and may be precipitated by hard water. Large quantities of chlorides prevent "plumping" in the tanning process and make the leather thin and flabby.[1]

Meat-packing industries use large quantities of water in the washing and preparation of the various by-products, and it is necessary that this water be free from organisms which may grow in and decay the finished goods. Soft water is also preferable, as much water is employed for heating.

PURIFICATION OF WATER.

FILTRATION.

TYPES OF FILTERS.

Filtration of water has long been used as a method of removing suspended matter, including bacteria, and of destroying dangerous organic matter. Two general types of filters are used, the "slow sand" type, in which the water is passed through sand the top layers of which are removed, cleaned, and replaced, as necessary; and the "rapid sand" type, in which filtration is preceded by induced coagulation so that the particles to be removed shall be larger, and the water is passed through sand layers which are washed in place at frequent intervals. The construction, operation, and efficiency of many plants of both types and disinfection and similar topics are discussed at length by George A. Johnson in "The purification of public water supplies."[2]

SLOW SAND FILTRATION.

Slow sand filters have been used for nearly a century and are constructed in essentially the same manner now as when first built. A series of perforated tiles or pipes connected with a discharge pipe is laid on the bottom of a large impervious basin, now usually constructed of concrete. Layers of gravel, graded in size from 25 to about 3 millimeters in diameter, are placed over this network to a depth of about 1 foot, and over the gravel is placed a layer of fine sand 2 to 5 feet thick. Regulating chambers, pumps, and sand-cleaning devices are secondary mechanical features of the plant. The filters are roofed where danger from freezing is serious. Where the climate is mild the beds may be left open, in order to lessen cost of construction. The filters are divided into beds usually less than

[1] Rogers, A., Leather, in Rogers and Aubert's Industrial chemistry, p. 798, New York, 1912.
[2] U. S. Geol. Survey Water-Supply Paper 315, 1913.

an acre in extent, so that units can be withdrawn from service for cleaning without interrupting filtration.

During filtration the water sinks through the sand, in which its suspended mud and bacteria are retained, and flows through the discharge pipe into the clear-water basin or the distribution system. The rate of filtration, ranging from 2,000,000 to 4,000,000 gallons per acre per day, depends on the physical condition of the filter, the thickness of the bed, the average size of the sand particles, the turbidity of the water, and its temperature. When the loss of head in the filter, as it becomes clogged with slime and detritus from the water, becomes great enough to cause too slow filtration, about half an inch of sand is removed from the top of the bed and filtration is resumed. The sand is washed and replaced before successive removals render the bed too thin to be efficient. The time between cleanings is materially shortened when very turbid waters are filtered, so the slow sand process is adaptable only to relatively clear waters or to those that have previously been partly clarified by sedimentation. Color is removed only slightly, hardness is not altered, and slight destruction of organic matter takes place.

The efficiency of the filtration depends only partly on the straining action of the sand particles, for it is greater in a filter that has been in service for a short time than in a clean one, possibly because of the absorption of materials as they pass through the coating of gelatinous muck, and possibly because of the colloidal agglutination and also the mechanical straining of the water through the jelly-like mass at the surface of the sand layer. Bacteriologic action in the deeper layers of the bed partly oxidizes the organic matter in the water and prevents further growth of organisms by destroying the available bacterial food.

The raw water is usually passed first through strainers, or "roughing filters," or detained in a sedimentation basin in order to remove excessive quantities of suspended matter. Water containing large amounts of iron is troublesome because of its tendency to assist growth of crenothrix, an iron-secreting alga, in the underdrains and discharge pipe. Water containing much iron may be aerated before filtration by being sprayed in fountain-like jets over the raw-water basin, thereby oxidizing and precipitating the iron. At several places, especially in Europe, preliminary sterilization, by ozone, ultra-violet rays, or other means, is practiced. A very high degree of purity is thus attained, but the method is applicable only to clear waters.

RAPID SAND FILTRATION.

A rapid sand filter contains two essential parts, the coagulation basin and the filter bed. The coagulation basin, generally an oblong tank, is of such size and construction that the water requires two to four hours to reach the outlet into the filter chamber. Time for sedimentation as well as coagulation is thus allowed. The filter chamber consists of a tank, circular in the early forms but rectangular in the larger modern types, fitted with a perforated bottom, the openings of which are small enough to prevent the sand grains from entering, but large enough to allow ready outflow of the filtered water. On the bottom is a bed of carefully graded sand, 30 or 40 inches deep and somewhat coarser than that used in slow sand filters. After the water, mixed with the dissolved coagulant, has stood for a proper period in the coagulation basin it flows into the upper part of the filter chamber and passes rapidly through the bed of sand into the drainpipes which conduct it to the clear-water basin for distribution. The rate of filtration is 80,000,000 to 190,000,000 gallons an acre a day, the usual rate being about 125,000,000 gallons.

Though several other coagulants are used the most common one is aluminum sulphate. When this substance is introduced in solution into the raw water it is immediately hydrolyzed to form aluminum hydrate and sulphuric acid. The sulphuric acid reacts with part of the carbonates, bicarbonates, and hydrates, setting free carbon dioxide and converting temporary into permanent hardness. While the aluminum hydrate precipitated in the alkaline solution as a gelatinous mass is forming and congealing, it enmeshes the suspended matter, including bacteria, and absorbs color. If the alkalinity of the water is not great enough to react with all the aluminum sulphate some of the coagulant remains in solution, the efficiency of coagulation is reduced, and the effluent is acid in reaction and consequently corrosive. This trouble is obviated by adding with the aluminum sulphate milk of lime or a solution of soda ash in proper proportion. The coagulant remaining in the water after the imperfect sedimentation in the coagulation chamber forms on the sand in the filter a slime that makes filtration more thorough. As rapid accumulation of this slime causes the loss of head to become excessive, the filter must be frequently cleaned—usually two to four times a day. This is done by passing clean water upward through the sand, and at the same time forcing compressed air through the perforations to break up any agglomerations of sand and dirt. The sand is thus thoroughly mixed at each washing, so that it can not segregate into pockets. The dirty water flows away over the top of the filter. About 4 to 8 per cent of the filtered water is consumed in washing, and the process usually takes from 6 to 12 minutes. Agitation of the sand during washing is effected in some of the older filters by means of revolving rakes with prongs extending downward into the sand.

The rapid sand filter affects the chemical composition of the water to a much greater extent than the slow sand filter. Color is greatly reduced, some iron is precipitated, carbonates, bicarbonates, and hydrates are replaced to some extent by sulphates, and the total mineral content may be slightly increased. If large amounts of lime are added, the hardness and total mineral content are decreased; otherwise the temporary hardness is decreased and the permanent hardness proportionately increased. With filters of this type highly turbid waters can be treated, smaller basins are required than for slow sand filters, and highly colored waters can be partly decolorized. As the method is used chiefly for filtering river waters whose quality is subject to frequent and important fluctuations, its economical operation requires constant and intelligent supervision.

STERILIZATION.

Some methods by which sterilization of water for domestic consumption has been attempted rely on direct destruction of the bacteria, and others on their indirect destruction by oxidation and consequent removal of their food material, but combinations of the two methods have generally proved most efficient.

Calcium hydrochlorite has recently been used with excellent success to sterilize contaminated water supplies, especially in emergencies, and several hundred cities in the United States are now applying such treatment, most of them in conjunction with other methods of purification. The action of the hypochlorite depends on the fact that its solution in contact with the water decomposes to form, first, hypochlorous acid, and, second, nascent oxygen. The immediate and chief effect is oxidation, although slower less thoroughly understood reactions[1] complete the destruction of organisms. The successful use of this substance and the ease with which its application can be controlled place it in first rank among disinfectants of water. If the sodium salt is used the water is softened, but if the calcium salt is used the hardness may be slightly increased; the effect of such change is, however, practically negligible, as the hypochlorite is applied in so small quantity.[2]

The early use of hypochlorite was attended by numerous complaints, because lack of definite knowledge regarding the proper quantity of reagent resulted in overdoing and thus imparting to the waters a strong medicinal taste or even an odor. Increased knowedge of the process proved that very small amounts of reagent are generally adequate to insure disinfection and that no odors or tastes result when the hypochlorite is properly applied.

Copper sulphate[3] has been used more often for the purpose of destroying algal growths than for destroying dangerous bacteria. Use

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[1] Rideal, Samuel, Water disinfection by chemical methods: Eng. News, vol. 68, p. 702, 1912.

[2] Johnson, G. A., The purification of public water supplies: U. S. Geol. Survey Water-Supply Paper 315, p. 67, 1913.

[3] A symposium on the use of copper sulphate and metallic copper for the removal of organisms and bacteria from drinking water: New England Waterworks Assoc. Jour., vol. 19, p. 474, 1905.

of it may, however, leave undesirable and even harmful copper salts in solution; alkaline salts may cause waste of the chemical by precipitating the copper at the moment of application. The usual method of application—towing a sack of solid reagent around the reservoir—is also crude and expensive. Copper sulphate has nevertheless proved to be a valuable algacide, and it has been decidedly beneficial to some waters.

Ozone is theoretically an ideal reagent for disinfection, as the only products of its complete reaction with organic materials are carbon dioxide and water. Considerable progress has recently been made in the use of this reagent, and sterilization by ozone is a valuable adjunct to filtration in Paris, St. Petersburg, and several other European cities. The chief drawbacks have been the expense of manufacturing the ozone and the mechanical difficulties of effecting application without wasting the reagent.

Ultra-violet rays have been successfully used in Europe to sterilize water, but the process is still in an experimental stage in the United States.

SOFTENING.

Water is softened for the purpose of removing suspended matter, iron, aluminum, calcium, magnesium, and sometimes sulphates, particularly before its use in boilers. Preheating alone removes enough of the objectionable materials from some waters, but further treatment of others may be required.

Many methods alleged to obviate boiler troubles consist in introducing into the boiler with the feed water some "boiler compound" and subsequently removing the deposits produced by it. Many so-called "boiler compounds" contain, in addition to considerable inert material, tannin or derivatives of tannic acid, which being corrosive are destructive to the boiler. Some containing acetic or other acids are harmful for similar reasons. Others contain organic material, such as glycerin, wood extract, or molasses, whose effects are solvent as that of glycerin, or mechanical as that of molasses. Starchy materials have also been employed. All such compounds are harmful by causing corrosion or even scale production, or by thickening and fouling water in the boiler. In general the introduction of reagents into the boiler is inadvisable and, where such practice is necessary because of inability to treat the supply before it enters the boiler, one or more of the inexpensive chemicals whose action and efficiency have been thoroughly established should be used.

Several really efficient reagents are available for softening water and preventing scale, the most widely used of which are lime, as caustic lime ($Ca(OH)_2$), and soda, as soda ash (Na_2CO_3), or more rarely as caustic soda ($NaOH$). Barium carbonate is very efficient chemically for softening some bad waters, especially those high in sulphates, but it and other salts of barium are little used because of their cost. "Permutite" (an artificial zeolite whose formula approaches $2SiO_2.Al_2O_3.Na_2O+6H_2O$) and the iron-alum reagents have also been used with reputed success.

The softening effect of lime is due to its formation of insoluble hydrates by reaction with certain basic radicles and calcium carbonate by reaction with the free carbon dioxide and the bicarbonate radicle in the water. Lime is not needed in hot treatment, as preheating accomplishes much the same work. Caustic soda, which is sometimes used instead of caustic lime, has the decided disadvantage of increasing the total dissolved alkalies and consequently the danger of foaming and priming. It has no real advantage over lime with soda ash, which can be added if desirable. As calcium sulphate is not precipitated by lime alone, soda ash also is used in some waters; it removes the calcium as calcium carbonate, but leaves in solution the sulphate radicle which could be removed by means of barium carbonate if the expense were not prohibitive for most waters.

The amount and nature of the reagents for softening water depend on the chemical composition of the water and on the method of treatment. Lime need not be added in hot treatment, as the bicarbonate radicle is decomposed by heat into free carbon dioxide, which escapes as a gas, and the carbonate radicle which precipitates all or part of the alkaline earths. Some waters produce sufficient carbonate in this manner to react with all the calcium and magnesium and therefore need only to be heated to purify themselves. Waters deficient in this respect may be treated with soda ash before being heated.

It is not economical to soften all hard waters. Some waters are so highly charged with incrusting materials that they can not be used profitably even after softening because the foaming ingredients are so greatly increased; others are so slightly mineralized that sufficient scale to interfere noticeably with steaming is not deposited except after long periods of service. Dole,[1] citing the findings of the committee on water service of the American Railway Engineering and Maintenance of Way Association, states that it is not advisable to soften waters containing more than 850 parts per million of nonincrusting material and much incrusting sulphates, but that it is generally economical in locomotive practice to treat waters containing 250 to 850 parts per million of incrustants and those containing less than the lower amount if a large proportion of the incrustants is sulphates. An approximate classification reproduced from Dole's paper is as follows:

[1] Capps, S. R., and Dole, R. B., The underground waters of north-central Indiana: U. S. Geol. Survey Water-Supply Paper 254, p. 244, 1910.

Approximate classification of waters for boiler use according to proportion of incrusting and corroding constituents.

Parts per million.		Classification.
More than—	Not more than—	
....	90	Good.
90	200	Fair.
200	430	Poor.
430	580	Bad.
680	....	Very bad.

METHODS OF ANALYSIS.

Daily samples of water were collected for a year or less at each station (see list on p. 8) and mailed to the laboratory, where 10 consecutive samples were united. The composites thus obtained were analyzed in accordance with the general methods described by Dole,[1] though some exceptions should be noted.

The total suspended matter in waters of great turbidity and high coefficient of fineness was determined by taking from 100 to 250 instead of 500 cubic centimeters of the water. In the determination of alkalies one additional treatment with barium hydrate, followed by treatment with ammonia and ammonium carbonate, was employed in order to insure complete removal of impurities. The final residue was evaporated and weighed in a platinum dish. Fiftieth-normal sulphuric acid was substituted for potassium acid sulphate in titration of alkalinity, as there is no apparent advantage in the use of the acid salt.

Besides the analysis of the composite samples, daily determinations of color and alkalinity were made for a great part of the time. Color was estimated by comparing the tint of the filtered samples with that of a series of shaded glasses that had been standardized by means of the usual solutions of cobalt and potassium-platinic chlorides.[2]

INTERPRETATION OF THE RESULTS OF ANALYSIS.

INDUSTRIAL INTERPRETATION.

Formulas for the industrial interpretation of water analyses have been developed by Stabler,[3] to whose articles the reader is referred for a full discussion of them. The formulas are as follows:

$A=11+1.79\ Fe+5.54\ Al+2.5\ Ca+4.11\ Mg+49.6\ H.$

$B=H+0.0361\ Fe+0.1116\ Al+0.0828\ Mg-0.0336\ CO_3-0.0165\ HCO_3.$

$C=0.00833\ Sm+0.00833\ Cm+0.0107\ Fe+0.0157\ Al+0.0138\ Mg+0.0246\ Ca.$

[1] Dole, R. B., The quality of surface waters in the United States, pt. 1: U. S Geol. Survey Water-Supply Paper 236, pp. 9-26, 1909.

[2] Report of the committee on standard methods of water analysis, Am. Pub. Health Assoc., p. 10, New York, 1912.

[3] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, p. 355, 1908; also The industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 165, 1911.

$D = 0.00833\ SiO_2 + 0.0138\ Mg + (0.016\ Cl + 0.0118\ SO_4 - 0.0246\ Na - 0.0145\ K)$.

$E = 0.00931\ Fe + 0.0288\ Al + 0.0214\ Mg + 0.258\ H + 0.00426\ HCO_3 + 0.0118\ CO_2$.

$F = 0.0167\ Fe + 0.0515\ Al + 0.0232\ Ca + 0.0382\ Mg + 0.462\ H - 0.0155\ CO_3 - 0.00763\ HCO_3$.

$k = \frac{2,040}{Cl}$ (when Na−0.65 Cl is zero or negative).

$k = \frac{6,620}{Na + 2.6\ Cl}$ (when Na −0.65 Cl is positive but not greater than 0.48 SO_4).

$k = \frac{662}{Na - 0.32\ Cl - 0.43\ SO_4}$ (when Na−0.65 Cl−0.48 SO_4 is positive).

A represents cost in cents of soap at 5 cents a pound required to soften 1,000 gallons of the water.

B represents corrosion coefficient, or relative tendency to produce corrosion in a boiler. Stabler states that if *B* is positive the water is certainly corrosive, if $B + 0.0503$ Ca is negative no corrosion because of the mineral constituents will occur, and if *B* is negative but $B + 0.0503$ Ca is positive, corrosion may or may not occur, the probability of corrosion varying directly with the value $B + 0.0503$ Ca.

C represents the number of pounds of scale which may be formed in the boiler per 1,000 gallons of feed water.

D represents, similarly, the number of pounds of hard scale; whence the relative hardness of the scale is $\frac{D}{C}$.

E is the number of pounds of 90 per cent lime required to soften 1,000 gallons of water.

F is the number of pounds of 95 per cent soda ash required to soften 1,000 gallons of water.

k, the alkali coefficient, is an index of the value of the water for irrigation; it is the depth in inches of water which on evaporation would yield sufficient alkali to render a 4-foot depth of soil injurious to the most sensitive crops.

Fe, Al, Ca, Mg, H, CO_3, HCO_3, Na, K, Cl, SO_4, SiO_2, CO_2, Sm, and Cm represent, respectively, the amounts in parts per million of iron, aluminum, calcium, magnesium, acidity (calculated as hydrogen), carbonates, bicarbonates, sodium, potassium, chlorine, sulphates, silica, free carbon dioxide, suspended matter, and colloidal matter (silica, iron oxide, and alumina).

The number of pounds of soap (*G*) necessary to soften 1,000 gallons of the water is obtained by dividing *A* by 5:

$$G = 2.2 + 0.336\ Fe + 1.1\ Al + 0.5\ Ca + 0.822\ Mg + 0.92\ H.$$

This formula practically becomes for most waters of Washington $G = 2.2 + 0.5\ Ca + 0.8\ Mg$. The cost of softening with an average soap can then be obtained by multiplying *G* by the price per pound in cents. In like manner the cost of softening by lime and soda ash can be obtained by multiplying *E* and *F* by the price per pound of the respective reagents.

Stabler classifies irrigation waters, in conformity with ordinary irrigation practice in the United States, as follows:

Classification of irrigation waters.

k.	Class.	Remarks.
More than 18	Good	Have been used successfully for many years without special care to prevent alkali accumulation.
18 to 6	Fair	Special care to prevent gradual alkali accumulation has generally been found necessary except on loose soils with free drainage.
5.9 to 1.2	Poor	Care in selection of soils has been found to be imperative and artificial drainage has frequently been found necessary.
Less than 1.2	Bad	Practically valueless for irrigation.

Whether injury actually would result from the application of a given water to any particular piece of land, however, depends on methods of irrigation, the crops grown, the character of the soil, conditions of drainage, and quantity and distribution of rainfall, and it should be clearly understood that the alkali coefficient in no way takes account of such conditions.

GEOCHEMICAL INTERPRETATION.

The geochemical interpretation of water analyses depends on the geologic significance of the materials entering into solution. The primary rock formations yield water containing a high percentage of alkalies, but sedimentary and metamorphic rocks yield waters containing greater proportions of the alkaline earths. Primary formations are usually siliceous and neither chlorides nor sulphates are prominent in them. Many secondary formations are rich in salts of these strong acid radicles, though carbonates also are abundant. Solutions of the alkaline materials from silicate rocks are high in carbonates. When surface waters collect in basins to form landlocked lakes dissolved matter is gradually concentrated, and salts are precipitated in accordance with their respective solubilities. A great proportion of the alkaline earths is usually removed from the solution during early stages of concentration; in chloride waters, however, magnesium chloride is one of the last materials to be deposited. Lake waters from volcanic regions produce carbonate waters on concentration; those from sedimentary regions may produce sulphate waters, and the final stage of continued concentration and deposition of salts produces the chloride waters, or true brines.

Palmer [1] has attempted to establish a system of geochemical classification of natural waters based on the above facts, and his paper on this subject is an important contribution to the science. His classi-

[1] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

fication depends on the relationship between the radicles in waters and the types of rock from which they are dissolved, and, secondarily, on the concentration of the waters. The positive radicles determined by analysis are grouped as (1) alkalies (sodium and potassium), (2) alkaline earths (calcium and magnesium), and (3) hydrogen (free acids).

The weak acid radicles (chiefly carbonate and bicarbonate) together are considered to measure the property of "alkalinity" and the strong acid radicles (chiefly chloride, nitrate, and sulphate) to measure the property of "salinity." As the alkalies are characteristic of the older or primary formations, alkalinity or salinity due to their salts is called primary alkalinity or primary salinity. As alkaline earths are characteristic of secondary rocks, alkalinity or salinity due to them is called secondary alkalinity or secondary salinity. Salinity due to free acids is called "tertiary" salinity.

In applying his classification Palmer has used the reaction coefficients of the radicles, as determined by Stabler,[1] which are the quotients obtained by dividing the valences of the radicles by their respective molecular weights. The reaction coefficients of the radicles commonly reported in water analyses are shown in the following table:

Reaction coefficients of common radicles.

Positive radicles.		Negative radicles.	
Ferrous iron (Fe)	0.0358	Carbonate (CO_3)	0.0333
Aluminum (Al)	.1107	Bicarbonate (HCO_3)	.0164
Calcium (Ca)	.0499	Sulphate (SO_4)	.0208
Magnesium (Mg)	.0822	Chlorine (Cl)	.0282
Sodium (Na)	.0435	Nitrate (NO_3)	.0161
Potassium (K)	.0256		
Hydrogen (H)	.992		

If the amount of a radicle obtained by analysis is multiplied by its reaction coefficient the product is the reacting value of the radicle. The quotients obtained by dividing the reacting value of each radicle by the sum of all the reacting values represent the percentage reacting values from which Palmer's classification is made. He divides waters into five classes, according to the relative numerical values of the various groups of percentage reacting values. If a, b, and d represent, respectively, the percentage reacting values of the alkalies, alkaline earths, and strong acids, any one of five numerical conditions may exist; d may be less than a, equal to a, greater than a and less than $a+b$, equal to $a+b$, or greater than $a+b$. He computes the properties of reaction of each class according to the following formulas:

[1] Stabler, Herman, The industrial application of water analyses: U. S. Geol. Survey Water-Supply Paper 274, p. 167, 1911.

Formulas for properties of reaction.

CLASS I.

d less than a.

$2d$, primary salinity.
$2(a-d)$, primary alkalinity.
$2b$, secondary alkalinity.

CLASS II.

d equal to a.

$2a$ or $2d$, primary salinity.
$2b$, secondary alkalinity.

CLASS III.

d greater than a; d less than $a+b$.

$2a$, primary salinity.
$2(d-a)$, secondary salinity.
$2(a+b-d)$, secondary alkalinity.

CLASS IV.

d equal to $a+b$.

$2a$, primary salinity.
$2b$, secondary salinity.

CLASS V.

d greater than $a+b$.

$2a$, primary salinity.
$2b$, secondary salinity.
$2(d-a-b)$, tertiary salinity (acidity).

Palmer found that surface waters belong chiefly to the first three classes and that sea water and brines form the greater number in Class IV.

SKAGIT RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Skagit River rises in the Cascade Mountains in British Columbia, flows southward between the main axis of these mountains and Custer Ridge across Whatcom County into Skagit County, where it turns westward, flowing first through a narrow and later through a broader valley and finally discharges through a delta into Puget Sound. It is a navigable stream with shifting bed for about 70 miles above its mouth, but in its upper course it is swift flowing and confined in a narrow bed.

The drainage basin includes the region between the main Cascade divide and Custer Ridge, the slopes of the Cascades north of Monte Cristo and Indian Pass, and, through Baker River, the southern slopes of Mount Baker. The most important of the many tributaries are Ruby Creek and Sauk and Baker rivers. Because of its position in the Puget Sound area and of the character of its basin, the river is unusual even for a stream on the western slope of the Cascade Range, for its run-off per square mile is probably greater than that of any other moderate-sized river in the United States.

The scanty data regarding the geologic features of the Skagit basin indicate that the northern part is composed largely of schists, slates, and sandstones, probably early Carboniferous in age. Certain outcrops near the Canadian boundary have been classed as Jurassic or Triassic, though the precise geologic series has not been established. The contact between the schist formations and the Tertiary coal measures, which form the surface rock of the middle valley, is near Hamilton. Bodies of limestone near Baker furnish raw material for the cement industry of Washington. The rocks near Marblemount are largely granitic. Sauk River drains an area of slates, shales, sandstones, and granite. The lower valley of Skagit River, well defined where it cuts through the glacial deposits of Puget Sound basin, and its slight slope are indications of advanced maturity.

Rainfall in the drainage area ranges from about 40 inches a year near the Sound to more than 100 inches in the mountains. At Monte Cristo, measurements made by the Weather Bureau between 1895 and 1901 recorded precipitation of about 120 inches a year. Precipitation probably is still greater at other places.

The upper section of the basin is heavily wooded below the snow line. Floods, some exceedingly destructive, are usual in spring. Discharge measurements by the Geological Survey on Skagit River during 1910–11 and gage heights recorded by the Corps of Engineers, United States Army, make it possible to compute the variations in run-off as well as the total discharge for the period of investigation shown in the table of analyses. On the assumption that run-off is 85 per cent of the rainfall, the precipitation estimated from this discharge is not less than 85 or 90 inches on the area above Sedro Woolley.

The river valley above Marblemount is practically uninhabited. Below this place, at Concrete and Baker, are the cement plants of the Washington and Superior Portland cement companies. Sedro Woolley is the center of the lumber, canning, dairying, and agricultural industries of the middle lower valley. Mount Vernon, near the mouth of the river, is the center of an extensive dairy country. Mount Vernon has at times used Skagit River as a source of municipal water supply, but the water at this point is too badly polluted for domestic use without purification. Sedro Woolley is supplied from a small upland stream, whose water is carried across Skagit River through a pipe line.

CHARACTER OF THE WATER.

Samples of water were collected daily from Skagit River at the Northern Pacific Railway bridge near Sedro Woolley from February 1, 1910, to January 31, 1911, inclusive, by E. J. Woods, bridge tender for the Northern Pacific Railway Co. The gaging station of the United States Geological Survey is at the same place and the drainage area above that point is 2,930 square miles.

The river water is soft and of good quality for ordinary industrial uses. The small amount of rather coarse suspended matter that it usually carries can be removed by sedimentation for 24 to 36 hours. The use of this water in boilers may at times result in corrosion that may be prevented by the addition of small amounts of soda ash or lime. The organic matter is the result of the presence of the immense schools of salmon which swim far up the river during the spawning season, and, dying off after spawning, litter the shores and fill the stream with the products of their decomposition. This organic material may induce corrosion or other troubles in boilers.

The excess of sulphate over the alkalies is entirely in accord with what is known of the geology of the basin, for the prevailing rocks are sedimentary and part of the strata is entirely unmetamorphosed. The slight variations in mineralization are shown mostly in chlorine, sulphate, and calcium. The relatively large variations in turbidity correspond to the fluctuations in stream flow.

The content of silica is much less than that usually found in waters flowing from lava formations, and it is characteristic of run-off from the metamorphosed Paleozoic rocks of the headwater region rather than that from the later formations of the lower reaches.

The rate of denudation in the drainage basin is greater than that of most areas on the western slope of the Cascades. For each square mile of surface drained, 258 tons of mineral matter in solution and 124 tons in suspension are annually carried to the ocean—a total of 382 tons per square mile, or about six-tenths of a ton per acre of land. Because of this high rate of erosion soil is practically lacking in the steeply sloping parts, the little that exists being held in place by the matter roots and fibers of the forest growth. Destruction of forests in the mountainous regions will quickly be followed by exposure of the rock surface over large areas, and drifts or eddies of soil will remain only in the hollows and crevices.

The determinations of the color and alkalinity of the water, made on samples collected daily from March 13 to June 15, 1910, inclusive, show the daily fluctuation only during flood stages, and therefore are more irregular than the determinations of the average fluctuations for the year would indicate. The water is not highly colored for spring-flood water, doubtless because no great amount of humus material accumulates in the mountains during winter to be washed into the streams during spring and summer. The alkalinity is so low that small amounts of soda ash or lime would probably have to be added at times if coagulants or hypochlorites were used in purifying the water.

Mineral analyses of water from Skagit River at Sedro Woolley, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Feb. 1	Feb. 10	4	4.2	1.05	15	0.30	9.4	2.7	3.2	0.0	39	11	0.63	0.5	65	38.64	10,386	118	1,820
11	20	3	3.2	1.07	15	.90	11	2.2	5.7	.0	41	12	.12	1.5	68	37.72	7,997	69	1,470
21	Mar. 2	15	18	1.20	15	.10	12	3.0	6.5	.0	49	8.3	.12	.7	69	38.48	10,085	490	1,880
Mar. 3	12	10	15	1.50	8.7	.05	8.4	2.6	3.1	.0	26	14	.50	.5	59	39.97	14,430	585	2,300
13	22	15	30	2.00	13	.08	7.4	2.4	3.6	.0	31	7.2	.30	.3	54	41.41	19,310	1,560	2,820
23	Apr. 1	9	9.1	1.01	7.2	.03	8.3	2.0	4.4	.0	38	8.5	.30	.5	49	40.24	15,220	374	2,010
Apr. 2	11	20	12	.60	14	Trace.	10	3.5	8.2	.0	48	6.9	....	2.0	79	39.90	14,110	458	3,010
12	21	8	6.4	.80	18	.30	9.2	2.0	4.9	.0	34	9.2	.30	.5	63	40.45	15,920	275	2,710
22	May 1	50	68	1.36	9.6	.01	7.6	3.0	4.7	.0	32	5.3	Trace.	.7	46	43.27	26,760	4,910	3,320
May 2	11	20	35	1.75	14	.06	7.6	1.5	5.8	.0	31	6.7	.00	.4	55	43.19	26,670	2,520	3,960
12	21	15	26	1.73	14	.05	7.6	1.6	3.9	.0	29	10	.00	.4	54	43.46	27,430	1,930	4,000
22	31	20	42	2.10	15	.05	6.8	1.4	4.1	.0	21	15	.00	.1	67	43.87	29,080	3,300	5,250
June 1	June 10	10	14	1.40	7.1	.04	7.5	1.2	3.5	.0	26	8.0	.00	.1	41	42.13	21,940	830	2,430
11	20	10	22	2.20	14	.04	7.4	1.3	3.1	.0	27	5.2	.00	.5	47	42.24	22,560	1,340	2,860
21	30	5	....	....	7.6	.03	6.1	1.5	3.0	.0	21	6.8	.00	.5	38	40.58	16,260	847	1,670
July 1	July 10	5	7.5	1.50	6.7	.05	6.0	1.3	2.9	.0	20	4.9	.00	.4	33	40.95	17,540	355	1,560
11	20	18	19	1.06	6.2	.04	5.2	1.3	3.6	.0	21	5.2	.00	.8	32	41.33	19,010	975	1,640
21	30	10	10	1.00	3.9	.03	6.3	1.3	3.3	.0	22	5.8	....	.9	34	39.85	13,860	374	1,270
31	Aug. 9	5	4.2	.84	6.5	.04	7.7	1.4	2.9	.0	28	5.4	....	1.4	41	39.20	11,880	135	1,310
Aug. 10	19	6	7.6	1.26	3.1	.02	5.9	1.4	3.8	.0	21	8.2	.75	1.1	32	38.89	10,050	206	870
20	29	5	7.3	1.46	6.0	.03	6.8	1.5	3.3	.0	24	6.5	.90	1.1	39	37.95	8,601	169	905
30	Sept. 8	5	3.4	.68	10	.01	7.8	1.5	2.9	.0	28	9.5	.00	.9	47	37.46	7,375	63	935
Sept. 9	18	5	3.5	.70	9.4	.02	8.3	2.0	3.0	.0	30	12	.31	.9	49	37.04	6,401	61	845
19	28	19	23	1.21	8.6	.10	8.3	1.5	3.1	.0	26	7.2	.10	1.8	47	37.56	7,636	475	970
29	Oct. 8	40	69	1.73	4.3	.18	5.9	1.6	3.3	.0	18	10	.70	1.2	40	41.79	21,720	4,050	2,340
Oct. 9	18	13	19	1.46	6.8	.11	7.0	1.3	3.6	.0	23	6.5	1.0	1.1	41	41.06	18,320	940	2,030
19	28	11	18	1.64	7.5	.13	7.1	1.4	3.2	.0	26	6.8	.85	1.5	41	40.87	18,278	887	2,020
29	Nov. 7	7	5.8	.83	7.1	.06	7.2	.7	2.9	.0	26	....	.70	1.7	41	39.70	13,630	214	1,510
Nov. 8	17	18	37	2.06	6.9	.05	7.5	.7	2.7	.0	25	8.3	.50	1.0	43	42.81	25,380	253	2,940
18	27	50	83	1.66	6.3	.06	6.8	.9	2.2	.0	22	7.6	Trace.	.8	42	43.54	29,340	6,570	3,330
28	Dec. 7	5	7.8	1.56	7.2	.02	7.6	1.4	2.8	.0	26	8.5	Trace.	.3	44	40.36	15,530	327	1,850
Dec. 8	17	5	5.8	1.16	7.5	.01	8.1	1.8	2.8	.0	29	8.2	.10	.5	46	39.52	12,910	202	1,600
18	27	6	5.4	.90	7.9	.01	8.2	1.1	2.8	.0	28	7.9	Trace.	.5	46	39.51	13,078	190	1,620
28	Jan. 6	3	4.1	1.37	9.5	.01	8.2	....	3.6	.0	29	6.6	Trace.	1.0	51	38.85	10,928	118	1,510
Jan. 7	16	3	3.5	1.17	9.4	Trace.	9.6	1.9	2.4	.0	31	7.9	.10	1.3	47	39.17	11,860	112	1,500
17	26	1	....	....	10	.03	10	1.8	2.8	.0	32	9.5	Trace.	1.3	50	37.76	8,114	64	1,090
27	31	1	1.0	1.00	9.5	.03	11	2.0	2.9	.0	35	9.3	Trace.	1.8	52	37.08	6,486	17	910
Mean		12	19	1.31	9.4	.08	7.9	1.7	3.6	.0	29	8.2	.24	.9	48	....	15,840	a 363,550	a 756,100
Percentage of anhydrous residue					20.3	b .2	17.0	3.7	7.8	30.9	....	17.7	.5	1.9	....	....	....	....	....

a Annual denudation.

b Fe_2O_3.

Color and alkalinity of the water of Skagit River at Sedro Woolley.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 13	14	0.0	30	May 7	8	*a* 14	13
14	16	.0	26	8	6	.0	23
15	14	.0	24	9	8	.0	23
16	20	*a* 2.2	33	10	8	*a* 6.0	13
17	22	.0	24	11	16	.0	18
19	14	*a* 8.4	28	12	16	.0	18
20	16	.0	31	13	20	.0	23
21	54	.0	46	14	15	.0	23
22	8	.0	31	15	12	.0	24
23	8	.0	27	16	16	.0	24
24	7	.0	29	17	12	*a* 14	8.5
25	7	.0	29	18	14	*a* 7.7	20
26	6	*a* 1.4	36	19	16	*a* 3.1	29
27	4	.0	37	20	8	*a* 6.2	23
28	5	.0	35	21	8	.0	24
30	11	.0	32	22	6	.0	23
31	7	.0	32	23	8	.0	20
Apr. 1	8	.0	34	24	10	*a* 4.3	23
3	8	.0	33	25	10	.0	24
12	0	.0	48	26	16	*a* 2.4	27
13	4	.0	29	28	16	.0	34
14	4	.0	36	31	12	.0	32
15	0	.0	30	June 1	12	.0	21
16	0	.0	33	2	10	.0	26
25	10	.0	35	3	7	.0	23
26	16	*a* 19	23	4	6	.0	23
27	17	*a* 3.8	14	5	8	.0	24
28	9	*a* 13	0	6	6	.0	21
29	9	*a* 4.6	18	8	10	.0	30
30	9	*a* 14	0	9	8	.0	23
May 1	8	*a* 17	0	10	14	.0	22
2	8	.0	17	12	40	.0	15
3	8	*a* 7.2	21	13	36	.0	18
4	6	.0	28	14	34	.0	21
5	10	.0	28	15	30	.0	22
6	8	.0	34				

a Abnormal; probably present as HCO_3 at time of collection.

WOOD CREEK.

GENERAL FEATURES OF DRAINAGE BASIN.

Wood Creek is a small stream that rises in the hills south of Everett and flows into Snohomish River. Its drainage basin, uninhabited and completely forested, is deeply covered by glacial drift. The stream is swift, its valley is narrow, and its discharge is small but widely variable. The creek is important only because with two small streams flowing from the same uplands it forms the water supply of Everett.

CHARACTER OF THE WATER.

Samples of water were collected daily from the creek at its point of discharge into the impounding reservoir of the city of Everett through the courtesy of Dr. A. P. Duryee, city health officer.

Though the water is moderately hard, the hardness is mostly temporary and can be removed either by preheating the water or by treating it with small quantities of milk of lime. Treating the water for boiler use, however, is not advisable as the amount of scale-forming matter is so small.

The water is characterized by primary alkalinity, which indicates that the prevailing rock material is of igneous origin. This fact is important as the underlying formations of this part of Puget Sound basin are supposed to be sedimentary rocks of Tertiary age, though the evidence of the water analyses indicates that the great blanket of glacial drift was derived from the intrusive or effusive rocks of the Cascade Range, not from the sedimentary rocks of the valley floor.

Mineral analyses of water from Wood Creek near Everett, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
Mar. 13	Mar. 22	10	15	1.50	26	Trace.	7.2	5.2	13	[a]13	34	6.1	Trace.	2.5	86
23	Apr. 1	25	44	1.76	37	0.01	8.6	3.8	8.2	.0	54	14	Trace.	.....	106
Apr. 2	11	20	28	1.40	20	Trace.	8.5	4.4	7.6	.0	43	7.9	Trace.	2.5	75
12	21	25	26	1.04	26	Trace.	9.4	4.6	8.5	.0	56	8.9	0.40	3.3	94
22	May 1	5	5.2	1.04	26	Trace.	9.0	4.4	7.6	.0	51	9.8	.20	3.5	87
May 2	11	50	51	1.02	....	.02	8.2	3.9	7.2	.0	51	11	.50	2.5	54
12	21	20	38	1.90	27	Trace.	8.2	4.2	7.9	.0	52	9.5	.00	2.8	91
22	31	5	4.0	.80	27	Trace.	8.5	5.2	8.0	.0	51	7.9	Trace.	3.0	90
June 1	June 10	15	20	1.33	23	Trace.	9.0	5.2	8.8	.0	57	8.9	Trace.	3.0	91
11	20	15	21	1.40	35	Trace.	11	5.0	9.8	.0	61	7.2	Trace.	3.3	107
21	30	10	14	1.40	19	Trace.	9.8	5.6	8.8	.0	56	7.7	Trace.	2.8	81
July 1	July 10	50	43	.86	41	.01	11	3.5	10	.0	55	8.9	.00	3.3	119
11	20	7	13	1.86	26	Trace.	8.8	.....	8.7	.0	52	12	....	.....	90
21	30	5	2.4	.48	23	Trace.	9.2	5.2	7.6	.0	55	6.9	.00	3.0	83
31	Aug. 9	7	5.8	.83	27	Trace.	9.0	6.7	8.0	.0	57	6.9	.45	2.6	94
Aug. 10	19	15	11	.73	21	Trace.	9.3	5.0	8.4	.0	49	7.1	Trace.	3.3	82
20	29	2	1.4	.70	28	Trace.	9.6	5.2	7.6	.0	54	7.6	1.9	3.2	90
30	Sept. 8	15	13	.87	25	.01	8.0	4.6	7.8	.0	57	5.1	.00	3.1	82
Sept. 9	18	5	3.4	.68	21	.01	10	3.6	8.2	.0	54	6.9	Trace.	3.5	86
19	28	Trace	0	......	21	.01	9.2	4.4	10	.0	63	5.3	.65	2.8	101
29	Oct. 8	5	3.7	.74	18	.05	7.1	4.8	6.7	.0	50	6.6	Trace.	2.5	85
Oct. 9	18	3	1.8	.60	30	.06	7.2	4.6	6.9	.0	50	5.0	.75	2.8	85
19	28	5	11	2.20	28	.06	8.6	4.8	7.2	.0	50	12	.63	3.3	89
29	Nov. 7	2	1.6	.80	30	.07	7.2	4.4	6.1	.0	48	6.5	.75	3.0	86
Nov. 8	17	4	1.7	.42	29	.03	7.7	4.4	6.5	.0	50	5.4	.70	2.5	83
18	27	1	.8	.80	26	.05	8.8	4.8	6.8	.0	48	9.7	2.0	2.8	87
28	Dec. 7	3	......	......	26	.01	7.6	5.0	5.7	.0	49	6.9	.50	2.5	84
Dec. 8	17	2	......	......	27	.01	7.6	4.4	4.9	.0	48	6.9	.10	2.8	80
18	27	3	.7	.23	15	.03	6.8	4.2	5.7	.0	48	7.6	Trace.	2.1	83
28	Jan. 6	2	6.0	3.00	22	Trace.	7.7	4.2	6.1	.0	45	6.9	.05	2.6	78
Jan. 7	16	3	7.1	2.37	24	.01	6.9	3.6	5.6	.0	42	5.6	Trace.	2.5	73
17	26	3	3.0	1.00	20	Trace.	9.6	3.5	6.8	.0	39	8.6	....	.....	73
27	31	4	2.8	.70	16	.01	8.2	2.8	5.7	.0	37	5.3	.10	2.8	65
Mean		10	13	1.15	25	.01	8.6	4.5	7.6	.0	51	7.8	.31	2.9	86
Percentage of anhydrous residue........					30.6	.0	10.5	5.5	9.3	30.7	......	9.5	.4	3.5	....

[a] Abnormal; computed to HCO_3 in average.

CEDAR RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Cedar River rises on the western slopes of the Cascade Mountains near Yakima Pass, flows northwestward through Cedar Lake, and, after following a general westerly course, unites with White River near Renton to form Duwamish River, which enters Elliott Bay on

Puget Sound south of Seattle. In its upper course Cedar River flows through rugged, heavily timbered country, from which it emerges a short distance above its junction with White River.

In the Cascade Mountains the river flows over exposed metamorphic and igneous rocks (largely andesites with some basalts and rhyolites), but lower down it traverses outcrops of Tertiary sandstones and shales that include coal seams. Near its mouth it flows over the deep glacial drift that overlies bedrock around Puget Sound.

Annual precipitation in the basin ranges from less than 40 inches near Puget Sound to more than 100 inches on the mountains. The winter precipitation in the mountains is chiefly snow; in the lower valley it is principally rain. The snows remain unmelted on the mountains during winter, except when a chinook wind induces sudden and usually rapid thaws. When this occurs the river is in flood, and if the chinook is accompanied by heavy rains the freshets may become violent. Spring floods are caused by rains and melting snows, and still another period of high water is caused by autumn rains.

The water supply of Seattle is taken from Cedar River below Cedar Lake near Ravensdale. The drainage from the main line of the Chicago, Milwaukee & St. Paul Railway, which skirts the river for several miles above the intake, is either filtered through thick beds of graded filtering material or carried into the near-by drainage basin of Snoqualmie River by a carefully planned system of ramparts and drains. Special regulations also prohibit the deposition of any train wastes at any place within the watershed. In addition to this protection the Seattle water department employs a regular system of patrol over the basin to prevent trespass by campers, hunters, or tramps. The city has recently taken steps to purchase by condemnation the small part of the drainage area still privately owned, so that the whole area tributary to the river above the intake may be controlled by the city, thus insuring for all time a pure water supply.[1] The supply is conveyed to the city through a pipe line emptying into a reservoir at Volunteer Park, which crowns a high hill in the heart of the city. The annual consumption is about 13,780 million gallons, or 160 gallons per capita per day.[2] Though Seattle is built around two fresh-water lakes—Lakes Union and Washington—as well as on Puget Sound, only an insignificant part of the water used in local industries is obtained from these sources.

According to the United States census the population of Seattle in 1910 was 237,194. The principal industries are lumber milling and shipping, although several breweries, as well as car shops, machine

[1] See also Freeman, J. R., Chances of pollution of Seattle water supply: New England Waterworks Assoc. Jour., vol. 20, p. 464, 1906. Possible pollution of Seattle water supply (anon.): Eng. News, Aug. 30, 1906.

[2] Personal communication in 1911 from Mr. John Lamb, of the Seattle water department.

shops, foundries, paper mills, brick and tile works, gas works, and others are located there. The city's importance results chiefly from its commerce, but manufacturing is rapidly increasing.

Renton is the only other important town in the basin of Cedar River. Its principal industries depend on near-by coal mines, although it also has a brick works, a car manufactory, and a glassware factory.

CHARACTER OF THE WATER.

Water from Cedar River near Ravensdale was collected for this investigation by Mr. George Landsburg, through the courtesy of the board of public works of Seattle. As the daily samples were taken from the running water above the dam at the intake of the Seattle waterworks, the suspended matter normally carried by the stream is included. Sedimentation in Cedar Lake decreases the amount of material carried in suspension to some extent, but as the upper stream is usually clear, the effect is slight. The stream-flow data in the table of analyses are compiled from the records of the gaging station at the dam. The drainage area above the station covers 149 square miles.[1] Discharge is somewhat regulated by the storage of Cedar Lake, but seasonal variations are nevertheless pronounced.

Cedar River carries little suspended matter, and sedimentation above the dam and in the distribution reservoirs at Seattle keeps the city supply free from unpleasant turbidity except at times of exceptionally heavy rains and rising water. Dissolved mineral matter also is small in amount, ranging from less than 30 to little more than 80 parts per million. The content of silica, which shows the greatest variation, may be materially affected by algæ and diatoms in Cedar Lake and in the sluggish water above the intake dam. Silica increases during storage of some samples after collection, and it is therefore permissible to consider unusually high estimates of silica abnormal; yet the average, 13 parts per million, may be regarded as accurate within the ordinary limits of analysis. The marked daily variation in content of chlorine is often greater than the amount which would be added to the water by a population of many thousand people on the drainage area, so no normal value of chlorine can be established from analyses of this water.

The water is calcic carbonated in type, and is admirably adapted for all household uses. It does not foam in boilers and deposits only a slight amount of scale, which differs somewhat in texture from day to day but is usually rather hard. As the scale is siliceous no improvement in that respect can be obtained by treatment with soda ash or lime. It is known that free carbon dioxide and oxygen are sometimes present in large amount though no determinations of them

[1] Henshaw, F. F., and Parker, G. L., Water powers of the Cascade Range, pt. 2: U. S. Geol. Survey Water-Supply Paper 313, p. 103, 1913.

were made during this study. Owing to the presence of these two dissolved gases, one a solvent and the other a precipitant by virtue of its oxidizing power, service pipes are frequently corroded and rust is formed, so that it is not unusual for the first flow from taps in Seattle to be red. This condition, which is not at all unusual for waters coming from regions similar to that around the headwaters of the Cedar River and is aided by the low mineral content of the water, can be overcome by artificially hardening the water by the addition of lime. The exact amount of the reagent necessary at any time can be ascertained only by analysis of dissolved gases, but enough should be used to add about 10 or 15 parts per million of lime (CaO) to the water. This would not render the supply unduly hard for use in boilers.

Color and alkalinity were determined on daily samples of water from Cedar River at Ravensdale from March 6 to July 14, 1910, inclusive. The water was usually colorless or nearly so and the alka linity was small. If filtration were adopted the water could advantageously be passed through slow sand filters, on account of its softness and its freedom from color or suspended matter. The alkalinity, which is sometimes too low to insure proper precipitation of coagulants, would then be a matter of indifference.

Mineral analyses of water from Cedar River at Ravensdale, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium ($Na+\frac{3}{4}K$).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Dissolved solids (tons per day).	Suspended matter (tons per day).
Feb. 1	Feb. 10															1.25	708	a 108	a 7.7
11	20															1.10	606	a 161	a 11
21	Mar. 2	2	5.8	2.90	31	0.05	6.3	2.4	4.7	Trace.	34	7.4	Trace.	1.3	84	1.50	940	213	15
Mar. 3	12	5	2.1	.42	16	.05	5.0	1.8	4.3	0.0	26	7.1	Trace.	1.3	50	2.25	1,644	222	9
13	22	8	5.6	.70	26	.05	4.8	1.8	4.0	.0	28	3.8	0.00	.5	66	2.35	1,677	298	25
23	Apr. 1	10	9.6	.96	12	.01	6.4	1.5	3.0	.0	24	6.7	.10	.8	47	1.70	1,056	213	43
Apr. 2	11	8	6.9	.86	20	.01	6.1	1.4	3.8	.0	28	3.4	.20	1.3	58	1.60	972	149	18
12	21	10	7.3	.73	19	.01	7.0	1.4	3.5	.0	31	6.3	Trace.	.8	59	1.60	963	152	19
22	May 1	30	34	1.13	13	.01	5.2	1.5	3.3	.0	24	5.1	Trace.	.9	48	1.85	1,186	154	11
May 2	11	10	8.0	.80	17	.01	6.4	1.8	3.3	.0	29	5.3	.10	.8	53	1.40	815	116	18
12	21	5	4.4	.88	15	.02	6.4	1.7	4.2	.0	33	5.3		1.0	50	1.55	935	126	11
22	31	12	7.1	.59	20	.01	6.7	1.5	4.6	.0	32	5.2	.10	.6	58	1.25	674	105	13
June 1	June 10	5	3.3	.66	16	.01	6.7	1.3	3.0	.0	28	5.8	.20	.8	53	1.00	514	73	5
11	20	5	3.7	.74	14	.01	8.4	1.9	4.1	.0	44	6.6		1.1	57	.90	421	65	4
21	30	1	.2	.20	16	.01	9.6	2.1	3.5	.0	32	9.0		.8	59	.80	382	61	.2
July 1	July 10	3	3.0	1.00	22	.01	7.2	2.1	3.8	.0	34	5.7		.9	63	.75	351	60	2.9
11	20	1	.5	.50	11	.01	7.6	2.1	3.2	.0	34	3.6		1.2	47	.60	249	32	.4
21	30	2	.5	.25	12	.01	8.0	2.0	3.8	.0	37	5.2		.9	54	.50	213	31	.4
31	Aug. 9	2	2.1	1.05	9.5	.01	5.8	1.5	4.9	.0	27	3.5	.50	1.3	44	.50	200	24	1.1
Aug. 10	19	5	2.7	.54	12	Trace.	8.2	1.3	3.2	.0	29	6.4	.00	4.0	49	.45	181	24	1.3
20	29	1	.1	.10	9.5	.01	7.2	1.4	4.1	.0	31	3.4	.10	1.8	44	.45	173	21	.5
30	Sept. 8	2	.1	.05	12	Trace.	7.8	1.6	2.8	.0	32	5.0	.00	.9	46	.50	205	25	.6
Sept. 9	18	7	2.0	.28	11	.01	7.0	1.3	3.1	.0	31	5.0	.00	.9	45	.55	236	29	1.3
19	28	5	1.1	.22	12	.01	7.7	1.2	4.0	.0	29	8.0	.70	1.3	48	.55	222	29	.6
29	Oct. 8	5	3.9	.78	14	.02	6.4	1.4	4.8	.0	29	7.3	1.0	1.8	54	.80	390	57	4.1
Oct. 9	18	5	1.5	.30	9.2	.01	6.3	1.5	4.0	.0	26	9.4	.76	1.0	45	.80	382	46	1.5
19	28	2	1.0	.50	9.8	.08	6.0	.8	3.3	.0	22	5.6	.50	1.3	41	.85	406	45	1.1
29	Nov. 7	1			8.9	Trace.	5.9	.8	3.5	.0	21	5.7	.80	1.4	41	.95	480	53	a 13
Nov. 8	17	3	5.8	1.93	7.1	.01	4.4	.7	2.7	.0	17	4.6	.20	1.3	34	2.15	1,506	138	24
18	27	2	3.2	1.60	8.8	.02	5.5	1.0	2.7	.0	18	4.6	Trace.	1.2	37	2.15	1,572	157	14
28	Dec. 7	3	3.9	1.30	10	.02	5.6	1.1	3.3	.0	22	6.5	Trace.	1.0	40	1.40	807	87	8.5
Dec. 8	17	2	1.7	.85	8.0	.01	6.2	1.1	2.9	.0	21	8.2	.20	1.0	37	1.40	791	79	3.6
18	27	3			7.5	.01	7.3	1.0	3.4	.0	23	5.3	.00	1.1	39	1.10	578	61	a 2.5
28	Jan. 6	1			9.5	.02	6.9	.6	2.5	.0	21	4.6	Trace.	1.2	40	1.25	691	80	a 1.6
Jan. 7	16	3	.3	.10	12	.02	7.4	.5	3.2	.0	23	4.9	Trace.	1.3	43	1.50	879	102	7.3
17	26	2	.2	.10	9.9	Trace.	8.3	.9	3.0	.0	23	5.9	Trace.	1.2	42	1.05	546	62	
27	31	1			9.0					.0	26			1.8	45	.95	456	55	a 4.0
Mean		5	4.2	.74	13	.02	6.7	1.4	3.6	.0	28	5.7	.20	1.2	49		685	b 34,855	b 2,960
Percentage of anhydrous residue					28.5	c .1	14.7	3.1	7.9	30.2		12.5	.4	2.6					

a Estimated. b Annual denudation. c Fe_2O_3.

Color and alkalinity of the water of Cedar River at Ravensdale.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 6	4	0.0	24	May 22	2	[a]6.0	24
7	4	.0	33	23	0	[a]7.4	21
8	6	.0	28	24	0	[a]6.0	21
9	7	.0	27	26	55	.0	28
10	16	.0	34	27	2	.0	22
11	8	.0	28	28	4	.0	23
12	12	[a]1.9	30	29	0	.0	24
13	8	[a]18	16	30	6	[a]1.4	36
14	7	.0	22	31	2	[a]4.6	29
15	8	.0	23	June 1	8	.0	24
16	8	[a]4.1	20	2	2	.0	26
17	8	.0	26	3	0	[a]4.8	26
30	4	.0	27	5	4	.0	33
31	4	.0	24	19	7	.0	28
Apr. 1	4	.0	24	20	8	.0	43
2	4	[a]1.7	25	22	8	.0	34
3	4	.0	26	23	7	[a]4.8	28
4	0	.0	24	26	5	.0	31
6	4	.0	22	27	5	.0	30
8	6	[a]2.4	23	28	4	.0	31
9	8	.0	21	29	16	.0	30
10	0	[a]8.6	13	July 1	8	.0	....
11	0	[a]9.1	13	2	4	.0	33
12	2	[a]8.4	13	3	8	[a]13	22
13	0	.0	27	4	4	[a]2.4	33
17	0	.0	22	5	4	.0	40
18	0	[a]20	.0	10	8	.0	31
19	0	[a]16	1	11	8	.0	33
20	0	[a]19	.0	12	8	.0	38
May 20	0	[a]4.8	25	13	8	.0	32
21	2	[a]2.2	34	14	6	.0	34

[a] Abnormal; probably present as HCO_3 at time of collection.

GREEN RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Green River rises near Stampede Pass in the Cascade Mountains, in King County, flows in general northwest, and joins White River near Auburn. In its upper course, above the point where samples for this investigation were collected, it drains an area whose rocks are almost entirely andesitic. Some basalts and rhyolites are found, as are also small amounts of tuff, but pyroxene andesite and dacite form the main portion of the surface rock.

CHARACTER OF THE WATER.

Samples of water were collected from Green River at the bridge near the hotel at Hot Springs daily from February 1 to August 18, 1910, inclusive, by J. M. Corcoran. Forest fires, which devastated the valley and destroyed all habitations at this place, forced the discontinuance of the station in midsummer. No discharge data for Green River are available.

The water is typical of rivers draining areas in which the rainfall is large and the surface formations are Tertiary andesites. The content of magnesium is less than might be expected. Though the average content of calcium is only 1.1 parts per million less than that of Crater Lake, Oreg.,[1] where andesites also predominate, the content of magnesium is 1.5 parts per million less, and the calcium-magnesium ratio, which is 1 to 2.5 for the water of Crater Lake, is 1 to 4.6 for the water of Green River.

The water is suitable for industrial use without treatment. It is nonfoaming, but will deposit small amounts of hard siliceous scale. Though true corrosion from such waters is unlikely, burning and resultant pitting may occur beneath the silica scale if boilers are improperly managed.

Green River receives pollution from many sources along its entire course and below the village of Lester can not be considered a safe source of domestic supply without purification. Tacoma has recently constructed works for the utilization of the water of Green River as its municipal supply.

Mineral analyses of water from Green River at Hot Springs, 1910.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
Feb. 1	Feb. 10	3	2.6	0.87	17	0.11	5.4	2.0	......	0.0	25	12	0.45	2.5	58
11	20	3	1.6	.53	18	.04	6.5	1.3	6.9	.0	29	10	.10	1.0	57
21	Mar. 2	10	6.0	.60	35	.26	6.8	2.1	11	.0	51	8.6	.30	1.4	109
Mar. 3	12	4	16	4.00	6.6	.06	5.9	1.5	6.6	Trace.	24	8.9	.00	1.3	56
13	22	10	25	2.50	16	.05	4.8	1.9	8.2	.0	26	10	.00	1.0	51
23	Apr. 1	8	6.3	.79	9.2	.06	4.1	1.0	3.5	.0	20	3.7	Trace.	1.3	39
Apr. 2	11	9	6.2	.69	14	.02	5.4	1.7	7.1	.0	24	6.1	.10	1.0	50
12	21	10	8.9	.89	13	.04	4.3	1.3	6.6	.0	29	5.3	.35	1.3	60
22	May 1	8	6.7	.84	15	.01	5.3	1.0	5.4	.0	27	6.5	.50	1.5	44
May 2	11	10	9.6	.96	20	.01	6.0	1.4	4.0	.0	25	3.2	.30	1.0	56
12	21	5	5.2	1.04	25	.01	5.4	1.2	3.3	.0	27	2.3	.50	1.0	56
22	31	5	3.3	.66	20	.01	5.3	1.2	4.5	.0	23	5.2	.00	2.0	55
June 1	June 10	15	11	.73	18	.01	5.6	1.3	5.6	.0	30	6.1	.00	1.0	55
11	20	10	9.6	.96	12	.01	7.3	1.1	5.0	.0	29	3.6	.00	1.0	43
21	30	5	4.4	.88	23	.01	6.0	1.4	6.0	.0	27	3.5	.00	.8	58
July 1	July 10	4	3.3	.83	17	.01	7.2	1.3	5.1	.0	31	4.9	.00	1.3	54
11	20	5	9.1	1.82	17	.01	6.1	1.0	5.1	.0	28	6.4	.00	1.3	55
21	30	3	2.9	.97	12	Trace.	8.5	.9	4.7	.0	34	3.4	.00	1.5	51
31	Aug. 9	1	0.4	.40	11	Trace.	6.8	.8	3.5	.0	29	3.6	.00	1.8	45
Aug. 10	18	1	1.0	1.00	12	Trace.	7.1	.8	4.1	.0	28	5.2	.00	1.8	48
Mean......		6	7.0	1.10	17	.04	6.0	1.3	5.6	.0	28	5.9	.13	1.3	55
Percentage of anhydrous residue....					33.3	[a] .1	11.7	2.5	11.0	27.0	......	11.6	.3	2.5	....

[a] Fe_2O_3.

CHEHALIS RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Chehalis River rises in the Coast Range in Lewis County, flows northeastward to Chehalis, then northward for a short distance, and finally northwestward to Grays Harbor, through which it passes to the Pacific. At Chehalis it is joined by Newaukum River, and at

[1] Van Winkle, Walton, and Finkbiner, N. M., Composition of the water of Crater Lake, Oreg.: Jour. Ind. and Eng. Chemistry, vol. 5, p. 198, 1913.

Centralia by Skookemchuck River. Satsop, Wynoochee, and Whishah rivers, its most important tributaries, enter in its lower course. Its valley is broad and the general elevation of the headwaters is not great. Much of the basin is covered with a good stand of fir and other conifers, and lumbering is an important industry in the valley.

Sedimentary rocks of Tertiary age, overlain by Quaternary marine deposits are probably the chief formations of the region. The Tertiary rocks include extensive beds of lignitic coal which is almost useless for steaming but valuable for gas production.

CHEHALIS RIVER AT CENTRALIA.

CHARACTER OF THE WATER.

Samples of water were collected daily from Chehalis River at the bridge near Centralia by John Arveson, from February 1, 1910, to January 31, 1911. A gage was installed at this point October 3, 1910, and approximate estimates of daily discharge have been made from that date until the end of the sampling period.

The water is soft, usually turbid, and subject to frequent and great changes in its content of dissolved matter. The content of chlorine, which is noticeably greater than that of water from most of the other streams, is due largely to solution of saline matter from the sedimentary rocks of the basin and to wind-borne salt from the Pacific Ocean in the rainfall on the coastal mountains. Sulphates form about 11 per cent and carbonates about 26 per cent of the dissolved matter.

The water is suitable for use in boilers if it is first clarified. It will deposit small amounts of hard scale and might also become corrosive under some conditions of service though it ordinarily requires no treatment. As it contains large amounts of organic matter and is grossly polluted with sewage, it is unfit without purification for domestic use or for any use requiring potable water.

Color and alkalinity were determined in the samples collected daily from March 16, 1910, to January 26, 1911.

Many of the marked variations in alkalinity can be traced directly to changes in stream flow. Sometimes, as on October 17, 1910, the rainfall was accompanied by a temporary increase in alkalinity, probably caused by increased solution of surface material during gentle rain. Nearly always, however, rainfall and consequently increased stream flow was followed by decrease of alkalinity—an effect of dilution. Alkalinity gradually increased with falling stage of the river until July 22, when it dropped suddenly, then increased gradually until July 29, when it once more dropped. No rain fell at Centralia during July, but precipitation occurred at various places in the Cascade and Olympic region on July 21 and 22, and another slight rainfall was recorded in some localities on July 28 and 29. The drops in alkalinity evidently reflect the rainfall in the upper part of the basin. The determinations of alkalinity occasionally show normal carbonates that probably resulted from reactions after the samples were collected. Experiments made by the writer on waters from Chehalis River showed that one of the most marked changes during standing is a gradual loss of bicarbonate and equivalent gain of normal carbonate. The absorption of carbon dioxide by organic matter may influence this change.

The water is usually highly colored, and appears decidedly brown at times even in small bulk. Whether some of the color is caused by colloidal suspended matter in the nature of carbon from coal, whether it is of peaty origin, or whether it was entirely algal is not known. The fact that strong color is synchronous with great turbidity is circumstantial evidence that the color is due to peaty matter, for the peat swamps overflow into the river during floods and thus deliver to the stream large quantities of highly colored water.

Mineral analyses of water from Chehalis River at Centralia, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Feb. 1	Feb. 10	18	16	0.89	18	0.18	5.0	2.5	6.5	0.0	24	12	0.5	3.3	62				
Mar. 3	Mar. 12	70	63	.90	14	.05	4.4	2.3	5.4	.0	19	9.9	.05	2.5	45				
13	22	40	27	.68	20	.08	5.9	1.9	6.5	.0	36	5.4	.00	3.1	65				
23	Apr. 1	20	21	1.05	15	.04	4.9	1.8	5.5	.0	28	7.6	.20	3.3	58				
Apr. 2	11	50	37	.74	17	.05	7.4	1.7	6.2	.0	34	5.4	.18	3.6	62				
12	21	15	12	.80	13	.01	5.9	1.3	6.5	.0	24	8.0	.10	3.3	53				
22	May 1	15	6.7	.45	18	.05	6.0	2.1	7.0	.0	33	4.9	.15	4.1	60				
May 2	11	8	8.0	1.00	14	.04	6.6	1.4	5.4	.0	33	5.1	Trace.	7.3	58				
12	21	5	8.9	1.78	20	.01	9.3	2.7	5.2	.0	38	5.2		4.5	67				
22	31	5	6.0	1.20	33	Trace.	9.2	2.2	10	.0	49	7.1	Trace.	5.8	100				
June 1	June 10	10	9.1	.91	24	Trace.	11	2.0	7.7	.0	40	6.8	.15	5.7	81				
11	20	25	47	1.88	27	.05	11	3.2	14	.0	56	6.7	Trace.	6.5	114				
21	30	5	4.6	.92	19	.24	8.3	1.9	7.6	.0	33	6.7	.10	5.3	70				
July 1	July 10	6	5.1	.85	21	Trace.	9.5	2.0	8.7	.0	38	7.0	Trace.	5.8	76				
11	20	7	4.3	.61	16	.02	9.0	2.2	7.6	.0	39	10	Trace.	6.6	72				
21	30	10	7.6	.76	19	.01	9.1	1.9	7.8	.0	41	7.8	.00	7.2	76				
31	Aug. 9	5	4.8	.96	14	.05	9.2	2.5	5.9	.0	35	6.2	.00	8.6	67				
Aug. 10	19	13	14	1.08	8.9	Trace.	8.1	2.2	6.6	.0	40	4.6	.12	8.5	61				
20	29	4	4.3	1.08	14	.08	8.1	2.6	8.4	.0	40	4.9	.75	6.0	70				
30	Sept. 8	12	15	1.25	13	.01	9.5	2.3	6.6	.0	40	7.0	Trace.	7.2	67				
Sept. 9	18	7	8.8	1.26	19	.03	10	2.4	8.6	.0	48	6.9	.60	7.3	79				
19	28	5	1.6	.32	16	.05	8.1	2.6	7.8	.0	38	8.5	.40	8.3	71				
29	Oct. 8	15	18	1.20	14	.18	6.4	1.9	6.4	.0	27	7.2	Trace.	5.0	61				
Oct. 9	18	10	4.9	.49	14	.10	6.4	2.0	5.8	.0	27	5.9	Trace.	4.0	55	3.780	1,833	24	272
19	28	10	5.5	.55	15	.05	5.4	1.4	5.1	.0	26	4.9	Trace.	4.0	57	3.325	1,555	23	240
29	Nov. 7	10	5.5	.55	15	.08	6.2	1.6	5.7	.0	29	6.5	Trace.	4.8	48	2.950	1,350	20	175
Nov. 8	17	35	40	1.15	13	.20	5.1	1.2	5.5	.0	23	5.1	Trace.	3.3	57	7.855	5,055	546	776
18	27	55	70	1.28	13	.30	4.6	1.2		.0	17	4.6	Trace.	2.8	50	10.075	7,145	1,350	965
28	Dec. 7	25	35	1.40	15	.20	4.8	1.0	4.8	.0	17	6.7	Trace.	3.8	50	6.730	3,947	372	534
Dec. 8	17	12	16	1.33	13	.10	6.1	1.7	4.9	.0	21	4.5	.10	5.5	53	5.130	2,758	119	394
18	27	18	24	1.33	14	.13	5.4	1.5	4.8	.0	20	6.3	Trace.	4.8	51	4.980	2,652	172	365
28	Jan. 6	10	15	1.50	15	.15	5.6	1.4	4.4	.0	21	3.6	Trace.	4.5	51	5.175	2,748	111	378
Jan. 7	16	10	9.5	.95	14	.10	6.1	1.4	4.3	.0	22	5.8	Trace.	5.0	50	4.300	2,153	55	291
17	26	35	42	1.20	15	.12	5.3	1.2	3.8	.0	20	4.8	Trace.	5.0	53	6.545	3,883	440	555
27	31	10	11	1.10	14	.15	4.5	1.2	4.2	.0	18	5.5	Trace.	5.0	48	5.430	2,914	87	377
Mean		17	18	1.01	16	.08	7.1	1.9	6.5	.0	31	6.4	.10	5.2	63				
Percentage of anhydrous residue					27.3	[a].2	12.1	3.2	11.1	26.1		10.9	.2	8.9					

[a] Fe_2O_3.

Color and alkalinity of the water of Chehalis River at Centralia.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 16	16	0.0	22	June 6	9	0.0	35
17	16	.0	43	7	8	.0	43
18	12	.0	23	8	17	.0	38
19	20	.0	36	9	8	.0	43
20	16	.0	23	10	15	.0	42
21	24	.0	24	11	16	.0	....
22	32	.0	23	12	8	.0	33
23	20	[a]4.1	30	22	16	.0	43
24	20	.0	23	23	8	.0	30
26	14	.0	28	24	18	.0	30
27	14	[a]0.7	39	25	21	.0	28
28	16	[a]3.8	36	26	16	.0	32
29	16	.0	32	27	17	.0	34
30	12	.0	26	28	16	.0	35
31	14	.0	29	29	16	.0	40
Apr. 1	8	.0	27	30	16	.0	33
2	20	.0	34	July 1	16	.0	34
3	32	.0	25	3	13	.0	34
4	36	.0	22	4	11	.0	37
5	32	.0	21	5	15	.0	37
6	30	[a]1.0	37	6	16	.0	41
7	36	.0	30	7	17	.0	38
8	36	.0	21	8	17	.0	45
10	62	.0	18	9	16	.0	39
11	48	.0	19	10	8	.0	40
12	16	[a]5.0	13	11	32	[a]2.4	33
13	24	.0	21	12	16	.0	39
14	14	.0	25	13	16	.0	38
15	10	.0	23	14	16	.0	38
16	14	.0	25	15	17	.0	34
17	10	.0	21	16	19	.0	39
18	12	.0	24	17	16	.0	41
19	54	[a]0.2	15	18	8	.0	52
20	8	.0	26	19	15	.0	41
22	12	[a]14.4	14	21	8	.0	71
23	10	.0	31	22	8	.0	71
24	12	.0	30	23	9	.0	40
25	14	[a]12.0	16	24	16	.0	41
26	16	[a]7.2	32	25	16	.0	48
27	14	[a]7.2	15	26	17	.0	40
28	9	[a]4.8	21	27	16	.0	38
29	14	[a]11.8	9.8	28	16	.0	39
30	14	9.8	9.5	29	8	.0	63
May 1	16	[a]15.6	11	30	6	.0	40
2	8	.0	30	31	14	.0	40
3	8	.0	30	Aug. 1	16	.0	37
5	10	.0	32	2	16	.0	40
6	8	.0	34	3	16	.0	40
7	16	.0	27	4	17	.0	40
8	15	[a]19.2	....	5	16	.0	41
9	15	.0	32	6	16	.0	40
10	14	.0	33	7	16	.0	40
11	9	.0	33	8	16	.0	43
12	15	.0	39	9	16	.0	39
13	17	.0	31	10	8	.0	38
14	15	.0	32	12	16	.0	39
15	14	[a]28.0	....	13	15	.0	35
17	16	.0	32	14	14	.0	40
18	15	[a]6.0	33	15	16	.0	39
19	....	.0	44	16	16	.0	43
20	10	[a]14.4	17	17	16	.0	40
21	9	[a]16.3	14	18	15	.0	40
22	9	[a]5.8	28	19	16	.0	37
23	17	.0	46	21	26	.0	39
24	18	[a]8.2	32	22	15	.0	39
25	10	[a]12.0	29	23	16	.0	38
26	10	.0	39	24	16	.0	44
27	15	.0	35	25	16	.0	41
28	15	[a]Trace.	43	26	16	.0	37
29	15	[a]6.5	32	27	16	.0	40
30	15	.0	50	28	16	.0	41
31	15	.0	33	29	16	[a]7.2	24
June 1	15	[a]3.1	38	31	15	.0	40
3	16	.0	45	Sept. 1	16	.0	34
4	15	.0	43	2	16	.0	35
5	17	.0	44	3	16	.0	45

[a] Abnormal; probably present as HCO_3 at time of collection of samples.

Color and alkalinity of the water of Chehalis River at Centralia—Continued.

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.			
Sept. 4	16	0.0	37
5	16	.0	39
6	14	.0	40
7	16	.0	39
8	8	.0	39
9	16	.0	26
10	14	.0	40
11	8	.0	46
12	8	.0	48
13	8	.0	43
14	16	.0	43
15	8	.0	46
16	8	.0	43
17	8	.0	46
18	8	.0	43
19	8	.0	43
22	16	.0	41
23	16	.0	37
24	16	.0	37
25	16	.0	41
26	16	.0	38
28	16	.0	43
30	15	.0	40
Oct. 1	10	.0	37
3	16	.0	23
4	76	.0	33
5	78	.0	28
6	36	.0	23
7	24	[a]3.6	16
9	24	.0	24
10	24	[a]4.8	15
11	24	.0	28
12	24	.0	27
13	22	.0	26
14	22	.0	34
15	10	.0	39
17	16	.0	52
18	20	.0	45
20	22	.0	28
21	22	.0	28
22	22	.0	22
23	20	.0	33
24	16	.0	29
26	20	.0	33
27	20	.0	30
28	16	.0	33
Nov. 2	16	.0	33
3	16	.0	38
4	24	.0	35
5	22	.0	31
6	24	.0	28
8	250	.0	18
9	108	.0	22
10	436	.0	16
11	86	.0	17
12	78	.0	16
13	60	.0	20
14	62	.0	18
1910.			
Nov. 15	32	0.0	23
16	32	.0	23
20	58	.0	19
21	164	.0	15
27	40	.0	22
29	30	.0	21
30	36	.0	22
Dec. 1	40	.0	18
5	78	.0	30
6	78	.0	29
7	78	.0	17
8	32	.0	22
9	32	.0	9.8
10	18	.0	24
11	16	.0	24
12	14	.0	26
13	15	.0	24
14	16	.0	21
15	14	.0	22
16	16	.0	28
17	28	.0	24
19	30	.0	26
20	16	.0	24
21	15	.0	26
22	13	.0	24
23	34	.0	24
24	98	.0	17
25	62	.0	17
26	40	.0	22
27	40	.0	22
28	42	.0	18
29	19	.0	22
30	54	.0	21
1911.			
Jan. 1	50	.0	20
2	32	.0	17
3	34	.0	22
4	32	.0	24
5	32	.0	23
6	20	.0	24
7	16	.0	24
8	16	.0	25
9	24	.0	23
10	40	.0	22
12	36	.0	21
13	16	.0	22
14	18	.0	27
15	18	.0	22
16	12	.0	23
17	48	.0	18
18	....	[a] .1	17
19	110	[a] .05	13
23	32	[a] .05	18
24	32	[a] .05	19
25	30	.0	23
26	36	[a] .1	18

[a] Abnormal; probably present as HCO_3 at time of collection of samples.

WYNOOCHEE RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Wynoochee River rises on the slopes of Mount Churtan, in the Olympic Mountains, and flows southward into Chehalis River below Montesano. The upper part of its basin is heavily timbered and receives an annual precipitation of 100 inches or more, much of it occurring as snow. Except at the extreme headwaters of the river the exposed geologic formations are of Upper Cretaceous age.[1]

Wynoochee River is locally important because of its proposed use as a source of supply for Aberdeen, to which water is to be carried by gravity from a point near that at which samples were collected. Almost the only habitations in the basin are temporary lumber camps.

CHARACTER OF THE WATER.

Samples of water from Wynoochee River at Frye's logging camp, 20 miles above Montesano, were collected from July 17 to August 19, 1910, inclusive, after which period it was impossible to obtain samples. As the river was low during the sampling period the analyses probably indicate more highly mineralized water than a year's average would have shown. The water is soft and excellent for municipal and boiler use. No treatment is necessary before using the water for industrial purposes. The river should provide a satisfactory supply for Aberdeen if its volume can be made sufficient at all times by storage and its basin kept free from lumberers and trespassers. The principal dissolved materials in the water are silica, calcium, and bicarbonates. It was thought that large amounts of cyclic chlorine would characterize the water of this river, but the average content, 2.1 parts per million, is not so large as that of waters draining the humid regions of the Coast Range in Oregon, which are comparable in rainfall with the Olympic Mountains. This surprising fact is not yet adequately explained.

Mineral analyses of water from Wynoochee River near Montesano, 1910.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
July 17	July 20	1	1.0	1.00	11	0.02	8.6	2.4	5.8	0.0	37	9.7	0.50	2.0	55
21	30	1	1.3	1.30	16	.02	8.4	2.1	4.7	.0	39	......	Tr.	1.9	59
31	Aug. 9	1	......	......	11	.01	8.1	2.2	3.6	.0	34	3.7	Tr.	2.0	50
Aug. 10	19	5	2.4	.48	5.8	Tr.	7.7	2.2	5.2	.0	33	3.6	.65	2.4	47
Mean........		2	1.6	.93	11	.01	8.2	2.2	4.8	.0	36	5.7	.29	2.1	53
Percentage of anhydrous residue.....					21.2	.0	15.8	4.2	9.2	34.0	......	11.0	.6	4.0	....

COLUMBIA RIVER BASIN.

GENERAL FEATURES.

The drainage basin of Columbia River comprises about 259,000 square miles in northwestern United States and southwestern Canada. Its eastern border is the crest of the Rocky Mountains and its north-

[1] Willis, Bailey, Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, pp. 572, 778, Pl. I, 1912.

western limit is among the peaks of the Cascades; its lower portion receives drainage from the Coast ranges. The basin is divided among several States and British Columbia as follows: [1]

	Square miles.		Square miles.
Oregon	55,370	Nevada	5,280
Washington	48,000	Wyoming	5,270
Idaho	81,380	British Columbia	38,700
Montana	25,000		

Columbia River, the trunk stream of the system, rises in Columbia Lake in the eastern part of the Kootenai district of British Columbia. It flows northwestward to the fifty-second parallel, turns abruptly southward, nearly paralleling its former course, passing through a series of narrow lakes until it crosses into Washington near the Idaho line. After a slight westerly deflection it then resumes its progress southward to the Oregon-Washington line at the forty-sixth parallel, where it swings west, and finally discharges through an estuary into the Pacific Ocean. It is navigable in places for 760 miles, and 2,136 miles in the entire system are navigable.

The important tributaries of Columbia River are listed below:

Principal tributaries of Columbia River.

Entering from north and west:	Entering from south and east:
Kettle River.	Kootenai River.
Sanpoil River.	Clark Fork.
Okanogan River.[2]	Colville River.
Methow River.	Spokane River.[2]
Chelan River.	Snake River.[3]
Entiat River.	Walla Walla River.
Wenatchee River.[2]	Umatilla River.[3]
Yakima River.[2]	Willow Creek.
Klickitat River.[2]	John Day River.[3]
White Salmon River.	Deschutes River.[3]
Lewis River.	Hood River.
Kalama River.	Willamette River.[3]
Cowlitz River.	Clatskanie River.

The drainage basin of this system includes all varieties of topography from the bold peaks of the Cascade Range and the west slopes of the Rocky Mountains to the flat, sandy plains of the "Big Bend country," lying east of the river between the mouth of the Spokane and that of the Snake. Much of the area is forested, and although extensive lumbering has been carried on the proportion of forest lands has been only slightly decreased.

Precipitation is unevenly distributed as to both time and place. Summer rainfall is small in most of the region. In some places, as along the coastal strip and at the summits of the Cascade Range, the

[1] U. S. Geol. Survey Water-Supply Paper 272, p. 64, 1911.
[2] Studied in connection with investigations in Washington.
[3] Studied in connection with investigations in Oregon.

average annual precipitation is 100 inches or more, but it decreases rapidly eastward from the peaks of the mountains, and in the arid lands of eastern Oregon and the low valley of central Washington it is 9 inches or less. In the coastal belt the climate is mild, the summers being cool and the winters warm. In the valleys between the Coast and the Cascade ranges the climate is still mild but is less even. In the high plateaus of the interior high summer and low winter temperatures prevail, and on the elevated headwater regions the climate is extremely rigorous.

It has been estimated that at least one-third of the available water power of the United States is afforded by the streams of this drainage basin, but only a small part, probably less than 200,000 horsepower, has yet been developed, though several large power projects now planned or under construction will materially increase this amount. Many sites along Columbia River itself are capable of developing as much power as is now used in Oregon. The utilization of some of these sites, located on lines of both water and rail transportation and in regions of favorable climate, will do much for the industrial development and prosperity of the Northwest. The only generally important industries of the region are lumbering and agriculture. Some mining is carried on in the mountains, especially in the Rockies.

Ancient strata, largely metamorphic and ranging from Proterozoic quartzites to Jurassic and Triassic or even younger sediments, are exposed at the heads of the tributaries rising in the Rocky Mountains, Mesozoic intrusives cover large areas in Idaho and southern British Columbia, and pre-Cambrian gneisses occur in parts of Idaho; but the greater part of the basin, including most of the valleys of Snake and Columbia rivers in the United States, is covered by thick sheets of basalt of Tertiary age. The soil of the basin in Washington is generally rich and fertile, but that covering much of the basaltic plateau is "volcanic ash," or pumiceous sand and disintegrated basalts, and it lacks humus and is poor in phosphorus.

SPOKANE RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Spokane River rises in Cœur d'Alene Lake, in western Idaho, flows generally westward and northwestward and joins Columbia River at Fort Spokane, Wash., just above the "Big Bend." From Cœur d'Alene Lake to the city of Spokane the river flows through a broad, shallow valley, but below that city it enters the narrow, gradually deepening canyon which characterizes its lower course.

Granitic rocks predominate in the mountainous wooded region around its headwaters. The lower river traverses the prairies of eastern Washington, where the underlying formations are Tertiary basalts and tuffs. A ledge of basalt blocks the channel of the river at Spokane and produces Spokane Falls, from which 12,000 horsepower is developed. Other plants along the river produce an additional 45,000 horsepower.

The mean annual precipitation is 17 inches at Spokane and is probably less than 20 inches throughout the drainage area. The prairies are suitable for raising grain, and the valley lands support productive fruit orchards. The soils are rich and fertile, the generally slight rainfall being insufficient to cause too great leaching of lime and potash from them.

Though the upper valley of the Spokane is well populated, few people dwell along the lower river. Spokane, with a population of 104,402[1] in 1910, is the largest city in Washington east of the Cascade Mountains and the second city in size in the State. Its principal industrial establishments are lumber mills, flour mills, and machine shops. It is the chief distributing center for what is known locally as the "inland empire" and it has exceptional railroad facilities. Its water supply, which is obtained from wells driven in the sands of the river bed, is considered satisfactory for ordinary purposes, although the water is very hard.

CHARACTER OF THE WATER.

Samples of water from Spokane River about 8 miles above the falls were collected under the direction of the city health officer from January 1 to June 1, 1910, but thereafter, until January 31, 1911, owing to the difficulty and resulting irregularity of collection, the samples were taken in the city at the gaging station of the United States Geological Survey by the gage reader, A. C. Lingle. The drainage area above the gaging station is 4,000 square miles.

The river furnishes a calcium-carbonate water, low in mineral matter and excellent for all ordinary industrial uses. Ordinarily it will probably not corrode boilers, but it is likely to be actively corrosive when organic matter is high. Corrosive action at such times could, however, doubtless be prevented by leaving in boilers a thin coating of the medium hard scale that would be deposited. Though the water is subject to considerable variation in amount and character of incrusting material, the content is always too small to make chemical treatment necessary or advisable before boiler use.

If the river water were properly filtered or otherwise purified, it would make a most acceptable supply for the city and would save the community large sums each year by decreased soap consumption alone.

[1] Thirteenth Census of the United States, 1910.

Mineral analyses of water from Spokane River at Spokane, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Dissolved solids (tons per day).	Suspended matter (tons per day).
Feb. 1	Feb. 10	4	1.2	0.30	12	0.12	9.6	3.3	6.3	0.0	38	....	0.15	0.8	60	19.45	4,744	765	15
11	20	8	6.4	.80	....	....	....	....	....	....	....	....	.10	.6	76	19.45	4,748	970	82
21	Mar. 2	8	8.2	1.02	14	.02	9.4	....	7.9	a 17	6.1	18	....	.4	64	18.85	3,988	690	88
Mar. 3	12	3	2.4	.80	8.8	.02	7.6	....	4.1	a 9.6	15	9.9	.00	.10	48	23.30	12,512	1,620	81
Apr. 2	Apr. 11	15	16	1.07	9.0	.04	8.0	2.6	8.3	.0	38	19	....	1.2	54	26.70	20,980	3,060	907
12	21	25	28	1.12	18	.05	8.0	3.1	9.4	.0	44	22	....	....	70	27.85	24,180	4,560	1,630
22	May 1	10	6.4	.64	12	.04	....	2.4	....	.0	31	....	....	.2	59	28.15	25,090	3,930	434
May 2	11	5	4.7	.94	15	.03	6.2	1.7	4.6	.0	28	5.4	....	.5	51	26.85	21,500	2,960	273
12	21	6	6.2	1.03	15	.03	5.5	1.9	4.9	.0	33	6.6	....	.6	51	26.10	19,380	2,760	336
22	31	5	3.2	.64	13	.02	9.6	1.8	5.2	.0	42	6.2	.00	.2	59	24.35	14,910	2,380	129
June 1	June 10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
11	20	5	....	....	17	.01	12	2.6	5.3	.0	52	6.2	.00	.4	72	19.50	4,799	930	....
21	30	3	1.6	.53	17	.01	11	1.9	3.7	.0	48	6.9	.00	.3	60	18.75	3,691	600	16
July 1	July 10	5	3.4	.68	13	.01	12	4.2	5.0	.0	57	8.6	.00	.1	71	18.40	3,165	606	29
11	20	3	2.0	.67	13	Trace.	11	3.8	4.7	.0	50	4.0	.00	.2	65	18.45	3,273	574	18
21	30	10	8.6	.86	10	Trace.	10	4.0	5.7	.0	50	5.1	.00	.3	61	18.30	3,083	510	71
31	Aug. 9	10	3.4	.34	9.6	Trace.	14	5.2	5.0	.0	66	6.9	.00	.1	69	17.85	2,485	464	23
Aug. 10	19	10	1.2	.12	11	.01	13	5.0	5.7	.0	67	5.1	.00	.1	75	17.55	2,160	437	7
20	29	15	.7	.47	6.2	.01	13	5.2	5.4	.0	66	5.8	.00	.7	73	17.55	2,118	416	40
30	Sept. 8	2	1.2	.60	6.8	.01	12	5.0	5.4	.0	63	11	.10	.3	72	17.55	2,146	417	7
Sept. 9	18	2	1.6	.80	3.8	.01	14	4.4	5.2	.0	72	9.5	.44	.3	82	17.35	1,928	426	8
19	28	3	1.4	.47	5.2	.01	14	5.2	7.9	.0	63	11	.05	.9	69	17.40	1,953	364	7
29	Oct. 8	4	.2	.05	11	.03	14	5.2	5.2	.0	62	10	1.2	.5	75	17.55	2,163	439	1.2
Oct. 9	18	1	Trace.	....	8.0	.01	15	5.2	6.9	.0	68	9.2	.40	.8	76	17.55	2,136	438	0
19	28	4	2.6	.65	11	.02	15	4.6	5.1	.0	57	13	.50	.5	74	17.60	2,170	434	15
29	Nov. 7	3	1.0	.33	11	.01	14	4.0	6.0	.0	55	8.9	.50	1.5	71	17.60	2,220	425	6.0
Nov. 8	17	2	.8	.40	9.0	.01	11	4.0	4.6	.0	52	4.6	.65	1.5	64	17.75	2,402	415	5.2
18	27	5	Trace.	....	8.0	.06	7.8	24	3.6	.0	33	9.7	.00	.5	48	19.80	5,327	690	0
28	Dec. 7	1	1.9	1.90	9.2	.01	6.8	2.0	3.2	.0	28	7.9	2.0	.5	45	20.60	6,634	805	34
Dec. 8	17	1	2.1	2.10	11	.01	7.7	2.6	2.8	.0	30	8.3	.20	.3	47	20.30	6,115	742	35
18	27	2	1.2	.60	11	Trace.	8.4	3.5	3.0	.0	39	6.4	.25	.1	53	19.40	4,683	670	15
28	Jan. 6	5	5.8	1.16	9.3	Trace.	9.0	3.2	4.9	.0	41	9.4	Trace.	.4	56	18.80	3,760	569	59
Jan. 7	16	3	2.6	.87	10	Trace.	9.5	3.2	4.5	.0	43	8.9	Trace.	.4	58	18.50	3,345	524	23
17	26	2	2.1	1.05	22	Trace.	9.6	3.6	6.5	.0	43	11	Trace.	4.5	66	18.50	3,302	589	19
27	31	1	1.6	1.60	10	Trace.	9.1	3.2	3.2	.0	45	11	Trace.	.3	59	18.25	2,996	426	13
Mean........		5	4.1	.79	11	.02	11	3.6	5.3	.0	48	9.2	.23	.6	63	....	....	b 404,900	b 45,900
Percentage of anhydrous residue....			....	....	17.0	c.1	17.0	5.6	8.2	36.6	....	14.2	.4	.9	....	....	....	....	....

a Abnormal; computed to HCO_3 in average.

b Annual denudation.

c Fe_2O_3.

Color and alkalinity of the water of Spokane River at Spokane.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 16	9	0.0	24	May 10	9	[a] 7.2	12
18	7	.0	28	11	8	[a] 16	....
21	9	[a] 3.8	42	12	8	[a] 12	2.4
May 2	8	.0	23	14	9	.0	26
3	8	[a] 4.3	17	15	8	[a] 12	16
4	10	[a] 2.4	18	16	8	.0	22
5	12	[a] 11	21	18	8	[a] 3.6	21
6	10	[a] 8.4	24	23	8	.0	29
7	10	[a] 19	3.7	24	10	.0	28
9	10	.0	27				

[a] Abnormal; probably present as HCO_3 at time of collection of samples.

OKANOGAN RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Okanogan River, rising in Okanogan Lakes, British Columbia, flows southward across the international boundary through a chain of long, narrow lakes and joins Columbia River near Brewster. Its drainage basin is broken and mountainous and except in the river valleys is well timbered. The annual precipitation is 20 inches or less and occurs mostly in winter. Discharge measurements on Okanogan River itself are lacking, but measurements on tributaries[1] indicate that maximum discharge occurs in the late spring as a result of melting of snow on the higher parts of the basin.

The prevailing rocks in the region are gneisses and schists, but limestones and granites are found in some localities. The southeastern part of the basin is largely overlain by basalt. The soil is usually very fertile, the rainfall being insufficient to leach out excessively the soluble salts.

Lack of adequate transportation facilities has undoubtedly retarded development of this region, but the reclamation of 10,000 acres of prairie land by the United States Reclamation Service and the construction of new railroads, both now in progress, will furnish the impetus necessary to place this section of the State in its proper rank. Lumbering and agriculture are the principal industries. The river valley is well suited to orchards, and fruit growing is destined to become a leading occupation. Population is at present sparse and the towns are few and small.

[1] Stevens, J. C., and Henshaw, F. F., Surface water supply of the United States, 1907-8, pt. 12: U. S. Geol. Survey Water-Supply Paper 252, p. 120, 1910.

CHARACTER OF THE WATER.

Samples of water were collected daily from Okanogan River at Okanogan by employees of the United States Reclamation Service from March 13, 1910, to January 16, 1911, inclusive.

This calcium-carbonate water of moderate mineral content would deposit less than two-thirds of a pound of scale for every 1,000 gallons of it evaporated in a boiler, and artificial softening of it would therefore be unnecessary, though preheating might effect removal of some scale-making material and the dissolved gases capable of causing corrosion. The water is excellent for agricultural use. It is typical drainage from a country of mixed limestone and volcanic rocks and shows also the presence of much sulphate rock—possibly gypsum.

Color and alkalinity of the water of Okanogan River were determined daily from March 14 to May 4, 1910, inclusive. The great variations in color do not bear any apparent relation to the variations in alkalinity. The color decreased from March 14 until April 20, with slight interruptions, and the rains of March 17, 19, and 22 and April 9 caused slight additional decreases in color. Alkalinity also decreased on March 17, but increased on March 19 and 22 and April 9. The lower alkalinity on the days following the rain, however, probably indicates the effect of the rainfall. The irregularities in color and alkalinity may be referable to changes in temperature and precipitation in the Canadian part of the basin, for which climatologic data are not available.

The alkalinity due to bicarbonates decreased steadily during the period of observation, and although carbonate alkalinity increased total alkalinity decreased. This seems remarkable, as the weather was rather dry and the discharge of the river might be expected to have been decreasing, but as a matter of fact the snow on the higher areas was melting at that time, and the decrease in alkalinity was undoubtedly due to the dilution of water from that source.

Mineral analyses of water from Okanogan River at Okanogan, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
Mar. 3	Mar. 12	20	24	1.20	18	0.02	27	7.8	10	0.0	92	25	0.20	0.7	145
13	22	20	16	.80	20	.03	28	7.5	7.9	.0	115	22	.00	.3	148
23	Apr. 1	50	......	......	16	.05	20	5.5	11	.0	96	16	.40	.6	116
Apr. 2	11	18	37	2.06	23	.03	17	5.7	9.6	.0	73	17	.25	.8	115
12	21	45	63	1.40	4.9	.03	15	5.0	8.0	.0	68	17	.50	.3	86
22	May 1	250	117	.47	14	.04	16	1.9	7.9	.0	60	8.5	......	.8	89
May 2	11	40	37	.93	15	.04	16	3.6	7.9	.0	66	8.8	.20	.8	90
12	21	50	51	1.02	12	.05	13	2.9	7.7	.0	58	8.4	.35	.3	76
22	31	60	54	.90	9.8	.01	12	2.4	6.1	.0	54	8.2	......	Tr.	72
June 1	June 10	13	14	1.08	10	.01	13	3.5	6.1	.0	57	5.1	......	.1	67
11	20	30	34	1.13	6.4	.01	12	2.9	5.0	.0	51	6.1	.00	.1	65
21	30	30	35	1.17	6.8	.01	17	2.5	8.4	.0	72	7.0	.00	Tr.	90
July 1	July 10	20	69	3.45	87	.02	13	2.7	9.8	.0	60	8.6	.00	1.6	182
11	20	55	75	1.36	15	.02	16	2.7	9.5	.0	70	8.4	.00	1.3	93
21	30	12	19	1.58	9.0	.02	17	4.0	12	.0	78	12	Tr.	.8	96
31	Aug. 9	3	Tr.	......	12	.01	24	4.7	9.0	.0	92	13	......	.5	117
Aug. 10	19	5	4.8	.96	16	.01	24	4.5	12	.0	98	14	.20	1.5	124
20	29	10	20	2.00	12	Tr.	26	5.8	9.6	.0	95	18	Tr.	.5	128
30	Sept. 8	15	33	2.20	6.4	.04	16	5.8	11	.0	67	18	.50	.8	96
Sept. 9	18	8	4.6	.57	11	Tr.	29	5.8	7.2	.0	109	18	.00	.4	130
19	28	5	6.8	1.36	7.4	.02	28	5.2	8.5	.0	98	21	.80	.5	136
29	Oct. 8	7	2.8	.40	12	.02	27	5.4	11	.0	101	24	.39	1.0	129
Oct. 9	18	5	7.2	1.44	8.6	.02	21	3.8	9.1	.0	74	19	.42	1.2	99
19	28	1	3.4	3.40	12	.01	23	4.0	9.6	.0	77	15	2.5	2.8	101
29	Nov. 7	7	2.8	.40	11	.02	18	4.0	6.9	.0	70	13	.50	1.8	95
Nov. 8	17	6	1.0	.17	14	.01	20	4.5	7.4	.0	77	20	.60	.5	104
18	27	5	6.2	1.24	6.4	.01	21	4.6	6.6	.0	78	20	Tr.	.5	100
28	Dec. 7	5	1.4	.28	11	Tr.	22	5.0	6.0	.0	78	23	.00	2.3	109
Dec. 8	17	3	2.6	.87	5.4	.01	24	5.2	8.7	.0	90	20	Tr.	.5	115
18	27	5	3.2	.64	10	.01	31	6.4	6.1	.0	102	24	Tr.	.6	130
28	Jan. 6	4	2.0	.50	13	Tr.	27	6.2	5.3	.0	95	20	Tr.	.8	126
Jan. 7	16	5	6.6	1.32	14	Tr.	30	6.8	10	.0	113	22	Tr.	1.3	143
Mean........		25	24	1.21	14	.02	21	4.6	8.5	.0	81	16	.28	.8	110
Percentage of anhydrous residue.....					13.3	.0	20.0	4.4	8.1	38.0	.....	15.2	.3	.7	....

Color and alkalinity of the water of Okanogan River at Okanogan.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 14	20	[a] Trace.	121	Apr. 12	8	[a] 3.6	87
15	18	[a] Trace.	118	13	5	[a] 7.0	85
16	18	.0	116	14	6	.0	96
17	18	[a] 3.84	107	15	6	.0	95
18	8	[a] 9.6	109	16	6	[a] 1.2	98
19	8	.0	109	20	4	[a] 17.8	61
20	24	[a] 1.2	88	21	4	[a] 25.7	25
22	16	[a] 4.3	104	22	8	[a] 15.4	41
23	20	[a] 10.6	84	23	8	[a] 45.0	....
25	40	[a] 19.4	71	25	10	[a] 11.5	45
26	16	.0	94	26	54	[a] 20.6	39
30	8	.0	94	27	32	[a] 17.0	24
Apr. 1	12	.0	91	29	12	[a] 38.0	0
4	8	[a] 3.6	96	30	6	[a] 25.5	13
5	8	.0	99	May 2	10	[a] 7.2	43
6	6	.0	96	3	8	[a] 31.0	22
7	9	.0	106	4	8	[a] 18.3	34
9	6	[a] 21.0	77				

[a] Abnormal; probably present as HCO_3 in sample as collected.

WENATCHEE RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Wenatchee River rises in Cady Pass, among the peaks of the Cascade Mountains in north-central Washington, flows eastward through Wenatchee Lake, and then generally southward and southeastward to its junction with the Columbia near Wenatchee. The upper river skirts the southwestern border of its broad valley and at one place, above Leavenworth, actually leaves its true valley and flows in the steep, narrow Wenatchee Canyon, cut for about 6 miles through hard granite. It reenters its valley at Leavenworth, and thence to its mouth pursues a more normal course. The upper valley is well timbered, but the lower valley except for its orchard lands is almost treeless, the principal growth being sagebrush.

In its upper reaches the Wenatchee exposes schists and sandstones lying between the gneisses and granitic formations, of which all the highest elevations are composed.

The Entiat Mountains, which form the northern border of the valley, are largely schistose, mica and hornblende schists predominating.[1] The rocks of the Wenatchee Mountains, on the south, are granitic, and serpentine representing altered peridotite is locally abundant. Arkosic sandstone is widely distributed in the upper portion of the valley, but the middle and lower portions, except at the Leavenworth cut-off, are deeply gravel filled.

The soil, though usually poor in lime, is rich and fertile. Orchards thrive, and the apples of this valley have become famous for their flavor and shipping qualities. Precipitation is abundant in the upper part but somewhat deficient in the lower part of the valley; at Wenatchee it is about 16 inches a year and occurs mostly as snow.

The city water supply of Leavenworth is taken from the river and one of its tributaries. Typhoid fever, prevalent at times in Leavenworth, has probably been caused by infection of the water by construction camps on the river bank above the intake. Cashmere also uses the water for city supply.

CHARACTER OF THE WATER.

During the period of this study, from February 1, 1910, to January 31, 1911, samples of water were collected daily by W. R. McManus from Wenatchee River at a point below the United States Geological Survey gaging station at Cashmere but above the city drainage. No samples could be collected during the floods of March, 1910. The drainage area above this point is 1,200 square miles.[2]

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[1] Russell, I. C., A preliminary paper on the geology of the Cascade Mountains in northern Washington: U. S. Geol. Survey Twentieth Ann. Rept., pt. 2, p. 83, 1900.

[2] Henshaw, F. F., and others, Surface water supply of the north Pacific coast, 1910: U. S. Geol. Survey Water-Supply Paper 292, p. 141, 1913.

The water of Wenatchee River contains little dissolved or suspended matter, and will deposit a very little but rather hard scale in boilers. Notwithstanding its low average content of dissolved matter, Wenatchee River carries down to the Columbia each year in solution approximately 160 tons of rock material per square mile of drainage area, or nearly 190,000 tons. The water has secondary salinity. Silica is remarkably variable in the analyses, but it is believed that the high figure of the report for April 2 to 11 does not represent the water as collected. Many diatoms were found in the composite sample for July 1 to 10, and it is believed that these organisms, having grown rapidly in the water after collection, passed through the filters that were used to remove suspended matter, and thus caused abnormal dissolved silicas. Magnesium was determined by the gravimetric method in the first seven analyses, and the precipitates may have contained weighable impurities. Subsequent determinations by the volumetric method gave much lower but probably more nearly accurate results.

Color was noticeable in March but not later. The river was rising during the period—between March 1 and June 15—covered by these tests of color and alkalinity, and the alkalinity decreased with considerable regularity during that period. If a coagulant is added in purifying the water for use as a municipal supply, care will have to be exercised either not to add reagents in excess of the reacting capacity of the alkalinity, or to increase the alkalinity when necessary by adding soda ash or milk of lime.

Mineral analyses of water from Wenatchee River at Cashmere, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second feet).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Feb. 1	Feb. 10	3	1.6	0.53	20	0.20	7.3	4.3	7.6	0.0	45	8.1	0.34	1.2	70	1.50	1,476	64	279
11	20	2	1.6	.80	22	.15	8.0	4.1	8.2	.0	50	8.4	.33	.5	75	1.40	1,382	60	282
21	Mar. 2	2	.4	.20	25	.16	9.5	5.2	7.2	.0	59	13	.20	1.0	85	1.40	1,421	15	327
Mar. 3	12	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2.25	2,626	a 407	a 599
13	22	35	53	1.51	15	.07	7.6	4.2	5.0	b 19	11	4.1	.15	.5	58	3.60	5,558	800	871
23	Apr. 1	10	10	1.00	19	.01	7.4	2.9	4.6	.0	37	6.4	.41	1.2	63	3.80	5,957	160	1,010
Apr. 2	11	20	11	.55	37	.14	10	4.5	10	.0	54	15	Trace.	.5	111	2.90	3,869	115	1,160
12	21	8	11	1.38	15	.04	6.0	4.2	6.3	.0	32	7.5	Trace.	.8	51	3.45	5,489	162	755
22	May 1	40	38	.95	8.3	.02	5.2	1.9	3.5	b 9.7	4.9	4.5	.30	1.5	40	5.80	13,197	1,350	1,420
May 2	11	18	16	.89	16	.01	4.6	1.9	3.9	b 8.4	9.8	4.1	.15	1.0	46	5.65	12,808	467	1,350
12	21	10	12	1.20	8.7	Trace.	4.2	1.4	4.4	.0	22	7.2	Trace.	1.1	41	5.65	12,440	404	1,380
22	31	25	15	.60	18	.01	4.2	1.5	4.4	.0	20	13	Trace.	1.2	51	6.05	14,280	579	1,960
June 1	June 10	8	3.7	.46	10	Trace.	4.7	1.4	3.4	.0	20	6.5	.00	1.0	38	4.75	8,896	89	912
11	20	18	11	.61	9.2	Trace.	4.4	1.6	2.8	b 6.0	7.3	5.0	Trace.	1.3	34	4.65	8,624	256	791
21	30	8	5.9	.74	15	Trace.	4.3	1.7	3.1	b 2.4	12	10	.00	1.0	45	3.70	5,571	89	676
July 1	July 10	8	12	1.50	......	.01	3.9	1.7	5.0	.0	23	7.6	Trace.	.5	......	3.85	6,018	195	a 568
11	20	10	1.6	.16	6.8	.03	3.4	1.1	3.4	.0	13	11	Trace.	.8	33	3.50	5,154	22	460
21	30	12	......	......	6.4	.01	4.2	1.6	3.8	.0	22	7.2	.00	.7	35	2.55	3,176	21	300
31	Aug. 9	8	3.5	.44	5.2	.02	5.0	2.0	4.0	.0	23	8.0	.00	1.3	37	2.05	2,247	21	224
Aug. 10	19	17	6.5	.38	7.9	Trace.	4.8	1.8	2.7	.0	23	5.4	Trace.	1.0	37	1.75	1,839	32	184
20	29	1	.5	.50	12	.01	6.8	2.4	3.0	.0	31	6.2	Trace.	1.0	47	1.20	1,191	2	129
30	Sept. 8	7	1.6	.23	5.6	.01	6.0	2.8	4.3	.0	32	6.7	Trace.	1.2	43	.95	960	4	111
Sept. 9	18	3	2.4	.80	9.5	.01	6.4	3.0	4.9	.0	34	5.7	.70	1.3	47	.70	795	5	101
19	28	1	.9	.90	8.5	Trace.	5.8	2.4	3.6	.0	29	5.2	1.00	1.0	42	.90	892	2	101
29	Oct. 8	5	3.6	.72	6.7	.02	5.0	2.0	3.9	.0	26	8.3	.20	1.0	38	2.05	2,539	25	260
Oct. 9	18	4	3.8	.95	6.6	.01	4.2	1.5	3.5	.0	20	4.7	.05	1.0	31	2.50	3,053	31	255
19	28	5	.2	.40	6.6	.02	5.3	1.6	2.8	.0	20	7.7	.32	1.8	33	2.35	2,830	2	252
29	Nov. 7	2	1.3	.65	7.5	.06	4.3	1.3	3.1	.0	19	5.8	.00	1.3	35	2.00	2,176	8	206
Nov. 8	17	5	1.7	.34	6.2	.01	4.2	1.4	2.7	.0	17	5.8	.90	1.1	31	2.00	3,833	18	320
18	27	4	6.5	1.62	6.1	.01	5.3	1.8	3.4	.0	18	11	4.0	.8	36	3.60	5,958	105	580
28	Dec. 7	2	1.1	.55	8.2	.01	4.9	1.8	3.4	.0	18	12	2.0	1.5	40	2.25	2,651	8	286
Dec. 8	17	2	.7	.35	9.0	.01	5.0	2.2	3.0	.0	26	6.3	.05	.3	39	1.70	1,750	3	184
18	27	5	.1	.02	9.4	Trace.	5.4	2.4	3.1	.0	31	6.1	Trace.	.8	41	1.45	1,437	.4	159
28	Jan. 6	2	1.0	.50	9.6	Trace.	5.8	2.0	3.8	.0	28	4.1	Trace.	.8	44	1.35	1,343	3.6	159
Jan. 7	16	1	1.4	1.40	10	.01	5.4	2.5	3.9	.0	28	5.2	Trace.	.8	44	1.35	1,367	5.2	162
17	26	1	1.8	1.80	11	.02	5.4	2.2	3.2	.0	31	5.7	Trace.	.5	43	1.30	1,259	6.1	146
27	31	1	1.0	1.00	11	.01	5.6	1.4	3.5	.0	29	6.5	Trace.	.7	44	1.10	1,070	2.9	127
Mean		9	7.0	.76	12	.03	5.5	2.3	4.2	.0	28	7.4	.31	1.0	46	......	......	c 55,400	c 189,830
Percentage of anhydrous residue					25.8	d .1	11.8	5.0	9.0	29.5	......	15.9	.7	2.2	......	......	......	......	......

a Estimated. b Abnormal; computed to HCO_3 in average. c Annual denudation. d Fe_2O_3.

Color and alkalinity of the water of Wenatchee River at Cashmere.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 11	14	0.0	50	May 6	7	[a] 13	6.3
12	16	.0	48	7	8	.0	25
13	16	.0	51	8	16	[a] 9.6	....
15	16	.0	53	9	14	[a] 11	2.4
16	18	.0	48	10	8	[a] 4.8	10
17	16	.0	47	11	7	[a] 32	0
18	16	[a] 10	42	12	6	.0	20
19	12	.0	45	13	8	.0	16
20	16	.0	40	14	8	.0	21
21	18	.0	38	15	6	.0	19
22	18	.0	35	16	6	.0	19
23	12	.0	38	17	6	[a] 14	5.4
24	8	.0	40	18	5	[a] 4.8	11
25	8	.0	33	21	8	.0	21
26	6	.0	49	22	8	[a] 1.2	31
27	Trace.	[a] 2.4	40	23	8	.0	26
28	4	[a] 2.6	39	24	8	.0	15
29	2	.0	41	25	10	.0	24
30	10	[a] 9.1	36	26	8	.0	17
31	28	[a] 4.8	40	27	6	.0	19
Apr. 1	16	[a] 12	25	28	8	[a] 6.7	9.0
2	8	[a] 4.3	34	29	4	.0	18
3	8	[a] 6.7	31	30	....	.0	20
4	8	[a] 11	34	31	6	.0	15
5	6	.0	39	June 1	8	[a] 9.1	16
20	8	[a] 1.4	22	2	6	.0	20
22	8	[a] 10	8.5	3	6	.0	20
23	10	.0	31	4	4	.0	20
24	8	.0	42	5	6	.0	16
25	8	[a] 11	12	6	6	.0	15
26	12	.0	22	7	8	.0	19
27	12	[a] 5.8	6.8	8	8	.0	18
28	12	.0	25	9	4	.0	20
29	20	[a] 12	....	10	4	.0	16
May 1	14	.0	29	11	6	.0	15
2	6	[a] 4.8	16	12	6	.0	22
3	8	[a] 13	0	13	10	.0	17
4	8	[a] 13	0	14	8	.0	19
5	7	[a] 12	2.9	15	8	.0	16

[a] Abnormal; probably present as HCO_3 in water at time of collection.

YAKIMA RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Yakima River heads in Keechelus Lake 2,458 feet above sea level, near Snoqualmie and Yakima passes in the Cascade Mountains. It flows in general southeastward about 150 miles, and discharges into the Columbia a few miles above the town of Kennewick. The upper river flows through heavily forested, mountainous country, about 5,500 feet above sea level. Precipitation is abundant, averaging 26 inches at Clealum and increasing rapidly to over 60 inches a year at Keechelus Lake. As the greater part of the precipitation occurs in fall and winter, much of it as snow, and as midsummer precipitation is almost nothing, there are annually two periods of low water and two periods of high water. Low water occurs usually during the midwinter months, while snow is accumulating. Spring thaws cause high water, which generally reaches a maximum late in the spring and gives way to the low-water stage of summer. Rains late in the autumn bring a second, less pronounced high-water stage, which in turn gives place to the low water of winter.

In its middle and lower courses the river flows through a series of wide, fertile valleys that extend to the plains of the Columbia. Rainfall is deficient, ranging from 10 inches at Ellensburg to 6 inches at Kennewick, and this part of the drainage area is practically unforested, except among the mountains that form the western wall of the valley and among the Wenatchee Mountains on the north. Naches River, Tieton River, Cowiche Creek, and Atanum Creek flow from the west to join the middle Yakima. Toppenish and Satus creeks drain the southern highlands, and several small streams, entering from the north near and above Ellensburg, head in the Wenatchee Mountains and form the only important tributaries from the north and east sections of the drainage area. The lower Yakima is in a semiarid country and has no tributaries.

The upper Yakima River valley exposes pre-Eocene schists, slates, serpentines, and volcanic rocks, Eocene sandstones, conglomerates, shales, and basalts, and in places Miocene and later basalts. Above Ellensburg the river crosses an exposure of Miocene basalt and enters the later Tertiary sedimentary deposits known as the Ellensburg formation, and in its lower course flows across basalt and sandstone.

NACHES RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Naches River, a tributary of Yakima River, rises in the Cascade Mountains, in the western part of Kittitas County, and flows southeastward, discharging into Yakima River a short distance above North Yakima. Its total length is about 50 miles, but its headwaters drain a stretch of the Cascade Mountains 50 miles in extent. Precipitation is abundant around its headwaters, and although its valley lands are semiarid its annual discharge is equivalent to a depth of about 20 inches on its drainage area. A large part of the basin is forested with yellow pine, red and yellow fir, tamarack, and some hemlock and other conifers.

The geologic formations exposed near the source of the river include large areas of Tertiary sandstones and lavas, together with some more recent andesite.

CHARACTER OF THE WATER.

Samples of water were collected daily from Naches River below the entrance of Tieton River at the power house near the town of Naches from February 1 to June 30, 1910, when the station was discontinued. A gaging station is maintained by the United States Geological Survey 5 miles above Naches and below the mouth of Tieton River. The drainage basin above it comprises 930 square miles.

The water has a slight amount of temporary hardness but is not usually concentrated enough to render treatment for boiler use necessary. It is a calcium-carbonate water with minor proportions of alkalies and sulphates. As the samples were collected during spring freshets, the amount of suspended matter is probably much greater and the amount of dissolved matter probably less than they would have been throughout the year.

The water is well suited for irrigation, the chief use to which it is to be put. It will become more unsafe as a source of municipal supply as the population of the drainage basin increases, and it now furnishes an undesirable supply to North Yakima. The water is treated by adding to it sodium hypochlorite in the proportion of 8 or 10 pounds of the reagent to 1,000,000 gallons of water, but the city health officer states in a personal communication that the treatment is not always effective and that it is evidently unskillfully performed.

The determinations of the color and alkalinity of water from Naches River, made daily from March 3 to June 26, 1910, show a gradual but irregular decrease in both qualities, but the variations bear no apparent relation to rainfall. Probably melting snow on the Cascades has the most pronounced influence, for the snow melted more and more rapidly as the season advanced, and alkalinity and color show a more or less regularly increasing dilution. The color in early spring was high and caused considerable complaint among those who used the supply for drinking. Coagulation and rapid sand filtration followed by properly supervised addition of hypochlorite would decolorize the water and render it safe and satisfactory for municipal use.

Mineral analyses of water from Naches River at Naches, 1910.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+$\frac{3}{2}$K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.
Feb. 1	Feb. 10	5	3	0.60	26	0.10	8.8	2.4	7.4	0.0	45	8.6	0.22	0.4	80
11	20	5	4.8	.96	31	.13	10	2.4	7.2	.0	52	8.9	.50	.6	89
21	Mar. 2	100	84	.84	25	.20	9.4	a 2.5	8.5	.0	47	12	Trace.	.7	82
Mar. 3	12	20	32	1.60	24	.15	8.8	3.1	5.7	b 4.3	37	8.9	Trace.	.4	74
13	22	30	73	2.45	20	.25	8.1	2.7	6.8	b 11	22	8.1	Trace.	.4	74
23	Apr. 1	40	37	.92	20	.02	9.5	3.1	7.7	.0	48	3.5	.20	.2	67
Apr. 2	11	25	19	.76	26	.08	9.6	3.2	6.9	.0	48	5.8	.00	.4	76
12	21	60	61	1.02	17	.05	8.4	3.1	7.0	.0	52	3.1	Trace.	.5	66
22	May 1	28	34	1.21	30	.01	7.5	2.2	5.5	.0	44	6.3	Trace.	.5	79
May 2	11	....	a 30	.....	....	.....	.....	.....	.....	.....	....	.....	....	....	....
12	21	25	26	1.04	32	.02	6.7	2.4	6.3	.0	39	2.6	.00	.3	76
22	31	15	17	1.13	18	.01	6.5	2.0	4.5	.0	34	2.5	.00	.3	52
June 1	June 10	10	6.8	.68	16	.01	6.7	1.9	2.4	.0	31	3.9	....	.3	59
11	20	10	6.0	.60	16	.01	.....	.....	5.8	.0	29	.....	....	.3	61
21	30	21	1.4	.70	22	.01	6.8	2.2	4.3	.0	37	2.8	.00	.3	65
Mean.......		27	29	1.04	23	.08	8.2	2.5	6.1	.0	43	5.9	.08	.4	71
Percentage of anhydrous residue......					34.1	c .2	12.2	3.7	9.0	31.4	.....	8.7	.1	.6	....

a Estimated. b Abnormal; computed to HCO_3 in average. c Fe_2O_3.

Color and alkalinity of the water of Naches River at Naches.

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 3	65	0.0	38	Apr. 8	8	0.0	44
4	30	[a] .7	46	9	8	[a] 9.6	27
13	54	.0	49	10	8	[a] 19.2	4.9
14	58	[a] 2.4	44	22	8	[a] 16.8	6.1
15	....	....	40	26	10	[a] 21.6	0
16	52	.0	45	29	9	[a] 38.0	0
17	24	.0	44	30	10	[a] 14.4	11
18	56	Trace.	52	May 16	8	.0	34
20	78	.0	38	17	8	.0	33
22	36	Trace.	40	18	8	[a] 12.0	6.1
23	16	.0	38	19	8	[a] 12.0	18
24	16	.0	44	20	8	[a] 12.0	11
25	20	.0	45	21	10	.0	30
27	8	.0	45	24	18	[a] 7.2	26
28	8	.0	40	25	16	.0	30
29	8	.0	40	26	16	.0	27
30	12	.0	40	27	14	.0	55
Apr. 1	2	.0	41	29	8	.0	37
2	6	.0	43	30	8	.0	37
3	....	.0	41	June 22	7	[a] 4.8	32
4	8	.0	41	23	8	[a] 4.8	28
5	....	.0	46	25	8	.0	40
6	8	[a] 4.8	41	26	8	[a] 6.0	24
7	8	.0	46				

[a] Abnormal; probably present as HCO_3 in sample as collected.

YAKIMA RIVER AT CLEALUM.

GENERAL FEATURES.

Clealum is situated on Yakima River 6 miles above the mouth of Teanaway River and 3 miles below the mouth of Clealum River, at an elevation of 1,908 feet above sea level. The surrounding country is rough and mountainous and contains several important coal deposits. The winter climate is severe but changeable. The annual precipitation, mostly snow, is about 26 inches. Floods occur in Yakima River late in the fall or early in the winter and late in the spring; the spring freshets are usually though not always the greater. Yakima River at Clealum carries the waters of Keechelus, Kachess, and Clealum lakes, and its water is therefore representative of all the principal headwaters of the river. Storage in the lakes regulates the discharge of the river so that it is not so "flashy" as it otherwise might be.

CHARACTER OF THE WATER.

Samples of water were collected by S. A. Mortland from the river near the left bank about 100 yards below the bridge near Clealum. A gaging station is maintained at the highway bridge just above Clealum; the drainage area above that point is 500 square miles.

The water is soft and free from large amounts of either suspended or dissolved material. As it usually contains much organic matter, probably of vegetable origin, it may at times cause corrosion in boilers, but gives little trouble from scale and needs no corrective treatment for boiler use. Slow sand filtration would probably be sufficient to render it suitable for domestic use.

The water is characterized by slight secondary salinity, which indicates that the predominating rock formations are sedimentary. Though andesites, basalts, and rhyolites, with some older schists and slates, predominate at the headwaters of this stream, they are succeeded by Tertiary sandstones, shales, and basalt. The Tertiary materials are the most readily soluble and probably give the water its distinguishing characteristics.

Both color and alkalinity are low, as shown by the accompanying table. The alkalinity decreased slightly because of dilution by rain and melted snow.

Mineral analyses of water from Yakima River at Clealum, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+$\frac{3}{5}$K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl.).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Dissolved solids (tons per day).	Suspended matter (tons per day).
Feb. 1	Feb. 10	3	......	......	10	0.12	6.4	2.5	......	0.0	32	7.2	0.06	0.5	52	2.90	1,199	168	a 7.3
11	20	3	2.4	0.80	17	.18	......	2.4	......	.0	44	9.9	Trace.	.5	60	2.70	1,005	163	6.5
21	Mar. 2	......	......	......	......	......	......	......	......	......	......	......	......	......	......	2.85	1,170	a 218	a 21
Mar. 3	12	10	6.0	.60	12	.06	6.3	3.1	2.2	.0	28	9.1	.00	.8	45	2.85	2,249	273	36
13	22	19	22	1.16	11	.01	......	3.8	4.1	b 9.6	9.8	7.4	.35	1.5	55	5.35	5,102	758	304
23	Apr. 1	12	12	1.00	12	.03	5.6	2.7	3.7	b 9.6	13	8.4	.50	.8	56	5.10	4,434	668	143
Apr. 2	11	6	15	2.50	16	.01	5.5	2.7	3.3	b 9.8	12	6.7	.00	.5	53	4.30	2,919	416	118
12	21	15	13	.87	15	.01	6.0	2.7	3.5	b 1.2	31	9.1	.20	1.5	54	5.00	4,189	610	147
22	May 1	10	13	1.30	3.2	.01	7.6	2.0	5.0	Trace.	28	3.6	Trace.	2.5	39	6.55	7,923	833	278
May 2	11	20	13	.65	7.3	Trace.	6.3	2.0	4.5	.0	31	6.0	Trace.	1.7	43	5.80	6,056	704	212
12	21	10	8.2	.82	11	.01	5.8	1.6	4.6	.0	28	5.6	Trace.	1.4	47	5.80	5,918	750	131
22	31	3	1.3	.43	15	.01	5.8	2.2	4.2	.0	33	5.2	Trace.	1.7	52	5.40	4,918	690	17
June 1	June 10	15	.8	.57	22	Trace.	7.4	1.6	5.7	.0	41	5.4	Trace.	2.2	71	4.55	3,370	646	7.2
11	20	Trace.	Trace.	......	9.9	Trace.	5.6	1.7	3.8	.0	31	5.5	Trace.	1.1	44	4.15	2,693	320	......
21	30	15	8.9	.59	9.2	.01	6.0	1.8	3.5	.0	24	5.2	Trace.	3.8	44	3.20	1,501	178	36
July 1	July 10	2	.2	.10	15	.01	6.0	1.7	4.1	.0	28	2.8	Trace.	3.6	54	2.95	1,266	185	6.3
11	20	10	7.9	.79	9.9	.01	5.3	2.2	5.4	.0	35	3.6	Trace.	2.0	50	2.80	1,136	153	24
21	30	6	5.1	.85	6.2	.01	6.7	2.1	5.4	.0	33	7.2	Trace.	2.3	43	2.50	871	101	12
31	Aug. 9	10	18	1.80	5.8	.01	7.8	2.1	4.7	.0	37	4.4	Trace.	.9	42	2.55	907	103	43
Aug. 10	19	4	7.3	1.82	9.7	.01	7.6	2.5	5.2	.0	40	4.2	Trace.	1.2	48	2.85	1,144	148	23
20	29	5	3.4	.68	8.0	Trace.	7.8	2.8	4.0	.0	39	4.4	Trace.	1.9	49	2.80	1,134	150	10
30	Sept. 8	2	1.6	.80	14	Trace.	12	3.9	3.3	.0	60	6.9	Trace.	1.7	68	2.25	690	127	3.0
Sept. 9	18	5	......	......	9.0	Trace.	6.7	......	2.7	.0	31	6.9	Trace.	1.7	39	2.00	508	54	a 13
19	28	1	.6	.60	8.0	.01	6.4	2.1	3.2	.0	31	6.9	.20	1.1	42	1.60	336	38	.5
29	Oct. 8	1	1.6	1.60	7.8	.01	6.2	2.0	4.1	.0	29	8.6	.36	2.3	40	2.60	1,123	121	7.2
Oct. 9	18	5	2.4	.48	7.4	.01	5.8	2.2	5.0	.0	31	5.0	1.5	3.1	43	3.50	1,856	216	12
19	28	3	1.3	.43	7.9	.01	6.2	2.1	2.7	.0	28	4.7	.05	2.2	40	3.45	1,777	192	6.3
29	Nov. 7	4	2.3	.58	7.7	.01	5.6	2.0	2.7	.0	24	3.8	.40	1.1	38	3.20	1,501	154	9.3
Nov. 8	17	2	......	......	7.6	.01	5.6	2.1	2.4	.0	24	4.3	.75	1.3	37	4.05	2,564	256	a 50
18	27	5	7.4	1.48	7.8	.04	5.9	1.8	2.8	.0	25	4.0	3.5	1.7	41	5.05	4,595	516	92
28	Dec. 7	2	3.8	1.90	6.7	Trace.	5.8	2.3	3.2	.0	23	10	Trace.	1.2	37	3.90	2,320	232	24
Dec. 8	17	1	1.6	1.60	8.7	.01	6.2	2.1	2.5	.0	29	11	Trace.	.8	43	3.30	1,604	186	6.9
18	27	1	.7	.70	6.8	Trace.	7.1	1.9	2.4	.0	32	4.6	Trace.	1.0	39	2.85	1,153	121	2.2
28	Jan. 6	2	1.7	.85	10	.01	8.4	2.3	3.3	.0	31	8.1	.50	1.4	47	2.75	1,087	138	4.9
Jan. 7	16	1	4.1	4.10	8.5	Trace.	8.9	2.1	3.4	.0	32	8.1	.60	1.7	46	2.75	1,050	130	12
17	26	1	1.7	1.70	7.4	.01	7.3	2.1	2.8	.0	28	5.3	Trace.	1.4	40	2.45	844	91	3.9
27	31	3	4.6	1.53	7.5	Trace.	7.1	2.2	3.8	.0	32	5.1	Trace.	1.4	43	2.20	659	77	8.2
Mean........		6	5.8	1.12	9.9	.02	6.7	2.3	3.7	.0	32	6.2	.25	1.6	47	......	......	c 108,460	c 18,336
Percentage of anhydrous residue............					21.3	d .1	14.4	5.0	8.0	34.0	......	13.3	.5	3.4	......	......	......	......	......

a Estimated. b Abnormal; computed to HCO_3 in average. c Annual denudation. d Fe_2O_3.

Color and alkalinity of the water of Yakima River at Clealum.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 14	4	0.0	34	May 5	2	0.0	28
16	Trace.	.0	33	6	0	[a] 10.8	10
18	4	.0	31	8	0	.0	30
20	4	.0	34	9	0	.0	29
22	3	.0	30	10	4	.0	27
23	3	.0	29	11	12	[a] 8.4	12
26	Trace.	[a] 2.9	32	12	8	.0	27
27	2	.0	31	13	4	.0	34
28	2	.0	36	14	8	.0	24
29	Trace.	.0	35	15	6	.0	20
30	0	.0	39	16	....	.0	28
Apr. 1	2	.0	35	17	....	.0	28
2	2	.0	33	18	8	[a] 7.2	27
3	2	.0	33	19	....	.0	32
4	0	.0	33	21	4	[a] 15.6	13
5	2	[a] 2.4	33	23	0	.0	27
6	Trace.	.0	33	25	4	.0	24
7	Trace.	.0	28	26	0	.0	30
8	3	.0	31	27	....	.0	29
9	4	.0	30	28	0	.0	26
12	0	[a] 29.0	44	29	....	[a] 4.8	33
13	0	[a] 5.3	22	30	....	[a] 3.4	33
14	2	[a] 12.0	12	31	4	.0	32
15	0	.0	33	June 1	0	.0	30
16	0	[a] 4.8	27	2	0	.0	27
17	0	[a] 26.0	....	3	....	.0	30
18	0	[a] 14.9	12	4	0	.0	27
19	0	[a] 16.3	4.1	5	0	[a] 3.6	28
22	0	[a] 20.4	24	6	0	.0	17
23	2	.0	30	7	0	.0	25
24	2	[a] 19.7	....	8	2	.0	29
25	8	[a] 12.0	7.3	9	0	.0	27
26	8	[a] 5.8	16	10	8	.0	28

[a] Abnormal; probably present as HCO_3 at time of collection.

YAKIMA RIVER AT PROSSER.

GENERAL FEATURES.

Prosser is situated in western Benton County in a rich agricultural section of lower Yakima Valley, which includes the Sunnyside project of the United States Reclamation Service.

This arid valley is fertile where water is applied to well-drained tracts, but poorly drained places are "spotted" by black alkali. The soil is rich and contains much potash and phosphate, and it is rendered very productive by irrigation. Series of Tertiary lake sediments and vast stretches of Yakima basalt are exposed in the basin. Most of the tributaries of Yakima River below Clealum flow from a region of basaltic and tuffaceous effusives.

CHARACTER OF THE WATER.

Samples of water from Yakima River at Prosser were collected at the flouring mill by Albert Smith from January 21 to June 20 and by Dr. D. M. Angus, county health officer, from August 20, 1910, to January 31, 1911. The amount of material carried in suspension and in solution between June 20 and August 20, 1910, has been estimated by interpolation in order to complete the yearly estimates of denudation. A gaging station is maintained at Kiona, 14 miles below Prosser. The drainage area at Kiona is 5,230 square miles and at Prosser is 5,050 square miles. The estimates of discharge entered in the table of analyses have been corrected for the difference in size of the basin.

The water is characterized by temporary hardness and can be softened for boiler use by adding small amounts of lime or by preheating in open heaters; it will probably cause no trouble by corrosion or foaming, though it contains much organic matter and is badly polluted by sewage. The writer has seen solid particles of sewage in the river above the outlets of the sewers at Prosser. North Yakima, notwithstanding prohibitive legislation, was discharging its untreated sewage into Yakima River in 1910, and this sewage undoubtedly passed Prosser less than one day later. Investigation[1] has recently demonstrated that much of the typhoid fever in this district is due to contaminated water supplies, and it is evident that the water of Yakima River is being grossly polluted with sewage and is entirely unfit for domestic use in its present state.

Daily determinations of the color and alkalinity of the water of Yakima River at Prosser were made from March 13 to January 24, 1911. Color was strong during the spring but decreased gradually until midwinter when the water was nearly colorless. As the water of Yakima River at Clealum and that of Naches River are both less highly colored than that of the Yakima at Prosser the latter probably obtains much of its color from tributaries other than the headwaters. The streams flowing from the Tertiary lake beds comprising the Ellensburg formation possibly contribute some color. Sudden great increases of color accompanied general rainstorms—as, for example, early in April.

The alkalinity of the water decreased during spring and increased during summer, so far as the incomplete records of conditions in summer indicate, and decreased again during winter. Alkalinity, therefore, varied inversely with stream flow.

Coagulation and rapid sand filtration would be the most satisfactory treatment for this water, if it were used as a municipal supply.

[1] Lumsden, L. L., The causation and prevention of typhoid fever with special reference to conditions observed in Yakima County, Wash.: U. S. Pub. Health Service Pub. Health Bull. 51, 1912.

Mineral analyses of water from Yakima River at Prosser, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean discharge (cubic feet per second).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Feb. 1	Feb. 10	30	20	0.67	25	0.24	17	6.8	13	0.0	78	20	0.95	4.5	121	4,401	237	1,437
11	20	10	23	2.30	50	.25	16	5.8	22	a 5.8	78	23	.46	6.7	169	3,271	203	1,495
21	Mar. 2	125	79	.63	27	.40	15	6.5	17	.0	94	18	.15	4.3	130	4,313	455	1,514
Mar. 3	12	35	16	.46	31	.42	13	4.5	13	.0	73	16	Trace.	1.9	115	12,158	525	3,776
13	22	20	26	1.30	24	.29	11	6.0	9.5	.0	67	12	Trace.	1.6	98	17,010	1,195	4,510
23	Apr. 1	25	14	.56	23	.08	11	5.0	9.1	.0	65	6.9	.20	1.5	88	17,610	667	4,180
Apr. 2	11	18	22	1.22	15	.15	13	6.5	9.9	.0	72	10	.40	1.9	89	9,369	656	2,250
12	21	50	62	1.24	20	.02	12	4.8	8.5	.0	63	7.6	.00	2.0	90	10,486	2,520	2,548
22	May 1	15	20	1.33	14	.09	10	3.4	6.1	.0	50	7.9	.00	1.4	69	17,120	924	3,189
May 2	11	15	12	.80	10	.20	13	3.5	6.3	.0	57	6.6	.20	1.5	73	11,620	376	2,289
12	21	25	26	1.04	13	.15	11	3.4	6.6	.0	49	13	.35	1.2	71	12,880	904	2,470
22	31	25	33	1.32	13	.12	12	3.1	9.0	.0	54	10	.10	1.3	80	9,858	878	2,160
June 1	June 10	10	12	1.20	16	.15	10	3.4	7.4	.0	56	8.7	.00	1.8	78	6,999	227	1,473
11	20	20	11	.55	9.6	.20	12	3.4	7.2	.0	55	16	.10	1.9	75	5,136	153	1,040
21	30	....	b 11	....	....	....	....	....	....	....	....	....	....	....	b 96	2,718	b 81	b 700
July 1	July 10	....	b 11	....	....	....	....	....	....	....	....	....	....	....	b 118	1,589	b 47	b 506
11	20	....	b 10	....	....	....	....	....	....	....	....	....	....	....	b 139	1,174	b 32	b 440
21	30	....	b 10	....	....	....	....	....	....	....	....	....	....	....	b 160	528	b 14	b 228
31	Aug. 9	....	b 10	....	....	....	....	....	....	....	....	....	....	....	b 182	328	b 6.9	b 162
Aug. 10	19	....	b 9.8	....	....	....	....	....	....	....	....	....	....	....	b 203	529	b 14	b 288
20	29	10	9.6	.96	20	.01	29	11	30	.0	143	43	.60	12	225	408	11	223
30	Sept. 8	10	2.4	.24	19	Trace.	19	12	27	.0	116	46	.00	14	202	400	2.6	218
Sept. 9	18	15	8.0	.53	27	.02	37	14	35	.0	174	62	.00	16	284	373	8.1	286
19	28	12	12	1.00	23	.02	30	11	28	.0	140	50	.50	13	232	421	13.6	264
29	Oct. 8	4	5.0	1.25	25	.02	30	11	28	.0	138	49	1.9	13	230	970	15.7	602
Oct. 9	18	5	5.6	1.12	16	.01	24	7.4	15	.0	106	22	3.0	6.0	144	2,578	39	1,036
19	28	4	6.0	1.50	17	Trace.	16	5.4	13	.0	73	21	.10	6.0	119	1,941	31.4	624
29	Nov. 7	5	1.0	.20	11	.05	15	4.4	12	.0	73	20	.85	4.8	129	2,204	6.0	768
Nov. 8	17	13	18	1.38	6.4	Trace.	16	4.8	5.4	.0	49	14	....	4.5	85	4,937	240	1,133
18	27	38	59	1.55	16	.10	11	4.2	7.6	.0	52	13	Trace.	4.3	80	7,729	1,231	1,669
28	Dec. 7	10	15	1.50	17	.01	13	4.4	11	.0	59	19	.50	3.1	87	5,561	225	1,306
Dec. 8	17	4	2.8	.70	16	.03	13	4.2	11	.0	65	18	Trace.	4.5	99	3,947	29.9	1,055
18	27	3	1.2	.40	17	Trace.	15	5.2	12	.0	73	18	Trace.	5.5	111	2,867	9.3	858
28	Jan. 6	4	2.8	.70	15	.01	16	5.2	11	.0	73	17	Trace.	5.8	110	2,656	20.1	789
Jan. 7	16	3	1.0	.33	13	Trace.	16	5.2	11	.0	74	17	Trace.	4.8	109	2,539	6.8	747
17	26	3	1.6	.53	16	Trace.	15	5.2	10	.0	73	14	Trace.	4.3	107	2,288	9.9	661
27	31	3	1.8	.60	17	Trace.	18	7.2	11	.0	79	23	Trace.	4.8	125	2,046	9.9	758
Mean........		18	17	.94	19	.10	16	6.1	14	.0	80	21	.34	5.2	123	....	c 120,193	c 492,730
Percentage of anhydrous residue..............					d 15.7	.1	13.2	5.0	11.6	32.5	....	17.3	.3	4.3	....	....	....	....

a Abnormal; computed to HCO_3 in average. b Estimated. c Annual denudation. d Fe_2O_3.

Color and alkalinity of the water of Yakima River at Prosser.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.			
Mar. 13	208	0.0	78
16	90	.0	63
17	62	.0	65
18	62	.0	61
19	65	.0	61
20	60	.0	62
27	86	[a] 17.3	38
28	86	[a] 7.2	55
29	38	.0	58
30	36	.0	64
31	58	.0	58
Apr. 1	32	[a] Trace.	67
2	78	.0	62
3	208	.0	68
4	168	.0	69
5	172	.0	61
6	54	[a] 6.0	59
7	20	.0	66
8	16	.0	68
9	80	.0	63
10	78	.0	62
12	32	.0	61
13	24	.0	42
16	36	[a] 5.0	50
18	16	[a] 15.4	40
19	8	[a] 20.4	30
25	....	[a] 14.4	23
26	15	[a] 4.8	39
27	16	[a] 15.6	22
28	17	.0	51
May 3	32	.0	49
4	16	[a] 10.8	.2
5	16	.0	45
6	22	.0	56
8	....	.0	54
10	24	.0	56
11	19	.0	47
12	16	[a] 3.6	51
13	16	.0	38
20	48	[a] 3.6	39
21	42	.0	44
23	22	[a] 21.4	14
24	16	[a] 3.6	46
25	16	[a] 9.6	37
30	78	[a] 9.6	30
31	30	.0	51
June 1	16	[a] 13.2	26
2	16	.0	50
3	17	.0	48
6	78	.0	72
7	32	.0	57
8	16	[a] 8.4	40
9	24	[a] 8.4	39
11	90	[a] 2.4	57
13	58	.0	63
14	32	[a] 9.6	30
15	90	.0	48
16	54	.0	55
17	90	.0	52
18	78	[a] 7.2	38
19	24	.0	55
20	98	[a] 3.6	43
June 21	18	0.0	56
Sept. 23	8	.0	164
24	8	.0	171
26	8	.0	172
Oct. 3	8	.0	166
4	8	.0	164
5	8	.0	170
6	8	.0	....
7	16	.0	71
8	15	.0	78
9	8	.0	69
10	8	.0	59
12	8	.0	61
13	8	.0	62
14	8	.0	150
17	4	.0	147
19	4	.0	73
20	4	.0	74
21	2	.0	75
24	16	.0	78
28	4	.0	70
Nov. 21	8	.0	59
22	8	.0	56
23	40	.0	40
24	32	.0	39
28	8	.0	46
30	8	.0	49
Dec. 1	6	.0	50
3	8	.0	61
5	8	.0	57
6	7	.0	61
7	8	.0	63
8	8	.0	61
9	8	.0	66
11	12	.0	62
12	8	.0	63
13	8	.0	63
14	4	.0	67
16	8	.0	66
17	8	.0	63
19	8	.0	67
20	4	.0	67
22	6	.0	68
25	8	.0	78
26	8	.0	76
27	6	.0	76
1911.			
Jan. 4	4	.0	71
5	4	.0	78
6	0	.0	76
7	2	.0	76
8	8	.0	73
9	8	.0	74
10	8	.0	74
11	8	.0	77
12	9	.0	74
13	6	.0	71
17	4	.0	74
21	4	.0	72
23	16	.0	73
24	12	.0	68

[a] Abnormal; probably present as HCO_3 when sample was collected.

SNAKE RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Snake River flows from its source in Yellowstone National Park across Idaho, then northward between that State and Oregon and Washington through a steep canyon to Lewiston, Idaho, where it is joined by the Clearwater; it there turns sharply and flows westward through Washington to its confluence with the Columbia below Pasco. The river drains an area of 109,000 square miles. The river crosses the Columbia River basalt and throughout its entire lower course occupies a steep-walled canyon about 2,000 feet deep. According to Russell[1] solid rock is exposed only in the canyon walls which in many places rise nearly vertically from the talus slopes at their base. He believed that the canyon was formerly filled with gravel and that the work of reopening the bed is not yet completed. The gradient below Lewiston is about 2.5 feet to the mile, but many rapids interrupt the smooth flow of the stream.

The soil in the Washington part of the Snake River basin is fine and deep and is practically free from pebbles, and where only a sparse desert growth exists it is readily swept by the winds into great dunes. The depth and richness of the soil, however, render it eminently suitable for agriculture, and though the plateau has a forbidding, desert-like aspect, it is capable of producing abundant crops when it is properly watered. Precipitation is heavy in the mountain portion and is mostly snow, but in the lower valleys it amounts to only 8 or 10 inches a year. The temperature of the central valleys ranges from about 100° or higher in summer to considerably below zero in winter.

There are many sites along Snake River where immense amounts of power can be developed, but few have yet been utilized. Power plants are in operation on Snake River at American Falls, Shoshone Falls, and the Minidoka dam, and on Payette and Boise rivers, tributaries of the Snake.

CHARACTER OF THE WATER.

Samples of water were collected from Snake River at the Northern Pacific Railway bridge near Burbank from March 13, 1910, to January 31, 1911, inclusive, by Albert Ellis, station master at Burbank. A gaging station is maintained at the same point, above which the drainage area is 109,000 square miles.

The quality of the water is subject to considerable variation, according to discharge. The turbidity of a stream may be expected to increase with rising flood and to decrease after the first flood waters have passed. Dissolved matter may be expected to decrease with rising stage and to reach a minimum at or shortly after the maximum flood stage, when the disintegrated rock material and other partly soluble matter that has accumulated on the drainage area during low water has been thoroughly leached. Thus a rise in stage is attended by a quick rise in turbidity with early maximum and slow decline and a slower decrease in dissolved material, the minimum often

[1] Russell, I. C., A reconnaissance in southeastern Washington: U. S. Geol. Survey Water-Supply Paper 4, pp. 15, 21, 1897.

being apparent during falling stage. The analyses of Snake River water clearly exemplify these conditions. The first crest of the spring freshets occurred at about the time of the highest turbidity; after a slight drop another rise took place, not quite so high as the first but of longer duration and unaccompanied by increased turbidity. Suspended matter reached a minimum almost a month after the date of the first flood and during the second one; a second but less pronounced low value is recorded during the falling stage in June. Maximum dissolved matter occurred during the first stages of the autumnal rise, when the first leachings of the summer accumulations of soluble matter were brought down the river. The seasonal variation of dissolved matter is about one and a half times the minimum content.

The water of Snake River at Burbank is usually turbid and should be clarified before being used for drinking or manufacturing; its average hardness is about 70 parts per million. It would not corrode boilers or cause foaming under ordinary conditions of operation. If it were used in boilers without sedimentation it would deposit about $1\frac{1}{8}$ pounds of medium soft scale per 1,000 gallons of water injected. Treatment in a preheater or by sedimentation is all that is advisable as preliminary to its use in boilers, and unless large amounts of steam are generated it would probably be most economical to omit all treatment and to rely upon occasional cleaning to remove the sludge.

The daily alkalinity, as shown by the table, varies within rather narrow limits, but the color varies with great irregularity. High color is caused chiefly by the washing of humus, in spring from the upland soils and in autumn from the autumn-plowed lands of the lower parts of the basin. The spring maximum is the greater. The turbidity, color, and alkalinity indicate that coagulation and filtration would be advisable if the supply were purified for municipal use.

Mineral analyses of water from Snake River at Burbank, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Dissolved solids (tons per day).	Suspended matter (tons per day).
Mar. 13	Mar. 22	240	201	0.84	24	0.20	14	5.1	12	*a* 4.8	56	15	Trace.	3.5	124	344.70	163,700	54,800	88,800
23	Apr. 1	185	210	1.14	26	.10	13	2.3	10	.0	59	14	0.28	3.8	102	45.66	185,000	50,900	104,900
Apr. 2	11	60	96	1.60	32	.05	17	3.7	9.4	.0	74	15	.25	4.5	120	43.10	127,900	41,400	33,200
12	21	60	91	1.52	14	.20	12	2.7	8.0	.0	52	15	.23	3.2	79	45.38	178,000	38,000	43,700
22	May 1	40	90	2.25	6.6	.01	10	3.5	8.5	.0	50	12	....	3.3	69	46.93	214,500	39,900	52,100
May 2	11	10	31	3.10	15	.01	13	4.3	9.1	.0	57	21	.00	3.5	90	45.28	175,400	42,600	14,700
12	21	15	48	3.20	20	.02	13	3.2	9.3	.0	55	18	.00	2.2	93	45.49	180,600	45,300	23,500
22	31	12	42	3.50	16	.02	12	3.2	9.0	.0	54	14	.00	2.2	84	43.66	139,400	31,600	15,810
June 1	June 10	20	50	2.50	19	.02	13	3.9	9.0	.0	60	12	.10	3.1	88	42.75	120,800	28,700	16,310
11	20	12	53	4.42	13	.01	14	3.9	8.4	.0	57	15	.10	4.1	80	40.45	77,840	16,600	11,000
21	30	25	26	1.04	13	.01	14	3.3	8.2	.0	59	15	1.3	4.7	89	38.47	47,640	11,400	3,340
July 1	July 10	20	69	3.45	18	.02	16	4.7	10	.0	71	17	Trace.	5.6	105	37.21	32,330	9,170	6,020
11	20	15	15	1.00	20	.01	19	5.4	15	.0	82	17	Trace.	5.8	121	36.35	24,350	7,960	1,310
21	30	15	13	.87	21	.01	22	5.4	15	.0	93	20	.95	7.3	138	35.79	20,600	7,680	723
31	Aug. 9	15	7.2	.48	19	.02	22	6.5	16	.0	96	19	2.5	7.8	137	35.17	17,390	6,430	338
Aug. 10	19	65	110	1.69	13	.09	18	6.5	17	.0	99	20	Trace.	8.5	141	34.79	15,760	6,030	4,700
20	29	19	20	1.05	20	.05	22	7.1	18	.0	100	22	1.7	10	154	34.44	14,450	6,010	780
30	Sept. 8	20	25	2.25	17	.01	23	7.4	15	.0	101	22	.00	10	149	34.78	15,720	6,330	1,060
Sept. 9	18	18	14	.78	19	.05	24	7.7	19	.0	104	25	1.0	11	158	34.69	15,360	6,180	580
19	28	135	104	.77	19	.28	25	7.0	20	.0	104	31	1.7	11	171	35.51	19,050	7,090	4,310
29	Oct. 8	100	77	.77	24	.20	24	7.7	21	.0	109	28	.50	13	177	35.80	21,290	10,200	4,430
Oct. 9	18	20	24	1.20	21	.02	22	7.2	18	.0	95	24	2.5	13	159	36.17	22,990	9,870	1,240
19	28	15	16	1.06	19	.03	24	7.6	17	.0	101	24	1.1	13	160	36.29	23,950	10,300	1,034
29	Nov. 7	20	22	1.10	19	.03	23	7.6	17	.0	101	26	.75	13	160	36.26	23,660	10,200	1,400
Nov. 8	17	10	29	2.90	17	Trace.	21	7.0	15	.0	89	32	Trace.	8.6	143	37.79	39,630	15,200	3,080
18	27	18	54	3.00	19	.01	20	5.8	13	.0	83	23	Trace.	8.0	135	37.99	41,660	15,300	6,100
28	Dec. 7	35	40	1.14	19	.10	21	6.4	15	.0	90	27	Trace.	8.8	146	38.14	43,340	17,000	4,680
Dec. 8	17	90	67	.75	24	.05	20	5.6	14	.0	92	19	.40	10	146	37.85	39,650	15,600	7,170
18	27	60	45	.75	23	.02	23	5.6	15	.0	85	23	Trace.	10	160	36.93	29,410	12,700	3,580
28	Jan. 6	11	23	2.09	22	Trace.	25	6.4	16	.0	102	24	.50	13	162	36.56	26,110	10,000	1,620
Jan. 7	16	2	4.8	2.40	21	.01	24	6.3	15	.0	98	23	.50	13	155	36.55	26,010	10,500	337
17	26	3	7.8	2.60	20	Trace.	26	6.4	14	.0	100	22	Trace.	14	161	36.93	29,530	12,800	621
27	31	6	5.8	.96	22	Trace.	28	7.8	18	.0	109	35	.50	14	168	36.44	25,100	11,400	393
Mean........		42	52	1.76	19	.05	19	5.6	14	.0	83	21	.53	8.1	131	....	....	*b*6,824,000	*b*5,049,000
Percentage of anhydrous residue..........					14.8	*c*.1	14.8	4.4	10.9	31.9	....	16.4	.4	6.3	....	....	....	....	....

a Abnormal; computed to HCO_3 in average.

b Annual denudation.

c Fe_2O_3.

Color and alkalinity of the water of Snake River at Burbank.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 20	90	0.0	65	June 22	16	0.0	57
21	96	.0	60	23	8	.0	61
23	138	.0	66	24	8	.0	62
24	106	[a]13	50	25	10	.0	63
25	106	.0	57	26	9	.0	60
26	90	[a]1.2	59	July 1	8	.0	65
27	90	[a]1.2	57	2	8	.0	70
28	56	[a]1.2	62	3	8	.0	67
30	48	.0	72	4	8	.0	73
31	48	.0	63	5	8	.0	68
Apr. 1	48	.0	71	6	8	.0	73
2	56	[a]2.4	68	7	24	.0	52
3	54	[a]4.8	68	8	16	.0	72
4	50	.0	68	9	16	.0	78
5	54	[a]7.2	62	10	16	[a]9.6	61
7	32	.0	65	11	8	[a]4.8	66
8	36	.0	58	14	18	.0	72
9	36	.0	61	15	15	.0	73
10	50	.0	61	16	16	[a]25	49
11	54	.0	55	17	16	.0	82
14	8	[a]1.8	44	18	16	[a]2.4	77
16	10	.0	52	19	8	.0	85
17	16	.0	58	20	8	[a]6.0	72
21	8	[a]21	6.3	21	8	.0	86
27	18	[a]9.1	24	22	9	[a]11	61
May 1	8	.0	49	23	16	[a]1.2	84
2	9	[a]8.4	32	24	5	[a]6.0	76
5	9	[a]16.1	....	25	8	[a]4.8	76
6	16	.0	57	26	7	[a]12.0	59
7	16	[a]23	12	27	8	.0	100
8	16	.0	60	28	9	[a]9.6	85
9	16	[a]12	32	Aug. 3	8	[a]3.6	82
10	14	[a]13	29	4	9	[a]7.2	76
11	15	.0	51	5	8	.0	94
12	16	.0	44	6	7	.0	92
13	15	[a]8.6	30	7	8	.0	90
14	15	[a]12	25	8	8	.0	94
15	15	[a]10	21	9	8	[a]3.6	87
16	16	[a]6.7	34	10	8	[a]2.4	88
17	16	[a]1.2	45	11	16	[a]3.6	87
18	16	[a]7.9	39	12	10	[a]6.0	83
19	16	[a]15	27	13	8	.0	95
20	14	[a]12	27	14	8	.0	98
21	10	[a]14	30	15	7	[a]1.2	92
22	16	[a]18	37	16	8	[a]6.0	87
23	16	[a]11	36	17	8	[a]13	73
24	8	[a]12	33	18	8	[a]9.6	76
25	15	[a]9.6	35	20	8	.0	98
26	16	[a]22	19	21	16	.0	93
27	13	[a]2.4	46	22	16	.0	100
28	18	[a]7.2	48	23	16	.0	106
29	58	.0	44	24	9	[a]4.8	93
30	15	.0	44	25	8	.0	101
31	15	[a]6.5	36	26	8	.0	102
June 1	16	.0	57	27	8	.0	99
2	16	.0	43	28	8	.0	100
3	15	.0	43	30	7	[a]12	77
4	10	.0	57	31	8	.0	105
5	16	[a]9.6	41	Sept. 1	8	.0	101
6	16	[a]2.4	45	2	7	[a]6.0	91
7	14	[a]1.2	55	3	8	.0	104
8	24	.0	56	4	8	.0	102
9	10	[a]7.4	51	5	8	.0	100
10	16	.0	63	6	7	.0	101
11	9	.0	67	7	7	[a]1.4	99
12	8	.0	15	8	8	.0	96
13	16	.0	62	9	8	.0	102
14	8	[a]7.2	48	10	8	[a]6.0	89
15	8	[a]3.6	51	11	7	[a]6.0	90
16	10	[a]3.6	52	12	8	[a]14	77
17	7	[a]3.6	51	13	8	[a]17	74
18	14	[a]7.2	39	14	6	.0	109
19	15	.0	55	15	4	.0	106
20	16	.0	55	16	8	[a]7.2	92
21	16	.0	55	17	4	.0	114

[a] Abnormal; probably present as HCO_3 at time of collection.

Color and alkalinity of the water of Snake River at Burbank—Continued.

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.			
Sept. 18	4	0.0	109
19	....	.0	102
24	8	[a] 2.4	101
25	16	.0	100
28	32	.0	110
30	32	.0	111
Oct. 1	32	[a] 3.6	111
2	32	.0	127
3	16	.0	126
4	8	.0	114
5	8	.0	118
9	24	.0	85
11	22	.0	95
12	15	[a] Trace.	100
14	10	.0	98
15	8	.0	99
17	8	.0	111
21	7	.0	103
22	8	.0	99
23	20	.0	96
24	10	.0	94
25	8	.0	111
26	7	.0	104
27	12	.0	101
31	14	.0	....
Nov. 2	6	.0	105
3	8	.0	106
4	6	.0	104
5	7	.0	107
6	16	.0	99
7	14	.0	100
10	12	.0	100
14	8	.0	71
16	7	.0	79
20	8	.0	111
21	8	.0	62
22	8	.0	88
23	16	.0	89
24	16	.0	74
25	18	.0	79
26	18	.0	87
27	14	.0	87
28	17	.0	90
29	22	.0	82
1910.			
Nov. 30	22	0.0	85
Dec. 1	16	.0	85
8	32	.0	87
11	40	.0	87
12	32	.0	88
13	16	.0	87
14	17	.0	90
15	16	.0	96
16	16	.0	98
17	14	.0	102
19	13	.0	102
20	54	.0	96
21	32	.0	95
22	30	.0	93
23	32	.0	101
25	32	.0	101
26	16	.0	101
27	16	.0	98
28	15	.0	101
31	16	.0	100
1911.			
Jan. 1	15	.0	102
2	16	.0	105
3	15	.0	104
4	16	.0	104
5	16	.0	119
6	8	.0	100
7	8	.0	109
8	8	.0	101
9	8	.0	104
12	16	.0	101
14	....	.0	99
17	6	.0	105
18	8	.0	102
19	5	.0	106
22	8	.0	103
23	10	.0	105
25	10	.0	106
26	6	.0	107
29	12	.0	109
30	....	.0	107
31	12	.0	105

[a] Abnormal; probably present as HCO_3 at time of collection.

KLICKITAT RIVER.

GENERAL FEATURES OF DRAINAGE BASIN.

Klickitat River rises on the eastern slopes of the Cascade Range in southern Washington, flows in general southward, and joins Columbia River at Lyle. At the headwaters of the main stream is Goat Rocks, more than 8,000 feet above sea level. Mount Adams, whose glaciers feed the river through several tributary streams, reaches an altitude of 12,307 feet, but the elevation of Columbia River at Lyle is only 75 feet. As Klickitat River is about 105 miles long, its average slope is 80.2 feet per mile. The average slope per mile in the lower 70 miles is 44.1 feet, and the river has not yet eroded its bed to base level at its mouth. The stream is confined in a narrow box canyon during much of its course down this steep juvenile valley.

Though three-quarters of the drainage basin is covered mostly by yellow pine and red and yellow fir, only about 4 per cent is included in national forests.

Volcanic rocks, especially basalt, predominate, and extensive exposures of columnar or massive basalts overlain by a shallow soil composed of the disintegrated country rock appear in the river canyon. The upper portion of the basin contains many level valleys, some of which are swampy during the wet season. As the porous rocks and soil allow ready percolation, stream flow is somewhat regulated by the addition of seepage waters during the dry season. Several soda springs in the drainage basin bear excellent local reputations, but no authoritative analyses of them are available.

The river is of some agricultural importance in its upper course, but irrigable lands along the lower river are not extensive, and the chief value of the stream is for power development. The results of a careful study of the system in respect to its value for power production have been published by the Geological Survey.[1]

CHARACTER OF THE WATER.

Daily samples of water for this investigation were taken from Klickitat River at the gaging station of the United States Geological Survey near Klickitat, 14 miles above the mouth of the river, by Mrs. M. A. Young. At this point the swift river is confined by steep rocky banks and its bed is gravel and cobblestones. The drainage area above the gaging station is 1,090 square miles.

The quality of the water strongly reflects the lithologic conditions in the drainage basin. The calcium-carbonate water is characterized by primary alkalinity; the quantity of the sulphate radicle varies widely because of the admixture in varying proportions of the waters of the tributaries flowing over different types of rock. There is no apparent relation between discharge and dissolved solids or discharge and the sulphate content.

The water is excellent for use in boilers or for irrigation, but its suspended matter should be removed before it is allowed to pass through turbines, as otherwise the casings will be badly abraded.

The alkalinity and color of the water of Klickitat River were determined daily from April 15 to June 6, 1910. As the water is of little importance except for power and irrigation these determinations were omitted after June 6, and the tabulated results are presented without comment.

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

Mineral analyses of water from Klickitat River at Klickitat, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended mater.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3)	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).	Mean discharge (second-feet).	Dissolved solids (tons per day).	Suspended matter (tons per day).
Feb 1	Feb. 10	25	8.8	0.35	33	0.65	7.4	3.8	9.3	0.0	45	7.7	0.71	4.7	103	3.50	2,859	795	68
11	20	20	12	.60	38	.40	7.0	3.4	11	.0	51	8.6	.43	1.5	97	3.00	2,193	574	71
21	Mar. 2	25	19	.76	32	.15	7.6	4.5	8.8	.0	50	9.5	Trace.	1.2	92	4.55	4,509	1,120	231
Mar. 3	12	25	21	.84	28	.19	....	4.0	6.3	.0	48	5.8	Trace.	1.5	87	6.00	6,591	1,540	373
13	22	15	18	1.20	32	.17	7.6	3.5	7.1	.0	52	7.1	Trace.	1.1	90	5.90	6,428	1,560	312
23	Apr. 1	15	20	1.33	30	.07	6.3	2.6	6.8	.0	44	7.6	....	.5	78	4.55	4,424	931	248
Apr. 2	11	15	12	.80	27	.07	8.4	2.7	6.3	.0	45	11	....	.1	80	3.80	3,330	718	108
12	21	50	26	.52	37	.06	6.3	2.9	7.6	.0	43	5.7	.10	.9	86	4.00	3,578	830	251
22	May 1	20	30	1.50	20	.02	5.6	3.9	8.0	.0	37	14	.10	.8	68	4.20	3,961	728	321
May 2	11	40	59	1.48	11	.02	5.3	3.2	7.1	.0	35	11	.10	.1	54	3.95	3,542	515	564
12	21	7	8.1	1.16	28	.04	5.2	2.4	5.3	.0	37	3.5	Trace.	1.2	70	3.65	3,094	585	68
22	31	10	8.2	.82	26	.04	5.5	2.1	5.4	.0	37	3.5	.00	1.2	67	3.40	2,771	502	61
June 1	June 10	10	8.1	.81	30	.01	6.8	2.9	5.6	.0	43	7.3	Trace.	1.1	75	3.00	2,230	451	49
11	20	25	24	.96	22	.04	5.6	3.2	5.4	.0	44	5.5	....	.5	63	2.80	1,943	330	126
21	30	8	15	1.87	38	.05	7.9	3.0	6.0	.0	48	7.2	.00	1.2	93	2.50	1,586	398	64
July 1	July 10	18	18	1.00	24	.03	7.4	3.0	8.4	.0	49	9.1	.00	1.2	76	2.40	1,454	298	71
11	20	22	24	1.09	29	.23	6.0	3.4	5.2	.0	44	....	....	1.0	75	2.30	1,368	277	89
21	30	9	12	1.33	25	.13	7.6	2.8	6.1	.0	40	7.7	....	1.2	72	2.15	1,167	227	38
31	Aug. 9	15	12	.80	21	.07	6.3	2.8	6.2	.0	40	5.1	....	1.1	69	2.05	1,090	203	35
Aug. 10	19	10	13	1.30	26	.05	5.8	3.1	5.4	.0	41	4.8	.05	.8	71	2.00	1,025	197	36
20	29	20	23	1.15	25	.16	6.1	3.4	6.4	.0	40	7.0	.45	1.2	75	1.90	945	192	59
30	Sept. 8	10	15	1.60	30	.06	6.4	3.3	5.2	.0	48	5.3	.00	.1	73	1.85	887	175	39
Sept. 9	18	5	5	1.00	30	.02	9.2	4.6	6.3	.0	64	6.0	.13	.8	85	1.80	849	195	11
19	28	15	16	1.06	24	.24	6.9	3.2	5.2	.0	41	8.9	.05	1.1	77	1.85	892	185	38
29	Oct. 8	30	34	1.13	25	.07	6.2	3.0	6.9	.0	42	9.3	.70	1.7	76	2.05	1,097	225	89
Oct. 9	18	4	4.3	1.08	27	.02	7.6	3.4	7.3	.0	49	....	.35	2.0	83	1.95	980	220	11
19	28	3	3.3	1.10	27	.15	7.3	3.0	6.1	.0	46	5.5	.05	1.5	76	1.95	980	201	9
29	Nov. 7	3	1.7	.57	21	.04	7.6	3.5	6.5	.0	48	....	.36	2.0	84	1.85	868	197	4
Nov. 8	17	10	8.7	.87	....	.03	5.9	2.7	5.3	.0	39	4.4	.80	1.0	68	2.30	1,368	251	32
18	27	4	13	3.25	21	.02	8.2	3.0	5.7	.0	38	5.6	.20	1.1	72	2.50	1,628	316	57
28	Dec. 7	10	12	1.20	26	.30	9.2	3.2	5.4	.0	43	11	Trace.	1.0	81	2.60	1,711	375	55
Dec. 8	17	10	5.0	.50	27	.50	6.2	2.2	6.1	.0	41	3.6	Trace.	.7	83	2.50	1,585	354	21
18	27	3	2.2	.73	28	.12	8.1	3.0	5.2	.0	44	3.8	Trace.	1.0	81	2.25	1,301	284	8
28	Jan. 6	5	4.8	.96	28	.05	9.1	3.2	6.9	.0	45	8.5	Trace.	1.1	80	2.15	1,185	256	15
Jan. 7	16	3	3.6	1.20	....	.07	8.0	3.0	6.9	.0	47	5.1	Trace.	.9	80	2.00	1,045	226	10
17	26	8	6.4	.80	28	.25	9.0	3.6	7.2	.0	45	11	Trace.	1.2	86	2.40	1,463	340	25
27	31	12	15	1.25	29	.35	8.1	3.6	7.4	.0	46	6.7	Trace.	1.4	85	2.20	1,218	279	49
Mean.......		15	15	1.08	27	.13	7.1	3.2	6.6	.0	44	7.2	.15	1.2	79	....	....	a169,100	a 36,920
Percentage of anhydrous residue					36.3	b.3	9.5	4.3	8.9	29.2	....	9.7	.2	1.6	....	....	....	....	....

a Annual denudation.

b Fe_2O_3.

Color and alkalinity of the water of Klickitat River at Klickitat.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Apr. 15	8	[a] 2.4	33	May 17	8	[a] 7.2	19
16	6	[a] 10	27	18	6	[a] 16	18
18	7	[a] 10	17	19	7	.0	32
19	7	[a] 26	0	20	48	.0	34
22	120	.0	34	21	24	.0	43
23	16	[a] 16	....	22	8	....	35
24	8	[a] 16	9.8	23	8	.0	33
25	16	[a] 20	....	24	8	[a] 11	26
May 5	7	.0	36	25	8	.0	30
6	8	.0	36	28	7	.0	33
7	....	.0	34	29	8	.0	38
8	72	.0	16	30	....	[a] 8.9	27
9	8	.0	35	31	9	.0	34
10	8	.0	29	June 1	0	.0	31
11	9	[a] 10	15	2	4	.0	35
12	9	[a] 6.0	18	3	8	[a] 7.0	32
13	8	0	31	4	8	[a] 6.0	34
14	....	[a] 14	16	5	4	[a] 7.2	35
15	8	....	....	6	8	[a] 6.0	32
16	8	.0	32				

[a] Abnormal; probably present as HCO_3 at time of collection.

COLUMBIA RIVER AT NORTHPORT.

GENERAL FEATURES.

Northport is a mining town in the northern part of Stevens County, on Columbia River about 10 miles below its entrance into the United States. Clark Fork empties into the Columbia just north of the international boundary, but no large tributaries join the river between the boundary and Northport. Analyses of the water collected at this point therefore represent the quality of the Columbia as it enters the United States. At Northport Columbia River flows through a narrow valley, walled in by steep, broken hills, but the stream itself is broad and navigable. Sewage from upstream settlements pollute the water somewhat, but mineral pollution from mines and similar sources is not apparent.

CHARACTER OF THE WATER.

Samples of water were collected daily from Columbia River at the ferry at Northport by F. G. Janneck from January 22, 1910, to January 31, 1911, inclusive. A gaging station has been established at this point by the United States Weather Bureau, but readings are made only in summer and the accuracy of those reported is questionable.

The water is soft and good for most industrial operations and may be used without treatment, though a small reduction in the already low content of scale-forming ingredients might be effected by preheating or treating it cold with a little milk of lime.

Determinations of alkalinity, which were made daily from March 14 to May 21, 1910, inclusive, show frequent occurrence of normal carbonates, but the water as sampled probably contained only bicarbonate, part of which was converted into monocarbonate by the withdrawal of half-bound carbon dioxide from the water as a result of organic reactions. The total alkalinity did not vary with regularity during this period, which was one of rising stage, and the daily fluctuations were sometimes large.

Mineral analyses of water from Columbia River at Northport, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean gage height (feet).
Feb. 1	Feb. 10	4	3.2	0.80	16	0.10	21	5.5	7.9	0.0	86	14	0.45	0.6	99	....
11	20	5	2.4	.48	18	.05	20	4.9	7.2	a Trace.	86	14	.25	.8	111	....
21	Mar. 2	3	1.6	.53	11	.08	19	5.6	6.0	a 7.2	66	13	Trace.	.2	91	....
Mar. 3	12	6	6.4	1.07	15	.01	20	5.5	5.0	.0	83	14	.10	.2	99	− 5.23
13	22	5	5.0	1.00	12	.05	20	5.5	4.7	.0	83	11	.00	.4	101	− 2.94
23	Apr. 1	7	5.0	.72	12	.02	17	5.2	4.3	.0	76	15	Trace.	.5	94	+ .57
Apr. 2	11	10	....	....	16	.04	20	5.0	4.2	.0	82	9.8	Trace.	.8	98	1.00
12	21	35	41	1.17	7.6	.01	15	4.9	4.7	.0	66	11	.00	.8	77	3.55
22	May 1	5	12	2.40	16	.05	15	4.8	4.6	.0	74	10	.00	.4	77	9.45
May 2	11	5	8.0	1.60	8.4	Trace.	14	5.2	4.6	.0	62	14	.00	.4	74	16.23
12	21	4	4.4	1.10	8.0	.07	19	5.4	4.7	.0	72	13	.00	.3	81	20.86
22	31	3	4.0	1.33	9.6	.05	19	5.8	5.2	.0	72	11	.80	.6	85	21.76
June 1	June 10	4	4.2	1.05	8.4	.06	19	5.6	5.2	.0	73	14	.20	.2	85	21.17
11	20	7	20	2.86	9.3	.01	18	4.2	3.3	.0	68	8.5	.00	.3	80	20.49
21	30	2	.3	.15	13	.01	17	4.4	3.2	.0	74	9.1	.00	.2	88	18.22
July 1	July 10	4	3.6	.90	9.4	.04	14	5.4	5.0	.0	76	11	.30	.2	87	15.06
11	20	5	4.6	.92	7.8	.01	20	4.1	5.8	.0	72	11	.00	.2	85	13.26
21	30	3	3.2	1.07	9.4	.01	20	5.1	5.8	.0	74	9.5	1.0	.8	87	12.59
31	Aug. 9	15	....	....	7.4	Trace.	17	3.6	4.7	.0	72	12	.30	.4	81	7.64
Aug. 10	19	1	.4	.40	4.2	.01	18	4.2	4.7	.0	67	8.1	.00	.3	73	5.77
20	29	1	.6	.60	3.4	Trace.	17	4.3	3.3	.0	65	6.7	.35	.6	71	3.66
30	Sept. 8	3	....	....	6.4	.01	19	3.9	3.3	.0	68	7.4	.00	.1	74	− .25
Sept. 9	18	3	....	....	5.4	Trace.	19	3.8	3.5	.0	68	7.2	.21	.1	73	− 2.74
19	28	1	Trace.	....	2.2	.01	16	3.3	3.8	.0	68	9.4	.67	.1	81	− 3.66
29	Oct. 8	1	1.0	1.00	3.4	.02	18	3.6	3.8	.0	68	8.7	.38	1.0	74	− 1.97
Oct. 9	18	1	Trace.	....	4.0	.01	20	3.5	6.1	.0	67	12	.46	1.0	75	− .97
19	28	1	1.0	1.00	5.8	.01	19	4.6	5.5	.0	70	11	.55	.3	77	− .12
29	Nov. 7	5	....	....	5.2	.01	20	3.8	3.6	.0	67	13	.05	1.4	80	− 1.08
Nov. 8	17	2	1.0	.50	7.2	.01	19	4.2	3.2	.0	71	15	.90	1.2	80	− 1.58
18	27	3	2.2	.73	5.4	.10	20	4.3	4.1	.0	71	15	.20	.5	80	− 1.38
28	Dec. 7	2	6.4	3.20	17	.01	16	4.8	5.5	.0	74	12	.10	.8	99	....
Dec. 8	17	2	4.2	2.10	6.8	.01	19	4.3	4.4	.0	73	11	.30	.8	85	....
18	27	2	.4	.20	1.4	Trace.	21	5.2	4.6	.0	79	13	.30	.3	86	....
28	Jan. 6	1	Trace.	....	7.0	Trace.	20	5.6	4.3	.0	77	15	Trace.	.8	87	....
Jan. 7	16	1	Trace.	....	7.0	Trace.	20	5.2	5.0	.0	76	14	.40	.5	88	....
17	26	2	.2	.10	8.2	Trace.	20	5.2	4.3	.0	79	15	Trace.	.6	89	....
27	31	5	4.6	.92	9.4	Trace.	15	4.4	4.4	.0	57	9.7	.30	2.5	72	....
Mean		5	4.7	1.07	8.7	.02	18	4.7	4.7	.0	73	12	.23	.6	84	....
Percentage of anhydrous residue					10.2	b .1	21.2	5.5	5.5	42.4	....	14.1	.3	.7	....	....

a Abnormal; computed to HCO_3 in average.

b Fe_2O_3.

Color and alkalinity of the water of Columbia River at Northport.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 14	4	0.0	82	Apr. 20	2	*a* 5.5	57
15	6	*a* 4.3	82	21	0	*a* 14	44
16	3	.0	83	22	1	*a* 13	57
17	2	.0	86	23	0	*a* 19	44
18	3	.0	81	24	0	*a* 13	60
23	6	.0	75	25	6	*a* 14	51
24	8	.0	75	26	0	*a* 17	42
26	4	.0	78	27	2	*a* 6.0	59
27	7	.0	77	28	4	.0	74
28	6	.0	81	29	2	*a* 5.3	59
30	7	.0	78	May 1	2	*a* 2.9	68
31	5	.0	88	2	2	*a* 5.3	65
Apr. 1	4	*a* Trace.	80	3	4	*a* 15	40
2	5	.0	76	4	2	*a* 9.6	62
3	8	.0	77	5	2	.0	74
4	6	.0	80	6	1	*a* 13.2	46
5	6	.0	82	7	2	*a* 7.2	61
6	4	.0	83	8	2	*a* 15	41
7	4	.0	61	9	2	.0	68
8	10	.0	78	10	2	*a* 19	30
9	6	.0	81	11	3	*a* 7.2	60
10	0	*a* 1.2	81	12	3	*a* 4.8	63
11	0	.0	71	13	4	.0	73
12	2	*a* 20	41	14	2	*a* 1.0	71
13	1	*a* 17	59	15	2	*a* 5.3	62
14	2	*a* 15	61	17	2	*a* 3.1	68
15	0	*a* 11	64	18	1	*a* 7.7	54
16	1	*a* 9.1	61	19	2	.0	74
17	0	*a* 12	63	20	24	.0	69
18	0	*a* 17	51	21	2	.0	72
19	0	*a* 14	51				

a Abnormal; probably present as HCO_3 at time of collection.

COLUMBIA RIVER AT PASCO.

GENERAL FEATURES.

Pasco is in the southern part of Franklin County, on Columbia River about 4 miles above the mouth of Snake River and 6 miles below the mouth of Yakima River. It is surrounded by rolling sandy prairie whose soil is deep and rich but devoid of vegetation except sagebrush and kindred desert plants because of deficient rainfall. Several irrigation projects have been established in the vicinity, and these, together with the strategic location of the city opposite the mouth of Yakima Valley, at the entrance to the great central plains of Washington, on a navigable portion of Columbia River at the junction of the Spokane, Portland & Seattle Railway and the Walla Walla branch and main line of the Northern Pacific Railway, and near a branch of the Oregon-Washington Railroad & Navigation Co.'s line, give Pasco great potential importance.

The large tributaries of Columbia River between Northport and Pasco are, from the east and south, Colville River and Spokane River; from the west and north, Kettle, Sanpoil, Okanogan, Methow, Chelan, Entiat, Wenatchee, and Yakima rivers. Though these streams and smaller ones add large amounts of water to the river, they change its chemical character very little from that indicated by analyses of river water from Northport. (See p. 82.) The waters of Okanogan, Wenatchee, Yakima, and Spokane rivers also were studied and analyses of them are given on pages 59, 62, 68 and 71, and 56, respectively.

CHARACTER OF THE WATER.

Samples were collected daily from the Columbia just above Pasco from February 1 to April 21, 1910, by William Norton, through the kindness of the Pasco Light & Water Co., and by Harry Dickerman from May 2, 1910, to January 31, 1911, inclusive. All the samples were collected from the intake of the pump used to force water into the city reservoir. The entrance to the intake is not screened to remove suspended matter, and is located in the main channel above the bottom of the river. The estimates of discharge in the table of analyses were made by F. F. Henshaw, district engineer at Portland, Oreg., by adding the discharge of the Yakima at Kiona or Richland. While not accurate to the highest degree, they are sufficiently so for all purposes of this report. The drainage area above Pasco is 103,000 square miles.

Columbia River at this point is used to supply water to Pasco and Kennewick and all the railroads. The water is moderately hard and forms in boilers some scale, which is soft, however, and easily removed. Though the water might be corrosive under some conditions of service, the addition of lime and soda ash in very small quantities would correct that tendency for the feed water of boilers.

Columbia River annually carries by Pasco 11.5 million tons of dissolved mineral matter, which is equivalent to a denudation of 111 tons per square mile of drainage area. This is almost identical with the amount estimated by Dole and Stabler[1] as being removed by like processes from the drainage area of Mississippi River. If the average specific gravity of rock is assumed to be 2.6, it will take 1,700 years to remove 1 inch from the drainage area above Pasco by solution alone, while 1 inch would be removed by combined solution and suspension of eroded material in 1,600 years. The denudation in several thousand square miles of the area is, however, practically nothing; the greatest activity is in the basins along the east slope of the Cascade Mountains.

The daily variations in total alkalinity from March 13 to June 12, 1910, are insignificant. The daily variations of color, though greater than those of alkalinity, are not great. The water was highly colored during March, but was clear during the rest of the period.

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[1] Dole, R. B., and Stabler, Herman, Denudation: U. S. Geol. Survey Water-Supply Paper 234, p. 91, 1909.

Mineral analyses of water from Columbia River at Pasco, 1910–11.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean discharge (second-feet).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Feb. 1	Feb. 10	40	25	0.63	11	0.17	17	4.2	10	0.0	82	13	0.40	1.5	95	64,440	4,340	16,500
11	20	5	3.4	.68	11	.08	19	4.9	8.4	.0	82	14	.22	.4	97	56,850	521	14,900
21	Mar. 2	8	5.6	.70	11	.10	19	5.7	7.1	[a] 6.5	67	15	Trace.	.6	93	57,890	874	14,500
Mar. 3	12	70	47	.67	13	.32	18	5.0	7.6	.0	71	21	.00	.1	93	73,790	9,360	18,500
13	22	18	15	.83	8.0	.09	16	5.4	6.3	[a] 26	18	9.5	.00	.3	81	92,400	3,760	20,100
23	Apr. 1	50	35	.70	18	.08	15	4.0	8.8	.0	62	16	.15	1.3	100	145,900	13,800	39,400
Apr. 2	11	5	1.0	.20	14	.07	16	5.7	9.0	.0	73	12	.40	.8	95	138,100	373	35,400
12	21	20	16	.80	11	.50	12	7.0	8.6	.0	65	13	.00	.8	85	154,500	6,670	35,400
22	May 1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	[b] 12,100	[b] 49,800
May 2	11	10	22	2.20	7.8	Trace.	16	4.6	7.7	.0	66	12	.00	.3	80	297,400	17,600	64,200
12	21	15	27	1.80	6.6	Trace.	15	3.9	6.6	.0	67	7.4	.00	.7	73	352,700	25,800	69,500
22	31	6	12	2.00	7.0	Trace.	15	4.9	7.0	.0	66	7.5	....	.5	74	347,100	11,200	69,400
June 1	June 10	10	6.4	.64	8.6	Trace.	17	3.8	5.3	.0	68	8.7	.10	.8	79	333,300	5,760	71,000
11	20	1	.2	.20	11	Trace.	19	5.9	8.5	.0	71	9.9	....	.2	88	306,800	164	72,800
21	30	1	.4	.40	4.6	Trace.	17	4.9	7.2	.0	71	8.6	....	.3	75	288,200	312	58,400
July 1	July 10	3	2.0	.66	7.2	Trace.	17	4.5	7.0	.0	73	7.9	.30	.3	77	260,200	1,410	54,100
11	20	2	1.4	.70	6.0	Trace.	17	4.8	5.5	.0	72	7.5	....	.2	76	239,300	904	49,000
21	30	2	1.8	.90	11	.01	19	4.0	5.8	.0	70	7.5	.50	.2	84	226,500	1,100	51,500
31	Aug. 9	1	.6	.60	3.0	.01	18	4.6	5.7	.0	73	7.2	.32	.3	74	179,300	290	35,800
Aug. 10	19	1	.6	.60	4.0	.01	19	4.4	6.8	.0	74	8.6	.00	.4	78	147,100	238	31,000
20	29	3	3.8	1.27	12	Trace.	18	4.1	6.6	.0	76	9.4	.00	.4	91	123,200	1,260	30,300
30	Sept. 8	4	.2	.05	4.6	.01	18	3.4	3.8	[a] 4.8	59	11	.10	.3	74	90,600	49	18,100
Sept. 9	18	2	.2	.10	3.2	.01	18	4.1	4.3	.0	71	11	Trace.	.3	74	74,560	40	14,900
19	28	3	1.6	.53	5.2	.01	20	4.2	3.9	.0	74	10	.30	.4	82	66,880	288	14,800
29	Oct. 8	2	Trace.	....	3.6	.03	19	3.2	5.7	.0	72	11	.15	.6	77	69,810	Trace.	14,500
Oct. 9	18	1	.2	.20	3.8	.05	20	3.1	6.3	.0	71	11	.13	.9	79	77,810	42	16,600
19	28	4	.6	.15	5.0	.02	19	3.2	4.3	.0	71	14	.40	.3	78	86,730	140	18,300
29	Nov. 7	2	1.4	.70	6.0	.02	19	3.6	5.3	.0	67	11	.30	4.0	77	82,660	312	17,200
Nov. 8	17	2	.4	.20	6.4	.03	18	4.0	3.8	.0	71	11	Trace.	1.0	83	78,400	84	17,600
18	27	1	Trace.	....	5.6	.01	18	3.8	3.5	.0	71	13	Trace.	1.5	80	85,830	Trace.	15,500
28	Dec. 7	2	1.8	.90	5.4	Trace.	18	4.4	3.8	.0	68	13	.15	.9	81	83,720	405	18,300
Dec. 8	17	3	2.6	.87	7.2	Trace.	19	4.4	3.3	.0	71	12	Trace.	.7	81	74,390	523	16,200
18	27	3	2.0	.67	5.4	Trace.	19	4.6	3.6	.0	80	11	Trace.	.5	83	66,650	360	14,900
28	Jan. 6	2	1.6	.80	7.2	Trace.	20	5.0	4.6	.0	78	10	Trace.	.5	85	61,900	267	14,200
Jan. 7	16	10	2.0	.20	7.8	Trace.	20	4.6	5.4	.0	79	12	.30	1.3	86	58,150	313	13,500
17	26	2	.6	.30	8.0	.01	20	5.0	5.2	.0	81	11	.20	.8	88	54,680	88	13,000
27	31	1	1.0	1.00	7.4	.01	19	5.4	5.0	.0	78	11	Trace.	1.2	87	53,780	145	12,600
Mean		9	6.7	.70	7.7	.04	18	4.5	6.0	.0	73	11	.14	.7	83	....	[c] 1,208,200	[c] 11,454,000
Percentage of anhydrous residue					9.2	[d] .1	21.4	5.3	7.1	42.8	....	13.1	.2	.8	....	....	....	....

[a] Abnormal; computed to HCO_3 in average. [b] Estimated. [c] Annual denudation. [d] Fe_2O_3.

Color and alkalinity of the water of Columbia River at Pasco.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 13	45	[a] Trace.	68	May 21	10	0.0	65
14	49	0.0	73	22	16	.0	65
15	45	.0	71	23	4	.0	66
16	46	.0	73	24	4	[a] Trace.	63
21	24	.0	70	25	16	.0	62
23	36	.0	71	26	4	.0	63
25	16	.0	66	27	0	.0	68
28	26	.0	62	28	0	.0	60
30	20	.0	66	29	50	.0	66
May 4	4	[a] 13	36	30	0	[a] Trace.	66
6	6	[a] 15	37	31	0	.0	69
7	6	.0	65	June 1	0	.0	67
8	6	[a] 15	32	2	6	.0	67
9	6	[a] 14	30	3	4	[a] Trace.	76
10	8	[a] 17	37	4	12	.0	76
11	6	.0	61	5	8	.0	67
12	4	.0	64	6	8	.0	68
13	8	[a] 16	26	7	4	.0	65
14	6	[a] 13	37	8	4	.0	69
16	10	[a] 9.1	37	9	0	.0	66
17	6	.0	76	10	20	.0	67
18	6	[a] 5.5	66	11	0	.0	68
19	6	.0	70	12	8	.0	67
20	6	.0	65				

[a] Abnormal; probably present as HCO_3 at time of collection.

COLUMBIA RIVER AT CASCADE LOCKS.

GENERAL FEATURES.

Cascade Locks are situated on the Oregon side of Columbia River, nearly opposite Stevenson, Wash., 35 miles below The Dalles, at a place where the river flows in a deep, narrow gorge cut through the basalts of the Cascade Mountains and over a basalt ledge in a series of rapids known as the Cascades. The river at this place is now almost at grade, and at low water the river at The Dalles is only 45 feet above mean sea level. Cascade Locks, therefore, mark the lowest place on Columbia River unaffected by tides, and consequently the lowest place where representative samples of water and trustworthy discharge measurements could be obtained, though the current much nearer the mouth is strong enough to prevent the water from becoming saline.

The largest tributaries of Columbia River between Pasco and Cascade Locks are, from the west and north, Klickitat River and White Salmon River, and from the east and south, Snake, Walla Walla, Umatilla, Willow, John Day, Deschutes, and Hood rivers. These streams contribute more than 35 per cent of the discharge at Cascade Locks. Analyses of the water of Klickitat and Snake rivers are given on pages 79 and 75, respectively. The waters of Umatilla, John Day, and Deschutes rivers and their tributaries were studied in 1911 and 1912 in cooperation with the State engineer of Oregon.

CHARACTER OF THE WATER.

Samples of the water of Columbia River were collected daily at Cascade Locks from March 13 to December 31, 1910, and from August 1, 1911, to August 14, 1912, in the swift current above the rapids. The collections were made by Val W. Tompkins, inspector at Cascade Locks, through the courtesy of the district engineer of the Engineer Corps, United States Army. Samples could not be collected between January 3 and January 18, 1912, because there was no reasonably safe place at which containers could be lowered to flowing water through the ice. The estimates of discharge included in the table of analyses have been computed from those obtained at the gaging station at The Dalles by correcting them for the difference in drainage area. The basin of Columbia River above The Dalles covers 237,000 square miles and above Cascade Locks only 2,600 square miles more.

Mineral analyses of water from Columbia River at Cascade Locks, 1910.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium ($Na+\frac{3}{4}K$).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean discharge (second-feet).	Dissolved matter (tons per day).	Suspended matter (tons per day).
Jan. 1	Mar. 12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	a4,234,000	a 2,740,000
Mar. 13	22	70	175	2.50	27	0.25	17	4.2	5.3	b 18	32	12	0.12	2.4	108	274,700	80,200	129,500
23	Apr. 1	100	184	1.84	23	.18	14	4.3	9.7	.0	55	16	.22	1.8	103	373,200	103,900	185,500
Apr. 2	11	60	75	1.25	19	.09	14	3.9	7.9	.0	59	15	.65	2.0	93	279,200	70,100	56,600
12	21	60	74	1.23	17	.05	9.4	4.1	8.7	.0	57	6.6	.45	1.5	85	348,700	80,000	69,800
22	May 1	50	77	1.54	14	.05	12	3.1	8.2	.0	48	13	.32	2.0	80	477,900	103,100	99,400
May 2	11	30	81	2.70	10	.04	14	1.9	6.5	.0	60	9.9	.27	1.2	77	521,700	108,000	114,000
12	21	30	76	2.53	14	.04	15	2.4	7.9	.0	57	10	.60	.8	c 82	613,300	135,800	125,800
22	31	20	28	1.40	12	.04	15	4.7	6.6	.0	57	9.9	.20	1.0	80	559,500	120,900	42,300
June 1	June 10	15	36	2.40	14	.05	16	4.8	6.0	.0	60	11	.50	.8	84	523,800	118,500	50,800
11	20	9	13	1.44	14	.01	14	4.4	6.0	.0	66	9.4	.00	.6	82	445,100	98,500	15,600
21	30	5	8.4	1.68	4.3	.01	16	4.2	4.1	b 17	32	11	.20	1.3	71	372,600	71,300	8,460
July 1	July 10	13	17	1.31	9.4	.02	17	5.6	6.1	.0	70	8.7	.20	.8	81	302,200	66,100	13,900
11	20	10	11	1.10	8.8	.01	17	5.2	5.7	.0	70	12	.20	1.0	99	238,100	63,600	7,080
21	30	18	21	1.17	11	.02	16	4.5	4.7	.0	70	9.7	.25	1.3	83	216,000	48,400	12,200
31	Aug. 9	10	20	2.00	8.8	.02	18	4.4	5.2	.0	68	13	.20	2.5	88	191,800	45,500	10,400
Aug. 10	19	5	11	2.20	7.8	.01	18	4.9	6.6	.0	71	11	.20	1.3	82	161,500	35,700	4,800
20	29	20	111	5.55	9.2	.01	17	4.3	5.0	.0	71	9.1	.20	2.3	85	140,700	32,300	42,200
30	Sept. 8	28	48	1.71	6.2	Trace.	19	4.0	5.0	.0	73	8.2	1.10	1.4	83	113,800	25,500	4,750
Sept. 9	18	8	20	2.50	12	.13	19	3.4	7.1	.0	73	12	.40	2.3	94	92,850	23,600	5,020
19	28	5	4.8	.96	13	.03	19	4.2	11	.0	78	17	1.80	3.0	106	85,430	24,400	1,110
29	Oct. 8	21	80	3.81	11	.12	19	4.6	11	.0	79	18	1.0	3.5	104	89,390	25,100	19,300
Oct. 9	18	12	31	2.58	8.8	.01	18	4.3	10	.0	70	14	.00	4.3	92	102,000	25,300	8,540
19	28	22	38	1.73	10	.04	17	5.2	7.6	.0	68	14	.98	4.0	94	109,700	27,600	11,300
29	Nov. 7	15	50	3.33	10	.01	18	4.8	7.6	.0	76	19	.60	2.0	94	110,900	28,100	15,000
Nov. 8	17	12	34	2.83	12	Trace.	17	4.4	7.7	.0	71	20	.45	2.2	97	121,700	31,800	11,200
18	27	30	59	1.97	14	Trace.	16	4.7	8.0	.0	70	15	.65	2.0	94	132,500	33,600	21,100
28	Dec. 7	12	25	2.08	11	Trace.	16	4.0	7.2	.0	67	13	.30	2.0	90	134,700	32,700	9,100
Dec. 8	17	20	43	2.15	17	.01	16	3.9	5.7	.0	68	9.4	.20	3.0	97	124,800	32,600	14,500
18	27	40	53	1.32	17	Trace.	19	4.0	7.7	.0	72	19	.64	3.0	102	97,670	26,900	14,000
28	31	25	46	1.84	14	Trace.	17	4.8	6.8	.0	76	14	Trace.	3.0	80	98,930	21,300	12,300
Mean........		26	52	2.09	13	.04	16	4.2	7.1	.0	67	13	.43	2.0	89	....	d21,510,000	d14,022,000
Percentage of anhydrous residue ...		....			14.6	e.1	18.0	4.7	8.0	37.2	....	14.6	.5	2.3	....	....	....	....

a Estimated denudation during period Jan. 1 to Mar. 12, 1910, inclusive. b Abnormal; computed to HCO_3 in average. c Estimated. d Annual denudation. e Fe_2O_3.

Mineral analyses of water from Columbia River at Cascade Locks, 1911–12.

[Parts per million unless otherwise stated.]

Date. From—	Date. To—	Turbidity.	Suspended matter.	Coefficient of fineness.	Color.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Dissolved solids.	Mean discharge (second-feet).	Suspended matter (tons per day).	Dissolved matter (tons per day).
Aug. 11	Aug. 20	12	19	1.60	2	23	0.06	19	4.5	9.3	0.0	76	10	1.4	1.0	103	187,419	9,614	52,120
21	30	5	11	2.20	1	9.4	.03	18	3.3	9.5	.0	73	13	.56	1.7	88	147,235	4,380	35,050
31	Sept. 9	12	18	1.50	....	10	1.1	20	5.0	6.0	.0	70	13	.56	1.8	91	129,529	6,300	30,780
Sept. 10	19	10	29	2.90	....	10	.01	17	5.8	6.3	.0	71	9.5	.36	2.0	89	125,161	9,820	30,100
20	29	5	32	6.40	....	10	.05	20	4.9	8.2	.0	74	15	.44	2.3	95	108.720	9,380	27,800
30	Oct. 9	5	11	2.20	Trace.	12	Trace.	20	6.4	9.5	.0	79	17	.52	3.0	113	93,170	2,760	28,400
Oct. 10	19	12	34	2.83	Trace.	16	.01	16	5.0	9.6	.0	67	13	.44	2.8	87	85,571	7,850	20,100
20	29	10	38	3.80	2	14	Trace.	21	5.6	11	.0	88	7.3	.56	5.0	114	81,808	8,400	25,200
30	Nov. 8	25	39	1.56	0	9.2	.02	21	6.4	7.9	.0	84	13	.60	4.8	115	74,710	7,860	23,200
Nov. 9	18	40	120	3.00	0	13	Trace.	19	5.3	11	.0	81	15	.66	4.4	111	73,765	25,500	23,600
19	28	20	40	2.00	3	14	.02	19	5.0	10	.0	77	14	1.2	4.9	108	86,640	9,360	25,200
29	Dec. 8	10	6.4	.64	2	13	Trace.	19	6.7	8.4	.0	71	17	.78	4.0	109	75,587	13.100	22,300
Dec. 9	18	4	a 57	b 14.25	3	15	.01	18	4.6	10	.0	79	13	.60	4.0	107	71,902	11,050	20,750
19	28	4	28	7.00	2	16	.02	19	4.4	11	.0	84	16	.32	4.3	116	70,255	5,300	21,900
29	Jan. 3	5	11	2.20	1	15	.03	22	4.4	12	.0	82	16	.14	5.2	119	60,603	1,800	19,450
Jan. 4	17	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	72,633	c 1,950	c 21,500
18	27	80	78	.98	17	18	.06	17	4.4	10	.0	71	11	.56	4.0	102	93,329	1,960	25,610
28	Feb. 6	100	155	1.55	25	19	.11	14	3.6	11	.0	61	9.4	.52	3.3	129	196,789	82.500	68,600
Feb. 7	16	45	64	1.42	16	20	.01	15	6.2	6.1	.0	64	10	.48	3.8	99	110,293	19.050	29,620
17	26	60	58	.97	60	21	Trace.	13	4.0	9.8	.0	60	9.1	.69	3.8	104	133,810	20,900	37,550
27	Mar. 7	30	66	2.20	15	20	.06	15	3.6	11	.0	70	13	.90	3.5	107	91,251	16,250	26,300
Mar. 8	17	20	38	1.90	7	20	.03	18	3.9	13	.0	79	14	.45	4.5	117	78,761	8,060	24,800
18	27	20	22	1.10	8	19	.05	19	4.0	12	d 2.4	74	11	.30	9.8	115	80,570	4,790	25,000
28	Apr. 6	50	52	1.04	25	22	.35	17	3.8	11	d Trace.	74	11	.94	5.0	116	118,150	16,600	37,100
Apr. 7	16	80	65	.81	40	18	.18	14	2.6	8.5	d 7.2	44	8.2	.30	3.0	90	190,495	33,400	46,200
17	26	40	41	1.02	16	15	.16	14	2.4	8.2	.0	57	8.9	.24	2.3	89	200,755	22,200	48,100
27	May 6	45	44	.98	20	15	.12	14	2.4	6.3	.0	51	5.4	.27	2.3	80	246,561	29,300	53,300
May 7	16	50	34	.68	9	9.2	.10	16	3.0	9.1	d 6.5	42	11	.24	2.4	79	324,073	29,800	69,200
17	26	25	31	1.24	10	12	.12	15	2.4	6.9	.0	50	8.6	.26	1.9	75	517,870	43,400	104,900
27	June 5	20	22	1.10	9	14	.07	15	2.5	7.9	.0	53	9.9	.27	2.0	76	610,266	36,200	125,000
June 6	15	32	15	2.11	12	10	.10	14	1.8	4.7	.0	50	7.6	.28	1.0	68	624,854	53,900	114,000
16	25	20	25	1.25	8	11	.13	17	1.3	4.4	d Trace.	57	8.6	.32	1.4	74	573,314	38,600	114,200
26	July 5	11	20	1.82	5	7.8	.05	17	2.8	6.5	d 2.9	54	7.9	.30	1.2	72	519,810	28,000	103,500
July 6	15	10	26	2.60	5	8.0	.06	18	2.3	6.9	.0	65	12	.20	1.6	83	374,009	26,200	83,800
16	25	10	20	2.00	5	13	.05	19	2.2	6.3	.0	65	9.4	.28	1.6	82	275,672	14,300	58,600
26	Aug. 4	25	29	1.16	15	4.8	.03	18	2.0	6.9	.0	65	10	.24	2.5	80	223,503	175,00	48,200
Aug. 5	14	50	57	1.14	13	7.2	.04	19	2.6	13	.0	72	17	.16	2.3	93	196,649	30,300	49,400
Mean		27	40	1.97	11	14	.06	17	3.9	e 8.9	.0	69	12	.48	3.2	97	....	f 7,000,000	f 17,000,000
Percentage of anhydrous residue		....	....	....	....	14.9	g .1	18.1	4.1	(e)	36.2	....	12.8	.5	3.4	....	....	....	....

a Sand blown from shores. b Omitted from average. c Estimated. d Abnormal; computed to HCO_3 in average.
e Alkalies separated in composite residue, giving Na=7.5 and K=1.8, which in percentage of anhydrous residue gives Na=8.0 and K=1.9 per cent.
f Annual denudation. g Fe_2O_3.

The water is suitable for most industrial uses, as it is low in mineral content, belongs to the calcium-carbonate type, and is characterized by temporary hardness and by low permanent hardness. Its content of scale-forming ingredients might be decreased somewhat by preheating or by adding small amounts of lime, but that treatment is unnecessary, because the scale which would be deposited is small in amount, soft, and easily removable from boilers. The water might cause corrosion under some conditions, but trouble from that cause would be slight.

The water is excellent for irrigation, for which a large amount of it will probably be used along the river above The Dalles on large areas of arid land which can be made very productive if they are supplied with water. It will be practicable to pump the water to these lands as soon as cheap summer power is developed at such places as Celilo, on the Columbia, or the falls on the upper Deschutes.

Columbia River is more highly mineralized at Cascade Locks than at Pasco, and the differences in character involve increases in proportion of silica, alkalies, and chlorides and decreases in proportion of alkaline earths and bicarbonates. Most of these changes can be explained by the influence of Snake River, for Umatilla River and John Day River, though more highly mineralized than Columbia River, discharge to it relatively small amounts. The increase in content of silica between Pasco and Cascade Locks, which is not proportionate to the other changes, is probably due to the introduction of larger amounts of this substance by all tributaries, because those entering below Pasco are all highly siliceous. The changes in mineral content between Pasco and Cascade Locks and the chemical composition of the water of Snake River are summarized in the following table:

Average quality of the water of Columbia River at Pasco and at Cascade Locks and of Snake River at Burbank.

[Parts per million.]

	Columbia River at Pasco, 1910.	Columbia River at Cascade Locks, 1910.	Columbia River at Cascade Locks, 1911–12.	Snake River at Burbank, 1910.
Suspended matter	6.7	52	40	52
Silica (SiO_2)	7.7	13	14	19
Iron (Fe)	.04	.04	.06	.05
Calcium (Ca)	18	16	17	19
Magnesium (Mg)	4.5	4.2	3.9	5.6
Sodium and potassium (Na+K)	6.0	7.1	8.9	14
Carbonate radicle (CO_3)	.0	.0	.0	.0
Bicarbonate radicle (HCO_3)	73	67	69	83
Sulphate radicle (SO_4)	11	13	12	21
Nitrate radicle (NO_3)	.14	.43	.48	.53
Chlorine (Cl)	.7	2.0	3.2	8.1
Dissolved solids	83	89	97	131

The water of the lower Columbia is mixed drainage from a very extensive basin, the upper part of which contains large amounts of Paleozoic and older sediments, now more or less completely metamorphosed, and the lower chiefly basalts and other lavas. The water of Columbia River at Northport exhibits secondary salinity. The water of the river at Pasco lies near the border between secondary saline and primary alkaline water. Columbia River at Cascade Locks is also in the border class, but is more nearly in the class of secondary saline waters, for the average of all the analyses shows it to have a slight excess of strong acids over alkalies, though it had very slight primary alkalinity in 1911–12. The effect of the addition of primary alkaline waters in Washington and Oregon is to destroy the secondary salinity of the water of Columbia River at Cascade Locks, but not to give it pronounced primary alkalinity.

The values of sodium and potassium in the accompanying analysis of water of Columbia River at Mayger, Oreg., about 30 miles above the mouth, are evidently erroneous, as the excess of potassium over sodium content is entirely abnormal for river waters of North America. The average potassium content of seven composite samples from the same source, each of which represents one month's water, is reported in a private communication from the director of the Oregon Agricultural College experiment station as 0.97 part per million, which is in accord with the writer's determinations on water from Cascade Locks. If sodium is corrected to 6.5 and potassium to 1.6 parts per million, the analysis indicates that the water of Columbia River at Mayger is characterized by primary alkalinity. This is chiefly the result of the addition of the primary alkaline waters of Willamette River and Lewis River, which drain regions where volcanic rocks predominate

Analysis of water of Columbia River at Mayger, Oreg., in August, 1909.[a]

	Parts per million.	Percentage of anhydrous residue.
Silica (SiO_2)	2.4	4.6
Oxide of iron and alumina ($Al_2O_3+Fe_2O_3$)	2.2	4.2
Calcium (Ca)	8.7	16.8
Magnesium (Mg)	2.5	4.8
Sodium (Na)	4.0	7.7
Potassium (K)	4.1	7.9
Ammonium radicle (NH_4)	.42	.8
Bicarbonate radicle (HCO_3)[b]	33	[c]31.8
Sulphate radicle (SO_4)	5.5	10.6
Chlorine (Cl)	5.5	10.6
Phosphate radicle (PO_4)	.08	.2
Total solids at 180° C	52	....

[a] Analysis by B. Pilkington: Oregon Agricultural College Experiment Station Bull. 112, 1912.
[b] Computed from reported CO_3.
[c] Computed as CO_3.

Determinations of color and alkalinity of the water of Columbia River at Cascade Locks, Oreg., were made daily from March 15 to December 30, 1910, inclusive, when sampling was temporarily discontinued. All carbonates were probably present as the bicarbonate radicle when the samples were collected, as reactions before analysis doubtless convert part of the bicarbonate alkalinity to normal carbonate alkalinity. Such change explains the difference between the amount of normal carbonates reported for the daily samples and that for the 10-day composite samples. The total alkalinity, which is correct, did not vary greatly and it was always sufficient to react with the quantity of coagulant or disinfectant that might be introduced in connection with filtration.

Early in the spring the water was noticeably colored; during the rest of the year it was nearly colorless, but only once did colorimetric determinations show a complete absence of any tint.

Color and alkalinity of the water of Columbia River at Cascade Locks.

[Parts per million.]

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
Mar. 15	43	0.0	56	May 16	8	[a] 13	28
16	54	.0	73	17	16	.0	70
17	40	[a] 7.2	65	18	16	[a] 17	23
18	40	[a] 14.	60	19	14	.0	71
19	38	.0	62	20	6	[a] 29	15
20	36	.0	65	21	10	[a] 20	32
21	44	[a] 4.3	62	22	8	[a] 20	22
22	54	.0	66	23	12	[a] 12	50
23	54	.0	62	24	12	.0	69
24	70	.0	63	25	6	[a] 12	42
25	96	[a] 1.2	68	26	6	[a] 7.4	46
26	90	.0	62	27	10	.0	68
27	62	[a] Trace.	67	28	8	.0	56
28	88	.0	60	30	6	.0	57
29	32	[a] Trace.	62	31	6	[a] Trace.	58
30	32	.0	57	June 1	6	[a] 4.8	54
31	28	.0	65	2	8	.0	61
Apr. 1	32	.0	62	3	8	[a] 7.2	52
2	26	.0	59	4	8	.0	54
3	20	.0	63	5	14	.0	62
4	12	.0	68	6	10	.0	57
5	8	.0	65	7	8	.0	60
6	24	.0	65	8	10	[a] 2.4	63
7	20	.0	66	9	8	[a] 1.2	65
8	20	.0	67	10	30	.0	62
9	32	[a] 9.1	58	11	8	.0	63
10	16	[a] 2.4	68	12	8	.0	64
11	24	.0	63	13	8	.0	62
13	16	.0	65	14	8	.0	64
15	20	.0	69	15	8	[a] 1.2	64
16	14	.0	67	16	12	.0	62
17	16	.0	72	17	14	[a] 1.2	61
18	12	.0	73	18	16	.0	63
19	10	.0	....	20	8	[a] 1.2	63
20	8	.0	64	21	10	.0	65
21	14	.0	57	23	16	.0	67
22	8	.0	....	24	8	.0	68
23	10	.0	57	25	7	.0	70
24	12	.0	57	29	6	.0	69
25	16	.0	54	July 4	8	.0	76
26	8	.0	....	6	8	.0	68
27	12	.0	52	8	8	[a] 3.6	63
28	12	.0	50	9	8	.0	72
May 2	16	[a] 14	26	10	11	.0	67
3	12	[a] 12	28	11	8	[a] 7.2	52
4	14	[a] 20	17	12	10	[a] 1.2	67
5	12	[a] 12	33	16	8	.0	67
6	12	[a] 11	42	18	8	[a] 1.2	67
7	8	[a] 14	32	19	10	.0	67
8	8	[a] 25	18	20	7	[a] 7.2	56
9	14	[a] 12	40	21	15	.0	41
10	10	[a] 25	9.8	22	17	.0	40
11	12	.0	59	23	8	.0	67
12	8	[a] 8.2	41	25	8	.0	69
13	40	[a] 14	27	26	8	.0	70
14	8	[a] 6.7	42	27	8	.0	69
15	12	[a] 11	35	28	4	.0	68

[a] Abnormal; probably present as HCO_3 at time of collection.

Color and alkalinity of the water of Columbia River at Cascade Locks—Continued.

Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Date.	Color.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).
1910.				1910.			
July 29	7	0.0	71	Oct. 14	4	0.0	70
30	8	.0	69	15	6	.0	69
31	8	.0	70	16	20	.0	72
Aug. 2	16	.0	71	18	8	.0	70
3	9	.0	71	19	6	.0	71
4	9	.0	72	20	6	.0	71
5	8	[a]4.8	65	22	6	.0	69
6	8	.0	69	24	8	.0	72
7	7	[a]1.2	68	25	6	.0	72
8	8	.0	71	26	4	.0	68
9	8	.0	71	27	6	.0	71
10	8	.0	69	31	6	.0	76
11	48	.0	70	Nov. 2	4	.0	78
12	8	.0	66	4	6	.0	76
13	7	.0	66	5	10	.0	79
14	7	.0	68	6	6	.0	73
15	8	.0	68	7	4	.0	74
16	8	.0	65	8	8	.0	78
17	8	.0	68	10	4	.0	67
22	0	.0	68	11	2	.0	68
23	8	.0	68	12	6	.0	72
30	8	[a]16	48	21	2	.0	63
31	8	[a]20	41	22	4	.0	65
Sept. 1	8	.0	71	23	4	.0	66
2	7	.0	71	25	2	.0	71
3	7	.0	....	26	3	.0	63
6	8	.0	74	28	2	.0	62
7	7	.0	76	29	16	.0	76
8	8	.0	77	Dec. 1	9	.0	68
10	4	.0	73	4	10	.0	67
12	6	.0	76	5	8	.0	67
13	4	.0	73	6	12	.0	70
14	4	[a]7.2	60	7	16	.0	73
16	4	.0	74	9	8	.0	63
17	8	[a]9.6	57	10	8	.0	66
23	8	[a]9.4	65	11	8	.0	65
24	8	[a]12	61	15	8	.0	62
Oct. 1	8	.0	77	16	8	.0	68
3	8	.0	74	17	8	.0	68
7	8	.0	84	19	10	.0	68
8	8	.0	78	22	4	.0	74
9	8	.0	77	23	6	.0	73
10	8	.0	78	24	8	.0	62
11	8	.0	67	29	9	.0	76
12	8	.0	70	30	8	.0	82
13	4	.0	70				

[a] Abnormal; probably present as HCO_3 at time of collection.

AVERAGE CHEMICAL COMPOSITION OF RIVER WATERS.

The accompanying table summarizes the chemical composition of the river waters that were examined. Their low mineral content is noteworthy. The muddiest and the most strongly concentrated water, that of Snake River near its mouth, after the stream has traversed an arid plain, contains only 131 parts per million of dissolved and 52 parts of suspended matter. The drainage of the Coast, Olympic, and Cascade ranges, as indicated by analyses of water from Skagit, Cedar, Green, Chehalis, Wynoochee, Klickitat, Naches, Yakima, and Wenatchee rivers, and Wood Creek, carries less than 90 parts per million of dissolved solids and several mountain streams frequently carry as little as 50 parts. (See fig. 1, p. 94.)

The mineral content of the water of Columbia River is slightly increased between Pasco and Cascade Locks, chiefly by the stronger influent, Snake River. That the mineral content and composition at Pasco are practically the same as at Northport is due to lack of appreciable drainage from the semiarid section of the Columbia plains.

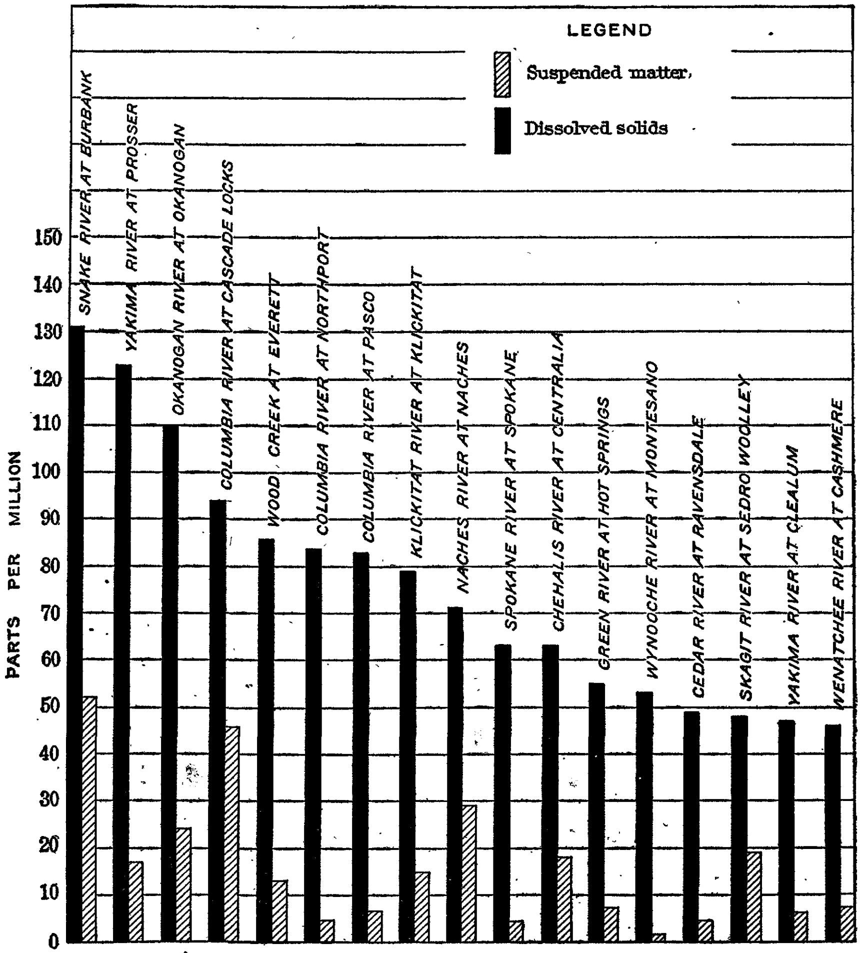

FIGURE 1.—Diagram showing relative amounts of dissolved and suspended material carried by rivers of Washington.

All the waters belong to the calcium-carbonate type—that is, the alkaline earths, calcium and magnesium, and carbonates or bicarbonates predominate. The content of sulphate is not large and chlorine is very low. Silica, though not present in very great quantity, constitutes, of course, a large proportion of the mineral matter in such dilute solutions. Iron is generally so low as to be almost inappreciable.

Average chemical composition of the surface waters of Washington.

Mineral content in parts per million.

River.	Locality.	Turbidity.	Suspended matter.	Coefficient of fineness.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
Cedar	Ravensdale	5	4.2	0.74	13	0.02	6.7	1.4	3.6	0.0	28	5.7	0.20	1.2	49
Chehalis	Centralia	17	18	1.01	16	.08	7.1	1.9	6.5	.0	31	6.4	.10	5.2	63
Columbia	Northport	5	4.7	1.07	8.7	.02	18	4.7	4.7	.0	73	12	.23	.6	84
Do	Pasco	9	6.7	.70	7.7	.04	18	4.5	6.0	.0	73	11	.14	.7	83
Do	Cascade Locks, 1910	26	52	2.09	13	.04	16	4.2	7.1	.0	67	13	.43	2.0	89
Do	Cascade Locks, 1911–12	27	40	1.97	14	.06	17	3.9	8.9	.0	69	12	.48	3.2	97
Green	Hot Springs	6	7.0	1.10	17	.04	6.0	1.3	5.6	.0	28	5.9	.13	1.3	55
Klickitat	Klickitat	15	15	1.08	27	.13	7.1	3.2	6.6	.0	44	7.2	.15	1.2	79
Naches	Naches	27	29	1.04	23	.08	8.2	2.5	6.1	.0	43	5.9	.08	.4	71
Okanogan	Okanogan	25	24	1.21	14	.02	21	4.6	8.5	.0	81	16	.28	.8	110
Skagit	Sedro Woolley	12	19	1.31	9.4	.08	7.9	1.7	3.6	.0	29	8.2	.24	.9	48
Snake	Burbank	42	52	1.76	19	.05	19	5.6	14	.0	83	21	.53	8.1	131
Spokane	Spokane	5	4.1	.79	11	.02	11	3.6	5.3	.0	48	9.2	.23	.6	63
Wenatchee	Cashmere	9	7.0	.76	12	.03	5.5	2.3	4.2	.0	28	7.4	.31	1.0	46
Wood (Creek)	Everett	10	13	1.15	25	.01	8.6	4.5	7.6	.0	51	7.8	.31	2.9	86
Wynoochee	Montesano	2	1.6	.93	11	.01	8.2	2.2	4.8	.0	36	5.7	.29	2.1	53
Yakima	Clealum	6	5.8	1.12	9.9	.02	6.7	2.3	3.7	.0	32	6.2	.25	1.6	47
Do	Prosser	18	17	.94	19	.10	16	6.1	14	.0	80	21	.34	5.2	123
Percentage composition of anhydrous residue.[a]															
Cedar	Ravensdale				28.5	0.1	14.7	3.1	7.9	30.2		12.5	0.4	2.6	
Chehalis	Centralia				27.3	.2	12.1	3.2	11.1	26.1		10.9	.2	8.9	
Columbia	Northport				10.2	.1	21.2	5.5	5.5	42.4		14.1	.3	.7	
Do	Pasco				9.2	.1	21.4	5.3	7.1	42.8		13.1	.2	.8	
Do	Cascade Locks, 1910				14.6	.1	18.0	4.7	8.0	37.2		14.6	.5	2.3	
Do	Cascade Locks, 1911–12				14.9	.1	18.1	4.1	9.9	36.2		12.8	.5	3.4	
Green	Hot Springs				33.3	.1	11.7	2.5	11.0	27.0		11.6	.3	2.5	
Klickitat	Klickitat				36.3	.3	9.5	4.3	8.9	29.2		9.7	.2	1.6	
Naches	Naches				34.1	.2	12.2	3.7	9.0	31.4		8.7	.1	.6	
Okanogan	Okanogan				13.3	.0	20.0	4.4	8.1	38.0		15.2	.3	.7	
Skagit	Sedro Woolley				20.3	.2	17.0	3.7	7.8	30.9		17.7	.5	1.9	
Snake	Burbank				14.8	.1	14.8	4.4	10.9	31.9		16.4	.4	6.3	
Spokane	Spokane				17.0	.1	17.0	5.6	8.2	36.6		14.2	.4	.9	
Wenatchee	Cashmere				25.8	.1	11.8	5.0	9.0	29.5		15.9	.7	2.2	
Wood (Creek)	Everett				30.6	.0	10.5	5.5	9.3	30.7		9.5	.4	3.5	
Wynoochee	Montesano				21.2	.0	15.8	4.2	9.2	34.0		11.0	.6	4.0	
Yakima	Clealum				21.3	.1	14.4	5.0	8.0	34.0		13.3	.5	3.4	
Do	Prosser				15.7	.1	13.2	5.0	11.6	32.5		17.3	.3	4.3	

[a] Iron computed to Fe_2O_3; bicarbonates computed to CO_3.

ECONOMIC VALUE OF THE RIVERS.

The streams furnish good water for use in boilers. If the small amount of suspended matter usually carried is removed by brief sedimentation the waters are capable of forming in boilers only one-fourth to three-fourths pound of scale per 1,000 gallons of water consumed. The high percentage of silica is likely to make the scale rather hard, but not excessively so, and the total quantity of incrustants is too small to justify artificial softening of the waters. Certain organic reagents, such as logwood or tannin, are helpful in remedying the trouble caused by silica, but as those reagents are injurious for other reasons their use ordinarily is not recommended. Foaming would not occur if the customary blowing off is practiced. The free carbon dioxide and the organic matter might possibly cause slight corrosion under some conditions, but that trouble can readily be obviated by treatment of the waters with a little milk of lime. The general use of boiler compounds or other reagents is not advisable.

All the river waters that were examined are entirely suitable for irrigation and will not noticeably increase the alkali of the soil except on land that entirely lacks drainage. Analyses of the waters from the west slope of the Cascades indicate that the soils in many parts of that region are deficient in lime, and this conclusion is corroborated by the results of published analyses of the soils. Analyses of the intermountain and eastern waters, however, give evidence that the soils there are not deficient in lime and their marked fertility accords with that evidence.

The surface waters of Washington are much like those of New England in respect to their availability for domestic use. They carry relatively small quantities of somewhat coarse suspended matter. They range from 20 to 70 parts per million in total hardness expressed as $CaCO_3$, and may therefore be classed as soft. Many streams are tinted by organic matter derived from peat, swamps, and general decaying vegetation, but they are not so highly tinged as the well-known "green-tea" waters of New England, though the proportion of color in some is great enough to render advisable removal of it by means of a coagulant during filtration. None of those tested contains enough iron or other mineral substance to be perceptible to taste or objectionable for domestic use. The data in the accompanying table indicate the characteristics pertaining to general use of the waters. The average, maximum, and minimum colors and alkalinities are based on the daily estimates. The reports of turbidity and dissolved solids probably do not represent the maximum range of those ingredients because they are based on the analyses of 10-day composite samples. The hardness of each water has been computed from the average chemical composition by means of the formula

$$\text{Total hardness as } CaCO_3 = 2.5Ca + 4.1Mg.$$

Average and range of certain constituents of the surface waters of Washington.

[Parts per million.]

River.	Locality.	Color.			Total alkalinity expressed as HCO_3.			Turbidity.			Dissolved solids.			Total hardness as $CaCO_3$.
		Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	Highest.	Lowest.	Average.	
Cedar	Ravensdale	55	0	6	52	21	31	30	1	5	84	34	49	22
Chehalis	Centralia	436	6	25	71	9.8	33	70	4	17	114	45	63	26
Columbia	Northport	24	0	3	93	61	78	35	1	5	111	71	84	64
Do	Pasco	49	0	12	77	55	67	70	1	9	100	73	83	63
Do	Cascade Locks	96	2	14	88	40	67	100	4	26	129	68	94	58
Green	Hot Springs							a 15	1	6	109	39	55	20
Klickitat	Klickitat	120	0	14	52	16	40	50	3	15	103	54	79	31
Naches	Naches	78	2	18	76	27	42	100	5	27	89	52	71	31
Okanogan	Okanogan	54	4	13	128	57	98	250	1	25	182	65	110	71
Skagit	Sedro Woolley	54	0	12	61	15	29	50	1	12	79	32	48	28
Snake	Burbank	138	4	18	127	15	83	240	2	42	177	69	131	70
Spokane	Spokane	12	7	9	50	22	33	25	1	5	82	45	63	42
Wenatchee	Cashmere	28	Trace.	9	64	15	31	40	1	9	111	31	46	23
Wood (Creek)	Everett							50	Trace.	10	119	54	86	40
Wynoochee	Montesano							a 5	1	2	a 59	a 47	53	30
Yakima	Clealum	12	0	2	102	17	35	20	Trace.	6	71	37	47	26
Do	Prosser	208	0	30	172	22	68	125	3	18	284	69	123	65

a Short record.

DENUDATION.

The material carried in suspension by a river represents loose soil washed in and particles of rock detached from the sides and bottom of the stream bed. Though the removal effected by this washing of the soil is great, it is small in Washington compared with the effects of direct solution and chemical reaction, which are equivalent to an annual removal of 0.0003 to more than 0.001 inch of solid rock material from the entire area.

The first table below shows the amount of denudation by suspension and solution in Washington rivers and the number of years required for the removal of 1 inch of rock material from each drainage basin. The second table shows the rate of denudation in the eastern and western Cascade regions, the Columbia plains region, and the whole Columbia River basin. Tons per day of material, as reported in the tables of analyses in the preceding text, has been computed by multiplying together the content of suspended or dissolved matter, the mean discharge during the corresponding period, and the factor 0.00270. The columns of the following table headed "Material removed from drainage area in 1 year" express the amount of material carried through the cross section at each station during the year in which samples of water were collected, and the denudation in millionths of an inch has been computed by dividing tons per square mile per annum by 0.1917. The last column is the reciprocal of the sum of denudation in millionths of an inch of suspended and dissolved matter.[1]

Denudation by streams of Washington.

River.	Locality.	Drainage area (square miles).	Material removed from drainage area in 1 year.						Years required to remove 1 inch.
			Dissolved (tons).	Suspended (tons).	Dissolved (tons per square mile).	Suspended (tons per square mile).	Dissolved (millionths of an inch).	Suspended (millionths of an inch).	
Cedar	Ravensdale	149	34,855	2,960	234	19.8	1,221	103	760
Columbia	Cascade Locks (1910).	239,600	21,510,000	14,022,000	89.8	58.5	468	305	1,300
Do	Cascade Locks (1911-12).	239,600	17,000,000	7,000,000	71.0	29.2	370	152	1,900
Do	Pasco	103,000	11,454,000	1,208,200	111	11.7	579	61	1,600
Klickitat	Klickitat	1,090	169,100	36,920	155	33.9	809	177	1,000
Skagit	Sedro Woolley.	2,930	756,100	363,550	258	124	1,346	647	500
Snake	Burbank	109,000	6,824,000	5,049,000	62.6	46.3	327	242	1,800
Spokane	Spokane	4,000	404,900	45,900	101	11.5	537	60	1,700
Wenatchee	Cashmere	1,200	189,830	55,400	158	46.2	825	241	940
Yakima	Clealum	500	108,460	18,336	217	36.7	1,132	191	820
Do	Prosser	5,050	492,730	120,193	97.6	23.8	509	124	1,600

[1] Dole, R. B., and Stabler, Herman, Denudation: U. S. Geol. Survey Water-Supply Paper 234, p. 80, 1909.

Denudation by grand divisions.

River.	Locality.	Years required to remove 1 inch.
East slopes of Cascades:		
Wenatchee	Cashmere	940
Yakima	Clealum	820
Do	Prosser	1,600
West slopes of Cascades:		
Cedar	Ravensdale	760
Skagit	Sedro Woolley	500
East tributaries of Columbia River:		
Spokane	Spokane	1,700
Snake	Burbank	1,800
Entire basin of Columbia River:		
Columbia	Pasco	1,600
Snake	Burbank	1,800
Columbia	Cascade Locks (1910)	1,300

Denudation is progressing rapidly in the Cascade Mountains. The rate in the basin of Columbia River is slightly less than the rate on the north Atlantic coast,[1] and the eastern tributaries of the Columbia are much less active than the western tributaries. The eastern tributaries are denuding their drainage areas at about the same rate as the rivers entering the Gulf of Mexico from the west.

INFLUENCE OF NATURAL FEATURES.

PRECIPITATION.

Surface waters from arid regions are more concentrated than those from humid regions, though the latter have greater erosive action and consequently carry away greater quantities of dissolved matter in a given period. This is clearly exemplified by the waters of Washington. The average mineral content of the water of Skagit River, which drains a region of large precipitation, is only 48 parts per million, while the water of Snake River, which drains an arid region, contains 131 parts per million of dissolved solids. The other rivers examined show similar relationship between rainfall and mineral content. Accumulation of soluble salts takes place where rainfall is very slight because the run-off can not remove the soluble products of rock decomposition as fast as they are formed.

WIND-BORNE MATERIAL.

The quantities of the soluble products carried by many streams of Washington are so large that the influence of minor features, such as nearness to the ocean, is not noticeable. In the arid regions only the effects of differences of precipitation and lithologic characteristics are readily discernible. The quantities of sodium and chlorine in surface waters near the ocean are increased by wind-borne oceanic salt,

[1] Dole, R. B., and Stabler, Herman, op. cit., p. 85.

which falls with the rain, and the farther inland the rainfall the less is the amount of this "cyclic salt." The effect of this addition is not apparent in Washington, except possibly in streams in the coastal basin, in those flowing from the west slopes of the Cascades, and in the upland waters of the east slopes of the Cascades. In those waters there appears to be relationship between chlorine content and distance from the ocean, but it is not simple and no definite indication of isochlors by means of the available analyses is possible. The daily variations in chlorine are frequently as great as regional differences.

Windstorms in some places, as at Cascade Locks on the Columbia, increase the content of suspended matter chiefly by blowing silt and sand into the streams. The quantity and relative coarseness of the suspended matter in Snake River at Burbank indicate that similar action takes place along that stream.

FORESTATION.

Forests undoubtedly inhibit the removal of suspended matter by rivers, but they also aid rock disintegration and soil loosening, and thus by their own chemical work and by the greater seepage from areas covered by them increase the amount of dissolved matter in drainage from them. These influences are, however, so involved and information in relation to them is so meager that the effects of forests on mineral content of Washington waters can not now be determined.

CHARACTER OF THE ROCKS.

The character of the rocks in the drainage basins undoubtedly has great determinative influence on the chemical composition of the waters, though available information regarding the distinctive lithologic characteristics of the basins above the sampling stations in Washington is so meager that generalizations are rather inconclusive and may even be misleading. In respect to reaction three classes of water have been differentiated in the accompanying table, in accordance with the classification outlined on pages 33–35. Solutions in which strong acids exceed alkalies in reacting weight are called secondary saline waters and belong in Class III; those in which alkalies exceed the strong acids are called primary alkaline waters and belong in Class I; and one that is characterized by neither primary alkalinity nor secondary salinity is placed in Class II. The small numerical differences between the reacting weights of the acid and basic radicles are obliterated by assuming that the ratio of Na to K is 4 and by assigning the remaining difference, due mostly to error of analysis, to bicarbonates.

The waters of three streams whose basins comprise mostly effusive rocks exhibit notable primary alkalinity. None of the streams has very marked secondary saline characteristics, though half of them possess secondary saline reaction and some of them drain basins that contain extensive areas of sedimentary formations. Primary salinity and secondary alkalinity are highest, the former ranging from 13 to 31 per cent and the latter from 63 to 83 per cent. As the large rivers, however, carry contributions of mineral matter from all kinds of rock—effusive, intrusive, metamorphic, and sedimentary—their waters are mixed in type, and analyses of them do not afford bases for very definite conclusions.

An extremely well marked effect of lithologic character is the low mineral content of the surface waters of Washington because of the great predominance of igneous rocks and materials formed by their mechanical disintegration. The waters even from the arid section of the State do not approach in mineral content the drainage of some humid regions where soluble sedimentary rocks are abundant.

Geochemical classification of surface waters of Washington.

River.	Locality.	Primary salinity.	Secondary salinity.	Primary alkalinity.	Secondary alkalinity.	Class.	Lithologic character of basin.
Cedar	Ravensdale	25.2	0.7	0.0	74.1	III	Metamorphic and effusive rocks.
Chehalis	Centralia	34.8	1.0	.0	64.2	III	Sedimentary rocks.
Columbia	Northport	13.3	4.9	.0	81.8	III	Metamorphic rocks, etc.
Do	Pasco	16.5	.0	.1	83.4	I	Metamorphic, effusive, and sedimentary rocks.
Do	Cascade Locks (1910).	20.0	3.5	.0	76.5	III	Do.
Do	Cascade Locks (1911-12).	22.6	.0	1.6	75.8	I	Do.
Green	Hot Springs	25.2	.0	11.5	63.3	I	Andesite.
Klickitat	Klickitat	20.8	.0	10.2	69.0	I	Basalt.
Naches	Naches	15.5	.0	13.9	70.6	I	Effusive rocks.
Okanogan	Okanogan	20.0	.2	.0	79.8	III	Metamorphic and effusive rocks.
Skagit	Sedro Woolley	22.1	7.1	.0	70.8	III	Metamorphic, sedimentary, and intrusive rocks.
Snake	Burbank	29.5	4.3	.0	66.2	III	Sediments at headwaters, effusives in lower course.
Spokane	Spokane	19.9	.0	1.0	79.1	I	Granitic and basaltic rocks.
Wenatchee	Cashmere	27.6	1.6	.0	70.8	III	Metamorphic and sedimentary; some intrusive rocks.
Wood (Creek)	Everett	22.3	.0	6.3	71.4	I	Glacial débris.
Wynoochee	Montesano	23.0	.0	2.4	74.6	I	Intrusive and sedimentary rocks.
Yakima	Clealum	22.9	3.3	.0	73.8	III	Mostly effusive rocks, some sedimentary.
Do	Prosser	31.2	.0	.0	68.8	II	Effusive and later sedimentary rocks.

CONCLUSION.

The river waters of Washington are low in mineral content and are good for general industrial use or for irrigation. What little suspended matter they carry is coarse and readily removable. The color of some renders it advisable to purify them by coagulation and rapid sand filtration rather than by slow sand filtration.

Columbia River enters the State as a secondary saline water, but it receives large additions of alkaline water and finally carries a water of mixed type with a slight tendency toward primary alkalinity.

The Cascade Mountain region is being eroded and dissolved at the rate of 1 inch in 500 to 900 years, and the rate of denudation near the summits is nearly equal on both sides of the divide. The rate in the lower altitudes is greater on the western than on the eastern slope and greater in the Cascade intermountain region than in the Columbia plains. The rate in the basin of Columbia River is about 1 inch in 1,300 years, according to the analyses made in 1910. As denudation is not uniform throughout the basin, but is most pronounced in the watercourses themselves, the rivers are deepening and widening their canyons and valleys.

No lakes are known whose waters are economically important as sources of commercial salts. Waters from the coulee lakes of Washington contain a greater proportion of common salt than the lake waters of southeastern Oregon and are therefore less valuable for recovery of soda.

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