Water for Oregon

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Report based mainly on work accomplished cooperatively with the State Engineer of Oregon and other State, municipal, and Federal agencies

Geological Survey Water-Supply Paper 1649

WATER FOR OREGON

FIGURE 1.—West side of Crater Lake from the south rim, about 900 feet above the lake. Wizard Island, built by a weak volcanic resurgence after the formation of the main crater, in the foreground. National Park Service photograph by George A. Grant.

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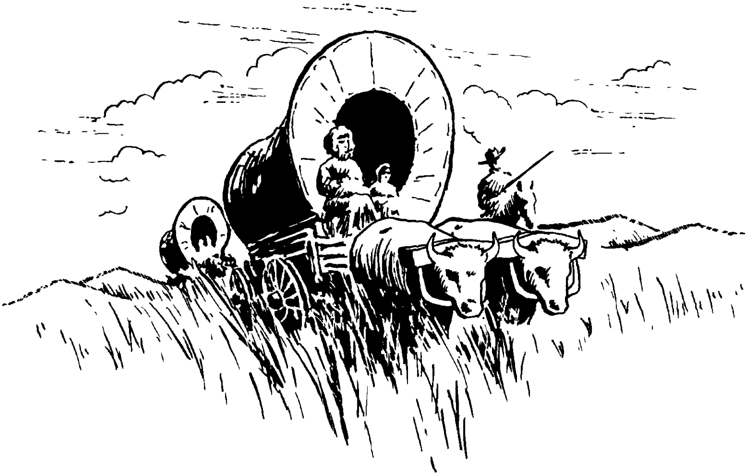


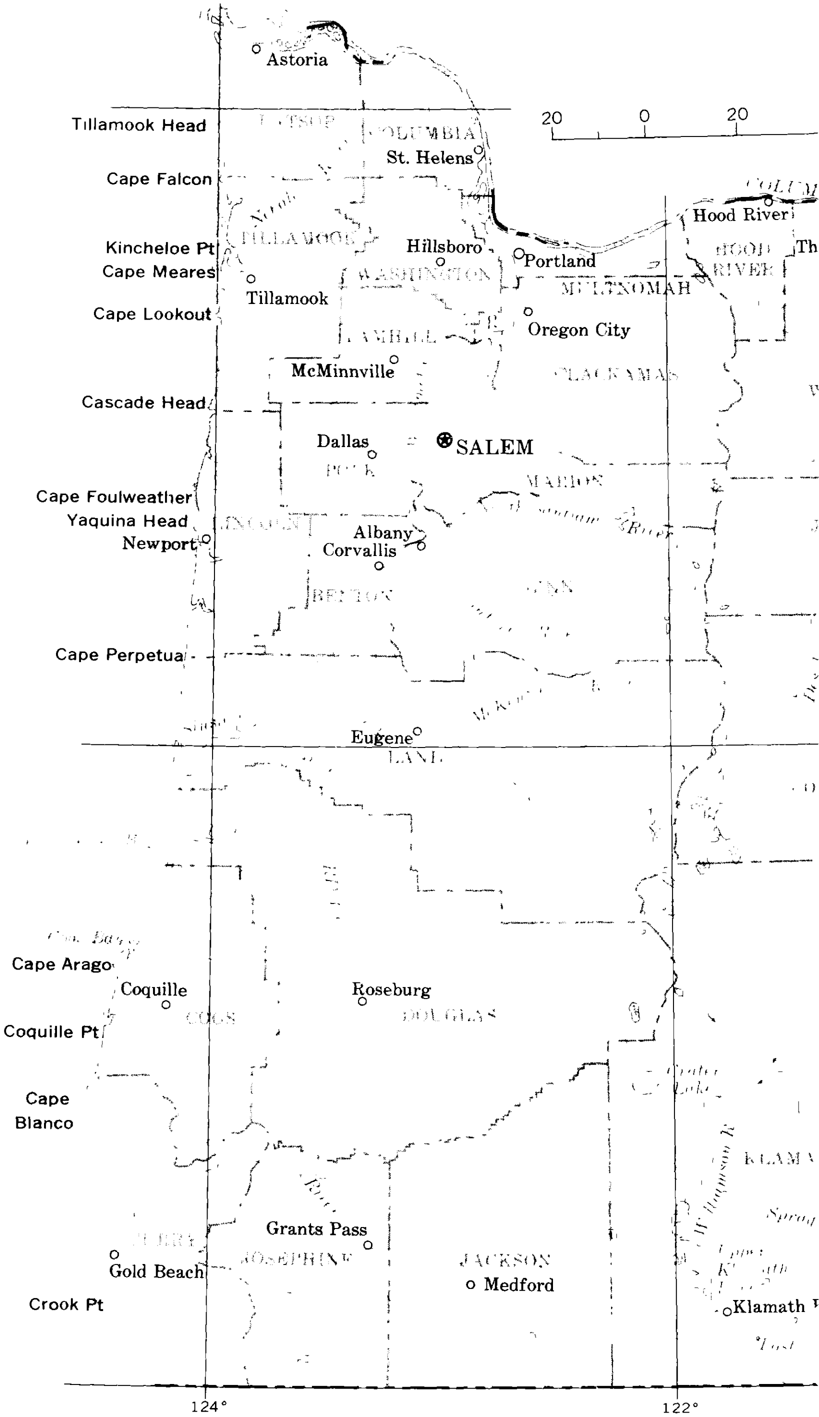
INTRODUCTION

But the land, whither ye go to possess it, is a land of hills and valleys, that drinketh water of the rain of heaven.

—Deuteronomy 11:11

The early American immigrants to the Willamette Valley may have seen it as another Promised Land, but before the Oregon Territory achieved statehood in 1859, its citizens knew their land possessed water contrasts almost without equal. In some places the average annual precipitation is 140 inches, but over other large areas it is less than 8 inches. Nearly all of this precipitation comes during the rainy winter season; the summer season is almost everywhere dry. The soils of Oregon are varied, and the altitude ranges from the level of the sea to snow-clad peaks above 10,000 feet.

The pioneers recognized that the region and its water conditions, in a general sense, are divided by the north-south Cascade Range. (See figs. 2, 3.) Western Oregon has adequate or even excessive gross supplies of water, but much of eastern Oregon has a gross overall shortage. Along the State's eastern and northern borders, large rivers flow from distant mountains; Oregon and its neighboring States are planning to make full use of these border streams.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Cape
Blanco
Gold Beach
Crook Pt
St. Helens
Hillsboro
Portland
Tillamook
Oregon City
McMinnville
Dallas
SALEM
Albany
Corvallis
Eugene
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Coquille
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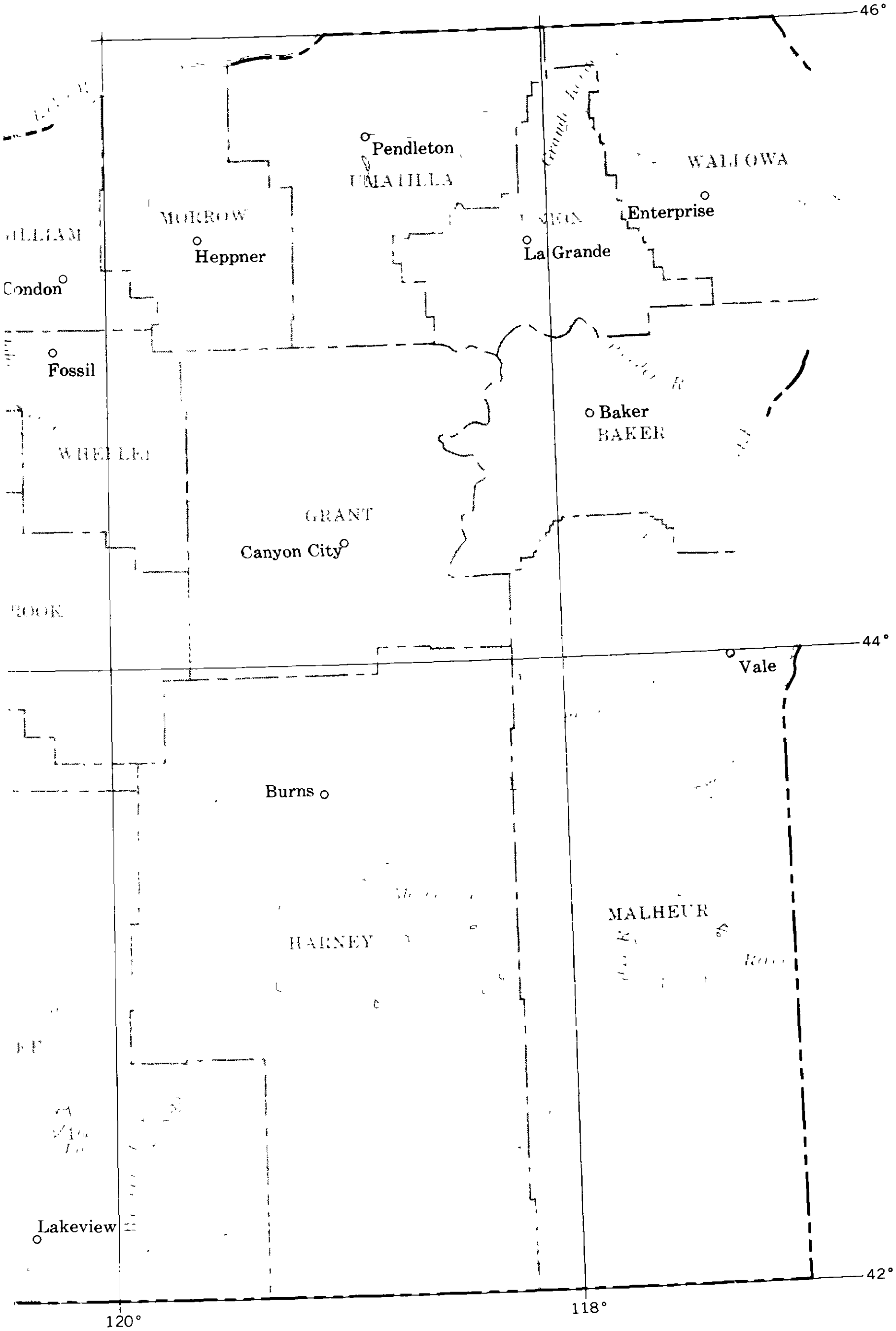
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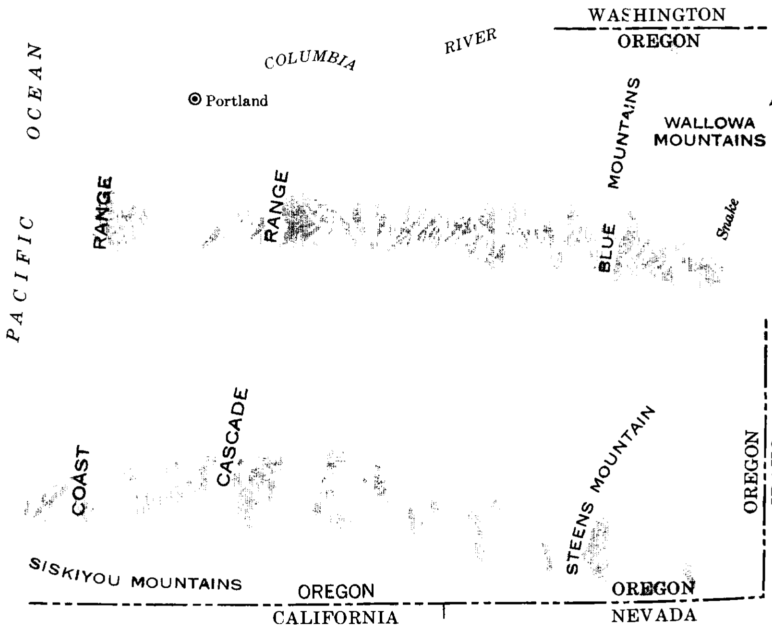

FIGURE 3.—Relief map of Oregon. Much of the State is mountainous. Near the west boundary of the State, the Coast Range extends from the southern boundary northward to the Columbia River. About 100 miles inland from the Coast Range is the parallel and higher Cascade Range. In eastern Oregon, the rugged Blue Mountains and Wallowa Mountains dominate the skyline. Steens Mountain in the southeast is the greatest of the fault-block mountains.

The pioneer settlers could hardly have visualized the rapidity with which the water would be put to use. The easily available water would all be used within 150 years of the date of the first settlements, and the descendants of the pioneers are now preparing plans for the full use of all the resources of fresh water.

Thus, within 100 years after achieving statehood, Oregon has developed a variety of water problems. Certain local areas have abundant water and other areas have an excess in some seasons, but most of the State is deficient, either in the amount or in the distribution of water. The high standard of living in the whole State and the normal growth of its industries and population will soon require much greater use of present water resources, more control of water waste and damage, and perhaps the development of water sources now not fully recognized.

WATER FOR THE PIONEERS

For millenniums before the coming of the white man, Indian life was virtually dependent on the runs of salmon in the streams, on the wildlife that followed waterways, and on the plants that grew in the marshes and along the streams; the waterways were also the Indians' principal routes of travel and transportation. The explorers and fur traders traveled these same natural avenues, and the earlier white settlers built their homes near them.

The early settlers, like the fur traders, depended upon the waterways for transportation of their heavier loads. As roads were constructed, wheeled vehicles took over some of this traffic, but waterways were still the principal routes for heavy transport during the first half of the 19th century. At that time the usual requirements for domestic water were small; it was enough to have a clean stream, a nearby spring, or a dug well with bucket and windlass.

Placer mining of gold started in the Rogue River valley in the 1850's and in the Powder and Malheur River valleys of eastern Oregon in the 1860's. Sawmills were located on the streams, down which logs could be floated from the abundant upstream stands of timber. Commercial fisheries flourished on the strong runs of salmon. Flour mills, sawmills, and woolen mills were operated by waterpower, and industrial use of water was started. By 1850 there were about 13,000 permanent settlers, most of them living in the lower Willamette Valley, and the stage was set for a rapid exploitation of the rich land, timber, and water resources.

There was an influx of settlers in the 1850's and 1860's. Warfare with the larger Indian tribes was over by 1860, and gold mining started in the Rocky Mountain areas in the 1860's. These two factors helped to bring about the settlement of the valleys of eastern Oregon, and the settlement in turn brought about diversions of streams to irrigate parts of many of the valley plains. Irrigation increased until most of the summer flow of many creeks and rivers had been applied to the land. Squabbles between claimants of water had developed in some valleys by 1880.

Water traffic on the Columbia and Willamette Rivers was the dominant means of heavy transport in the period 1850–87. Astoria, The Dalles, Umatilla, Oregon City, Champoeg, Salem, Albany, and Dayton were port cities. Inland commercial shipping also operated on other lakes and rivers, among them the Yamhill, Tualatin, Snake, and Umpqua Rivers. Portland was the main transfer point where the lumber, grain, and livestock were shipped out and manufactured goods came in. Milwaukie was considered the head of practical navigation on the lower Willamette, and Oregon City the lower terminus of the upper Willamette. To bypass the 40-foot Willamette Falls at Oregon City, shipping locks were constructed, but they came into use only a short time before the construction of the railroads. The rail lines took over much of the pioneer traffic from the rivers. Thereafter, river navigation decreased and was confined to the tidal reaches of the Columbia and Willamette Rivers, until the development of locks and dams in recent years.

The latter part of the 19th century saw the pioneer phase of settlement giving way to the stabilized situations of growing communities. The pattern of water use was already in operation. In the eastern part of the State, conflicts had developed for the right to divert the summer flow of streams for irrigation. In many valleys, more land had been prepared for irrigation than the streams could possibly water in most years. The courts were swamped by legal contests for water rights, and there arose a demand for legal as well as engineering and technical direction of water supplies. The measurement of the flow of water in streams was started, in some places on order from a court.

Periodic measurement of the Owyhee and Malheur Rivers was begun in 1890, of the Umatilla River in 1891, and of the Deschutes and Hood Rivers in 1897. Similar measurements were started on several other streams of eastern Oregon in the years 1903–5, and on some in western Oregon in 1905–6.

In response to the demand for technical direction in the allotment of rights to water, the office of the State Engineer was created in 1905. Continuously since that date, the U.S. Geological Survey has cooperated with the State Engineer in the collection of data on the water resources of the State.

A State water code was enacted in 1909, to provide an orderly and legal basis for the appropriation of rights to the public water of Oregon. The water of all nonnavigable streams was declared to be public water, and rules were laid down for the granting of rights according to the doctrine of priority of appropriation and beneficial use. The original water code of 1909 has been amended from time to time. In 1955, ground water was declared a part of the public water of the State and was brought under the regulatory supervision of the State Engineer.

The original diversions for irrigation were made by settlers at points where the water could be applied most readily to land. Large projects were constructed and operated by groups of settlers; successful irrigation districts were formed and a permanent water supply obtained for them. Some ill-advised projects failed, with great hardships to the settlers and the investors, because there was not enough information on the sustained yield of the proposed water source.

After the passage of the National Reclamation Act of 1902, the U.S. Reclamation Service (administered at that time by the Geological Survey, but in 1907 made a separate bureau of the Department of the Interior) constructed many of the larger irrigation projects, including the Klamath, Owyhee, and Deschutes projects.

Experiments at Corvallis in the years 1907–8 demonstrated that irrigation would more than double the per-acre yield of field crops in the Willamette Valley, where the rainfall is deficient during the growing season. Adoption of irrigation as a standard farming method in that valley was slow but continuous. In recent years the custom of late-summer irrigation of pastures has been extended to the coastal areas, where the annual rainfall in places exceeds 90 inches.

The streams that descend from the mountains contain many cascades and steeply plunging reaches where water wheels were installed to drive the pioneers' flour and saw mills. Waterpower was thus an important factor in the early industry of the region. The first "long-distance" transmission of electrical energy in the United States was over the line constructed in 1889 to carry electricity 13 miles to Portland from the new hydroelectric plant at Willamette Falls.

During the first 60 years of settlement, most of the domestic and public water supplies were obtained from dug wells, springs, or streams. Much of that water was carried by hand to kitchens, and the total use was small. Progressive settlement called for sources that were safer from contamination and of greater capacity. New supplies were obtained by piping water from streams or by using springs or steel-cased wells. Purifying treatment was started. Some cities abandoned their pioneer nearby sources and secured rights to the water of mountain streams with protected watersheds. Portland's Bull Run River supply was first used in 1895. Salem's original Willamette River supply replaced pioneer wells, and the Santiam River supply was developed in 1938. Pendleton's Umatilla River infiltration system was first used in 1914, Eugene's McKenzie River supply in 1925, and Medford's Big Butte Springs source in 1926.

The framework of water utilization in Oregon was largely established by 1910, but waste disposal became a serious problem that later required restraining measures. Water supply became the all-important vital force to economic, industrial, and agricultural development in western Oregon and to its limitation in eastern Oregon.

NATURE'S SUPPLY OF WATER

A few rivers bring to Oregon's borders a supply of water that originated in other States; however, most of the supply available for use within the State is brought in as part of the atmospheric circulation and falls as rain or snow.

This atmospheric circulation arises largely from one path of storms. A hemispheric pattern of circulation is set up by interaction of the warm air that rises in the tropics and flows northward with the cold air that sinks in the polar regions and flows southward. At the latitudes where the warm and colder airmasses meet, a series of storm centers is formed. These storms migrate eastward across the Pacific Ocean with the prevailing winds. In the colder months the eastward-moving storms, laden with moisture picked up in their ocean passage, strike the Pacific coast in the general latitude of Oregon. In the warmer months the tropical air flows farther north, and the latitude of storm formation, between the cold and warm airmasses, shifts northward. The belt of potential storms is thus deflected, and Oregon is therefore largely free of the strong eastward-moving storms during the warmer months.

The atmospheric circulation provides the basic west-to-east movement of the moisture, but the topography of the land to a large extent determines where precipitation falls. The air over the ocean is generally warmer in the winter months than the Oregon landmass; hence, the air becomes chilled as it begins to pass over the land. The lifting of the air and its natural expansion as it passes up the west slopes of the mountains is even more effective as a cooling agent. As a result, the water can no longer be carried as an invisible vapor; tiny droplets condense to form clouds or fog and, as they cool, these droplets join together and rain or snow begins to fall. The greatest precipitation predictably occurs on the west slopes of the Coast Range and the Cascade Range, where the cooling is most rapid as the airmasses rise. (See fig. 4.) The Coast Range is first in line and accomplishes the greatest extraction of the incoming moisture as it forces the clouds up over its general 3,000-foot crest. The west slope of the Coast Range is part of one of the areas of greatest precipitation in the United States. The Cascade Range, next in line, extracts a great deal of the remaining moisture from the clouds by deflecting them upward to an altitude of 4,000 to 7,000 feet.

East of the Cascade Range are local mountainous sections—the Blue and the Wallowa Mountains of northeastern Oregon, the Fremont Mountains, Steens Mountain, and the mountains of central Oregon—that also obtain precipitation from the eastward-moving storms. The storms that commonly bring the heaviest precipitation to southern and southeastern Oregon are those that strike the coast in northern California and move northeastward across the Siskiyou Mountains and the southern part of the Cascade Range. Much of the moisture is removed in crossing these barriers, and as a result the broad plateaus of southern and southeastern Oregon have rather meager precipitation.

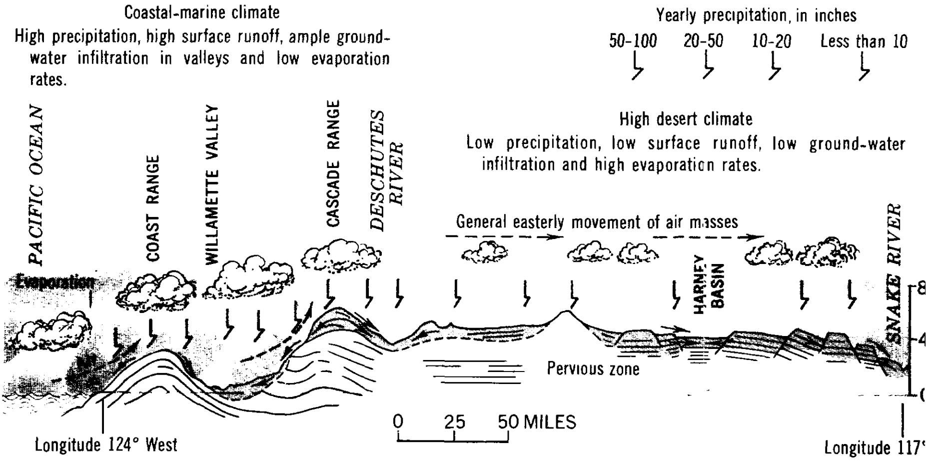

FIGURE 4.—Generalized east-west cross section of Oregon showing the general pattern of air circulation of the water of the State. The winds bring water vapor from the Pacific Ocean and move generally eastward across the land. The heaviest precipitation occurs on the west slopes of the Coast Range and the Cascade Range. East of the Cascade Range, the drier air has greater ability to pick up moisture evaporated from the open water surfaces; however, the amount of moisture available for evaporation is not great because large areas are arid.

The eastward-moving storms move down the east or lee side of the north-south ranges, and in descending they become warmer by compression, owing to the weight of the mass of air above them. Warming of the air and the water vapor stops the condensation of water rather abruptly. Hence, these lee areas receive much less precipitation than the west slopes and crest areas of the mountain ranges, and for that reason are said to be in "rain shadows." Some writers have suggested that a better phrase would be "dry shadows." The average annual rainfall for the Willamette Valley is about 40 inches; in the Coast Range it is 80 to 140 inches, and in the lower parts of the Deschutes-Klamath plain about 10 inches.

The average annual precipitation for the entire State has been estimated as about 27 inches. This would be enough to cover 139 million acres 1 foot deep. The total volume is somewhat uncertain because of the scarcity of rain gages in the more remote mountain localities. In some localities, records of streamflow indicate that precipitation may be greater than can be determined from the available records of rain and snowfall.

NATURE'S DISPOSAL OF WATER

The water which falls on Oregon's land surface is disposed of by one or a combination of the natural processes of surface runoff, infiltration, evaporation, and transpiration. The amount of water taking each disposal course is determined by the topography, temperature, vegetation, and precipitation of each drainage basin.

In order to accept much infiltration, the soil must be underlain by permeable rock materials. Where the soil and bedrock are not permeable, more of the precipitation must stay on the surface; where the slope is steep, more of the water will run off regardless of the other factors. Low temperatures increase the temporary storage of precipitation as snow and ice and decrease the evaporation and transpiration losses.

Vegetation affects the water yield of an area in three ways: It decreases the runoff by transpiring water; it increases the runoff by decreasing the evaporation from the surface; and it benefits the timing of the runoff and the clarity of the water by increasing the storage as snow, by retarding erosion, and by delaying the sedimentation of surface storage basins.

The character of the precipitation—its intensity and duration, the state of its arrival (as rain or snow), its amount and distribution through the year—influences the water yield of any drainage basin.

Some of the precipitation that falls on Oregon is evaporated from streams, ponds, lakes, and storage reservoirs. The amount evaporated from the surface-water bodies in an average year has been computed as 2 million acre-feet, or only a little more than 1 percent of the total precipitation. Of this amount, about 750,000 acre-feet is evaporated from the brackish lakes and marshes of basins that have no outlet to the sea. The rivers carry to the ocean some 88 million acre-feet per year. (See fig. 5.) The remainder of the total annual supply falling as precipitation, about 49 million acre-feet, evaporates from the land surface or is transpired by trees and natural or cultivated plants, or is used consumptively by man.

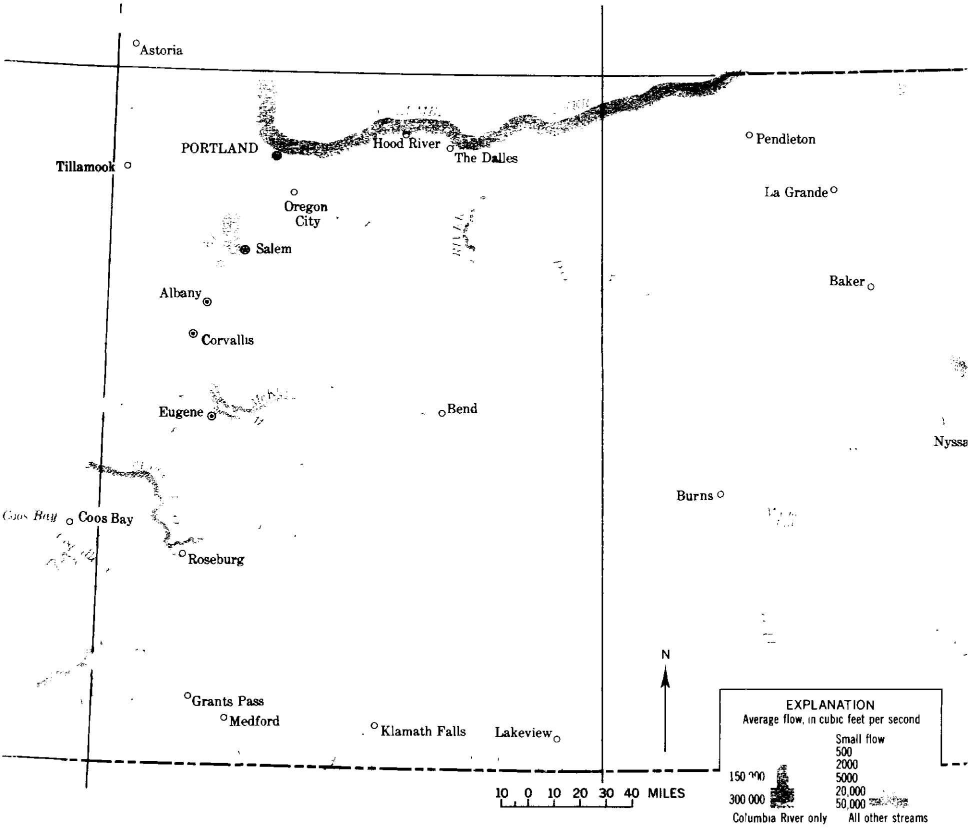

FIGURE 5.—Rivers of Oregon. The Columbia and Snake Rivers bring water to Oregon from other States and from Canada. Other rivers originate within Oregon. This map illustrates the distribution of water in Oregon's streams. Rivers on the west slopes of the Coast and Cascade Ranges carry much more water in proportion to the area drained than the streams draining the rain-shadow areas east of the mountains.

WHAT IS WATER?

To a great many people, the term "water" means just plain water. The chemist tells us that water is a colorless and odorless liquid consisting of two atoms of hydrogen and one of oxygen for each molecule of water. The geologist reminds us that water is also a mineral having a definite crystal structure and melting point. It can change the physical form of other minerals by dissolving them or by combining with them to form new minerals. Everyone knows that distilled water tastes as if something is lacking, and even rainwater does not taste normal to us. We all know that the oceans are salty and that stagnant waters are unsavory, but few of us stop to think what is in the clear water we draw at the tap or drink at the fountain.

Because water is such a good solvent, it picks up both gases and solids as it falls from the sky or flows over or under the earth's surface. Even rainwater contains dissolved gases, mineral solids, and organic material and, in some areas dust and smoke particles. Rain falling near the seacoast dissolves common salt swept in as a spray from the ocean.

As soon as water arrives on the surface of the earth, things begin to happen to it. It ordinarily dissolves and unites with some carbon dioxide from the air, the soil, and the animal or vegetal materials in or on the soil. From the time it receives its first carbon dioxide and forms carbonic acid, it is no longer a benign and inert liquid. It is then an active, though weak, chemical reagent ready to dissolve any soluble rock material. It immediately begins its attack on the rocks and soils.

Through this process all natural waters contain dissolved mineral matter; the nature of the rock and soil materials in the drainage basin determines the character of the water. The amount and composition of the dissolved solids in the water depend upon the water's environment, because opportunities for water to dissolve minerals will not necessarily be the same in all drainage basins.

Time is also a factor determining the character of water. The quantity of mineral matter dissolved by natural water depends not only on the types of rocks and soils that it touches but also on the length of contact. Ground water commonly contains more dissolved matter than surface runoff because it remains in contact with rocks and soils for longer periods of time. Streams that are fed by both surface runoff and ground water from springs and seeps reflect during dry periods the chemical character of the ground water, which has a greater concentration of dissolved solids; during periods of heavy surface runoff, the river water becomes more dilute, because of the addition of rain or snow water. The amount of dissolved solids in a river's water may be increased by waste water from mines, irrigated fields, cities, and industries.

Besides the dissolved materials, water moving on the land surface may pick up and carry along some fine materials in suspension. The finer grained solids are carried along by the turbulent motion of the water. This suspended material is commonly referred to as sediment. It ranges from microscopic-particle to sand-size grains. The suspended load, as it is called, may be extremely variable throughout the year or among streams. It is influenced by river stages, soils, terrain, bank conditions, and land use. Some soils erode easily, others do not. In some basins, as much as 90 percent of the total sediment load for the year may be carried by the stream in a few days.

All streams carry some natural sediment. The greatest manmade loads of sediment and solid debris in streams and drainageways result from poor soil-management practices. These unnatural loads result primarily from improper types of farming on slopes, overgrazing, placer mining, and poorly planned timber operations.

Within the framework briefly described above, Nature allots and disposes of Oregon's water refreshment. Let us examine what that allotment is in each of the State's main physical subdivisions.

RIVER BASINS OF OREGON

COLUMBIA RIVER

> * * * the continuous woods
> Where rolls the Oregon, and hears no sound
> Save his own dashings * * *
>
> —*William Cullen Bryant*

When the young poet composed the sonorous lines of "Thanatopsis" in 1817, the little-known river to which he referred already had borne another name for a quarter of a century. On the early morning of May 11, 1792, Captain Robert Gray had sailed the American vessel *Columbia* through the breakers and dropped anchor 10 miles upstream in the legendary "Great River of the West." A few days later he gave his ship's name to the river.

The Columbia River brings to Oregon an immense supply of excellent water. For 309 miles it serves as Oregon's northern boundary; in that distance it descends the 340 feet from McNary Reservoir to sea level. Tidewater extends from the mouth 145 miles upstream to Bonneville Dam.

The river is 1,214 miles long. It drains an area of 259,000 square miles, including areas in Oregon that have mean annual precipitation ranging from 8 inches near Umatilla to more than 100 inches on the western slopes of the Coast and Cascade Ranges.

In an average year the river carries to the sea enough water to cover an area of a million acres 197 feet deep. But of course the "normal" year seldom occurs; some years are

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wet, others dry, and in any year there is a wide seasonal variation in flow. The Dalles is the farthest downstream place at which the river is regularly gaged. Above that point the drainage area is 237,000 square miles, and measurements of the flow have ranged from a low of 35,000 cfs (cubic feet per second) on January 12, 1937 (during a freezing period), to the memorable flood of 1,240,000 cfs on June 6, 1894.

Upstream reservoirs already constructed are capable of storing sufficient water to reduce floodflows materially, and the daily discharge at The Dalles during the low-flow season now seldom drops below 80,000 cfs. According to the U.S. Army Corps of Engineers, construction of additional planned reservoirs will make possible reduction of the peak discharge of a flood like that of 1894 to 600,000 cfs and to increase the average low flow to 149,500 cfs (Report of Chief of Engineers, Mar. 31, 1961, p. 5, 15, *in* House Doc. 403, U.S. 87th Cong., 2d sess.). As the dependable flow of the river is increased, more and more water is being put to work to develop electric power for industry, to float waterborne commerce, and to serve a host of other uses (fig. 6).

The rate of flow in the main stem of the Columbia River follows an annual pattern that is fairly predictable. Because most of the water in flood periods is derived from melting snow, the flow is greatest in late spring and early summer, least in the period October to February. Thus, the greatest flows come at a time of comparatively dry weather, and the low flows occur in the wetter part of the annual rainfall cycle. The flows complement those of rivers in the western part of the State that are normally highest in the period November through March. The difference in the timing of the floodflows in the two river systems helps to make possible the fuller development of the water resources of both.

During the first half of the 19th century, a few of the settlers ran their flatboats and rafts laden with household goods and farm equipment downstream through the Cascade Gorge as a perilous but faster alternative to the Oregon Trail. But the same cascades that delayed the Lewis and Clark party in 1805 were an even more formidable barrier to the settlers' clumsy rafts, and river traffic above the mouth of the Willamette remained small even though por-

FIGURE 6.—Above, Tugs moving barges upstream on the Columbia River. River freight consists principally of petroleum products going upstream and wheat and forest products downstream. View from the Bridge of the Gods at Cascade Locks. Photograph by Bonneville Power Administration. Below, Log rafts being lowered through the locks (right center) around Willamette Falls, West Linn papermills in center, Oregon City and Willamette Falls in the left background. Photograph by U.S. Bureau of Land Management.

tage roads were built around the rapids. Some impetus was given to upriver navigation by completion of Cascade Locks at the lower rapids in November 1896. The town of Cascade Locks grew up around the locks and took its name from them. Celilo Canal and locks, bypassing Celilo Falls, were opened to river traffic in April 1915.

Later, navigation was stimulated by the building of the great dams and shipping locks. Bonneville Dam and locks (fig. 7), completed in 1938, at the head of tide, created a slackwater reservoir 47 miles long and submerged the falls at Cascade Locks. The Dalles Dam, completed in March 1957, drowned Celilo Falls and created a reservoir extending another 24 miles upstream to the mouth of John Day River; thus there is now deep navigable water for 217 miles upstream from the mouth of the river. Some 75 miles still farther upstream, McNary Dam was completed in April 1953 and created a pool at 340 feet altitude that extends well upstream from the Oregon-Washington line.

John Day Dam is under construction (1964) at a site just downstream from the mouth of John Day River. When it is completed, river steamers, barges, and log rafts will have deep navigable water upstream for 325 miles from the mouth of the great river, and on up the Snake River. As a result of these river improvements, traffic on the Columbia River above Portland has grown sensationally since 1938.

The excellence of the chemical and physical quality of the water of the Columbia River adds to the importance of this great stream. At Rufus the water has a mean dissolved-solids concentration of slightly more than 100 ppm (parts per million) and is relatively soft; it averages about 70 ppm in hardness. The sediment load is very low for a stream of its size. Because of its great flow, the Columbia River serves many industries and municipalities as a means of waste disposal. The increasing use of the water for this purpose lowers its quality and, if continued, will in time make it undesirable or even unusable for an increasing number of purposes.

Water bounds the State of Oregon for nearly a thousand miles. When the Oregon Territory was admitted to the Union by Act of Congress on February 14, 1859, the act described the western boundary as being "one marine

FIGURE 7.—Bonneville Dam on the Columbia River near the head of tidewater, 145 miles from mouth of the river. Powerhouse, shipping lock, southern fish ladder, and diversion for the Bonneville Hatchery are on the south side of Bradford Island. Spillway section and northern fish ladder are to the north of the island. Photograph by Bonneville Power Administration.

league" at sea, from the 42d parallel of latitude northward to a point opposite the mouth of the Columbia River; this boundary has since been measured as 429 miles of salt-water shoreline, plus 60 miles of island shoreline. The northern boundary was taken as the middle of the Columbia River to the point where the 46th parallel of latitude crosses the river, thence east along the 46th parallel to the middle of the Snake River.

SNAKE RIVER

The eastern boundary of the State extends southward from the 46th parallel of latitude for 216 miles up the middle of the Snake River to the mouth of the Owyhee River, thence south to the 42d parallel.

The Snake River is one of the larger streams of the United States in point of drainage area, and is the largest tributary of the Columbia. It drains a total of 109,000 square miles, of which 19,950 square miles lies in eastern Oregon. The past, present, and future prosperity of the Snake River basin is inseparably linked with its supply of water. The runoff from winter rains and melting snow is stored in more than 80 reservoirs in Wyoming, Idaho, Nevada, and Oregon, to supplement the flow available for irrigating about 3 million acres of land. Storage in reservoirs has materially reduced flood hazard in the section where the river is the boundary between Oregon and Idaho.

The use of water for irrigation has had little effect in reducing the low-water flows, for much of that low flow comes from a multitude of large springs that are nourished in part by deep percolation from irrigation water. Additional irrigable land in Oregon exists only in rather small tracts near the tributaries, not adjacent to the Snake River itself; the future irrigation of these lands will reduce only slightly the low-water flow of the Snake River.

To Oregon, much of the economic value of the Snake River lies in its potential for hydroelectric power (fig. 8), for spawning areas for salmon, for reservoir space, and for the recreational value of its water.

FIGURE 8.—View downstream (north) in the Grand Canyon of the Snake River 80 miles below Huntington. Part of the canyon is cut more than 5,000 feet below the mountainous upland between the Wallowa Mountains in Oregon and the Seven Devils Mountains in Idaho. Hells Canyon Dam is now (1964) under construction in this gorge. Photograph by Bonneville Power Administration.

WILLAMETTE RIVER

Onward ever, lovely river,
Softly calling to the sea
—*Samuel L. Simpson, "Beautiful Willamette"*

The Willamette is the largest river wholly in Oregon. Its drainage basin totals 11,150 square miles, or 11.5 percent of the State. (See fig. 9.) However, that basin is much more significant in population than in area; it contains two-thirds of the people in the State.

The concentration of people in the Willamette Valley is easily explained. The river itself provides a fresh-water harbor at Portland that, combined with other harbors on the Columbia between Portland and the sea, handles about 23 million tons of ocean and river traffic annually (1961). The

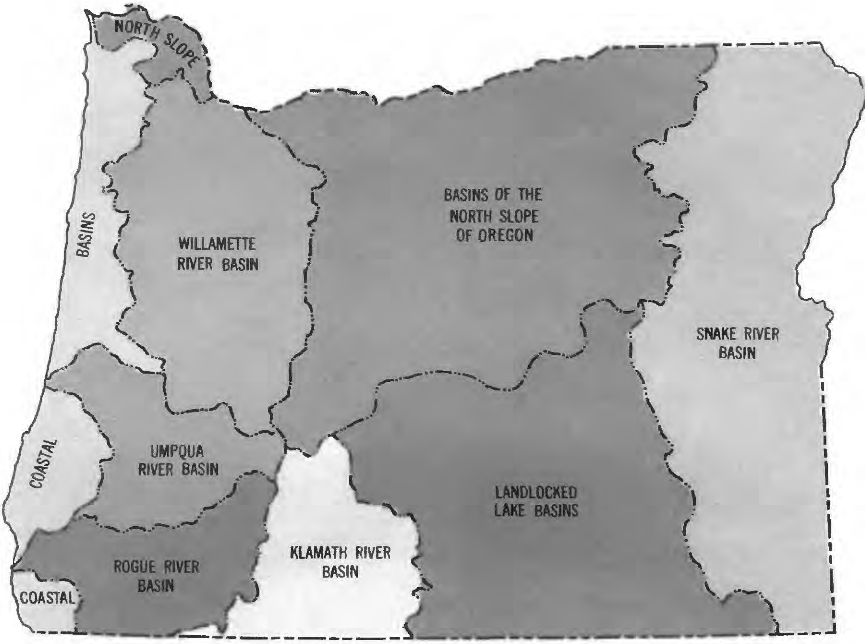


FIGURE 9.—Major drainage basins of Oregon.

wide expanse of fertile valley supports Oregon's largest agricultural community. The adjacent slopes of the forested foothills and mountains of the Cascade and Coast Ranges provide lumber products which nourish a growing industry, and on these slopes the bountiful winter precipitation gives rise to the multitude of rills, brooks, springs, lakes, and creeks whose runoff swells the flow of the main river. Relatively warm, wet winters follow cool, dry summers to form a dependably mild climate, well suited to agricultural and industrial development. The north-south trend of the valley permits water-grade transportation from Portland to points throughout the floor of the valley and toward the markets of California.

The main stem of the Willamette River (Middle Fork) rises in a group of tiny lakes (see fig. 10) in the Cascade Range, from whence the water flows 260 miles to join the Columbia River below Portland. The tributaries which join the main stem along its course differ one from another in the characteristics of their annual discharge.

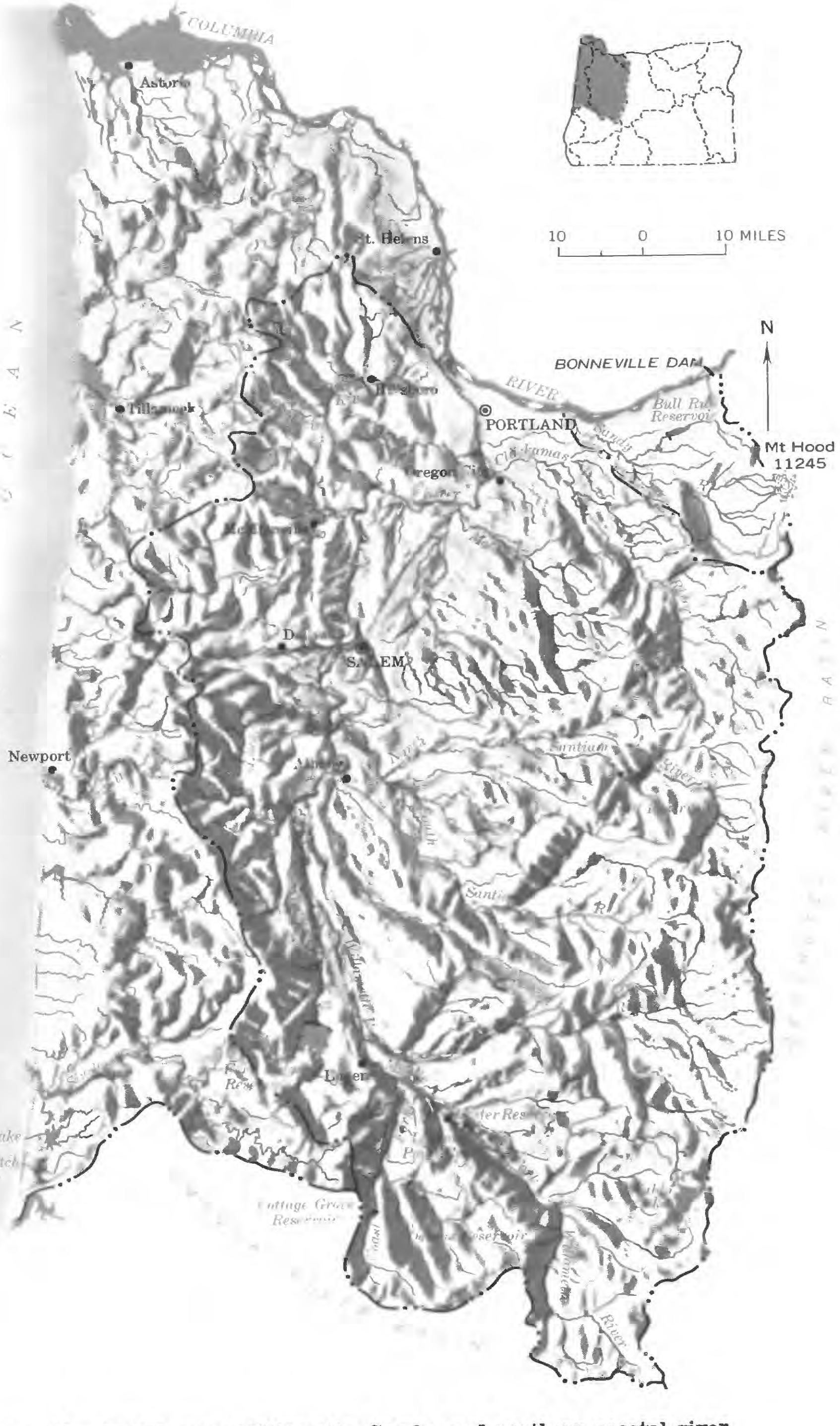
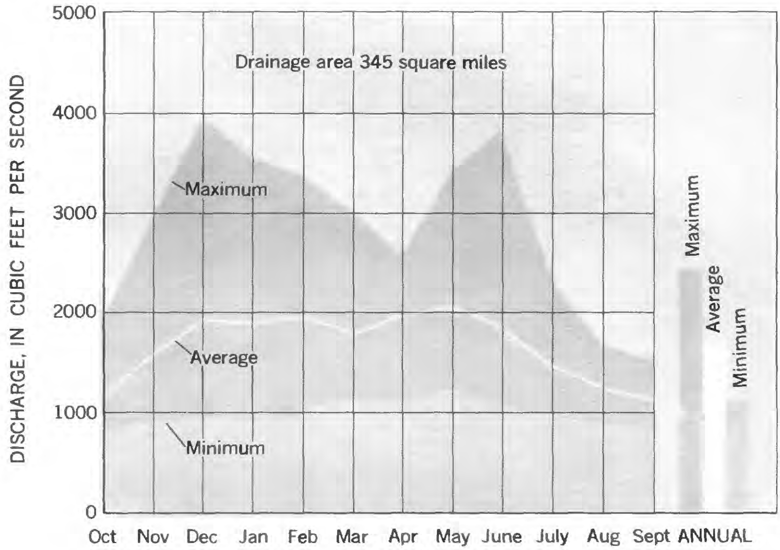


FIGURE 10.—Sketch map, Willamette, Sandy, and northern coastal river basins.



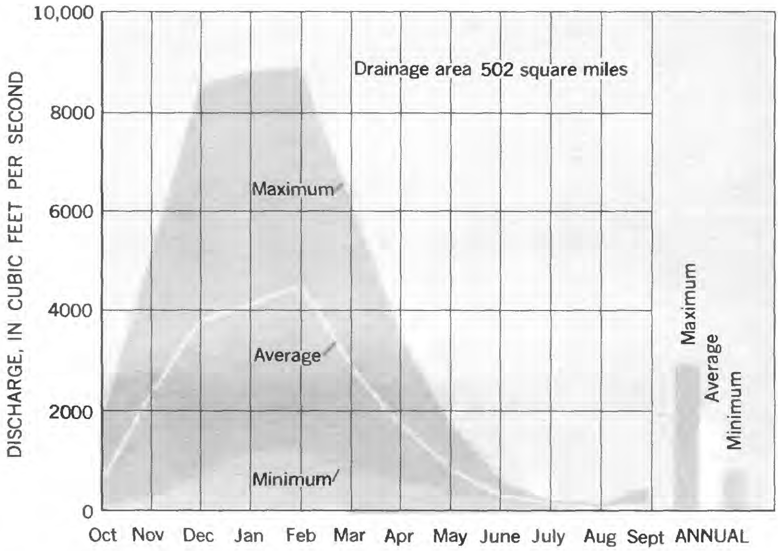


FIGURE 11.—Maximum, minimum, and average monthly and annual discharge of McKenzie River at McKenzie Bridge (above) and South Yamhill River near Whiteson (below). The McKenzie River has the steady flow typical of many spring-fed streams rising in the volcanic rocks of the Cascade Range. The South Yamhill responds quickly to rain, as do all the streams rising in the less permeable sedimentary rocks of the Coast Range, but its summer flow is very small.

Most of the streams that come from the Coast Range, the west side of the valley, have high runoff from November to March and very low flows from July to October. (See fig. 11). The Coast Fork, Long Tom, Marys, Luckiamute, Yamhill, and Tualatin Rivers are streams of this type; in periods of low flow, they discharge about 0.1 to 0.3 cfs for each square mile of drainage area.

On the right, or east bank, steady summer flows are fed chiefly by snowmelt and ground-water outflow from large mountain springs. This characteristic is common to North Fork of Willamette River, McKenzie River, North Santiam River, Clackamas River, and other streams. These streams, where they emerge from the mountains, have a summer flow of about 0.7 to 2.0 cfs per square mile of drainage area.

The difference between the Coast Range and the Cascade Range tributaries is due in part to the higher altitude and greater snowpack in the Cascade Range. To a greater extent it is due to the presence in the high Cascade Range of porous soils and volcanic rocks that store rainfall and snowmelt for gradual release in springs, some of which are remarkable for their size and constancy.

There has been a growing awareness of the need for controlling floods and for using the water resources to produce electric energy, improve navigation, abate pollution, increase recreation, and augment the production of game and commercial fishes. This need led to the adoption by the Corps of Engineers of plans for the Willamette River Basin Project. (See fig. 12.) Already, dams have been built and are in operation at Hills Creek, Lookout Point, Dexter, Cottage Grove, Dorena, Fern Ridge, Cougar, Detroit, and Big Cliff; dams at Fall Creek, Blue River, Green Peter, and Foster are under construction (1964). Completion of other recommended projects will result in control of floods on the main stem of Willamette River and on most of its tributaries, but many other possibilities exist for profitable use and control of the formerly wasted water of the basin. These water-control projects improve conditions for fish (fig. 13).

The Willamette River basin contains two principal areas of ground-water storage. One is formed by the fragmental

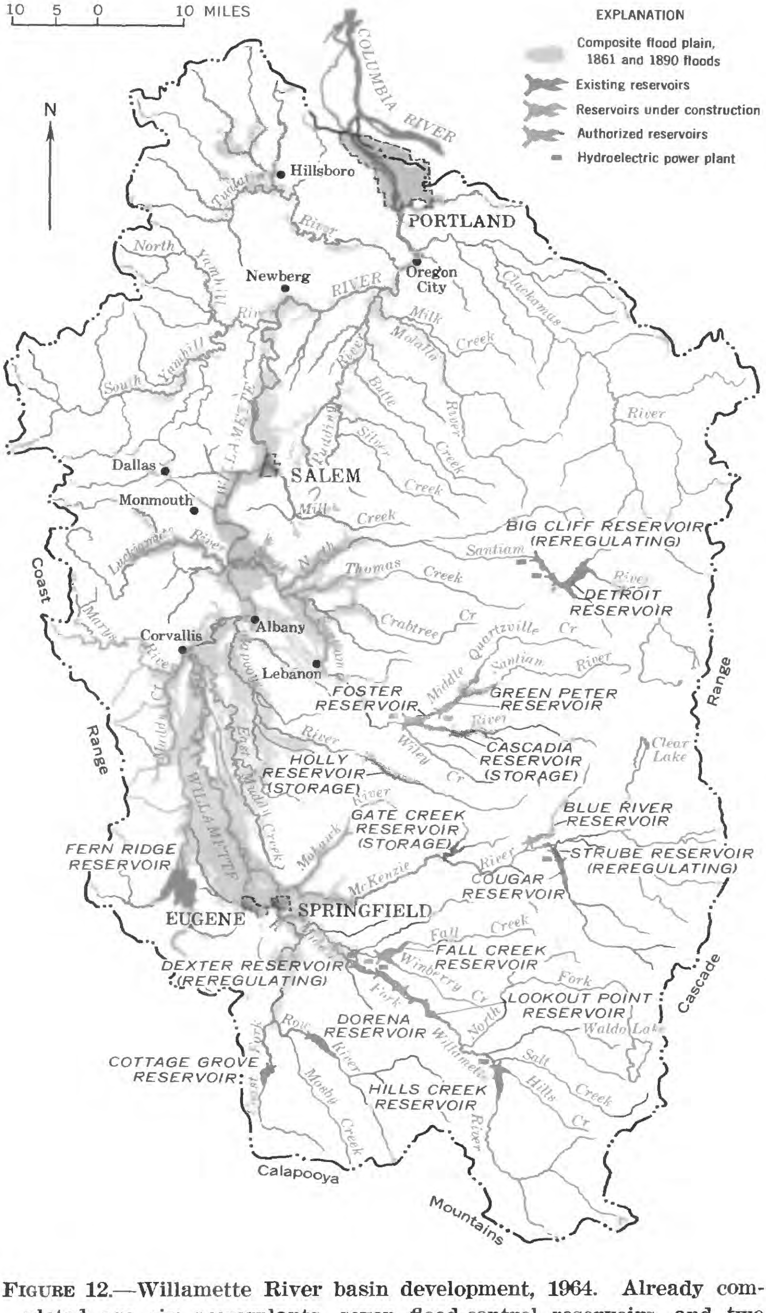


FIGURE 12.—Willamette River basin development, 1964. Already completed are six powerplants, seven flood-control reservoirs, and two reservoirs to "reregulate" or iron out fluctuations in streamflow caused by powerplant operation. Under construction are four more multiple-purpose dams. Authorized projects include four more multipurpose dams.

volcanic rocks of the higher parts of the Cascade Range. The ground water issuing from these rocks feeds the headwater streams and larger tributaries of Willamette River. The other area consists of the terrace and river-bottom lands in the eastern half of the valley floor, which are underlain by permeable deposits of sand and gravel. The ground water in the latter area yields water to many wells, and the groundwater reservoir serves to regulate the flow of the valley streams to some extent.

FIGURE 13.—View southeast toward the eastern part of Willamette Falls and Oregon City, showing spring Chinook salmon jumping a ledge. Photograph by Oregon Fish Commission.

The Willamette tributaries draining the Cascade Range and the Coast Range contain very low amounts of dissolved material. Water of these rivers contains about 30 to 50 ppm dissolved solids, the main constituents being calcium and sodium bicarbonates, sulfate, and 5 to 20 ppm of silica. The water of the Willamette itself reflects the sizable contribution of water from these mountain sources. The analysis of samples collected daily at Salem from 1951 through 1960 gave an average dissolved-solids content of 50 ppm and a maximum of only 69 ppm. Thus, the Willamette River contains water that not only is low in hardness and dissolved solids but also is comparatively uniform in chemical quality.

The ground water that occurs in the fragmental volcanic formations of the high parts of the Cascade Range is low in dissolved-mineral content. It issues as large springs from the lower ends of these youthful volcanic deposits and has excellent quality.

The ground water in the extensive alluvial deposits of the Willamette Valley is moderately hard. Its content of dissolved solids ranges from 100 to 200 ppm and consists principally of calcium and sodium bicarbonates.

The plain of the Willamette Valley is underlain at various depths by bedrock that was laid down in the ocean and still contains much saline water. The continued compaction of these sedimentary rocks forces out small quantities of the depositional water, which seeps out in "soda springs" around the bedrock edges of the valleys. In places the compaction also causes the saline water to enter other formations. This intruded water of inferior quality has been found in the lava rocks by deep wells in Portland along the foot of the West Portland ridge, in the basalt in the central parts of the Tualatin Valley, and at Gladstone. Saline ground water is commonly found in marine deposits by deep wells around the margins of the Willamette Valley.

ROGUE RIVER

The Rogue River is not the largest of Oregon rivers, nor is it the smallest, but it is perhaps the most widely known. From the time of the arrival of the early pioneers, the river and its tributaries have had a profound effect on the lives of the people who live in its basin.

The river rises (see fig. 14) on the slopes of Mount Mazama, the volcanic mountain that contains Crater Lake, and flows westward 210 miles to the Pacific Ocean at Gold Beach. The drainage basin covers 5,080 square miles, nearly all of which lies in southwestern Oregon. The basin may be divided into three parts, widely different in climate, soil, runoff, and works of man.

Figure 14.—Rogue and Umpqua River basins and the southern coastal river basins of Oregon.

The upper section, from the headwaters to the vicinity of Trail, is mountainous and heavily timbered; it has an average annual precipitation of 40 to 70 inches. The pumice soils and lava formations of the higher mountains are very permeable, and much of the precipitation and snowmelt sinks into the ground, to reappear in large, clear springs of very uniform flow. As a result, many of the upper tributaries have a summer flow of 1 to 3 cfs per square mile of drainage area. The clarity of the water, the uniformity of flow (see fig. 15), the steepness of river gradient, and the comparative scarcity of population in the area make these streams ideally suited for electric power and recreation—uses that frequently appear to conflict. Modern powerplants near Prospect now produce power from the falling waters of Middle Fork, Red Blanket Creek, and the main river.

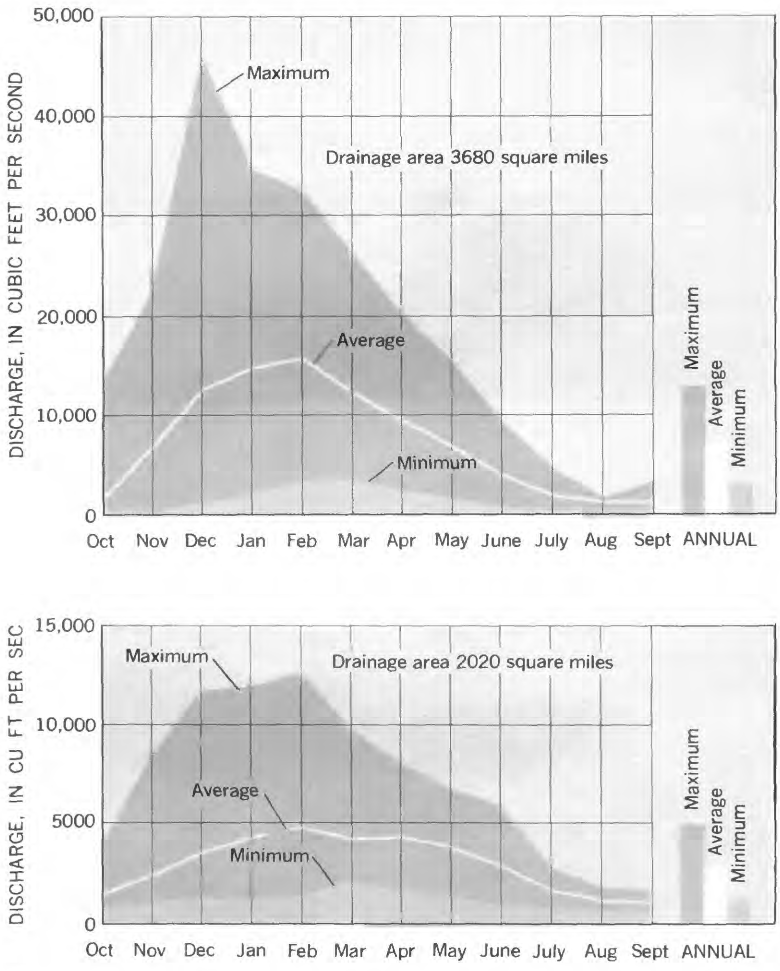


Figure 15.—Maximum, minimum, and average monthly and annual discharge of Umpqua River near Elkton (above), and Rogue River at Raygold near Central Point (below). These two basins have very similar climate, geology, and runoff patterns.

The middle section of the river basin has a semiarid climate from near Trail to the vicinity of Merlin and including the Illinois River basin above Selma. There are large and populous areas of rich irrigated land, notably near Medford and Grants Pass. The soils and underlying rocks are relatively impermeable, hence runoff is rapid and the streams rising here are not as clear as those of the upper basin. The summer flow of streams rising in this area generally ranges from 0.1 to 0.3 cfs per square mile of drainage area. On many streams the entire summer flow is diverted for irrigation. Additional consumption will require (a) diversion from the main stem of the Rogue River, (b) use of reservoirs to store winter flow, or (c) use of some return flows. Ground-water sources are generally lacking. The alluvial gravels underlying Agate Desert north of Medford and the Illinois Valley south of Cave Junction contain small or moderate quantities of ground water.

The chemical quality of the Rogue River has been measured in this section by the analysis of daily samples collected at Grants Pass from 1953 to 1958. The dissolved-solids content has averaged 77 ppm, and the hardness 35 ppm. This water is of excellent quality.

The ground water in and below the alluvial gravel is of variable quality. That underlying Agate Desert, for instance, contains considerable calcium and (or) sodium bicarbonate; its dissolved solids range from less than 300 to more than 1,000 ppm. The ground water containing the higher concentrations comes from the sedimentary bedrock below the alluvial deposits. The ground water of the Illinois River valley is largely of a magnesium-bicarbonate type, and is much more dilute; most sampled sources in the valley contain less than 150 ppm dissolved solids.

In Bear Creek valley, saline ground water is commonly found in the marine bedrock. In places this water contains enough excess fluoride and boron that its use for mixing orchard sprays has caused damage to trees. The mineral springs locally called "Lithia Springs" lie along a fault zone cutting the Umpqua formation east of Ashland. Now the spring water is pumped from deep wells, and carbon dioxide gas is separated, compressed, and sold as "dry ice."

The third or downstream section of the basin lies below Merlin and in the Illinois River basin below Selma. Here the topography is extremely rugged; the rivers flow in deep canyons as they wind through the Coast Range. Most of the area is timbered. Precipitation is generally heavy, especially on the west slopes of the higher mountains. Shallow soils, impermeable bedrock formations, and steep topography all contribute to rapid runoff during and after periods of rain. Most of this area lies within national or State forests and

FIGURE 16.—Hydraulic mining for gold in the Rogue River basin near Waldo. The jets of water scour gold-bearing gravel off the bedrock surface and wash it to the hydraulic lift from which it is piped to the trommel screens and concentrating process. This historic type of mining in places introduced unnatural debris loads into streams. It is now required that the waste be retained on the property. Photograph by Oregon Department of Geology and Mineral Industries.

is very sparsely populated. A few logging roads enter the area, but access to some sections still is dependent upon widely separated trails. Streamflow drops to low rates in dry periods. However, little is known as to total water yield of this part of the Rogue River basin, partly because of poor accessibility. Some very small tracts of land are irrigated and a little gold mining is carried on (see fig. 16), but on the whole the streams are little used except for recreation. The wildness of the region, its forests and mountains, and its abundance of fish and game have a strong appeal for campers and for owners of the summer homesites along this section of the Rogue River.

Sport fishing for trout and salmon constitutes not only a source of recreation for fishermen but an income for suppliers of their needs. State laws prohibit the building of high dams that would interfere with fish passage within the middle and downstream sections of the main river, a fact which must be considered in any plans for use of these waters.

UMPQUA RIVER

The Umpqua River is formed by the junction of its north and south forks, 6 miles northwest of Roseburg. The river drains 4,700 square miles, nearly all in Douglas County and about 80 percent forested. The river usually has a summer flow in excess of 1,000 cfs and is navigable from Scottsburg to its mouth.

The North Umpqua drains 1,350 square miles and supplies about 90 percent of the low-water flow at the confluence; the South Umpqua drains 1,800 square miles and supplies only 10 percent of the low flow. The reasons for the contrast in flow lies in the geologic character of the two headwater areas: The North Umpqua reaches into the ground-water storage area of the permeable volcanic rocks, the South Umpqua does not. Both basins are mountainous and densely forested and both receive moderately heavy precipitation, from 30 to 75 inches. However, a large part of the North Umpqua basin has soil and geologic formations that readily absorb and store water and release it gradually through large clear, steady-flowing springs, but in the South

Umpqua basin such formations are scarce, and runoff follows quickly after rain. Some of the water in the South Umpqua is diverted for irrigation in summer.

The wide contrast in the flow of the streams may be seen by comparing Clearwater River, a spring-fed tributary of North Umpqua, with Lookingglass Creek in the South Umpqua basin. (See fig. 17.) Clearwater River at its

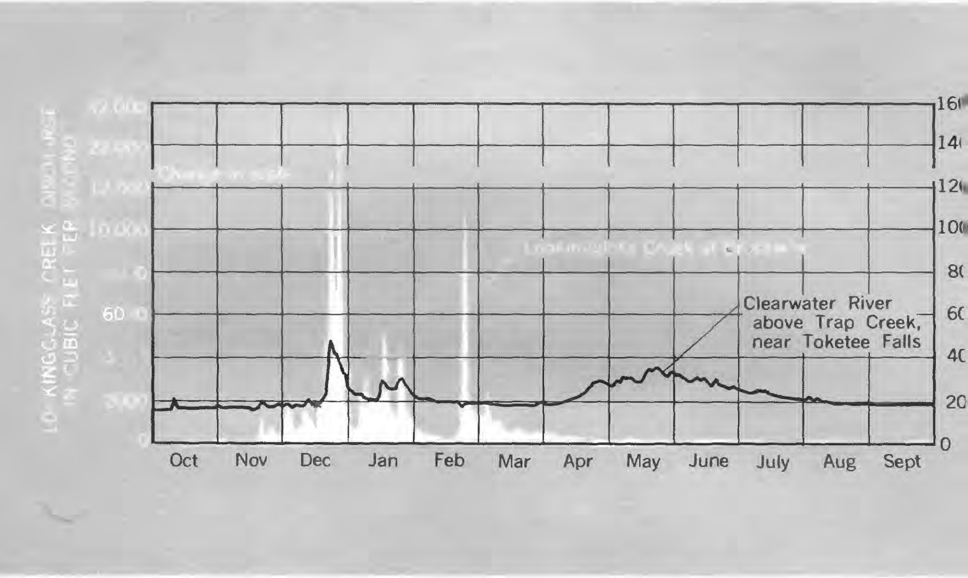


FIGURE 17.—Daily discharge, in cubic feet per second, of two streams in the Umpqua River basin, widely differing in areal geology. Lookingglass basin (drainage area 158 sq mi) has impervious soils and rock formations; the stream floods in winter and its very small summer flow is all diverted for irrigation. Clearwater River basin (drainage area 41.6 sq mi) has porous soils and rock formations and a large volume of ground-water storage; the stream has a steady flow at all seasons and no diversions for irrigation.

mouth drains 76.6 square miles; the low-water flow is about 3 cfs for each square mile of drainage area and the greatest known flood is only six times as great. Lookingglass Creek drains 158 square miles; it is dry in summer, but had floodflow in December 1955 at the rate of 222 cfs per square mile of drainage area. The difference in streamflow is due almost entirely to differences in soil and rocks of the two basins.

Not all the tributaries in the North Umpqua basin have a flow as uniform as that of the Clearwater River. Steamboat Creek, Rock Creek, and Little River all have high floodflows and relatively low summer flows, and Sutherlin Creek has no flow at times. Control or use of these streams may require storage reservoirs.

The principal tributaries below the confluence of the North Umpqua and the South Umpqua are Calapooya Creek, Elk Creek, Mill Creek, and Smith River. These streams all have high floodflows and low but continuous summer flows.

The water of the Umpqua River and most of its tributaries is soft and contains small amounts of minerals. The large springs issuing from the volcanic deposits in the North Umpqua basin provides much water of excellent quality. However, a large part of the area is underlain by impermeable marine formations containing small amounts of saline water, as in the Willamette basin. Deep wells in many parts of the Umpqua valley penetrate this salty water.

SMALLER COASTAL STREAMS

The west slope of the Coast Range is the most uniformly humid zone in Oregon. From the sea to the 3,000-foot crest of the range the annual precipitation varies considerably, but everywhere it is in the range of wet to very wet. The narrow canyons and sharp ridges are covered with a dense growth of forest and undergrowth, the timber being in all stages of growth, maturity, and removal. Narrow terraces of fertile land along the larger streams have been cleared for farming, and level plains beside the tidal reaches of the rivers provide year-round green pastures for a substantial dairy industry.

The soil and underlying rocks have a rather small capacity for storing water, and snow does not generally remain long in this area; hence the low-water flow is relatively small in the coastal rivers. On most of the coastal streams, from Chetco River on the south to Nehalem River on the north, the summer flow ranges from 0.1 to 0.5 cfs per square mile

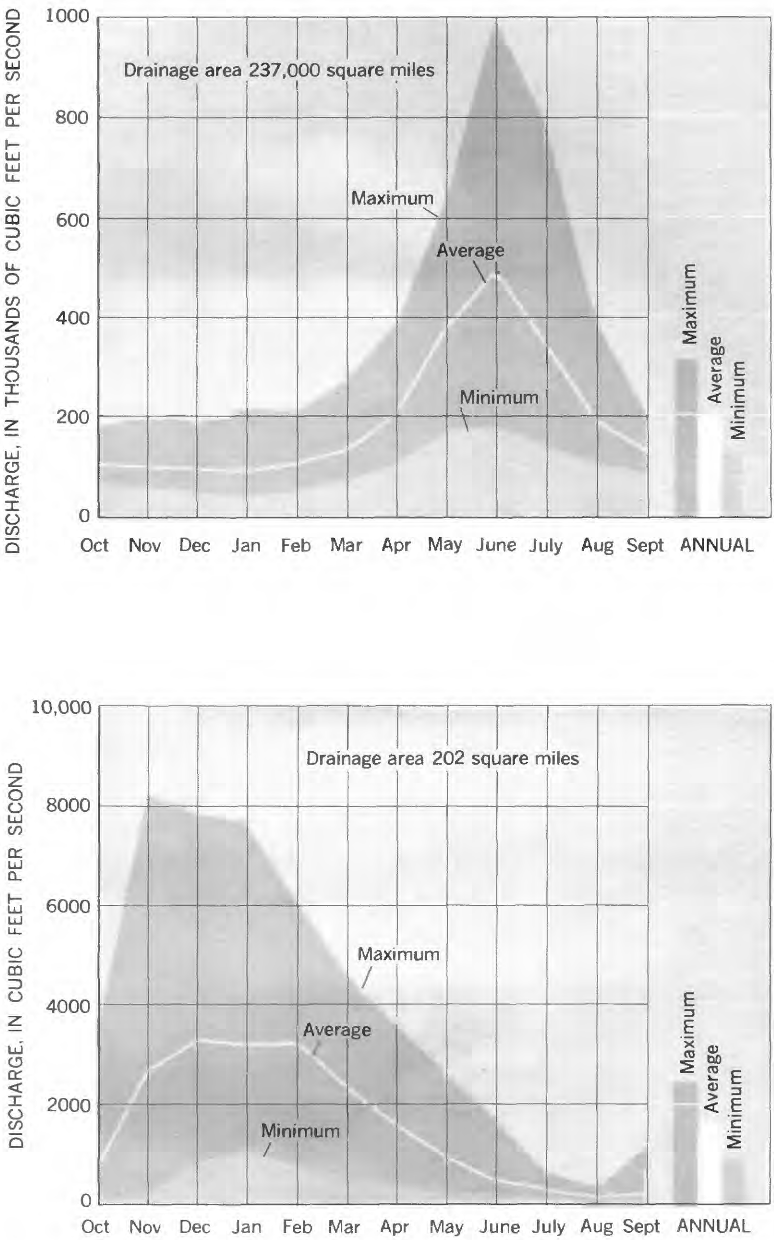


FIGURE 18.—Maximum, minimum, and average monthly and annual discharge of Columbia River near The Dalles (above) and Siletz River at Siletz (below). The Columbia River has a low flow from October to March, and a much higher flow from April to September. The Siletz River and all other streams rising in the Coast Range have high flows in the fall and winter months and lower flows in spring and summer.

of drainage area. The flow declines steadily during periods of no rainfall, which in some years may last 60 days or more.

Because of the uneven distribution of rainfall, irrigation is profitably practiced on farmland and dairy pasture, even where the average annual rainfall ranges from 80 to 100 inches. Some streams are not always able to supply water to meet the current and potential peak irrigation demands, even in an area that has a copious overall supply.

From November to March the runoff is heavy, and floodflows in excess of 200 cfs per square mile of drainage area have been recorded.

Development of the short coastal streams for generation of electric power has not appeared to be profitable because their flow is small in summer. However, because the coastal streams have their greatest flow in the period November to March each year, just at the time when the natural flow of Columbia River is normally low (see fig. 18), the use of these rivers will become more feasible after the powersites on the Columbia River are developed. Electric power produced by these small streams would in effect be equivalent to power that otherwise would be expensively produced by fuel or by stored water.

A growing recreational use of all these small rivers, based largely on fishing for trout and salmon, requires that conservation and improvement of the fishery resource be included in plans for water use in these basins.

Between the headlands at the western edge of the narrow coastal plain, the prevailing westerly winds have thrown up several chains of large sand dunes. Some of the dunes have dammed stream channels and thus created small fresh-water lakes. (See fig. 19). Little is known of the lakes' water-yielding capacity. Some are used extensively for public recreation and for propagation of fish and waterfowl, some are used for municipal water supply, others for floating logs. The sand dunes soak up large amounts of rainfall, and the dune areas, therefore, are a possible source of conveniently located water.

The water in the coastal streams is generally very soft and low in dissolved minerals. The ground water of the coastal sand deposits is soft and contains only 20 to 80 ppm of dissolved solids. Sodium chloride, or common salt, makes up a large part of these solids. Presumably it is derived from the rainfall along the coast, where sea water may at times be lifted from wind-whipped wave tops and mixed in the rainfall near the coast.

FIGURE 19.—View north along the coast in a logged-over area just north of the Nestucca River. Cape Lookout in the left background. The small streams are impounded by sand from the beach. Photograph by U.S. Forest Service.

CRATER LAKE AND KLAMATH RIVER BASIN

Crater Lake, commonly and justly rated as one of the natural wonders of the world, lies astride the summit of the Cascade Range in the caldera of Mount Mazama, an extinct volcano. (See frontispiece.) Beyond question, the lake is the best known of its type in the United States, if not in the world. Its dramatic geologic history, its scenic beauty and picturesque surroundings, the mystery of its great depth (1,932 ft), and the brilliance of its blue water serve to cast a spell over its annual multitude of visitors.

The water is very clear. It contains only 80 ppm dissolved solids (which is about the same as the streams of that area), and it differs from the other surface waters only in that it has slightly higher chloride, sulfate, and sodium contents. The water is mostly snowmelt and rainwater; a slight addition of minerals has been dissolved from the lake walls and possibly from the residual gases or fumes of volcanic origin.

The lake has no surface outlet, and there is no progressive increase in the altitude of the lake surface, although the annual evaporation is only about one-third the 69-inch precipitation. The excess water from its 26.2-square-mile drainage area must seep through the walls of the caldera and become spring flow. Over a period of years, this excess flow would average about 90 cfs. Where the flow reappears is not known: It may be in the basin of the Rogue, the Umpqua, or the Klamath River, or perhaps in all three. (See fig. 20.) In these three basins, and within a radius of 25 miles of Crater Lake, there are cold clear springs having an aggregate steady flow of about 1,200 cfs. Nearly all of this spring flow must be derived from ground water in the extensive pumice and lava that surrounds Mount Mazama, and not from Crater Lake itself. Most maps arbitrarily place Crater Lake in the drainage basin of the Klamath River, but the actual direction of its leakage is unknown; the lake could be considered as contributing to the Rogue River or to the Umpqua River.

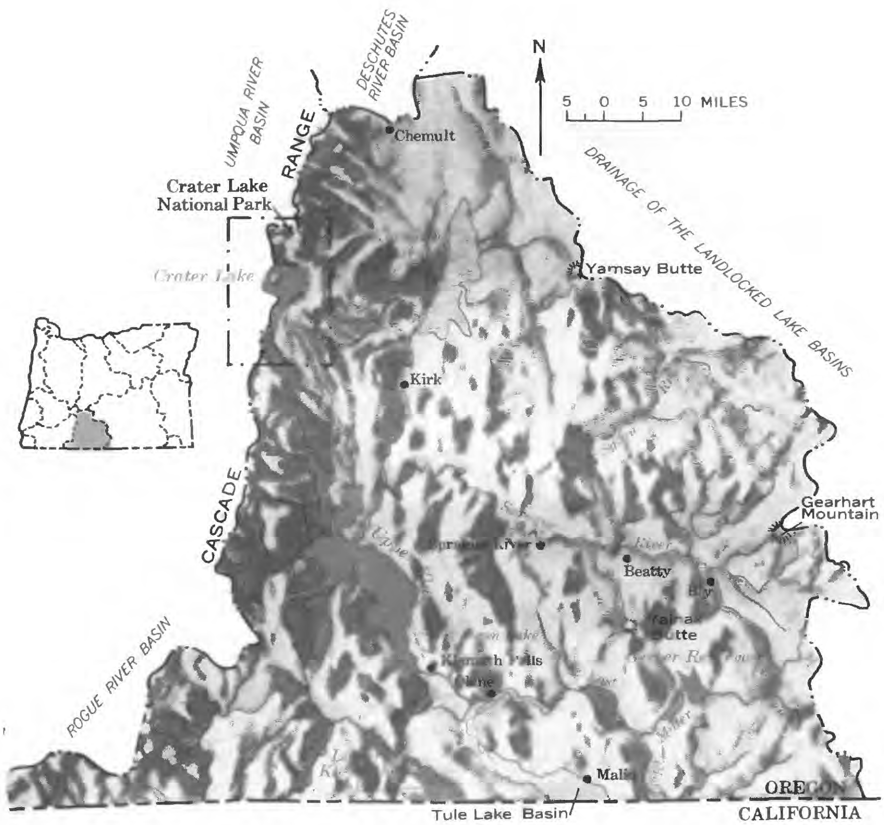


FIGURE 20.—Klamath River basin in Oregon.

Because Crater Lake has no outlet, any excess water that it receives in a wet season causes the lake level to rise slowly until the excess inflow is balanced by more seepage; in dry seasons the water level falls slowly. The lake level thus acts as an indicator of climatic trends. The highest level ever observed, 6,179.06 feet (from watermark) in 1958, was the result of a succession of wet years. Somewhat uncertain high-water marks suggest that the lake may have been as high as 6,180.5 feet at some time in recent centuries. After a rise about 1904, there was an almost continuous decline to the low level of 6,163.2 feet in 1942. By July 13, 1956, the lake had risen to a level of 6,177.2 feet.

The Klamath River drains the southern part of the east slope of the Cascade Range and plateau and the valley land east of that range. Most of the land lies between 4,000 and 5,000 feet in altitude. The basin in Oregon is mostly forested, but there are large areas of farmland, open grazing land, marsh, and lake. The water is soft and is low in dissolved solids. The drainage area of the basin to the Oregon-California State line and including the basin of Crater Lake is about 4,100 square miles. Not included in that figure is the basin of Lost River which is commonly treated as a part of the Klamath River basin.

The Lost River has its headwaters in the plateau lands of northeastern California; it flows into Clear Lake, where much of the flow is dissipated by evaporation, and from there north across the State line into Oregon where many diversions take most of its water. The Lost River receives additions from its East Fork, from Miller Creek, from return flow from irrigation water, and from strong spring inflows near Bonanza. From Bonanza the river loops west and south through the Poe and Klamath River valleys and back into California. The residual flow is dissipated as evaporation in Tule Lake or is pumped through a tunnel into Lower Klamath Lake basin, from which it flows into Klamath River near Keno. Just south of Klamath Falls the divide between the Klamath and Lost Rivers is so low that excess water in either basin may be diverted into the other by means of the Lost River diversion canal, which was built by the U.S. Bureau of Reclamation about 1911.

Before the completion of the large land-reclamation projects in Langell Valley and Tule Lake valley, the flow was naturally dissipated by evaporation and seepage from Tule Lake in California which was then a large shallow lake. Most of the Lost River being now diverted, little water reaches Tule Lake, and much of the former lakebed is farmed intensively.

The topographic basin of Lost River includes 1,070 square miles in Oregon and 1,370 square miles in California. Except in wet years, almost all the water of the Lost River basin is used for irrigation and wildlife refuges.

The principal headwater stream in the Klamath River basin is Williamson River. It is joined by the Sprague River a few miles above its mouth in Upper Klamath Lake.

FIGURE 21.—Oblique aerial view northward up the 2-mile-long Link River; part of Upper Klamath Lake in background and Lake Ewauna in foreground. Fields at edges of the upper lake are protected by dikes and pumps; "A" Canal (not visible) diverts water eastward from Link River above the control dam near the head of the river. Canal to powerhouse is visible along the west bank, as is the penstock and surge tank on the east side. The well field that provides Klamath Falls' public supply is on the east side of the river upstream from the bridge. Photograph by Oregon Klamath River Commission.

That lake, covering about 84,000 acres, is the largest lake wholly in Oregon. Some of the lakebed has been reclaimed by diking. The lake serves as a reservoir for irrigation and for power; the altitude of the lake surface is controlled between 4,136 and 4,143 feet. The controlled outflow passes steeply down the Link River, less than 2 miles in length, into Lake Ewauna, at Klamath Falls. (See fig. 21.) The Klamath River proper begins at the outlet of Lake Ewauna, and 34 miles downstream it crosses into California. Below Keno the river flows in a steep rocky canyon where the 1,300-foot fall to the State boundary is being developed for hydroelectric energy.

The ground-water body beneath the Klamath River basin is nourished by infiltration through the pumice mantle, a large part of which was scattered over the northern part of the basin by explosive outbursts from ancestral Mount Mazama. It percolates through extensive lava rocks that afford large yields of water to wells. Land in several of the valleys is irrigated by water from wells.

At least half of the discharge of Klamath River comes from springs, some of which are large and have a steady flow. Probably many seeps and some large springs enter the channel unnoticed. Some of the larger spring-fed creeks and springs, and their approximate flow, are listed below:

	Cubic feet per second
Spring Creek near Chiloquin	250 to 340
Wood River springs near Fort Klamath	200 to 300
Fort Creek near Fort Klamath	70 to 90
Crooked Creek at Klamath Agency	80 to 100
Sevenmile Creek near Fort Klamath	40 to 100
Lenz Spring (Big Spring Creek)	0 to 90
Kamkaun Spring (Sprague River)	36 to 74
Source Spring (origin of Williamson River)	10

The variation of flow shown by the occasional gagings of Lenz Spring tells a story of fluctuation in the water level of the aquifer from which the spring derives its flow. The first four gagings, made in 1913 and 1914, show a steady flow ranging from 62 to 71 cfs. There was a marked decrease in the next few years. From 1920 to 1923, the flow ranged from 31 to 21 cfs, as shown by eight gagings. By 1927, the flow had decreased to about 6.5 cfs. From 1930 to 1950 the spring did not flow, and pipe wells were driven in the dry spring channel for windmills to pump water for livestock. The wet years of the 1940's served to recharge the ground water, and in 1951 the spring began to flow again. By September 1952 the flow was 58 cfs, and by September 1954 it had reached 89 cfs, the greatest flow so far observed. No other spring in Oregon is known to have had such a wide range in flow; in fact, most springs in Oregon are remarkably steady. The outlet of this spring may be near the top of the ground-water body and may act as a spillway rather than as an orifice under pressure.

By contrast, the flow of Spring Creek at Collier State Park, near Chiloquin, just a few miles away from Lenz Spring but several hundred feet lower, ranged in the same period from 267 to 342 cfs. Only rarely was the flow less than 280 or more than 320 cfs. The two springs have the same variations in climate, and similar soil and geology, but Spring Creek near Chiloquin has a much larger underground reservoir above its spring openings.

The chemical quality of the ground water in the Klamath basin differs from place to place. In most places the water is of good quality, having a moderate to low hardness and dissolved-solids content ranging from less than 100 to several hundred parts per million. The ground water is poor along the linear belts of hot rocks which characterize some geologic faults in the Klamath basin. This hot ground water contains principally sodium sulfate. The content of dissolved materials is more or less proportional to the heat present. The warm water, of less than 100°F temperature, has only moderate concentrations of minerals and is suitable for some industrial and irrigation use; but the hot water of 150° to 226°F contains too much sodium for most uses other than heat extraction.

In some respects the water resources of the basin are not so great as foreseeable demands for water. Above the city of Klamath Falls, much water is diverted for irrigation, and increased use is expected.

A large amount of water is lost by evaporation and plant transpiration in the marshes, lakes, and reservoirs of the Klamath River basin. The outflow from Upper Klamath Lake in midsummer may be visualized as three large streams: (a) "A" Canal of the Klamath reclamation project, about 1,000 cfs, (b) Link River, whose flow varies from 500 cfs in dry years to 1,800 cfs in years of more plentiful runoff, and (c) an upward "river" of evaporation, 700 to 1,000 cfs in July and August. Reduction of the evaporation loss, which might be done by confining swamps and shallow lakes to smaller areas with dikes or by suppression of evaporation by chemical treatment, would increase the total usable water resources of the area.

In recognition of the vital part that the water of this basin plays in the welfare of Oregon and California, those States in 1957 ratified the Klamath River Basin Compact. The purposes of the compact are in part: "To facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control" of the water resources, and to provide for "equitable distribution and use of water among the two States and the Federal Government." The compact has been ratified by the U.S. Congress and was placed in operation August 30, 1957.

LANDLOCKED LAKE BASINS

A large part of south-central Oregon adjacent to California and Nevada lacks drainage to the sea. (See fig. 22.) The thick lava flows that form the crust of the earth in this semiarid region have been sheared and tilted up or down, and there are many plateaus and basins where the runoff is dissipated by evaporation from shallow lakes. Each basin and lake has a character of its own that results from local variations in climate, topography, geology, and works of man. The climate determines the total water supply, the topography and geology affect its geographic and seasonal distribution, and man determines its use and to some extent the amount and quality of the water at downstream points.

The lakes in these landlocked basins generally contain saline water of variable mineral content. The minerals have accumulated during a long period of concentration through evaporation, alleviated for some lakes by occasional overflow and by deposition and burial of salts during periods when the lakes were dry.

Many of these lakes have filled within historic time and spilled over into creeks or other lake basins. Such lakes include Goose Lake in Pit River basin, Lower Klamath Lake in the Klamath River basin, Malheur Lake, and the upper 10 of a series of 11 lakes in Warner Valley (named, successively northward, Pelican, Crump, Hart, Anderson, Jones, Mugwump, Flagstaff, Upper Campbell, Lower Campbell, Stone Corral, and Bluejoint Lakes). These lakes are not as salty as Summer, Abert, Alkali, Christmas, and Harney Lakes, none of which overflow.

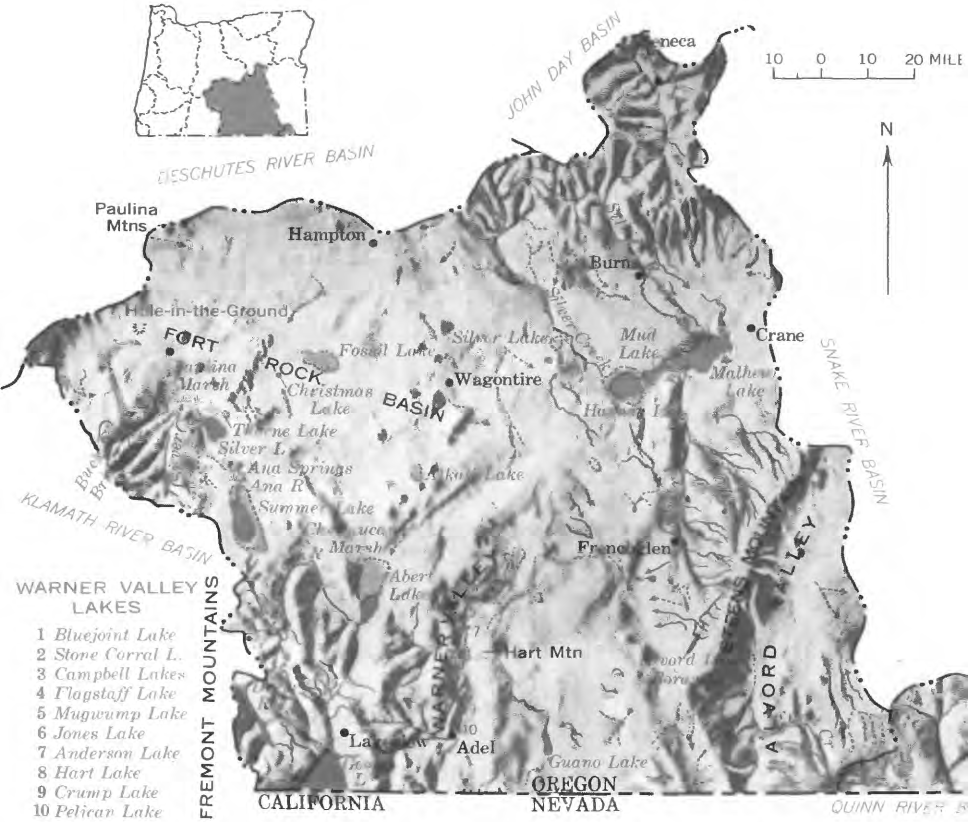


FIGURE 22.—Landlocked lake basins.

The variations in level of all the lakes of the closed basins are due chiefly to variations in rainfall and runoff. Irrigation of lands around the lakes has some effect on the lake levels, but a succession of wet years may still result in lake levels almost as high as any in historic times.

The lakes that overflow contained a dissolved-solids content in 1912 of 135 ppm for Crump, 267 for Hart, 300 to 400 for Lower Klamath, 423 for Flagstaff, 484 for Malheur, 1,010 for Goose, and 2,830 for Silver Lake in Harney Basin. Recent data (1963) for most of these lakes indicate concentrations about 50 ppm greater than those observed in 1912, except Malheur Lake, which has a lower dissolved-solids content than in 1912—258 ppm on November 29, 1961. In comparison, the nonoverflowing lakes range from 10,000 to 23,000 for Harney, 5,000 to 36,000 for Summer, and 30,000 to 80,000 for Abert Lake. The water of the undrained lakes is too saline for most uses.

The lakes provide valuable resting places for migratory waterfowl. (See fig. 23.) In the less saline lakes and in the even less saline inflow areas of the nonoverflowing lakes, the water is sufficiently dilute that pondweed, tules, and other plants grow profusely and provide good feeding and nesting areas for wildfowl.

All the basins are similar in altitude, their floors lying within a few hundred feet of the 4,200-foot mark. Let us look at some of these landlocked lake basins.

FIGURE 23.—Trumpeter swans on open water at the south side of Malheur Lake. The Malheur Migratory Waterfowl Refuge is one of the principal breeding and resting areas for thousands of birds. A determined attempt is being made to save the swans from extinction. Photograph by U.S. Bureau of Sport Fisheries and Wildlife.

Malheur and Harney Lakes

The largest closed basin in Oregon, some 5,300 square miles in extent, drains into Malheur and Harney Lakes. The Silvies River, the largest stream entering the basin, rises in the mountains of central Oregon and enters Malheur Lake from the north. Its summer flow is mostly used for irrigation near the lumbering and cattle-raising centers of Seneca and Burns. The Silvies basin is almost completely forested, but the average yearly flow at the gaging station (drainage area 934 sq mi) is extremely variable, ranging from 415 cfs in 1903–4 to 15.0 cfs in 1933–34. (See fig. 24.)

The second largest stream, the Donner und Blitzen (Thunder and Lightning) River, drains the unforested west slope of Steens Mountain and enters Malheur Lake from the south. Its abundant summer flow is derived from large springs in the permeable basalt into which the river canyons have been carved. Much of the flow of the Donner und Blitzen from Frenchglen northward 40 miles to Malheur Lake is used for irrigation and for operation of a large migratory waterfowl refuge. As a result, little water reaches Malheur Lake in a dry year, and in many years the surface of the lake is continuously below its natural outlet.

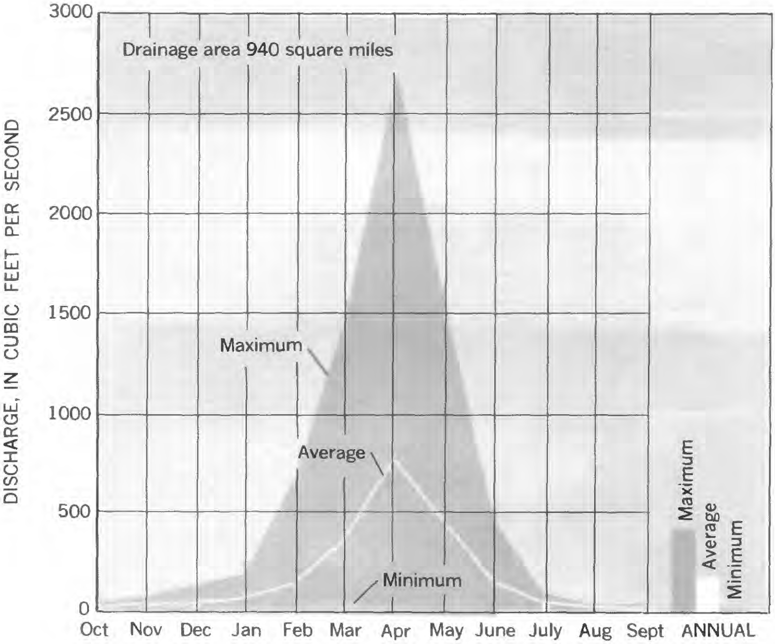
Malheur Lake has ranged from complete dryness (1934) to an area of about 100 square miles. When the lake level is above altitude 4,091.5 feet, the lake overflows westward into Mud Lake at "The Narrows," and when it is above 4,093.5 feet, there is overflow from Mud Lake westward through the "Sand Gap" into Harney Lake. Because of this occasional overflow, the water of Malheur Lake is comparatively fresh.

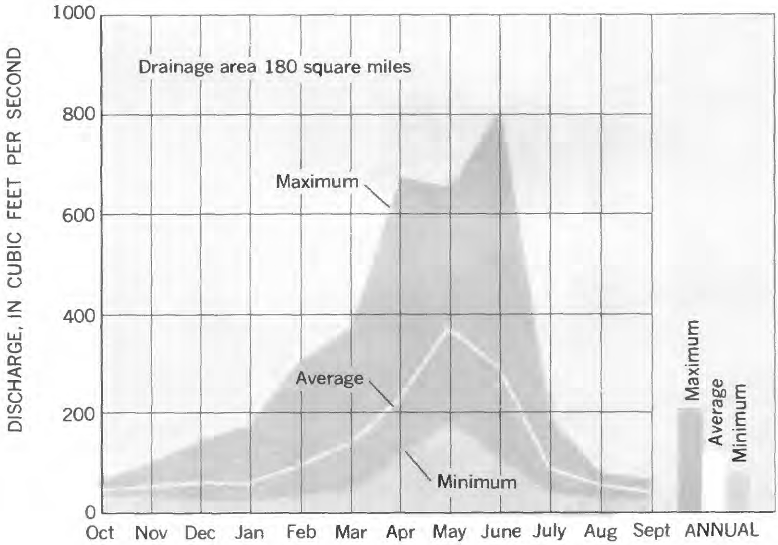
Harney Lake has no outflow streams. Its inflow originates as spill from Malheur and Mud Lakes, from the runoff of Silver Creek (very slight in dry seasons), and from springs around the lake. In dry years, the water surface in Harney Lake may be as much as 10 feet lower than Malheur Lake. Because evaporation serves to concentrate the salts naturally dissolved in the inflow streams, the waters of Harney Lake are not usable for stock watering, for game fish, or

FIGURE 24.—Opposite page. Maximum, minimum, and average monthly and annual discharge of Silvies River near Burns (above) and Donner und Blitzen River near Frenchglen (below). These nearby streams have similar climate but widely different geology and forest cover. The Silvies River basin has a pine-forest cover, but the underlying rocks do not readily store and transmit water; the summer flow is very small. From a much smaller drainage area covered only with desert vegetation, the spring-fed Donner und Blitzen derives a steadier flow because of the presence of thick layers of jointed volcanic rocks.

for irrigation. At times (1930–34, 1962), Harney Lake has been dry except for a few pools around springs, but in wet seasons it covers about 50 square miles.

The Silvies and Donner und Blitzen Rivers and Silver Creek are perennial streams that provide excellent habitat





for game fish and for waterfowl. The lumbering industry makes use of some water in the Silvies River basin, but most such water is returned to the streams. Irrigation of hay and pasture fields uses practically all streamflow in dry seasons. A dependable surface-water supply for additional land can be obtained only by storing the excess runoff in wet seasons or by pumping from wells in the young lava rocks south of the lakes.

Some of the smaller streams in the basin have no flow except during periods of precipitation or snowmelt. Despite the aridity of the region, the Malheur Lake basin and much of the rest of those areas of the landlocked lake basins are fairly well watered for grazing purposes. The many lava caps beneath the plateau lands afford seepage springs at their margins, and in most of the lower areas the water table can be reached by wells 200 to 400 feet deep.

Alvord Lake

Alvord Valley is a long north-south fault trough east of Steens Mountain in one of the driest parts of Oregon. Alvord Lake itself is a playa, or intermittent lake, usually dry every summer except for a small pool known as Borax Lake, which is kept filled by a warm spring. Each year a very shallow pool or lake is created by rain and snowmelt, chiefly runoff from Trout Creek, a spring-fed stream flowing out of the mountainous area to the southeast. The alkaline waters of the lake are not usable for irrigation, and the wide flats that are periodically flooded are barren and do not support even the alkali-resistant plants.

Warner Valley

Warner Valley is a long narrow, nearly level depression lying between fault-block ridges in eastern Lake County and extending about 40 miles northward from the California line. The drainage basin, of about 1,250 square miles, is arid or semiarid, and some parts produce little or no runoff. The two largest streams, Twentymile Creek and Deep Creek, enter the marshes at the south end of the valley and join near Adel. From that point northward there is a succession of irrigated valley land, marshes, and shallow lakes, the area of the water bodies varying greatly from one year to another. At Plush, Honey Creek enters the valley from the plateau to the west and flows into Hart Lake. Some of the marshes and lakes are diked, and the water levels are controlled. Below Hart Lake the water is increasingly alkaline. In dry years, the entire runoff is used for irrigation of hay and grain crops or stored in some of the upper lakes, and the beds of some of the lower lakes are farmed or used to pasture cattle. The creeks, lakes, marshes, and fields provide excellent habitat for waterfowl.

Large yields of water are obtained from a few wells which tap aquifers in the lava bedrock, but little of the available ground water is used. Wells near the west escarpment at Crump Lake yield hot water, and some have had either continuous or intermittent geyser discharges.

Warner Valley was first described in December 1843, when a party of United States topographical engineers under Capt. John C. Fremont visited the region. Although this visit was during the early part of a dry period, there seems to have been some water in all the lakes. In 1868 the lakes were very high, and several may even have been united into one long, narrow lake. The middle 1880's were dry; by 1889 teams were being driven across the shallow parts of Hart Lake, and the lower lakes presumably were dry. Later, wet and dry periods alternated, and the lake levels responded to changes in water supply. Bluejoint Lake was dry in 1913, again in 1914, and in many later years, owing in part to storage of water in Hart Lake since 1914 and to a gradual increase in diking and in upstream diversions. Now water is in Bluejoint Lake only in wet years.

Goose Lake

In a sense, the Goose Lake basin is not closed; on at least two occasions, prior to the diversion of Drew and Cottonwood Creeks, the lake overflowed southward into the North Fork Pit River. It is reported that for a short period in 1868 the lake was full and overflowed the southern rim; in 1881, a severe windstorm from the north caused the lake to overflow again. These and prehistoric overflows have served to prevent the water from becoming as strongly alkaline as it would otherwise be. The lake when full covers about 194 square miles, being 28 miles long in a north-south direction and 4 to 10 miles wide. More than half of the area of the lake is in California. The valley-floor area, from 4,700 to 5,000 feet altitude, receives about 14 to 16 inches of precipitation annually; the forested slopes and mountain areas of the basin receive somewhat more.

In 1912, when the lake level was high, about 3 feet below the outlet, an analyzed sample of water contained 1,010 ppm of dissolved mineral matter.

In 1926 the lake dried completely and exposed old wagon-road ruts in the lakebed some 10 miles south of the State line. These tracks were believed to represent the route of pioneers who also found the lakebed dry at that point in the 1840's. The outlet is at 4,716 feet altitude and the lowest part of the lakebed is about 4,692 feet. In recent years the lake level at New Pine Creek has been observed to range from below 4,697 feet on November 13, 1950, to 4,707.8 feet in 1958 (from watermark); the water contained 1,340 ppm dissolved solids in September 1953 and 1,270 ppm in April 1962.

The largest streams tributary to Goose Lake are Drew Creek, Cottonwood Creek, and Thomas Creek, all in Oregon. Water is stored in reservoirs on Drew and Cottonwood Creeks, and about 32,000 acres of land is irrigated in the basin in Oregon. This use of water reduces the inflow to the lake and it seems unlikely that the lake will again overflow.

Some springs flowing warm or hot water occur along the faultlines at the east edge of Goose Lake Valley, but their total contribution is small compared to that received by stream runoff and precipitation directly on the lake surface. The valley alluvium contains large amounts of ground water, the water table being near the level of Goose Lake. Wells constructed to extract water from sand or fine gravel obtain large water yields. The ground water is little used except by the city of Lakeview and by a few farmers.

Abert Lake

Abert Lake is a shallow evaporating sump for Chewaucan River, lying in a fault-block valley bounded by prominent scarps. At its greatest extent, the lake covers 68 square miles, being about 14 miles long and 7 miles wide near the north end. The water contains a high concentration of dissolved salts and is unfit for irrigation. The lake was reported to be entirely dry in 1924 and in some later years. In more recent years the water surface has varied in altitude from 4,246.60 feet on November 11, 1950, to 4,260.5 feet on June 22, 1958. At the 4,269.7-foot level there is a well-defined beach line that marks what is probably the highest stand of the lake for several centuries.

The Chewaucan River drains 490 square miles and flows into Abert Lake. About 40 percent of the basin is rather barren and arid, having about 10 inches of precipitation annually; the forested upland on the other 60 percent is somewhat better watered. Practically all the runoff comes from the mountain areas. About 41,000 acres of wild-grass meadow and pasture is irrigated, chiefly in Chewaucan Marsh and along Crooked Creek. At the gaging station on Chewaucan River 2 miles southwest of Paisley, the natural water yield over the periods 1912–21 and 1924–63 has been 136 cfs from a drainage area of 275 square miles. Few if any streams in the basin have a higher unit runoff.

The town of Paisley is built on the alluvial fan where Chewaucan River emerges from its mountain canyon. Occasional flooding there is aggravated by ice jams.

Summer Lake

Summer Lake occupies the center of the floor of a basin bounded on the west by the bold scarp of forested Winter Ridge and on the east by gentler slopes covered only with desert vegetation. The lake water is shallow and saline. White crusts of crystalline minerals coat the dry part of the lakebed. In May and June 1941, the water surface was at 4,147.2 feet altitude and the greatest depth was found to

FIGURE 25.—Measuring artesian flow in Summer Lake valley (view northeastward).

be "less than 2.5 feet" by a survey party of the U.S. Bureau of Land Management. The lake is practically dry at times. The lowest recorded water level was measured by leveling as 4,144.86 feet on September 30, 1961. The highest recorded lake level occurred from February to April 1905 at 4,151.4 feet.

Most of the inflow comes from spring-fed Ana River. The springs appear at the head of Ana River about 4 miles north of the lake, beneath the water surface of a reservoir behind a diversion dam completed in 1923. The total flow of the springs has decreased from about 140 cfs, 1905–14, to about 90 cfs, 1951–63. The decrease is due in part to back pressure caused by submerging the springs and to diversions by wells from the same underground source of water.

The water of Ana River is used to irrigate meadowlands and to maintain a large refuge for migratory waterfowl. The decrease in spring flow coupled with increased use of water for irrigation and wildfowl propagation has caused less water to reach the lake; in recent years, therefore, the lake level has been consistently about 4 feet lower than it was from 1905 to 1912, and the concentration of dissolved mineral matter is correspondingly greater. The water of streams and springs entering the lake is relatively soft and is good for irrigation and domestic use.

A bed of silt and clay on the valley floor extends onto the foot of the adjoining rock slopes for about 100 feet above the present level of Summer Lake. The high level of this alluvial deposit testifies to the previously much greater extent of Summer Lake. The clayey alluvium confines the extensive ground-water body in the volcanic bedrock. This ground water has a water table (pressure level) sufficiently high that the water will flow out over the clay confining layer at 50 to 100 feet above the level of the lake. Consequently, drilled wells and natural breaks in the confining blanket of clay allow the artesian ground water to flow from the lava bedrock. (See fig. 25.) Numerous springs spill over the edge of the clay around the west and north sides of the basin, and a few rise in artesian fashion through the clay near the north end of the basin; Ana Springs is the largest of these.

Silver Lake

Silver Lake lies about 6 miles east of the post office of Silver Lake, in a basin bounded by high hills to the east, south, and west. The principal inflow stream is Silver Creek, which drains 520 square miles of arid desert and semiarid forest land. Runoff varies greatly from year to year. At the gaging station 2 miles southwest of Silver Lake post office, the drainage area is about 180 square miles. The flow is affected somewhat by upstream storage and diversion. The average rate over a long period is 27.9 cfs, and there is a range of average annual flow from 2.4 in the driest year (1931) to 86.4 in the wettest (1956). Bridge and Buck Creeks to the northwest and Silver Creek flow into Paulina Marsh, which drains southward to Silver Lake.

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The lake reached its highest known level of 4,311.8 feet in the spring of 1904, when Silver and Thorn Lakes, to the north, were connected by a channel 50 to 200 feet wide. In the autumn of 1918, Silver Lake became dry, or nearly so. After a rise of several feet in 1921, the lake became dry again in 1922 and remained dry until 1950; crops of hay and grain were raised annually on the lakebed. During the period while the lake was dry, its overflow channel northward into Thorn Lake was blocked by drifting sand and also by a levee built along the north shore for State Highway 31. In March 1951, several hundred acres of temporary cropland in the bed of the lake was flooded, and by 1956 the water covered about 10,000 acres. The highest level reached since about 1907 was 4,309.05 feet on June 26, 1958.

Thorn Lake itself is merely a shallow playa that is dry most of each year, except when it was filled by overflow from Silver Lake. It is reported that Thorn Lake overflowed into Christmas Lake basin farther northeast in 1890.

Silver Lake was high in 1882, and was then joined to Thorn Lake. It was reported dry in 1889, and it seems likely that it has been dry at other times. The water of the lake is soft, and even the lakebed when dry is not too alkaline for successful growing of grain and hay.

Fort Rock Basin

Northeast of Silver Lake basin, and separated from it by low passes, is the broad, flat-floored Fort Rock Basin. It includes Thorn Lake, a historic overflow sump for Silver Lake, and farther east the playas known as Christmas Lake and Fossil Lake. The basin takes its name from a bold amphitheaterlike rock eminence, a remnant of the hardened rock around a former volcanic vent now etched out by erosion. The flat floor of the basin extends generally east-west for 45 miles and varies in north-south width from 5 to 15 miles. There are no year-round streams reaching this valley floor from the extensive slopes. The snowmelt and winter runoff spread out in playas; much of it percolates down to the water table, and the rest evaporates. The ground water is the sole source of domestic and irrigation water in the basin.

The water table lies 25 to 60 feet below the basin floor, and slopes slightly toward the northwest to a steeper subterranean descent almost directly below a depression called "Hole-in-the-Ground," 7 miles northwest of Fort Rock post office. The ground water may drain from this point through the Newberry lavas westward to the Deschutes River, though the direction of that ground-water movement is not known.

Pumping for irrigation has increased steadily since electric power was distributed in 1955. In 1960 about 6,000 acres of land was under irrigation. The growing season is short. Wells obtain large yields of water from porous lava flows, fragmental volcanic tuff beds, or alluvial sand and gravel. In spite of increased pumping, the water table has been rising slowly in recent years.

STREAMS THAT FLOW INTO THE SNAKE RIVER

Many small and medium-sized streams drain the eastern fringe of Oregon and flow into the Snake River. (See fig. 26.) In size and shape this part of the State is somewhat like the western strip whose waters flow directly into the Pacific, but the two areas differ greatly in climate, vegetation, geology, and stream behavior. The coastal climate is relatively cool at all seasons and wet except in summer, but the valleys, plateaus, and mountains in the eastern fringe are warmer in summer, colder in winter, and dryer at all seasons. In the Blue Mountain and Wallowa Mountain areas, the moderate annual "catch" of rain and snow is enough to support pine forests, which are somewhat less dense than the rain forests of the coastal areas; in the lower plateaus and valleys near the Snake River, the annual rainfall is about 7 to 12 inches, and here desert vegetation prevails. The flashy runoff in the coastal strip is caused by the rains of winter; the much smaller floods of the rivers that swell the Snake are due chiefly to the melting of snow in spring and early summer.

The Snake River tributaries differ in runoff characteristics among themselves; toward the northern part of this strip there is a marked increase in runoff for a given size of basin.

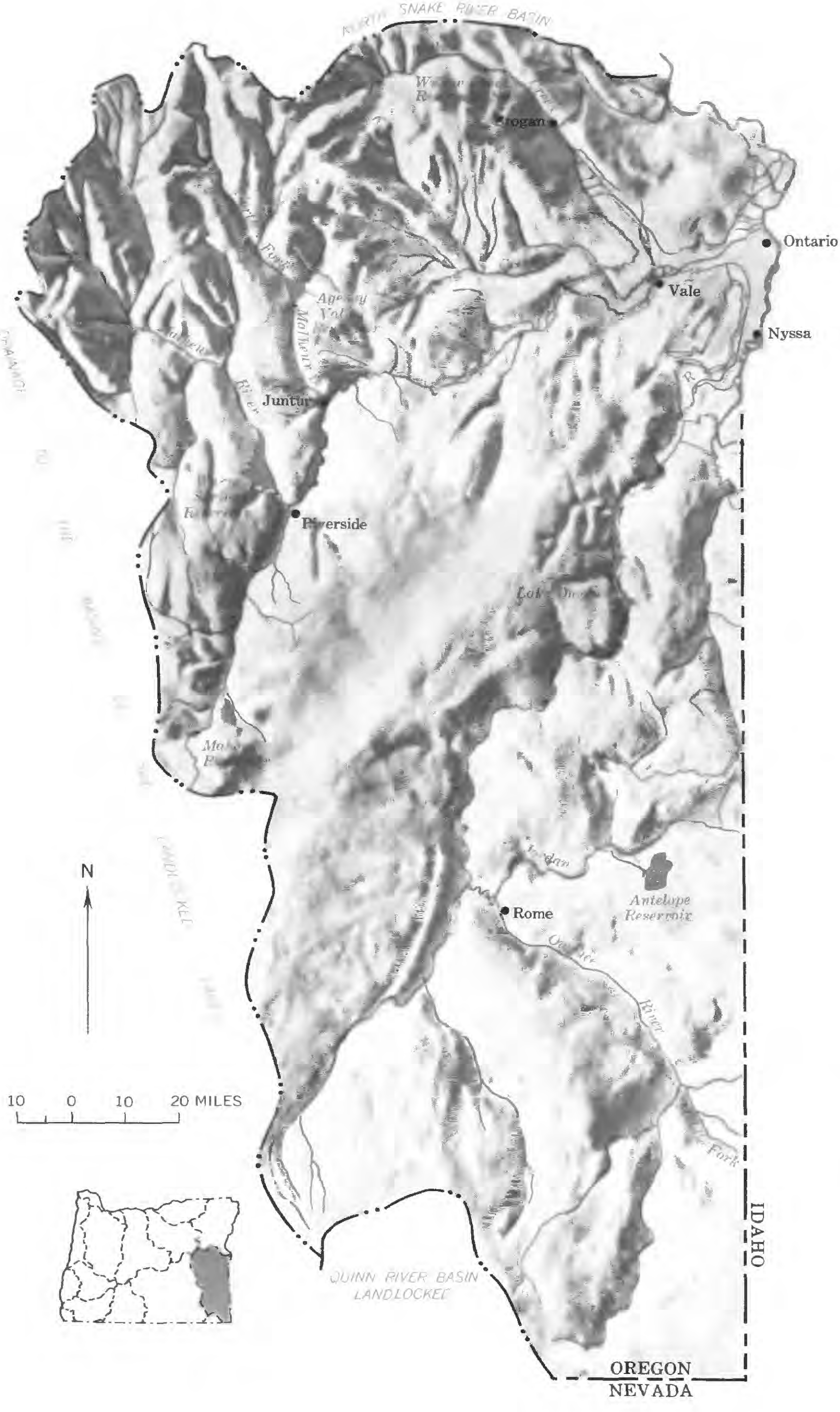


FIGURE 26.—Southern part of the Snake River basin in Oregon.

Owyhee River

In respect to the size of its drainage basin, the Owyhee River is a large stream. The total drainage area of 11,400 square miles is equally divided, half in Oregon and half in the adjacent States of Nevada and Idaho. Except for the few miles of the Snake River above Nyssa, the Owyhee is the only large river that flows into Oregon from another State. The South, Middle, and North Forks, carrying most of the water, flow out of Idaho and unite in Oregon near the southeast corner of the State. The combined flow courses for about 80 miles through deep canyons carved in a vast, inhospitable lava plateau, to reach the quiet water of Owyhee Reseroir. This 50-mile-long lake was created by the high dam built by the Bureau of Reclamation in 1932. The stored waters are used to irrigate hay, fruit, sugar beets, and other crops in the fertile delta area near Nyssa. In dry seasons, the entire yearly runoff is used in this area, and more water would be welcome.

Smaller reservoirs store the surplus winter and spring runoff of tributaries which enter below the village of Rome. A spring a few miles southwest of Rome is remarkable for the constancy of its flow, about 24 cfs. Many of the tributaries in Oregon are dry gulches except in periods when the skimpy snowfall is melting fast enough to produce runoff.

The average annual runoff that reaches Owyhee Reservoir amounts to only 1¼ inches of water spread over the whole area of the drainage basin (fig. 27). By contrast, the corresponding figure for either Wilson River near Tillamook or Siletz River near Siletz, near the opposite corner of the State, is more than 100 inches. The observed flow is, of course, a residual—what is left over after evaporation, transpiration by natural vegetation, and irrigation—but the total supply from rainfall in the Owyhee drainage basin is not enough to support the needs of a pine or oak forest, even if all the rain could be controlled as to timing and rate. The Owyhee basin is one answer to those who have the impression that it rains all the time in Oregon!

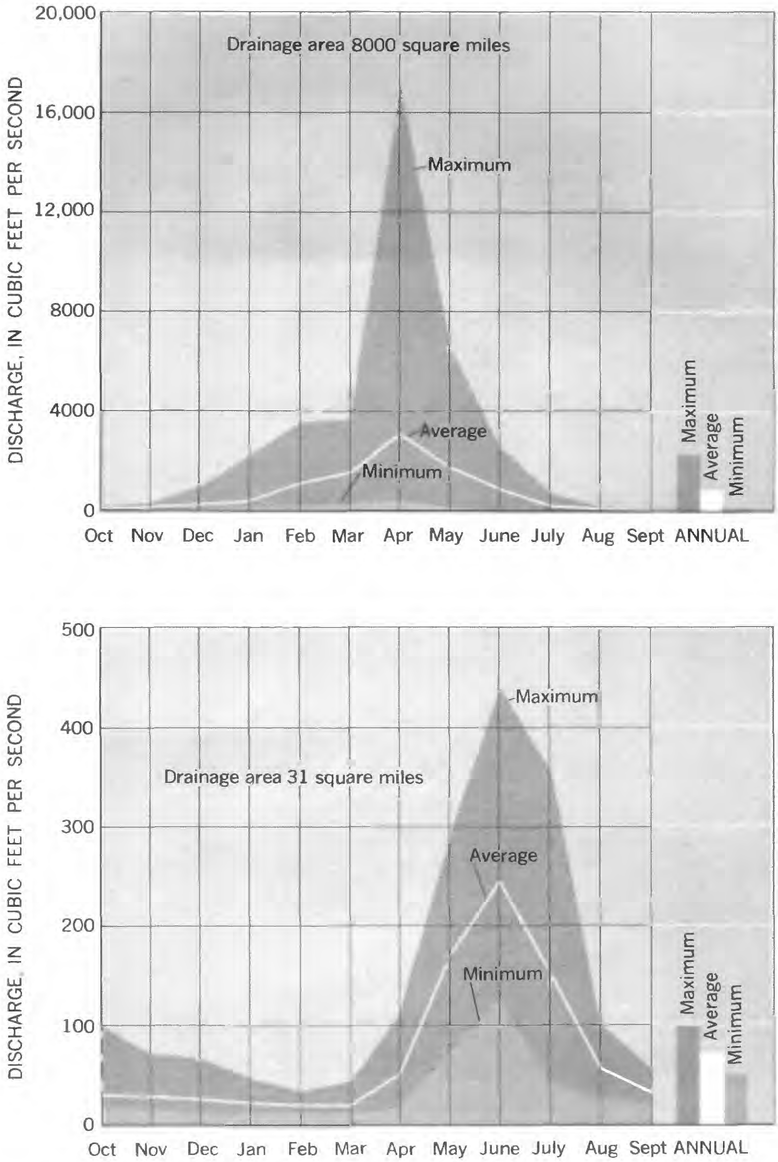


FIGURE 27.—Maximum, minimum, and average monthly and annual discharge of Owyhee River near Rome (above) and of Hurricane Creek near Joseph (below). The Owyhee River drains a desert area in which melting snow and spring rains provide a flashy runoff, typical of a large part of southeastern Oregon. Hurricane Creek rises in the higher and more humid Wallowa Mountains, from which the melting snows provide a strong summer flow; the lowest flow comes in the wettest season, December to March.

Malheur River

The loss of a cache of furs on a then-unnamed stream caused some early French trappers to call it "Rivière au Malheur," or River of Misfortune, but for thousands of modern farmers and cattlemen the river brings each year a liquid fortune to water their fields of hay, grain, fruit, vegetables, hops, and sugar beets. The trappers and fur traders could hardly have foreseen the reservoirs, diversion dams, and far-flung canals that would be built by a later generation.

Some of the excess water of winter and spring is stored in Warmsprings Reservoir near Riverside, in Agency Valley Reservoir north of Juntura, and in Willow Creek Reservoir above Brogan. These reservoirs, built since 1910 for irrigation use, control the flow from 1,830 square miles of the total basin area of 4,690 square miles, but they are sometimes filled before the period of greatest runoff, and consequently the flood at Vale on February 24, 1957, nearly equaled the record flood of March 2, 1910. The U.S. Bureau of Reclamation is now (1964) building a reservoir to store the floodwaters of Bully Creek.

There are many hot springs in the basin, the best known being the one that supplies water at the bathing resort at Vale. A few drilled wells near the springs also yield hot or mineralized water, but most ground-water supplies are cool and fresh. Wells in Cow Valley near Brogan tap a source of ground water in an upland basin and provide water for irrigating fields and watering cattle. This small basin is one of the very few areas in Oregon where the withdrawal of ground water from wells is now controlled by the Oregon State Engineer to prevent pumpage in excess of the rate of natural recharge.

Burnt River

The small stream called Burnt River and its tributaries lie just north of the Malheur River (see fig. 28), and the two river basins are much alike in climate, altitude of drainage basin, and the rate and timing of runoff. Burnt River drains

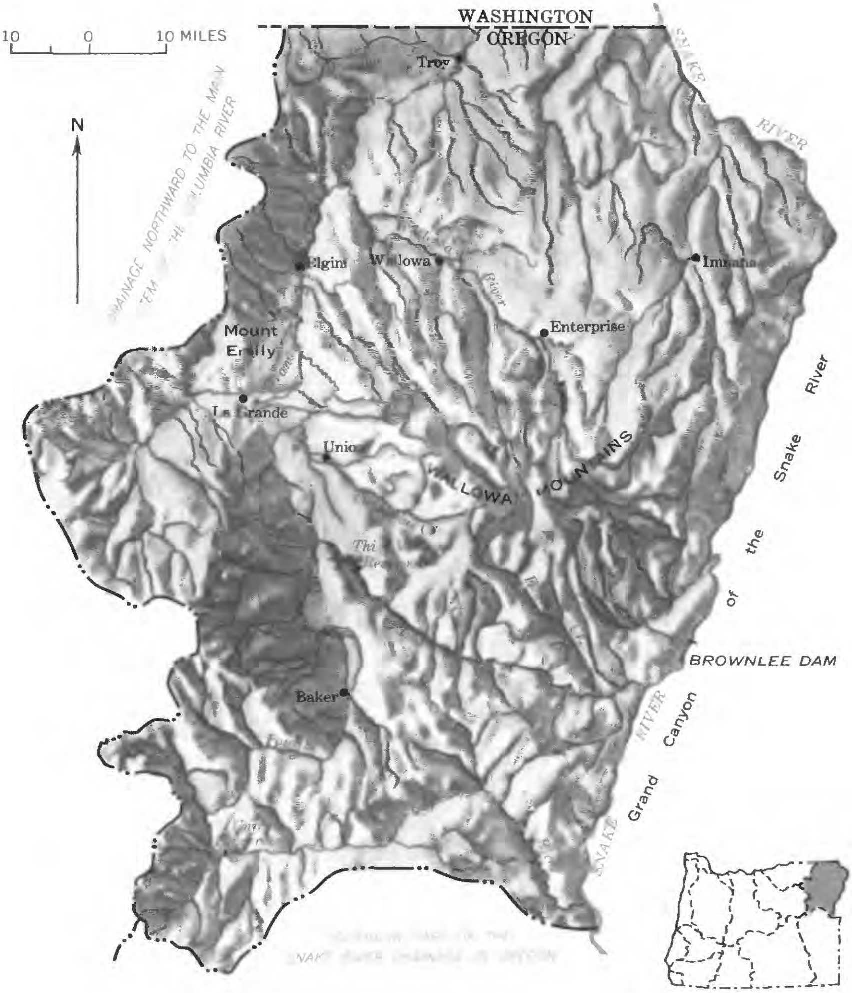


FIGURE 28.—Northern part of the Snake River basin in Oregon.

an area of 1,100 square miles that is forested in the upper reaches and has only desert vegetation in the lower reaches. Water is stored in the fairly large Unity Reservoir and in a small private reservoir on the South Fork; both reservoirs are near the post office of Unity. The stored water and the natural flow of other streams in the basin are used for irrigation, mostly on the narrow fertile terraces that line the banks of the river.

The average flow of the river at Unity Reservoir is 81 cfs, from a drainage area of 309 square miles. Downstream tributaries have lower yields, and many of them are dry in summer. The greatest known flood occurred in 1894, when water entered the roundhouse at Huntington.

Powder River

Like the Malheur and Burnt Rivers to the south, the Powder River rises in the Blue Mountains. The peaks beside the headwater reaches of the river are the highest in the range, many of them rising to altitudes of 8,000 to 9,000 feet. From these mountains a multitude of little streams tumble swiftly down the steep canyons. They flow past the boulder dumps of the dredges that formerly used the water to wash gold from the gravel bars and past the narrow terraces where water supports the growth of hay and grain for livestock. The growing river flows more gently through the round, open valleys near Baker, then more rapidly again through alternating canyons and small irrigated valleys, to join the Snake River at Robinette. The lower 10 miles of the river became a part of the reservoir behind Brownlee Dam on the Snake River in 1958. At Richland the river is joined by Eagle Creek, the largest stream that flows out of the southern slope of the high and rugged Wallowa Mountains.

Thief Valley Reservoir, east of the town of North Powder, stores water for irrigating lands in the lower part of the river basin. The low-water flow of many of the streams, including Eagle Creek, is completely used for irrigation. The water of Rock Creek is used to develop electric power, and Goodrich Creek furnishes the municipal water supply for Baker. At the higher mountain lakes, summer fishing and winter skiing alternate as recreational attractions. There is as yet no upstream storage to control the floods that occur at rare intervals. Flooding is sometimes due, at least in part, to ice jams as the late winter rains swell the streams. That sort of flooding occurred at Baker as recently as February 1957.

Where the river emerges into open valleys, it has deposited its bedload of gravel and sand to construct alluvial fans, such as the one on which Baker is located. These gravelly deposits yield moderate supplies of water to wells.

Grande Ronde River and the Wallowa Mountain area

The large fault-block valley that lies between Union and Elgin became known to early French trappers as Grande Ronde, a name that soon was transferred to the river. The local pronunciation of "Grand Round" is applied both to the valley and to the river.

Rising in the snowbanks and springs of the Blue Mountains, the river meanders lazily through the large, flat valley, much of the flow confined in a straightened cutoff channel known as the State ditch. In this valley reach, the principal tributary is Catherine Creek, which drains the southwest side of the Wallowa Mountains; it reaches the valley floor at Union, and from there it winds north through the valley to join the old channel of the Grande Ronde near Cove. The river has built a gravelly fan extending from its mountain canyon several miles eastward from La Grande. Catherine Creek also flows across a gravel fan before reaching the Grande Ronde. From their confluence, the river meanders widely over a very flat part of the valley floor as far as the bedrock canyon carved through Pumpkin Ridge, below which the river enters the smaller Elgin Valley.

Economical supplies of water can be obtained from wells in the lava bedrock, in the gravelly alluvial-fan deposits, and in the sand and fine gravel beds within the valley alluvium. The water table stands close to the level of the valley floor, and springs flow from the bedrock and gravel aquifers around the edges of the valley. Springs rising along faultlines at Hot Lake contain water that is near boiling temperature.

Below Elgin the Grande Ronde River flows in a canyon for 99 miles; it drops more than 1,800 feet to the Snake River, the lower 38 miles being in the State of Washington.

The river drains 3,950 square miles, mostly mountainous and forested. Precipitation over the area is moderate. At Troy, where the drainage area is 3,275 square miles and the lowest streamflow measuring station is operated, the average flow is 3,200 cfs after the upstream needs have been taken out. This flow is about twice the total net inflow contributed to the Snake River by all other Oregon streams, although the drainage area at Troy is less than a fifth of the total of the combined Snake River tributaries in Oregon (19,150 sq mi).

The annual runoff, about 10 times as great as the yield of the Owyhee, would cover the basin more than 13 inches deep if it could be spread uniformly over it. Two factors apparently govern the difference in the runoff from the two basins: First, there is more annual precipitation in the Grande Ronde basin than in the Owyhee, perhaps 30 inches as compared to about 12 inches. Second, runoff is the residual, what is left over after the demands of nature and man have been met; the forests, meadows, and irrigated fields of the Grande Ronde basin consume or evaporate about 18 inches of water, in contrast to the 10 to 11 inches consumed by the desert terrain of the Owyhee; in each instance the remainder of what falls as rain or snow appears as runoff in the river.

The Wallowa River, largest of the Grande Ronde tributaries, rises in the myriad snowfields and lakes of the Wallowa Mountains. The principal headwater stream flows through Wallowa Lake (see fig. 29), a beautiful 4-mile-long body of water in a classic alpine setting, lying in a trough of a valley that was deepened and then dammed by a mountain glacier. In 1927 a party of students from the University of Oregon measured the depth of the lake in many places, the greatest depth found being 283 feet. Below the lake, the river and its tributaries are used for irrigation in the open valley that begins at Joseph and extends some 20 miles to the northwest. This beautiful valley was the home of the Wallowa branch of the Nez Perce tribe. For possession of this valley, Chief Joseph led the Nez Perce into a rebellion, which ended with his retreat, against U.S. Army troops in 1877.

The gravelly soils of the gently sloping valley lands seem to require a copious supply of water in the summer, a demand that fortunately can be met by the snow-fed rivers. These streams commonly have their greatest flow in the warm, clear weather of June and July, when plant growth demands an ample supply of moisture.

FIGURE 29.—View southward of Wallowa Lake and the skyline of the Wallowa Mountains. The terminal and lateral moraines deposited by the former mountain-valley glacier are clearly evident around the near end of the lake. Photograph by U.S. Forest Service.

The second largest tributary is the Wenaha River, which rises in the timbered mountains in Oregon and Washington and joins the Grande Ronde at Troy. Except for recreation and wildlife propagation, the water of the Wenaha is little used. The stream is an important spawning ground for salmon, and at one time it was called Little Salmon River.

A few very small streams are used to develop a small amount of electric power. Wallowa Lake is the only large reservoir in the basin.

The Imnaha River is a small stream that flows off the eastern end of the Wallowa Mountains, turns abruptly northward, and then boils steeply down a very deep canyon parallel to the Snake River, to join that river 20 miles north of the village of Imnaha. At one point in its upper reaches, the Imnaha is almost 2,500 feet higher than the Snake, only 5.5 miles to the east through the sharp ridge that separates them. The flow of the little river is sustained by rather large springs and by melting snow, and is more than adequate for irrigating the thin strips of river-terrace land that line its banks.

The Snake River and its Oregon tributaries contain greater amounts of dissolved minerals than the rivers of western Oregon. The Wallowa, Grande Ronde, and Burnt Rivers contain soft water of relatively low mineral content. The Powder and the Malheur River waters have a somewhat greater concentration of dissolved materials. The Powder River has the higher content: 190 to 200 ppm dissolved solids, of which about 30 ppm is silica. The Snake and the Owyhee Rivers contain even more dissolved solids. The Snake River has a maximum average dissolved-solids content of about 400 ppm near Nyssa, and progressively declines to about 190 ppm at the Washington boundary. The Owyhee River has an average dissolved-solids content of 193 ppm at Owyhee Dam. However, at the mouth of the river, irrigation return flow has increased this value to about 800 ppm.

The ground water in the alluvial deposits of the valleys in the eastern and drier part of the State is generally harder, that is, it contains more calcium bicarbonate than the ground water in the valleys farther west.

The ground water found under water-table conditions beneath the Snake-Malheur plain near Ontario, Vale, and Nyssa has about 200 to 300 ppm hardness and a dissolved-solids content of about 500 ppm; most of the dissolved material is bicarbonate of calcium and sodium. Ground water in the alluvium of the Grande Ronde Valley ranges from soft to only moderately hard; it varies in chemical content from place to place and from time to time in accordance with the interplay of this ground water with the adjacent surface runoff.

Warm to hot ground water occurs along geologic faults in the Malheur, Powder, and Grande Ronde River basins. This water, which carries large amounts of silica, sodium bicarbonate, chloride, and sulfate, is of poor quality.

RIVERS OF THE NORTH SLOPE OF OREGON

The Snake River enters the Columbia River in Washington. In flowing from there to the sea, the Columbia passes through climatic zones that have a wide range in annual precipitation: 8 inches at Umatilla, 15 inches at The Dalles, 31 inches at Hood River, 76 inches at Cascade Locks, down to 40 inches at Portland, and up again to 76 inches at Astoria.

FIGURE 30.—North slope of Oregon from Walla Walla River to John Day River.

The northward-flowing streams (see fig. 30) which bring their tribute to this reach of the Columbia reflect these variations, although all the streams have their sources in the higher and somewhat wetter mountain regions. These tributaries drain almost 25,000 square miles in Oregon, exclusive of the Willamette River basin, and include some rivers that significantly affect Oregon's present and future prosperity.

Walla Walla River

The Walla Walla River is just what its Indian name implies, a small, rapid river. It rises in the Blue Mountains in Oregon and flows northwest out of the mountains and across its own fertile alluvial fan near Milton-Freewater. The headwater areas in the Blue Mountains receive about 40 inches of precipitation per year, and deep snows melt each spring to run off the sloping land into South Fork, North Fork, and Mill Creek, the main headwater tributaries. The South Fork is fed by large springs that keep the summer flow up to about 110 cfs, and hydroelectric power has been developed near Milton. In the valley above and below Milton, the entire low-water flow is used for irrigation.

During flood seasons the river loses water in crossing the permeable alluvial fan, and ground-water bodies for several miles on either side are replenished by the seepage out of the river channel. The river water of April may be the ground water of June and river water again a month or a year later. This interdependence of surface- and ground-water supplies exists in many places. Here in the Walla Walla valley it helps to stabilize the summer water supply and the economy of the area. The ground water in the bedrock lavas is less closely associated with the surface water, but it supplies many productive wells.

Umatilla River

The Umatilla River rises in the forested slopes of the Blue Mountains and flows northwest to join the Columbia at Umatilla, 4 miles below McNary Dam. Much of the headwater area lies on the Blue Mountain upland and slope; the lower parts of the drainage basin consist of rolling land, much of which is planted to wheat or other grains in alternate years. Erosion of loess soils is a problem. (See fig. 31.) There is a storage reservoir on McKay Creek south of Pendleton, and an off-channel reservoir near Cold Springs, which is fed by a diversion from Umatilla River. The natural summer flow of the river and the water stored in these reservoirs are almost entirely used for irrigation in dry seasons.

At Pendleton, where the river drains 637 square miles and where there are many small diversions above the gaging station, the average flow in a 29-year period was 495 cfs, but the summer flow may be less than one-tenth of that rate. Floods occur occasionally, caused either by general winter rains on top of the snow and frozen ground or by torrential local cloudbursts in the spring and summer.

The volcanic bedrock is warped into broad folds. The Blue Mountain and Horse Heaven ridges are the principal upward-folded structural features, and the Umatilla and the Agency synclines, the latter running northeastward from Pilot Rock to Athena, are the principal downwarped features. In the downfolds, the bedrock lavas yield large quantities of water to wells. This region and the neighboring Walla Walla River basin offer opportunity for much greater development and use of the ground water of the volcanic bedrock.

Willow Creek

Willow Creek drains 850 square miles, but its contribution to the flow of the Columbia is very small. For a large part of the year the stream is almost dry near the mouth, the small flow being used entirely for irrigating the narrow terraces along its banks. The creek carries a heavy load of sediment whenever a warm rain falls on the frozen ground of the wheatfields and the fallow land which make up a large part of the total area.

The region is also subject to torrential storms of cloudburst type in spring and summer. The most notable flood of that sort occurred on June 14, 1903. On that date a flash

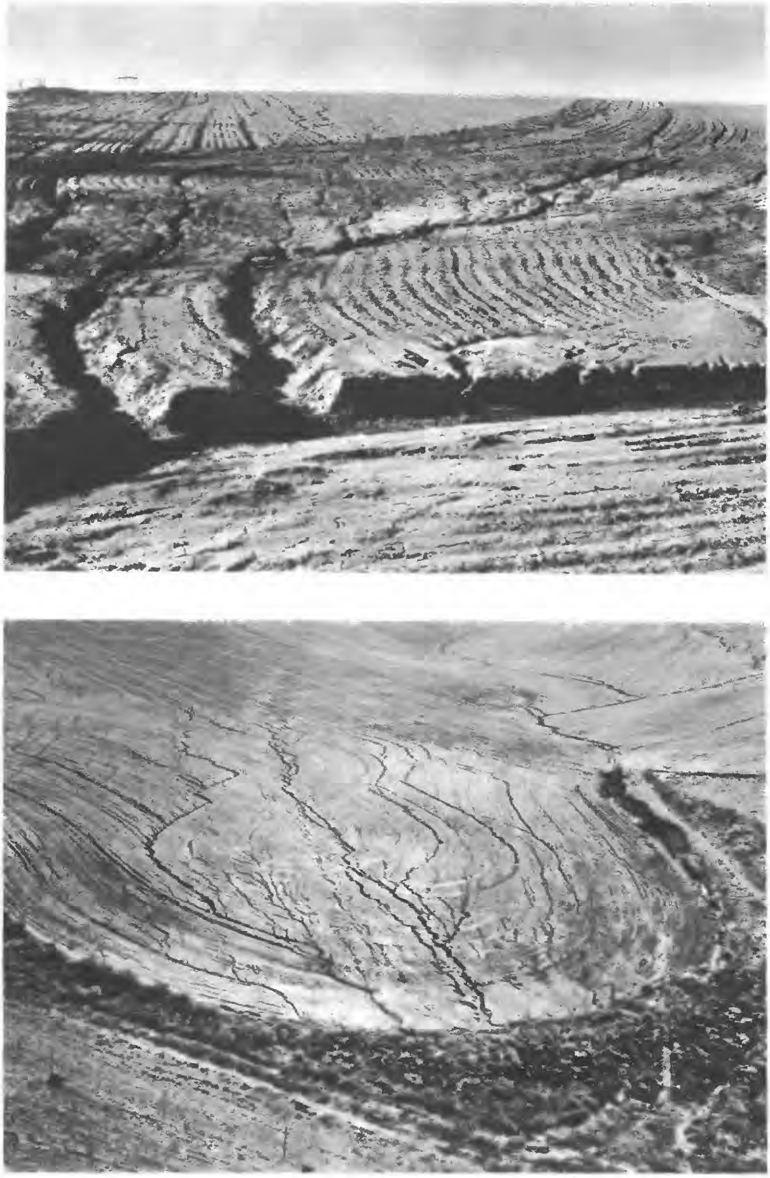


FIGURE 31.—Above, Close view of sheet-wash, rill, and gully erosion of loess soil in a field of young winter wheat in the Umatilla basin. Photograph by U.S. Soil Conservation Service. Below, Distant view of erosion of loess soil in young winter wheat in the Umatilla basin. The prevalence of rills and gullies on the steeper slopes, gullying in the drainageways, and the concentration of rills by the rows of the grain drill are evident. Much of the sediment carried from fields like these reaches the rivers of the region.

flood of 36,000 cfs swept down Balm Fork and engulfed the town of Heppner. More than 200 lives were lost, and a large part of the business and residential sections of the town was completely destroyed. That flood lasted less than 2 hours. The total volume of the flood surge has been computed as only about 1,100 acre-feet of water. Natural storage in the creek channel so reduced the flow downstream that there was no serious flooding below Lexington. Design of a flood-control dam at a site downstream from Balm Fork has been authorized.

The stream rises on the partly forested plateaus and western ridges of the Blue Mountains. It flows northwestward to Heppner and then turns northward to descend 1,700 feet in 35 miles down the regional ramp-slope to the Columbia River. For most of its course, the creek flows in a shallow canyon whose bed is a hundred feet or so above the regional water table. A small cross fold in the bedrock causes the water table to stand near the surface at the town of Ione. Because of the depth to the water table, most of the farms on the plateaus above the canyon have only small-diameter wells for domestic use and stock watering. Irrigation from ground water is limited to small tracts.

John Day River

The John Day River drains a 7,830-square-mile area that ranges in altitude from 9,038 feet on Strawberry Mountain to 160 feet at its mouth. Above 3,500 feet altitude, most of the basin is covered with moderate to dense stands of pine, fir, hemlock, larch (locally called "tamarack"), and other forest trees. The higher areas receive moderate precipitation, much of it in the form of snow.

The deep canyons carved by the mountain streams expose many types of old crystalline rocks of low permeability in the central part of the headwater uplands; cappings of lava flows occur extensively. Because some of the lava flows are permeable enough to store and transmit ground water, they give rise to many small and medium-sized hillside springs. These springs have value as a water supply for thousands of cattle, deer, and elk that range the mountains.

The opportunities for developing moderate quantities of water from wells is limited to the few places where the lava rocks extend down into the valleys. The city of John Day has taken advantage of such a situation with two public-supply wells.

About 95 percent of the total runoff is derived from the higher half of the basin, the runoff from areas below 3,000 feet in altitude being generally negligible except during excessive rain or snowmelt. Ground water is only a small contributor to the stream discharge.

In dry seasons, practically all the water in the upper part of the river is used for irrigation. The larger irrigated tracts are near Prairie City, Dayville, and Monument. The river water, particularly in the upper valley areas, is quite satisfactory in quality for irrigation and stock water.

Extensive areas of lakebed deposits of volcanic ash are exposed in the river canyons near the towns of Dayville and Mitchell and the small settlement of Service Creek. The ash beds are a source of much scientific interest because of the fossil remains of plants and animals of earlier geologic ages that are preserved in them. Many of the beds are brilliantly colored—brown, yellow, cream, or red. These formations support little vegetation, and their rapid erosion is responsible for a large part of the load of fine sediment carried by the John Day during the late winter and spring. In 1962–63 at McDonald Ferry, 16 miles above the mouth, the river carried 1,150,000 tons of suspended sediment and a total load of about 1,250,000 tons of sediment in a 12-month period. This total load is equivalent to 4,750 pounds per minute, on the average. The daily load varied with the seasons, and for many periods the stream was practically clear.

At McDonald Ferry, the average flow is 2,000 cfs and has a recorded range from 4 to 39,100 cfs from a drainage area of 7,580 square miles. (See fig. 32.) Many of the streams in the basin of John Day River rise suddenly with rain and quickly recede to a low flow. This tendency to flash floods is especially noticeable because in size, shape, altitude, and forest cover the river basin is similar to the adjacent basin of the Deschutes River; however, the regimen and turbidity of the two rivers are markedly different.

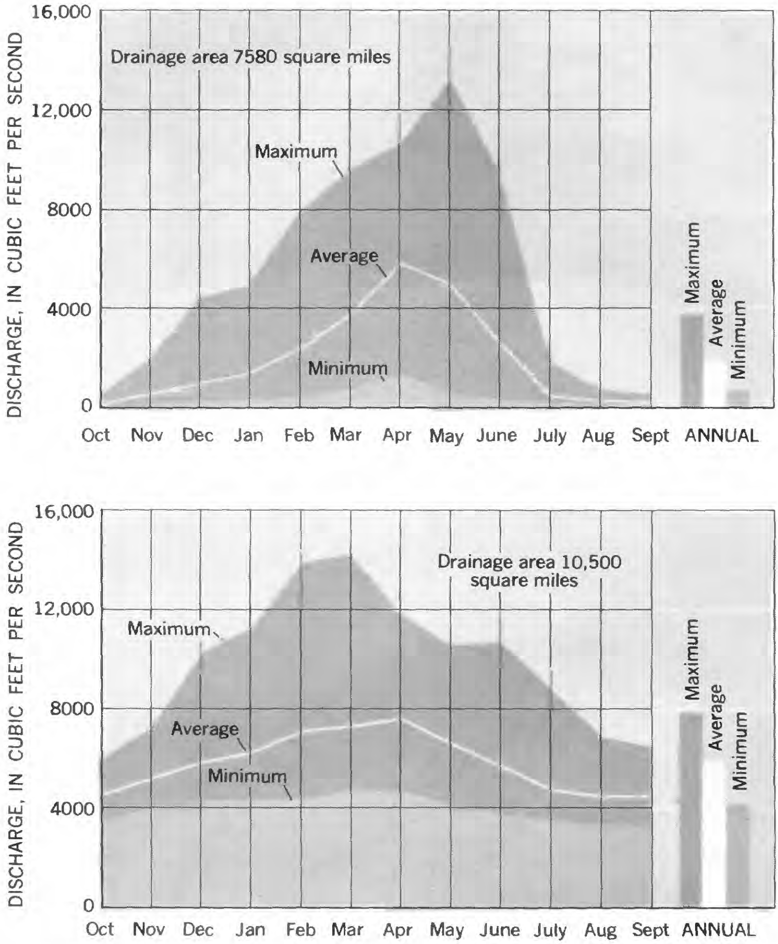


FIGURE 32.—Maximum, minimum, and average monthly and annual discharge of John Day River at McDonald Ferry (above) and Deschutes River at Moody (below). The low-water flow of the Deschutes River is about 20 times that of its next-door neighbor, the John Day River. The difference is due chiefly to the porous soil and thick deposits of open-jointed lava rocks in the basin of the Deschutes. Both streams have many diversions for irrigation.

The extreme cases of flash floodflow occur in cloudburst type of rainfall. Such a cloudburst near Mitchell on July 13, 1956, created a flash flow of 14,400 cfs in Bridge Creek, normally only a trickle, and 54,000 cfs in Meyers Canyon a few miles farther north.

Deschutes River

The Deschutes River has a more nearly uniform flow than any other river of its size in the United States. It rises in lakes and springs in the Cascade Range and flows generally northward to join the Columbia River 16 miles east of The Dalles and 13 miles upstream from The Dalles Dam. In its middle and lower courses the river has carved a spectacular canyon (see fig. 33) through a series of nearly horizontal lava flows, interspersed with lakebed deposits formed mostly of volcanic ash and associated sedimentary materials.

FIGURE 33.—View northward down the Deschutes River canyon from a point 15 miles above the mouth of the river. The layered lava rocks of the canyon walls slope northward about at the water grade; north of the Columbia River they are warped up to form the distant upland in the center background. Photograph by Oregon Game Commission.

The Deschutes basin covers 10,500 square miles. (See fig. 34.) The annual precipitation ranges from about 9 inches along the lower course of the river to 90 inches in

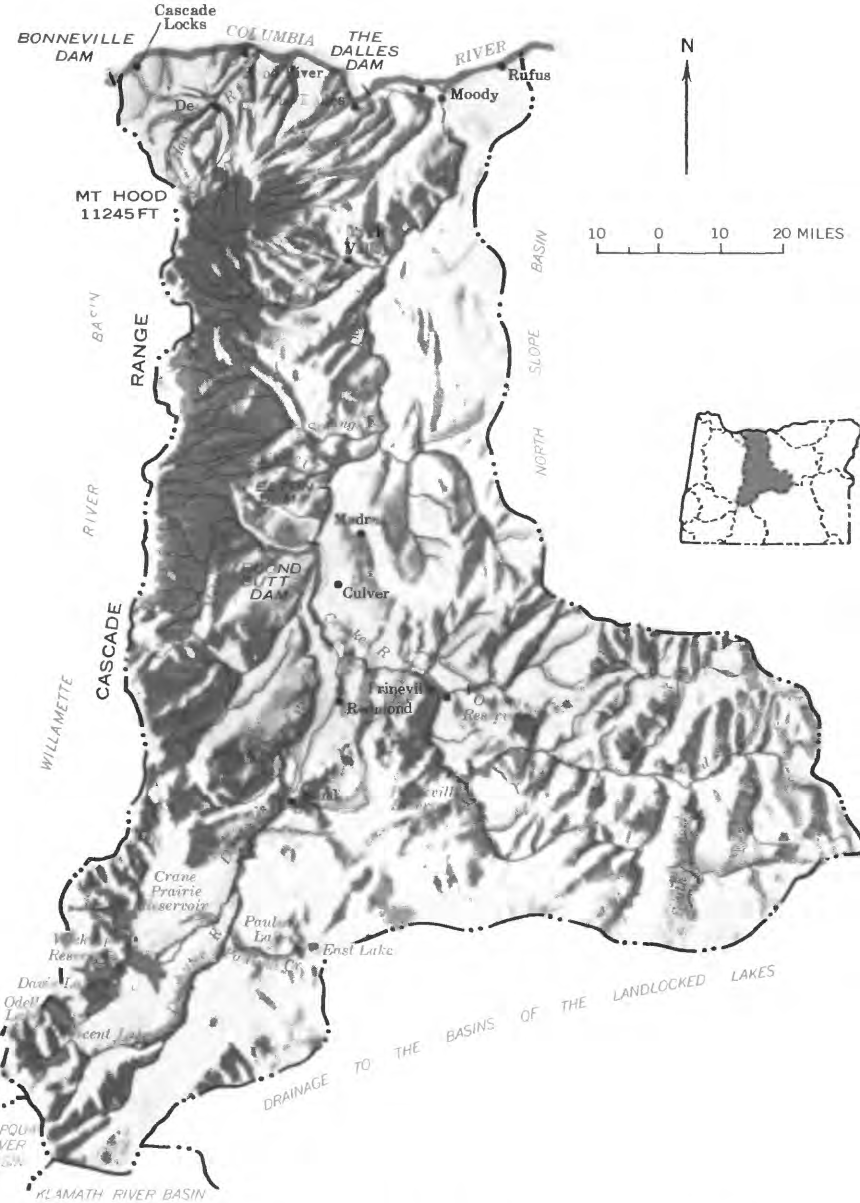


FIGURE 34.—The Deschutes River and adjacent drainage basins.

places along the crest of the Cascade Range. In general, the precipitation decreases eastward from the Cascade Range and northward along the river. Vegetal cover varies with moisture available: Hemlock, fir, and cedar cover most of the higher mountain slopes; yellow pine and juniper carpet the progressively lower and more arid tablelands; desert vegetation prevails in areas receiving less than about 14 inches of precipitation annually.

The uniform flow of the river cannot be attributed to the presence of forests, for many other streams (and one large tributary of the Deschutes River itself) have flash flows from forested areas. Indeed, the removal of the entire supply of commercial timber might not materially alter the flow of the river. The constancy of flow is due rather to the presence of large areas of spongelike pumice soil and lava rock, which receive the precipitation and conduct much of it down to vast underground reservoirs. This ground water percolates out through the porous lava rocks to emerge as large, clear, steady-flowing springs. Taken either individually or as a group, these springs are among the largest in the world. One tributary alone (Metolius River) has an average flow of 1,479 cfs, almost entirely derived from springs, some of which are constantly discharging water that fell years earlier.

Lakes in the headwater areas also serve to stabilize the flow of the Deschutes River. Some, such as Crescent Lake and Odell Lake, were dammed by moraines of former mountain glaciers; others were dammed by lava flows. The entire outflow of Davis Lake is by leakage into and through such a lava flow. Still other lakes occupy depressions formed in the lava, and much of their outflow sinks into the ground. East Lake occupies a large volcanic crater, from which the water is lost by evaporation and seepage. Paulina Creek, leaving Paulina Lake as a strong-flowing stream, gradually sinks into the pumice and most of its flow disappears before reaching the Deschutes River. Manmade lakes include Crane Prairie, Wickiup, Ochoco and Prineville Reservoirs, and the pools formed by Round Butte and Pelton dams near Madras.

Near Bend, most of the natural flow, and all the water released from storage in Crescent Lake, Crane Prairie, and Wickiup Reservoirs, is diverted for use in irrigation. The irrigated land lies on broad plateaus near Bend, Redmond, and Madras; only small tracts on the narrow terraces are along the river itself. Large springs in the deep river canyons near Culver and additions from the Crooked and Metolius Rivers swell the summer flow from less than 200 cfs below Bend to about 4,000 cfs 40 miles downstream near Madras.

Below Madras, the small east-side streams are inadequate for irrigation needs, and their contribution to the Deschutes River is negligible. Practically all the inflow in this reach comes from the west side. Shitike Creek and the Warm Springs River have well-sustained flows fed by winter snows and by large springs; their waters are used to irrigate some cropland in the Warm Springs Indian Reservation. White River is fed by springs and snows of Mount Hood. Its water is at times milky with the fine sediment known as "glacier flour" derived from White River Glacier.

A small hydroelectric powerplant has been constructed to utilize the flow of the Deschutes River at Bend. Most of the potential waterpower lies in the stretch of river below the mouth of the Metolius River, where a dependable flow of about 4,000 cfs could be dropped through a total of 1,800 feet to develop more than 600,000 horsepower continuously. The only large powerplants that have been built to date are the Pelton and Round Butte plants near Madras, of 355,000 kilowatts combined installed capacity.

The Deschutes River and its lakes are famous for trout fishing, and some salmon come up the river to spawn in the gravel beds of its tributaries. At the Pelton powerplant, a fish ladder 2½ miles long was required to permit the migrating fish to pass upstream and downstream.

The rivers of the north slope of Oregon vary in chemical quality. The John Day and Umatilla Rivers contain moderate amounts of dissolved solids, usually less than 200 ppm. The Crooked River water has an average dissolved-mineral content of about 250 ppm; the Deschutes River water has a much lower concentration.

In the plateau lava rocks and other volcanic deposits of north-central Oregon, the ground water is moderately hard to hard and commonly carries 200 to 300 ppm dissolved solids, largely sodium and calcium bicarbonates. However, snowmelt in the Cascade Range does supply some excellent water to the fragmental volcanic formations. For example, water from the large springs contributing to the Metolius River in the Deschutes River basin is unexcelled in quality.

Lower Columbia tributaries

Downstream from the Deschutes River, the principal tributaries to the Columbia in Oregon are Fifteenmile Creek and the Hood, Sandy, and Willamette Rivers. In addition, there are many small, short streams in the humid zones in the Columbia River Gorge, 20 to 60 miles east of Portland, and below the Willamette River north and west of Portland. These small streams are used chiefly for propagation of fish and for recreational activities—swimming, picknicking, and fishing. Dozens of these small streams form picturesque waterfalls in parks set aside for public enjoyment, whose recreational value—if it could be appraised in dollars and cents—must far exceed the value for any other single purpose. The best known of these is Multnomah Falls which, in two adjacent leaps, tumbles 607 feet to join the Columbia at tidewater level, 29 miles east of Portland.

Fifteenmile Creek enters Columbia River 3 miles east of The Dalles. Its drainage basin covers 351 square miles, mostly in rolling semiarid land devoted to wheatfarming by summer-fallow methods. The small summer flow is used for irrigation. Flash floods occur at rare intervals. Some winter and spring runoff could be stored for later use.

The Hood River enters the Columbia at the town of Hood River. Although its basin of 329 square miles is smaller than that of Fifteenmile Creek, the runoff is much greater, especially in summer. The difference is due to a combination of factors. The Hood River basin has more precipitation because it is a higher mountain area that includes some of the slopes of Mount Hood as far as the 11,235-foot summit. In that high area the heavy snowfall of winter serves to store the water and to maintain summer flow by its slow melting. Newton Clark, Eliot, Coe, and Ladd Glaciers all add their milky-white melt water (called "gletscher milch" in alpine Europe) to the upper tributaries of Hood River. The waters of East, West, and Middle Forks are used for irrigation in Hood River valley, chiefly for the production of high-quality apples and pears. Water is used for a log pond at Dee and for hydroelectric power near the mouth of the river. After diversion for irrigation, the river at the mouth still has an average flow of 1,100 cfs and a low flow of about 460 cfs.

The Sandy River drains about 500 square miles of mountain and forest, including the south and west slopes of Mount Hood, and flows into the Columbia River at tidewater near Troutdale. The snowfields and glaciers of Mount Hood sustain the summer flow. The river is discolored at times each year by fine sediment, typical of melt water from glaciers, but most of the tributaries are relatively clear, even during flood. The stream was called Quicksand River by Lewis and Clark upon observing the sandy plain over which the river enters the Columbia. The average runoff is high: At the mouth of the river it is equivalent to a depth of about 70 inches spread over the entire basin.

The Bull Run River, a tributary of the Sandy, is the source of water supply for the city of Portland and the surrounding suburban area. The water of the Bull Run River is derived from surface runoff, springs, and lakes so clear and soft that unfiltered tapwater is commonly used for many of the ordinary uses of distilled water. The runoff of the Bull Run River has ranged from 62 to 141 inches in depth over the drainage basin (average 97 in). The precipitation must be at least 20 inches greater, to support the dense forest cover, and some parts of the basin certainly must be wetter than the average; hence it appears that the total precipitation in some years may be about 180 inches in the wetter places, though no rain gage in Oregon has ever actually recorded that amount.

Hydroelectric power is developed at Bull Run, near the mouth of the Bull Run River, by using water from the Sandy and Bull Run Rivers. Water in the basin provides

FIGURE 35.—Netting smelt on Sandy River.

recreation, especially in the summer-homesite areas along the upper tributaries. Unappropriated water of the basin is reserved for domestic use and for recreation. Salmon and steelhead trout still provide incentive for the sports fisherman, but the most remarkable phase of recreation on the Sandy River has centered around the migrations of the small eulachon, or smelt, which once ascended the lower reaches of the stream almost every spring in uncountable millions to spawn in the sandy bed of the river, and in their brief passage provided exciting sport for thousands of dip-netters. (See fig. 35.)

LAKES OF OREGON

Scattered in many parts of the State, but clustered in some particular areas, are more than a thousand lakes. (In Lane County alone, for instance, there are more than 200 lakes, but Morrow and Washington Counties have none.) More than half the total number lie close to the summit of the Cascade Range. Some are so small they have never been given names. At least seven counties have a "Fish" Lake, a fact which suggests the most common use of lakes in Oregon. The lakes vary greatly in size, in depth, in water quality, in geologic origin, and in their adaptibility for the use and pleasure of man.

For general discussion, the lakes can be grouped according to the natural agencies that formed them. (See fig. 36.) This grouping also helps to describe the lakes by subareas of the State, because most of the lakes in each particular subarea were formed in the same manner.

SAND-DUNE LAKES

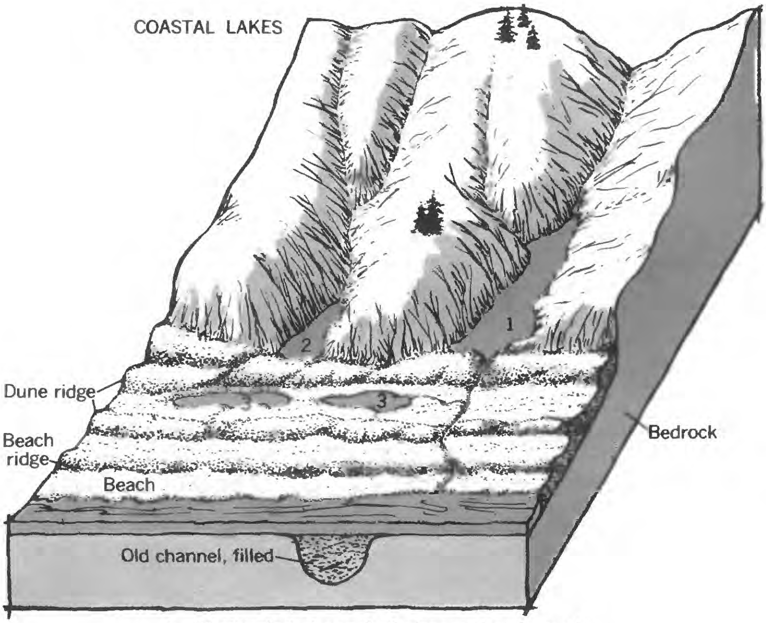
Lying within a few miles of the Pacific Coast in Oregon are many lakes that have been formed by sand dunes and by barrier beach sand which has drifted across the channels of some streams that did not have sufficient flow in summer to wash away the windborne sand. Typically these lakes are clear shallow bodies of soft water, never frozen over. The larger sand-dune lakes (Tenmile Lake, Siltcoos Lake, and Tahkenitch Lake) lie in drowned river valleys that were carved when the sea level stood lower than it does now. Other lakes, such as Horsfall Lake north of Coos Bay and Sunset Lake north of Gearhart, are caused by the rise of ground water in fresh-water lagoons behind beach ridges. All the lakes provide vacation sites and recreation for thousands of swimmers, fishermen, and hunters. The larger ones provide potential storage areas and quantities of water adequate for industrial and public supply. Clear Lake furnishes municipal water for Reedsport, and Empire Lakes for the town of Empire.

LANDSLIDE LAKES

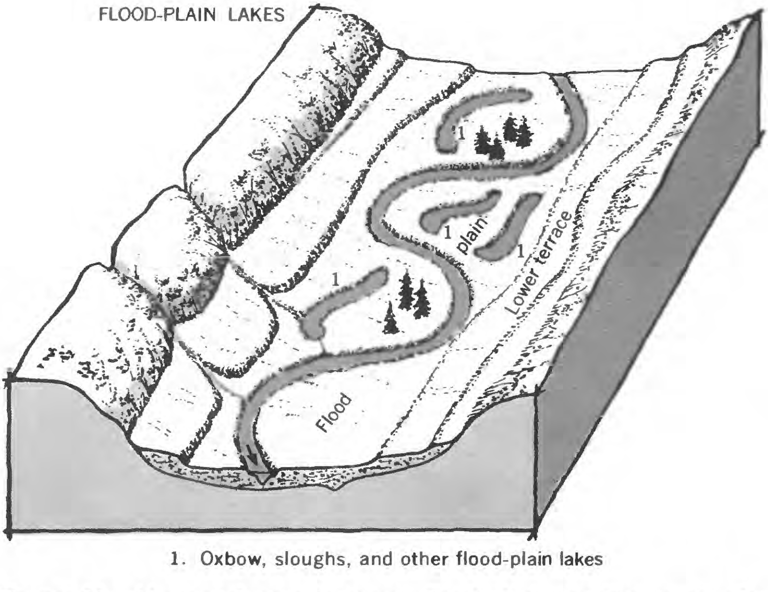
The low mountains of the Coast Range have been carved into a series of deep canyons separated by sharp narrow ridges that in part are underlain by weak sedimentary rocks. The heavy winter rains usually keep the surface soils and any porous underlying rocks saturated from November to March each year. These factors all tend to produce slipping and minor landsliding. Here and there landslides have dammed river valleys and created small mountain lakes. Squaw Lakes, Esmond, Loon, and Triangle Lakes were thus formed. Most of these lakes lie in remote canyons and are little used except by hardy fishermen, but the few that are easily accessible are used extensively for recreation.

FLOOD-PLAIN LAKES

On flat alluvial plains, rivers tend to meander, or wander from side to side. Occasionally a river will cut across a loop and will dam both ends by sedimentation; a section of former channel will thus be isolated as a bayou, slough, or oxbow lake. Beaver and Colorado Lakes, near Corvallis, and Hayden and Humbug Lakes, near Independence, are such lakes. Some of these river-made lakes are now protected by flood-control dikes or dams (Kellogg Lake at Milwaukie, Blue Lake near Portland, Sturgeon Lake on Sauvie Island), and some have been drained and are used intensively for



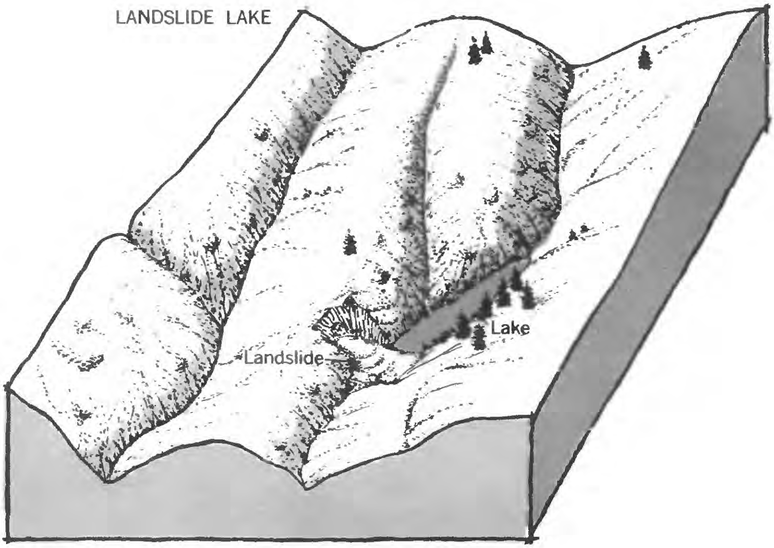
1. Obstructed channel of stream that formerly drained to the ocean at a lower level
2. Small stream obstructed by encroaching sand
3. Lagoonal lakes at level of water table in the sand



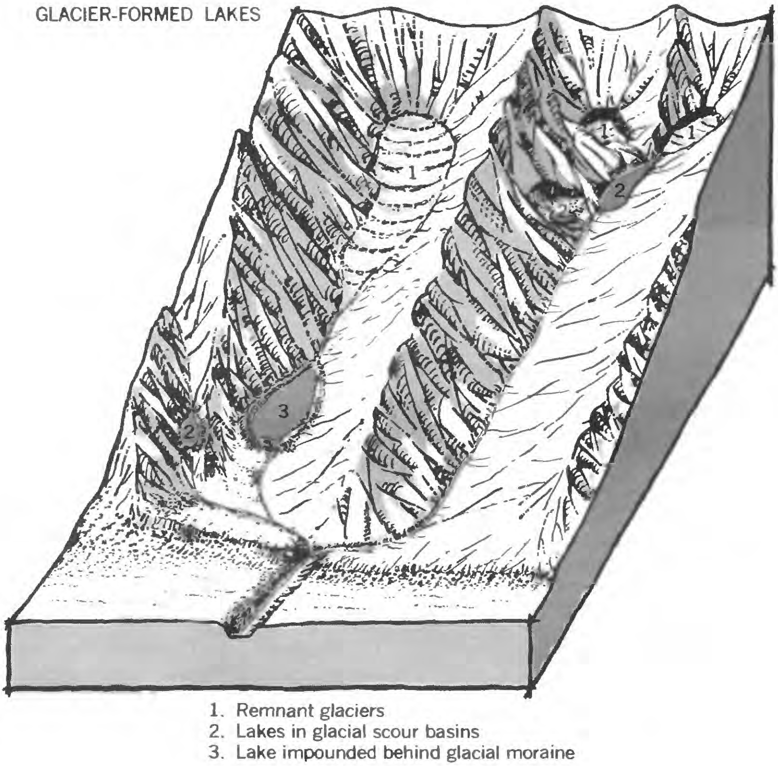
1. Oxbow, sloughs, and other flood-plain lakes

FIGURE 36.—Above and opposite page. Block diagrams illustrating the origin of lakes formed by sand dunes and by other agents.

LANDSLIDE LAKE



GLACIER-FORMED LAKES



1. Remnant glaciers
2. Lakes in glacial scour basins
3. Lake impounded behind glacial moraine

vegetable gardening (Labish Lake near Salem, Wapato Lake at Gaston). The waters of some are used for irrigation as well as for fishing, hunting, and other recreational purposes.

GLACIER LAKES

Most of the hundreds of lakes that lie along the crest of the Cascade Range and Wallowa Mountains were caused, or their shapes were determined, by former mountain glaciers. On some of the higher mountains, glaciers that still exist have receded from their most advanced positions and have left small lakes impounded above the ridges of boulders and earth that geologists call "terminal moraines." A far greater number of tiny lakes occupy little basins that have been scooped out of the rock by former glaciers; such lakes are sometimes called "tarns." Ice Lake and Aneroid Lake in the Wallowa Mountains and Blue Lake near Santiam Pass are examples of tarns. Wallowa Lake is a classic example of a lake in a trough that was excavated by an alpine glacier and then dammed by the glacier's terminal moraine; Odell Lake is another. By coincidence, both lakes have about the same depth, slightly less than 300 feet. Fourmile, Diamond, Crescent, and Waldo Lakes were formed by the scouring action of large fan-shaped bodies of ice, and in part were dammed by glacial moraines. In the Blue Mountains, Strawberry, Magone, and Anthony Lakes are of glacial origin. Some of these lakes are used to store water for irrigation, and all have a constantly expanding recreational use.

Glaciers themselves are similar to lakes and reservoirs in that they store large quantities of water and release it later. Living glaciers of modest size occur on the high slopes of Mount Hood, Mount Jefferson, and The Three Sisters; smaller glaciers are on Broken Top Mountain, Diamond Peak, and Three Fingered Jack, all in the central and northern part of the Cascade Range. In general, the glaciers have been receding or melting away since about 1740, when the greatest recent advance occurred. A few small glaciers have disappeared within the present century, and others appear to be almost "dead" or stagnant. Some of the larger glaciers are now at least 400 feet thinner in places than they were about 200 years ago.

Water-supply engineers are sometimes asked: "What will happen to the summer flow in my river if the glaciers should disappear completely?" To answer that question, let us consider where the summer flow has its source. Most of it comes from springs and from melting snow, and that part may be considered as a steady income that presumably will be continued. A very small amount represents the annual reduction in the volume of the ice, and that part may be considered as drawing upon a savings account built up in past years. Therefore, if the glacier were to disappear because of a warmer climate, the summer flow of streams would be very little less than at present. But if the climate became drier, then the reduction in spring flow and snowmelt would deplete both the summer and the winter flow much more than would the absence of a relatively small body of ice.

For an illustration of the rather minor effect of the small Oregon glaciers on riverflow, consider the Hood River and its tributary glaciers—Newton Clark, Eliot, Coe, and Ladd. The four glaciers cover about 830 acres. If they lose 2 feet of ice each year, between July 1 and September 30, the total volume of water drawn from the savings account is only 1,600 acre-feet, equivalent to an average flow of 9 cfs for 90 days. But at the mouth of the river the average flow during this period is 550 cfs. The figures are not exact, but it can be concluded that the draft on the savings account is only a small part of the total seasonal income, for no other Oregon stream has more glaciers in its headwater area.

The long period of glacier recession may be about over—in fact, glaciers on several peaks in Washington are now growing thicker or advancing. It may well be that some of the icefields on mountains in Oregon soon will be growing larger rather than smaller, and may thus be building up a savings account for some Oregon rivers.

SPRING POOLS

A few springs form pools large enough to be called lakes. Hot Lake near Union is an example. This lake is a large steaming mineral spring which rises along a faultline.

Another mineralized pool is Borax Lake, east of Steens Mountain in Harney County. Little Crater Lake on the headwaters of Oak Grove Fork of Clackamas River is a clear spring pool of fresh water about 100 feet in diameter and 40 feet deep; it is not a true crater lake as the name suggests.

LAVA-DAMMED LAKES

Much of the Cascade Range and parts of southeastern Oregon are covered by lava flows that are relatively young, as geologists reckon age. These flows coursed down the steepest slopes, just as thick molasses would do; some reached the channels of large streams, and there they created dams that ponded the water into lakes. (See fig. 37.)

One of the most notable of the lava-dammed lakes is Clear Lake on the McKenzie River. Here the forest trees that were growing in the canyon of the river, before the eruption of the lava, were killed by the rising waters of the lake. In time the trees rotted down to water level, but below the surface the wood was preserved from decay by the fresh water. The stumps or snags of the former forest (about 3,000 years old by radio-carbon dating in 1963) may still be seen just below the surface of the lake.

Fish Lake in Jackson County and another Fish Lake in Linn County are other examples of streams dammed by flows of lava.

Large bodies of water occur underground in parts of the State, and many continue into open lake areas level with the water table. One such underground water body has an open "window" that permits inspection by anyone who has enough interest to walk half a mile down the smooth floor of a lava tunnel. This lava tunnel, called Malheur Cave, is in young lava about 50 miles southeast of Burns. The small underground "lake" is at the level of the local water table. Within the cave the lake is navigable by rowboat or canoe, and because it has a setting of unusual geological and scenic interest, it creates a recreational value likely to increase as the cave and pool become better known.

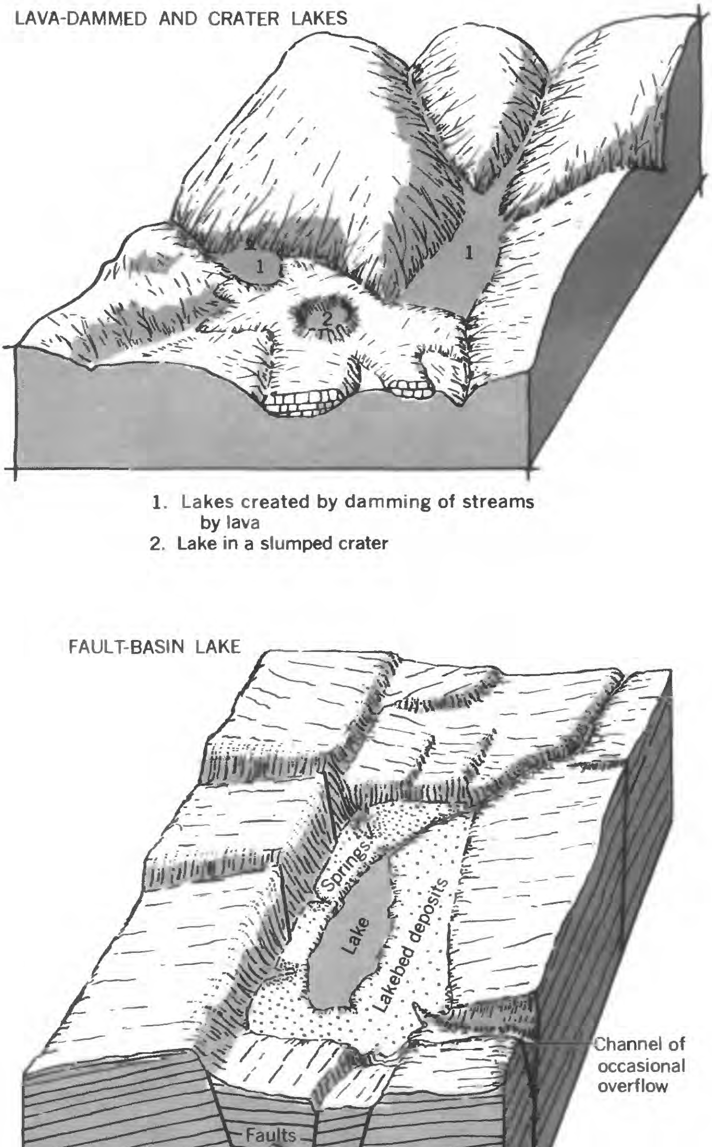


FIGURE 37.—Block diagrams illustrating the origin of lakes formed by volcanic action and by faulting.

CRATER LAKES

The calderas of several extinct volcanoes now contain lakes. The best known is Crater Lake, in Klamath County. (See frontispiece.) Similar but somewhat smaller lakes, known as East Lake and Paulina Lake, exist in the twin craters of the extinct Newberry Volcano in Deschutes County. East Lake is 40 feet higher in elevation than Paulina Lake, and it has no outlet except by seepage through the lava and volcanic-ash deposits that enclose it. The smallest crater lake in the State is also the highest of all the lakes. It is a small unnamed lake in the crater of South Sister volcano, at about 10,200 feet in altitude. These lakes are valuable recreational and scenic attractions.

FAULT-BASIN LAKES

Over thousands of years in time, the crust of the earth may be tilted or sheared, or moved up or down; drainage is disrupted and lake basins are created (fig. 37). Such movements of the earth's crust have taken place and several large lakes—Abert, Summer, and Warner Valley Lakes among them—have been thus formed in the southeastern part of Oregon. Some of these lakes lack adequate outflow, and their water is salty; in some there is dense brine in dry seasons. The fresh-water parts of these lake basins are wildfowl nesting and resting places, and they include shooting grounds dear to the hearts of Oregon's duck and goose hunters.

PLAYAS

A playa is a shallow lake whose bed is usually dry in dry seasons, except perhaps for very small spring-fed pools; some are dry for years at a time. The lakebeds may contain minerals left by the evaporation of the water. In Oregon, the best known examples are Alvord, Guano, Alkali, Thorn, and Christmas Lakes, all in the southeastern part of the State. The term "playa" is sometimes applied to lakes that are seldom dry, such as Malheur, Mud, and Harney Lakes. There are others that are normally or almost always dry, such as Fossil Lake and Dry Lake in the northeastern part of Lake County. There is little or no use of the saline water of the playas.

MANMADE LAKES

Though the previously described lakes are natural, most have been changed to some extent by man's activities. Some ephemeral lakes have been made permanent, or deeper, by dams; some permanent and semipermanent lakes have been diked or drained, or dried up by diversion of their inflow streams. But there are also lakes which did not exist before the white settlers came. The long, narrow reservoirs above Bonneville, The Dalles, McNary, and Brownlee Dams are manmade interstate lakes. Owyhee Dam, completed in 1932 on the Owyhee River, forms a lake 50 miles long and over 300 feet deep. Other reservoirs by the hundreds range in size down to small millponds and stock-watering ponds.

WATER PURITY

'Til taught by pain, men really know not what good water's worth.—*Lord Byron*

An observant tourist driving along any major highway in Oregon will soon see a roadside fountain with a sign DRINKING WATER. He may see other springs or streams bearing signs IMPURE WATER—DO NOT DRINK. The quality of the water may be further impressed on his mind by signs referring to places such as Stinkingwater Pass, Drinkwater Pass, Clear Creek, Medical Springs, Hot Lake, Spring Creek, Alkali Lake, and Cold Springs. The tourist may wonder, "By what standards should water be judged?"

Water is the most abundant compound on earth and it serves many purposes. The use of water for drinking and other domestic purposes has always been and universally remains the primary, the highest, the most essential use of water. The physical, chemical, and bacteriological qualities of drinking water in the United States are now commonly evaluated by the U.S. Public Health Service drinking-water standards of 1962.

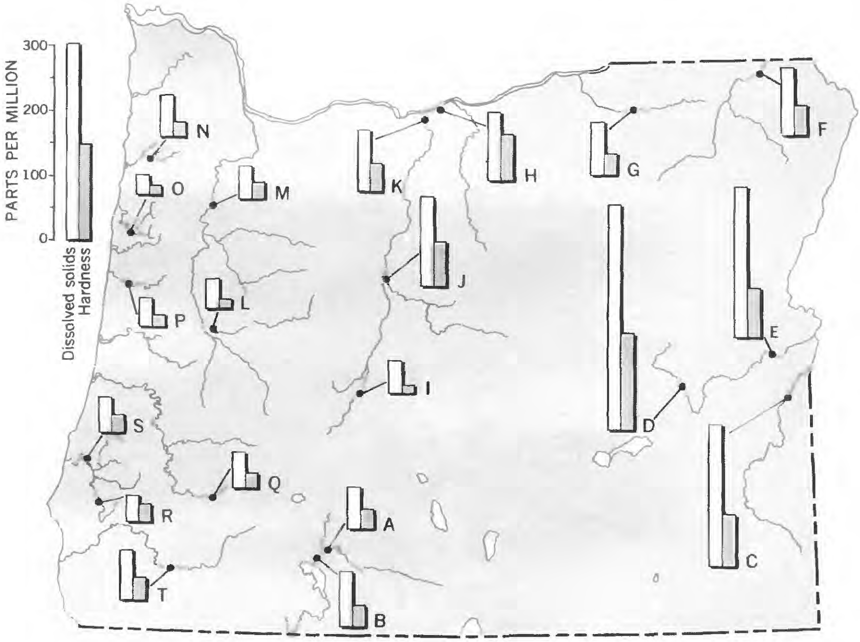
The physical standards set the upper limits for turbidity, color, taste, and odor of filtered water supplies. Chemical standards, on the other hand, have mandatory requirements for certain substances and recommended limits for others: mandatory limits have been established for lead, barium, cadmium, silver, selenium, and hexavalent chromium; recommended limits are given for copper, iron, manganese, carbon chloroform extract (soluble organic material), zinc, chloride, nitrate, sulfate, phenols, alkyl benzene sulfonate (ingredient in household detergents), and total solids. Mandatory as well as recommended limits are set for arsenic, cyanide, and fluoride. Standards for bacteriological quality limit the number of organisms of the coliform group.

Hardness of water in respect to both domestic and industrial use receives great attention. Hardness is recognized by the difficulty in obtaining a lather without an excessive consumption of soap. Scale forms in containers in which hard water is boiled. Industry is concerned with hardness because of scale deposit in hot-water pipes, steam boilers, and water heaters. This deposit costs money because heat is lost, fuel consumption is increased, and pipe capacity is reduced. One arbitrary rule classifies water of 0–60 ppm hardness as soft, 61–120 ppm as moderately hard, 121–180 ppm as hard, and more than 180 ppm as very hard. On the whole, Oregon is a "soft-water" State; for example, 15 major public supplies have an average hardness of 33 ppm.

The quality requirements of the many industrial processes differ far too much to allow many broad generalizations. One desired characteristic of primary importance to all industries is constancy in the quality of the water, because variations in concentration in industrial-process water require continued attention and may require costly treatment.

L. B. Laird (U.S. Geol. Survey Prof. Paper 417–D) and John F. Santos (U.S. Geol. Survey Water-Supply Paper 1784) have prepared reports covering the water quality of many of the streams of Oregon. Laird and Santos conclude that the water of Oregon's rivers is generally low in mineral content and is acceptable for most uses. The water of streams in the western part of the State is generally exceptionally soft and low in dissolved-solids content, being comparable in these respects with the best surface-water bodies of New England, northern New York, and northern Wisconsin. The water of rivers of eastern Oregon is not uniform in character: The Deschutes, Grande Ronde, and Wallowa Rivers have soft water, but the Crooked, John Day, Owyhee, Powder, Snake, and Umatilla Rivers have hard water that contains much greater quantities of dissolved solids than water of streams of western Oregon. (See fig. 38.)

Irrigation water is classified on the assumption that it will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crops. Quality ratings are based on salinity and alkali hazards, boron and bicarbonate concentrations, and such factors as drainage and management practices. Little irrigation water in the State fails to have a satisfactory rating.



A, Sprague River near Chiloquin
B, Williamson River near Chiloquin
C, Owyhee River below Owyhee Dam
D, Malheur River at Drewsey
E, Malheur River near Hope
F, Grande Ronde River at Troy
G, Umatilla River at Pendleton
H, Columbia River near Rufus
I, Little Deschutes River near Lapine
J, Crooked River near Culver
K, Deschutes River at Moody
L, McKenzie River near Eugene
M, Willamette River at Salem
N, Nestucca River near Blaine
O, Siletz River near Siletz
P, Alsea River at Tidewater
Q, South Umpqua River at Tiller
R, South Fork Coquille River near Powers
S, Coquille River at Coquille
T, Rogue River at Grants Pass

FIGURE 38.—Surface-water quality. All surface water contains some dissolved minerals. Water in streams in the rain-shadow area is more mineralized and is generally harder than water in streams on the west slopes of the mountains.

Some of the chemical constituents in water are important health factors. Among these are fluorides and iodine compounds. Because of the lack of iodine in food and water in some parts of western Oregon, goiter was once endemic there. (See "Endemic Goiter in Oregon," by Robert Oleson, U.S. Public Health Service Repts., v. 42, no. 40, Nov. 18, 1927.) A deficiency of fluorides can result in an unusual prevalence of dental caries in children; too much can cause a mottling of the teeth, as has occurred in a few places in southwestern Oregon. Water containing more than 2 ppm fluorides may be detrimental. The water of northwestern Oregon is deficient in fluorides; that of the volcanic plateaus of eastern Oregon has a more desirable content of natural fluorides.

In a general discussion of water quality, consideration must be given to movement of sand, silt, and clay by streams as suspended sediment. The sheet erosion from fallow or newly seeded grainfields on sloping land is noticeable in northeastern Oregon, where the Umatilla, Walla Walla, and John Day Rivers and Willow Creek carry heavy loads of this unnatural soil loss. The greatest amount of soil reaches the streams when a quick thaw in winter or spring causes the soil on some slopes to flow as a mass over the still-frozen subsoil. Some of these single mass movements of soil disrupt the normal channels of small streams and virtually bury crops in lower valleys. The U.S. Soil Conservation Service is charged with providing assistance in abating these water-contaminating and soil-wasting situations. So far no Federal or State laws directly penalize negligent practices that permit rapid erosion; real abatement depends largely on the voluntary action of the landowner.

The accelerated erosion from some newly logged or fire-swept timberlands is usually worst during the first few years after the land is denuded. In places, accelerated runoff has resulted also in disruption of normal stream channels, abnormal overflow, burial of lands downstream, and damage to fish and wildlife habitat. Forest authorities are revising logging procedures to reduce this contamination of streams by silt and debris. Heavy timber stands on steep slopes

FIGURE 39.—Above, Areas logged in the Salem Hills by staggered-plot or patch-logging arrangement, one method now practiced where clear cutting of the timber is necessary. The intervening patches and creek-bank strips are left forested until reforestation has in part restored natural soil retention and runoff conditions to the logged areas. Below, An area in the Rogue River basin where selective logging of Douglas fir has left the forest growth in condition to prevent undue erosion and to moderate the rate of runoff. Photographs by U.S. Bureau of Land Management.

that must be "clear cut" may be cut at intervals of time, and in patches, so as to lessen the danger of erosion and to hasten the reestablishment of natural forest conditions (fig. 39).

Silt and fine erosion products are the most common physical contaminants, but certain industrial wastes may be more obnoxious locally. Disposal of sawdust, bark, and wood scraps in Oregon rivers once caused major debris problems, but the practice is now rare. Stream disposal of tannery wastes has been restricted by health authorities. Sporadic disposal of waste tar and oil to water has had serious effects on wildlife, especially birds, and has made some beaches temporarily unfit for recreation.

The temperature of river water varies somewhat with air temperature, but has a much smaller range both daily and seasonally. Running water freezes at 32°F; hence, moving streams of fresh water never are colder than that. Water of most Oregon streams seldom rises above 70°F, though water of small streams in wide, shallow channels may rise to about 80°F at times. Only rarely does the temperature of moving water in a large creek or river vary as much as 10°F in any one day. The temperature of any stream is affected by its tributaries, and especially by nearby springs. Many of the large springs in the Cascade Range have a temperature of about 43°F, summer and winter. Ice rarely forms near or downstream from these large springs, and it almost never forms across rivers rising in the warmer and more humid environment of the Coast Range.

The shallower lakes in the high mountains do become frozen over, some to considerable depths and for long periods, but ice does not form at the flowing outlets of these lakes, and lake-derived water keeps the rivers free of ice for some distance downstream. Water under the ice in a lake is always a few degrees above the freezing point because under normal conditions water is heavier at 39.2°F than at any other temperature, and therefore, when any part of the lake water is chilled to a temperature of 39.2°F, it settles toward the bottom. When the entire lake has been cooled to that temperature, any further cooling causes the water to expand slightly and become lighter; hence, when a lake is

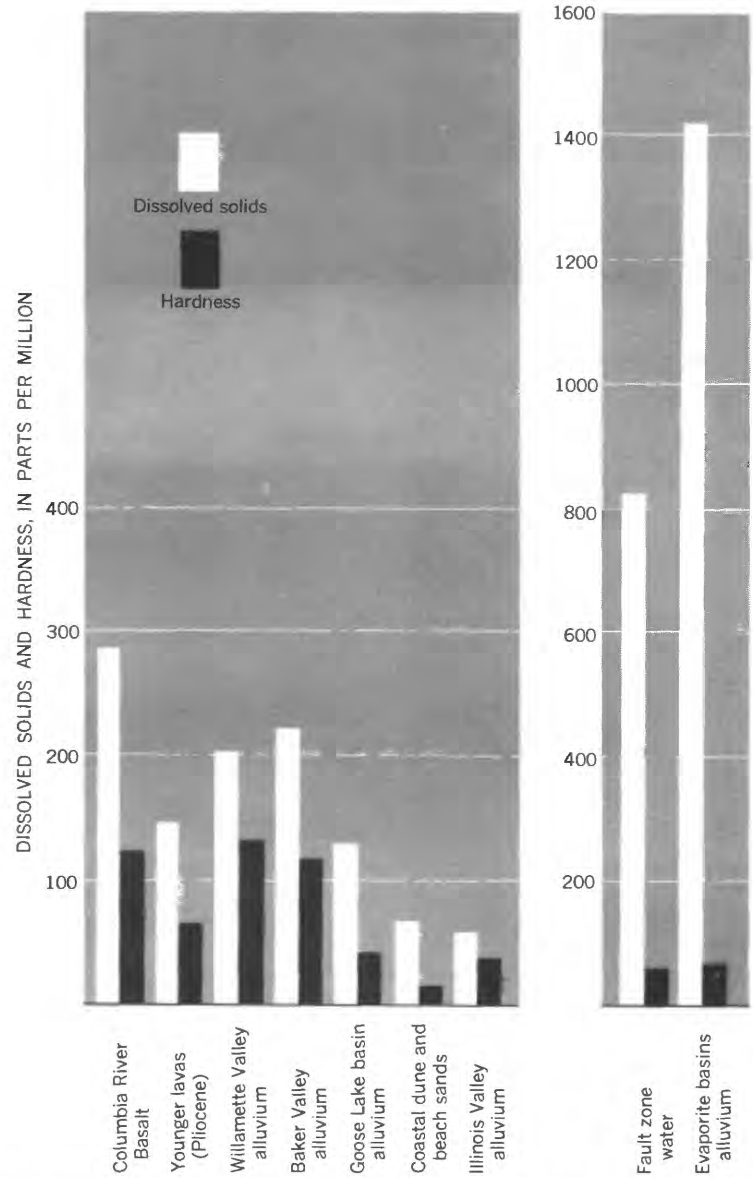


FIGURE 40.—Ground-water quality. Ground water in most places contains more dissolved minerals and is generally harder than surface water.

covered with ice, the water underneath will range in temperature from 32°F just under the ice to 39.2°F in the next hundred feet of depth.

The temperature of the ground water as a whole is approximately the same as the mean annual air temperature at its location, plus 1.8°F for each 100 feet of depth of its occurence below the first 100 feet; however, there are many minor and some major exceptions to this rule. In places the cold snowmelt and winter rain enter the shallow aquifers and reappear soon after as spring flow without having become fully warmed to the mean annual ground temperature of the locality. Thus, the ground water in springs flowing from the shallow gravel aquifer below Milton-Freewater may in places be at only 45°F during the summer months.

In other places, particularly in lava rocks, the earth's temperature gradient is higher than that generally taken as "normal," and the ground water from these rocks may be from 1° to 10°F above the temperature considered "normal" for ground water at that depth and location.

The warmest ground water is that along earth fault zones. Near some of the faults it is commonly 10° to 170°F above ground temperature elsewhere. Springs issuing along these faults are termed "warm springs" or "hot springs" according to their temperatures. The hottest water, observed in wells drilled along these faults, has been measured at 220° to 226°F at Klamath Falls and Lakeview. Ground water at such temperatures erupts in geyser fashion from wells at Lakeview and in Warner Valley north of Adel.

Ground water is also mineralized. The degree of mineralization varies greatly from place to place; it is generally greater in dry than in wet areas. (See fig. 40.) For any specific site and aquifer, the physical and chemical quality of the water is generally the same at all seasons.

WATER PROBLEMS

LOW FLOWS OF STREAMS IN LATE SUMMER

One of the severest and most common water problems arises from the annual cycle of precipitation and runoff. In many basins the streamflows are deficient during the warm months of the year. In the eastern part of the State most of the smaller streams have little natural flow by July, and many are dry by August. The larger streams, such as the Umatilla, Grande Ronde, Powder, Malheur, Owyhee, Silvies, John Day, and Chewaucan Rivers, follow a similar pattern but do provide some late-summer discharge, much of which is commonly diverted for irrigation. The Deschutes and Klamath Rivers and the short Ana River obtain much of their flow from large springs and maintain substantial discharge throughout the dry months of the year.

West of the Cascade Range many of the streams have a similar weak flow during the late summer. Only those streams that drain from snowfields or from the ground water in the younger volcanic rocks of the high parts of the Cascade Range maintain a substantial natural discharge during the late summer and fall. The boundary rivers, the Columbia and the Snake, obtain much of their water from snowfields in the Rocky Mountains, and their delayed runoff fortunately maintains high stages in these rivers through much of the summer.

The apparent remedy for the short supply of water during the annual period of low streamflows is natural or artificial storage of excess flows. In some river basins, either surface or underground storage is possible, but other basins lack both suitable reservoir sites for surface storage and permeable rocks for underground storage. As seasonal water shortages become an increasing obstacle to the growth of communities, greater use will undoubtedly be made of storage to ease the water shortages of the annual low-flow period; however, in many of the eastern Oregon basins where the total precipitation is small, even the storage of all the runoff would not provide enough water for the potential needs of the basin.

TOO LITTLE WATER

In those places where full use of all the water does not satisfy the normal requirements, the area must either receive diversions of water from water-surplus areas or remain on a water-deficient economy. There may always be a shortage of water for lands in the high-plateau region in Klamath, Lake, Harney, and Malheur Counties. There the general altitude of 4,000 to 6,000 feet and the corresponding short growing season limit the use of most of the land to grazing. Despite the overall water shortage, that region is reasonably well supplied with surface- and ground-water sources of drinking water for livestock.

In water-short areas the stretching of the supply commonly requires maximum conservation and reuse of the available water. For such situations the nonconsumptive uses of some industries and recreation can be fitted into the multiple-use plan ahead of those that result in consumptive use. Limited supplies can be used to the best advantage when the water is first devoted to nonconsumptive uses, such as hydroelectric generation, cooling, washing, and other manufacturing processes, before such consumptive uses as irrigation or evaporation in wildlife refuges.

Some areas that have more than 100 inches annual rainfall are plagued by a shortage of easily accessible water for domestic, irrigation, and other uses during the warmer months.

This shortage is caused by the lack of natural water storage and cheap artificial storage. The shortage is especially acute for lands and slopes well above the water courses. There are many places in the foothills of the Coast Range, on the slopes of the Rogue and Umpqua River valleys, and on the west slopes of the Willamette Valley where it is economically difficult to obtain sufficient dependable supplies even for domestic use from the usual type of surface or ground sources. The pumping of water from distant streams and springs, the storing of roof drainage, and other unusual methods may be needed to obtain domestic water supplies cheaply at some places.

TOO MUCH WATER

The need to reduce the height of flood crests and the damage done by unusually high stages of the streams is urgent in some river valleys. Particularly vulnerable to damage are parts of the populated lowlands along the tributaries of the Umpqua, Rogue, Willamette, and Columbia Rivers and the short coastal streams. Many of the rivers have some settlements along their banks that are occasionally damaged by unusually high stages. Nearly all the streams except the rivers fed by ground water, such as the Deschutes and Klamath Rivers, have the potential of occasional flood destruction (fig. 41).

Most of Oregon's cities and towns have been built above the channels and flood plains of the streams. The narrow flood plains of many of the smaller streams are sparsely inhabited, and here flood damage is minor compared with that suffered in other States. Flood plains are partly protected by dikes along the Willamette and Columbia Rivers downstream from Portland and along the lower Coquille, Coos, Trask, and Wilson Rivers. The flood plain of the Willamette River is now partly protected by the storage of floodwaters behind dams on the Long Tom River, McKenzie River, Coast Fork, Middle Fork, and Row River headwater branches of the Willamette River, and by Detroit Dam on North Santiam River. Dams under construction (1964) on Fall Creek and Middle Santiam River will provide further protection. Annual high stages of the Willamette River at Portland are usually caused by backwater from the high levels of the Columbia River that occur in May and June and that can be adequately controlled only by additional upstream storage.

FIGURE 41.—Floodwater of the Coquille River spread across its flood plain southeast of Coquille, December 23, 1945. Photograph by U.S. Corps of Engineers.

In general, the rivers of eastern Oregon are comparatively free of flood damage except where they empty from mountain canyons onto local valley plains, as the Walla Walla River does at Milton-Freewater, the Umatilla at Pendleton, the Grande Ronde at La Grande, the Powder at Baker, the Malheur at Vale, and the Chewaucan at Paisley. All these streams are subject to flash floods from cloudburst type of precipitation or from warm rains on snow. The hazard of flash floods is especially great in the central Oregon mountains, but it is present to lesser extent in the mountain slopes of nearly all of eastern Oregon. The logical protection against flash flooding lies in the proper location of towns, habitations, and improvements, rather than in expensive remedial works after man's installations have been placed in hazardous areas.

CONFLICT OF INTEREST AMONG WATER USERS

In addition to the problems arising from too little and too much water, there are those which arise from conflicts of interest among actual or potential users of the water. Wherever multiple use of the water is undertaken, people like to retain all previous benefits as each new use and each new benefit is obtained. This worthy objective requires that many potential conflicts of interest be foreseen and be resolved in advance.

Divergent views about use of the State's waters are frequently aired. Irrigation rights are weighed against rights for stock watering, for fish and wildlife propagation, and for power generation. Needs for power generation are evaluated against those for fish life. The use of water for hydraulic mining has been opposed by sportsmen and by irrigation districts. The use of streams for disposal of untreated domestic and industrial wastes has been a controversial issue, now resolved by required treatment.

Other possible sources of contention are as numerous and as varied as the many uses by which water affects our individual lives. High on the list of these fields of interest is that of the regulation of water levels in streams, lakes, and ground water. The general public often overlooks the interest which some users have in simple matters like the levels at which water stands in stream channels, lakebeds, and ground-water reservoirs. An extremely high level in a lake may be of no significance to one owner but ruinous to his neighbor. Water level is very important to many people in its relation to the volume and time of runoff, its effect on waterlogging and subirrigating land, and its influence on buildings, other structures, and stored goods.

Other problems exist, such as the passage of migratory fish at dams or other obstructions. Ideally the upstream course of the brood fish should be assisted, and the downstream return of fingerlings should bypass turbine blades and pressure tubes. The chemical and physical character of water returned to the streams and to the ground as well as the artificial water losses due to evaporation also present continuing problems.

POLLUTION

As the population of Oregon has grown, some of the streams that the pioneers found clear and pure have become fouled by pollution not only from sewage wastes but from wastes of industry as well.

The largest single chemical contaminant of Oregon streams is the waste from pulp and paper mills. It results from the digestion of wood by a solution of calcium sulfite and is known as ligno-sulfonic acid. The acid is a dark, thin, syrupy fluid which contains the resins, sap, and nonfiber elements of the wood. About 40 percent of each log which goes into such a papermill to be shredded and digested for its fiber leaves the mill in this solution. The liquor has a phenomenal hunger for oxygen, and the outflow from a mill is capable of consuming the oxygen content of a large river for many miles downstream. Fish cannot live in this oxygenless water, the normal combustion of organic material cannot proceed, and the water becomes foul with undecomposed waste and slimy organisms which can live without oxygen.

The abatement of this condition is proceeding in four ways: (a) Changing the mills to different processes in which the wastes can be purified before discharge to the river; (b) evaporating the liquid and burning the residue; (c) storing the liquids until high water, at which time the dilution and the current eases the effect of the waste on the river; (d) research into methods of extracting and using this resinous waste in the chemical industry.

Pollution by sewage offers a different set of problems. Sewage contains organic matter in suspension and solution, as well as mineral substances in solution. The organic matter is largely in an unstable condition, and it eventually breaks down into compounds that are stable. If this breakdown or decomposition occurs in the presence of a sufficient supply of oxygen, the active nuisance is greatly reduced; however, putrefaction results if the organic matter breaks down in the absence of oxygen. The presence of sewage in a stream generally means that pathogenic or disease-producing organisms also are present.

Only a few decades ago, sewage outfalls were commonly piped to the river. As the region became more settled and the waters came into more intensive use, conflicts developed from this practice. For many years the Willamette River was so devoid of oxygen from pulpmill wastes that it could not oxidize the heavy sewage loads, and all swimming and most recreation uses in the lower part of the river were prohibited by health authorities. The once-strong migrations of salmon had been reduced to a struggling few "spring chinooks" that were able to move upstream during the spring freshets. The use of our waterways for waste disposal became so offensive that public demand caused the formation of the State Sanitary Authority in 1938. Most people were agreeable and willing to abate the nuisance but needed to be told when they must expend the funds for treatment plants.

Soon after the end of World War II the main part of the cleanup got underway. The city of Portland constructed a trunk sewer pickup line and a primary-treatment plant from which the treated effluent is discharged to the Columbia River. Other municipalities and districts put in treatment plants. In 1939 only 49 plants were treating sewage from 16.9 percent of Oregon's sewer-connected population, but by 1963, 212 plants were serving 96.5 percent. Further treatment of waste products is planned to maintain the quality of our water resources as population and industry grow; by the year 1975 secondary treatment will be required of all municipal sewage in Willamette River basin.

None of the organisms that cause disease are ordinarily found in ground water. They may gain entry to ground water and even survive during the percolation of the water for short distances underground. However, wells that have been properly located, cased, and sealed usually yield water free of germs. Just as proper filtration of water through a few feet of sand in a purification plant will remove single-celled parasites and many of the bacteria, so does the percolation of ground water through clean soil and rock tend to remove these organisms. The replacement of large-diameter, poorly curbed dug wells by smaller steel-cased wells has done much to abate waterborne disease in this country. The biological quality of water can be guarded by proper construction and water treatment.

LACK OF INFORMATION ON WATER

It is generally recognized that we need to know more about our water resources. We do not have enough information to plan for efficient multiple use. The needed information is being derived progressively in modestly financed Federal and State investigative programs aided by some counties, cities, and private corporations and individuals.

Since the first stream measurements were made nearly 70 years ago, the basic inventory of our surface waters has been continued and expanded. (See fig. 42.) We now know the discharge of most of our streams at some point for at least a short period of record, but some streams have not been measured because of lack of immediate interest in use or control of their water. The network of measuring stations needs to be expanded and continued to provide more long-period records of streamflow. The lakes are insufficiently known to permit proper planning for their wisest use.

The statewide ground-water resources are, in general, moderately well known, and the resources of the larger valley areas have been described with some detail. However, some valley areas are still without published sources of information on their local ground-water situation, many other

FIGURE 42.—Above: Instrument shelter at the stream-gaging station on Santiam River at Jefferson. The concrete shelter extends into the ground to a depth below the river bottom to form a well that is connected to the river through open pipes. The water level in the well is thus always the same as the water level in the river. A copper float supported on the well-water surface activates a continuous water-stage recorder. Frequent measurements of water stage and concurrent discharge furnish data for a chart relating stage to discharge. The continuous stage record is thereby converted to a continuous discharge record. Below: Measuring the flow of Lake Creek, the outflow of Diamond Lake. Mount Thielsen and the volcanic upland of the Cascade Range are in the background.

potentially important areas are unstudied, and the relationship between ground water and surface water in many river basins is little known.

The quality of the surface and ground waters is known only in general terms. Specific ground-water-quality data are available for only a very few locations, and the quality of water of few streams is well defined.

ECONOMY OF WATER

There's an old saying that "we never miss the water 'til the well runs dry." As long as the supply of water is ample there is little demand for economy in its use, but as the unused supply decreases, economy becomes imperative. Industry is now coming to that transition period in water use where factories must conserve water by recycling or reconditioning. Mechanical means are replacing water for moving materials within the plant. Stream disposal of industrial waste is being discontinued.

One of the principal industrial uses of water is for cooling. Formerly, after one cycle of cooling, the water was discarded, and some of it was not available for reuse. Now, much of this cooling water is being recycled through cooling towers for reuse, and there is less drain on the source. Much of the water used for washing is being reclaimed and reused. More water is being reconditioned by filtration and purification.

Basic plant design is being pointed toward more economical use of water. Many modern pulpmills use only one-half to one-quarter as much water as pulpmills of older design.

Water economies in irrigation are possible. These potential economies lie largely in greater efficiency of application of water to the soil, in reduction of conveyance losses, in recapture and reuse of excess water, and in general efficiency in the layout of the whole irrigation system. Farmers know that soil nutrients are lost by using too much water. Some newer irrigation districts and some individual sprinkler systems do economize in the use of water, but many of the older irrigated tracts continue to waste water and soil nutrients. Conveyance losses are high, especially from unlined canals and ditches that traverse sandy and gravelly soils or shallow soils over porous volcanic rocks. Some of the water lost is beyond recapture. The complete water tight lining of canals may not be economically feasible now, but as the value of water increases, some means of decreasing conveyance losses must be found.

Some of the early irrigation communities were not carefully planned in advance but "just grew," the land along the center of the valley having the rights to all the streamflow available for appropriation. Some of these tracts now use water wastefully on near-stream lands that hold the surface-water rights and also have the only feasible sites for ground-water pumping. Here the lowlands are waterlogged and poorly productive; above them the fertile slopes are dry and idle. Pumping of ground water for lands in the valley center would have bonus benefits: waterlogged lands could be restored to good productivity, and the water thus saved could be devoted to irrigating the slopes and benchlands.

Reduction of evaporation loss could save a great deal of water. About 80 percent of the evaporation commonly occurs in the dry and windy period April 1 to September 30, hence the principal saving of evaporation loss may be made by reducing the area of open-water surface during that part of the year. The average annual evaporation for the entire State is about 36 inches. The magnitude of this loss can be illustrated by computing the loss from the 84,000 acres of Upper Klamath Lake, about 252,000 acre-feet per year, or one-sixth of the average inflow.

The average annual evaporation has been measured at a sparse net of stations. These few observations indicate that annual evaporation loss ranges from 24 inches of water from open-water surfaces along the coast to 45 inches in the drier parts of eastern Oregon. In an area of high evaporation a shallow impoundment may result in the loss of more water than is made available by that storage. Thus, some broad and shallow reservoirs may make water available at the desired time but still cause a prohibitive overall loss through evaporation.

The storing of large amounts of water may require reducing evaporation losses to gain the highest returns. Research is now being made for chemicals that will spread a very thin film across water surfaces and reduce evaporation. Tests have indicated that some alcohols hold promise in reducing evaporation without damaging the water for any purpose. Other water economies may be effected by the proper management of reservoirs in areas of high evaporation toll. The diking off of large areas over which water spreads with shallow depth and in which water-storage gains do not justify the evaporation losses may be warranted in some lakes and reservoirs.

A little water can be saved by reducing transpiration of worthless vegetation. Water-consuming plants of low value transpire water from valley areas in eastern Oregon; in western Oregon large areas of brushy shrubs transpire water with small economic return. The reduction of transpiration losses by clearing such brush may offer worthwhile local water economies.

A start is now being made toward the appraisal of water losses due to useful but excess vegetation, such as the losses that result from the interception of snowfall on some closely spaced forest trees. Results of preliminary studies show that judicious thinning of some forest trees may increase both production of commercial timber and water yield from the drainage basin. A promising site for the trial of this method of augmenting the water yields of drainage basins lies in the vast areas of lodgepole pine on the pumiceous soil of the Klamath and Deschutes River basins. The possibility exists for the management of some of the forests for the maximum yields of water as well as for timber and other products.

WATER USE

The pioneers' small water needs could readily be satisfied with the water supplies in their natural environment. As population increased, both quantity and quality of supplies became problems. The problem of inadequate supply for parts of a year was solved by building reservoirs. Quality of supplies is maintained by regulating the use of streams for disposal of waste. However, almost every type of use affects the quantity or quality of the available supplies, as the following description of the uses of water in Oregon shows.

USES THAT RESULT IN SOME WATER LOSS

Irrigation, or the application of water to land in order to stimulate plant growth, is the greatest single consumptive use of water in Oregon. It ranks second to hydroelectric power in respect to the amount of water used. Nearly all of the natural flow of some streams is diverted during the growing season. Some excess winter flows are stored and diverted, but other streams do not have enough natural flow to meet demands for irrigation, even if all winter flows could be stored. Ground water is diverted through wells and applied to the land.

The following tabulation shows the acreage irrigated in each county in 1954 and in 1959, and the estimated amount of water needed to supply fully all the lands now under irrigation.

Irrigation in Oregon in 1954 and 1959

County	Acres irrigated (thousands of acres)				Estimated diversion by source (thousands of acre-feet) [1]		
	1954 [2]	1959 [2]	Change, 1954–59	Expected, 1975 [3]	Surface water	Ground water	Total
Baker	127. 5	119. 9	−7. 6	136. 8	350	30	380
Benton	9. 1	9. 7	+. 6	18. 7	13	1	14
Clackamas	8. 1	11. 1	+3	10	15	1	16
Clatsop	. 8	. 9	+. 1	5	1	0	1
Columbia	4. 7	4. 7	0	6	6	0	6
Coos	6. 3	7. 4	+1. 1	5. 6	10	0	10
Crook	45. 8	40. 3	−4. 5	67. 1	200	3	203
Curry	1. 7	1. 6	−. 1	2. 4	2	0	2
Deschutes	44. 4	44. 2	−. 2	40. 0	200	0	200
Douglas	10. 8	11. 9	+1. 1	17. 3	23	1	24
Gilliam	2. 8	3. 3	+. 5	5. 3	10	0	10
Grant	41. 6	41. 5	−. 1	53. 3	130	0	130
Harney	136. 6	84. 2	−52. 4	170. 0	250	24	274
Hood River	18. 9	18. 4	−. 5	24. 1	36	2	38
Jackson	53. 7	51. 8	−1. 9	49. 8	130	3	133
Jefferson	54. 8	53. 2	−1. 6	67. 7	240	0	240
Josephine	20. 8	18. 4	−2. 4	42. 4	50	3	53
Klamath	277. 3	231. 5	−45. 8	338. 6	600	80	680
Lake	120. 1	107. 5	−12. 6	130	220	20	240
Lane	19. 5	22. 5	+3	50	30	4	34
Lincoln	1. 5	1. 1	−. 4	4	2	0	2
Linn	19. 1	23. 5	+4. 4	34. 9	32	3	35
Malheur	204. 3	210. 8	+6. 5	213. 3	570	50	620
Marion	42. 1	44. 9	+2. 8	108. 3	60	9	69
Morrow	11. 4	14. 0	+2. 6	25. 5	30	4	34
Multnomah	4. 7	10. 2	+5. 5	10	15	1	16
Polk	8. 8	9. 5	+. 7	23	14	1	15
Sherman	. 6	1. 5	+. 9	1. 8	3	1	4
Tillamook	6. 4	6. 6	+. 2	10	7	1	8
Umatilla	56. 6	56. 3	−. 3	97. 8	250	27	277
Union	31. 1	27. 1	−4	40	60	2	62
Wallowa	43. 9	42. 6	−1. 3	47	130	2	132
Wasco	15. 2	16. 8	+1. 6	24. 6	40	10	50
Washington	16. 7	15. 2	−1. 5	26	22	1	23
Wheeler	10. 1	[4] 12. 5	+2. 4	15	30	0	30
Yamhill	12. 5	13. 5	+1	35	19	1	20
State	1, 490. 4	1, 389. 8	−100. 6	1, 956. 3	3, 800	285	4, 085

[1] Estimated diversion in a year of ample supply for lands now under irrigation.
[2] From U.S. Census of Agriculture, 1959, p. 146–149; rounded to nearest thousand acre-feet.
[3] Prediction by Oregon Conservation Needs Committee, 1962.
[4] Revised, Oregon Agricultural Extension Service, 1964.

The above table shows that the total acreage irrigated decreased 100,600 acres from 1954 to 1959; the decrease in Harney, Klamath, and Lake Counties was almost 111,000 acres. In those counties, the latter year was one of less than average runoff, but in the counties west of the Cascade Range, most of which had ample water supply in both years, there was an overall increase of 17,000 acres irrigated in the same period. The decrease shown in the eastern counties was temporary, but the increase in the western counties is expected to continue.

Acreage under irrigation varies from year to year because of fluctuations in market prices and costs of production and freight rates, as well as fluctuations in water supply. About 1,600,000 acres in Oregon is now (1964) irrigated at times.

The above table also shows the acreage expected to be irrigated by 1975. The total area of 1,956,000 acres represents an increase of about 25 percent over the present area irrigated in years of adequate water supply. The larger increases are expected to occur in the Klamath River basin (157,000 acres more than in 1959) and in the Willamette River basin (154,000 acres more than in 1959). Other large increases are foreseen in Crook, Jefferson, and Umatilla Counties, and in nearly all counties west of the Cascade Range.

Improved irrigation equipment and techniques have made possible the increase of irrigation in the Willamette Valley from 3,000 acres in 1930 to about 160,000 acres in 1959. Yields of many irrigated field and row crops are double the yields of the same nonirrigated crops, and yield from irrigated pasture may be more than double the yield of nonirrigated pasture. Furthermore, because of improved quality of produce, food-processing plants now frequently require irrigation as a condition to fulfillment of contracts for vegetables and fruits. Irrigation is practiced for hay, vegetable, grain, and legume crops, pasture for livestock, fruit trees, and berries. An additional area of about 600,000 acres in the Willamette Valley is irrigable, and the annual water requirements would be 1,200,000 acre-feet.

In river basins tributary to the main stem of the Columbia River east of the Cascade Range, more than 300,000 acres is irrigated and the average annual diversion is nearly 4 acre-feet per acre. Rainfall during the growing season is generally insufficient to produce crops of hay, fruit, and vegetables. Of nonirrigated crops, wheat and green peas are most important. The crops of peas and wheat are rotated on lands of more than average precipitation; crop failures occur in dry years. In addition to the land presently irrigated, more than 250,000 acres of land is considered suitable for future irrigation; about 1 million acre-feet of water would be required each year, and most of it would probably have to be pumped from the Columbia River.

Livestock raising is the main occupation in the Grande Ronde, Wallowa, Powder, and John Day River basins. Hay is the principal field crop, and there is considerable production of peas and seed in the Grande Ronde valley. An average diversion of about 3 acre-feet of water per acre is required for irrigation. At present (1964), about 110,000 acres of land is under irrigation in the Power River basin. In the Grande Ronde basin about 75,000 acres is irrigated, mostly in the broad valleys near La Grande and Enterprise. Because of the low flow of the streams in summer and the lack of storage, some of the land does not receive enough water. It is estimated that irrigation could be extended to an additional 100,000 acres in this region.

In south-central and southeastern Oregon (Crook, Deschutes, Harney, Jefferson, Klamath, Lake, and Malheur Counties), about 900,000 acres is irrigated. Here livestock raising is a major industry, and irrigation is necessary to grow hay for local livestock feed and alfalfa for shipment and sale. Sugar beets, hops, potatoes, and small grains are produced in large quantities in the Malheur and Owyhee basins. Development of ground water in these counties will probably make irrigation practicable for another 100,000 acres or more, and storage of winter runoff will permit still further expansion. At present (1964), one storage dam is under construction on Bully Creek near Vale, and others are planned for building on Chewaucan River and Lost River. Expansion of irrigation from surface sources in the Klamath River basin after 1957 is limited to 200,000 acres by the terms of the Klamath River Basin Compact between Oregon and California.

In the Rogue and Umpqua River basins, precipitation is insufficient during the growing season for full crop produc-

FIGURE 43.—View of row irrigation of onions in Sams Valley of the Rogue River basin. This method of water application works well on clayey soil and requires less labor once the fields are leveled and prepared. Table Rock appears in right background. Photograph by U.S. Bureau of Reclamation.

tion. Principal crops are fruit, hay, truck, and grass seed. About 90,000 acres of land is now (1964) under irrigation, and about 50,000 additional acres has been proposed for irrigation. Diversion requirement in this area is about 2.3 acre-feet per acre.

Along the coast, the mean annual precipitation ranges from 60 inches to more than 80 inches. Despite this seeming abundance, irrigation is needed for crops during July and August. Main agricultural activities are dairying and the raising of hay and silage, cranberries, seed crops, and bulbs. About 20,000 acres is now irrigated; the diversion requirement is about 1.0 to 1.5 acre-feet per acre. Estimates foresee 30,000 additional acres under irrigation in the future.

The "duty of water" for land is the average depth of water that is necessary to produce a full yield of the common field crops. East of the Cascade Range it is commonly taken as 2 to 4 feet, in the Willamette Valley as 1 to 2 feet, and in the coastal sections it is 1½ feet or less. The duty of water varies with the local soil, the crop grown, the length of the growing season, the natural moisture received during the growing season, and other conditions.

The water is applied under a variety of practices that use surface, sprinkler, and subsurface irrigation. Most of the irrigated land is watered by distribution of the water on the surface by rill, basin, or flood methods of spreading. (See fig. 43.) On rolling land and land that has highly permeable soil or subsoil and on fields that require only 1 to 2 feet of water, the application of water from pipelines and sprinkler heads is common. (See fig. 44.) This practice is also usual where water is pumped to the field. The French Prairie section of the Willamette Valley, between Salem and St. Paul, is one of the areas in which sprinkler irrigation is predominant.

The rate of application commonly varies with the duration of the natural water supply, some of the most rapid application resulting from the practice of flooding land for which only a spring and early-summer supply of water is expected. Places where the water supply is deficient in the

FIGURE 44.—View of sprinkler irrigation in Bear Creek Valley in the Rogue River basin. This method uses slightly less water and is preferred for sandy soil and subsoil and for unleveled land. Photograph by U.S. Bureau of Reclamation.

latter part of the growing season are especially hard hit economically by a series of dry years.

The amount of water diverted from the stream is always somewhat greater than the amount that eventually reaches the plants in the fields. The transit losses of water are greatest in the canals and ditches of some long distribution systems on highly permeable soil and subsoils; they are ordinarily least where water is withdrawn directly from a well or stream and applied to the land through a pipe and sprinkler system.

Of the water applied to the ground, some may go to: (a) transpiration by plants, (b) incorporation in the structure of the crop plant, (c) storage in the soil, (d) percolation beyond root depth in the ground, (e) runoff on the surface, and (f) evaporation from the surface. The first three processes are normal and proper irrigation uses; the latter three are normally unproductive.

The loss of water to deep percolation varies with circumstances, the most significant of which are the permeability of the subsoil and the rate and duration of the application of the water. As much as three-fourths of the water applied on gravelly soils over permeable subsoils may thus be lost. Some occasional loss to deep percolation helps to carry down harmful salts that otherwise might become concentrated in the root zone, but good irrigation practice avoids large losses. Evaporation from the surface is generally a minor loss, but it may be as much as one-fourth of the water applied. Excessive runoff of water on the surface is usually a sign of poor land preparation or water application.

Excess irrigation water may run off the surface or escape to deep percolation and thus return to the stream or to the ground water and become reusable, in amounts as great as 50 percent of the water diverted. As irrigation practices improve, such losses and return flow become smaller.

Irrigation results in a depletion of flow downstream. The consumptive use of water in irrigated tracts east of the Cascade Range in Oregon has been estimated as ranging from 1.0 to 2.0 acre-feet per acre irrigated (U.S. Geol. Survey Water-Supply Paper 1220, p. 22). Transit losses that do not return to the same stream may further deplete the downstream flow. The total depletion in streamflow because of irrigation in Oregon is estimated as about 2½ million acre-feet per year.

The use of water for irrigation affects its chemical quality. In percolating through the soil, water dissolves more salts and the concentration of dissolved mineral matter is thus increased. If the water diverted is low in dissolved minerals, the addition is usually not significant; however, when the water has a marginal concentration prior to its use, the additional minerals may render the water returned to the stream or ground water unusable for many other purposes as well as for irrigation.

Industrial uses of water include some which result in only minor water losses and others which have the effect of a large water loss. Minor water losses from industrial use result from evaporation and from the inclusion of water in the finished product.

Most water diverted for industrial purposes other than hydroelectric power generation is used for washing or for cooling. Other common uses in Oregon are for log ponds, log sprinkling, transport of raw materials and products, manufacturing process solutions, and heating. The metallurgical plants for aluminum reduction, steel casting and rolling, and other metal production use water mostly for cooling. Some mineral-treatment plants use water for transporting crushed ores. The timber-products operations use water mostly for transporting materials, maintaining moisture in unsawed logs, and washing. In the past, industry has used water extensively for waste disposal; such contamination may ruin large quantities of water for further use.

The food-processing and canning plants use large quantities of water as a washing agent or a processing liquid. Most of that water is returned to the streams or to the ground. Some processing liquids require purification to fit the water for reuse. Water requirements of most canneries are markedly seasonal and are greatest when streamflow is low.

The diversion of water for producing power is commonly done without water loss. However, large shallow reservoirs

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may cause a significant evaporation loss. About 160,000 acre-feet of water is now (1964) lost each year in Oregon by evaporation from reservoirs used chiefly for power.

The following rough estimates, in million gallons per day (mgd) and acre-feet per year, are made of water losses that result from diverting water for industrial use in Oregon:

Loss from—	Total used (mgd)	Loss (estimated)	
		Million gallons per day	Acre-feet per year
Evaporation in cooling, wetting, washing, and transporting materials	75	5	5, 500
Evaporation from reservoirs, in generation of hydroelectric power	180, 000	143	160, 000
Contamination (process water only)	20	20	22, 000

The nearly 2 million inhabitants of Oregon draw water at a rate that varies seasonally from about 20 to more than 340 gpd (gallons per day) for each person. The average total withdrawal for domestic and public water supply is about 150 mgd. About 30 mgd, or 33,000 acre-feet per year, is estimated as lost by evaporation from lawns, parks, streets, and reservoirs. The remainder returns to streams by way of purification plants and deep percolation.

Evapotranspiration occurs from large areas of shallow water reserved as nesting and feeding areas for migratory birds. About 200,000 acre-feet of water is lost each year in this way; half of the loss is from 35,000 acres of refuge water areas located chiefly in the Malheur Lake, Summer Lake, and Klamath River basins.

The estimated total depletion by man's use of water other than for irrigation appears to be about 400,000 acre-feet per year by evapotranspiration and 22,000 acre-feet by direct contamination. Until it has been treated, this contaminated water has the capacity to ruin many times that amount of water beyond usability for some purposes.

USES THAT ARE WITHOUT WATER LOSS

Some industrial uses of water involve a simple diversion through the plant and a return of the water almost unchanged to its original source. Among these uses are generating power, cooling and heating, and transporting raw materials or manufactured products within the plant.

The proper use of water in the streams, lakes, and snowfields for recreation ordinarily involves little water loss, except that lost by evaporation from game refuges. Recreation is a multimillion-dollar use of water, if a monetary value can actually be assigned. The tourist business, a large part of which is stimulated by Oregon's water, has exceeded $100 million per year for several years. Additional expenditures by Oregon residents for fishing, boating, duck and goose hunting, skiing, and other water-dependent hobbies make the recreational use of water a major industry.

Commercial fishing has been a basic Oregon industry since pioneer days. The three major classes of Oregon's commercial fisheries items are salmon and other "sea-run" species; ocean-dwelling fish, including sole, cod, rockfish, and tuna; and shellfish, of which clams, crab, and shrimp are the main items. Oyster "farms" are operated on some of the tidal areas. Commercial fishing for salmon was formerly done in the main rivers, but commercial river fishing is now limited to the tidal reaches of the Columbia River. Commercial fish range from the small eulachon, or smelt, to the large sturgeon; including shellfish, the annual catch ranges from 40 to 60 million pounds.

The mainstay of the fisheries industry has been the salmon (fig. 45). The names and nicknames of the different species are so loosely used that the average person is somewhat confused as to what salmon inhabit the waters of Oregon. Of the four species of the salmon genus (*Oncorhynchus*) in Oregon, the chinook (species *tshawytscha*) is the largest, adult specimens weighing generally from 15 to 40 pounds; the silver (*kisutch*), an intermediate-size fish of 5 to 15 pounds, usually spawns in coastal or near-ocean streams; the blueback (*negra*), a small 4- to 5-pound fish, runs in certain streams that contain lakes; and the chum (*keta*), which averages about 10 pounds, appears in small numbers as far south as the Columbia River.

The salmon belong to the group of fish called anadromous because of their custom of migrating up rivers to spawn. The young fish live in the streams for nearly 2 years before going to the ocean where they mature and return to spawn and die in their fourth or fifth year. The precocious males which follow the spawning run of mature fish are commonly referred to as "jacks."

The steelhead is a seagoing variety of rainbow trout (*Salmo gairdneri*) which becomes mixed with the commercially harvested salmon because of its migrating habits. Unlike the salmon, it does not die after the first spawning, but retires, thin and haggard, to the ocean from which it may return for several more spawning trips before dying as an aged fish weighing 10 to 20 pounds. The steelhead is a premier sports fish, and its continued classification with commercial fishes is of lively concern to the sports fishermen.

FIGURE 45.—Indians netting salmon at their historic fishing grounds, Celilo Falls on the Columbia River. Their rights were purchased and the falls were submerged when The Dalles Dam was closed in 1957. Photograph by U.S. Bureau of Sport Fisheries and Wildlife.

WATER FOR URBAN CENTERS

Primitive man obtained his drinking water from streams and springs where animals drank, assuming that water safe for them should be safe for him. This early test of a water source by animal reaction was a crude check on purity of the supply. Primitive man, prehistoric man, historic man, modern man, all have looked for water, adequate in quantity and of assured quality.

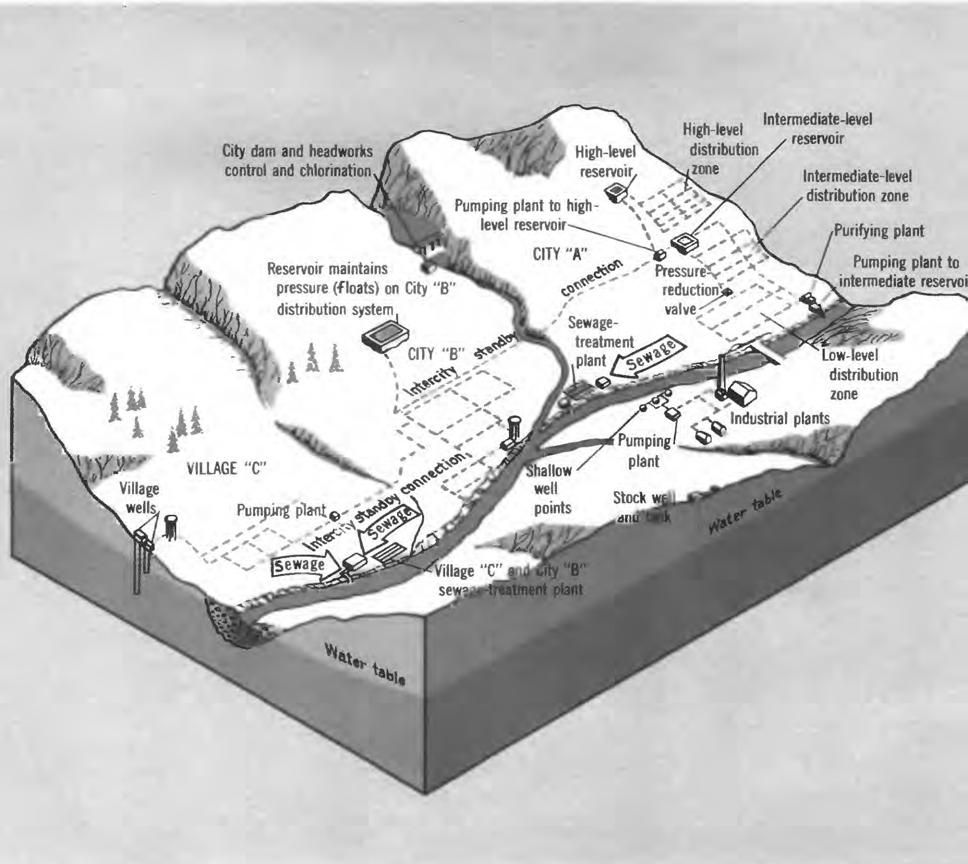
As civilizations developed, complicated public water systems were built. By the time of the Caesars, the Romans had a public water supply not equaled again in Europe until after the Industrial Revolution; spring water flowed by gravity from distant mountains to the cities through masonry aqueducts supported across low places by stone piers and arches. In the United States the first piped water supply was in operation in 1652 at Boston; there townspeople filled their water buckets from a 12-foot-square tank fed by conduits from springs and wells.

When we turn the tap at the kitchen sink, we expect the water to flow. Only when it fails, or alarming reports suggest its possible failure, are we jarred into a realistic consideration of our public water supply. Then we realize that this on-call source of pure clear water, so generally available in Oregon homes, actually furnishes many of the comforts which we include under the term "our high standard of living." People of the United States lead the world in the use of water, both internally and externally, and Oregonians hold up their end of the habit at about the national average.

For the pioneer Oregonian, 5 to 10 gallons of water per person per day was sufficient. This comparative trickle may be contrasted with the daily quota of more than 400 gallons per person that the 20 largest water systems were prepared to supply during the summer of 1963. The development of public-supply systems (fig. 46), the shifting of population centers from rural to urban and suburban areas, the introduction of numerous water-using appliances in the home, and the widespread use of water by industry have all contributed to this increased demand.

Oregon has almost 300 incorporated towns and cities whose central public-supply systems serve about 1,300,000 people. More than three-fourths of those people live in or

FIGURE 46.—Block diagram illustrating the principal features of public water-supply sources and systems.



near 20 of the larger cities or principal commercial centers whose community water sources and disposal points are shown in the following list:

Water supply and disposal for the larger communities in Oregon

[Data as of December 1963, estimated in part]

Principal city	Population served	Source of water supply	Average daily use (mgd)	Waste disposal discharge to—
Albany	13,000	South Santiam River	2.8	Willamette River.[1]
Ashland	11,000	Ashland Creek	4.0	Bear Creek.[1]
Astoria	12,000	Bear Creek	1.7	Columbia River.[2]
Baker	10,000	Lake, well, and springs.	3.0	Powder River.[1]
Bend	14,000	Tumalo Creek	3.3	Lava sinks.[3]
Coos Bay-North Bend.	21,500	Pony Creek	2.6	Coos Bay.[3]
Corvallis	22,700	Rock Creek and Willamette River.	3.7	Willamette River.[1]
Eugene	72,500	McKenzie River	12.7	Do.[1]
Grants Pass	10,700	Rogue River	2.0	Rogue River.[1]
Hillsboro	18,500	Tualatin River tributaries.	2.0	Tualatin River.[1]
Klamath Falls.	24,100	10 wells	2.5	Lake Ewauna.[1]
La Grande	10,000	4 wells and Beaver Creek.	1.7	Catherine Creek.[1]
Medford	35,400	Springs	10.1	Bear Creek.[1]
Milwaukie	13,200	5 wells and Portland standby.	1.1	Willamette River.[1]
Pendleton	15,500	3 wells, 3 springs	4.8	Umatilla River.[1]
Portland	577,700	Bull Run River	70.0	Columbia River.[1]
Roseburg	13,500	North Umpqua River.	3.1	South Umpqua River.[1]
Salem	58,500	North Santiam River and 4 wells.	13.1	Willamette River.[1]
Springfield	21,600	8 wells	3.5	Do.[1]
The Dalles	13,000	3 wells, Mill Creek, Dog River.	1.5	Columbia River.[1]
Total	988,400		149.2	

Average per capita gallons per day 151

[1] Treated. [2] Not treated. [3] Part treated.

Of the water furnished by the 20 largest public-supply systems, about 90 percent is drawn from rivers and creeks and about 10 percent from wells and springs. Medford, Klamath Falls, Pendleton, and Milwaukie are the largest cities using ground-water sources entirely, although the larger cities of Salem and Springfield use ground sources recharged by induced infiltration.

In addition to the 20 largest systems, there are smaller cities, towns, and suburban water districts which have public water systems supplying about 300,000 people. These smaller localities obtain their water about equally from surface and ground water. More than 95 percent of the rural dwellings have private piped-water supplies, obtained mostly from wells and springs.

Many of the cities still use the original source, a spring, well, or creek, but other sources have been developed to keep up with increased demands. In other places, original sources of public water supply have been replaced by larger or cleaner supplies and are now of only historical significance. The progressive succession of water sources is illustrated at Portland, where individual wells that originally served the inhabitants were succeeded by a system that drew water from several creeks, which in turn was outgrown and succeeded by a system that pumped water from the then "pure" Willamette River. The first water mains were laid in 1857 and consisted of bored logs. Portland replaced its Willamette River sources in 1895 with the original conduit of the present supply from Bull Run River, but the Willamette pumphouse still stands on the west bank of the river midway between Portland's south boundary and Oswego, and the 12-inch steel pipe which formerly carried this water north to Portland now carries Portland water south to Oswego and the Palatine Hill District.

The utilization of surface-water sources for public supplies is well illustrated in western Oregon. In this part of the State, clean and strongly flowing streams are present near most cities, and large bodies of permeable rocks are not commonly available to furnish ground water in adequate quantities. Some of the riverbank cities purify water pumped from the adjacent river, whereas other cities divert water from rivers and creeks far upstream in the headwater areas. The diversions in the upriver areas require expensive conduits, but usually they provide a purer and less turbid water; another advantage of upriver diversion works is that they

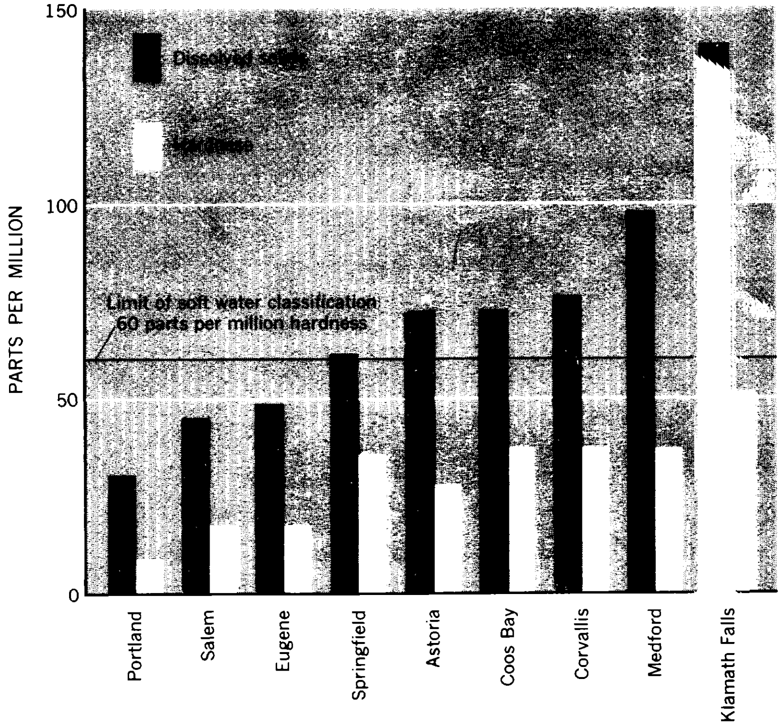


FIGURE 47.—Dissolved solids and hardness of selected public water supplies in Oregon.

are commonly built high enough that the water flows by gravity to the main distribution reservoirs. The least flows in most streams come during the summer and fall months, which are the period of greatest consumer demand; hence, many systems using surface water need considerable storage. This storage is commonly obtained by building dams on the source stream or by building additional concrete or steel reservoirs at the head of the water-distribution system.

The small range in mineral content and hardness of nine major public water supplies in Oregon is shown in figure 47.

PORTLAND

The Bull Run River, source of the Portland municipal water, is the most extensively developed Oregon river, and it supplies by far the greatest number of users. The Bull Run watershed, tributary to Sandy River, comprises an area of about 136 square miles on the west side of the Cascade Range. The densely forested basin was set aside as a protected watershed reserve in 1892, and is closed and policed.

The altitude of the drainage basin ranges from about 4,500 feet on the ridges at the head to about 240 feet at the channel mouth. The diversion at the headworks of the conduits is at an altitude of about 747 feet.

The drainage area of about 102 square miles provides an average flow of about 760 cfs at the diversion headworks. The average precipitation at the headworks has been measured as about 86 inches per year; however, the rainfall must be considerably larger than that for the basin as a whole, because the measured flow of the river at the headworks is equivalent to an average annual runoff of 101 inches of water over the drainage area. The flow of springs in summer is substantially strengthened by late snowmelt, and snow accumulation is therefore important to water storage in the basin.

To assure an adequate minimum streamflow at the headworks during the summer, four dams have been built above the headworks; the reservoirs store a total of 21.4 billion gallons of water. Dams at eight other sites are planned to serve future needs.

From the headwaters, three conduits carry the water to the main reservoirs on Mount Tabor in the eastern part of Portland; completed in 1911, 1925, and 1953, they are 52, 58, and 66 inches in diameter. The rated capacities are respectively 50, 75, and 100 mgd to the main reservoirs. An earlier pipeline completed in 1894 was abandoned in 1953.

The four reservoirs on Mount Tabor have an aggregate capacity of about 157 million gallons; the two in Washington Park, on the west side of the city, have a capacity of 34 million gallons. Those on Mount Tabor range in altitude from 229 to 412 feet, and those in Washington Park are at 230 and 300 feet. In addition to these reservoirs, there are 34 concrete and steel tanks and standpipes which range in altitude from 200 to 1,144 feet and are mostly located on the hillside areas of Portland's west side. The combined maximum storage of these tanks is about 25 million gallons.

The terraces and slopes on which the main part of Portland is located are divided into four main elevation zones for distribution of water by gravity from the reservoirs. The zones are called the "high gravity," the "intermediate," the "low gravity," and the "Vernon Standpipe." The ridgelands of west Portland and other high points are served by pumping to the storage tanks and reservoirs located on high points. The main lines to distribution-service mains include pressure-reduction valves to limit the maximum water pressure for consumers to 80 pounds per square inch. The normal minimum water pressure to customers is 40 pounds. In addition to the 440,000 residents of Portland proper, about 138,000 people outside the city limits are supplied by more than 50 local water districts and companies that purchase water from the city system. All services are metered.

From the principal water mains the water is led to the network of distribution mains. These are mostly pipes of 12-inch diameter in the business districts and of 6-inch diameter in the residential area. On lines which must supply fire hydrants, the smallest pipe used is 4 inches in diameter. Within the city there are 122,000 customer connections, 1,370 miles of pipelines, 7,400 fire hydrants, and 12 pumping stations.

The average consumption during the warm dry summer is about 150 mgd. On an annual basis, the average daily use from the system is 70 million gallons and the average per capita consumption 121 gallons per day. The sources are adequate to supply a much larger population than the present (1964), and plenty of water has been available at the reservoirs since the latest conduit was constructed in 1953. However, as a result of overdraft during warm periods of the summer, low pressures occur at times near the ends of undersized water mains serving rapidly growing communities. Lawn sprinkling has been limited to alternate days during part of the summer.

An example of household use of water may be taken from the home of one of the writers. This household of four people uses about 150,000 gallons of water per year, or an overall daily rate of 410 gallons and an average of 103 gallons per person. During the seven cooler months, October to

April, only 45,000 gallons of water is used, a daily use of 52 gallons per person. Thus, on a year-round basis, the total inside-the-house use of water is about 78,000 gallons, and the average use per day per person is near 55 gallons. The use outside the house during the five months May to September is 72,000 gallons, or an average of 475 gallons per day, largely for partial irrigation of a half acre of lawn and garden. This irrigation use exceeds that of the average homesite within the city.

The citywide average per-capita consumption of 121 gallons of water per day includes about 55 gallons used within the dwelling, about 30 gallons outside the dwelling, and about 36 gallons used elsewhere by industries commercial establishments, transient lodgers in hotels, city-park irrigation, public drinking fountains, street washing, public swimming pools, fire-control operations, and pipeline leaks.

Within the city limits there are about 60 drilled wells that draw water from the gravel strata beneath the terrace lands or from the volcanic bedrock. The capacities of the wells range, according to their size and construction characteristics, from 5 to 1,200 gpm (gallons of water per minute). Water from these wells is used principally by industries and public buildings for heating, cooling, and air conditioning, and the piping systems are separate from the municipal waterlines. Some of the outlying water districts have wells as supplementary supply to meet demands during the summer when their long pipelines from the Portland system may be unable to deliver enough water for their greatest needs.

The quality of the Bull Run water is excellent. It is clear, cool, and oxygen-laden, and it contains only a very small amount of dissolved solids—it is virtually pure rainwater and snowmelt. The solids content averages about 30 ppm. The water has a hardness of about 10, which is low in soft-water classification, and a neutral pH of 7.0 (neither acid nor alkaline). The only treatment given is the addition of about 0.2 ppm of chlorine injected at the headworks. There is little or no residual chlorine when the water reaches the consumer, and, because of the low content and the odorless character of the ammoniated chlorine, few users are aware that the water has been chlorinated.

The copious supply of excellent water for Portland, and many other cities of the State, is a point of justified pride to Oregonians. Portland's water supply stands as a constant testimonial to the wisdom and foresight of all concerned with its selection, construction, and maintenance, and to the bountiful good fortune of its residents.

SALEM

Salem obtains her supply of water from infiltration galleries (pipes) near the upper end of Stayton Island in the North Santiam River, 15 miles southeast of the city. The pipes underlie the sand and gravel floors of shallow basins which can be flooded at will by the river water. The sand and gravel serve to filter the river water before it reaches the infiltration galleries. From the gallery collectors the water is led to the lower end of Stayton Island, where it passes through sand traps and fine screening basins before entering the 36-inch and 54-inch conduit lines, which have a combined capacity of 70 mgd. The water is chlorinated near the head of the conduits which convey it 8 miles to the 100-million-gallon Franzen Reservoir near Turner and then 7 miles farther to the 10-million-gallon Fairmont Reservoir at Rural and John Streets in Salem. Chlorine is added as the water leaves Franzen Reservoir. The city also has 4 wells for standby supply.

The Fairmont Reservoir floats on the distribution system and thus maintains a pressure of about 70 pounds per square inch in the mains serving the principal section of the city. The water leaves the reservoir through a 30-inch pipe and is distributed through a 186-mile network of smaller mains that range from 30 inches down to 2 inches in diameter. All connections are metered. Local areas of high ground, mostly in the western and southern parts of the city, are served by pumps which raise the water to the tanks and reservoirs that maintain water pressure in the distribution pipes of those areas.

About 18,000 people in five independent water districts outside Salem are supplied with water, in addition to the city population of about 40,000.

Four deep wells in West Salem are used to supplement the supply during periods of peak water use. Some raw (untreated) water from Mill Creek is brought by a separate pipe to the State Capitol grounds where it is used for irrigation, but that waterline is not a part of the municipal system.

The peak water use has increased rather uniformly from 8 mgd after the Stayton Island system was first put into use in 1938, to about 28 mgd in 1960. The average flow through the system in 1960 ranged from 5 mgd during December to 20 mgd during August. The per-capita consumption averaged 164 gpd for the year, and the maximum day's use was 487 gallons per person.

The water is excellent in quality; an analysis made of water sampled on December 14, 1960, shows the water had 80 ppm dissolved solids, a hardness of 25 ppm, a very low salinity, and a pH of 7.4.

EUGENE

Eugene diverts water from the McKenzie River near Hayden Bridge about 6 miles northeast of the city. The water passes through a coarse screen and a concrete canal to a pumping basin from which it is pumped a third of a mile through a 36-inch pipe to the 37½-mgd filter plant. The treatment consists of prechlorinating, coagulating, settling, and filtering to remove the sediment. A 45-inch pipeline carries the water from the clear well at the plant to the city, where 23 million gallons of storage space is provided in one 15-million-gallon, two 3-million-gallon, and five smaller reservoirs. The reservoirs are between 605 and 850 feet in altitude on Skinner Butte, College Hill, Fairmont, and College Crest. More than 130 miles of main water pipes distribute the water to users.

The system serves 72,500 people (1963), including those living in eight water districts outside the city.

The total quantity of metered water supplied has increased progressively from an average of 2.74 mgd in 1934 to 12.7 mgd in 1963. Water consumption in the summer months is about three times that in the winter months.

All connections are metered except those solely for fire-protection purposes; a flat monthly charge is paid for that service.

The water is of excellent quality, is soft and of low salinity, and is very similar to that of Salem. An average of the analyses made on daily samples in 1957 showed that the water had dissolved solids of 37 ppm, hardness of 19 ppm, and a very slightly alkaline reaction expressed as a pH of 7.1.

MEDFORD

Medford has obtained its water since 1927 from Big Butte Springs, 30 miles northeast of the city. The springs issue from porous young lava rocks, and have a combined discharge of about 45 cfs from several spring orifices. The water is collected in concrete galleries, a tunnel, and underground perforated pipes, and is transmitted by gravity through two conduits varying from 20 to 30 inches in diameter. At the city, three main reservoirs with 12.2 million gallons total capacity and one concrete standpipe on Pierce Hill (200,000 gallons capacity) serve as distribution storage. By gravity descent from the 2,640-foot level of the intake to the 1,590-foot level of the reservoirs, the conduit will transmit 26 mgd. A water pressure of 70 to 95 pounds per square inch is generally maintained in the distribution lines from the reservoirs.

There are about 10,000 active service connections including those of three towns and eight water districts outside the city. The average daily consumption during the month of maximum use is about 16 million gallons. Fifty-five percent of the service connections are metered. In 1963 the average daily use was 10.1 million gallons.

The quality of the water is excellent. It is clear, soft, of low salinity, and without harmful constituents. An analysis of March 11, 1958, shows the water had 85 ppm dissolved solids, a hardness of 32 ppm, and a pH of 7.2. Analyses indicate that the content of dissolved materials is uniform throughout the year. The water is not treated. The temperature of the water at the intake varies between 41° and 44°F.

KLAMATH FALLS

Klamath Falls obtains its water from 10 wells ranging in depth from 143 feet to 850 feet and located on the east bank of Link River in the southwest part of the city. The wells flow by artesian pressure to three centrifugal pumps whose combined capacity is 8,000 gpm. The wells will flow 2,000 gpm, and a pump withdrawal of 5,000 gpm lowers the water to a level only 10 inches below the surface. Maximum dependable yield of the four wells commonly in use is 12 mgd. The water from the wells is pumped through three mains into the low-distribution system. The combined capacity of 4.3 million gallons of water in six steel reservoirs floats on the system. One high-level reservoir on the ridge of the eastern part of the city is served by a separate 200-foot pump lift from the low-distribution system, and stores 400,000 gallons for the high-distribution system.

In 1963 there were 8,862 connections, all metered, serving a population of 24,100. The average daily consumption in 1963 was 2.5 mgd. Daily use exceeds 10 mgd at times.

A few industrial and commercial establishments have their own wells. Many homes in a residential part of the eastern side of the city are heated by natural hot water from individual deep wells along a fault zone; these well waters are at temperatures of 180° to 220°F.

Klamath Falls' water is treated with about 0.1 ppm chlorine. The water is of excellent quality, clear, soft, of low salinity, and has a pH of 7.7. Like most ground water in the volcanic rocks, it contains a relatively large amount of dissolved silica (55 ppm). The temperature of the water is 67°F throughout the year, and it contains 141 ppm dissolved solids.

CORVALLIS

The source of Corvallis' gravity water supply is Rock Creek, southwest of the city. Dams divert the north and south forks and the tributary Griffith Creek. The Rock Creek water is treated in a plant of 4.5 mgd capacity, and is conveyed in a 20-inch line to three reservoirs of 6.75 million gallons total capacity, on Bald Butte northwest of the city.

The water from the reservoirs is fed into 14-inch and 20-inch mains, which supply the distribution pipe net. Philomath, population 1,400, is supplied water from the line leading to the reservoirs.

The Corvallis distribution net serves the State university as well as the city. All 5,750 connections are metered. Average daily consumption is 3.7 million gallons, the range being from about 2 mgd to about 8 mgd.

The water is soft and low in salinity, dissolved solids, turbidity, and color. Fluorides are added to the water at the rate of 1 ppm.

The greater needs of the summer season are met by supplementing the Rock Creek supply with water diverted from the Willamette River. In 1957 a pumping plant and treatment works that were constructed in 1951 were equipped with a new intake structure having a capacity of 16 mgd.

PENDLETON

Pendleton's basic supply is obtained from four infiltration areas in the gravel along the Umatilla River at Thornhollow, 15 miles east of the city. The gallery system is divided into the lines necessary to pick up water from Wenix Spring, Simons Spring, Shapplish Spring, and the Long Hair line. Flow from Wenix Spring is gathered by five infiltration lines, three of them on South Wenix Spring (the original source of the city's Thornhollow system) and two on North Wenix Spring. Simons Spring is gathered in by three infiltration pipelines totalling 2,000 feet. Shapplish Spring is picked up by four lines having a total infiltrating length of 4,000 feet. A linear layout of about 500 feet of porous pipe, called the Long Hair line, is the most recently constructed unit. The total yield of the Thornhollow source varies from time to time, but the amount withdrawn is controlled by the 5-mgd water right and the 5¼-mgd capacity of the 24-inch conduit to the city's south reservoirs.

As standby supply, the city uses three deep wells of their own plus those of the Smith Cannery and the Oregon State Hospital. The wells draw water from the basaltic bedrock of the area, range from 665 to 1,008 feet deep, and are within or near the city. The capacities of the pumps are 2,500, 1,800, and 585 gpm for the three city wells, 900 gpm for the Smith Cannery well, and 800 gpm for the hospital well. The wells can thus provide 6,585 gpm, or a daily total of about 9.5 million gallons of water, which can be pumped directly into the distribution system.

The main supply to the distribution system is from the two 1-million-gallon reservoirs at about 1,260 feet altitude on the south side of town. Four other reservoirs with a total capacity of 2.2 million gallons are supplied by booster pumps from the main distribution lines.

There are 4,100 connections, nearly all metered. The system serves a population of 15,500. The average daily consumption in 1963 was 4.8 million gallons and the minimum daily consumption about 2 million gallons. The maximum water consumption of about 10 mgd occurs in June or July when the canneries are operating at peak capacity. The unusually heavy demand during cannery season is a major problem because it requires a supply that may be as much as four times the normal rate. Similar problems exist at nearby Athena and Milton-Freewater. At Pendleton during canning season, a draft rate as great as 13 mgd has been metered for short periods.

The water from Thornhollow is soft and is low in dissolved solids. It is chlorinated in the conduit 5½ miles east of the city, and fluoride is added to this gravity supply to provide 1 ppm. Each deep well has its own chlorinator. The water from the wells is moderately hard and carries two to three times the amount of dissolved solids of the Thornhollow supply. However, the quality of the well water is good and it carries about one-half ppm of fluoride, near the lower limit at which fluoride in drinking water has been found beneficial to children's teeth.

COOS BAY AND NORTH BEND

The two cities of Coos Bay and North Bend jointly own and operate their municipal waterworks system. The supply is obtained from the logged-off 2,400-acre catchment basin of nearby Pony Creek. The water is impounded in two reservoirs, the higher having a capacity of 550 million gallons and the lower one of 100 million gallons. The lower reservoir lies behind an earthfill dam 1.5 miles northwest of Coos Bay; from the reservoir the water is taken for treatment with activated carbon, alum, and chlorine, and is pumped three-quarters of a mile southeast to the 1.15-million-gallon settling basin at the filter plant. The water is put through pressure filters and further treated with lime, chlorine, fluoride, and ammonia. From the 5¼-million-gallon clear well at the filter plant the water flows by gravity through 14-inch and 16-inch lines to the low-zone distribution system of the two cities. Pumps lift water from this low-zone net to a million-gallon reservoir which serves the smaller high-zone distribution net. Other high areas are supplied by separate pumps.

The system has a capacity of 6 mgd; it serves 4,750 metered connections and a population of 21,500, including those in seven nearby towns and water districts. The average consumption is 2.58 mgd, minimum demand about 1.6 mgd (1957).

Like most of the surface supplies of western Oregon, the water is soft; it has a low dissolved-solids content, low salinity, and a nearly neutral pH of 6.9. The creek water is colored at times by vegetation, and filtration and treatment are required to obtain a satisfactory municipal supply.

SPRINGFIELD

Springfield's water is supplied by a private company from a field of eight wells which tap water in the gravel alongside the Middle Fork of the Willamette River, 1½ miles southeast of the city. The wells are 30 to 44 feet deep, and the withdrawal of water from them induces percolation of water from the river, the intervening gravel acting as a filter. During the summer, some artificial recharging of the ground water is practiced by pumping from the river into seepage basins and into three recharging wells at the well field. Thus, although the system draws water entirely from wells, the ultimate source of water is the river. From the producing wells the water is pumped into a 20-inch steel main which feeds into the distribution net.

The distribution system includes a 1.5-million-gallon reservoir, and a 50,000-gallon tank for the high-zone distribution net in the northwest part of town that is supplied by pump lift from the low zone.

There are over 4,000 connections, including one large sawmill; most of the connections are not metered. The average day's consumption is about 3.5 million gallons and maximum day's use is about 9 million gallons.

The water is soft and of low dissolved-mineral content. It is chlorinated at the wells.

ASTORIA

Astoria draws its water supply from Bear Creek, 10 miles southeast of the city. The city-owned watershed contains three dams which impound 326 million gallons of water on one branch and on the main stem of the creek. From the lowest reservoir, at an altitude of 620 feet, the water is carried 12 miles in a 22-inch steel conduit to a hill in the southeast part of the city. At that point a 20-million- and a 6-million-gallon reservoir supply the distribution net.

The creek water is passed through screens and the water is treated with ammonia and chlorine. At times, copper sulfate is used to suppress algae growth. Fluorides are added to the water as it leaves the main reservoir in the watershed. The water is soft and contains very little dissolved solids. Because of the forested watershed, it does have some dissolved organic materials; at times it has slight turbidity.

There are 3,300 connections, all metered, serving a population of 12,000 in 1963. The average consumption is 1.7 mgd, and the maximum about 3.5 mgd. Water is supplied to outlying water districts and to some individuals near the pipeline.

WATER FOR OTHER CITIES

The water supplies of other cities are derived from sources similar to those described above. West of the Cascade Range, the Roseburg supply is taken by a private water company from the North Umpqua River above Winchester. It is treated and piped 5 miles to the city. Albany obtains its supply from the Albany Power Canal, into which water is diverted from the South Santiam River near Lebanon; the water is extensively treated. Hillsboro obtains water from the upper part of the Tualatin River and from Sain Creek; the water requires only chlorination. Tillamook has small dams and diversions on Killam and Fawcett Creeks 7 miles south of the city. Grants Pass pumps water from the Rogue River, and purifies it in a complete treatment plant. Ashland stores and diverts water from Ashland Creek above the city.

East of the Cascade Range, Bend gets water from Tumalo Creek that requires only chlorination. The Dalles diverts water from Dog River, in the Hood River drainage basin, across the divide to their Mill Creek treatment plant and diversion; this supply is at times supplemented by pumping from a well into Mill Creek and from three deep wells in the city. The city of Hood River pipes water from Cold Spring and Stone Spring 17 miles southeast of the city. Milton-Freewater diverts some water from the Walla Walla River, but also uses six deep wells which tap ground water in the basaltic bedrock; the system provides for the high demands that occur during the canning season even though several of the canneries have deep wells of their own. Baker's primary supply is obtained from several mountain streams and springs and from Goodrich Lake, 20 miles northwest of the city; a deep well in the city is used for standby supply. Burns uses two deep wells as its basic supply. La Grande impounds a mountain creek and pipes the water to the city, but also has four deep wells in the city to supply water during the height of water needs in summer and during cold periods in winter. All these cities obtain soft water of excellent quality, low in dissolved solids.

Ontario, Nyssa, and Vale, the triple cities of the Malheur-Snake River plain of east-central Oregon, obtain their water supply from wells. The water is hard but otherwise of good quality. Parts of this area have the hardest water at shallow depths in Oregon. Ontario and Nyssa have located their wells close to the Snake River in order to induce infiltration of softer water. Most of the water is softened before it is chlorinated and distributed.

SPECIAL FEATURES OF OREGON'S MUNICIPAL WATER

All the cities and nearly all the smaller towns are situated where water can be obtained in quantities sufficient to support double or triple their present populations. A few towns and smaller cities have neared the capacity of their present sources or distribution systems, but other supplies are available. These new sources may be more expensive, but they still are cheap as compared with the cost of water at many places in less favored regions. Some cities need more water to meet the expected demands of industry. For most of the systems, technical plans have been prepared for different degrees of future expansion of their supply and facilities.

Since about 1940, many of the Oregon municipal water systems have been feeling the strains of a general population increase. Needs for additional water and for enlargement of the distribution system have been almost universal. One of the most widespread needs has resulted from suburban housing developments. These additions required lengthening and enlarging the service mains, an expansion which commonly had to be carried back through the whole system. Along with these suburban water-supply problems, some of the additions have presented difficult problems in drainage and sewage disposal.

At present none of the cities using surface water need to take their water supply downstream from the outfall of untreated or raw sewage from a city, an advantageous situation which has resulted from the clean-stream campaign of the Oregon State Sanitary Authority.

WATER IN OREGON'S FUTURE

In rivers, the water that you touch is the last of what has passed and the first of that which comes; so with time present.—*Leonardo da Vinci*

Wise development and use of Oregon's water resources require a prophetic look to the future. Large water projects are expensive to alter or replace, and design is a major part of the undertaking. Though the future may not be entirely ours to see, a continuing record of what water we now have is a fair guide to what we may expect in the future. Certain lines of reasoning may visualize future water use in Oregon well enough to guide development in the right direction.

WHAT WATER NEEDS ARE TO BE EXPECTED?

The projection of the population trend and the adjusted rate of water use provides a simple base from which future water needs may be estimated. The increase in Oregon's population since 1900 has ranged from 147,000 to 460,000 per decade. The smallest increase occurred in the period 1930–40 and the greatest from 1940 to 1950. Since 1900, the annual average increase in population has been about 22,500.

The average-per capita use of water from public supply systems will probably increase only moderately from the present rate, which is between 100 and 150 gallons per day. The phenomenal increase in the average per-capita use of water in the past has coincided with the addition of modern sanitary facilities and large industrial drafts from public water-supply systems. As a result of the relative standardization of these rates of use, the per-capita withdrawal of water from public systems in Oregon for the next 40 years may rise but little.

Almost certainly, there will be an increase in the number of industrial plants using water, both from municipal supplies and from their own sources. It also seems certain that these plants will be more economical in water use than older plants. The trend of industrial development is toward manufacture of finished goods. Foodstuffs, paper and wood products, finished metallic and nonmetallic articles, garments and fabrics, and similar merchandise will be produced more extensively, rather than bulk grain, lumber, metal bars, raw ores, baled wool, and such basic raw materials which have been Oregon's chief exports in the past.

More water will be used for irrigation. Though many of our basic agricultural products are now in a period of oversupply, the past history of these periods of surplus, the growing national population, and other factors point toward great future needs for agricultural products. Many of the irrigation districts that now have not enough water during dry years will augment their sources by storage and diversions. More land will be brought under irrigation in both the eastern and western parts of the State.

The uses which involve little water loss are undoubtedly due for a great increase. The market for electrical energy, like some other human wants, seems to know no limit. The construction of the John Day Dam on the Columbia River just below the mouth of the John Day River completes the harnessing of the Columbia throughout the usable part of its 340 feet of fall where it bounds Oregon. The 1,300 feet of fall in the Snake River, where it bounds the State, is now being developed for electric generation. There are numerous unused hydroelectric-power sites on the somewhat smaller rivers within the State. For Oregon and the Pacific Northwest, waterpower possesses many advantages over the use of fossil fuels (coal, oil, and natural gas) and sawdust for electrical generation.

Nuclear power is not economically competitive in this region. This process may in time become competitive, but the belief is widespread that the hydroelectric plants will continue to be the most economical sources of energy for a long time.

The recreational uses of water are burgeoning. This fact is apparent to anyone who is locked in a traffic jam at one of the beach towns or who looks out over almost any river on a weekend, attends a boat show, or tries to elbow his way to the creek bank on the opening day of fishing season. The beaches of Oregon below high-tide line are State property and are reserved for public use. The State and local agencies are interested in improving access and providing facilities for the greater public use of recreational areas. The recreational use of waterways involves little loss in water resources, and this water use may well expand to the general benefit of the community. It will be an integral part of any multiple-use plan for the water resources.

POSSIBLE NEW SOURCES OF WATER OF GOOD QUALITY

The aforementioned economies and the solutions to some of our present water problems should result in an increase in water supply. Other sources of water are available. Storm runoff may be stored either on the surface or underground, and unfit, contaminated water may be made usable.

Fresh water can be made from sea water or brackish inland water. At present (1964) the cost of removing the salt is too great to make such fresh water competitive with naturally available water in Oregon. The Federal government has recently constructed several pilot plants to make full-scale tests of desalting both sea water and brackish inland water by different methods. Continued testing may lead to some means of producing water by desalting that is less costly than natural fresh-water supplies available in some arid and semiarid regions.

Attempts at artificial weather modification in Oregon by the seeding of clouds have not conclusively demonstrated benefits from increased precipitation. In the present state of knowledge, this process seems to offer little aid in the search for additional sources of water for Oregon.

WHAT ARE THE RESOURCES TO MEET FUTURE NEEDS?

Comparisons of available water supplies with estimates of future water needs show a gradually varying picture ranging from overall abundance, but some seasonal shortage, along the coast to critical shortages in eastern Oregon. We still have flowing to the sea large quantities of water beyond the amount necessary to maintain channel and navigation conditions and to provide for recreation and adequate water supplies in the lower reaches of the rivers.

The rivers that drain the west slope of the Coast Range, from the Chetco at the south to the Necanicum at the north, contain unused water for 6 to 7 months of the year. Most of this excess water flows to the ocean during the period of high runoff. The Willamette, Umpqua, and Rogue Rivers have excess winter flow; the summer flow is now used at least once in parts of these basins, as in the basins of Bear and Little Butte Creeks.

In eastern Oregon the Owyhee, Silvies, and Lost Rivers, Drew and Cottonwood Creeks, Willow Creek of northern Malheur County, and many lesser creeks are now entirely used during the drier years. The Walla Walla, Umatilla, Powder, Chewaucan, and Malheur Rivers are used except for winter and spring runoff. The Grande Ronde and the lower part of the John Day and the Deschutes Rivers are the only ones which commonly have unused water in the summer months. The Klamath River has an excess only in the spring season in wet years.

The boundary rivers will soon be harnessed for hydroelectric generation from the 2,070-foot altitude above Brownlee Dam on the Snake to tide level below Bonneville Dam on the Columbia. Much of the same water will be used for many other purposes such as industrial processing, public supply, navigation, recreation, and fish propagation.

Where suitable demonstration of a higher priority is established, requests to withdraw water for consumptive uses also may find favor, just as water is now being withdrawn from the Columbia River at Grande Coulee Dam for irrigation of the large Columbia Basin Irrigation Project. Any such future diversion of large amounts of water for consumptive uses during periods of low flow in the Columbia River may adversely affect downstream fisheries and water transportation. There is not enough water now during low-flow periods to dilute properly all the wastes that enter the lower part of the Columbia River, and a reduction of that pollution load is needed for the protection of aquatic life (Oregon State Sanitary Authority Ann. Rept., 1963, p. 2). The maintenance of the proposed 40-foot channel, 750 feet in width, downstream from the Portland-Vancouver area may also require all the flow during low-water periods.

The unequal distribution of the water in both time and place throughout the State creates problems of storage and diversion of the water. A more nearly equal areal distribution could be provided by the transfer of water eastward within the State. The transfer may start with the eastward diversion of excess headwaters across the crests of the Coast and Cascade Ranges. The storage and diversion projects will probably progress from the cheapest to the most expensive, but they can and should be constructed within a master plan for water in Oregon's future.

In summary, then, there is still a large amount of unused runoff—many millions of acre-feet of water each year—with which Oregon may meet its future needs. This water is mostly in the western part and along the northern border of the State, far from some of the places of greatest need; its development will surely be more expensive than that of the water used to date.

Besides the surface sources of additional water for the future, the ground-water reservoirs in many parts of Oregon contain water and storage space not much utilized so far. Ground-water practices which have been little used in Oregon include the artificial recharge of ground-water aquifers with excess surface water, the extraction of water from fine-grained valley alluvium, and the systematic management of water-bearing strata as reservoirs. A larger and better engineered development of ground water will help meet Oregon's future water needs, and will make it easier to provide water in some parts of the State.

Waste will have no place in Oregon's future water plans. Economy in water use will provide additional supplies. In exploiting these economies, it is well to heed the lessons of the drought years. The good water years which have generally prevailed since 1941 will not continue indefinitely, and periods of below-average precipitation are sure to test the structure of Oregon's water supply, as a drought period did in the 1930's. A water plan for Oregon's future must assume that drought periods will come, as they have in the past.

WHAT CAN BE DONE TO ASSURE OREGON'S WATER SUPPLY?

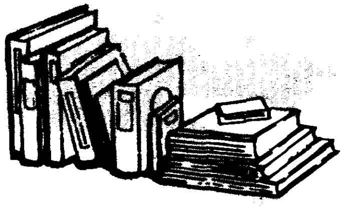
In assuring Oregon's water supply, the first basic principle is to retain the excellent quality that was and is native to our water. In this operation the services of the State Sanitary Authority, the State Engineer, the U.S. Soil Conservation Service, the U.S. Forest Service, and other agencies are vital; but the responsibility belongs to all, and the effective execution of this clean-water enforcement needs the participation of an informed public.

Another basically sound principle is to prevent waste of water. This course may encompass many water savings ranging from economies in the use of diverted water to abatement of excess evaporation and storage of flood runoff. These practices all help to make water available when and where it is needed.

A third basic principle calls for acquiring and integrating as much information as possible on our water resources. No one can design an efficient hydroelectric powerplant, a flood-control dam, an irrigation district, a public water-supply source, an industrial water supply, or any other water-use or control facility unless he knows the approximate quantity of water their structures will use or control. The quality of the water and characteristics of its movement are other basic facts which the designer must consider. At present our engineers must estimate from inadequate records, or must select prospective dam and storage sites without geologic maps, or even must estimate drainage areas without adequate topographic maps of the watersheds. The users pay the tolls imposed by that lack of information.

The U.S. Geological Survey, the U.S. Soil Conservation Service, the U.S. Weather Bureau, and the State Engineer are agencies charged with obtaining and publishing basic information on water resources. Other agencies obtain data as it directly affects their sphere of operations. A list of the principal agencies concerned with water is appended to this report. But again, like the enforcement of water-quality protection, the collection of water data is a field in which an informed public will take a progressively greater part. The full benefits will be derived from Oregon's water supplies only by the use of a fully adequate fund of basic engineering information.

A fourth basic principle calls for a soundly integrated long-range plan for the development of water resources. The Oregon State Water Resources board is the agency responsible for developing such a plan.



PUBLISHED INFORMATION ON WATER IN OREGON

Precipitation and weather records—
- U.S. Weather Bureau:
  - Monthly and annual publications (weather data and some stream stages).
- U.S. Soil Conservation Service:
  - Seasonal publications (snow data).

Streams, records of flow—
- U.S. Geological Survey:
  - Prof. Paper 272–D (evaporation loss).
  - Water-Supply Papers 680 (drought, 1930–34).
    - 771, 1080, 1137, 1650, 1689 (floods).
    - 1220 (depletion by irrigation).
    - 1330 (requirements for industry).
    - 1669–S (yearly variations).
    - 1734, 1735, 1737, 1738 (summaries, 1951–60; introduction lists reports giving data for earlier years).

Ground-water occurrence—
- U.S. Geological Survey:
  - Water-Supply Papers 489, 494 (principles of ground-water hydrology).
    - 569–B (the Dalles area).
    - 841 (the Harney Basin).
    - 890 (the Willamette Valley).
    - 1475–E (Cow Creek-Soldier Creek area).
    - 1539–K (sand dune area near Florence).
    - 1650 (Umatilla River basin).

Quality of water—
U.S. Geological Survey:
Prof. Paper 417–D (chemical quality, Snake River basin).
Water-Supply Papers 363 (surface water).
659–B, 841, 890 (ground water).
679 (thermal springs in the United States).

Waterpower potential—
U.S. Geological Survey:
Water-Supply Papers, 344, 637–C (Deschutes River).
636–F (Umpqua River).
638–B (Rogue River).
1329–B (Wilson River).
1610–B (Trask River).
U.S. Army, Corps of Engineers:
87th Congress, 2d Sess., House Doc. 403 (Columbia River and tributaries).

Tidal waters—
U.S. Coast and Geodetic Survey:
Navigation charts.

WHERE TO ASK QUESTIONS ABOUT—

Coast, ocean, and harbors:
U.S. Coast and Geodetic Survey.
U.S. Army, Corps of Engineers.
Local port authorities.

Data on water resources:
U.S. Weather Bureau (precipitation and weather).
U.S. Geological Survey (occurrence, quantities, quality).
U.S. Soil Conservation Service (snow storage).
Oregon State Engineer (quantities, water rights).

Development structures and facilities:
U.S. Army Corps of Engineers (flood control, navigation).
U.S. Bureau of Reclamation (reclamation of land).

Fish and wildlife habitat:
Oregon Fish Commission (commercial fisheries).
Oregon Game Commission (sport fisheries and game).
U.S. Fish and Wildlife Service (migratory fish and wildfowl).

Geology of drainage basins:
- Oregon Department of Geology and Mineral Industries.
- U.S. Geological Survey.

Hydroelectric power:
- Federal Power Commission (Federal permits and studies).
- Power companies and Bonneville Power Administration (generation and transmission.)
- U.S. Geological Survey (preliminary site and river surveys).

Laws, rights to water:
- Oregon State Engineer.
- U.S. Bureau of Indian Affairs (laws, rights on Indian reservations).

Management planning and policies:
- Oregon Water Resources Board.
- Columbia Basin Interagency Committee.
- Columbia Basin Interstate Compact Commission.
- Federal Power Commission.

Recreational uses of water:
- U.S. Fish and Wildlife Service (fish and game conservation).
- U.S. Park Service (National parks).
- Oregon Game Commission (sport fishing and hunting).
- Oregon Fish Commission (commercial fishing).
- Oregon Highway Commission, Parks Department (camps and beaches).
- U.S. Forest Service (camps and facilities).

Sanitation and health:
- Oregon Board of Health (public water supplies).
- U.S. Public Health Service (interstate matters and Federal reservations).
- Oregon Sanitary Authority (pollution and contamination of water).
- City water departments.

Soil management and water in soil:
- U.S. Soil Conservation (erosion abatement, snow surveys).
- U.S. Department of Agriculture, Extension Service, Oregon State University, Corvallis.

Topography of drainage basins, delineation of streams:
- U.S. Geological Survey (topographic quadrangle and river maps).
- Army Map Service (tactical maps).
- U.S. Coast and Geodetic Survey (navigation charts).