Water Resources of King County, Washington

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1852

Prepared in cooperation with the Board of King County Commissioners

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By DONALD RICHARDSON, J. W. BINGHAM, *and* R. J. MADISON

With a section on

SEDIMENT IN STREAMS

By R. C. WILLIAMS

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WATER RESOURCES OF KING COUNTY, WASHINGTON

By DONALD RICHARDSON, J. W. BINGHAM, and R. J. MADISON

ABSTRACT

Although the total supply of water in King County is large, water problems are inevitable because of the large and rapidly expanding population. The county contains a third of the 3 million people in Washington, most of the population being concentrated in the Seattle metropolitan area.

King County includes parts of two major physiographic features; the western area is part of the Puget Sound Lowland, and the eastern area is part of the Cascade Range. In these two areas, the terrain, weather, and natural resources (including water) contrast markedly.

Average annual precipitation in the county is about 80 inches, ranging from about 30 inches near Puget Sound to more than 150 inches in parts of the Cascades. Annual evapotranspiration is estimated to range from 15 to 24 inches.

Average annual runoff ranges from about 15 inches in the lowlands to more than 100 inches in the mountains. Most of the streamflow is in the three major basins of the county—the Green-Duwamish, Lake Washington, and Snoqualmie basins. The largest of these is the Snoqualmie River basin (693 square miles), where average annual runoff during the period 1931–60 was about 79 inches. During the same period, annual runoff in the Lake Washington basin (607 square miles) averaged about 32 inches, and in the Green-Duwamish River basin (483 square miles), about 46 inches. Seasonal runoff is generally characterized by several high-flow periods in the winter, medium flows in the spring, and sustained low flows in the summer and fall.

When floods occur in the county they come almost exclusively between October and March. The threat of flood damage is greatest on the flood plains of the larger rivers, but in the Green-Duwamish Valley the threat was greatly reduced with the completion of Howard A. Hanson Dam in 1962. In the Snoqualmie River basin, where no such dam exists, the potential damage from a major flood increases each year as additional land is developed in the Snoqualmie Valley.

Only moderate amounts of sediment are transported by most streams in the county, except during short periods of heavy rain in the winter. The temperature and chemical quality of surface waters are well suited to the requirements of fisheries and for municipal, industrial, and domestic supplies. Little treatment is needed for most uses of surface water, except where the water is subject to pollution.

Most recoverable ground water in the county occurs in the Puget Sound Lowland, where great volumes of unconsolidated sedimentary deposits were left by the continental glaciers of the Pleistocene Epoch. Bedrock, most of which is in the Cascade Range, contains very little ground water. Numerous springs, largely undeveloped, occur in several parts of the county.

Most of the ground water is of good to excellent quality except for excessive iron, which in some places may require treatment of the water before it is suitable for domestic or industrial use.

Excluding water used for hydroelectric power, recreation, and fisheries, more than 80 percent of the water used in the county is provided by municipal-supply systems. Each of the major river basins includes municipal watersheds that provide large supplies of excellent water. By the 1980's, more than 90 percent of the county's population will probably be served by the Seattle municipal supply. With full development, Seattle's water system would have a capacity sufficient to supply more than 2 million people with 300 gallons per person per day. Most industrial and commercial establishments in the county obtain water from public-supply systems.

The most serious water problem in the county at present (1965) is the threat of pollution in the densely populated areas. The immediate threat in the Seattle area is being reduced by the sewage-treatment program of the Municipality of Metropolitan Seattle, which will eliminate the discharge of waste into Lake Washington. Expected increases in population and industry will introduce new problems that will require additional planning to assure adequate water quality for fisheries, recreation, and other uses.

INTRODUCTION

The Puget Sound country of the Pacific Northwest is noted for its abundance of water, and King County, in the heart of the Puget Sound country, has its generous share of this resource. Why, then, should water problems exist in an area of abundance? The reasons lie in such factors as mode of occurrence, variability in quantity and quality, and the great diversity of uses for which the resource is needed. Because water use directly involves people, water problems inevitably will increase as the population of the area continues to grow. Solutions to those problems will depend on sound planning for both utilization and conservation of this vital resource. Such planning must be based on facts—how much water is there, where and when it is available, how good it is for the planned use, and what factors limit its development.

Many volumes of facts have been published concerning water in King County, but they are not readily available in a convenient form to those responsible for the planned utilization and conservation of the resource. In recognition of such a need, the Board of King County Commissioners provided cooperative support for an investigation to summarize the available data and to prepare a report that would relate the data to the water problems of the county. The present report results from those studies. It describes the physical setting of King County as it relates to the total water supply and to the occurrence of water on and beneath the land surface. It then describes the hydrologic setting in terms of total supply (precipitation), natural loss (evapotranspiration), runoff (streamflow), and underground storage (ground water). Finally, the report discusses the present and future uses of water and the problems related thereto.

Much of the information in the report has been obtained by the U.S. Geological Survey as a part of cooperative programs with the State Division of Water Resources. Many other State, Federal, and local agencies also have provided data or have assisted in its collection. The report was prepared under the supervision of L. B. Laird, district chief, Water Resources Division, U.S. Geological Survey, Tacoma, Wash.

GEOGRAPHIC SETTING

King County, in western Washington, extends from Puget Sound to the summit of the Cascade Range. It is probably most noted for its principal city, Seattle, a thriving seaport and industrial center, but the county contains numerous farms, forests, lakes, and mountains as well. Within its area of 2,206 square miles there are great contrasts in types of terrain, in weather, and in cultural development.

PHYSIOGRAPHY

King County includes segments of two major physiographic areas (fig. 1). The eastern half of the county is part of the Cascade Range and the western half is part of the Puget Sound Lowland.

In the Cascade Range the topography is rugged and the drainage pattern is irregular. The mountain ridges are deeply incised with steep-walled glaciated valleys, which have numerous tributaries because of the abundant precipitation. Many of the valleys and tributaries head in deep cirques—amphitheaterlike basins carved by alpine glaciers. Some of the higher peaks near the summit of the Cascade Range normally have some snow all year, and several of the highest peaks harbor small glaciers on their northern slopes. The crest of Mount Daniel, at 7,986 feet, is the highest point in King County.

As shown in figure 1, the Puget Sound Lowland is subdivided into physiographic areas designated as glaciated bedrock, till plains, and major valleys. The impact that the continental glaciers had on the landscape in the western part of the county is evidenced by the general north-south trend of the principal physical features—the large lakes, major valleys, and linear ridges on the upland. Glaciated bedrock hills have rounded profiles that were smoothed and striated by the Puget lobe of the continental glaciers. The till plains have low relief on which many stream courses are poorly defined and local closed depressions are occupied by lakes or swamps. The plains terminate in steep bluffs along the major valleys and above the shores of Puget Sound.

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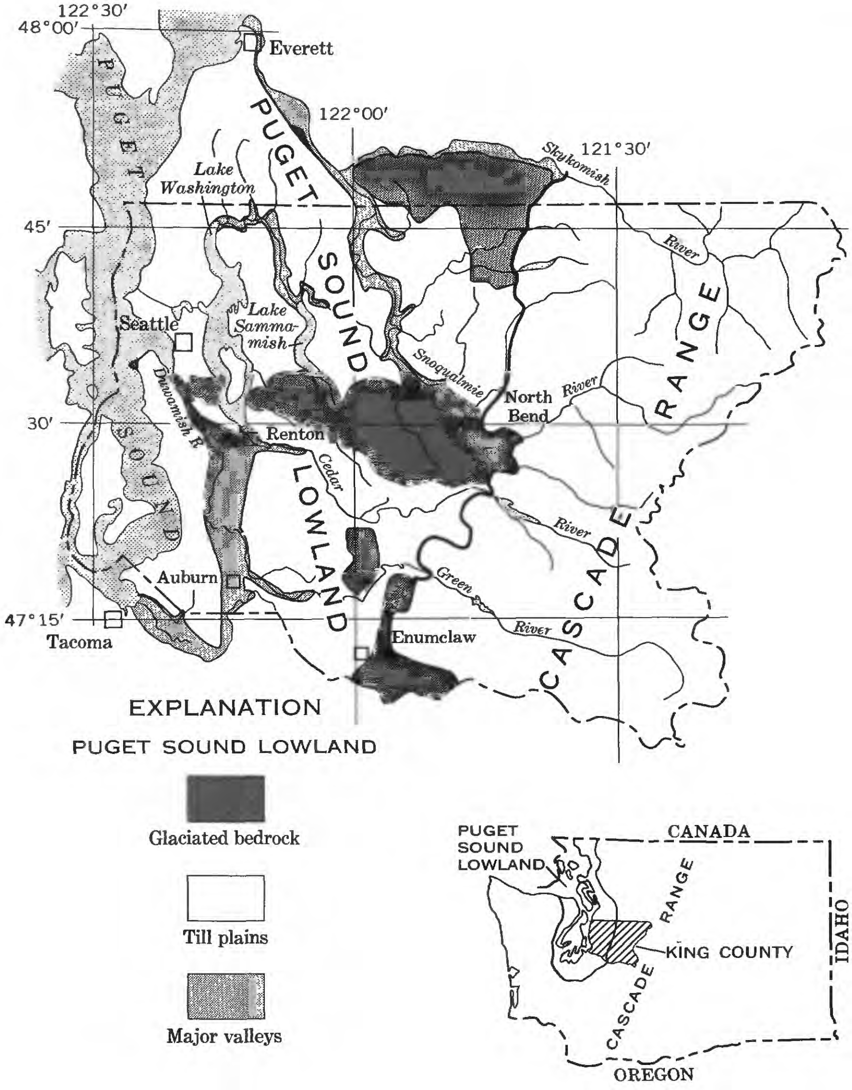


FIGURE 1.—Physiographic areas in King County.

A part of Puget Sound occupies one of the deep troughs in the county; other troughs contain Lakes Washington and Sammamish. Lake Washington, on the east side of Seattle, is the second largest natural lake in the State; it is 19½ miles long and more than 200 feet deep. A few miles to the east and in the same drainage basin is Lake Sammamish, 8 miles long and about 100 feet deep. Numerous smaller lakes and reservoirs also lie in King County; Walcott (1961, p. 85–201) has listed 423 that are below an altitude of 2,500 feet, and 337 at higher altitudes.

CLIMATE

The climate of King County is predominantly a marine type, with cool summers and mild winters. Marine air from the Pacific Ocean, 90 miles to the west, is to a large degree the source of the equable year-round temperature. The Cascade Range is also partly responsible for the mild winters, because the mountains usually block the westward movement of cold continental airmasses into the county from eastern Washington.

Climatic conditions that are characteristic of western Washington, including King County, have been described by Phillips (1960, p. 2):

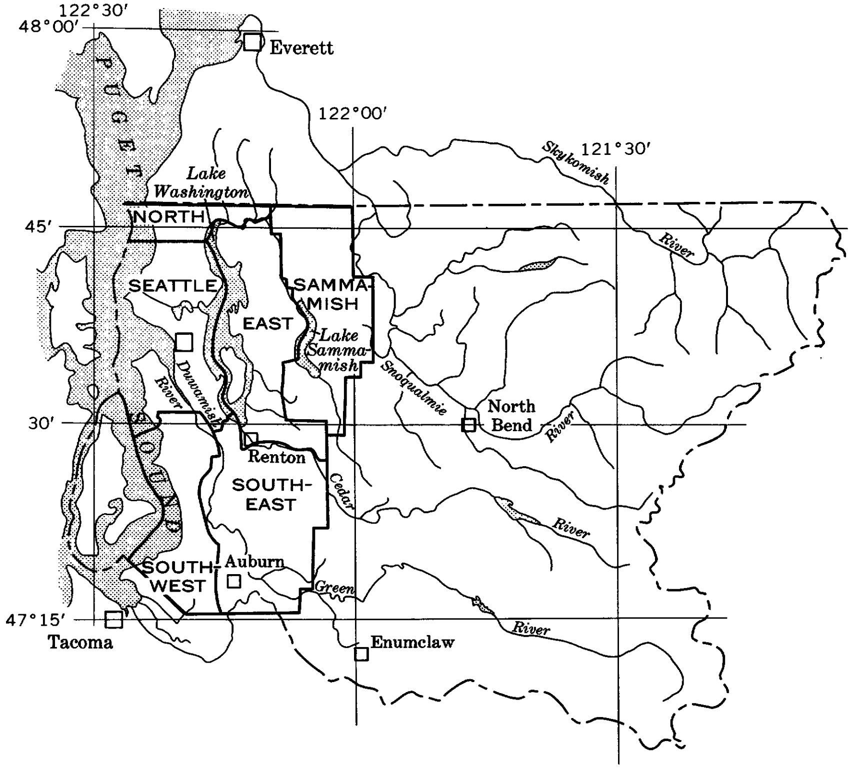
> The percent of possible sunshine recorded in Seattle ranges from 24 percent in December to 61 percent in July. This is considered rather representative of the State west of the Cascades, other than along the immediate coast which receives less sunshine during the summer. The number of days on which measurable precipitation falls ranges from approximately 150 days in the interior valleys to 190 days along the coast. Usually less than 6 or 8 thunderstorms occur each year, other than in the higher elevations of the Cascade and Olympic Mountains. Damaging hail storms rarely, if ever, occur in most localities of western Washington. December and January are the wettest months, and July and August are the driest months.

The part of the county adjacent to Puget Sound is in the eastern edge of the "rain shadow" of the Olympic Mountains. The amount of rain and snow increases rapidly with an increase of altitude eastward from the Sound. In Seattle, snow seldom remains for more than a few days, whereas at Snoqualmie Pass, annual snowfall averages about 400 inches, and the depth of snow ranges from 9 to 12 feet during most winters. Precipitation in the county is described in more detail on page 8.

CULTURE

About a third of the 3 million people in Washington State live in King County. In 1960, the county's population was 935,000; in 1965 it is estimated to be close to a million. A large part of the population is concentrated in Seattle and in several other cities in the lowlands near Puget Sound.

As in most of the nation's large metropolitan areas, there has been a tendency during the past three decades for suburban communities in King County to grow at a faster rate than the densely populated cities. This tendency is expected to continue. A report of the King County Planning Department (1964) shows the projected population of six urban planning areas near Seattle in 1970 and 1985, compared to the population of those areas in 1960 (fig. 2). The six areas constitute about a fourth of the land but contain 97 percent of the people in the county. This percentage is not expected to change appreciably by 1985, but a remarkable change is expected in the distribution of



Urban planning area	Population		
	1960	1970	1985
Seattle	557, 000	572, 000	585, 000
Southwest	116, 930	174, 100	260, 000
East	100, 200	174, 000	311, 400
Southeast	64, 000	94, 000	189, 000
North	54, 800	70, 000	81, 500
Sammamish	13, 390	60, 800	163, 100
Total urban area	906, 320	1, 144, 900	1, 590, 000
Rest of county	28, 680	40, 100	73, 000
Total county	935, 000	1, 185, 000	1, 663, 000

FIGURE 2.—Location and population of urban planning areas in 1960, with projections to 1970 and 1985. (Data after King County Planning Department, 1964, p. 2, 3.)

population within the urban areas. The greatest change is predicted for the Sammamish area, where the population is expected to be 12 times as large in 1985 as it was in 1960. During the same period, the population of the east and southeast planning areas is likely to become three times as large as in 1960.

The prevailing economy of King County is indicated by the existing types of employment. Table 1 shows the number of people who were employed in March 1965 in industries covered by the Washington Employment Security Act. These figures show the importance of manufacturing in the county's economy; 35 percent of the jobs shown in table 1 are in this category. By far the largest manufacturer in the county, and in the Pacific Northwest, is the Boeing Co.

TABLE 1.—*Employment in King County in March 1965*

[Data from Washington State Employment Security Department (1965, p. 29-30)]

Industry	*Employment*
Manufacturing (transportation equipment, 62,444)	102, 120
Retail trade	54, 286
Services (such as medical and personal)	37, 962
Wholesale trade	27, 623
Finance, insurance, and real estate	23, 601
Transportation and allied services	16, 237
Contract construction	16, 069
Communications and utilities	7, 907
Agriculture, forestry, and fishing	1, 042
State and local government	720
Mining and quarrying	306
Not classified	2
Total	287, 875

The growth of population and industries in King County has been accompanied by a decline in the amount of farmland. According to the U.S. Bureau of the Census (1961, p. 143), the area of farmland in the county decreased from 145,111 acres in 1954 to 114,719 acres in 1959, and the number of farms decreased from 4,107 to 2,952. Despite the reduction in total farmland, the irrigated acreage increased from 5,503 to 7,671 acres during the same period. These statistics reveal a trend being experienced in much of the country; farms are becoming fewer but larger, and irrigation is being used more extensively. In King County, irrigation, mostly by sprinkler, uses only a small part of the available water supply.

The natural resources of the Pacific Northwest—land, water, timber, fish, wildlife, and minerals—were largely responsible for the early rapid growth of the economy of King County. With the growth of industries and with the prospect of large concentrations of people in the Northwest, there is a growing awareness of the need to protect the value of these resources for future use.

HYDROLOGIC SETTING

The hydrologic cycle can be used to describe in general terms the source and movement of the total water supply in King County. Moisture-bearing winds from the Pacific Ocean provide the "input"—that is, rain or snow—to this cycle. Eventually, the same water must either evaporate or flow into Puget Sound. If the gross amounts of water could be measured accurately, the resulting figures would show that the total volume of precipitation in the county is equal to the volume of water evaporated or discharged to the Sound, assuming negligible net storage gains or losses.

The following sections describe the occurrence of water in the several phases of the hydrologic cycle: as precipitation, the incoming water; as native evapotranspiration, the part beyond man's control that returns to the atmosphere; and as streamflow and ground water, the part that is available for man's use.

PRECIPITATION

The average annual precipitation in King County is about 80 inches. This quantity is a measure of the gross amount of water in the county, but it does not indicate the large variations that occur with respect to time and location.

Areal differences in precipitation are great, as would be expected in an area that extends from sea level to the crest of the Cascade Range. Average annual precipitation, shown in figure 3, ranges from 30 inches in the northwestern part of the county to more than 160 inches in parts of the Cascades. Contrary to a common belief, the largest average amounts of precipitation occur 15–20 miles west of the crest of the Cascade Range rather than at the summit. The average precipitation pattern for the mountainous area is particularly difficult to define because of the scarcity of weather records, and because of the large variations that occur in short distances. Cells of heavy precipitation appear to be pronounced on the divide between the Cedar and Green River basins, and between the Snoqualmie and Skykomish River basins. Troughs of lesser precipitation extend up the valleys of the Green, Snoqualmie, and Skykomish Rivers.

Long-term variations in precipitation can be illustrated by the longest record available in the county, from 1878 to 1964, obtained at Seattle (fig. 4). During this 87-year period, the average annual precipitation at Seattle was 33.7 inches. The wettest year was 1879, when a total of 56.4 inches was recorded, and the driest year was 1952, when precipitation totaled only 19.5 inches. During some periods, wet years or dry years seem to be grouped together. For example, the 10-year averages shown in figure 4 range from 83 percent (1920–30) to 111

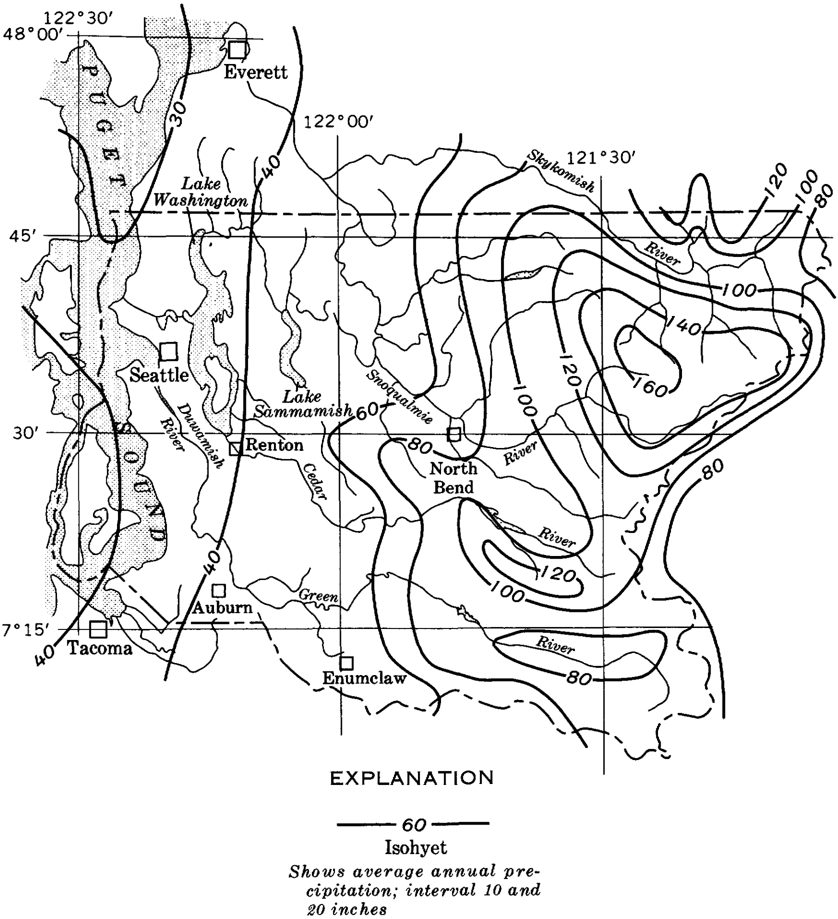


FIGURE 3.—Average annual precipitation.

percent (1890–1900) of the long-term average. This tendency for a grouping of dry and wet years is not predictable. For instance, after the large amount of precipitation recorded in 1950, who could have predicted that 1952 would be the driest year of record at Seattle?

A base period of 1931–60 has been used for some of the hydrologic summaries prepared for this report. Average precipitation for this 30-year base period is only 1 percent higher than the 87-year average at Seattle (fig. 4).

Yearly variations in precipitation are significant: the wettest and driest years of record at Seattle differ by a factor of 3. Areal variations are even greater: annual precipitation in the mountains may be 5 times that near the Sound. Larger still are the seasonal variations that normally occur every year: average monthly precipitation in December may be more than 10 times that in July.

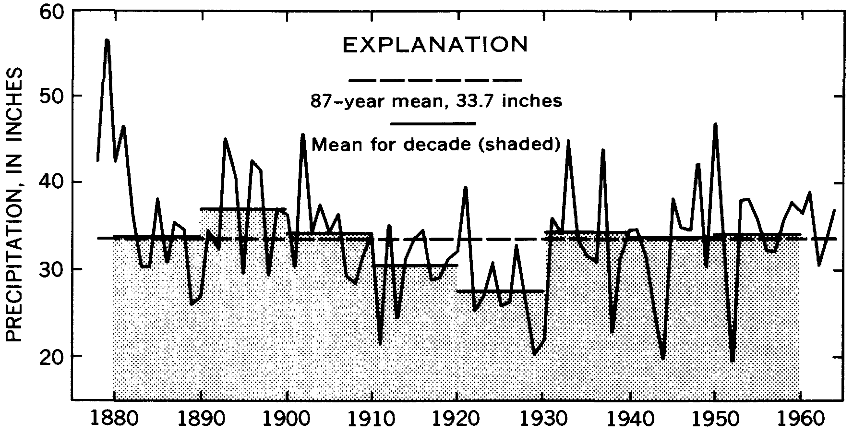


Figure 4.—Annual precipitation at Seattle, 1878–1964. Data from U.S. Weather Bureau.

The seasonal pattern is generally the same throughout the county even though the nature and total amounts of precipitation differ according to location. The typical pattern is shown by monthly precipitation at Snoqualmie Pass (fig. 5). There, at an altitude of 3,020 feet, amounts of rain normally are small from June to September. In October the heavier rains usually begin, changing to rain and snow in November and to mostly snow from late December until about April.

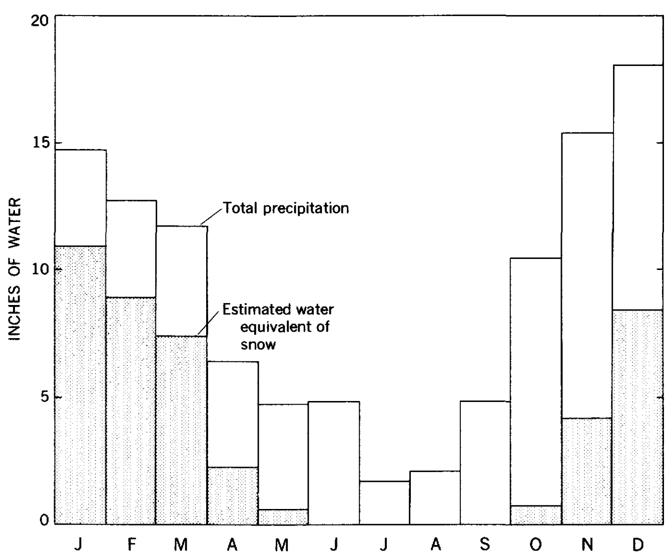


Figure 5.—Mean monthly precipitation at Snoqualmie Pass, 1930–59. Data from U.S. Weather Bureau. Water content of snow is estimated by assuming that 10 inches of new-fallen snow is equivalent to 1 inch of water.

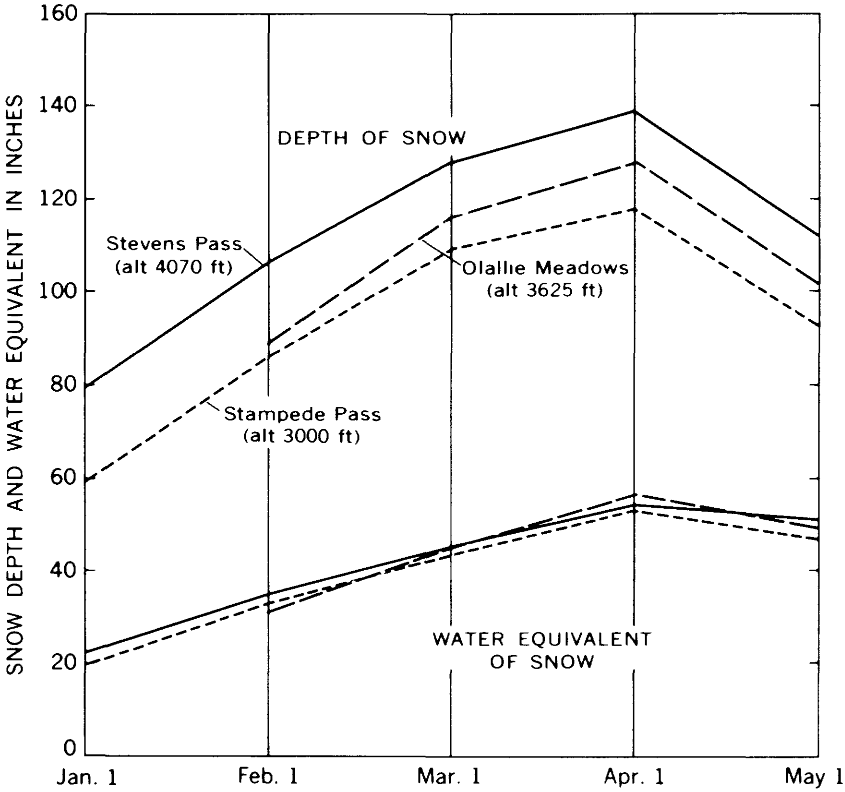


FIGURE. 6.—Average depth and water equivalent of snowpack at three snow courses, 1954–60. Data from Washington Division of Water Resources (1961(?), p. 36, 87, 94).

The deep snow that accumulates at Snoqualmie Pass and Stevens Pass during most winters has made those locations popular as winter sports areas. In addition to providing recreation for many people, the snow in eastern King County constitutes a very important part of the county's water resource. The amount of water stored as snow in the mountains is measured at several snow courses; figure 6 shows the average depth and water equivalent (that is, the amount of water that would be obtained if the snow were completely melted) at three snow courses in the county. Normally, the snow reaches a maximum depth about the first of April. The amount of water stored as snow in the mountains in April is commonly greater than the amount received as precipitation in the western part of the county during an entire year.

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EVAPOTRANSPIRATION

Not all the water that occurs as precipitation becomes streamflow and ground water. Some of it is lost by evaporation from water surfaces, snow, ice, and moist soil, and some is lost by the transpiration of trees and other vegetation. These water losses are usually referred to by hydrologists as total evaporation, or evapotranspiration.

The amount of water loss that can occur in an area by evaporation is limited to an amount known as potential evapotranspiration. This upper limit is fixed by climatic factors, chiefly temperature, humidity, windspeed, and solar radiation. Potential evapotranspiration cannot be attained, however, unless the area affords the opportunity for evaporation. In other words, water or moisture must be present near the land surface before evaporation can occur. Evaporation opportunity is related, therefore, to the available moisture supply, and is influenced by the volume and distribution of precipitation. It is influenced to a lesser degree by other factors, namely: soil, vegetal cover, topography, and geologic structure.

When precipitation and soil moisture exceed the potential evapotranspiration in an area, a water surplus exists, which adds to the total surface- and ground-water resources of the area. In much of the mountainous area of the Pacific Northwest, precipitation and soil moisture probably are adequate to satisfy the requirements of evapotranspiration at all times except during late summer. In the lowland areas, the potential evapotranspiration normally exceeds available moisture from May to September. This feature is illustrated by an annual water budget computed on the basis of weather records at Seattle (fig. 7). The term "water budget," as used here, is a graphical statement of the average monthly amount of water available in the form of precipitation and soil moisture and the average monthly demand of evapotranspiration. Beginning in January, in the middle of the water-surplus season, precipitation exceeds evapotranspiration, and this surplus condition normally persists until about April. The deficit season begins after April and continues through September. During this period water stored in the soil is depleted, the rate of depletion during dry weather depending on the moisture capacity of the soil. Assuming, for the purpose of illustration, that an average soil near Seattle has a moisture capacity of 6 inches of water, the average amount of evapotranspiration there during the deficit season is shown in figure 7 by the thin dashed line between April and September. Water loss at several places in King County, for two selected levels of available moisture capacity, has been estimated by the U.S. Weather Bureau and the U.S. Soil Conservation Service (1961), and is shown in table 2.

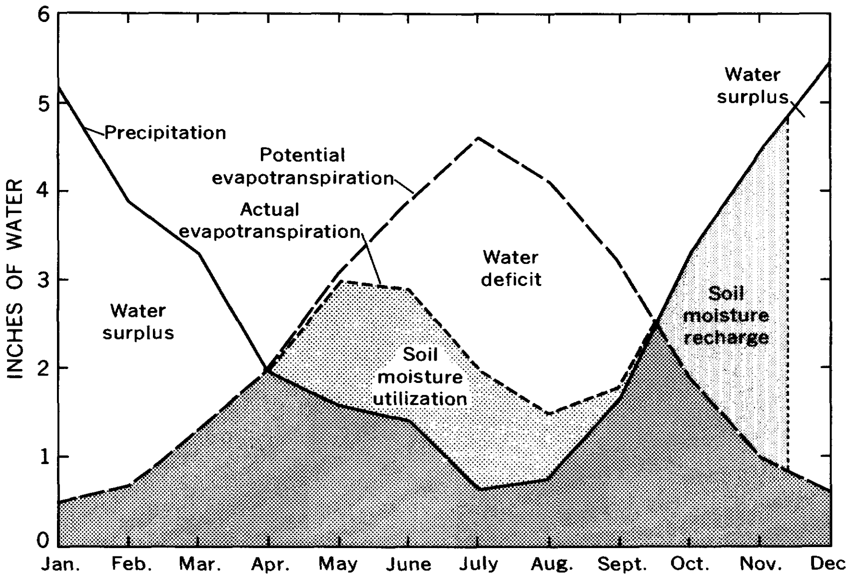


FIGURE 7.—Mean annual water budget at Seattle. The solid line denotes mean monthly precipitation for the period 1931–60. The heavy dashed line represents mean monthly potential evapotranspiration, computed by the Thornthwaite method (Thornthwaite, 1948).

TABLE 2.—*Estimated annual evapotranspiration at nine Weather Bureau stations in King County*

[Data from U.S. Weather Bureau and U.S. Soil Conservation Service (1961). Locations shown are those for which precipitation and temperature normals are available]

Station	Evapotranspiration, in inches		
	Potential	With 6-inch soil-moisture capacity	With 2-inch soil-moisture capacity
Lowlands:			
Bothell (2 miles N)	24. 7	20. 3	17. 6
Seattle-Tacoma Airport	25. 3	18. 4	15. 1
Seattle, city office	26. 7	19. 2	15. 8
Foothills:			
Buckley (1 mile NE)	25. 0	22. 8	20. 8
Landsburg	24. 5	22. 9	21. 4
Palmer (3 miles SE)	24. 7	23. 8	22. 8
Snoqualmie Falls	25. 4	23. 2	21. 3
Cascade Mountains:			
Cedar Lake [Chester Morse Lake]	23. 2	22. 6	21. 7
Stampede Pass	17. 7	16. 5	15. 1

The only known record of evaporation in King County is the one obtained by means of an evaporation pan at Maple Leaf Reservoir in Seattle. Monthly evaporation from this standard Weather Bureau pan, when corrected by applying a factor of 0.7, agrees closely with the estimated potential evapotranspiration. Evaporation from lakes and reservoirs in the county is estimated to range from about 18 inches per year in the Cascades to about 27 inches per year near Puget Sound.

STREAMFLOW

After the demands of evapotranspiration have been met, the water that remains is largely available as streamflow and ground water. Surface-water runoff has been measured at many gaging stations throughout King County. The sites where streamflow information is available as of September 30, 1964, are shown on plate 2.

The major river systems in King County include many tributary streams that flow throughout the year—a typical feature of humid regions. Seasonal runoff is generally characterized by several high-flow periods in the winter, medium flows in the spring, and sustained low flows in the summer and fall. Winter flows generally are high because of persistent and sometimes heavy precipitation, and because temperatures are seldom low enough to cause streams to freeze. In the spring and early summer, mountain streams are fed by the melting snowpack, and lowland streams receive large quantities of ground-water discharge. By late summer, most of the snowpack is gone and ground-water levels generally are down. If fall rains are delayed, the streamflow may continue to decline, and minimum flows may occur as late as November. If, on the other hand, fall rains are particularly heavy, severe floods may occur in November. Streamflow during November is less predictable, therefore, than during other months of the year. An example of the seasonal pattern in runoff is shown in figure 8. The large winter flows of the Snoqualmie River decline to the low flows of the following autumn, the decline being interrupted by increased flows from snowmelt in the spring.

Large year-to-year changes in the discharge of major streams in King County can also occur. For example, in 1941 the discharge of the Snoqualmie River near Carnation was only 60 percent of the average for the 1931–60 base period, whereas in 1959 it was 135 percent of the average.

Figure 9 shows the areal distribution of average annual runoff in King County for the period 1931–60. The pattern of average runoff is similar to that of precipitation (fig. 3), the principal difference at any location being the result of evapotranspiration. The differences in the two figures also reflect certain land characteristics that affect runoff. The two maps should not be compared closely, however, because available data are not sufficient to define accurately the pattern of precipitation and runoff in all parts of the county.

The three major river systems of King County are those of the Green-Duwamish, Lake Washington, and Snoqualmie basins. Those three drainage basins, shown in figure 10, have a total area of 1,780 square miles, all but about a hundred square miles of which lies within King County. The remainder of the county (about 24 percent) drains to the Skykomish River, to the White and Greenwater Rivers, which form the county's south border, and to small streams tributary to Puget Sound.

GREEN-DUWAMISH RIVER BASIN

The compound name "Green-Duwamish" is sometimes applied to the basin of the Duwamish River because the Green River is the only large stream that flows into the tidal estuary known as the Duwamish. Prior to 1906, the Duwamish River received the waters of the Green, White, and Black Rivers. In that year, flow in the White River was permanently diverted from the basin, leaving only the Green River to flow

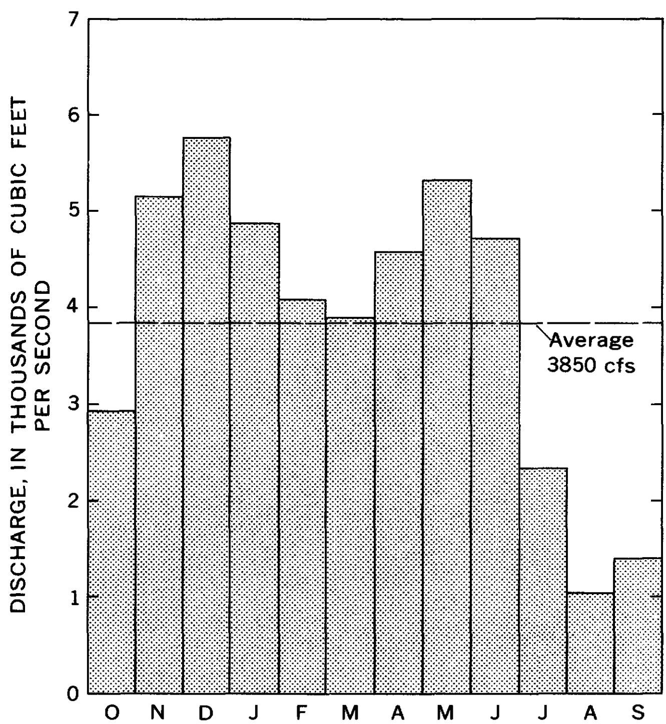
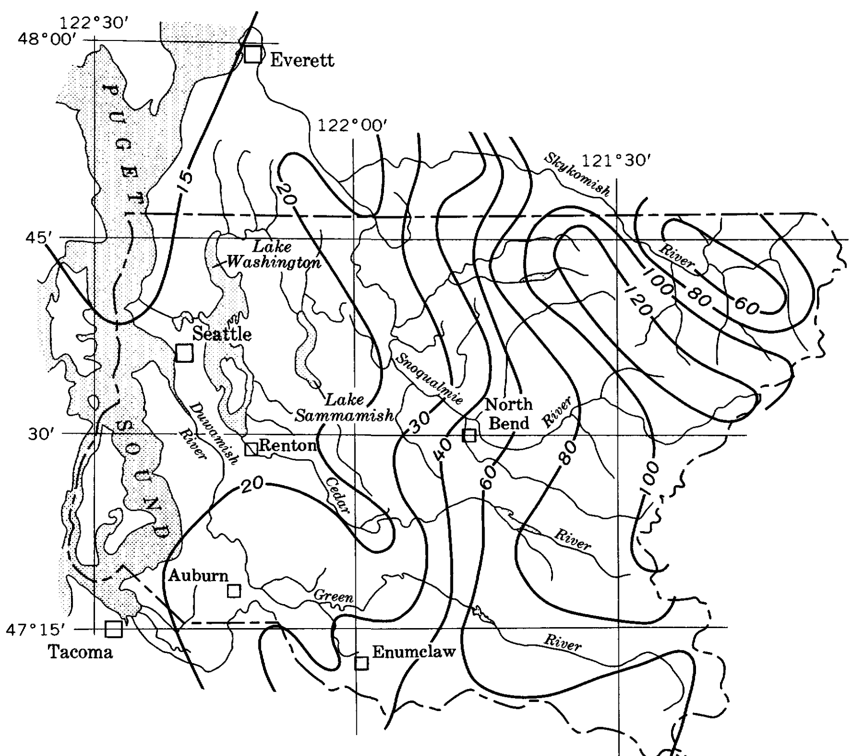


FIGURE 8.—Average monthly discharge of Snoqualmie River near Carnation, 1931–60.

northward from Auburn to its confluence with the Black River. In 1916, the Black River lost its identity as the outlet of Lake Washington when the Lake Washington Ship Canal was completed and the level of the lake was lowered about 9 feet. Thus, the major changes of 1906 and 1916 reduced the Duwamish River basin to a fourth of its former size. The basin now has a drainage area of 483 square miles.

The upper basin of the Green River is of particular importance for municipal water supply, because it has been the main watershed for the city of Tacoma since 1913. The 230-square-mile watershed heads in the Cascade Mountains near Stampede Pass and provides an excellent supply of mountain water. Within the watershed, Howard A. Hanson Dam was completed at Eagle Gorge in 1962 and now provides storage to control floods and to augment the summer low flows down-



EXPLANATION

——— 40 ———
Line of equal runoff
Shows average annual runoff. Interval, in inches, is variable

FIGURE 9.—Average annual runoff.

stream. The reservoir, with a maximum capacity of 106,000 acre-feet, is designed to prevent the flow in Green River from exceeding 12,000 cfs (cubic feet per second) near Auburn. Part of the reservoir storage, 22,000 acre-feet, is allocated to assure a minimum flow of 110 cfs in the river below the point at which Tacoma diverts water for municipal use.

Downstream from Palmer the Green River flows through a gorge for about 15 miles before emerging into the broad alluvial Green-Duwamish Valley near Auburn. In the gorge the river receives the flow of numerous springs; downstream, the only tributary streams of any size are Newaukum Creek and Big Soos Creek. Big Soos Creek is particularly important to the fisheries of the State because of the salmon hatchery on that stream.

Near Auburn, the character of Green River changes visibly as it begins to meander through the valley toward Renton Junction. As this valley becomes more and more industrialized and densely populated, pollution of the Green and Duwamish Rivers becomes increasingly difficult to control.

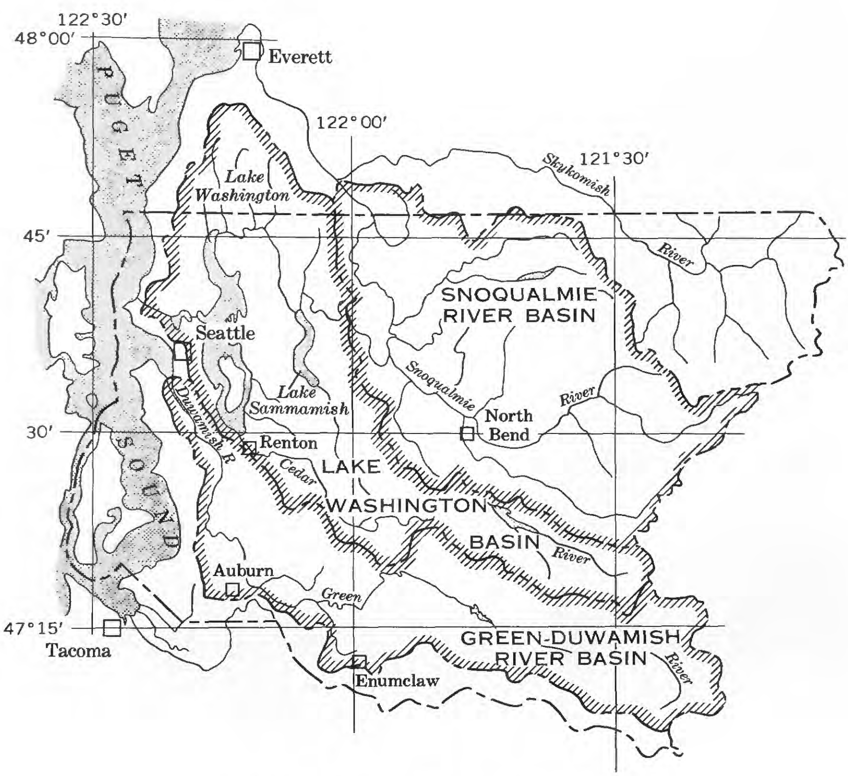


Figure 10.—Major drain basins.

LAKE WASHINGTON BASIN

North of the Green-Duwamish River system lies the drainage basin of Lake Washington (see fig. 10), which has a total area of 607 square miles above the Chittenden Locks. Within this basin, the two principal tributaries of Lake Washington are Cedar River and Sammamish River. Several minor streams also drain into the lake, which, in turn, drains to Puget Sound through the Lake Washington Ship Canal (fig. 11).

The Cedar River has a drainage area of 188 square miles, and heads in a mountainous area where precipitation is abundant. The upper basin of Cedar River has been Seattle's main source of water supply since 1901. Above the location near Landsburg where water is diverted to Seattle's gravity system, the area within the watershed is 119 square miles. This area yields a large supply of water: streamflow records show that the flow near Landsburg for the last 68 years has averaged 693 cfs, representing an average annual runoff of about 80 inches. Even this large amount of runoff, however, would not assure an adequate supply for Seattle without additional storage; during some months the city has used as much water as was available in the river.

FIGURE 11.—Aerial view of Lake Washington Ship Canal and Chittenden Locks at Seattle. View looking east (upstream) from Salmon Bay. Fresh-water discharge from Lake Washington joins salt water of Puget Sound at this point. Photograph by U.S. Army Corps of Engineers.

Some storage for municipal use is provided at Chester Morse Lake (formerly Cedar Lake) where a timber crib dam was built in 1904, and immediately downstream, in the Masonry Pool, where a second and larger dam (known as Masonry Dam) was completed in 1914. When the level of the Masonry Pool was raised in 1918, a washout occurred on December 23 in the glacial moraine that separates the Cedar and Snoqualmie River basins. The resulting flood in Boxley Canyon was a catastrophe that received much publicity and caused many years of legal controversy (McWilliams, 1955, p. 235). Since the washout of 1918, significant quantities of water have been lost from Chester Morse Lake by seepage (F. T. Hidaka, U.S. Geol. Survey, oral commun., 1965). That seepage loss is of concern to the future development of the lake, because utilization of Masonry Dam as originally planned has not been feasible. Ways of providing additional storage in the Cedar River watershed are a subject of continuing study.

Cedar Falls, below Chester Morse Lake, is one of the two places in King County where a significant amount of hydroelectric power is generated. The Cedar Falls plant, originally built in 1904, has had an installed capacity of 30,000 kw (kilowatts) since 1929. Except for Seattle's diversion at Landsburg for municipal supply, no other large development presently exists for the use of Cedar River water as it flows down the narrow valley to Renton and into Lake Washington.

The other main tributary of Lake Washington is Sammamish River, the outlet of Sammamish Lake. The river drains 240 square miles. Streams that flow into Sammamish Lake are small, draining foothills that are below an altitude of 3,000 feet. For that reason, the average discharge of Sammamish River is less than that of Cedar River, even though its drainage basin is larger. In other words, the flow at the mouths of the two streams is not proportional to their respective drainage areas.

Sammamish Lake is normally only about 12 feet higher than Lake Washington, and in former years properties along the lakeshore and on the river's flood plain were sometimes inundated. Prior to the lowering of Lake Washington in 1916, the valley between the two lakes was largely a swamp. A project of the U.S. Army Corps of Engineers, sponsored by King County and completed in 1964, improved the Sammamish River channel to permit more utilization of the flood plain for agricultural, commercial, and residential growth. The project was designed to maintain the existing minimum elevations of Lake Sammamish (about 26 ft above mean sea level) and to allow a discharge at the lake outlet of as much as 1,500 cfs without exceeding a lake elevation of 29 feet.

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Flow data are available for seven small streams—May, Coal, Mercer, Juanita, Lyon, McAleer, and Thornton Creeks—that discharge directly to Lake Washington, draining a total area of about 63 square miles. The average combined flow of these streams is about 87 cfs, which is only about 8 percent of the total contribution to the lake from all gaged streams.

Streamflow entering Lake Washington is a factor of vital importance to the quality of water in the lake. Concern over the rapidly deteriorating water-quality conditions in the lake has resulted in many investigations and lead to an extensive program to reduce pollution (Metropolitan Seattle sewerage and drainage survey, 1958, Brown and Caldwell, consulting engineers, 558 p). Another important factor affecting the condition of the lake is the amount of water required to operate the Chittenden Locks and fish ladders, and to flush out salt water that enters the Lake Washington Ship Canal through the locks. Those requirements have increased with more use of the locks, until under present conditions fresh water is not always sufficient during drier years to prevent salt water from intruding into the lake. The future condition of Lake Washington may depend, therefore, on the availability of additional fresh-water inflow during dry summer months. Conceivably, additional inflow could be provided by diversion from the Snoqualmie River basin.

SNOQUALMIE RIVER BASIN

Most of the streamflow in King County has its source in the Snoqualmie River basin, the largest and most productive of the county's three major basins. The total drainage area of the Snoqualmie River is 693 square miles, of which all but about 22 square miles lies within King County. A large part of the river's flow is contributed by the three forks that converge near North Bend to form the main stem of the Snoqualmie River. They are the Middle, South, and North Forks.

The Middle Fork is the largest of the three and it drains an area that receives, on the average, the largest amount of precipitation in the county (fig. 4). Heading in the rugged mountains near the crest of the Cascade Range, the upper basin of the Middle Fork lies in an area that is largely wilderness. Alpine lakes are numerous, and snowfields that persist on some of the northern slopes until late summer are evidence of the extremely heavy winter precipitation. An aerial view of the upper basin of the Middle Fork is shown in figure 12. The North Fork also drains some of the high mountain country, but much of its basin lies to the west of the Snoqualmie National Forest, where logging of private lands has made the area less attractive for recreation than along the Middle Fork. The branch of the Snoqualmie that

FIGURE 12.—Aerial view looking southeast, showing headwaters area of Middle Fork Snoqualmie River. Big Snow Lake and Big Snow Mountain are in foreground. The Middle Fork itself lies in valley between Big Snow Mountain and crest of Cascade Range, on skyline. Photograph by Washington State Department of Game, August 10, 1953.

is most familiar to the highway traveler is the South Fork, which heads near Snoqualmie Pass and flows westward through the deeply incised valley that is followed by U.S. Highway 10 and the Milwaukee Railroad. Because it lies at a lower altitude than the other two branches, the South Fork receives less precipitation and contributes less runoff per square mile of drainage area.

About 3 miles below the mouth of the South Fork, the Snoqualmie River plunges over a 270-foot drop at Snoqualmie Falls. This scenic landmark has been the site of a hydroelectric powerplant of the Puget Sound Power and Light Co. since 1900 (see fig. 13). The present installation is capable of producing 41,700 kw. This is a run-of-the-river plant, that is, it is one that must depend on natural streamflow, because storage above the falls is insufficient to allow more than slight regulation of the flow. During the summer months, all the flow above the falls is usually diverted through the powerhouses. Less than a mile below the falls, a fish hatchery is operated by the State Department of Game near the mouth of Tokul Creek. Three miles farther downstream, Raging River joins the Snoqualmie at Fall City. From Fall City to its confluence with the Skykomish River, the Snoqualmie winds for 35 miles through a broad valley where the average stream gradient is less than 2 feet per mile.

The largest tributary to the Snoqualmie River downstream from Fall City is the Tolt River. In the upper part of the Tolt River basin

FIGURE 13.—Snoqualmie Falls. In the foreground is a powerplant of the Puget Sound Power and Light Co.; another plant is in a cavern beneath the falls. The town of Snoqualmie and Mount Si are in the background to the east. Photograph by Puget Sound Power and Light Co.

a water supply has been developed in recent years for the city of Seattle. The development is on the South Fork Tolt River, where the average annual runoff, adjusted to the period 1931–60, is 131 inches. This remarkably high value indicates that annual precipitation in the watershed averages more than 150 inches. Even with such a large total supply of water, storage is required for periods of heavy demand, because minimum unregulated flows of the South Fork are normally only 15–25 cfs, or 10–16 mgd (million gallons per day). Completion of the South Fork Tolt Reservoir in 1963 provided a storage capacity of 57,830 acre-feet, which is equivalent to 42 percent of the long-term average annual runoff. The pipeline from the reservoir is capable of delivering 90 mgd (139 cfs) to Seattle. Sometime in the future, when the increased demand for water requires an additional supply, a similar development on the North Fork Tolt River should be capable of providing another 90 mgd to Seattle. Thus, the Tolt River watershed, like those of the Cedar and the Green, is one of the more important sources of water supply in King County.

FLOODS

A flood may be defined as a relatively high flow, and an annual flood as the highest flow in a given water year. (A water year is the 12-month period from October 1 through September 30, and is numerically designated by the year in which it ends; that is, the period October 1, 1963–September 30, 1964, is the 1964 water year.) Records of annual floods at a site for a period of years may be used to determine the "mean annual flood" for that period. Theoretically, the arithmetic mean of all annual floods at a given site has a recurrence interval (computed by the Gumbel method) of 2.33 years. Therefore, as defined by the Geological Survey, the "mean annual flood" is a flood having a recurrence interval of 2.33 years in an array on Gumbel plotting paper.

Even without a streamflow record at a particular site, the mean annual flood can be estimated on the basis of certain drainage-basin characteristics. The analysis by Bodhaine and Thomas (1964) provides a method for estimating the mean annual flood at a site for the period 1912–57. Values for the mean annual flood at many sites throughout King County are given in table 12, page 68. The probability (or frequency) of greater annual floods may also be estimated on the basis of the study by Bodhaine and Thomas.

Floods in King County occur, almost without exception, as a result of warm rainstorms during the period from October to March. Though the floodwaters are primarily rain runoff, they are often augmented by water from melted snow, especially if the snow mantle prior to the warm rainfall extended to low altitudes. Hydrographs of rain-runoff peaks in the county are characterized by high magnitudes and short durations. In contrast, spring floods may last for extended periods but are usually not severe at peak stage.

The floods of November 1959, which were particularly large on streams heading in the Cascade Range, are described in Water-Supply Paper 1750–B (U.S. Geological Survey, 1964). A brief excerpt from that paper is descriptive of the conditions that produce most of the severe floods in King County:

> Previous rains had raised the soil moisture content. The combined conditions of soil saturation from previous rains, heavy precipitation, and abnormally warm temperature produced a high rate of runoff. Discharges on practically all streams in the mountain regions approached or exceeded previously recorded peaks.

Discharge hydrographs for the flood of November 1959 at two gaging stations on the Snoqualmie River are shown in figure 14. The station near Snoqualmie is just below Snoqualmie Falls, and the one near Carnation is 17 miles downstream, where the valley floor is more than a mile wide. The hydrographs show that the peak flow on November 23, 1959, was greater at the upper station than it was near Carnation. The occurrence of higher peak flows at upstream points is not unusual during floods on some of the larger rivers. Heavy precipitation and melting snow in the Cascade Range produce most of the floodwaters in western Washington, and flow in the lower tributaries usually crests before the peak of the mountain runoff reaches the valley floor. After the peak flow from the headwaters reaches the lower valley, it may

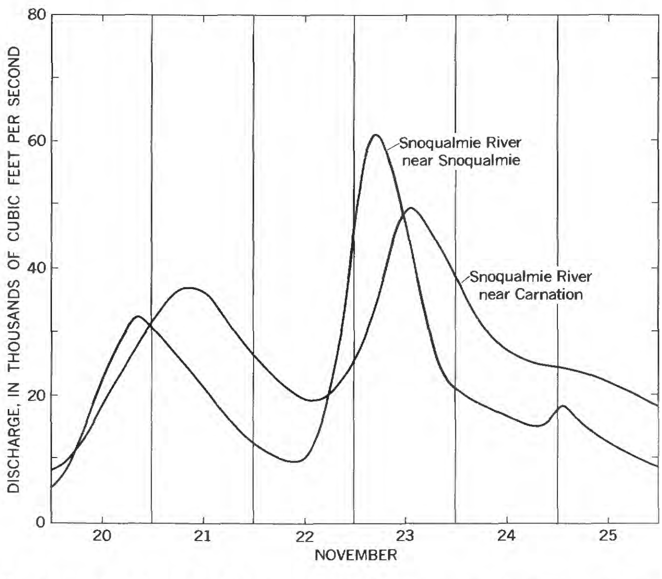


FIGURE 14.—Flow of Snoqualmie River near Snoqualmie and near Carnation during flood of November 1959.

actually be reduced downstream as the river overflows its banks and inundates the flood plain. The flood plain in this situation has an effect similar to that of a reservoir in reducing the peak flow. A view of the flooded lower valley of the Snoqualmie River is shown in figure 15.

Although the 1959 flood was severe in the mountain regions, it was not the greatest of record near Carnation or at other low-altitude gaging stations. Annual peak discharges of the Snoqualmie River near Carnation have been recorded since 1930, and are plotted in their order of magnitude on the flood-frequency curve of figure 16. The highest four peak flows shown on this figure are identified by their dates of occurrence; they show that three annual floods since 1930 have been higher than that of November 1959. (The peak flows of February and November 1932 are both considered to be annual floods because they occurred in separate water years.) The flood-frequency curve shows the average recurrence interval, or frequency, of floods near Carnation from 1930 to 1964. On the basis of this curve, a 50-year flood would have an estimated peak flow of 69,000 cfs under the same conditions that have prevailed since 1930. Such a flood, if it

FIGURE 15.—Aerial view of flooded Snoqualmie Valley, looking north toward town of Carnation (upper left), January 29, 1965. Normal river channel is seen meandering in valley bottom. A flood peak of this magnitude (41,400 cfs near Carnation) is expected to be exceeded about every 5 years, on the average. Photograph by Seattle Post-Intelligencer.

were to occur today, would probably cause damage in the Snoqualmie Valley amounting to millions of dollars. (It should be understood that a "50-year" flood, statistically, has a 2-percent chance of occurring in any given year; it is expected to occur not just at 50-year intervals, but perhaps more than once or possibly not at all during a 50-year period.)

Since the earliest history of settlement in King County, the amount of damage has been rising at an increasing rate with succeeding floods, not because the flood volumes have changed, but rather because the flood plains have increased in value. As more homes, industries, roads, bridges, and utilities have been located in the Snoqualmie and Green-Duwamish Valleys, the potential damage has also increased. The flood plains are now used so extensively that if the February 1932 flood, for example, were experienced today, the loss of property in King County would be tremendous.

In the Green-Duwamish Valley the possibility of another major flood has been greatly reduced by the construction of Howard A. Hanson Dam. (p. 16). Although the dam provides enough storage to keep the Green River within its banks, it cannot eliminate all inundation of the river's flood plain. Local flooding still occurs because the main river channel is perched so high between its leveed banks that water from tributary streams cannot always drain freely from the flood plain to the river. That condition may be aggravated at times by controlled releases from Hanson Reservoir, which may prolong high

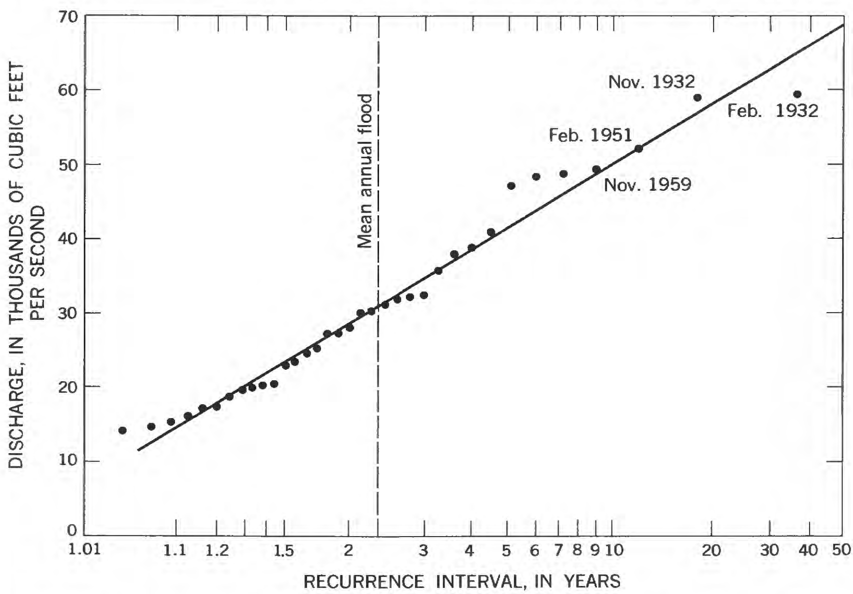


FIGURE 16.—Frequency of floods at Snoqualmie River near Carnation, 1930–64.

stages of the Green River. The drainage problem is being studied by the Soil Conservation Service, and improvement of drainage has been proposed in a plan prepared by that agency in cooperation with King County and the cities of Auburn, Kent, Renton, and Tukwila.

LOW FLOWS

Because of light rainfall in the summer months, minimum streamflows in King County nearly always occur between July and November. Most of the streams flow perennially, and even the smaller streams rarely go dry.

The magnitude of normal low flows and the probability of drought flows have been determined on the basis of an analysis of selected gaging-station records in the county. In this analysis, the lowest 7-day mean discharge in each year was used as a measure of the annual low flow. The annual values at the selected stations were determined or estimated for the period 1931–60 and were then plotted in their order of magnitude on a graph similar to that of figure 17. The six curves in figure 17 were drawn on the basis of values plotted in this manner, to show the frequency of low flows at the selected sites. For example, a minimum 7-day discharge of 450 cfs in the Snoqualmie River near Carnation is shown to occur, on the average, once in 10

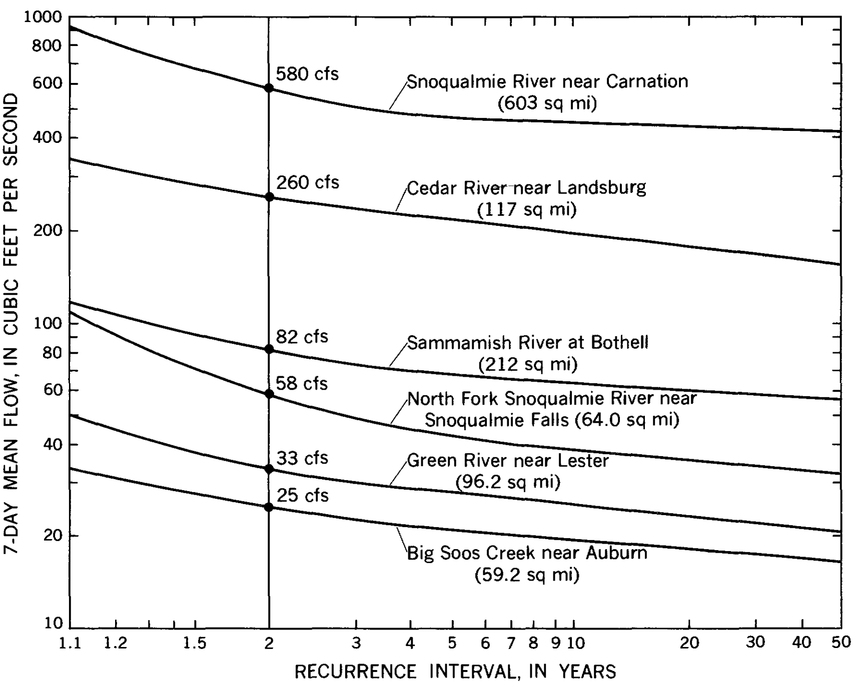


FIGURE 17.—Frequency of low flow in six streams, 1931–60.

years. The discharge at the 2-year recurrence interval represents the median annual low flow for each stream; this discharge can be considered the stream's normal low flow.

The six stations represented by the curves in figure 17 were selected on the basis of their usefulness in portraying low-flow characteristics of important streams in the county. The characteristics are variable, being affected by many factors in each stream basin. One of the factors is the size of the basin, but figure 17 shows that basin size alone does not explain the magnitude of normal low flow. The North Fork Snoqualmie River, for instance, drains a smaller area than the Green River near Lester, but its low flow is normally higher than that of the Green River. Likewise, the average annual discharge of a stream is not a good indication of its normal low flow. For example, the North Fork Snoqualmie River has a higher average discharge than the Sammamish River, but discharges less water during normal low flow. Reliable estimates of the amount of low flow to be expected on a particular stream can be obtained only from streamflow records.

The predominant type of geologic material underlying a stream basin has a pronounced effect on low flow in the stream. A good example of this effect is shown by a comparison of the recession curves in figure 18, which are based on flow records of Raging River near Fall City and Newaukum Creek near Black Diamond. The curved lines on the graph show how the flow of each stream normally recedes below a given discharge when there is no rain. (A discharge of 50 cfs was arbitrarily used as a starting point for the flow in both

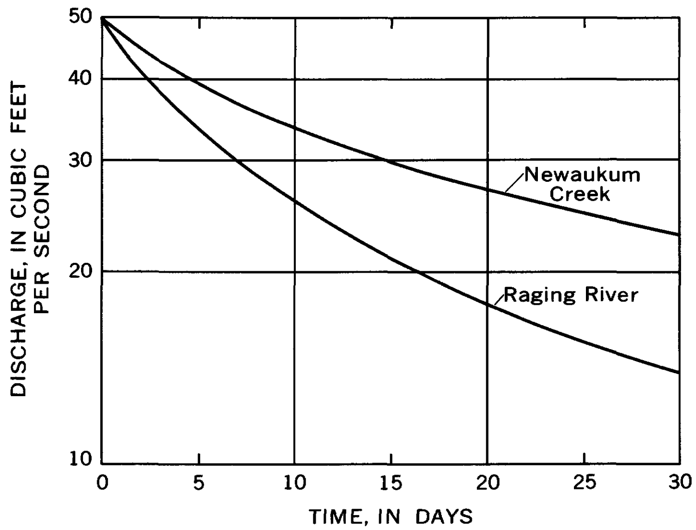


FIGURE 18.—Recession of dry-weather flow in Raging River and Newaukum Creek.

streams so that the two recession curves could be compared.) The drainage basin of Raging River is larger than that of Newaukum Creek, and it receives a greater amount of precipitation. Consequently, the average discharge of Raging River is more than twice that of Newaukum Creek, and one might therefore expect that the dry-weather flow would also be higher in Raging River. Such is not true, however, because materials that underlie the Newaukum Creek basin are more permeable than those that form the basin of Raging River.

Raging River's drainage basin, southeast of Issaquah, is in bedrock hills that are mantled by relatively impermeable glacial deposits. Much of the runoff of Raging River occurs during periods of rainfall, and when the rains cease the flow of the river recedes rather quickly, as shown by the lower curve of figure 18. Flow in Newaukum Creek, though it is the smaller of the two streams, recedes more slowly because it drains an area of permeable glacial material where the larger ground-water storage capacity provides more water to sustain the dry-weather flow.

Storage, whether it is in the form of snow, lakes, or reservoirs, or is in the ground, is the key to an ample supply of water in King County during periods of little precipitation. As the future demand for water increases and additional supplies are needed during periods of low streamflow, methods of providing more storage will be looked for. Reservoirs are the most obvious way of increasing the supplies of stored water, although other methods are also becoming available as a result of investigations in such fields as watershed management, snow hydrology, and artificial recharge of ground water.

GROUND WATER

Ground water occurs in rocks that vary greatly in their water-bearing characteristics, depending on the abundance and character of interstices (pore spaces) which in turn are characteristics of the rock type. Interstices act as minute water conduits in rocks, and are of fundamental importance to the occurrence and movement of ground water. Thus, the occurrence of ground water becomes better understood as the distribution of rock types is determined during the geologic mapping of an area.

GEOLOGIC ENVIRONMENT

Rocks of pre-Tertiary age (older than about 60 million years), representing the remnants of an old mountain range, are exposed only in the northeastern part of King County.

During much of the Tertiary Period, a large slowly subsiding basin occupied most of western Washington, within which flood lavas, volcanic debris, and sedimentary material were deposited (Snavely and Wagner, 1963). In the area now known as King County (pl. 1), the sedimentary materials, mostly clay, sand, and peat, were deposited largely in marine and swamp environments, and became interbedded with the volcanic materials. During a period of folding and faulting into northwest-trending ridges and valleys, the buried sedimentary deposits were slowly compacted into layers of shale, sandstone, and coal. In the last stage of the Tertiary Period, volcanic activity gradually shifted eastward, and large masses of magma were intruded in the central and southern Cascade Range as it was being uplifted (Fiske and others, 1963, p. 63).

The Quarternary Period, which started 2–3 million years ago, includes the Pleistocene and the Recent Epochs. During the Pleistocene Epoch there were repeated periods of continental glaciation in the Puget Sound Lowland and alpine glaciation in valleys of the Cascade Range (Crandell, 1963, p. 8–9). Between the periods of glaciation, sedimentary deposits accumulated in the lowland. The repeated glaciations and periods of sedimentation have left deposits of unconsolidated rocks that probably are more than a thousand feet thick in parts of King County.

The last major glaciation in the Puget Sound Lowland was the Fraser Glaciation, which lasted from about 25,000 to 9,000 years ago (Armstrong and others, 1965, p. 321, 324). Deposits of the Fraser Glaciation in the lowland part of the county are termed the Vashon Drift. Those deposits include till and various types of glacial outwash. The Vashon Drift forms a thin layer that mantles the surface of much of the Puget Sound Lowland as shown by the map and cross section in plate 1. The till plains shown in figure 1 are largely mantled by Vashon Drift.

Most of the Vashon glacier had melted from King County by about 13,500 year ago (Mullineaux and others, 1965, pp. 7–8). Since then, the Cedar, Green, and White Rivers have partly filled the Lake Washington-Duwamish Valley trough with aluvium between Renton and Sumner. Most of the alluvium is from the White River, which originates at Emmons Glacier on Mount Rainier and carries a heavy load of glacial silt. Some other deposits in the county are also from the Mount Rainier area, and are the result of mudflows and explosive eruptions. About 4,800 years ago, a catastrophic mudflow, the Osceola Mudflow (see pl. 1), filled the former White River valley south of Enumclaw and diverted the river to its present course (Crandell, 1963, p. 67). A lobe of this mudflow is deeply buried in the Duwamish Valley nearly as far north as Kent (Luzier, 1967).

Since the melting of the Vashon glacier, normal erosion processes have modified the landscape (and are continuing to do so) principally by the downcutting of rivers, by landsliding, and by the filling of estuaries with alluvium.

GROUND WATER IN BEDROCK

The bedrock in King County contains little ground water. Most of these rocks have a low porosity and permeability; joints in the rocks provide the more effective openings for the movement of water. The size and number of the joints vary with rock type and depth. Characteristically, little or no recoverable water occurs in the metamorphic and intrusive igneous rocks below a depth of about a hundred feet where joints become tight and sparse.

The bedrock includes pre-Tertiary metamorphic rocks and Tertiary igneous and sedimentary rocks. Virtually all the sedimentary rocks (sandstone, shale, conglomerate, and coal) are well consolidated and weathered, and are of low permeability. The largest yield from bedrock in the county is on the north side of the Newcastle Hills, just south of Eastgate. A conglomerate unit in that area is tapped by several wells, all of which yield enough water for domestic use.

GROUND WATER IN UNCONSOLIDATED DEPOSITS

The unconsolidated deposits in King County contain almost all the ground water available to wells. The water occurs within gravel and sand beds of glacial, nonglacial, and alluvial origin. The outwash deposits of gravel and sand from the continental glaciers generally are very permeable and comprise some of the best aquifers in the county. Fine-grained outwash materials (silt and sand) do not yield water readily to wells. However, water is able to move slowly through most of the fine-grained strata and recharge aquifers that occur below them.

The outwash deposits are of variable thickness; they may be thin (10–15 ft) or thick (50–75 ft), and areally extensive (5–10 sq mi) or, when occupying buried or abandoned stream channels, elongate and sinuous. The buried channels are difficult to trace, though in some places they might be followed by geophysical methods.

Glacial till is the most areally extensive and persistent of the unconsolidated deposits. The approximate extent of the surface exposure of the Vashon till is shown on plate 1. Very little water can be obtained from till, but some dug wells tap lenses or stringers of gravel or sand that occur sporadically within the till. Most dug wells obtain small domestic supplies from water that seeps through the soil zone and collects in small amounts on top of the till.

Lacustrine and marine deposits, not differentiated on the geologic map, are characteristically fine grained, laminated, and well sorted; most of them have high porosity but low permeability. Few wells obtain water from those deposits.

Many of the larger areas of alluvium shown on plate 1 are underlain by clay, silt, and sand; many of the long narrow areas are underlain by gravel and sand.

SPRINGS

Springs are abundant in King County, occurring mostly along the valley walls and along the bluffs near Puget Sound. Most of the large springs are the result of the percolation of ground water through Vashon outwash deposits, moving laterally atop the Vashon till, and emerging along valley walls.

Although more than 200 springs are used for domestic and municipal supplies, the amount of spring water used is a small part of the total spring flow in the county. Many undeveloped springs are adequate for domestic use, and some of the larger ones would be adequate for additional municipal supplies. One of the areas of largest spring flow is in a reach of about 11 miles in the Green River Gorge, downstream from Palmer. One of the springs in the reach has been used for many years as a water supply for the city of Black Diamond. Another nearby spring, the largest in the county, is the source of Icy Creek, which has been proposed as a supply for the city of Kent.

Springs contribute large quantities of ground water to many streams in the county, and sustained spring flow is essential to the maintenance of adequate stream discharges during the summer. Although some springs may be considered as wasted ground water, they are of great potential value to the economy of the county, and their use should be carefully planned.

VARIATION IN AMOUNTS OF GROUND WATER

Variations in the amount of ground water underlying King County are indicated by the fluctuation of water levels in wells. Ground-water levels have been measured in the county at the many observation wells shown on plate 2. Water levels and amounts of ground water in storage normally fluctuate because of seasonal changes in precipitation and natural or man-caused ground-water discharge. Smaller water-level fluctuations usually result from tidal loading and changes in barometric pressure.

The amount of ground water in storage increases and water levels rise when the amount of surplus soil moisture (recharge) exceeds the natural ground-water discharge to springs and streams. Conversely, water levels decline during the dry summer season, when less recharge reaches the ground-water reservoir and the discharge continues. At any particular well, the amount of seasonal rise and fall of the water table depends on the location of the well with respect to local geology, topography, and areas of recharge and discharge. Large changes in storage and water level can occur in a permeable aquifer near an area of appreciable ground-water discharge.

The effects of precipitation and pumping on water levels in a municipal well near Bellevue are shown by the hydrograph (fig. 19). That well was pumped for public supply from 1947 to 1954 and was on standby from 1954 to 1959, when it was destroyed. The hydrograph shows that generally lower water levels were prevalent during the period of pumping. The decline during summer months prior to 1954 was due to the increase in pumping and decrease in recharge. During 1954 the water levels returned to the regional normal and thereafter fluctuated with seasonal variations in recharge and discharge.

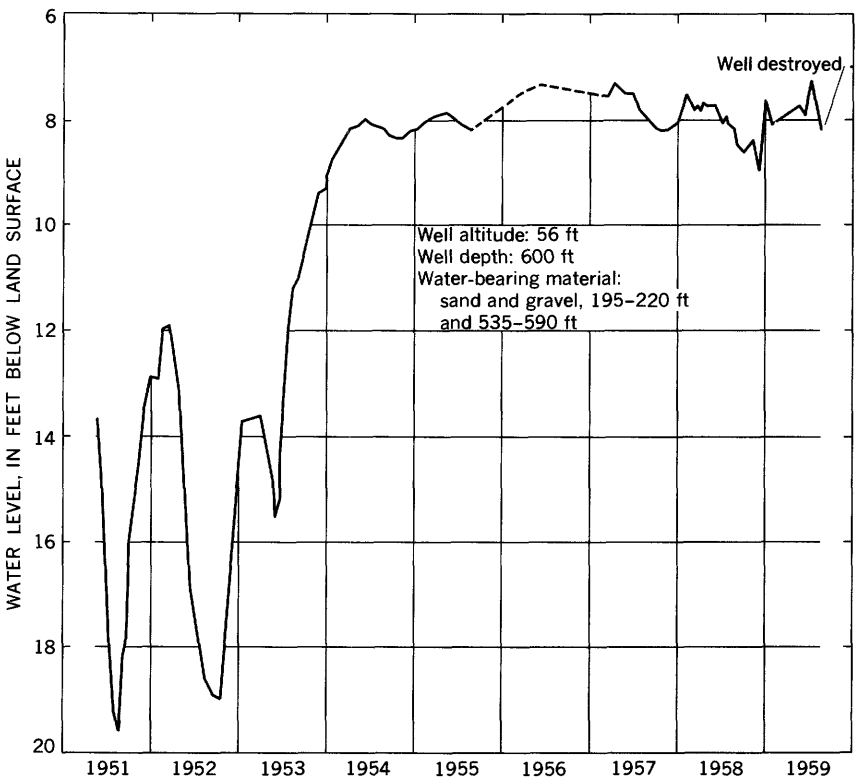


FIGURE 19.—Water level in Water District 68 public-supply well near Bellevue, 1951–59.

QUANTITIES OF WATER AVAILABLE

AVAILABILITY OF SURFACE WATER

The amount of runoff in King County has been determined on the basis of streamflow recorded at the gaging stations shown on plate 2. The length of record varies considerably: some of the stations were operated for less than a year; others have been in use for many years. The longest record available is for Cedar River near Landsburg, where a gaging station has existed since 1895. As of September 1964, 54 stations were in operation in the county; the streamflow data obtained at those stations are summarized in table 12.

To supplement the basic gaging-station data, miscellaneous flow measurements have been made at many sites, which are indicated by the dots on plate 2. The large number of dots shows that some information is available for most streams in the county. A compilation of the measurements made from 1890 to January 1961 is available in Washington State Water Supply Bulletin 23 (Washington Division of Water Resources, 1964, p. 90–127). Measurements after January 1961 are listed each year in "Surface Water Records of Washington," an annual report of the U.S. Geological Survey.

The average flow of any stream in the county can be estimated by using figure 9. First, the drainage-basin boundary upstream from the place of interest is delineated, and the average annual runoff for that basin is approximated on the basis of the isopleths in figure 9. Then the drainage area (in square miles) and the estimated average runoff (in inches) are used to calculate the average streamflow (in cubic feet per second) by the following formula:

$$\frac{\text{Drainage area} \times \text{runoff}}{13.6} = \text{average flow (cfs)}.$$

The annual runoff can also be expressed in acre-feet:

$$\text{Runoff (acre-feet)} = 53.3 \times \text{drainage area} \times \text{runoff (inches)}.$$

For the larger streams in the county, and for many of the smaller ones, estimates by this method are unnecessary because of the availability of streamflow records.

The downstream accumulation of flow in each of the principal streams is shown diagrammatically in figures 20, 21, and 22. Two curves are shown on each graph. The upper curve represents the average annual flow, based mostly on data in table 9, and the lower curve

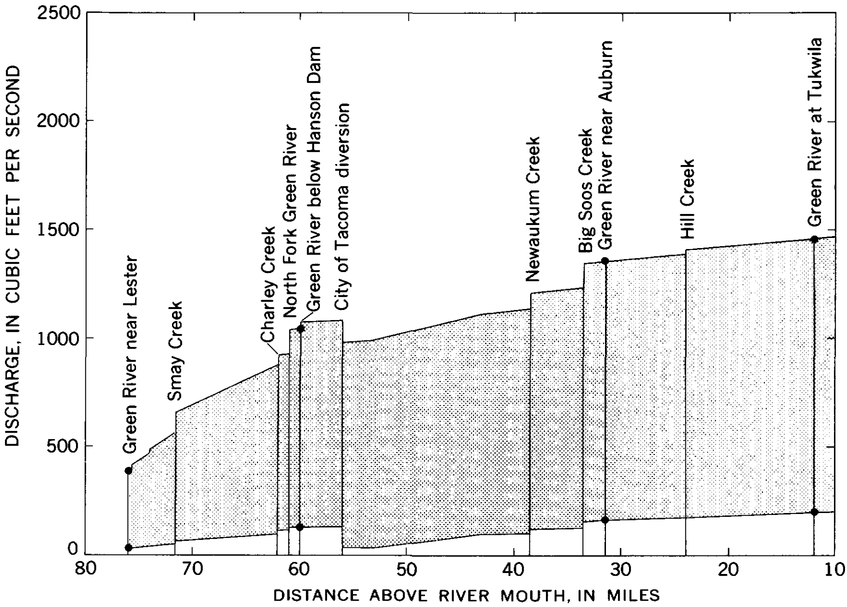


FIGURE 20.—Downstream accumulation of flow in the Green River. Graph shows average discharge (upper curve; most data from table 9) and normal low flow (lower curve). Circles indicate gaging stations.

represents the normal low flow. A normal low flow is defined as the median of annual 7-day mean low-flow discharges during the base period 1931–60. In general, streamflow exceeds the average annual discharge about 40 percent of the time, and it exceeds the normal low flow about 98 percent of the time.

For each of the major basins, the average annual runoff, in terms of acre-feet and equivalent basin-wide depth, is shown in the following table:

Basin	Drainage area (sq mi)	Average annual runoff, 1931–60, adjusted for diversions	
		Inches	Acre-feet
Green-Duwamish River	483	46	[a] 1, 180, 000
Lake Washington:	607	32	[b] 1, 030, 000
Cedar River	188	60	[b] 600, 000
Sammamish River	240	23	294, 000
Snoqualmie River:	693	79	2, 920, 000
Middle Fork	171	103	940, 000
North Fork	103	102	560, 000
South Fork	86	93	426, 000

[a] Includes average annual diversion of 69,000 acre-feet to Tacoma.
[b] Includes average annual diversion of 114,000 acre-feet to Seattle.

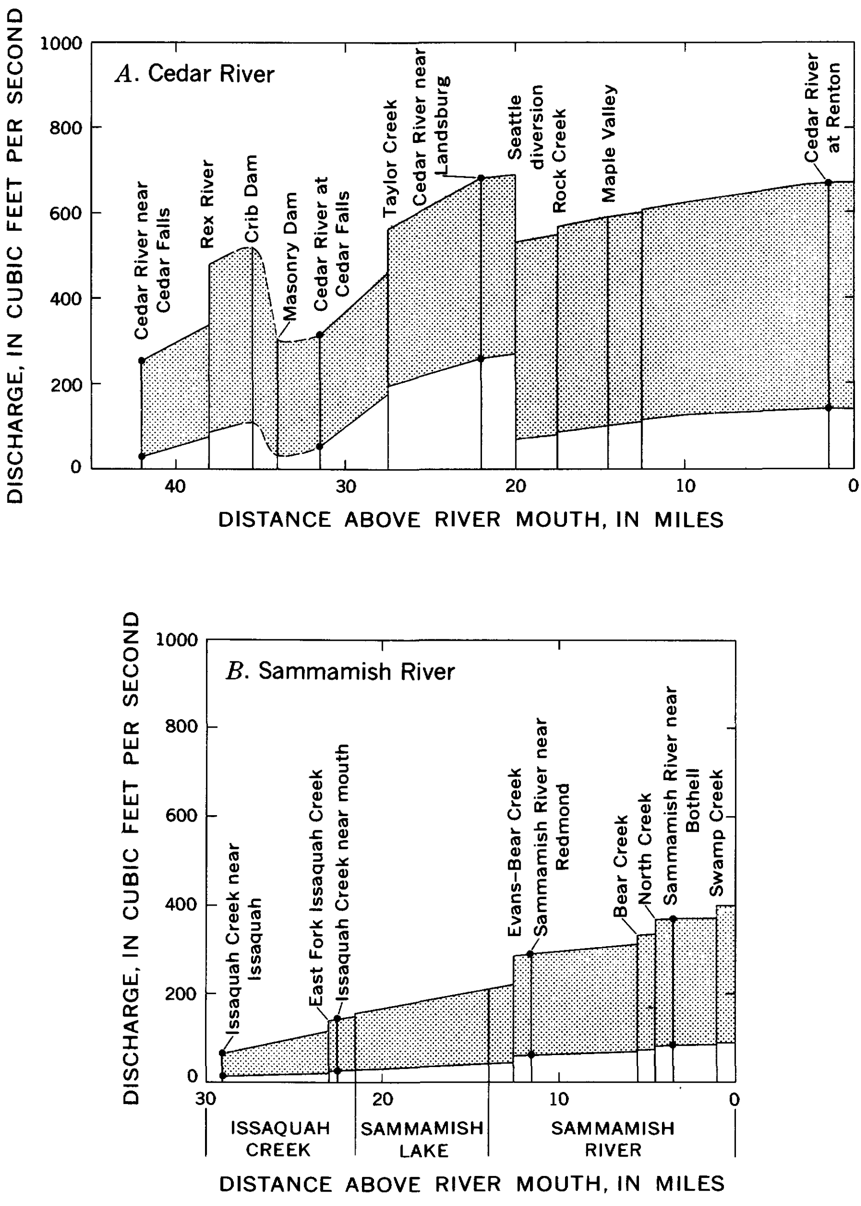


FIGURE 21.—Downstream accumulation of flows in principal streams of the Lake Washington basin. Graphs show average discharge (upper curves; most data from table 9) and normal low flow (lower curves). Circles indicate gaging stations. *A*. Cedar River. *B*. Sammamish River.

Quantities of runoff listed in this table are approximate, because they include estimated amounts downstream from the lowest gaging station in each basin and because the values are based in part on estimated runoff for periods of no record on some streams. Runoff figures for the Green and Cedar River basins include the average annual diversions to Tacoma and Seattle; hence all data in the table represent "natural" runoff.

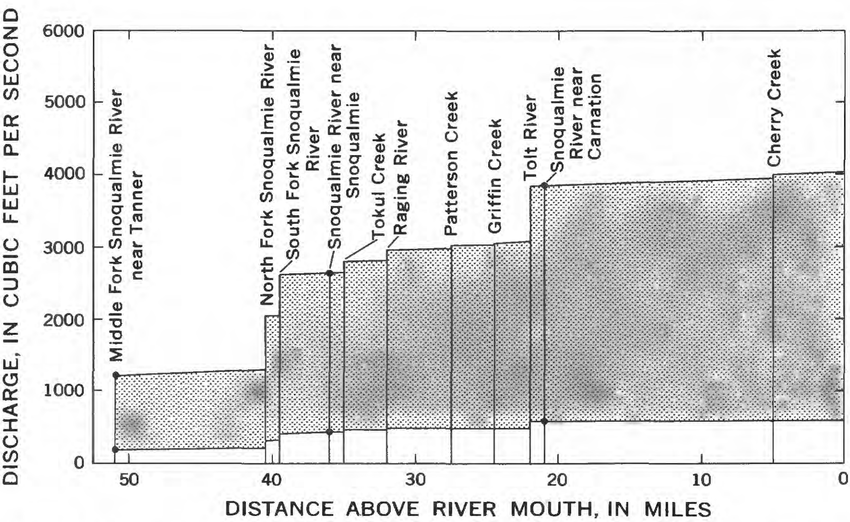


FIGURE 22.—Downstream accumulation of flow in the Snoqualmie River. Graph shows average discharge (upper curve; most data from table 9) and normal low flow (lower curve). Circles indicate gaging stations.

AVAILABILITY OF GROUND WATER

Each of the four physiographic areas shown in figure 1 is underlain by rocks whose water-bearing characteristics range from poor to good. The map showing the availability of ground water throughout the county (fig. 23) has been drawn from the best well records available (Liesch and others, 1963; Luzier, 1967) and from data on surficial geology, but remains a generalization and should not be used for detailed planning of ground-water developments. Much of the following discussion is based on the work of Liesch and others (1963) and Luzier (1967).

The Cascade Range consists of large masses of metamorphic and igneous rock that have available ground water only in the joints at shallow depths. Because the quantity of ground water stored in those joints is small, a well drilled into such rocks must penetrate many joints to provide an adequate yield for domestic use. The major valleys in the Cascade Range also contain much alluvium, including glacial materials. The alluvial deposits have variable permeabilities, and their water-yielding characteristics are unpredictable without a detailed study. Where the streams have reworked and washed away some of the fine-grained materials from the shallow alluvium, large quantities of water can usually be obtained. Thus, in the Cascade Range, adequate domestic ground-water supplies may be obtained from the alluvium or glacial deposits in the larger valleys, whereas very little or no ground water is available from the bedrock.

In the areas of glaciated bedrock (fig. 1), small quantities of ground water, generally 1–50 gpm (gallons per minute), are available. Ground-water data are almost nonexistent in the bedrock areas, except

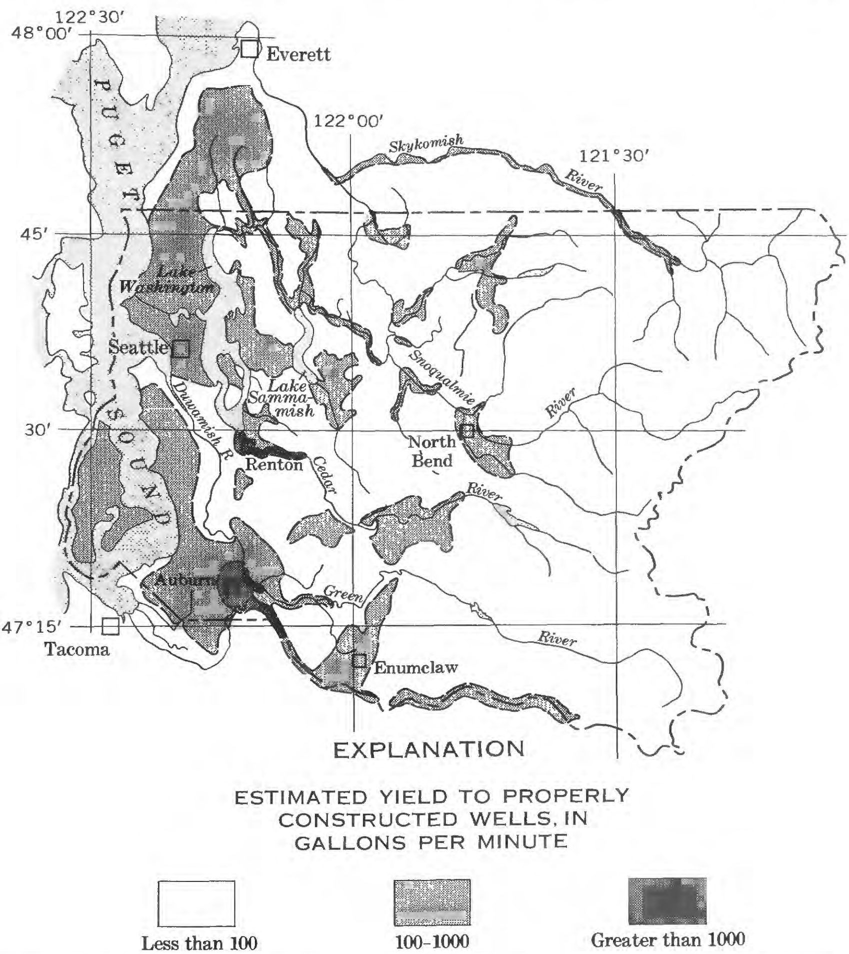


FIGURE 23.—Availability of ground water. Data for southwestern King County based largely on the work of Luzier (1967).

in the Newcastle Hills, where wells obtain yields that range from 35 to 75 gpm (Liesch and others, 1963, p. 27–28). Coal mines in the Newcastle Hills and Black Diamond areas intercept small quantities of ground water, which usually must be pumped from the active mines. At present, many of the old mines are abandoned and flooded. Those underground workings are, in effect, large dug wells, and they could provide a ground-water supply, although the yields would not be large.

The till plains shown in figure 1 are underlain by glacial and nonglacial deposits more than a thousand feet thick in many places. The deposits consist of many layers of gravel, sand, silt, clay, and any mixture of the materials. Ground water is obtained from gravel or sand (in some places from very fine sand) beneath the till plains. The location of the buried sand and gravel deposits is not known exactly and can only be inferred from drillers' well logs or geophysical data.

The quantities of water available from wells in the till plains vary from several thousand to only 1 or 2 gpm, depending on the type of material penetrated by the well. Sand and gravel of glacial outwash deposits and coarse-grained alluvium in surficial or buried channels are very permeable. Where saturated, the coarse sand and gravel consistently yield more than 100 gpm, and some wells obtain more than 3,000 gpm. In the areas where wells tap only sand or silt, yields may be as much as 15 gpm. Most wells completed in glacial till or lacustrine clay have inadequate yields in the summer. Many domestic wells in King County are dug 15–50 feet deep into the Vashon till and intercept the small quantities of water that percolate through the soil zone or the confined sand pockets. Many of the shallow dug wells are subject to contamination.

Municipal wells and the more productive domestic wells are drilled through the Vashon till, and generally obtain water at depths of 100–200 feet. Wells more than 400–500 feet deep commonly yield more than 200 gpm. At some places, a well must be drilled 500–1,000 feet to obtain a yield that is adequate for a water supply. Figure 23 shows the areas believed to be most favorable for large-capacity wells.

Vashon Island is one of the areas in the county where properly constructed wells are expected to yield at least 100 gpm (fig. 23). Geologic conditions on the island appear favorable for the occurrence of productive aquifers within the sand and gravel deposits that lie beneath much of the Vashon till. Although shallow wells in the Vashon till may not be adequate in some places, dependable water supplies could probably be developed from the deeper aquifers. The flow of springs and perennial streams on the island is an indication that ground-water supplies are not overdeveloped.

The major valleys shown on figure 1 are scoured troughs that have been partly filled with fluvial deposits carried by streams draining the Cascade Range. In those valleys the water table is near the ground surface, and shallow wells generally provide adequate domestic supplies. The fluvial deposits are mostly fine-grained sand and silt. Exceptions occur where the main rivers have deposited coarse gravel as they enter the major valleys near Auburn, Renton, Fall City, and North Bend. More than 200 gpm can be obtained from the coarse-grained fluvial deposits in most places, and small to moderate quantities (30–200 gpm) are characteristic of the finer-grained deposits. The areas near Renton and Auburn (fig. 23) are the most promising for potential development of large-yield ground-water supplies. For example, the city of Renton obtains 3,000 gpm from a well that taps the coarse alluvial deposits. The gravel deposits east of Issaquah and Carnation and near North Bend are likely to have high yields.

An additional area of high ground-water yields is located just north of Kent. There, some large discharges have occurred from flowing wells. The area is about 3 miles long and 1 mile wide and is below the east valley wall, starting about a mile north of Kent. The yields in that area range from 20 to 1,730 gpm for naturally flowing wells, and from 500 to more than 2,000 gpm for those that are pumped.

QUALITY OF THE WATER

CHEMICAL QUALITY OF SURFACE WATER

Surface water in King County is generally of excellent chemical quality. The relatively insoluble rocks and profuse rainfall in the Cascade Range result in water of low dissolved-solids content, averaging about 60 ppm (parts per million) except in the lower reaches of the major streams.

Chemical analyses of representative surface waters in the county are shown in table 3. The other streams sampled have water of chemical type and concentration ranges virtually identical with those listed in the table.

The major dissolved ions in the water are calcium, bicarbonate, and silica. Except in the Sammamish River and in reaches affected by tides, water in streams is generally soft. Hardness-of-water values average 25 ppm or less, and rarely exceed 40 ppm. Figure 24 shows the general chemical composition and dissolved-solids content of the surface waters at selected locations.

The downstream increase in mineralization of the major streams is significant only in the Duwamish River and in other streams in the Seattle area. Variations in the chemical quality of the Duwamish River at Tukwila are largely a result of salt water moving upstream

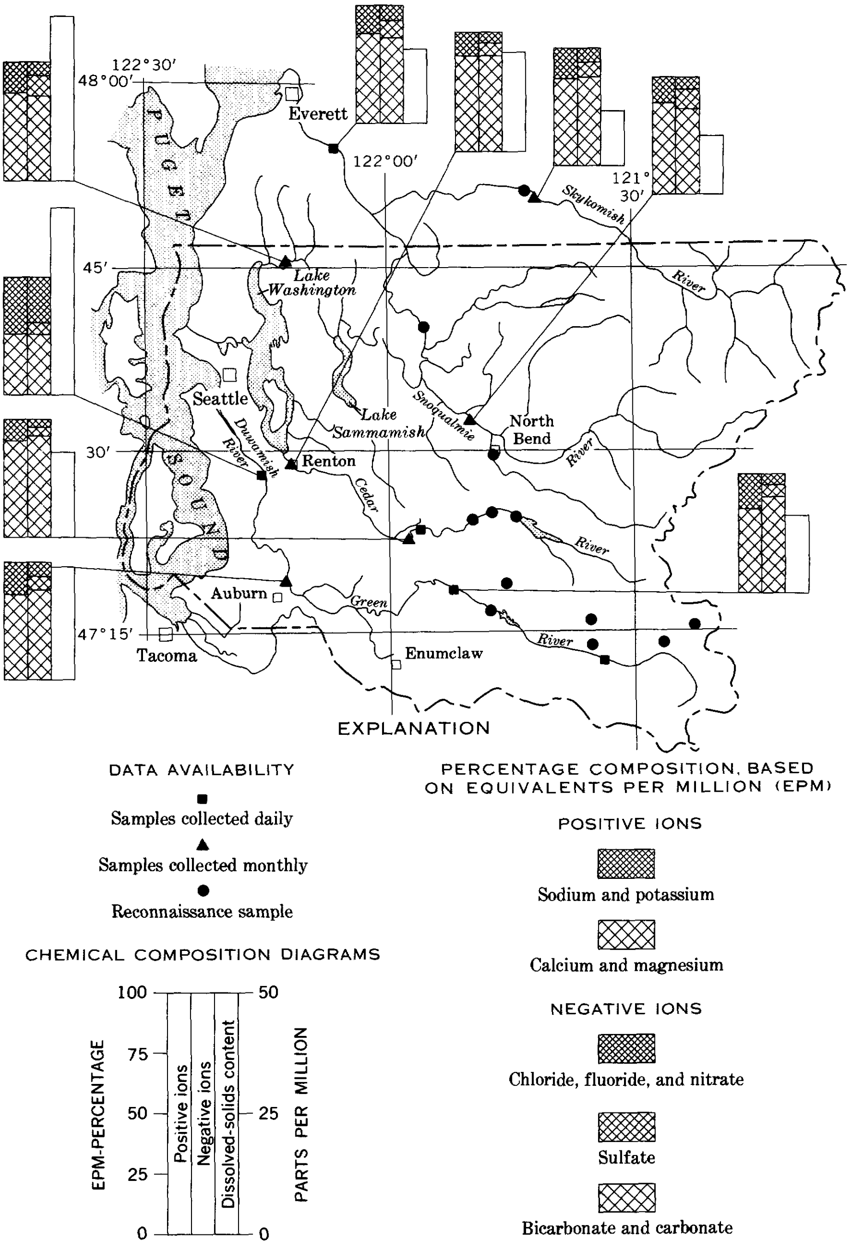


FIGURE 24.—Availability of chemical-quality data for surface water, and chemical composition of representative streams.

TABLE 3.—*Chemical analyses of surface water*

[Data for period July 1959–September 1964. Analyses by U.S. Geological Survey. Results in parts per million except as indicated. For stations 12-1070 through 12-1555, upper number is minimum value and lower number is maximum value]

Stream location (station No.)	Date or sampling period	Number of samples	Silica (SiO_2).	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) [a]	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Color (platinum-cobalt scale)
Duwamish River basin																			
Green River near Lester (12-1045).	May 23, 1961	1	12	[b]0.11	4.0	0.3	2.2	0.0	19	0.4	0.8	0.0	0.0	------	31	12	33	7.4	5
	Aug. 14, 1961	1	15	.02	7.0	.7	4.0	.3	30	3.0	2.0	.1	.2	------	52	20	58	7.3	5
North Fork Green River near Palmer (12-1057)	May 24, 1961	1	14	.01	3.0	.6	2.0	.5	17	.8	.8	.0	.1	------	34	10	30	7.3	5
	Aug. 15, 1961	1	16	.01	5.0	.5	2.8	.5	24	1.6	1.0	.0	.1	------	45	14	42	7.3	5
Green River at Palmer (12-1070).	July 1959–July 1961	17	12	------	3.5	.1	2.0	.0	17	1.4	.8	.0	.0	0.00	28	11	34	6.9	0
			14	------	6.5	1.4	3.3	.5	32	3.0	1.5	.2	.4	.06	46	22	62	7.5	10
Big Soos Creek above hatchery near Auburn (12-1126).	Oct. 1962–Sept. 1964	24	11	------	7.5	1.2	4.4	.6	31	5.8	1.0	.0	.6	.02	64	30	88	6.8	5
			20	------	12	4.1	6.3	1.8	54	12	3.5	.3	3.7	.13	79	42	108	7.7	60
Green River near Auburn (12-1130).	July 1959–Sept. 1964	63	11	------	4.0	.5	2.2	.0	20	2.0	.0	.0	.0	.00	37	14	38	6.2	0
			16	------	11	2.7	5.4	1.0	50	6.4	3.8	.3	1.7	.13	71	38	102	7.9	15
Duwamish River at Tukwila (12-1134) [c].	July 1959–Sept. 1964	147	11	------	4.0	.6	2.5	.1	18	2.0	.8	.0	.2	.00	34	12	43	6.4	5
			19	------	18	24	180	5.5	73	46	310	.3	4.8	.62	464	156	1,210	7.8	30
Lake Washington basin																			
Cedar River at Landsburg (12-1176).	July 1959–Aug. 1962	22	9.3	------	5.0	0.0	1.2	0.0	18	0.6	0.5	0.0	0.0	0.00	27	14	37	7.0	0
			12	------	11	1.6	2.2	.5	39	4.0	2.2	.2	.6	.04	51	31	73	7.8	5
Cedar River at Renton (12-1190).	July 1959–Aug. 1964	38	9.2	------	5.0	.6	1.6	.0	22	1.6	.5	.0	.0	.00	34	16	46	6.9	0
			15	------	11	2.7	3.7	.7	48	5.4	2.2	.1	1.5	.28	66	36	93	7.9	10
Sammamish River at Bothell (12-1265).	July 1959–Aug. 1964	43	6.2	------	7.5	2.5	3.5	.7	32	6.6	2.0	.0	.4	.00	57	31	82	6.6	5
			17	------	12	5.1	6.2	2.1	54	16	4.5	.3	6.3	.18	100	48	125	7.4	50

Snohomish River basin

Skykomish River near Gold	July 1959–Aug. 1964	29	3.8	......	2.0	0.1	0.6	0.2	10	0.6	0.2	0.0	0.0	0.00	13	7	20	6.5	0
Bar (12-1345).			7.6	......	5.0	.8	2.3	.9	20	3.2	1.8	.2	.6	.06	32	16	46	7.5	20
Snoqualmie River at Snoqual-	July 1949–June 1964	28	3.1	......	1.5	.0	.7	.1	7	.0	.0	.0	.0	.00	14	8	16	6.2	5
mie (12-1444).			7.9	......	6.0	1.0	1.8	.8	22	3.0	1.5	.2	1.8	.12	33	18	46	7.4	20
Tolt River near Carnation	July 1960–Aug. 1964	27	3.8	......	3.0	.3	1.0	.0	10	2.2	.2	.0	.1	.00	21	9	24	6.6	0
(12-1485).			10	......	8.0	1.8	2.1	.7	32	5.6	1.2	.1	1.0	.02	47	26	62	7.5	30
Snohomish River at Sno-	July 1959–Sept. 1964	90	3.3	......	2.0	.0	.8	.0	10	.8	.2	.0	.0	.00	14	8	20	6.6	0
homish (12-1555).			9.8	......	7.0	1.6	3.0	1.1	28	4.0	2.5	.3	2.6	.11	45	22	60	7.5	25

Vashon Island

Judd Creek near Vashon	Feb. 2, 1961	1	12	[b]0.27	5.5	2.6	2.6	1.4	16	12	3.2	0.3	3.2	0.08	[d]51	24	72	6.8	35
	Aug. 16, 1961	1	29	......	9.5	6.6	5.1	1.1	57	8.6	3.2	......	.6	.12	[d]92	50	118	7.6	50

[a] All carbonate (CO_3) values are 0 ppm.

[b] Total iron value, representing iron in solution, suspension, and sediment at the time of sample collection. All other values indicate only the iron actually in solution at the time of collection.

[c] Most maximum values are a result of tidewater in the Duwamish River.

[d] Calculated from analyzed constituents; bicarbonate expressed as carbonate.

from Puget Sound and of the discharge of sewage and industrial wastes.

During low-flow periods, the mineral content of surface water usually increases because a larger part of the flow is ground-water discharge, which is in general slightly more mineralized than surface runoff. During high-flow periods, dilute precipitation or snowmelt runoff is the larger contributor to streamflow, and mineral content is consequently less. In surface water, the difference in mineral content between high- and low-flow periods can be fairly large. However, this difference is not of significance for King County streams because the maximum dissolved-solids content is still small (table 3).

POLLUTION OF SURFACE WATER

Many uses of water cause changes in its quality. These changes may come from waste disposal by municipalities and industries, from irrigation, or from alterations of stream channels and the land surrounding them. In most parts of King County, man's use of the water resource has not seriously affected it. Bacterial contamination of streams and lakes is evident near the larger cities as a result of sewage discharge, but with normal chemical treatment and filtration the water quality is generally within tolerable limits for most uses.

The problem of greatest significance, and the one that could assume major proportions in the future, is municipal and industrial pollution in the metropolitan Seattle area. In 1958 raw sewage from about 53 percent of the total population of metropolitan Seattle was being discharged through about 60 outfalls along the shorelines of the Duwamish River and Puget Sound, and Lake Washington was receiving treated sewage from an estimated 80,000 persons and indirect discharges from at least 4,000 private septic tanks (Metropolitan Seattle sewerage and drainage survey, 1958, Brown and Caldwell, consulting engineers, 558 p.).

According to Peterson (1955), Lake Washington in 1955 was in the early stages of nutrient enrichment which promoted the growth of algae. The major reason for the trend toward increased growths was the increasing influx of raw and treated sewage. Even though treated sewage effluent in the lake was rendered bacteriologically sterile, treatment did not remove the nitrogen and phosphorus which nurtured the growth of algae. Algal growth in Lake Washington may also have increased because of salt-water intrusion from Puget Sound. At times in the past, the intrusion has penetrated the entire length of the ship canal; when such penetration has occurred, it has partially stabilized the bottom layer of the lake and thus prevented complete mixing of the lake water.

On the Puget Sound side, Seattle was discharging into shallow water more than 50 million gallons of untreated sewage per day. Because of the proximity to the shore and the patterns of currents in the sound, some of these discharges washed back on the beaches. By the middle 1950's, not a single salt-water beach from the Snohomish

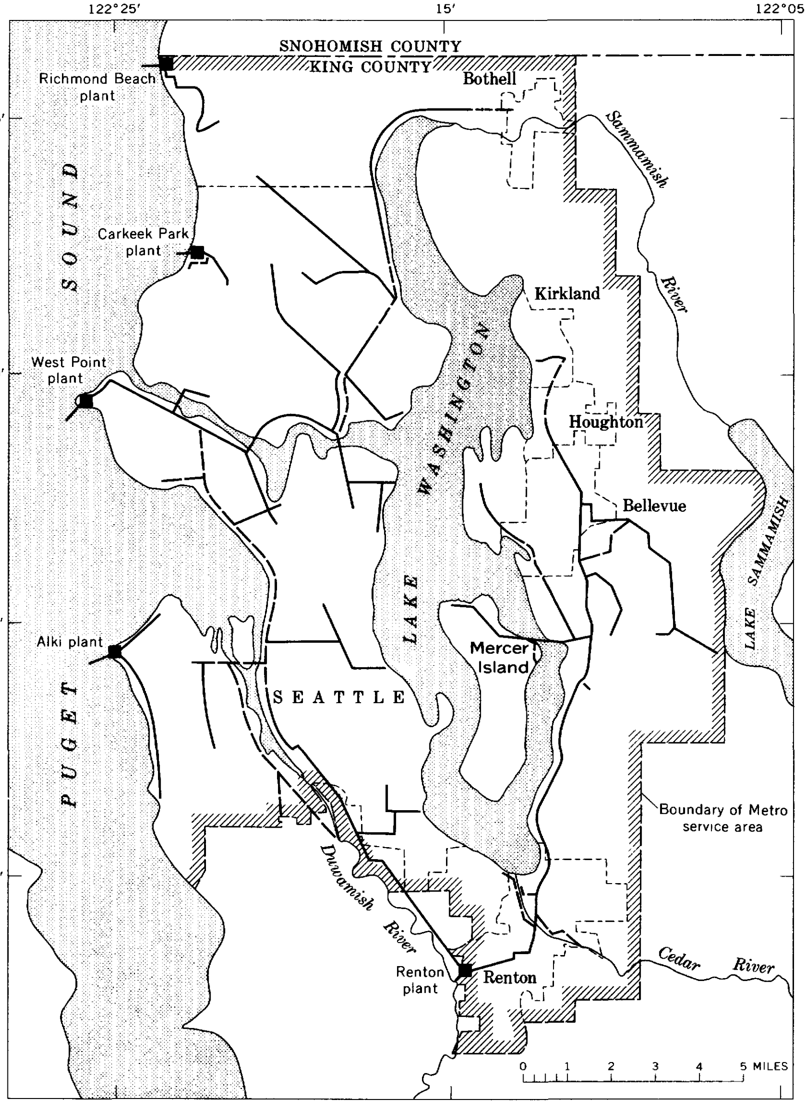


FIGURE 25.—Sewerage facilities existing in 1965 (solid lines) and proposed (dashed lines) in the Seattle metropolitan area. Data from Municipality of Metropolitan Seattle (1965).

County line to the south Seattle limits was safe for swimming (Municipality of Metropolitan Seattle, 1965, p. 2).

To establish a sewerage system with adequate capacity to prevent further contamination of water in the Seattle area, the Municipality of Metropolitan Seattle (Metro) was formed by an act of the 1957 State legislature and a vote of the people. The area served by Metro, shown in figure 25, extends from the northern King County line to the southern city limits of Seattle and Renton, and from Puget Sound east to Lake Sammamish. The population of this area in 1965 was about 775,000, of which 565,000 lived within the Seattle city limits.

A 10-year program was started by Metro in 1961 to effect the rehabilitation of Lake Washington and to protect the Puget Sound beaches. In 1965, the $121 million construction program was two-thirds completed, and the deterioration of Lake Washington reportedly had been checked (Municipality of Metropolitan Seattle, 1965, p. 2). In 1966, additional facilities diverted all sewage discharges away from the lake, and new treatment plants went into operation. Two major treatment plants, at Renton and West Point, are key phases of the Metro program (fig. 25). Digested sludge from these plants will be discharged through a submarine outfall to deep water in Puget Sound.

In addition to the facilities designed for completion in 1966, plans have been made to extend Metro's area of coverage to insure that the future sewage-disposal capacity will be adequate in a larger area of expanding population and industrial growth. The comprehensive sewerage plan proposed by Metro includes the urban areas which occupy most of the lowlands in King County, and the part of Snohomish County that drains to Lake Washington. Additional planning for those areas will be needed to provide for future increases in domestic, municipal, and industrial waste loads.

TEMPERATURE OF STREAMS

The major natural factors that affect stream temperatures are solar radiation, shade, snowmelt contributions, discharge, air temperature, and the amount, location, and temperature of tributary spring flow. The most important factor is solar radiation, which also affects air temperature; consequently, the temperature of streams is related in a general way to that of air. Daily variation of stream temperature is less than that of air temperature, but monthly mean temperatures of air and water are closely related at most stream locations.

Continuous records of water temperature have been collected by the Geological Survey at two locations (as of September 1964); these are the gaging stations on the Cedar River near Landsburg and the

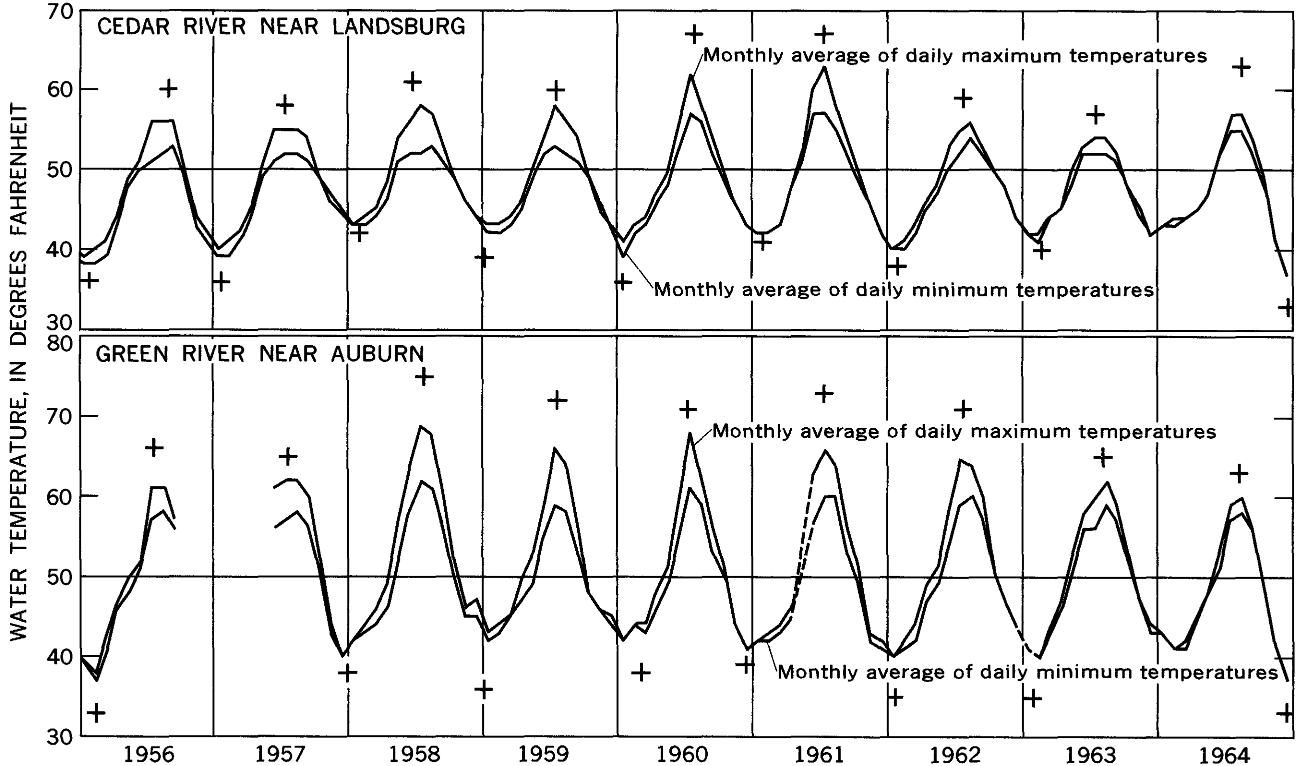


FIGURE 26.—Temperature of water in Cedar River near Landsburg and Green River near Auburn, 1956–64. Annual maximum and minimum temperatures are indicated by "+" symbols.

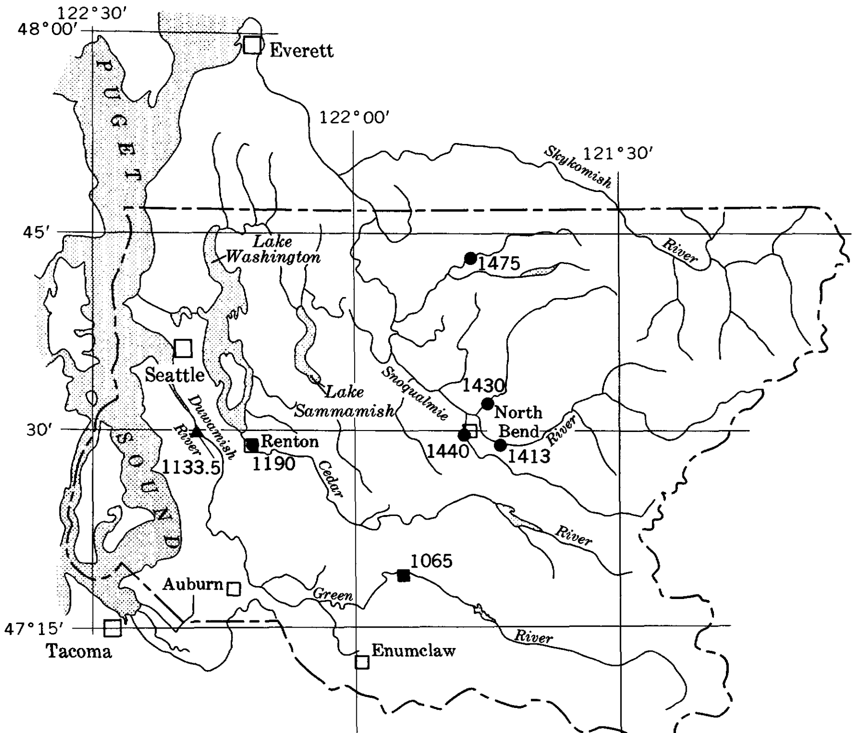
Green River near Auburn. The temperature of the water from 1956 to 1964 is shown in figure 26. The cyclic pattern of seasonal temperature change is about the same for the two rivers. During the summer the Green River is warmer than the Cedar River, largely because the latter is cooled by large amounts of ground water that enter the river near Landsburg. In general, ground water is warmer than surface streamflow in the winter and cooler in the summer, its temperature normally varying only a few degrees from the mean annual air temperature of the region. An example of this feature is shown by periodic temperature readings of Icy Creek near Black Diamond, which range from 42° to 48°F. The flow of Icy Creek is almost entirely from nearby springs the year around. By contrast, the temperature of water varies considerably in rivers such as the Green River near Auburn, where surface runoff is a large part of the streamflow. The normal temperature range of most streams in the county is within the limits required for fisheries and for domestic, municipal, and industrial supplies.

SEDIMENT IN STREAMS

By R. C. Williams

The amount of sediment transported by the streams of King County is small in relation to the large amount of runoff from the area. The sites for which suspended-sediment data are available are shown in figure 27. The data for the Green River near Palmer, collected during water years 1951–57 (Griffin and others, 1962, p. 48, 49) is the most comprehensive for any station in the county. Measurements of suspended-sediment discharge, principally during high flow, were obtained at six other sites in the county during water years 1963 and 1964.

In the streams of King County, large suspended-sediment concentrations are closely associated with high streamflow. The wide variation that can occur is indicated by the data shown for the Green River near Palmer (table 4) and for the six streams measured during water years 1963 and 1964 (table 5). Except for short storm periods, sediment concentrations are generally low, approaching the minimums shown in tables 4 and 5. The data for Green River near Palmer show daily mean values ranging from a trace to 1,350 ppm for the period 1953–57. The observed values for the other six sites show similar variation for the water years 1963 and 1964. At the stream sites investigated, suspended-sediment concentrations rise rapidly with the rise of streamflow, and they crest near the time of peak flow. Sediment concentrations recede almost as rapidly as they rise; by contrast, streamflow recedes much more slowly over a longer period of time. Except in glacier-fed streams, suspended-sediment concentrations rarely remain high for more than a few days.



EXPLANATION

■ 1065

Daily record of suspended-sediment discharge, August 1955–September 1957

▲ 1133.5

High-flow measurements available in water year 1963, and daily records available from October 1963 to present (1965)

● 1430

High-flow reconnaissance measurements available in water years 1963 and 1964

Numbers designate stations

FIGURE 27.—Suspended-sediment sampling sites.

Mean daily values of suspended-sediment discharge for Green River near Palmer (table 4) ranged from a trace to 49,000 tons per day during the years 1953–57. Instantaneous values had an even greater range. Measured suspended-sediment discharges at the six stream sites (table 5) indicate that similar variations exist in other parts of the county. Because maximum suspended-sediment discharges were not observed at the six sites, estimates were made of the instantaneous maximums that probably occurred during the period of streamflow record at each site. These estimates are based on the peak

TABLE 4.—*Summary of suspended-sediment data for Green River near Palmer, 1950–57*

[Data for 1950 from U.S. Corps of Engineers (1956) for calendar year. Remaining data from U.S. Geological Survey]

Water year	Runoff (acre-ft)	Sediment concentration (ppm)			Sediment discharge (tons)			Max daily sediment discharge as percentage of annual total	Annual sediment yield (tons per sq mi)
		Min daily	Max daily	Weighted mean	Min daily	Max daily	Total		
1950	1,039,000			49			69,000		300
1951	915,700			46			57,400		250
1952	639,100			7			6,370		28
1953	670,600	0.5	430	41	0.2	12,800	37,600	34	163
1954	936,700	.9	1,350	65	.7	49,000	82,400	59	358
1955	794,000	.3	607	40	.2	19,700	43,600	45	190
1956	1,021,000	.3	1,140	90	.2	42,700	125,000	34	543
1957	759,100	.3	779	63	.3	28,100	65,500	43	285

TABLE 5.—*Extremes for suspended-sediment measurements at six stream sites during 1963 and 1964 water years*

Stream location (station No.)	Measurements	Concentration (ppm)		Discharge (tons per day)	
		Min.	Max.	Min.	Max.
Green River at Tukwila (12-1133.5)	53	8	765	6	15,800
Cedar River at Renton (12-1190)	32	9	1,220	7	9,820
Middle Fork Snoqualmie River near Tanner (12-1413)	21	4	325	2	6,090
North Fork Snoqualmie River near North Bend (12-1430)	19	0	208	Tr.	2,030
South Fork Snoqualmie River at North Bend (12-1440)	22	0	968	Tr.	7,140
North Fork Tolt River near Carnation (12-1475)	15	0	32	Tr.	99

flow of record and the highest observed concentrations during water years 1963 and 1964. Values of maximum daily suspended-sediment discharge are also estimated. Both sets of estimated data are given in table 6.

Sediment discharge of streams in the county is seasonal, inasmuch as the runoff from storms which produce high sediment discharge is also seasonal. Data for the Green River near Palmer indicate that an average of 90 percent of the annual suspended-sediment load occurred during the 6-month period, November to April. Because the maximum daily tonnage is characteristically a large proportion of the annual sediment load, data summarized in table 4 suggest that high sediment discharges occur for only short periods of time. These data show that 43 percent of the suspended sediment in the Green River during the 5-year period (1953–57) was discharged in only 5 days. High sediment discharge is also of short duration in other streams of the county.

Nearly all fluvial sediment is transported during high stream flows that vary in number and magnitude each year. For that reason, much

TABLE 6.—*Estimated maximum suspended-sediment discharge at six stream sites*

Stream location (station No.)	Suspended-sediment discharge: Maximum instantaneous (tons per day)	Suspended-sediment discharge: Mazimum daily (tons)
Green River at Tukwila (12–1133.5)	27, 000	21, 000
Cedar River at Renton (12–1190)	22, 000	20, 000
Middle Fork Snoqualmie River near Tanner (12-1413)	43, 000	36, 000
North Fork Snoqualmie River near North Bend (12–1430)	4, 400	3, 200
South Fork Snoqualmie River at North Bend (12–1440)	39, 000	30, 000
North Fork Tolt River near Carnation (12–1475)	800	500

variability in annual loads can be expected. Data for the Green River near Palmer (table 4) show that the annual suspended-sediment load at that station ranged from 6,370 to 125,000 tons during the 7-year period 1951–57. Although data for the six streams measured during water years 1963 and 1964 are insufficient to show the complete range in sediment loads, the same year-to-year variability can be expected in those streams, as well as in other parts of the county.

To estimate the approximate range of annual suspended-sediment yield that might be expected in the county, annual yields were computed for the Green River basin upstream from the station at Palmer (table 4). The annual values ranged from 28 to 543 tons per square mile. The small amount of data for the six sites measured during water years 1963 and 1964 suggest a similar range of annual yields in other basins of the county.

The particle-size distribution of suspended sediment varies from one stream to another and from time to time in the same stream. Analyses of suspended-sediment samples from the Green River near Palmer and from four other sites in the county are summarized in table 7. This summary shows the mean particle-size distribution of the suspended sediment at the times of measurement. The values for Green River near Palmer are quite conclusive for the period of record (1951–57), whereas those for the other sites are too few to determine long-term averages. The mean values given (table 7) must be considered as suggestive only.

In addition to the sediment that is transported largely in suspension, significant amounts of sand, gravel, and coarser material are transported as stream bedload during high-water periods. Even dur-

TABLE 7.—*Mean particle-size distribution of suspended sediment at five stream sites*

[Analyses by U.S. Geological Survey]

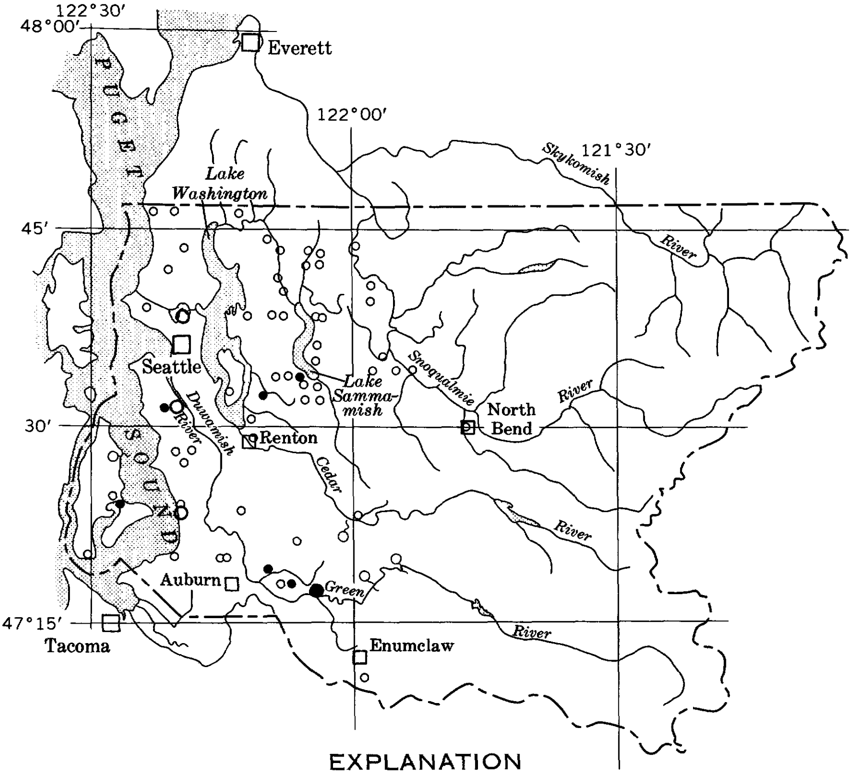
Stream location (station No.)	Period of record	Analyses	Percentage in size range (diameter, in millimeters)		
			Clay (finer than 0.004)	Silt (0.004–0.062)	Sand (0.062–2.00)
Green River near Palmer (12-1065)	1951–57	66	21	42	37
Green River near Tukwila (12-1133.5)	1963–64	6	19	36	45
Cedar River at Renton (12-1190)	1963–64	4	17	48	35
Middle Fork Snoqualmie River near Tanner (12-1413)	1963–64	3	33	49	18
South Fork Snoqualmie River at North Bend (12-1440)	1963–64	3	10	34	56

ing medium flows some movement of sand occurs as bedload, particularly in the lower Green River. In the Pacific Northwest, rivers that transport the largest amounts of both fine and coarse material are those that are fed by glaciers. The White River, on the southern border of King County, is such a stream. An investigation of the White River just downstream from Emmons Glacier on Mount Rainier, reported by Fahnestock (1963), indicated extreme daily fluctuations as well as high rates of suspended-sediment and bedload transport. In the three major basins of King County (p. 15), the streams are nonglacial, and sediment is less of a problem.

CHEMICAL QUALITY OF GROUND WATER

Most ground water in King County is of good to excellent quality. The dissolved-solids content generally is less than 150 ppm, and the hardness, expressed as parts per million of $CaCO_3$, characteristically ranges from soft (60 ppm or less) to only moderately hard (61–120 ppm). In most of the ground water the principal contituents are silica (SiO_2), calcium (Ca), and bicarbonate (HCO_3).

Representative chemical analyses of ground water sampled at 44 locations in King County are listed in tables 8 and 10. Of the samples from those sites and 22 others that are not included in the tables, six contained 250–500 ppm of dissolved solids, and only four contained more than 500 ppm (fig. 28). Water containing a few hundred to a few thousand parts per million of dissolved solids occurs locally near Puget Sound, where salt-water contamination can be important, and it also occurs in a few deeply buried inland aquifers of Tertiary or early Quaternary age. Water with a hardness greater than 120 ppm was found at only 7 of the 66 total sites sampled (fig. 29). Ground water that is classified as hard (121–180 ppm) or very hard (more than 180 ppm) generally is obtained from the older aquifers, which in most places are at greater depth.



EXPLANATION

Spring

No sampled spring contained more than 250 ppm of dissolved solids

WELLS, SHOWING DISSOLVED-SOLIDS CONTENT, IN PARTS PER MILLION

0-250	251-500	501-1000	More than 1000

FIGURE 28.—Dissolved-solids content of ground water.

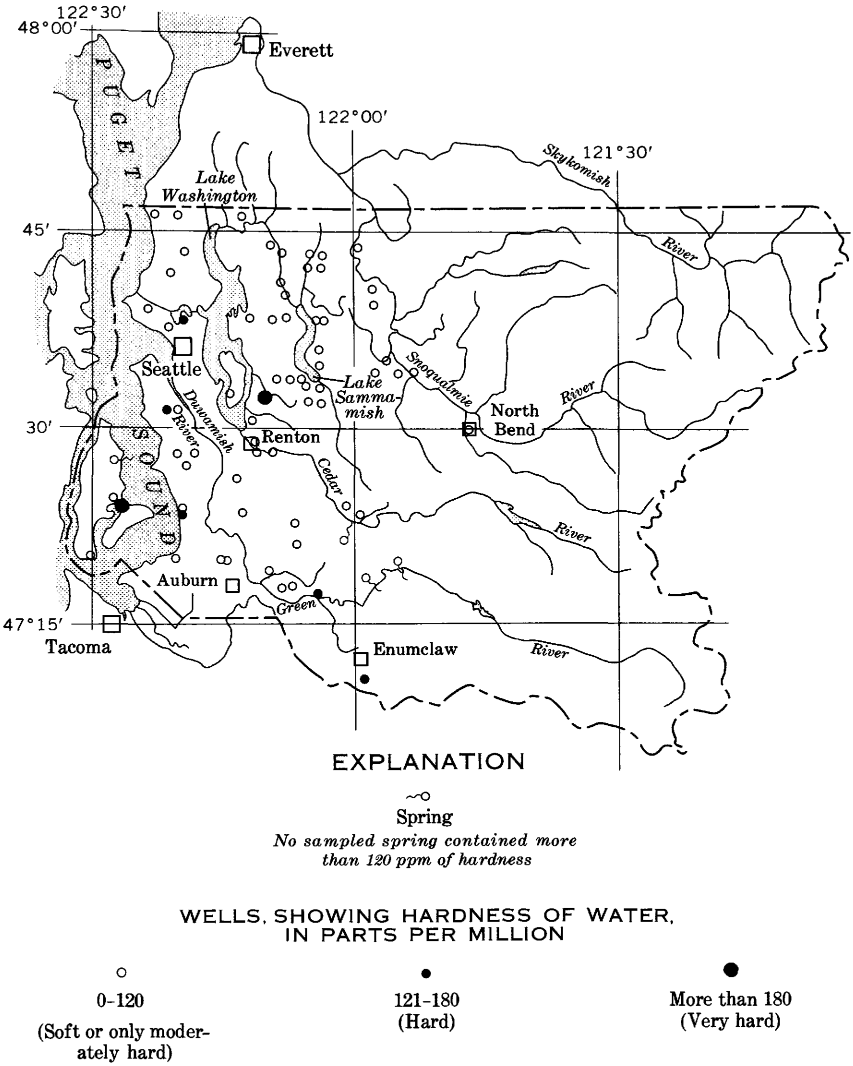


FIGURE 29.—Hardness of ground water.

According to standards defined by the U.S. Public Health Service (1962, p. 42–43), the iron content of water should be less than 0.3 milligram per liter (a milligram per liter is virtually equal to a part per million) "to prevent objectionable taste or laundry staining * * *." However, a water supply containing appreciably more than 0.3 ppm should not arbitrarily be rejected on this basis alone. Individuals vary considerably in their ability to taste threshold quantities of iron in solution or to tolerate staining of laundry fixtures and clothing. Furthermore, water treatment can remove all the iron content from water. Thus, a water supply containing appreciably more than 0.3 ppm of iron can be entirely acceptable under some circumstances.

Ground water containing more than 0.3 ppm of iron occurs in many places throughout King County (fig. 30). Of the 66 wells and springs sampled, 26 yielded water containing more than 0.3 ppm of iron. Amounts of iron in these samples were as high as 15 ppm, but some of the values do not reflect the actual concentration of iron in solution at the time of collection because the ground water was turbid or contained sediment when sampled. Because suspended material or sediment in a water sample may itself contain iron, values are reported as "total" iron for turbid or sediment-laden samples. Thus, "total" iron includes the amount in solution as well as that in the sediment or turbid suspension present at the time of collection.

No relation has as yet been discovered in the county between the location or depth of a well and the iron content of the water that it yields. The occurrence of appreciable iron in ground water is very localized. Where one or several wells in any area may be affected other nearby wells may yield water whose iron content is too low to be noticeable.

More than 0.50 ppm of orthophosphate occurs in water from many of the deeper wells in King County. This quantity is several times the usual amount of orthophosphate found in Washington ground waters. No clear-cut explanation of the presence of the orthophosphate is available. Van Denburgh and Santos (1965, p. 15) indicate that neither sewage contamination nor application of phosphate fertilizers, which can be important phosphate contributors, are thought to be as widespread as the region of unusual orthophosphate occurrence. Hence, the orthophosphate is probably derived from some mineralogic component of the aquifers themselves.

The many springs in the Green River basin between Palmer and Auburn were mentioned earlier (p. 32). Chemical analyses of flow from these springs indicate that the water is of excellent quality (table 8, spring in sec. 19, T. 21 N., R. 7 E.); it is soft and is low in dissolved-solids content. The major dissolved constituents are calcium, bicarbonate, and silica.

TABLE 8.—*Chemical analyses of water from wells and a spring*

[Analyses by U.S. Geological Survey. Analyses of five municipal ground-water supplies appear in table 10]

Location	Depth (ft)	Date of collection	Water temperature (° F)	Parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
NW¼NW¼ sec. 31, T. 20 N., R. 7 E.	102	10– 3–63	50	18	[a] 1.7	40	11	9.8	2.3	117	0	67	1.2	0.2	0.3	0.16	210	147	320	7.8
NE¼SW¼ sec. 1, T. 21 N., R. 2 E.	180	3– 3–61	47	38	.48	5.5	5.6	5.0	1.0	42	0	11	2.8	.1	.1	.18	91	36	104	7.4
SW¼SE¼ sec. 1, T. 21 N., R. 4 E.	178	1–25–63	47	37	1.5	17	5.2	17	1.3	109	0	.0	11	.2	.1	1.5	146	64	203	7.3
NW¼NW¼ sec. 14, T. 21 N., R. 5 E.	718	10– 3–63	61	17	[a] 6.4	14	4.5	72	2.0	159	0	44	24	.1	.4	.13	256	54	406	8.2
SW¼NW¼ sec. 14, T. 21 N., R. 5 E.	100	10– 3–63	53	23	.06	16	4.2	3.3	2.0	71	0	5.4	1.8	.1	.3	.35	92	57	137	7.7
SE¼SE¼ sec. 27, T. 21 N., R. 6 E.	1,461	10– 3–63	55	11	[a] 9.5	40	20	4,260	34	2,290	0	.7	5,330	------	37	.05	10,900	182	17,200	7.2
SW¼SE¼ sec. 19, T. 21 N., R. 7 E.	Spring	1–25–63	47	13	.00	6.5	1.7	3.2	.1	30	0	2.6	1.5	.2	1.4	.02	45	23	62	7.1
SE¼NW¼ sec. 16, T. 22 N., R. 3 E.	462	12–16 59[b]	54	41	[a] 1.3	45	19	43	7.4	346	0	.3	8.8	.3	.5	.59	338	190	545	7.6
SW¼SE¼ sec. 17, T. 22 N., R. 4 E.	1,001	10– 4–63	54	21	.37	47	15	162	2.2	180	0	.2	280	.0	.0	.72	617	178	1,160	7.3
NW¼SW¼ sec. 36, T. 22 N., R. 5 E.	106	3–30–63	51	23	.12	11	3.5	6.3	1.7	60	0	6.6	1.8	.1	.1	.09	84	42	112	7.6
NE¼NE¼ sec. 13, T. 22 N., R. 6 E.	118	1–23–63	48	20	.29	12	5.0	5.1	.8	71	0	3.0	1.0	.1	.1	.40	83	50	119	7.5
NE¼NE¼ sec. 4, T. 23 N., R. 4 E.	686	4–19–54	56	25	.14	16	19	314	8.4	284	0	1.9	348	.1	1.0	------	874	118	1,600	7.9
SE¼NE¼ sec. 34, T. 23 N., R. 4 E.	115	6–23–60[b]	60	32	.02	8.0	7.8	5.2	1.8	59	0	7.2	4.2	.1	3.7	.19	99	52	133	7.4
NW¼SW¼ sec. 23, T. 23 N., R. 5 E.	665	10– 3–62	56	----	------	------	------	------	------	160	0	------	22	------	------	------	------	41	304	8.0
SE¼SW¼ sec. 15, T. 23 N., R. 8 E.	12	1–25–63	----	9.5	[a] 5.0	7.5	1.2	1.8	.1	29	0	1.8	1.0	.1	.1	.00	37	24	56	6.4
SE¼SE¼ sec. 25, T. 24 N., R. 4 E.	154	4–11–58	62	23	.41	10	10	6.0	4.2	82	0	12	2.5	.0	.1	------	108	66	106	7.7
SW¼NW sec. 23, T. 24 N., R. 5 E.	385	4–11–58	55	48	.06	32	6.3	18	9.6	171	0	16	3.0	.1	.0	.24	217	106	307	8.0

SE¼SE¼ sec. 24, T. 24 N., R. 5 E	265	6-17-60	54	54	.07	24	4.7	17	3.3	122	0	14	3.5	.2	.1	.57	181	79	225	7.6
NW¼NE¼ sec. 32, T. 24 N., R. 5 E	72	10-6-60[b]	----	36	[a].16	17	7.4	13	3.8	113	5	1.6	1.8	.1	.0	.35	142	73	192	8.5
NE¼SE¼ sec. 9, T. 24 N., R. 6 E	210	10-6-60[b]	----	25	.20	7.0	3.8	3.9	.8	44	0	2.2	2.8	.1	.7	.14	69	33	85	7.3
NE¼SE¼ sec. 21, T. 24 N., R. 6 E	150	12-1-59[b]	50	39	.48	20	6.4	30	6.6	150	0	2.6	18	.2	.2	1.4	199	76	297	7.7
NE¼SE¼ sec. 28, T. 24 N., R. 6 E	54	8-20 51	----	22	.01	10	3.3	5.4	1.6	47	0	6.3	3.4	.2	3.5	------	79	38	105	7.0
NE¼SE¼ sec. 8, T. 24 N., R. 7 E	130	10-6-60[b]	51	30	.11	23	4.6	17	4.5	129	0	3.6	5.5	.2	.3	1.2	154	76	221	7.8
NE¼NW¼ sec. 10 T. 24 N., R. 7 E	52	8-24-51	----	19	15	12	4.3	6.3	2.4	69	0	1.0	4.8	.2	2.5	------	102	48	120	7.2
NE¼SE¼ sec. 14, T. 25 N., R. 3 E	545	10-26-60	51	42	[a].40	17	6.6	43	4.4	176	0	.2	20	.1	.3	2.4	223	70	323	7.7
NE¼NW¼ sec. 21, T. 25 N., R. 4 E	220	4-3-63	52	42	--------	30	13	212	9.8	477	0	2.4	148	.2	.3	2.0	695	129	1,140	8.2
SE¼SE¼ sec. 1, T. 25 N., R. 5 E	45	10-6-60	52	22	[a]4.6	11	4.7	10	1.6	78	0	2.8	4.0	.1	.5	.29	95	47	136	7.1
		5-23-61	52	21	1.1	18	8.1	11	2.0	102	0	7.6	9.0	.1	.4	.07	128	78	202	6.8
SW¼SE¼ sec. 21, T. 25 N., R. 5 E	100	8-24-51	----	33	.02	6.3	6.2	3.8	1.4	49	0	6.3	4.1	.2	.9	------	86	41	102	7.2
SE¼SE¼ sec. 24, T. 25 N., R. 5 E	75	4-9-58	54	19	[a]5.8	8.8	6.8	5.7	2.1	61	0	7.7	4.0	.0	.4	------	84	50	126	7.3
SE¼NE¼ sec. 19, T. 25 N., R. 6 E	108	10-6-60[b]	52	29	.34	22	8.8	9.2	1.6	128	0	2.4	4.0	.1	1.0	.40	142	91	211	7.6
SE¼SE¼ sec. 6, T. 25 N., R. 7 E	630	10-6-60[b]	54	27	1.1	22	9.2	22	4.2	164	0	7.6	3.0	.2	.0	.58	178	93	269	8.0
NE¼NW¼ sec. 18, T. 25 N., R. 7 E	101	4-24-61	54	21	[a].10	7.5	7.6	4.2	1.1	64	0	5.4	1.8	.1	.1	.00	81	50	116	7.5
NW¼NW¼ sec. 1, T. 26 N. R. 3 E	94	2-25-54	49	31	.00	13	13	7.8	2.7	74	0	20	10	.2	13	------	147	86	222	7.4
SW¼NW¼ sec. 5, T. 26 N., R. 4 E	565	5-14-54	50	40	.93	21	13	19	5.4	170	0	3.7	3.8	.2	4.7	------	195	106	285	7.8
SW¼SE¼ sec. 16, T. 26 N., R. 4 E	287	2-23-54	50	34	.00	18	1.5	6.1	2.2	60	0	9.9	3.5	.2	1.2	------	107	51	137	7.5
NW¼SE¼ sec. 30, T. 26 N., R. 4 E	260	2-25-54	50	36	.02	19	2.0	6.2	2.2	71	0	6.2	4.0	.2	1.8	------	113	56	145	7.2
SE¼SE¼ sec. 15, T. 26 N., R. 5 E	65	10-1-63	53	23	[a].62	10	7.9	5.0	1.4	61	0	8.8	4.5	.1	4.9	.09	96	58	141	6.8
NE¼SW¼ sec. 19, T. 26 N., R. 6 E	236	10-1-63	55	28	.25	6.0	6.1	4.5	.9	50	0	6.0	2.8	.0	1.1	.15	81	40	100	7.4
SW¼SE¼ sec. 30, T. 26 N., R. 6 E	53	4-24-61	50	29	.11	16	6.8	16	3.4	125	0	2.2	2.0	.2	.2	.98	139	68	199	8.1

[a] Total iron value. All other values are iron in solution at time of sample collection.

[b] Chemical quality of second sample collected 4-8 months later virtually identical.

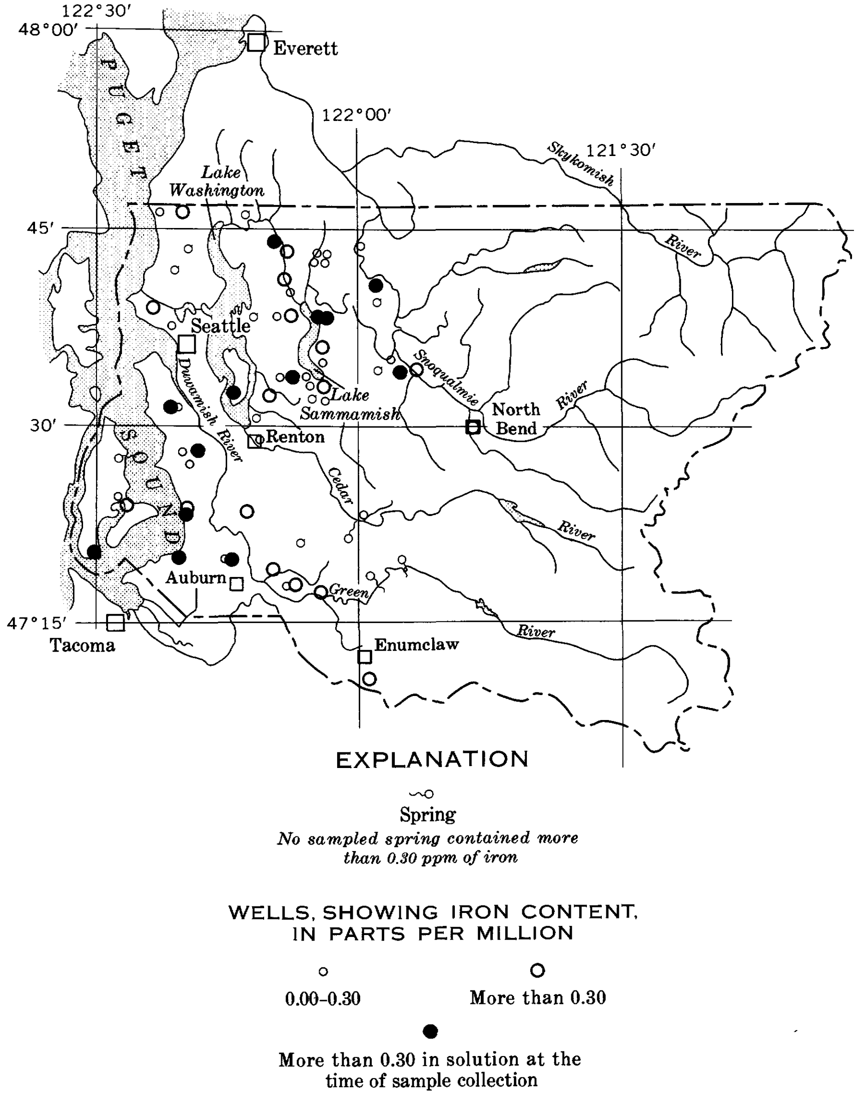


FIGURE 30.—Iron content of ground water.

Correlation of chemical quality of ground water with the stratigraphic position of the source aquifer is difficult in King County, because only a few analyses are available from wells known to yield water from a single stratigraphic unit; however, several tentative correlations can be made. Ground water from aquifers in the Vashon Drift and Recent alluvium normally contains a smaller dissolved-solids content than water from aquifers beneath these units. Eleven samples were obtained from wells known to produce from the Recent alluvium or Vashon Drift, and they had dissolved-solids contents ranging from 72 to 136 ppm. In contrast, 12 samples from wells that tap materials beneath the Vashon Drift had generally higher dissolved-solids contents, ranging from 104 to 196 ppm.

Analyses of the 23 samples mentioned above also show that ground water above or within the Vashon Drift generally contains less than 30 ppm of silica and 2.0 ppm of potassium, whereas most of the deeper water contains greater concentrations of these constituents.

WATER USE

Excluding water used for hydroelectric power, recreation, and maintenance of fish life, more than 80 percent of the water used in King County is provided by municipal-supply systems. In 1963, public water-supply systems served 934,000 people in the county (U.S. Public Health Service, 1964), or about 94 percent of the total population. Table 9 gives a list of the public systems, showing the sources of water, amounts of water provided, and number of people served by each system. The chemical quality of water provided by some of these systems is shown in table 10.

TABLE 9.—*Principal water-supply systems in King County, 1963*

[All data for 1963 except where noted. Facilities serving less than 100 persons are not included. Tacoma's Green River water supply is not included because nearly all the water is used outside King County. Figures in brackets are estimated]

Community or facility	Population served	Source of supply	Average output (mgd)	Maximum capacity (mgd)
Auburn	19,500	Springs and a well	2.5	10.0
Bellevue	25,000	Lake Washington [a]	3.0	9.4
Carnation (Tolt)	1,150	Spring	[.15]	
Crystal Water Association	230	Well	[.7]	
East Hill Community Well Co	700	2 wells	.6	
East Hill Water Co	350	2 wells	.3	
East Ridge	[400]	2 wells	.3	
Enumclaw	10,000	2 springs	1.3	2.0
Evergreen Water Improvement Association.	[500]	Well	[.05]	.11
Fall City (Water Co.)	1,000	Well and springs	.14	
Hamilton Road Water Co	[300]	2 wells?	[.03]	.08
Hilltop Community	125	Well [b]	.012	
Issaquah	2,100	Tradition Lake, well and spring.	.30	.20 (lake)
Kent	11,750	2 springs and a well	2.47	.18 (well)
King County Water Districts with independent supply:				
1. Yarrow Point	500	5 wells	.20	.31
4. Three Tree Point	1,700	Well and spring	.52	
22. Beaux Art	350	Well	.075	.108
24. Richmond Beach	3,200	8 wells	[.35]	
53. Angle Lake	800	2 wells	[.1]	.31
54. Des Moines	1,800	3 wells	.15	.9
56. Redondo	2,440	Cold Brook Springs	.20	1.52
64. Steel Lake	8,000	9 wells	[1.0]	2.9
66. Black Diamond	1,030	Springs	.10	4.3
72. Juanita	2,000	2 wells	.12	
82. Pine Lake	550	2 wells	.02	.15
83. Lake Forest	1,950	15 wells	.18	.86
94. Lake Lucerne	250	Well	[.05]	.43
97. Lake Hills	27,000	5 wells [a]	2.0	4.3
100. Lakehaven	10,000	7 wells	[3.0]	8.55
106. Lakota	500	Tacoma, springs		
114. Snoqualmie Falls	750	Tokul Creek	.9	1.0

See footnotes at end of table.

TABLE 9.—*Principal water-supply systems in King County, 1963*—Continued

Community or facility	Population served	Source of supply	Average output (mgd)	Maximum capacity (mgd)
Maple Valley	200	Springs	[.06]	
Maple Valley Heights	150	3 wells	.03	1.88
Maplewood Addition Water Co	350	2 wells	[.07]	
North Bend	1,500	Cough River (creek)		.5
North Lake Water System	250	Well	[.02]	.08
North Road Water Co	[300]	Well	[.03]	.072
Norwood Village Corp	450	Well [b]	.03	
O'Brien Water Association	260	Well	[.03]	.36
Orillia Water Co	250	Spring	[.03]	.50
Pacific City	1,900	Well and spring	[.2]	.50
Preston	200	Creek		.076
Redmond	2,100	2 wells	.12	.52 (wells)
Renton	24,500	Seattle, Springbrook Springs, 4 wells.	3.5	13.7
Seattle	[c] 808,000	Cedar and Tolt Rivers	100	300
Skykomish	550	Cold Creek, well	.05	.075
Snoqualmie	2,450	Spring and North Fork Snoqualmie River.	.50	
Snoqualmie Falls	750	Tokul Creek	.9	.2
South Auburn Water Assoc	160	Well	.02	.072
Star Lake Water Coop	510	2 wells	.07	.65
White River Valley Water Co	200	Spring	[.02]	
Vashon Island				
Burton	750	2 wells and springs		
Cedarhurst	400	Cedarhurst Creek		
Ellisport Water Co	280	Springs		
Dockton	200	Springs	0.02	0.14
Island Mutual Water Coop	1,000	Springs		
Maury Mutual Water Co	180	Springs		
Westside Water Co	600	Springs and Cedarhurst Creek.		
King County Water District 19	1,030	Springs		.025
Vashon Heights	620	Spring	.038	.14

[a] Began using water from Seattle in 1965.
[b] 1959.
[c] Includes population of all water districts and towns served by Seattle in 1963, approximately 200,000.

The average quantity of water used for public supplies in 1963 was more than 130 mgd, or about 140 gpd (gallons per day) for each person served. These figures include water used for commercial and industrial purposes; if those uses are excluded, the average domestic use from public supplies in the county is estimated at about 120 gpd per person.

Most industrial and commercial establishments in King County obtain water from public-supply systems. The largest of these users are listed in table 11. Although no industries within the county require exceptionally large quantities of water at present (1965), about half the 70-mgd water supply diverted from the Green River to Tacoma is used for production of pulp and paper.

Irrigation requirements in King County are minor. As noted on page 7, an estimated 7,671 acres was irrigated in 1959, mostly by sprinklers. A report by the Columbia Basin Inter-Agency Committee (1964) states that about 27 mgd of water was used for irrigation in the Green, Cedar, and Snohomish River basins in 1963. Because

TABLE 10.—*Chemical analyses of water from selected public-supply systems*

[Analyses by U.S. Geological Survey except as indicated]

Public supply	Date of collection	Parts per million															Specific conductance (micromhos at 25°C)	pH	Color (platinum-cobalt scale)
		Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Orthophospate (PO_4)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$			
Auburn	9-18-56	19	0.21	18	2.1	4.4	0.9	54	6	5.5	3.5	0.1	0.9	------	88	54	129	8.9	5
Bothell Water District (well 26/5-5E1)	8-24-51	47	.03	21	8.4	8.6	4.0	128	0	1.7	2.9	.3	.7	------	158	87	201	7.1	25
Duval (well 26/6-13D1)	10-6-60	16	.11	24	5.8	32	2.2	174	0	2.2	8.8	.0	.8	0.47	179	84	290	8.1	0
Fall City Water Co	8-20-51	47	[a] 1.6	20	6.8	6.6	3.4	104	0	5.4	2.5	.2	.2	------	143	78	175	7.7	10
Kent (spring 22/6-26L1s)	10-4-63	13	.04	11	2.0	3.3	.5	44	0	.8	2.2	.1	.9	.02	56	36	87	7.3	------
North Bend	1-29-63	------	------	------	------	------	------	14	0	------	------	------	------	------	------	------	29	6.9	------
North Road Water Co (near Kent)	10-4-63	37	[a] 1.3	15	12	6.7	2.7	103	0	14	4.5	.1	.2	.11	143	88	200	7.4	------
Renton (well 23/5-17F2)	6-23-60	14	.00	12	3.5	4.0	.5	49	0	10	2.2	.1	.8	.02	74	44	110	6.9	0
Richmond Beach	11-28-61[b]	38	.06	21	14	4.2	2.2	127	0	15	8.1	.2	.4	.69	111	78	175	7.0	0
Seattle Water District																			
Cedar River (Beacon Ave. sample top)	10-23-62[c]	9.0	0.0	7.7	0.8	1.8	0.1	19	0	2.6	2.4	0.0	------	------	42	22	------	7.1	------
Tolt River (South Fork Tolt River)	2-13-62[c]	5.0	.0	2.6	.4	1.8	.1	6	0	2.5	1.7	.0	------	------	25	8	------	6.7	------
South Seattle Water Co	10-4-63[b]	38	1.1	14	7.3	6.1	2.9	71	0	16	4.8	.1	0.3	0.28	126	65	159	7.8	------
King County Water Districts																			
19. Vashon (spring 23/3-29Qs)	3-3-61[d]	28	[a] 0.01	10	8.6	6.0	1.2	34	0	20	6.0	0.1	10	0.07	116	60	158	7.3	5
64. Steel Lake (well 6)	12-18-59	19	4.4	14	5.3	5.8	2.6	77	0	6.7	4.0	.4	.2	.09	102	57	157	7.6	15
82. Pine Lake	4-3-58	34	[a] 1.0	10	4.6	4.2	3.3	59	0	.5	1.8	.0	3.3	------	96	44	106	7.2	5

[a] Total iron value. All others are iron in solution at time of sample collection.
[b] Analysis by Washington State Dept. of Health.
[c] Analysis by city of Seattle.
[d] Sample collected before treatment.

TABLE 11.—*Major industrial and commercial water users in King County*

[Data after Seattle Water Department (1961, p. 4), Liesch and others (1963, p. 48), and unpublished data from U.S. Public Health Service]

User	Source ef supply	Approximate quantities used (mgp)
Boeing Airplane	City of Seattle	5.62
Univ. of Washington	do	1.11
Weyerhaeuser Co	Water District 75 (Midway)	1.01
Lakeside Gravel Co	Self-supplied	1.00
U.S. Navy	City of Seattle	.89
Todd Shipyards	do	.68
Bethlehem Steel Co	do	.66
Port of Seattle	do	.65
Pacific Car Co	City of Renton	.63
Boeing Airplane Co	do	.54
Seattle Packing Co	City of Seattle	.49
Seattle Brewing and Malting Co	do	.43
Darigold Farms	Self-supplied	.40
Puget Sound Bridge & Dredging Co.	City of Seattle	.32
Seattle Steam Corp	do	.31
Northern Pacific Ry	City of Auburn	.30
Arden Farms	City of Seattle	.27

much of the farmland in the Snohomish River Basin is north of King County, irrigation within the county doubtless requires considerably less than 27 mgd.

The use of water for irrigation is expected to increase, depending on such factors as the amount and type of farmland, types of fertilizer used, methods of irrigating, and the quality of the water applied. As competition for land use intensifies, the relative economic benefits of urban-industrial versus agricultural development will be an important factor in determining the amount of irrigated farmland in the county.

The amount of water required in the future for other uses will depend on increases in population, the growth and types of industry, possible changes in industrial processing methods, and types and quantities of waste discharges. On the basis of trends in water use from 1920 to 1960, the Seattle Water Department (1961) has predicted water demands for their system through the year 2000. As shown in figure 31, an average demand of 200 mgd is expected by the year 2000. With full development, the city's water supply system will have a transmission capacity sufficient to supply a population in excess of 2 million people with 300 gpd per person. This quantity, equivalent to 600 mgd, is far greater than the peak demand predicted for the year 2000.

In 1964, the Seattle supply served 81.5 percent of the total population of King County. If the present trend of growth continues in

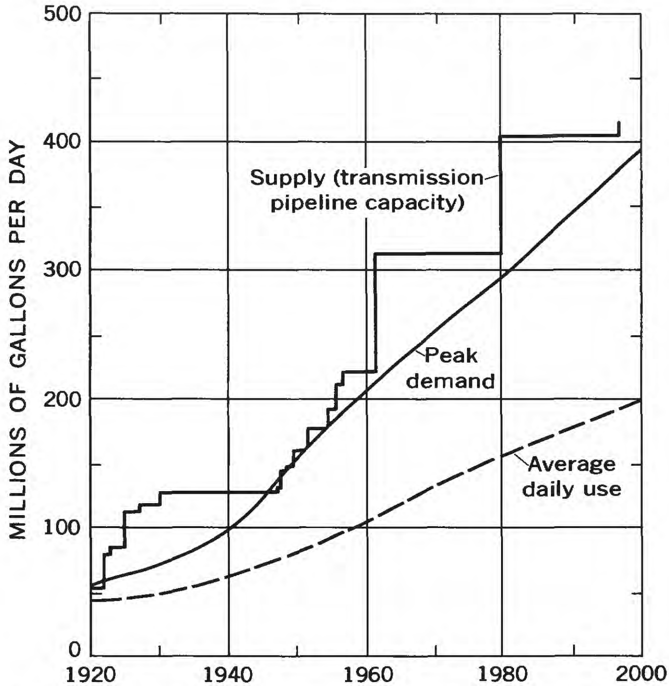


Figure 31.—Estimated average daily water use, peak water demand, and supply capacity for the Seattle water system. Data from Seattle Water Department (1961, p. 9).

the Seattle area, that figure may be well over 90 percent in the 1980's (Seattle Water Department, 1961, p. 9). The area which potentially can be supplied with water by the Seattle system is shown in figure 32. This area corresponds approximately with the urban planning areas (shown in fig. 2), where 97 percent of the population of the county lived in 1960 (p. 5).

Future industrial water requirements will depend on the type of industrial development. Industries similar to those presently in the county, which use small quantities of water, will probably continue to be served by public-supply systems. If industries requiring large quantities of water move into the area, additional sources will have to be developed.

The uses of water discussed above are "withdrawal" uses, which are provided for by pumping ground water or by surface-water diversions. An equally important use is that of fisheries, which depends on an adequate flow of suitable quality being available in streams at all times. The major streams of King County support a sizable population of anadromous fish, which are of considerable value for commercial and sport fishing. These fish are easily harmed by inade-

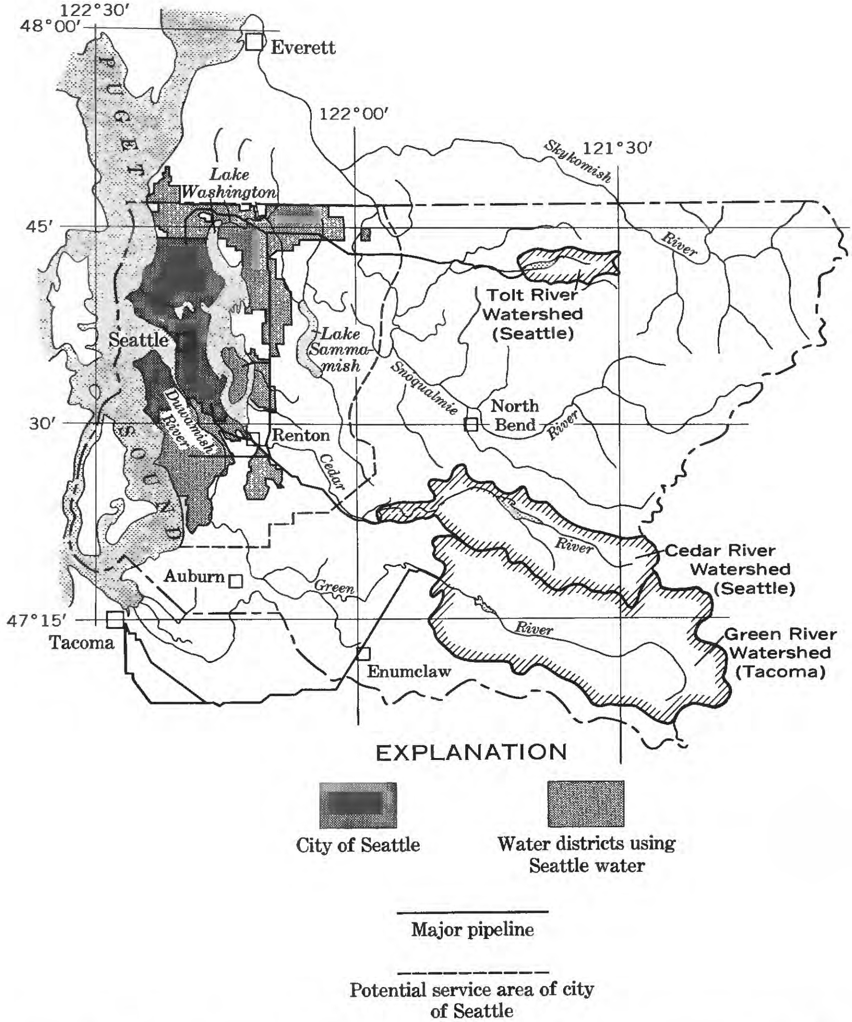


FIGURE 32.—Major municipal watersheds in King County, and area served by city of Seattle in 1963 (after Seattle Water Dept., 1964, p. 34).

quate low flows, by extremes of water temperature, and by poor water quality.

Burrows (1963) has summarized the temperature requirements for maximum productivity of salmon in fresh water; he shows an optimum temperature range of 45° to 60°F for upstream migration and maturation of adult salmon. For spawning and incubation of salmon eggs, the optimum temperature is below 55°F. During most of the year, temperatures of King County streams (two of which are represented in fig. 26) are within the range required for maximum productivity of salmon. During low-flow periods in the summer and fall, the optimum temperatures may be exceeded at times, particularly in the lower reaches of the main streams. Inasmuch as those streams are used increasingly for reservoirs, diversions, and return flows (waste discharges), the temperature of the water is likely to increase. To protect the commercial and sports fisheries of the county, development of the water resources will require careful planning to maintain stream temperatures that are suitable for the productivity of anadromous fish.

Standards of chemical quality have been established for many uses of water. To list all the standards would be beyond the scope of this report. Nevertheless, it is recognized that definition of the quality of water according to its chemical constituents is of little value unless it is related to intended use of the water. It is necessary, therefore, to consider how a particular water supply is to be used before it can be defined in terms of its suitability.

In general, the natural ground-water and surface-water supplies of King County are suitable for most uses. The high concentrations of iron commonly found in ground water throughout much of the area may make treatment necessary before use in many industrial applications. In addition, several industrial uses of water require a negligible silica content; ground water used for such processes would require treatment to remove the silica. Surface water in most of the county requires practically no treatment at all, unless it is to be used as a public supply and is subject to pollution.

FUTURE PROBLEMS

Problems concerning the water resources of King County are principally those of areal distribution and seasonal variations of the total water supply, quality of ground water, sedimentation of streams, and pollution.

Certainly there is no shortage of water on the long-term average; the total supply in the county is truly abundant. In a few isolated areas, however, sources of water supply may not be readily available locally. This condition would be a problem on Vashon Island if additional supplies could not be developed, because of the separation of the island from the large watersheds and aquifers of the mainland. Actually, the island's total supply has not yet been fully developed. Average precipitation on Vashon Island is about 45 inches per year. Although that is less than the average over most of the county, it should be sufficient to provide an adequate water supply for the island's population. As stated earlier (p. 39), geologic conditions are favorable for the occurrence of productive aquifers, and there is evidence that adequate ground-water supplies may be available. Because the water resources are not overdeveloped, the problem on Vashon Island evidently is not a lack of available water but a lack of adequate wells and distribution facilities.

The problem of seasonal variations in the supply of surface water occurs throughout the county. Too much water in the winter and too little in the summer may be balanced out by the development of additional storage facilities. Hanson Dam on the Green River is a good example of a storage project designed both for controlling floods and augmenting low flows downstream.

Dams are not the answer to all the water problems in King County. In the Green-Duwamish Valley for example, drainage problems still exist even though the Green River is controlled at Hanson Dam. With or without dams, the threat of flood damage in a basin may be reduced by the construction of adequate levees, by channel improvements, and by regulating developments on flood plains. Flood-plain zoning laws can be especially effective as a means of minimizing potential flood damage.

In the Snoqualmie River basin, the threat of floods is as great as ever. Floods as great as those of 1932 on the lower Snoqualmie River have not recurred to date (1965), and people therefore tend to forget how serious a major flood can be. Meantime, the Snoqualmie Valley continues to be developed, and the damage potential increases with each passing year. Flood-control projects now in the planning stages will eventually reduce the threat, but until such projects are completed, local residents and agencies should be aware of the increasing magnitude of potential flood damage.

Ground-water problems in King County are minor at present, inasmuch as water supplies are available for distribution to all parts of the county. Several problems may arise in the future as increased demands are made on the available supply. Increased ground-water withdrawal in the vicinity of Puget Sound could cause increases in salt-water contamination of some wells. Also, if future demands for ground water exceed the available supply from shallower aquifers, ground water of poor quality in the older and generally deeper aquifers could become a problem. To assure maximum beneficial use of water in the future, some controls on ground-water withdrawal will be necessary.

Sedimentation problems in the county are connected primarily with erosion of streambanks and roadways, and subsequent deposition on the flood plains of the lower valleys during high water. Erosion of logged-over land is evident particularly where logs jam some of the mountain streams and cause bank cutting and landslides. The fisheries resource is affected by scour and fill of alluvial sediments which serve as spawning beds in reaches of many streams in the county, and the migration of anadromous fish is hindered by excessive suspended sediment.

Most streams in the county transport only moderate amounts of sediment except during short periods of freshet activity in the winter. For most uses, the surface water of the county requires no treatment to remove sediment; for municipal water supply or other uses requiring low sediment content, some treatment may be necessary at times. As an extreme example, filtration or other treatment may be necessary for the use of water from streams such as the Middle Fork Snoqualmie River, which transports a suspended load composed of about 80 percent silt and clay (table 7). Sufficient off-stream storage capacity to meet the demand during short periods of high sediment discharge will generally insure water that will meet most turbidity standards. Whereas sedimentation problems are not acute now (1965), they can be expected to intensify with an increase of population and further development of land and other resources of the county.

The most serious water problem in King County today, and probably for the future as well, is the threat of pollution in the densely populated areas. The immediate threat in the Seattle area has been reduced considerably by the sewage-treatment program of the Municipality of Metropolitan Seattle. After 1973, plans call for the discharge of most waste effluents to Puget Sound, with only the Renton treatment plant discharging waste inland. Completion of the current Metro program is expected to eliminate most of the waste-water discharges to Lake Washington, but not to solve completely pollution problems in the Seattle area.

Expected increases in population and industry will introduce new problems, which will require additional planning to maintain adequate levels of water quality. The fisheries in particular must be protected from the effects of pollution, for the survival of this valuable resource will depend on the availability of adequate streamflows—adequate with respect to quantity, temperature, and chemical and sanitary quality. If streams and lakes are maintained in a condition suitable for the requirements of commercial and sport fisheries, the water will also be suitable for recreation and other uses in the future.

SUMMARY OF STREAMFLOW DATA

The following table presents a summary of streamflow data at gaging stations in operation September 30, 1964.

TABLE 12.—*Summary of streamflow data at gaging stations in operation September 30, 1964*

[Station: Numbers are those used in publication of surface-water records, except prefix 12 is omitted. Years: Number of complete water years included in the period of record. Estimated mean annual flood: Flood for the period 1912–57, estimated on basis of regional analysis]

Station No.	Gaging station	Drainage area (sq mi)	Period of record	Years	Average flow: For period of record (cfs)	Average flow: Estimated for 1931–60 (cfs)	Maximum flow for period of record: Cfs	Maximum flow for period of record: Date	Estimated mean annual flood (cfs)	Minimum flow for period of record: Cfs	Minimum flow for period of record: Date
Green-Duwamish River basin											
1035	Snow Creek near Lester	11.5	1945–	19	68.5	62.9	3,400	11–23–59	760	3.0	11–30–52
1040	Friday Creek near Lester	4.67	1945–	19	27.6	25.5	1,370	11–22–59	320	a 1.2	9– 6–58
1045	Green River near Lester	96.2	1945–	19	422	394	22,000	11–22–59	4,500	22	11–20–52
1047	Green Canyon Creek near Lester	3.23	1960–	4	12.9	12.7	b 177	11–20–62	180	1.4	9–19–61
1050	Smay Creek near Lester	8.56	1946–	18	52.1	48.2	2,380	11–23–59	650	4.2	11–21 to 12– 1–52
1057	North Fork Green River near Palmer	16.5	1956–	8	90.4	83.1	2,000	11–23–59	860	c 1.2	8–28 to 8–30–61
1059	Green River below Howard A. Hanson Dam.	221	1960–	4	d 1,050	1,040	12,200	2–21–61	----------	d 87	12–29–61
1065	Green River near Palmer	230	1931–63	3	d 1,095	1,079	27,800	11–23–59	12,100	d 81	9– 5–34
1067	Green River at purification plant near Palmer.	231	1963–	1	d e 1,160	e 984	d e 8,220	11–21–62	12,100	d e 40	6– 3–64
1073	Icy Creek near Black Diamond	(f)	1963–	1	29.0	23.5	113	1–27–64	(f)	3.6	10–25 to 10–28–63
1085	Newaukum Creek near Black Diamond.	27.4	1944–50, 1952–	18	65.4	60.9	1,820	2–17–49	800	8.0	10–14–52
1126	Big Soos Creek above hatchery near Auburn.	66.7	1960–	4	g 116	g 112	1,010	11–25–60	550	g 11	9– 5–63
1130	Green River near Auburn	399	1936–	28	d e 1,340	e 1,360	28,100	11–23–59	12,000	d e 81	9–23–52
1133.5	Green River at Tukwila	440	1960–	4	d e 1,510	e 1,470	11,500	2–22–61	12,000	d e 195	9–15–61

Lake Washington basin

1140	South Fork Cedar River near Lester	6.00	1944–	20	39.9	37.3	2,340	12- 9-56	530	1.9	11-28-52
1150	Cedar River near Cedar Falls	40.7	1945–	19	279	253	9,490	11-22-59	2,900	20	11-30-52
1155	Rex River near Cedar Falls	13.4	1945–	19	106	96.2	4,200	11-22-59	1,260	4.3	11-29-52
1161	Canyon Creek near Cedar Falls	f .19	1945–	19	17.4	15.6	102	12-19-46	(f)	.3	Many days.
1165	Cedar River at Cedar Falls	84.2	1914–	50	312	313	6,440	12-22-33	(h)	(h)0	11-25-17, 8-18-23
1170	Taylor Creek near Selleck	17.2	1945, 1956–	8	105	97.4	2,170	12-15-59	1,200	16	10- 2 to 10- 7-58
1175	Cedar River near Landsburg	117	1895–	69	695	680	i 14,200	11-19-11	5,600	83	9-19-98
1185	Rock Creek near Maple Valley	12.6	1945–	19	j 21.3	20.4	165	2-11-51	120	j 1.0	10-21-63
1190	Cedar River at Renton	186	1901–03, 1906–07, 1945–.	19	k 709	k 668			6,600	h k 30	7- 1-62
1195	May Creek near Renton	12.5	1945–50, 1955–58, 1963–.	8	21.2	18.7	401	2-17-49	182	1.7	Many days.
1197	Coal Creek near Bellevue	6.80	1963–	<1			249	1- 1-64	65	3.0	Many days.
1200	Mercer Creek near Bellevue	12.0	1945, 1955–	9	20.1	19.4	242	12-20-55	110	1.9	8- 6-58
1205	Juanita Creek near Kirkland	6.43	1945, 1963–	1	8.6	8.0	134	1- 1-64	57	1.1	9- 1-45
1210	Issaquah Creek near Issaquah	27.0	1945–	19	69.6	66.0	2,610	2- 9-51	600	9.4	8-21-58
1216	Issaquah Creek near mouth near Issaquah.	54.7	1963–	1	168	143	1,950	1- 1-64	860	28	Many days.
1217	Tibbetts Creek near Issaquah	3.90	1963–	1	8.8	7.0	171	1- 1-64	43	.2	Many days.
1230	Cottage Lake Creek near Redmond	10.7	1945, 1955–	9	13.7	13.2	132	1- 6-56 2-26-57	66	1.3	10- 9-63
1240	Evans Creek near mouth near Redmond.	13.0	1955–	9	21.8	21.1	145	12-22-55	120	4.5	10- 1-63
1260	North Creek near Bothell	24.6	1945–	19	35.7	34.2	680	3- 5-50	280	1.0	8-10-46
1265	Sammamish River at Bothell	212	1939–63	24	365	369	1,910	1- 6-56	1,500	62	8-23-51
1271	Swamp Creek at Kenmore	23.1	1963–	1	32.3	29.5	298	1- 1-64	270	3.4	7-27 and 8-24-64.
1273	Lyon Creek at Lake Forest Park	3.67	1963–	1	5.8	5.3	105	1- 1-64	29	1.3	8-24 and 9-12-64.
1276	McAleer Creek at Lake Forest Park	7.80	1963–	1	13.5	12.3	133	1- 1-64	53	5.6	10- 9-63
1280	Thornton Creek near Seattle	12.1	1945–46, 1961–	4	14.4	12.9	231	11-25-62	87	1.9	8- 7-61

See footnotes at end of table.

TABLE 12.—*Summary of streamflow data at gaging stations in operation September 30, 1964*—Continued

Station No.	Gaging station	Drainage area (sq mi)	Period of record	Years	Average flow: For period of record (cfs)	Average flow: Estimated for 1931–60 (cfs)	Maximum flow for period of record: Cfs	Maximum flow for period of record: Date	Estimated mean annual flood (cfs)	Minimum flow for period of record: Cfs	Minimum flow for period of record: Date
	Snoqualmie River basin										
1413	Middle Fork Snoqualmie River near Tanner.	154	1961–	3	1,278	1,210	[l] 22,800	11-19-62	16,000	140	8-28 to 8-30-61
1420	North Fork Snoqualmie River near Snoqualmie Falls.	64.0	1929–49, 1961	23	493	517	15,800	2-26-32	7,600	30	9-17 to 9-19-29
1422	Calligan Creek near Snoqualmie	7.31	1964–	<1					600		
1423	Hancock Creek near Snoqualmie	7.67	1964–	<1					650		
1430	North Fork Snoqualmie River near North Bend.	95.7	1907–26, 1929–38, 1960–	32	700	743	15,800	11-23-09	9,600	54	9- 1-30, 9- 1-34
1434	South Fork Snoqualmie River above Alice Creek near Garcia.	41.6	1960–	4	306		7,090	11-19-62	3,000	35	10- 5-60, 10-11-63
1436	South Fork Snoqualmie River at Edgewick.	65.9	1962, 1963–	1	515		2,190	1- 1-64	4,500	58	10-11-63
1437	Boxley Creek near Cedar Falls	[f] 1.57	1945–	19	28.4	25.4	182	12-22-46	([f])	0.1	Many days.
1440	South Fork Snoqualmie River at North Bend.	81.7	1907–26, 1929–38, 1945–50, 1960–	36	548	570	[m] 9,280	11-20-62	5,100	63	10-22-25
1445	Snoqualmie River near Snoqualmie	375	1898–99, 1902–04, 1907–32, 1958–	34	2,529	2,640	61,000	11-23-59	28,000	[n] 88	8- 8-60
1448	Beaver Creek near Snoqualmie	4.13	1964–	<1					190		
1455	Raging River near Fall City	30.6	1945–50, 1963–	5	161	145	3,420	2- 9-51	1,700	8.8	9-10-49
1460	Patterson Creek near Fall City	15.5	1947–50, 1955	12	32.7	29.7	480	2-17-49	190	6.4	7-22-56, 7-26-58
1470	Griffin Creek near Carnation	17.1	1945–	19	42.3	40.1	800	1- 7-62	320	1.1	Many days.
1485	Tolt River near Carnation	81.4	1928–32, 1937–	30	[o] 611	636	17,400	12-15-59	8,500	53	9-23-51
1490	Snoqualmie River near Carnation	603	1928–	36	3,787	3,850	59,500	2-27-32	34,000	[n] 239	9-24-38
1505	Cherry Creek near Duvall	19.2	1945–48, 1961–	6	56.7	52.7	918	2- 2-47	310	1.6	8-27 to 8-30-61

[a] Affected by minor diversion. The minimum natural flow observed was 1.3 cfs, Nov. 28–30, 1952.
[b] Peak flow on Nov. 22, 1959, was 359 cfs.
[c] Affected by seepage from channel. A loss of about 7 cfs during low flow has been estimated in a reach at the gage.
[d] Regulated by Hanson Reservoir since Dec. 5, 1961.
[e] Affected by diversion of about 110 cfs at city of Tacoma headworks since Mar. 1, 1948, and about 85 cfs prior to that time.
[f] Drainage area is insignificant; practically entire flow is from springs a short distance upstream.
[g] Affected by diversion to hatchery. As much as 14 cfs bypasses the station at times.
[h] Regulated by Chester Morse Lake.
[i] Peak flow caused by failure of flashboards at Chester Morse Lake.
[j] Affected by diversion to Kent.
[k] Affected by diversion to Seattle. Average flow diverted during 1931–60 was 158 cfs. Minimum flow shown at Renton is the minimum daily discharge of record.
[l] Peak flow on Nov. 23, 1959, was 49,000 cfs.
[m] Peak flow on Nov. 22, 1959, was 13,000 cfs.
[n] Regulated at Snoqualmie Falls. Figure shown is the minimum daily discharge.
[o] Affected by diversion to Seattle since 1963. Average flow diverted in 1964 was about 30 cfs.

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