Geology and Water Resources in the French Prairie Area, Northern Willamette Valley, Oregon

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1833

Prepared in cooperation with the Oregon State Engineer

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By DON PRICE

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By Don Price

ABSTRACT

The French Prairie area covers about 210 square miles of the main Willamette Valley plain between Salem and Newberg, Oreg.; it is principally agricultural, and pumpage of ground water for irrigation has increased markedly in recent years. There were nearly 600 irrigation wells in the area in 1963, compared with about 150 in 1950 and less than 50 in 1940.

The area is part of a broad northeastward-trending synclinal trough that is partly filled with nonmarine sedimentary deposits. These deposits range in age from early(?) Pliocene to Recent and consist mainly of fine-grained lacustrine materials that grade into coarser grained predominantly fluvial materials toward the south and east boundaries. Where fully penetrated by wells, the deposits are as much as 650 feet thick and are underlain by basalt of Miocene age.

The nonmarine sedimentary deposits contain the principal ground-water reservoir in the French Prairie area. Wells tapping these deposits supply most of the water for irrigation and almost all the water needed in the area for domestic, industrial, and public uses. Gravels of the Troutdale Formation (early Pliocene) and Recent alluvium of the Willamette River are the most permeable aquifers and yield as much as 1,600 gallons per minute to wells. Most wells tapping the Recent alluvium are less than 50 feet deep; wells tapping the Troutdale Formation are generally less than 200 feet deep.

The ground-water reservoir is recharged by downward percolation of precipitation, most of which occurs during the period November to April. In 1960, infiltration from about 28 inches of precipitation filled the reservoir to near capacity.

The reservoir is drained naturally by evapotranspiration and by discharge through seeps and springs. During the dry summers, drainage through seeps and springs (about 113,000 acre-ft per yr) helps to sustain flow of the Willamette River and its tributaries downstream from Salem. During the winter months, the water discharged is continually being replaced by natural recharge from precipitation, but during the summer months there is little natural recharge and the water table in the area declines. The decline is less than 5 feet along the alluvial plains and more than 20 feet in parts of French Prairie. In 1960, the seasonal net change of storage between early spring and late summer in the ground-water reservoir was about 182,000 acre-feet. Of this amount, less than 20,000 acre-feet was pumped from wells; the rest discharged through seeps and springs and by evapotranspiration.

The storage capacity of the ground-water reservoir in the French Prairie area is estimated to be about 4 million acre-feet between the depths of 10 and 200 feet.

The quality of water pumped from most wells tapping the nonmarine sedimentary rocks is excellent for irrigation and for most other uses. However, water from several wells in the vicinity of Keizer contained objectionable concentrations of sulfate derived from industrial waste dumped in the late 1940's. Also, water from several wells in the study area contained objectionable concentrations of dissolved iron.

Water from a well tapping the Columbia River Group in the northern part of the area contained unusually high sodium and chloride concentrations, 147 and 400 parts per million respectively, which suggests that saline water from underlying marine sedimentary rocks may have percolated upward into the basalt aquifers in that area.

The ground-water reservoir in the area can support considerably greater withdrawals than the estimated 20,000 acre-feet pumped in 1960. By increasing withdrawals, some of the ground water that is lost from the area by natural discharge could be intercepted for beneficial use within the area. It is estimated that about 100,000 acre-feet of water per year can be pumped from the ground-water reservoir in the area without causing serious overdraft. This amount would be sufficient to irrigate all the arable land.

Continued increases in pumping withdrawal, however, will ultimately lower the water table and result in noticeably decreased streamflow—particularly during low-flow periods. The decrease should be most noticeable in the smaller streams, whose flow depends almost entirely on ground-water seepage from the French Prairie area, and least noticeable in the larger streams.

The water table will be a few feet lower in some areas and a few tens of feet lower in others, if withdrawals increase to 100,000 acre-feet per year. Water levels will rise during nonpumping periods (which correspond with the recharge season) but probably not to their previous high levels. Once the adjustment is made, however, no further average decline of water level would be expected without a further increase in withdrawals.

One of the major problems in the area is the excessive wear of pumps and water-supply systems caused by sand seepage into wells. This problem could be largely eliminated by proper well design and wider use of modern well-development techniques.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The French Prairie area is in one of the most productive agricultural regions in Oregon. Use of ground water here has been increasing rapidly in recent years. Part of the increased use has been for industrial and public supplies, which are obtained almost entirely from wells; most of the increase, however, has been for irrigation. Although annual precipitation is moderately high, rain during the main growing season is usually insufficient for crops that otherwise would be suited to the area. To supplement the meager summer precipitation, more and more farmers are irrigating their crops with water from wells. Nearly 600 wells in the area were used for irrigation in 1962, compared with about 150 in 1950 and less than 50 in 1940. The use of ground water for irrigation doubtless will increase because less than half of the arable land in the area is now irrigated. Ground-water use for public and industrial supplies also is expected to increase rapidly, following present trends of urban and industrial growth in the area.

The purpose of this investigation is to provide information for the efficient development and effective management of the ground-water resources of the French Prairie area. The study included determination of (1) the sources, occurrence, availability, and movement of the ground water; (2) the amounts of ground water used; (3) the amounts available for further development; and (4) the chemical suitability of the ground water for irrigation and other uses.

Most of the fieldwork was done in 1960. Records of all known large-yield irrigation, industrial, and public-supply wells were collected, as well as records of about 275 selected domestic and stock wells; water-level measurements were begun in a network of observation wells, and samples of ground water were collected for chemical analysis. Subsequent fieldwork (1961–63) included reconnaissance geologic mapping, collection of pumpage records, continued periodic measurement of ground-water levels, and collection of drill cutting and auger samples for laboratory analysis.

The subsurface geology was emphasized in the geologic studies. Drillers' logs of representative wells were used to prepare a fence diagram showing the depth, thickness, and extent of each major lithologic unit. The logs were also used, together with laboratory data, to estimate water-storage capacities of the lithologic units. A surface geologic map was compiled partly from existing geologic data and partly from reconnaissance mapping.

Seasonal variations in ground-water storage were quantitatively estimated using water-level measurements made in early spring and late summer of 1960.

The study is a part of a continuing cooperative program between the Oregon State Engineer and the U.S. Geological Survey to evaluate the ground-water resources in Oregon and was made under the supervision of B. L. Foxworthy, district geologist in charge of ground-water investigations in Oregon.

LOCATION AND EXTENT OF THE AREA

The French Prairie area includes about 210 square miles in the northern Willamette Valley between lat 44°58′ and 45°18′ N. and long 122°43′ and 123°04′ W. (fig. 1). The area covers much of northern Marion County and a small part of southwestern Clackamas County. It is bounded on the west and north by the Willamette

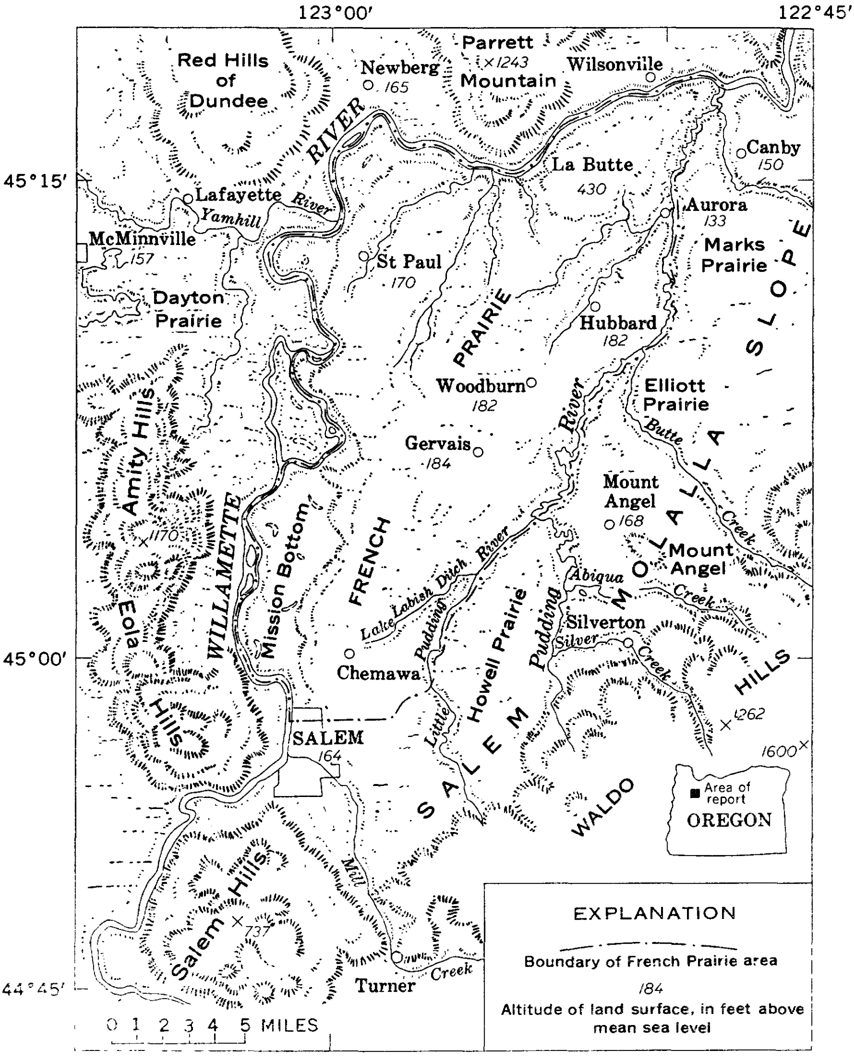

Figure 1.—Boundaries and general features of the French Prairie area.

River, on the east mainly by the Pudding and Little Pudding Rivers, and on the south by lat 44°58′ N., or, roughly, the north city limits of Salem.

PREVIOUS INVESTIGATIONS AND RELATED STUDIES

The French Prairie area has been included or touched upon in several earlier ground-water investigations. The earliest report of the ground-water resources of the Willamette Valley, including the French Prairie area, was by A. M. Piper (1942), who described the general geology and occurrence and dependability of the ground-water supply. More recent works include an unpublished administrative report prepared by F. D. Trauger of the U.S. Geological Survey in 1947, on contamination of ground water by industrial waste in the north Salem area, and an unpublished report written by J. E. Sceva in 1955, describing drilling conditions and availability of ground water in the west-central part of the area.

A brief description of the occurrence and availability of ground water in the French Prairie is given in a report that presents much of the basic hydrologic data collected during the first year of this investigation (Price, 1961). That report contains records of wells and other hydrologic data not included in this report.

Related ground-water studies have been made, or are in progress (1965), in adjacent areas. Hart and Newcomb (1965) completed a study of the Tualatin Valley, which adjoins the French Prairie area on the north. Studies are being made of the Salem–Molalla Slope area, the Salem Hills, and the Eola–Amity Hills area, which adjoin the French Prairie area on the east, south, and west respectively. Hampton (1963) included many hydrologic data in a preliminary report on the general ground-water conditions in the Salem-Molalla Slope area.

ACKNOWLEDGMENTS

Many data for this investigation were supplied by well owners and operators, by well drillers, and by pump companies and their representatives. The helpful cooperation of these people is gratefully acknowledged.

Special thanks are extended to the following persons: J. T. Miller, drilling contractor, and personnel of the Willamette Drilling Co., who collected drill-cutting samples for laboratory analysis; F. L. Zielinski and E. C. Cole, who allowed installation of continuous water-level recorders in their wells; J. P. Leavy, who allowed off-season pumping of his irrigation well for an aquifer-performance test; and F. G. Mackaness and officials of the Portland General Electric Co., who furnished the power-consumption data needed to estimate ground-water pumpage for irrigation in the area.

WELL-NUMBERING SYSTEM

Wells are designated by symbols that indicate location according to the official rectangular subdivision of public lands. For example, in the symbol for well 3/1W–25K1, the part preceding the dash indicates township and range (T. 3 S., R. 1 W.) south and west of the Willamette base line and meridian. The first digits after the dash indicate the section (sec. 25), and the letter indicates the 40-acre subdivision of that section, according to figure 2. The final

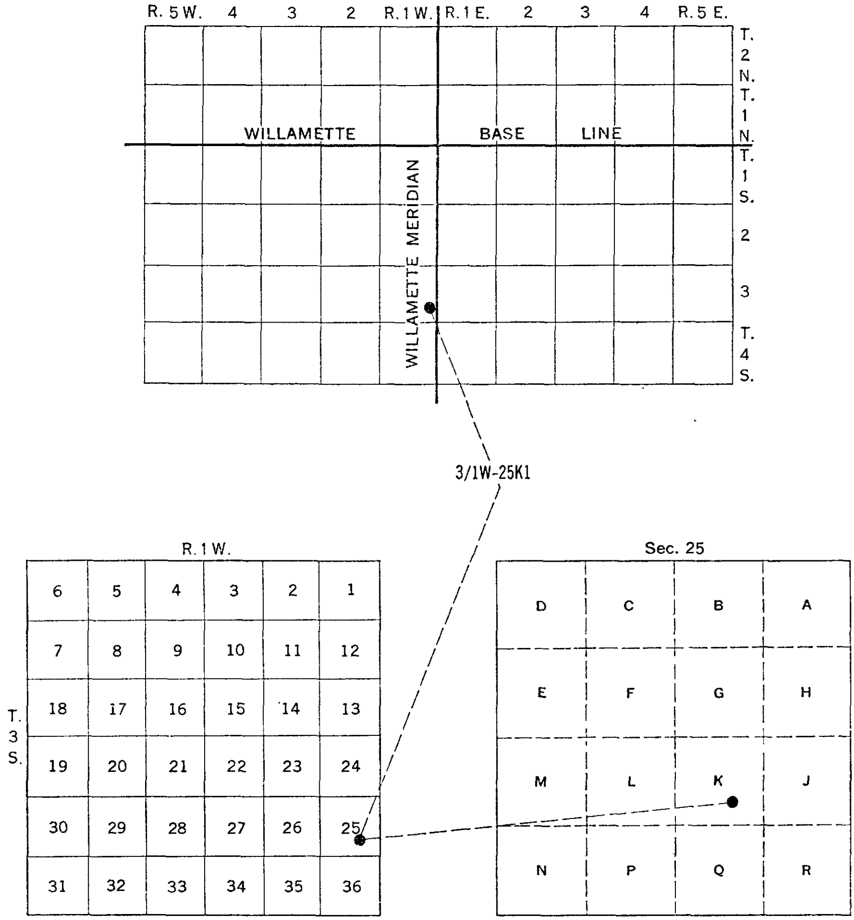

FIGURE 2.—Well-numbering system.

digit is the serial number for that particular well. Thus, well 3/1W–25K1 is in the NW¼SE¼ sec. 25, T. 3 S., R. 1 W., and was the first well in that tract to be listed. A well is identified on the map (pl. 1) by that part of its number following the dash, such as 25K1.

GEOGRAPHY

LANDFORMS

The French Prairie area is part of the main Willamette Valley plain, which is between the Cascade and Coast Ranges of northern Oregon in the Pacific Border physiographic province (Fenneman, 1931, p. 449). The study area is in a broad synclinal trough that was formed by structural deformation of volcanic and sedimentary rocks of Miocene age and older; the trough is partly filled with sedimentary and volcanic deposits.

Most of the surface features within the area have been formed by stream erosion after late Pleistocene time. The only surface structural feature is a small basalt-capped knoll (La Butte) on the north boundary of the study area (fig. 1). La Butte is apparently part of an upfaulted block.

Maximum relief within the French Prairie area is about 380 feet. La Butte, whose altitude is about 450 feet, is the highest point. Most of the area, however, is between 100 and 190 feet above sea level on two main levels—the present alluvial plain of the Willamette River and an older, higher plain. One of the most prominent physiographic features is the steep erosional scarp, 30–80 feet high, that separates the two plains.

FRENCH PRAIRIE

French Prairie is the largest of several broad plains, locally called "prairies," in the main Willamette Valley plain between Salem and Canby. It extends northward from Salem in the shape of a fan and covers about 170 square miles (fig. 1). It has an average altitude of about 180 feet and slopes gently to the northwest. At its highest point, near Salem, the plain is about 200 feet above mean sea level; near Gervais the altitude of the plain is about 180 feet, and near St. Paul it is about 170 feet. The slope continues across the Willamette River to near McMinnville, where the same general surface is referred to as Dayton Prairie. The altitude there is about 155 feet.

French Prairie is remarkably flat and featureless. Its continuity is interrupted only by the narrow ravines of several deeply incised streams and by Lake Labish, a broad and shallow abandoned stream channel that extends northeastward across the southern part of the study area (pl. 1).

FLOOD PLAIN OF THE WILLAMETTE RIVER

The present flood plain of the Willamette River is about 30–80 feet lower than adjacent parts of French Prairie. The flood plain has an average altitude of about 130 feet and slopes northward from Salem about 3 feet per mile. The plain ranges in width from about 4 miles just north of Salem to less than half a mile where the river flows between La Butte and Parrett Mountain (fig. 1). Discontinuous segments of the flood plain lie within the study area (east and south of the Willamette River). The largest segment is Keizer-Mission Bottom, which covers about 23 square miles; the other, smaller segments have a combined area of about 15 square miles.

The flood plain has many features characteristic of flood plains of low-gradient streams that have large variations in flow. It is marked by many oxbow lakes and meander scars and by numerous abandoned stream channels that contain water only during freshets.

SURROUNDING UPLANDS

The French Prairie area is virtually surrounded by lava-capped hills—the Salem Hills, the Eola and Amity Hills, the Red Hills of Dundee, Parrett and Petes Mountains, and the Waldo Hills—that rise above the valley floor to altitudes of more than a thousand feet (fig. 1). The lava rocks that cap these hills extend beneath parts of the French Prairie area and probably affect recharge of ground water.

DRAINAGE

Except locally south of Lake Labish, the study area is surrounded by streams. The Willamette River, the master stream, heads in the Cascade Range about 100 miles southeast of Salem. It enters the study area through a narrow gap between the Salem and Eola Hills and flows generally northward for about 25 miles; it then flows eastward and skirts the southern ends of Parrett and Petes Mountains before leaving the area through another narrow gap north of Canby (fig. 1). Between Salem and Canby, the river has a gradient of less than 3 feet per mile. Thus, it is a sluggish, meandering stream subject to periodic flooding during freshets. The gradient of the river is controlled by a natural dam across the river near Oregon City (p. 32).

The Pudding and Little Pudding Rivers, which together form the eastern boundary of the study area, head in the western slopes of the Cascade Range east of Salem. The Little Pudding River flows northeastward and drains into the Pudding River near Mount Angel; the Pudding River, in turn, joins the Molalla River about 4½ miles northeast of Aurora. About half a mile farther north, the Molalla River drains into the Willamette River. Like the Willamette River, the Pudding and Little Pudding Rivers are sluggish streams with many intricate meanders. They are clogged with trees and brush and often overflow their banks during freshets. Both the Pudding and the Little Pudding Rivers derive most of their summer flow from ground water discharging from the French Prairie and the Salem–Molalla Slope areas.

The southernmost part of the study area is drained in part by Lake Labish Ditch and in part by Claggett Creek (pl. 1). Lake Labish Ditch was dug to drain a shallow lake that occupied a broad abandoned stream channel called Lake Labish. The ditch functions as an open ground-water drain through which water flows in opposite directions from a divide in the vicinity of sec. 22, T. 6 S., R. 2

W. (pl. 1). Part of the flow empties into the Little Pudding River on the east, and part empties into the Willamette River on the west. Claggett Creek drains the extreme southwest end of the study area and empties into Clear Lake, an oxbow lake on the alluvial plain of the Willamette River.

Several small deeply incised streams rise directly on the surface of French Prairie and form a roughly radial drainage pattern. Their flow is maintained throughout the dry summer months by ground-water discharge. The largest of these streams flow northeastward and are from west to east: Mission, Champoeg, Case, Senecal, and Mill Creeks (pl. 1). Like the larger rivers, these streams are sluggish, owing to their low gradients toward the Willamette and Pudding Rivers into which they drain.

Amounts and variations in flow of the rivers and smaller streams that drain the study area are discussed on pages 34–40.

CLIMATE

Climate of the French Prairie area is characterized by warm, dry summers and cool, moist winters. The wettest months are from October to March, and the driest usually are July and August.

Figure 3 shows the average monthly precipitation during the period 1920–62 at Salem, which is near the south boundary of the study area, and at McMinnville, near the north boundary. At Salem, the average monthly precipitation ranged from less than an inch in July and August to about 7 inches in December. Summer precipitation at McMinnville was about the same as that at Salem, but winter precipitation was somewhat greater.

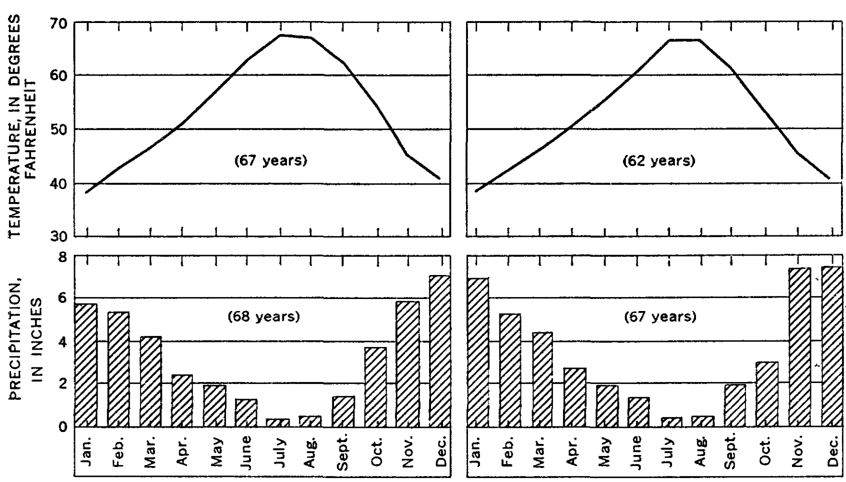

FIGURE 3.—Average monthly precipitation and temperature at Salem and McMinnville, Oreg. (Data from U.S. Weather Bur.)

Annual precipitation at Salem averaged slightly more than 40 inches during the period 1920–60, but ranged from as little as 25 inches to more than 60 inches (fig. 4). The average annual precipitation at McMinnville was 41.0 inches during the same period. The precipitation usually occurs as soft, gentle rains. Snow occasionally falls during winter, but it usually melts within a few days. Torrential rains fall only occasionally, usually during the beginning and end of the main rainy season.

Temperatures are generally moderate throughout the year. The average daily temperature ranges from about 30° to 43°F in January and from about 49° to 86°F in July. However, winter temperatures occasionally drop well below freezing, and the daytime summer temperatures occasionally rise to above 90°F. The coldest temperature ever recorded at Salem was —10°F, and the highest was 108°F. The average monthly temperatures at Salem and at McMinnville are shown in figure 3.

Evaporation data are not available for the French Prairie area, but such data are available from a class A Weather Bureau land pan at Corvallis, about 25 miles south of Salem. Because Corvallis is in an area climatologically similar to French Prairie, data from that station are probably representative of the French Prairie area. At Corvallis, the average evaporation is about 27 inches from April to September and only about 5 inches from October to March.

The growing season is from April to September. However, in some years, late spring rains delay soil preparation for seeding.

CULTURE AND INDUSTRY

The population in the French Prairie area is concentrated in small towns and cities along U.S. Highway 99E (pl. 1), which until recent years was the main highway between Salem and Portland. The rest of the area is largely rural. The largest city totally within the study area is Woodburn, which had a population of 3,527 in 1962. Other cities and towns in the area, in order of their 1962 populations, are Hubbard (627), Gervais (438), Aurora (312), St. Paul (254), and Donald (201).

Most of the larger nonagricultural industries in the northern Willamette Valley are centered around Portland, Oregon City, and Salem. Within the study area, gravel mining, canning and packing of produce, and water-well construction are the principal nonagricultural industries.

Agriculture is the major occupation in the area. According to the County Extension Agent (B. A. Newell, written commun., 1960), the estimated total gross agricultural income in Marion County in 1959 was $31,975,000. The principal farm crops in the French

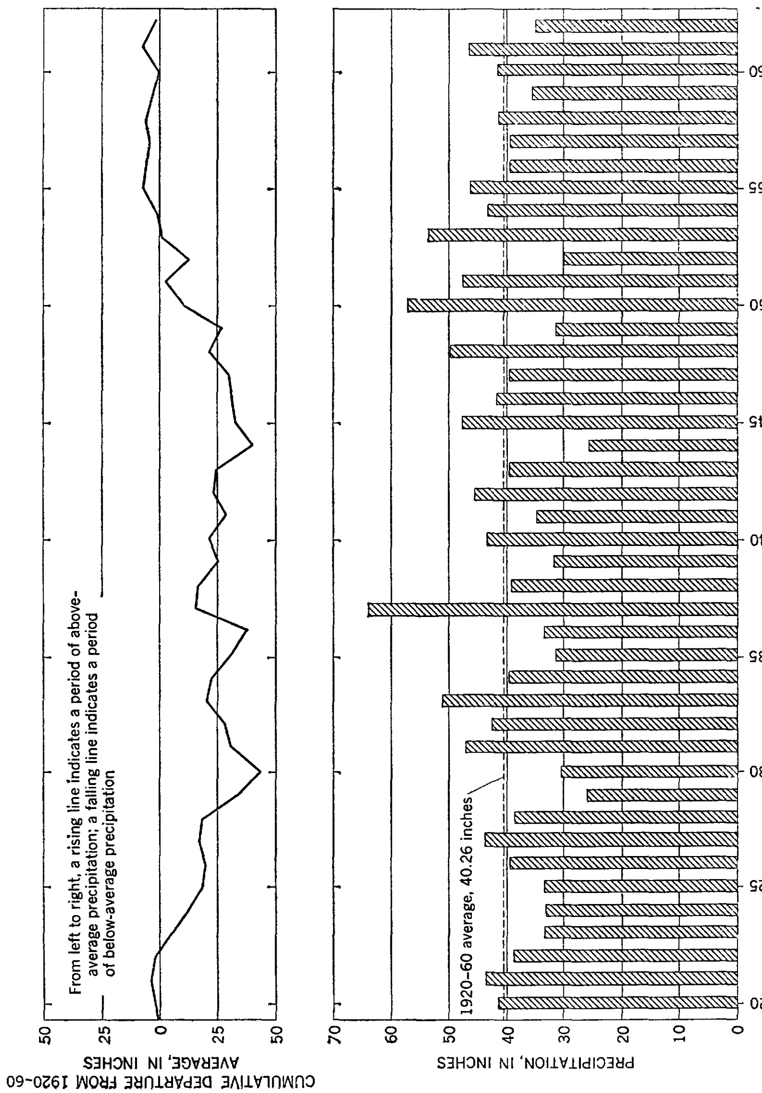

FIGURE 4.—Annual precipitation and cumulative departure from 1920–60 average at Salem, Oreg. (Data from U.S. Weather Bur.)

239-692—67——2

Prairie area are grains, grass seeds, hops, legumes, and onions. The principal horticultural crops are: (1) tree fruits, mainly cherries, apples, and pears; (2) nuts, mainly filberts and walnuts; and (3) strawberries and other small fruits, such as blackberries and raspberries. The principal livestock products are dairy and poultry goods, beef, hogs, and poultry.

About 30,000 acres, or 22 percent of the area, is under irrigation; the remainder consists of dry-farm, timber, or unfarmed land. A large part of the irrigated land is used exclusively for pasture.

DEVELOPMENT AND UTILIZATION OF GROUND WATER

Most of the water used for irrigation, and virtually all the water used for industrial, public, and domestic supplies in the area is pumped from wells.

During the early history of the French Prairie area, nearly all the wells were used for domestic and stock supplies. They were shallow dug wells that produced water very slowly. As more people settled in the area, the need for larger domestic and public water supplies grew. At the same time, water supplies for irrigation were sought and developed from ground water. Consequently, most of the dug wells were abandoned and replaced by deeper, more reliable drilled wells having greater yields. Today nearly all wells in use are drilled wells.

Most existing wells range in depth from 100 to 150 feet, are cased with steel, and are either left open at the bottom or are perforated opposite one or more water-bearing strata. In addition, many wells in the northern half of the area are constructed with artificial gravel packs—that is, with an envelope of gravel placed around the outside of the perforated segment of casing to reduce the influx of sand. Cable-tool drilling equipment has been used almost exclusively to construct wells in the area, but some of the more recent wells have been drilled with rotary equipment.

GEOLOGY

In the French Prairie area, as in any area, the geology (the kind and areal distribution of rock units) largely controls the occurrence, availability, and quality of ground water. The water-bearing properties of the rocks are determined mostly by depositional environments and by subsequent geologic processes such as deformation, compaction, and cementation. The storage and water-yielding capacities of the ground-water reservoir depend on the character of the rock materials that form the reservoir. Natural recharge of the reservoir depends largely on the available precipitation and the permeability of surficial materials in the recharge areas. Chemical quality of the ground water is influenced by the mineral composition and degree of weathering of the rocks through which the water moves.

GEOLOGIC SETTING

The French Prairie area is in a broad northeast-trending synclinal trough, which was formed by the downwarping of the Columbia River Group (Miocene) and older, marine sedimentary rocks. This structural trough has been partly filled with consolidated and semiconsolidated nonmarine sedimentary deposits and, at places, volcanic rocks which range in age from early(?) Pliocene to Recent.

These sedimentary and volcanic rocks have an aggregate thickness ranging from about 345 feet in the vicinity of St. Paul to about 650 feet about 3 miles northeast of Butteville. They are at least 200 feet thick in other parts of the study area, but become progressively thinner beyond its boundaries where they lap on to the Columbia River Group and marine sedimentary rocks.

Plate 2 is a geologic map of the French Prairie area with a diagrammatic cross section showing general geologic structure and relations of major geologic units.

The nonmarine sedimentary deposits and volcanic rocks include four lithologic units recognizable from surface geologic mapping and well logs. They are, from oldest to youngest: The Sandy River(?) Mudstone of early(?) Pliocene age, the Troutdale Formation of early Pliocene age, the Willamette Silt of late Pleistocene age, and alluvium of Recent age (pl. 2). In general, contacts between the respective units, as interpreted from drillers' logs, are easily discerned in the southern half of the study area but are less distinct in the northern half, where the entire sequence is predominantly fine grained. Consequently, contacts between respective units, as shown on plate 2 and in well logs (table 6), are approximate for the northern part of the area.

ROCK UNITS AND THEIR WATER-BEARING PROPERTIES

The major rock units that are exposed or have been penetrated by wells are described briefly in table 1. A more detailed discussion of the rock units and their water-bearing properties is given below.

MARINE SEDIMENTARY ROCKS

The oldest rocks known to underlie the French Prairie area are marine sedimentary rocks, probably of middle to late Oligocene age. These rocks are not exposed in the study area, but are believed to have been penetrated in at least one well (4/2W–18L1), about 1 mile northwest of St. Paul (pl. 1). Because they contain saline

TABLE 1.—*Summary of stratigraphy in the French Prairie area*

System	Series	Geologic unit	Approximate maximum thickness in area (feet)	Character of material	Water supply
Quaternary	Recent	Alluvium	90	Largely sand and gravel beneath the Willamette River flood plain; predominantly sand and silt beneath the flood plains of the Pudding River and smaller streams. Peaty soil and some sand and gravel underlie Lake Labish.	Sand and gravel deposits underlying the Willamette River flood plain and Lake Labish generally yield moderate to large quantities of water to wells; deposits underlying flood plains of smaller streams generally yield small quantities of water to wells.
		—Unconformity—			
	Pleistocene	Willamette Silt	130±	Tan to reddish-brown thinly bedded silt of uniform texture with some thin lenses of clay and very fine sand. Grades into predominantly fine sand near its base. Forms bluffs along Willamette River and tributaries. Formation locally contains fragments (as much as several feet in diameter) of rocks that are foreign to the Willamette River drainage basin.	Yields only small quantities of water to wells.
		—Unconformity—			
Tertiary	Pliocene	Troutdale Formation	250+	Alternating layers of clay, silt, sand, and gravel and, locally, boulders; gravel predominant beneath the southeastern part of the area; sand and clay predominant beneath the northwestern part. Deposits unconsolidated locally. Capped locally by a discontinuous layer of lava in the vicinity of Aurora.	Generally yields moderate to large quantities of water to wells in the southern part of the area and moderate quantities in the northern part.
		Local Unconformity?			
		Sandy River(?) Mudstone	300+	Penetrated at depth by several wells; consists largely of dark-gray clay and shale but also includes some thin beds of sand and fine gravel.	Sand and gravel strata yield moderate quantities of water to wells; unit as a whole has low permeability.
		—Unconformity—			
	Miocene	Columbia River Group	350+	Forms La Butte and caps surrounding hills. Consists of a series of basaltic lava flows; penetrated by 3 wells; may be discontinuous beneath the area. Deposited on uneven erosion surface developed on the marine sedimentary rocks.	Yield of wells tapping basalt depends largely on the number of saturated permeable interflow zones penetrated; formation generally yields small to large quantities of water to wells in adjacent areas but is not known to yield more than a few tens of gallons per minute to wells in the French Prairie area.
		—Unconformity—			
	Oligocene	Marine sedimentary rocks	1,000+(?)	Believed to have been penetrated at depth by at least 1 well. Directly underlies the Columbia River Group in adjacent areas where it consists mainly of tuffaceous siltstone and sandstone.	Generally yields only small quantities of water to wells. Locally yields highly mineralized water that is not suitable for human consumption or for irrigation.

water that could greatly affect utilization of ground water in the area, they are described in this report.

The nearest surface exposures of the marine sedimentary rocks are in the Eola, Amity, and Salem Hills, where they underlie the Columbia River Group, and in the Salem–Molalla Slope area, where they underlie the Columbia River Group and younger sedimentary and igneous rocks. In the Eola-Amity Hills they were mapped by Baldwin, Brown, Gair, and Pease (1955) as two units—an older tuffaceous siltstone equivalent in age to the late Eocene and early Oligocene Keasey Formation (Schenck, 1936, p. 62–63), and a younger fine- to coarse-grained sandstone equivalent to the middle Oligocene Pittsburg Bluff Formation (Schenck, 1928, p. 36). The rocks dip southeast and have an aggregate thickness of more than 4,000 feet in the Eola and Amity Hills.

In the Salem Hills and North Santiam River basin, Thayer (1939, p. 6–7) mapped mainly bedded tuffaceous marine rocks varying greatly in particle size—pebble conglomerates to massive white ash and fine silt. One formation, the Illahe, was considered by Thayer to be equivalent in age to the Pittsburg Bluff Formation. In the lower part of the North Santiam River basin, the Illahe Formation of Thayer generally dips to the northwest.

E. R. Hampton, U.S. Geological Survey, mapped marine sedimentary rocks in the Salem–Molalla Slope area. The rocks are largely tuffaceous sandstone strata, but clean quartzose sandstone, pebble conglomerate, bioclastic limestone, and, locally, basaltic breccia are also present (oral commun., 1963). The westernmost exposures of the marine sedimentary rocks in the Salem–Molalla Slope area dip generally to the west.

Attitudes of Oligocene rocks mapped in adjacent areas clearly indicate that the rocks extend beneath the study area, although their depths in most of the area are not known. Well 4/2W–18L1, about 1 mile north of St. Paul, probably penetrated marine sedimentary rocks between the depths of 610 and 781 feet (table 6).

None of the wells currently in use (1965) in the French Prairie produce water from the marine sedimentary rocks. Well 4/2W–18L1, which is no longer used, probably yielded some water from these rocks, but most of the water was reportedly from younger nonmarine sedimentary deposits. Where the marine sedimentary rocks have been penetrated by wells in other parts of the northern Willamette Valley, permeability was low and chemical quality poor, especially at the greater depths where there is little chance for fresh-water circulation (Hart and Newcomb, 1965, p. 55; Hogenson and Foxworthy, 1965, p. 17; Hampton, 1963, p. 6).

An analysis of water from well 4/2W–18L1 was not available; however, the owner reported that it was pumped a short time for irrigation of pastureland but yielded water that was too saline for that purpose.

A sample of water from near Aurora at Giesy Mineral Spring, which is believed to issue from the marine sedimentary rocks, contained high concentrations of chloride and other dissolved minerals (table 7).

COLUMBIA RIVER GROUP

The Miocene Columbia River Group, which is exposed on La Butte, unconformably overlies the marine sedimentary rocks. In adjoining parts of the northern Willamette Valley, basalts of the Columbia River Group are well exposed and cap or form hills of moderate to high relief (fig. 1).

Good exposures of the Columbia River Group in the Tualatin Valley were described by Hart and Newcomb (1965, p. 16), in the Eola and Amity Hills by Baldwin, Brown, Gair, and Pease (1955), and in the Salem Hills (Stayton Lava) by Thayer (1939, p. 7). The Columbia River Group is a series of concordantly layered basaltic lava flows which generally range in thickness from about 10 to 100 feet. The bottom of each flow is generally dense, whereas the upper part is glassy lava that is vesicular on scoriaceous. Some of the lava flows are separated by thin layers of sedimentary deposits.

Individual flows contain one or more fracture systems caused by contraction of the lava during cooling; the type of fracture system in any flow depends largely on the chemical composition and temperature of the lava when it was extruded, and on the rate of cooling. Most flows have vertical fracture systems which separate the lava into numerous vertical columns ranging from a few inches to several feet in diameter; this is commonly called columnar jointing. In some flows, cooling fractures are horizontal, which gives the flows a platy appearance; still other flows may have closely spaced vertical and horizontal fractures, which result in a cubical or "brickbat" appearance. Fracture systems enhance the water-bearing properties of the basalt.

At La Butte and in the surrounding hills, the Columbia River Group is deeply weathered. The decomposed basalt forms a thick reddish-brown saprolitic soil strewn with large boulders of weathered lava. The decomposed zone is generally 20–50 feet thick, but in some places, such as in the Tualatin Valley, it may be as much as 200 feet thick (Hart and Newcomb, 1965, p. 17). Similar thicknesses (up to 200 ft) of decomposed basalt extend beneath the valley fill locally.

Incompletely decomposed basalt may contain large boulders that have cores of relatively unaltered fresh lava surrounded by layers of successively more decomposed lava called weathering rinds. Some drillers may refer to this incompletely decomposed basalt as boulders, cobbles, or conglomerate. Similarly, the deep saprolitic soil formed by the completely decomposed basalt usually is logged as red clay by most drillers, some of whom recognize it to be decomposed basalt.

The Columbia River Group in the study area is believed to have been penetrated in three wells. The wells are 3/1W–27R1, about 3½ miles north of Aurora, and 4/2W–8F1 and 4/2W–18L1, about 2 miles north and 1 mile northwest of St. Paul, respectively. Well 3/1W–27R1 entered weathered basalt at a depth of 651 feet and was drilled to a total depth of 1,004 feet without reaching the base of the basalt, indicating that the basalt there is more than 350 feet thick.

Wells 4/2W–8F1 and 4/2W–18L1 penetrated "conglomerates" interbedded with thin layers of basalt and fine-grained sedimentary rocks at depths of 345 and 398 feet respectively (table 6). These deposits collectively are interpreted by the writer to be basalt of the Columbia River Group, some of which has been thoroughly decomposed. The basalt is at least 212 feet thick in well 4/2W–18L1; because the well was logged to a depth of only 610 feet, total thickness of the basalt there is not known.

Well 4/2W–8F1 penetrated 75 feet of "conglomerate interbedded with clay" (probably weathered basalt) before it was abandoned owing to a cave-in.

No other wells in the French Prairie area are known to have entered the basalt of the Columbia River Group, although there has been penetration in a number of wells in adjacent areas where the basalt is nearer the land surface. The basalt probably underlies most of the area, as shown in plate 2, but its depth in most places can only be estimated.

The basalt was extruded upon a surface having a relief of several hundred feet. This geologic formation was also structurally deformed and eroded prior to deposition of overlying rocks. Therefore, the basalt varies greatly in thickness from place to place, and it may be missing at places beneath the study area. Records of the few wells that penetrated the basalt at depth indicate that the top of the basalt is nearest the land surface beneath the southern boundary of the area, and is progressively deeper toward the north. For example, a well (7/3W–18A1; record not included in this report) less than 1 mile south of the south boundary of the study area reportedly penetrated the basalt at a depth of 160 feet, whereas well 3/1W–27R1 in the northern part of the area entered the basalt at a depth of about 651 feet.

The water-bearing properties of the basalt of the Columbia River Group are largely dependent upon the thickness and number of flow layers. Generally, the dense lava flows are relatively impermeable, whereas the interflow zones are moderately to highly permeable. However, such factors as fracturing, weathering, secondary mineralization, and structural deformation greatly affect the permeability of both the flow layers and interflow zones. Because of this, permeability of the Columbia River Group can vary considerably.

Many wells that tap the Columbia River Group in adjacent parts of the Willamette Valley obtain most of their water from several separate interflow zones, and in most, several hundred to more than a thousand feet of drilling was required to obtain sufficient water for irrigation. The three wells that penetrated the basalt in the study area are all more than 400 feet deep (table 5) but obtain little water from the basalt. Wells 4/2W–8F1 and 4/2W–18L1 yielded 200 and 420 gpm (gallons per minute), respectively, but both wells reportedly obtained most of their water from overlying nonmarine sedimentary rocks.

Well 3/1W–27R1, which is 1,004 feet deep, reportedly yielded only 50 gpm, by bailing, with a drawdown of 115 feet. That well penetrated about 350 feet of basalt. According to the driller, the most permeable water-bearing zone was penetrated between the depths of 986 and 1,004 feet. Before that zone was reached, the well yielded only 35 gpm, by bailing, with a drawdown of more than 200 feet. The water from that well was found to contain comparatively large concentrations of certain dissolved mineral constituents (table 7).

SANDY RIVER(?) MUDSTONE

The oldest nonmarine sedimentary rocks of the French Prairie area are predominantly fine-grained rocks deposited during the early(?) Pliocene Epoch on the eroded and folded surface of the Columbia River Group. The thick sequence is believed by the writer to be a southern extension of the Sandy River(?) Mudstone of the Portland area (S. G. Brown, 1963, p. 5–7; Trimble, 1963, p. 26–28; Hogenson and Foxworthy, 1965, p. 21). The Sandy River(?) Mudstone is not exposed in the study area but is believed to have been penetrated in several wells (table 6, logs of wells 3/1W–25K1 and 27R1; 4/1W–23A1, 4/2W–2G1, 8F1, and 18L1; 5/1W–17M2; and 5/2W–1J1). It probably underlies all but a few square miles in the southern part of the area. The nearest mapped exposures of the Sandy River(?) Mudstone are along Abernethy

Creek about 9 miles east of Canby. At Abernethy Creek and in parts of the East Portland area, the formation consists mainly of mudstone, siltstone, claystone, and very fine grained sandstone, with some thin conglomerate beds of local extent (Trimble, 1963, p. 26–28).

Where penetrated by wells in the French Prairie area, the Sandy River(?) Mudstone consists of thick layers of dark-gray to blue clay and shale separated by thin layers of sand and fine gravel, generally less than 5 feet thick. Drill cuttings collected from about the 600-foot depth during the drilling of well 3/1W–27R1 (table 5) consisted of blue to gray siltstone containing very fine quartz grains and abundant mica fragments. The sample was plastic when saturated with water, but after it dried it was hard and broke with concoidal fractures into small cubes.

The thickness of the Sandy River(?) Mudstone varies considerably from place to place. It is about 250–280 feet thick where fully penetrated in wells 4/2W–8F1 and 18L1, which are, respectively, about 1 mile northwest and 2 miles north of St. Paul, and slightly more than 300 feet thick where fully penetrated by well 3/1W–27R1, about 3½ miles north of Aurora (pl. 1). Drillers' logs of wells show that the Sandy River(?) Mudstone thins to the south and pinches out beneath the southern part of the study area. For example, a well about 1 mile south of the study area (not shown on map) penetrated Troutdale gravels directly overlying the Columbia River Group.

The top of the Sandy River(?) Mudstone is about 75 feet above mean sea level at well 4/2W–8F1, about 2 miles north of St. Paul; it is about 120 feet below sea level at well 4/1W–23A1, about 1½ miles south of Aurora; and it is about 165 feet below sea level at well 3/1W–27R1, about 3½ miles north of Aurora (pl. 2). These data indicate that the upper surface of the Sandy River(?) Mudstone has a total relief of about 240 feet beneath the study area. This suggests interfingering of coarser and finer materials of the Sandy River(?) Mudstone and the Troutdale Formation, or that the beds of the Sandy River(?) Mudstone underwent erosion and structural deformation prior to the deposition of the overlying Troutdale Formation.

The stratigraphic position of these rocks (directly overlying the Columbia River Group) and their lithologic character, as described in well logs and noted in the samples from well 3/1W–27R1, suggest that the Sandy River(?) Mudstone of the French Prairie is equivalent to the Sandy River Mudstone of Trimble (1963, p. 26–28). A deep basin of deposition, probably connected to the East Portland area basin, existed in the northern half of the French

Prairie area. This basin received fine-grained materials, mainly from the ancestral Willamette River and its tributaries, at the same time that the Sandy River Mudstone of Trimble was being deposited in the East Portland area.

The Sandy River(?) Mudstone is of low permeability because it is predominantly clay and silt; consequently, it yields water slowly to wells. This was especially evident during drilling of well 3/1W-27R1; the water seeped so slowly from the mudstone that water from another source was needed during the drilling operation.

Layers of fine sand and gravel do occur in the Sandy River(?) Mudstone and have been tapped by wells to which they yield enough water for limited irrigation. Well 4/2W-8F1, for example, reportedly yielded 200 gpm from 14 feet of sand and fine gravel. Well 4/2W-8G1, which had a pumping yield of 200 gpm, received at least part of its flow from sand layers in the Sandy River(?) Mudstone.

TROUTDALE FORMATION

The Sandy River(?) Mudstone is overlain by generally coarse-grained nonmarine sedimentary rocks believed to be an extension of the early Pliocene Troutdale Formation of the Portland area (S. G. Brown, 1963, p. 7; Trimble, 1963, p. 29–36; Hogenson and Foxworthy, 1965, p. 22) and of the Tualatin Valley (Hart and Newcomb, 1965, p. 19). At low-river stage, this formation is exposed in the study area along the channel of the Willamette River; it is not shown on the geologic map because it is exposed in nearly vertical streambanks and is overlain by alluvium. However, the Troutdale Formation has been penetrated by many wells (pl. 2) and is one of the principal water-bearing geologic units in the area.

The nearest surface exposures of the Troutdale Formation outside the study area are about 2 miles east of Canby (fig. 1), as mapped by Trimble (1963). The Troutdale Formation was also mapped by E. R. Hampton (1966) in the Salem–Molalla Slope area as far south as Molalla, where it dips beneath the east boundary of the French Prairie area. Because the formation can be traced by means of well logs from the exposures in the Salem-Molalla Slope area into the French Prairie area, there is little doubt of the continuity of the formation.

Where the Troutdale Formation is exposed at Champoeg State Park, it consists of poorly sorted gravel and thin layers of sand, derived mainly from mafic igneous rocks. The gravels range in size from small pebbles to cobbles several inches in diameter. They are loosely cemented with limonite in a matrix of sand and clay. The unit is deeply weathered and has a generally reddish-brown cast, and thus is easily distinguished from the overlying Willamette Silt and Recent alluvium.

Well logs show that the Troutdale Formation consists mainly of alternating layers of clay, silt, sand, and gravel, and, locally, cemented gravel and conglomerate. The materials were derived largely from andesitic and basaltic rocks and appear to have been deposited mainly by streams entering the area from the south and east. They are generally coarse grained in the southern and eastern parts of the study area and become progressively finer grained to the northwest.

During the Pliocene, the North Santiam River at times flowed through the gap now occupied by Mill Creek southeast of Salem (fig. 1) and deposited materials that now underlie a large buried alluvial fan that extends north from the gap to Gervais. The materials underlying this fan apparently interfinger with older alluvial deposits of the Willamette River on the west and with the materials underlying the coalesced fans of the ancestral Silver, Butte, and Abiqua Creeks. The coarse materials of these alluvial deposits grade into finer grained sediments at the lower ends of the fans; consequently, in the northwest part of the study area these alluvial deposits are not easily distinguished from the underlying Sandy River(?) Mudstone.

Results of mechanical analyses of three lithologic samples from the Troutdale Formation are summarized in table 2 and illustrated in figure 5 (samples 6–8). These three samples were collected from drill cuttings. Consequently, some of the coarser materials may have been broken into fine fragments by the drill bit; also, some of the finer materials may have been washed from the samples prior to collection. However, they were the best Troutdale Formation samples available in the study area. The samples from wells 5/1W–4A1 and 6/3W–26D2 (samples 6, 7) were fairly well sorted and generally ranged in size from medium sand to fine gravel and from fine sand to medium gravel, respectively. The sample from well 5/1W–7E1 (sample 8) was poorly sorted and ranged in size from clay to coarse gravel.

No data on mechanical analyses of materials from the northwest part of the area are shown in table 2 or in figure 5. However, drilling samples of the Troutdale Formation from the depth interval 160–195 feet of well 4/2W–2G1 were analyzed by Edward E. Johnson, Inc., St. Paul, Minn., and found to be almost entirely fine to medium sand. Well 4/2W–2G1 was a test well to determine the desirable slot size for a well screen. Information from the test aided in construction of a production well (4/2W–2G2) drilled during a demonstration at Champoeg State Park.

TABLE 2.—*Weight percentage of particles in lithologic samples collected from wells and auger holes in the French Prairie area*

[Analyses by U.S. Geol. Survey, Hydrol. Lab., Denver, Colo. Particle diameters in millimeters; clay and silt undifferentiated in samples 5–7]

Sample No.	Well or auger hole (A)	Formation	Depth of sample (feet)	Clay	Silt	Sand					Gravel			
				(0.004)	(0.004–0.0625)	Very fine (0.0625–0.125)	Fine (0.125–0.25)	Medium (0.25–0.5)	Coarse (0.5–1)	Very coarse (1–2)	Very fine (2–4)	Fine (4–8)	Medium (8–16)	Coarse (16–32)
1	4/1W-5P(A)	Willamette Silt	17.5	7.7	66.5	23.0	2.6	0.2						
2	4/2W-34R(A)	do	20	6.0	80.4	13.0	.6							
3	5/2W-21J(A)	do	16.5	5.7	62.9	26.2	5.2							
4	6/2W-5N(A)	do	23	6.0	58.8	31.0	4.0	.2						
5	5/2W-22Q1	do	123	11.8		10.4	34.6	36.4	6.4	0.4				
6	5/1W-4A1	Troutdale	135	2.1		1.2	6.9	24.2	18.5	15.8	22.1	9.2		
7	6/3W-26D2	do	140	3.4		3.7	12.6	18.8	13.8	11.3	14.2	12.1	10.1	
8	5/1W-7E1	do	130–135	2.2	6.2	2.7	7.3	16.9	7.6	13.2	17.6	11.0	5.0	10.3

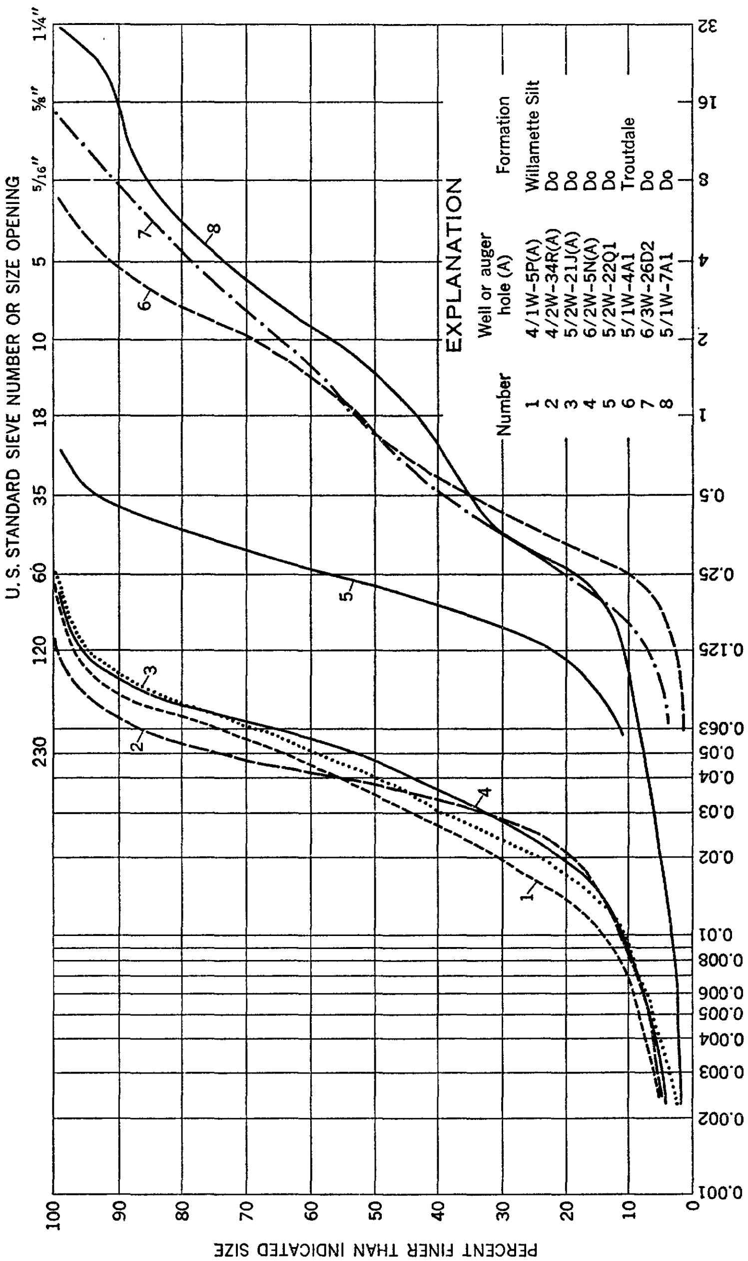

FIGURE 5.—Results of particle-size analyses of lithologic samples from wells and auger holes in the French Prairie area.

The Troutdale Formation varies considerably in thickness throughout the area (fig. 7). It is about 257 feet thick where it was fully penetrated by well 3/1W–27R1 in the northeastern part of the area; the formation is more than 188 feet thick in well 7/3W–11P1 near Keizer in the southern part, although it was not fully penetrated there. However, near St. Paul, in the northwestern part of the area, well 4/2W–18L1 penetrated only a few feet of sand and gravel, believed to be of the Troutdale Formation, before entering finer materials that may be the Sandy River(?) Mudstone; well 4/2W–8F1 penetrated only 3 feet of water-bearing sand, which may be within the Troutdale Formation. Apparently the area northwest of St. Paul was topographically high and received little or no sediment during deposition of the Troutdale Formation, or the area was elevated and considerably eroded following deposition of the Troutdale Formation.

The top of the Troutdale Formation has low relief and, except near St. Paul and La Butte, slopes gently to the northwest (pl. 2). Its altitude at the highest points is about 130 feet, as shown by well 7/2W–7E1 near Keizer and well 4/1W–18C1 near La Butte. Its altitude is only 35 feet at the lowest point in well 4/2W–19M1 south of St. Paul. From this lowest point, the top of the Troutdale Formation rises gently toward the north; the rise may indicate gentle warping.

The Troutdale Formation, originally named by Hodge (1938, p. 873), crops out extensively in the canyons of the Sandy River about 22 miles northeast of the French Prairie area. As originally described, the formation consisted of two units; these were later redefined and named the Troutdale Formation and the Sandy River(?) Mudstone by Trimble (1957). Plant fossils indicate that the Troutdale Formation of Trimble is of early Pliocene age, and the underlying Sandy River(?) Mudstone should probably have the same age assignment (Trimble, 1963, p. 28, 35, and map).

No fossils were found in the Troutdale Formation of the French Prairie area. However, this unit is correlated with the Troutdale Formation of the East Portland area on the basis of its stratigraphic position and general lithologic similarities. The Troutdale differs little in the respective areas except that in the study area it contains few or no quartzite cobbles and pebbles, whereas in the East Portland area it contains considerable quartzite. The lack or presence of a particular rock type is explained by differences of source areas. The Troutdale Formation in the East Portland area was deposited mainly by the ancestral Columbia River, which drained areas underlain by quartzite in parts of eastern Washington, Idaho, and British Columbia, whereas the Troutdale Formation in the French Prairie area was deposited mainly by the ancestral Willamette River and its tributaries, which drained parts of the Cascade Range underlain largely by basaltic and andesitic lavas.

A layer of lava was penetrated in several wells at shallow depths in the northeastern part of the study area (pl. 2). This lava ranges in thickness from a few feet to about 75 feet and is apparently limited in extent. It rests directly on the Troutdale Formation and may be equivalent to the Boring Lava, which ranges in age from late Pliocene to late(?) Pleistocene (Trimble, 1963, p. 36). However, because of its limited extent, it is shown as part of the Troutdale Formation on plate 2.

The source of this lava is not known. It may have entered the area from the northeast (where Boring Lava is exposed) and been deposited as a stream-channel filling. However, it cannot be traced north or east of well 4/1W–10N1 (pl. 1) on the basis of well logs; the basalt may possibly have risen along a fault in the vicinity of Aurora.

The Troutdale Formation is one of the major water-bearing units in the French Prairie area. Most of the large-yield wells in the area tap one or more sand, gravel, or sand and gravel beds in the formation.

Materials that make up the Troutdale Formation have a wide range in grain size. Because of this and other factors, such as compaction and cementation, the formation varies widely in its water-bearing properties. For example, the coefficient of permeability [1] of the five samples collected from the Troutdale Formation ranged from only 28 gpd per sq ft (gallons per day per square foot) for the sample from well 5/1W–7E1 to as much as 2,700 gpd per sq ft for the sample from well 4/1W–16P1 (table 3). The average coefficient of permeability for all five samples was about 1,000 gpd per sq ft. However, the permeability of most aquifers in the formation is probably higher considering that many wells tapping these aquifers have large specific capacities.[2]

The most permeable materials of the Troutdale Formation underlie the southern part of the area, where they are predominantly coarse grained and fairly well sorted. (See fig. 5, sorting curve of sample from well 6/3W–26D2.) Most wells tapping these materials

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[1] The coefficient of permeability can be expressed as the number of gallons per day of water at 60°F that will pass through a cross section of 1 square foot of the aquifer under a hydraulic gradient of 1 foot in 1 foot (R. H. Brown, 1953, p. 846). The field coefficient is the same, except that it is measured under the prevailing temperature.

[2] Specific capacity of a well is the ratio of the yield of the well to the distance the water level in the well is drawn down during pumping; it is usually expressed as gallons per minute per foot of drawdown.

TABLE 3.—*Laboratory analyses data for samples collected from water-bearing strata in the French Prairie area*

[Analyses by U.S. Geol. Survey Hydrol. Lab., Denver, Colo.]

Sample No.	Well or auger hole (A)	Formation	Depth (feet)	Porosity, repacked (percent)	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
1	4/1W-5P(A)	Willamette Silt	17.5	41.2	21.4	[1] 0.08
2	4/2W-34R(A)	do	20	43.6	24.1	[1] .8
3	5/2W-21J(A)	do	16.5	46.9	27.2	[1] 2
4	6/2W-5N(A)	do	23	44.9	28.2	[1] .3
5	5/2W-22Q1	do	123	44.0	32.6	63
6	5/1W-4A1	Troutdale Formation	135	35.4	28.3	620
7	6/3W-26D2	do	140	36.7	28	740
8	5/1W-7E1	do	130-135	33.7	20.9	83
9	4/1W-14C2	do	108-109	37.6	18.2	1,900
10	16P1	do	104	38.7	31.8	2,700
11	4/2W-2M1	do	206-217	41.9	27.0	28
12	6/3W-21R [2]	Recent alluvium	10	38.5	24.7	24,000

[1] Determined by using native ground water.
[2] Collected from wall of gravel pit below annual high ground-water level mark.

generally yield several hundred to more than a thousand gallons per minute, usually with only a few feet of drawdown. Well 6/3W-36Q1, which is believed to be the most productive well in the study area (1962), reportedly has a pumping yield of 1,600 gpm with only 12 feet of drawdown (table 5).

Although the Troutdale Formation that underlies the northeast part of the area contains considerable gravel, it is generally poorly sorted (fig. 5, sorting curve of sample from well 5/1W-7E1) and yields water more slowly to wells. However, wells producing as much as several hundred gallons per minute with less than a hundred feet of drawdown are common in the vicinity of Woodburn and Hubbard. For example, wells 5/1W-17M2 and 17M4, owned by the General Foods Corp., reportedly yielded 1,000 gpm (gallons per minute) with 50 feet of drawdown and 850 gpm with 85 feet of drawdown, respectively. Well 17M4 is one of the few wells in the study area with a well screen.

In the northwestern part of the study area, the Troutdale Formation consists predominantly of alternating layers of sand and clay. Some of the sand layers are fairly well sorted and yield moderate quantities of water to wells, but drawdowns are generally several tens to more than a hundred feet.

Scattered thin layers of gravel, apparently deposited in old stream channels, are interbedded with the sand and clay in the northwestern part of the area. One well tapping such a layer of gravel reportedly produces as much as 1,000 gpm (table 5, well 4/2W-21H1). However, most of the wells produce less than 500 gpm.

WILLAMETTE SILT

The Troutdale Formation and older rocks are unconformably overlain by a thick sequence of silt and very fine sand of late Pleistocene age that directly underlies much of the French Prairie (pl. 2) and adjacent areas in the northern Willamette Valley. The name Willamette Silt was applied to these deposits in the Albany quadrangle by Allison (1953, p. 12) and is also used to refer to them in this report.

The Willamette Silt is exposed along the bluffs of the Willamette River and its tributaries and in roadcuts throughout the study area. The best exposures (as much as about 80 ft thick) are on the north side of the Willamette River near Wilsonville and in an erosional scarp of the Pudding River in the NE¼ sec. 1, T. 4 S., R. 1 W., about 2 miles north of Aurora. Although the unit appears massive, the Willamette Silt is well bedded and most layers are only a few inches thick. Bedding is observable because of faint color differences between the finer and coarser layers of the formation.

The upper 80 feet or so of the Willamette Silt consists mainly of tan to reddish-brown silt of generally uniform texture with thin interbeds of clay and very fine sand. Logs of wells penetrating the formation indicate that particles become progressively coarser with depth and are mainly fine sand near the base.

The particle-size distribution of five samples of Willamette Silt collected at widely separated sites in the French Prairie area are shown in figure 5 and summarized in table 2 (samples 1–5). Samples 1–4 were collected with an orchard auger at depths of 16.5–23 feet; sample 5 was collected from drill cuttings (well 5/2W–22Q1) at a depth of about 123 feet. As figure 5 shows, the four auger samples had almost identical sorting curves and consisted of particles that ranged from 0.002 to about 0.250 millimeters in diameter, whereas the particles in sample 5 ranged from about 0.063 to about 0.750 millimeters in diameter.

Table 2 shows the distribution of the particles by various size classifications in percentage by weight of the total sample. Combined weight of the silt and very fine sand particles amounted to about 89 percent of the total weight in samples 1, 3, and 4, and 93 percent in sample 2. In contrast, the amount of silt and very fine sand in sample 5 was about 22 percent of the total weight, whereas the fine and medium sand was about 71 percent. However, some of the finer materials may have been washed away from sample 5 prior to its collection.

The Willamette Silt ranges in thickness in the area from 0 to about 130 feet; the unit is thickest where fully penetrated by well 3/1W–35N1. In most places, however, the formation is 75–100 feet thick (pl. 2).

The Willamette Silt was deposited in a lake that inundated the Willamette Valley in early Wisconsin (late Pleistocene) time. Low-

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ry and Baldwin (1952, p. 20) postulated that the ponding was caused by a eustatic rise in sea level, whereas others believe that it may have been caused by damming of the Columbia River downstream from Portland. Stream aggradation as a "damming" agent seems not to have been seriously considered in earlier discussions of late Pleistocene geology of the lower Willamette Valley, although it was mentioned by Treasher (1942, p. 13) and Trimble (1963, p. 64). The Willamette River may have been impounded to an altitude of more than 300 feet by alluvial deposits of the Columbia River. This gravelly alluvium underlies remnants of the 300-foot terrace noted by Treasher (1942) and probably functioned somewhat as he suggested; however, after advancing this idea, he rejected it (Treasher, 1942, p. 13). During the ponding, the water surface in the Willamette Valley rose to an altitude of more than 300 feet, and the silt was deposited to nearly that same altitude. Above the 200-foot level on La Butte and in the hills surrounding the study area, the silt is difficult to distinguish from the weathered Tertiary rocks that underlie it.

Fragments of metamorphic and crystalline igneous rocks foreign to the Willamette River drainage overlie the Willamette Silt throughout the French Prairie and adjacent areas. (See Allison, 1935.) Rocks of these types, however, are exposed extensively in headwater areas of the Columbia River and were probably rafted into the Willamette Valley on floating ice or in roots of trees carried by floodwater of the Columbia River. The rock fragments generally have irregular shapes and range in diameter from about an inch to about 3 feet. The largest erratics seen in the French Prairie area during this investigation were granite boulders about 2 feet in diameter.

The Willamette Silt of this report includes sedimentary deposits (except the Recent alluvium) that overlie the Troutdale Formation. The upper part of the Willamette Silt in the study area is the same age (Wisconsin) as the Willamette Silt in the type area in Irish Bend on the Willamette River, about 40 miles south of Salem (Allison, 1953, p. 12). However, the lower sand sequence, which in this report has been included in the Willamette Silt, may be somewhat older than Wisconsin.

As is common with most fine-grained materials, the Willamette Silt has relatively high porosities but low permeabilities. The porosities of five partly disturbed samples collected in the study area ranged from 41.2 to 46.9 percent and averaged about 44 percent. The coefficients of permeability of the same five samples, however, ranged from only 0.08 to 63 gpd per sq ft (table 3).

The laboratory determinations for the specific yield[3] of the five samples in table 4 averaged about 27 percent. This value is probably higher than the actual field specific yield of the silt because a centrifuge was used in the laboratory to accelerate drainage from the samples and the results for specific yield produced by the Hydrologic Laboratory are said to be equivalent to 100 years of drainage. Consequently, the average field specific yield of the samples may be as low as about 20 percent (p. 64).

Most of the wells tapping the Willamette Silt are old dug wells that have been replaced by deeper drilled wells. Those dug wells still in use yield sufficient water for stock and moderate household requirements, but yield water much too slowly to sustain large continual drafts such as are needed for irrigation.

The lower part of the formation, where it consists mainly of fine to medium sand, probably would yield moderate quantities of water to carefully constructed wells equipped with properly designed and fabricated well screens.

YOUNG ALLUVIAL AND LACUSTRINE DEPOSITS

Flood plains of the Willamette River and its tributaries in the study area are underlain by Recent alluvial deposits (pl. 2). The alluvium appears to lie directly on the Willamette Silt or, where the Willamette Silt has been removed by erosion, on the Troutdale Formation.

Alluvium of the Willamette River consists of alternating sand and gravel layers blanketed by several feet of silt. The unit has a maximum thickness of about 90 feet near Newberg but in most places is probably not more than about 50 feet thick.

The gravels were derived largely from rocks of the Cascade Range and consist mainly of basalts and andesites, with minor amounts of rhyolite and other igneous rocks. These well-rounded and fairly well sorted gravels range in size from small pebbles to 6-inch cobbles.

Alluvium of Recent age at Keizer-Mission Bottom (pl. 2) rests directly on gravel of the Troutdale Formation, and the two units are difficult to distinguish in well logs. The younger unit, however, appears in well logs to be generally less consolidated. Recent alluvium probably extends to a depth of about 40 feet in the vicinity of Keizer-Mission Bottom (fig. 5) and has been excavated to a depth of 20 feet in gravel pits.

Downstream from Keizer-Mission Bottom, the alluvium apparently becomes progressively finer grained and thicker. Wells 3/2W–

[3] Specific yield of a water-bearing rock unit is the ratio of the volume of water that will drain from the rock unit by gravity to its own volume; it is usually stated as a percentage.

29F1 and 29F2, which are on the flood plain near Newberg (pl. 1), each reportedly penetrated 88 feet of sand and gravel that is believed to be Recent alluvium of the Willamette River.

Alluvium that underlies flood plains of the Pudding River and smaller streams in the French Prairie area consists largely of reworked silt; it is generally fine grained and contains little or no gravel. Along these streams the alluvium is probably not more than about 30 feet thick.

Lake Labish channel is somewhat higher in altitude than the alluvial plains of the other streams in the study area and, according to J. L. Glenn, U.S. Geological Survey (oral commun., 1964), is filled to a depth of about 20 feet by peaty materials, which are probably underlain by sand and gravel. The total section is probably no more than 30 feet thick and in some places probably lies directly on the Troutdale Formation (fig. 7).

Few wells are known to tap the young alluvium that underlies Lake Labish and the alluvial plains of the Pudding River and smaller streams. There is currently little need for domestic supplies in those localities. Most of the water used for irrigation and stock is pumped directly from the streams. Although little is known of the water-bearing properties of Recent alluvium in the flood plains of the Pudding River and smaller streams, those materials are probably of low permeability. The peaty material that underlies Lake Labish also appears to be of low permeability. However, water percolating through this material from adjacent rock units helps to sustain the flow of Lake Labish Ditch, which is heavily pumped during the irrigation season.

In contrast to the alluvium that underlies Lake Labish and the flood plains of the Pudding River and smaller streams, the Recent alluvium of the Willamette River is generally very permeable and yields water readily to wells.

A gravel sample from the wall of a gravel pit in the SE1/4SE1/4 sec. 21, T. 6 S., R. 3 W., had a porosity of 38.5 percent and a coefficient of permeability of 24,000 gpd per sq ft (table 3, sample 12). A particle-size analysis was not made of that sample, but the gravel was mostly coarse to very coarse and fairly well sorted. Downstream from the gravel pit, the alluvium apparently becomes finer grained but has high permeability. For example, well 3/2W–29F1, which taps the alluvium across the Willamette River from Newberg, reportedly yields 750 gpm with no measurable drawdown.

The average reported pumping yield of 100 representative irrigation wells in the Willamette River flood plain was about 480 gpm in 1960. The specific capacities of those wells ranged from about

4 to as much as 700 gpm per foot, and averaged about 100 gpm per foot of drawdown.

SUMMARY OF GEOLOGIC AND PHYSIOGRAPHIC HISTORY

The geologic history of the French Prairie area can be traced back to late in the Oligocene Epoch. During that time, much of the northern Willamette Valley area was beneath the sea and received several thousand feet of generally fine-grained sediments. The sediments were largely tuffaceous silt and sand derived from explosive volcanic vents in the ancestral Cascade Range to the east. These are the rocks referred to as marine sedimentary rocks in this report.

By early Miocene time, the Oligocene marine sedimentary rocks were folded and uplifted, the sea receded, and a period of erosion followed, during which a landscape of moderate relief was carved.

Later, during the Miocene Epoch, lava erupted along fissures and flowed over much of the eroded surface of the Oligocene rocks in what is now the northern part of the Willamette Valley. The lava (Columbia River Group) was extruded in a number of separate flows, some of which were followed by periods of weathering, erosion, or sedimentary deposition. Aggregate thickness of the combined flows is about a thousand feet in several parts of the northern Willamette Valley (Hogenson and Foxworthy, 1965, p. 32); because the basalt was deposited on an eroded surface having moderate relief, it varies considerably in thickness. It is as much as 350 feet thick beneath the French Prairie area. The exact source of the basalt is not known, but east of French Prairie the flows appear to have entered the lower Willamette Valley area from the east.

During late Miocene or early(?) Pliocene time, there was another period of deformation during which the lava and marine sedimentary rocks were folded into a broad northeast-trending syncline—the Willamette Valley syncline. The axis of the syncline probably is roughly along a line from Salem to Wilsonville.

As the syncline deepened, an inland basin was formed whose lowest parts received several hundred feet of generally fine-grained sediments (Sandy River(?) Mudstone) derived from soils on hills surrounding the basin. Simultaneously, alluvial fans and (or) deltas composed of gravel and sand (Troutdale Formation) were being built at the edges of the basin so that the Sandy River(?) Mudstone and coarser materials of the Troutdale Formation interfingered at the edges of the basin. As the basin was filled, alluvial deposits at the mouth of the tributary streams along the front of the Cascade Range at the eastern edge of the basin spread westward across the finer grained Sandy River(?) Mudstone. For the most part, these deposits were in coalescing fans in the southern part and along the eastern margin of the study area. The alluvium grades into finer grained lacustrine-type deposits toward the northwest.

By late Pliocene time, the basin was nearly filled and parts of the area were eroded, whereas other parts continued to receive detritus from streams draining the Cascade and Coast Ranges. Some of the Troutdale Formation was removed during that period of erosion, leaving a surface of low relief.

At the close of the Pliocene or during early Pleistocene, there were probably additional orogenic adjustments in the northern Willamette Valley. Fissures were opened, forming conduits for renewed volcanic activity. The volcanic activity was most widespread north and east of the French Prairie area, but at least one flow, probably a stream-valley filling, did enter the area in the vicinity of Aurora, where it has been penetrated in several wells.

The lower Willamette Valley was inundated several times during the Pleistocene. At one time, the water level in the valley rose to an altitude of more than 300 feet. This occurred during the Wisconsin Interglaciation (late Pleistocene). The Willamette Silt was carried into the resulting lake by the floodwaters of the Columbia River and accumulated to a thickness of more than a hundred feet. Exotic rock fragments, some of which are more than 3 feet across, were floated in on blocks of ice or in the roots of large trees and are found randomly scattered atop the Willamette Silt.

As the water receded from the valley near the close of the Pleistocene Epoch, the Willamette River and its tributaries began sculpturing the present landscape. The Willamette Silt was easily eroded by the Willamette River and its tributaries, and those streams became entrenched as much as 80 feet below the main valley plain.

The Willamette River formerly flowed through the channels now partly occupied by Lake Labish Ditch and the Pudding River but changed to its present course by the close of the Pleistocene or early in the Recent Epoch. The cause of abandonment of the Lake Labish channel is not known, but it may have been structural uplift in the vicinity of Mount Angel, or perhaps a change in course resulting from extensive local flooding within the northern Willamette Valley.

At Oregon City, the Willamette River crosses a structural high, formed of basalt, that acts as a natural dam, the crest of which is the base level for the Willamette River upstream from the falls caused by the high. Resistance of the basalt to erosion, coupled with the continued slow rise of the structural high, has prevented entrenchment of the Willamette River in the French Prairie area; therefore, the river and its larger tributaries have carved rather broad plains underlain by deposits of Recent alluvium upstream from the high. Champoeg, Mission, Mill, and other small creeks draining French Prairie apparently began, and presently act, as ground-water drains. These streams are currently eroding headward, dissecting French Prairie.

WATER RESOURCES

THE HYDROLOGIC SYSTEM

The various courses that water takes over and through the earth from the time it falls as precipitation until it again reaches the atmosphere through evaporation and transpiration constitute the hydrologic cycle. The hydrologic system in the French Prairie area is largely controlled by the major elements of the hydrologic cycle of the northern Willamette Valley. Figure 6 illustrates the hydrologic cycle of the French Prairie area.

Water enters the area mainly as precipitation that falls on the area; some enters as underflow from the south and as surface flow in the Willamette and Pudding Rivers at high-river stages. Also, some water is piped into the area from adjacent streams for irrigation. Water leaves the area mainly by evapotranspiration and through seeps and springs along the major streams and their tributaries.

Part of the water that falls in the French Prairie area evaporates from soil and from surface-water bodies or is transpired by plants, and part runs off into streams. The precipitation that is not inter-

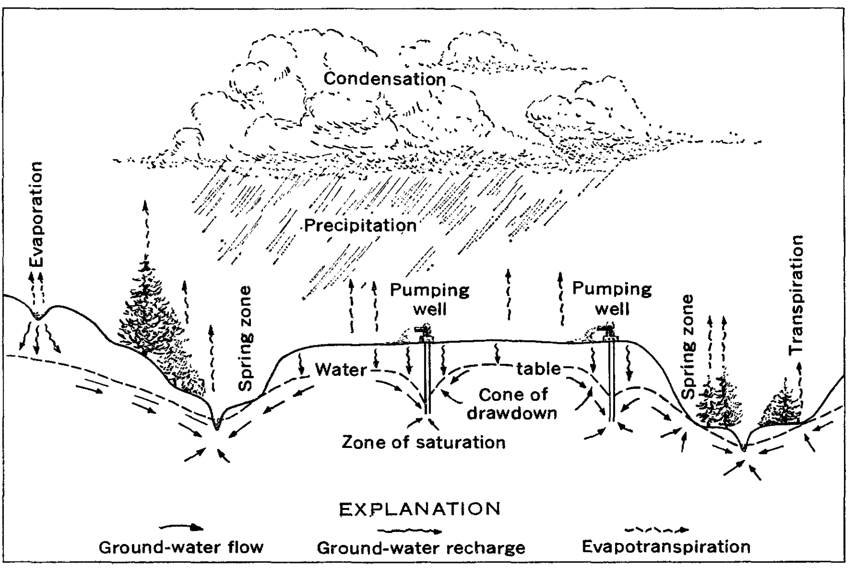

FIGURE 6.—Hydrologic cycle of the French Prairie area.

cepted by evapotranspiration or does not leave the area as storm runoff eventually percolates to the zone of saturation.

The ground-water body acts as a huge equalizing reservoir that receives replenishment mainly during the wet season and sustains the flow of streams during the dry season. As water recharges the reservoir, the water table (surface of the zone of saturation) rises and the hydraulic gradient steepens toward points of discharge, thereby increasing the rate of discharge through seeps and springs. As long as recharge exceeds discharge, as it generally does during late fall and early winter, ground-water storage increases. By spring, however, discharge nearly equals recharge, owing mainly to the steepening of gradients caused by the rising water table, and additional recharge does not increase ground-water storage, or increases it only slightly.

Ground water continues to discharge through seeps and springs throughout the year, even though recharge decreases markedly at the end of the rainy season (usually by May). Consequently, during the summer, discharge (increased somewhat by higher evapotranspiration rates) exceeds recharge, and the water table declines, reflecting a decrease in storage.

In the alluvial deposits along the major streams, there is a seasonal interchange of surface and ground water. During peak runoff of the Willamette and Pudding Rivers, some water percolates into the alluvium in the flood plains of those streams; as the stream levels decline below the adjacent water table, ground water percolates back into the channels.

Estimates of the annual amounts of ground-water recharge and discharge in the French Prairie area and estimates of the ground-water storage capacity and seasonal changes of ground-water storage are given later in this report (p. 46–65).

SURFACE WATER

STREAMFLOW

To record the streamflow in the Willamette Valley, the U.S. Geological Survey maintains gaging stations at various points along the Willamette River and its principal tributaries. In and near the French Prairie area, gaging stations are maintained on the Willamette River at Salem and at Wilsonville and on the Pudding River near Mount Angel and at Aurora (pl. 1). The streamflow records collected at these and other gaging stations in the Willamette River drainage basin are compiled and published in the U.S. Geological Survey Water-Supply Paper series entitled "Surface-Water Supply of the United States, Part 14, Pacific Slope Basins in Oregon and the Lower Columbia River Basin." Some of the data compiled in these reports for the Willamette and Pudding Rivers are presented in figures 7, 8, and 9.

WILLAMETTE RIVER

The average annual runoff measured at the Willamette River station at Salem, which records discharge from an area of about 7,280 square miles, was about 17 million acre-feet during the period 1925-61, but the total runoff varied considerably from year to year. The runoff was less than 10 million acre-feet in 1944 and about 27 million acre-feet in 1950 (fig. 7). In general, the years of greatest runoff of the river correspond to years of greatest recorded precipitation at Salem.

At Wilsonville, about 50 river miles downstream from Salem, the average annual runoff of the Willamette River was about 21.5 million acre-feet during the period 1948–61.[4] This was about 1.7 million acre-feet greater than the average annual runoff recorded at Salem during the same period of record. Between Salem and Wilsonville, however, the river drains an additional 1,120 square miles, including

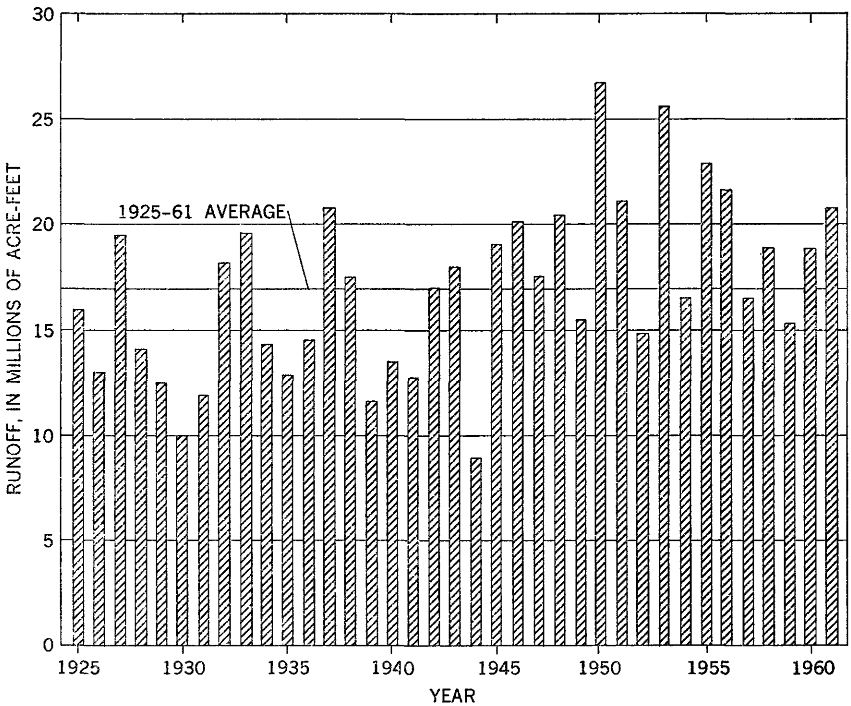

FIGURE 7.—Annual runoff of Willamette River at Salem, 1925–61.

[4] River stage-discharge relations of the Willamette River at Wilsonville during low, medium, and, occasionally, high flow are affected by variable backwater from a dam at Oregon City, about 12 miles downstream; discharge records collected at Wilsonville are adjusted to cancel out these backwater effects.

the drainage areas of the Yamhill River, Mill Creek, and much of the French Prairie area.

The gain in flow of the Willamette River between Salem and Wilsonville is attributed mainly to inflow from Mill Creek and the Yamhill River. Streamflow measurements of those two streams indicate that they have contributed an average of about 1 million acre-feet a year to the Willamette during the period 1948–61; the remaining 0.7 million acre-feet was derived largely from direct ground-water seepage to the river and from smaller tributary streams, such as Champoeg and Mission Creeks, which are fed almost entirely by ground water.

During the period 1949–62, average monthly runoff of Willamette River at Salem ranged from about 352,000 acre-feet in August to nearly 3 million acre-feet in January; at Wilsonville, it ranged from about 374,000 acre-feet in August to about 3.4 million acre-feet in January (fig. 8). Comparison of the average monthly runoff at those stations shows an average gain in flow between Salem and Wilsonville each month of the year. The average gain in flow between the two stations during August, when runoff is generally lowest, was about 22,300 acre-feet, or 6 percent of the average August runoff measured at Wilsonville; the average gain during January was more than 423,000 acre-feet, or about 12 percent of the average January runoff at Wilsonville.

The June to October gain in flow of the Willamette River between Salem and Wilsonville may be attributed almost entirely to ground-water seepage into the river and its tributaries, but the November to May gain in flow is attributed to both ground-water inflow and direct surface runoff.

PUDDING RIVER

Gaging stations are maintained on the Pudding River near Mount Angel and about 11 miles downstream at Aurora (pl. 1). Above the gaging station near Mount Angel, the river drains about 204 square miles; between Mount Angel and Aurora it drains an additional 275 square miles. Principal tributaries to the river between the two gaging stations are the Little Pudding River and Butte Creek.

At the gaging station near Mount Angel, the average annual runoff of the Pudding River is about 515,500 acre-feet (24 yr of record); at Aurora it is about 882,500 acre-feet (35 yr of record). Like that of the Willamette River, the annual runoff of the Pudding River varies considerably from year to year; at the Aurora station, it was less than 300,000 acre-feet in 1941 and more than 755,000 acre-feet in 1956.

Seasonal variation in flow was greater for the Pudding River than for the Willamette River during the period 1949–62. Average

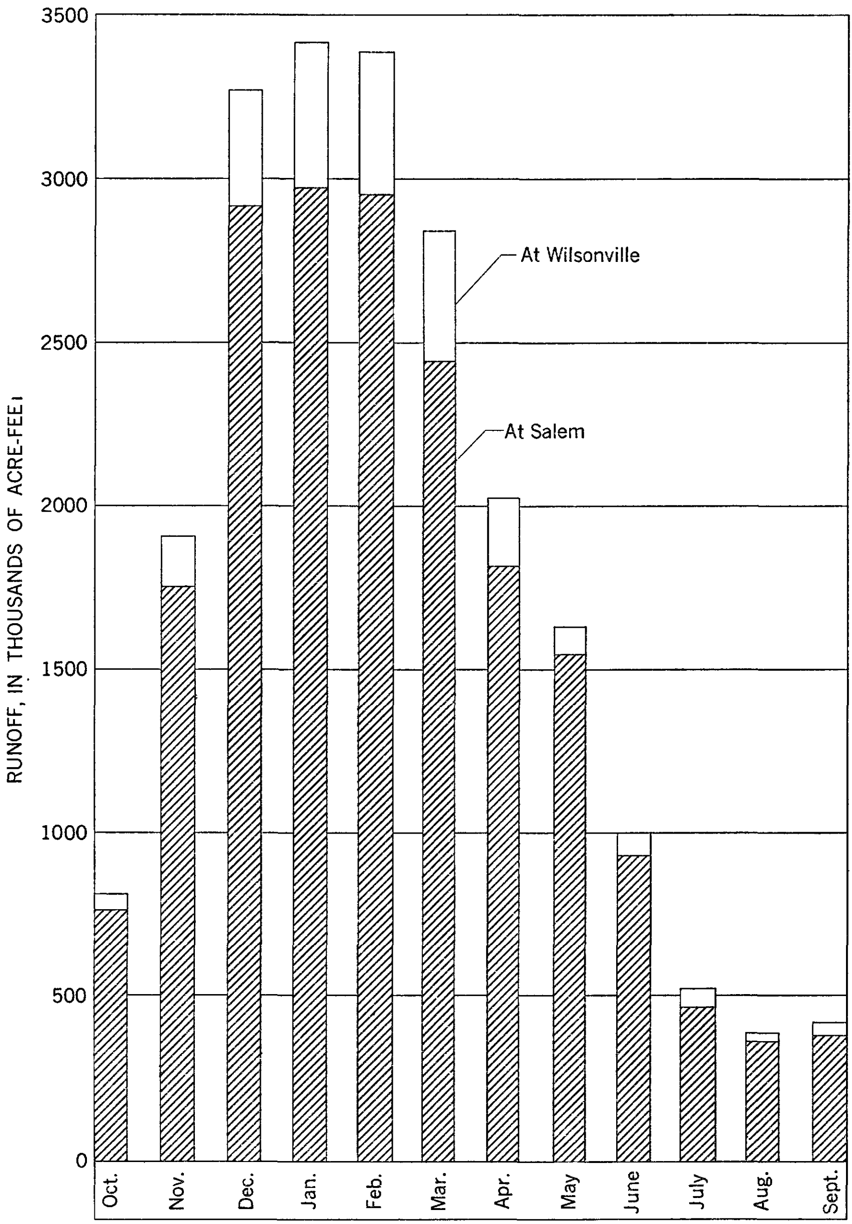

FIGURE 8.—Average monthly runoff, in acre-feet, of Willamette River at Salem and Wilsonville, 1949–62.

monthly runoff of Pudding River near Mount Angel ranged from about 1,850 acre-feet for August to about 102,600 acre-feet for January; at Aurora it ranged from about 4,000 acre-feet for August to nearly 188,000 acre-feet for January (fig. 9).

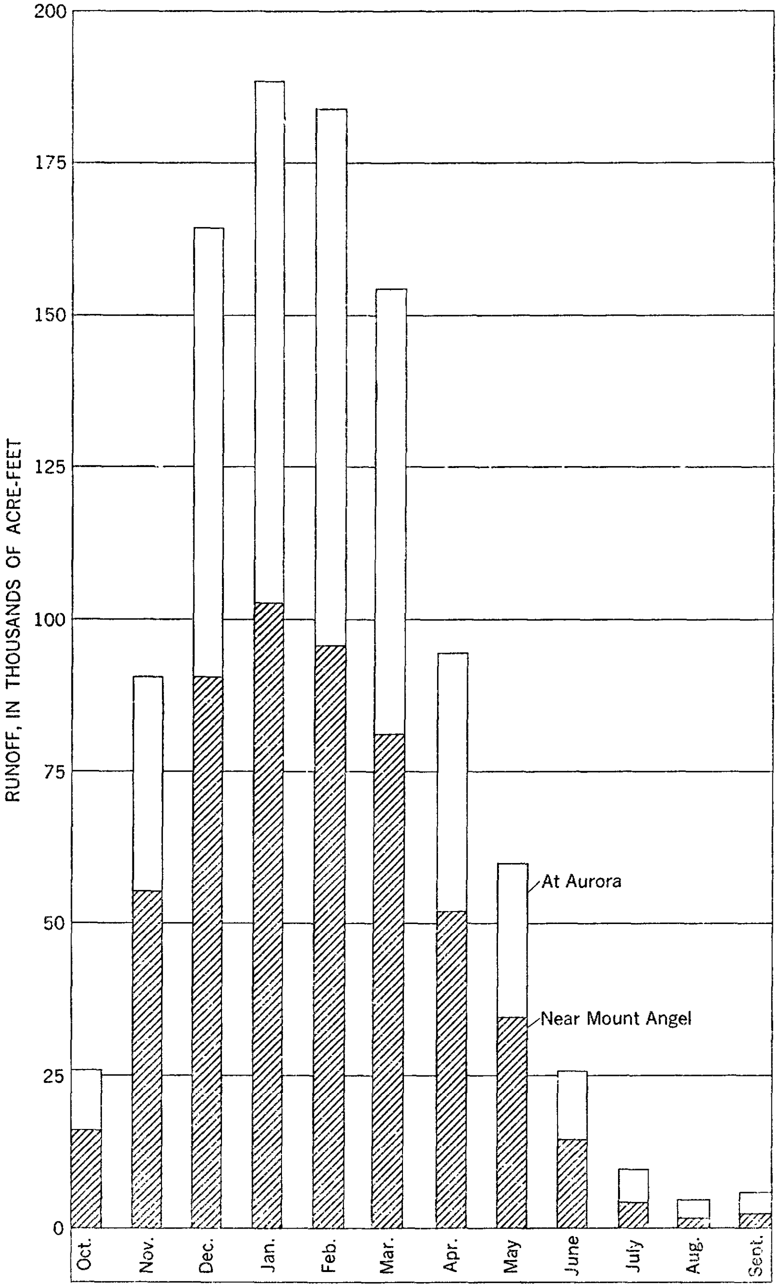

FIGURE 9.—**Average monthly runoff, in acre-feet, of Pudding River near Mount Angel and at Aurora, 1949–62.**

The total annual gain in flow of the Pudding River between Mount Angel and Aurora, as well as the gain in flow during the wetter periods, is largely the result of direct surface runoff from the intervening part of the drainage basin. During the wetter months—November–March (fig. 5)—probably more than 75 percent of the gain (fig. 9) is derived from small tributary streams that carry direct surface runoff and ground water into that reach of the river. The large percentage gain during those months is not surprising because the area draining to that reach of the river is larger than the drainage area upstream from the Mount Angel station.

The overland runoff part of the gain is derived largely from the eastern side of the stream, where the precipitation is greater and the drainage is more fully integrated. For example, in 1960 overland runoff between the two stations averaged about 20 inches, but probably less than 10 inches came from French Prairie. (See p. 54.)

During July, August, and September, the total gain is smaller, but the percentage gain in flow between the stations is larger. During the period 1949 to 1962, the average total gain for these 3 months was at least twice the flow at the Mount Angel station, even though runoff is usually negligible during this time of year and evapotranspiration losses from the stream are great. The writer attributes the gain in flow during July, August, and September almost entirely to ground-water discharge to that reach of the river; the amount of gain is used as a factor in estimating the volume of ground water discharged annually through seeps and springs from the French Prairie area. (See "Ground-Water Discharge" section, p. 51.)

SMALLER STREAMS

No flow measurements were made of the Little Pudding River and the smaller streams that originate within the study area. However, these streams drain into either the Willamette or Pudding Rivers and almost all their combined flow is measured in the total flow of the Willamette River at Wilsonville and of the Pudding River at Aurora. The flow of the individual streams is small in comparison with that in the Pudding River, and it varies considerably throughout the year.

Nearly all the smaller streams that drain the French Prairie flow throughout the year at their lower ends but cease to flow at their upper ends during late summer as the water table declines.

UTILIZATION OF SURFACE WATER

The Willamette River is used primarily for navigation and for irrigation of adjacent farmland. The Pudding River and smaller streams in the area are too small to be used for navigation but are used for irrigation and stock watering.

No tabulation was made of the volume of water pumped for irrigation from the Willamette River and its tributaries. It is estimated, however, that approximately 1,500 acres of land in the study area is irrigated from these streams. This is mainly pastureland, requiring as much as 26 inches of water each year (Becker, 1953, p. 16) ; therefore, the volume of surface water applied may be about 3,000 acre-feet a year.

GROUND WATER

Ground water is water under hydrostatic pressure that fills interstices in the rocks of the earth's crust. In the sedimentary deposits that underlie the French Prairie area, the interstices are between individual particles of clay, silt, sand, and gravel; in the older consolidated rocks they may be joint crevices and, as in the Columbia River Group, open vesicles. All saturated rocks in the area may collectively constitute a ground-water reservoir. Not all rocks yield water readily, however, and only those that will yield appreciable quantities of water to wells and springs are called aquifers.

Ground water in most shallow aquifers in the French Prairie area is unconfined; no confining rock layers retard the upward movement of the water during filling of the reservoir. Locally, however, some deeper aquifers are confined. Upward movement of ground water in those aquifers is retarded by confining rocks—that is, rocks of low permeability. Consequently, water in the confined aquifer is under a pressure greater than that of the atmosphere and will rise in wells tapping the confined aquifers above the base of the confining rocks.

GROUND-WATER SUBAREAS

In order to more conveniently discuss the ground water of the French Prairie area in subsequent sections of this report, the area was subdivided into three subareas, largely on the basis of the type of rock materials penetrated by wells and the availability of ground water. The subareas are (a) the Willamette River flood plain, (b) the Salem-Aurora subarea, and (c) the St. Paul-Donald subarea (fig. 10).

The Willamette River flood-plain subarea consists of the flood-plain segments of the Willamette River within the study area; these segments include Keizer-Mission Bottom, which covers about 23 square miles, and several smaller downstream segments which, combined, cover about 15 square miles. Nearly all the wells in the Willamette River flood plain tap Recent alluvium of the Willamette River and obtain moderate to large quantities of water at depths of less than 50 feet. The average specific yield of 100 irrigation wells in the subarea was about 100 gpm per foot of drawdown.

The Salem-Aurora subarea covers most of the southern half of French Prairie. Its northern boundary is an arbitrary line extending roughly from a point about 4½ miles west of Gervais to Aurora (fig. 10). The south and east boundaries are the limits of the study

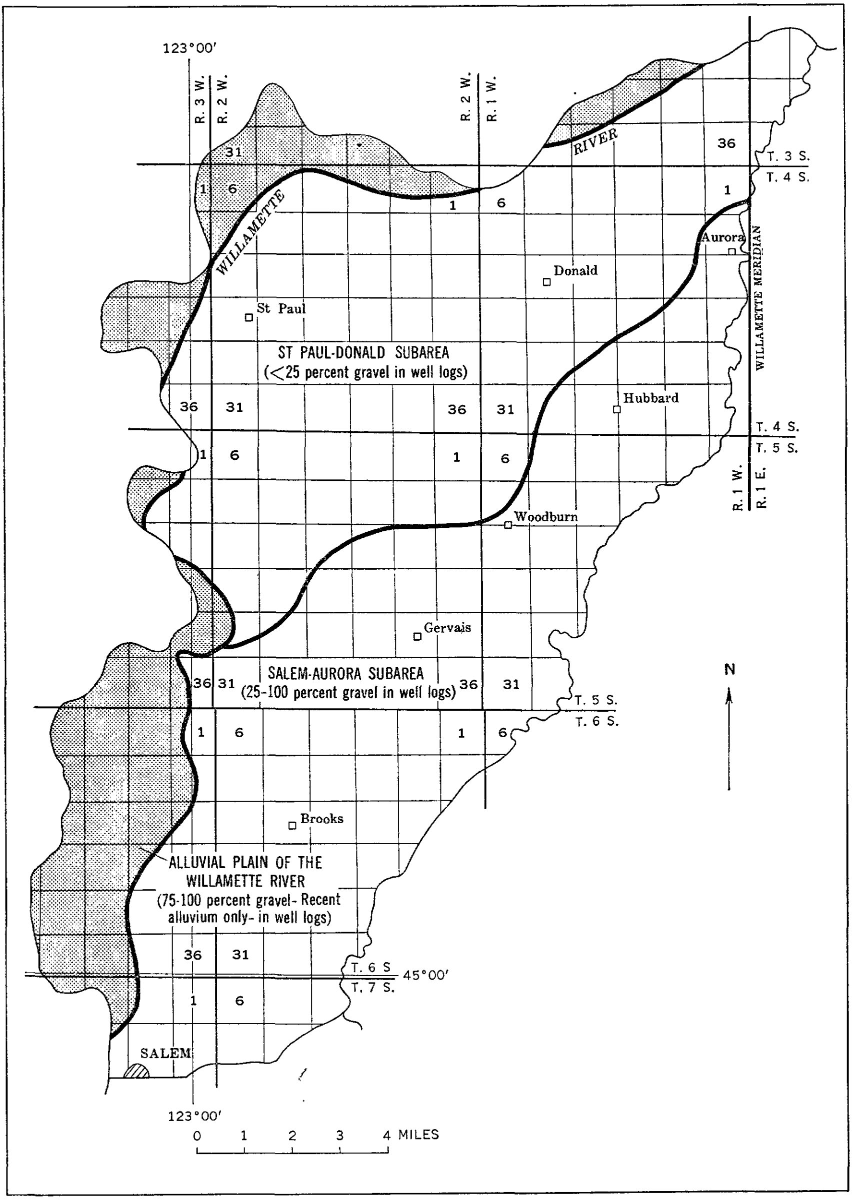

Figure 10.—Ground-water subareas delineated by the amount of gravel reported in logs of wells tapping the nonmarine sedimentary deposits.

area. This subarea is separated from the St. Paul-Donald subarea to the north on the basis of differences in the amount of gravel reported in logs of wells that tap the Troutdale Formation. The sedimentary deposits that underlie the Salem-Aurora subarea extend beyond the southern and eastern boundaries of the study area. These deposits consist largely of the alluvial-fan materials in the Troutdale Formation, which, in this subarea, contain considerable gravel. Well logs show 25–100 percent of the materials to be coarse gravel or gravel and sand for depths ranging from about 100 to 200 feet in this subarea. Most of the wells yield moderate to large quantities of water, but the specific capacities of those wells are generally lower than the specific capacities of wells in the Keizer–Mission Bottom district. For example, the specific capacities of 176 wells in the Salem-Aurora subarea averaged about 20 gpm per foot of drawdown.

The St. Paul-Donald subarea covers most of the northern half of French Prairie. It is underlain to depths as great as 650 feet by principally fine-grained lacustrine sediments. Although some well logs in this subarea show up to 25 percent gravel, or sand and gravel, most show no gravel. Also, when gravel is reported, it is usually described as fine or very fine in size. Because finer grained sedimentary deposits predominate in this subarea, water is yielded more slowly to wells, and specific capacities of the wells are generally lower than in the other two subareas. The average specific capacity of 106 wells was only about 10 gpm per foot.

WATER-TABLE AND WATER-LEVEL FLUCTUATIONS

Plate 1 shows the configuration of the water table as it was in early spring of 1960 and, again, in the fall of that year. For the most part, the water table has the shape of a broad mound, with steeply sloping sides dissected by deep, narrow ravines around the margins. The water table is very similar in shape to the land surface, except that relief of the water table is more subdued. It is flat beneath areas where the land surface is flat, and it slopes steeply beneath areas where the land surface slopes steeply.

The water table changes very little in overall shape as it fluctuates during the year. However, its shape is modified locally by cones of depression produced by seasonal pumping of wells. (See fig. 6.) During 1960, the overall fluctuations of the water table ranged from about 5 feet in the alluvial plains of the Willamette River and its larger tributaries to about 20 feet in the center of French Prairie (pl. 2).

Movement of ground water is generally at right angles to the contours of the water table; water flows downgradient toward the nearest stream or other point of discharge. In the study area, therefore, the general movement of the ground water is radially outward from the areas enclosed by the highest contours of the water table (west of Gervais and east of St. Paul) to the Willamette and Pudding Rivers and Lake Labish Ditch. Where the deeply incised streams that flow over the northern half of French Prairie have intersected the water table, the principal component of flow is toward those streams.

Water levels in wells indicate the height of the water table and fluctuate largely in response to changes in ground-water storage caused by pumping, natural discharge, and recharge. Other phenomena, such as earthquakes, tides, and changes in atmospheric pressure, can also cause ground-water levels to fluctuate, but fluctuations caused by such phenomena have not, knowingly, been observed in the study area. Figures 11 and 12 show the fluctuations of water levels in seven representative observation wells in the French Prairie area.

Figures 11 and 12 show that the ground-water levels in the study area are generally highest during the period January–May. During this period, the ground-water reservoir is being filled to near capacity and recharge from the late winter and early spring rains nearly equals natural discharge from the reservoir. However, by June, the seasonal precipitation decreases markedly, whereas discharge from the reservoir continues, accelerated by increased pumping withdrawal and use by vegetation. This causes a steady decline in the ground-water levels during the summer.

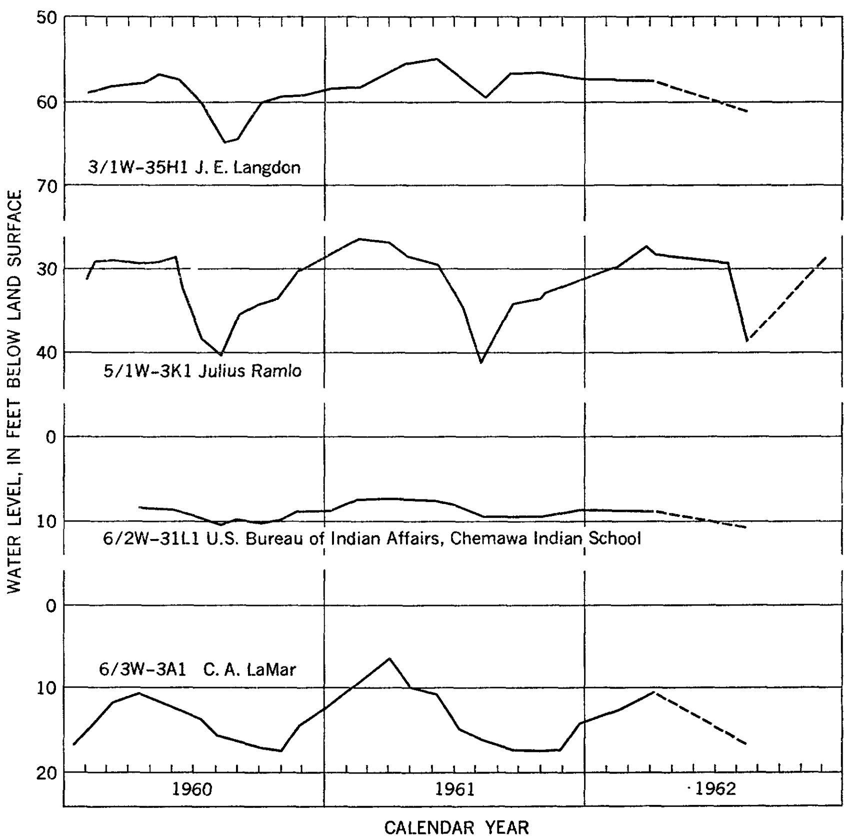

FIGURE 11.—Hydrographs of wells in the French Prairie area, 1960–62.

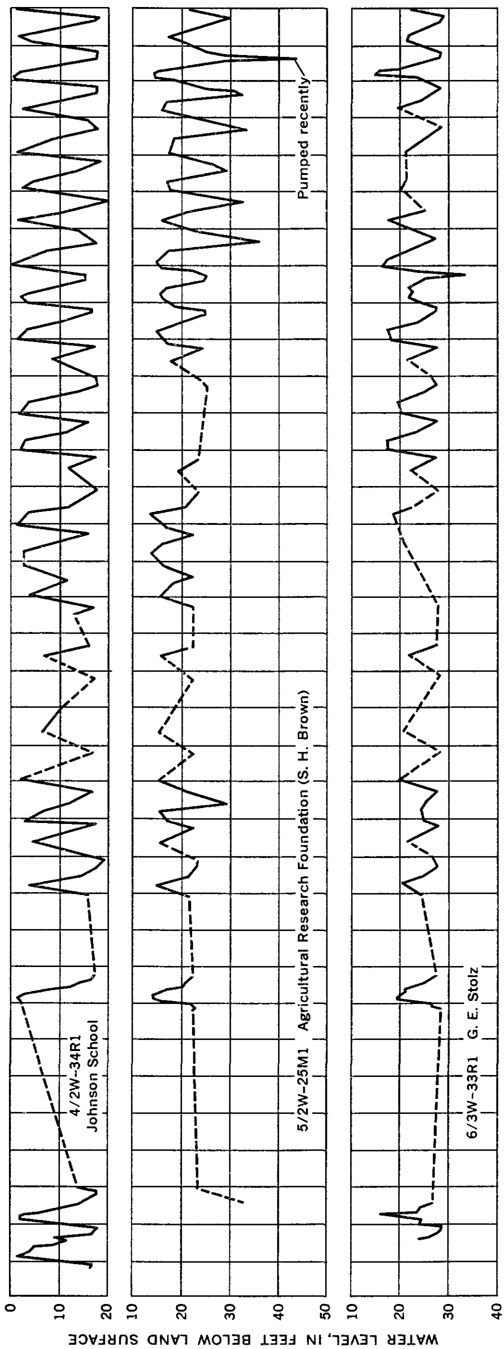

FIGURE 12.—Hydrographs of wells in the French Prairie area, 1928–62.

Ground-water levels in most observation wells begin to decline at about the same time each year (May or June). Levels in wells on the main valley plain decline much more rapidly than levels in wells in Lake Labish and on the flood plain of the Willamette River. For example, the levels in wells 3/1W-35H1 and 5/1W-3K1, near the north end of French Prairie, are generally at a seasonal low by August, whereas the levels in wells 6/2W-31L1 (in Lake Labish) and 6/3W-3A1 (on flood plain of the Willamette River) do not reach a seasonal low until about October (fig. 11). The reason for the lag in water-level decline is that the ground water beneath Lake Labish and the flood plain of the Willamette River is constantly being replenished during the summer by ground water moving from the center of the study area toward Lake Labish Ditch and the Willamette River. The comparatively small amplitude in seasonal fluctuations of water levels in wells 6/2W-31L1 and 6/3W-3A1 is also explained in this manner.

Figure 12 shows the hydrographs of three wells in the study area in which periodic water-level measurements have been made during the past 34 years (1928-62). The level in well 4/2W-34R1 represents the top of a semiperched water body, whereas the levels in wells 5/2W-25M1 and 6/3W-33R1 represent respectively the principal water table beneath French Prairie and beneath the alluvial plain of the Willamette River. All three wells are in or near relatively heavily pumped areas.

Correlation between long-term precipitation records and long-term water-level trends (at least for the past 34 years) is vague. Except for one year (1937) during the period 1933-41, annual precipitation at Salem was generally below the 1920-60 average; yet there is no indication from the few measurements made that the ground-water levels in wells 4/2W-34R1, 5/2W-25M1, and 6/3W-33R1 were much below average during that same period. Similarly, during the relatively wet period of 1945-55, levels in the three wells were not significantly above average. This is probably because the reservoir was filled to capacity each winter during each period, and much of the precipitation available for recharge was rejected (p. 47).

The increase apparent in the amplitude of seasonal fluctuation of the water level in well 5/2W-25M1 since about 1955 reflects increased pumping withdrawal in the vicinity of the well. Increased pumping for irrigation causes a local cone of depression each summer, which is superimposed on the natural seasonal decline of the water table. This condition probably exists locally throughout the study area where there is intensive pumping, but it does not mean that there is any local overdraft. The hydrograph shows that the water levels have recovered fully each winter regardless of the level during the previous summer.

QUANTITATIVE ESTIMATES

The major elements of the hydrologic cycle of the French Prairie area have been estimated for calendar year 1960 (when most of the hydrologic data were collected for this study) to show the relation among them. The estimates are summarized in the following table.

Estimated water budget for the French Prairie area for calendar year 1960, with estimated storage capacity in the 10- to 200-foot-depth zone and seasonal change of ground-water storage

[All figures rounded]

	Volume	
	Acre-ft	Inches on 210 sq mi
Inflow:		
Precipitation	460,000	41.0
Underflow from the south	3,400	.3
Imported water	[1]3,200	.3
Infiltration from irrigation and fluid-waste disposal	4,500	.4
Total	471,000	42.0
Outflow:		
Seeps and springs	113,000	10.0
Evapotranspiration	250,000	22.0
Overland runoff	[2]88,000	8.0
Pumpage	20,000	2.0
Total	471,000	42.0
Total ground-water storage (10- to 200-ft-depth zone)	4,000,000	370.0
Seasonal change of ground-water storage, 1960	182,000	16.0

[1] Consists of about 3,000 acre-ft pumped from streams into the area (p. 40) and about 200 acre-ft delivered to the south end of the area by the city of Salem.

[2] Overland runoff assumed to be difference between total inflow and sum of outflow by evapotranspiration, seeps and springs, and pumping; (See p. 39.) There was little or no overall change in surface- or ground-water storage.

A discussion of the amounts of water involved in ground-water recharge and discharge follows.

GROUND-WATER RECHARGE

PRECIPITATION

The principal means of recharge is direct infiltration of precipitation on the 210-square-mile study area (about 41 in. or 460,000 acre-ft in 1960). Much of the study area is very flat so that only small amounts of the precipitation run off directly. Also, the soils absorb moisture readily. Because most of the precipitation (about 40 in. per yr average) occurs in winter, little is lost by evaporation. Therefore, precipitation has ample opportunity to restore soil-moisture deficiencies and to percolate to the water table.

Recharge from precipitation is indicated by a rise of the water levels in wells—or of the water table. The first autumn rains restore the soil moisture that has been depleted during the dry summer; subsequent precipitation during the fall and winter percolates downward and causes the water table in the area to rise.

Figure 13 shows the relationship between daily precipitation recorded at Salem and the water level in well 6/2W–5N1 from July 18, 1960, to August 31, 1961. Well 6/2W–5N1 is in a locality where the water table is generally highest. Water-level fluctuations in this well are used as an index of the ground-water-reservoir content and also as a basis for estimating amounts of ground-water recharge and discharge. When the water level in the well is highest, the reservoir is considered to be filled (to near capacity); when the water level declines, ground water is being removed from storage. There are no large-yield wells in the vicinity of well 6/2W–5N1; therefore, changes of the water level in that well are due mainly to natural changes in ground-water storage.

As figure 13 shows, precipitation from July 18 to November 10, 1961, did not cause any appreciable rise of the water level in well 6/2W–5N1, although as much as 1.5 inches of rain fell during the 3-day period October 6–8. Apparently, most precipitation prior to November 10 was lost through evapotranspiration or became soil moisture. However, an additional 9.3 inches of precipitation during the rest of November caused the water level in well 6/2W–5N1 to rise almost 7 feet in less than 15 days. The water level declined about 1 foot from December 1 to 14 (when only 0.48 in. of rain fell) but rose again sharply (almost 3 ft) owing to recharge resulting from about 2.5 inches of rain December 15–18. Water level in the well continued to rise until March 15, 1961. By February 18, the ground-water reservoir was filled to near capacity and much of the water available for recharge from later rains was rejected. Evidence of this rejection was the very slight rise of the water level in the well from February 10 to March 15, 1961, despite an accumulative amount of precipitation in excess of 12 inches.

Infiltration from about 28 inches of rainfall had been sufficient to raise the water level in well 6/2W–5N1 from a seasonal low of about 17 feet in October 1960 to near the seasonal high of about 5.5 feet in March of 1961— or to almost fill the part of the ground-water reservoir that had been emptied by natural drainage the previous summer. The 28 inches of precipitation is equivalent to slightly more than 70 percent of the average annual precipitation recorded at Salem and may be a measure of the minimum amount necessary to replenish the ground-water supply each year in line with present withdrawals.

UNDERFLOW FROM THE SOUTH

Recharge to the ground-water body in the French Prairie area also occurs as underflow from the adjacent area on the south. In the area between the Lake Labish channel and Turner Gap (fig. 1), unconfined water occurs in shallow alluvial deposits. Natural recharge in that area is by direct infiltration of precipitation and, possibly, by

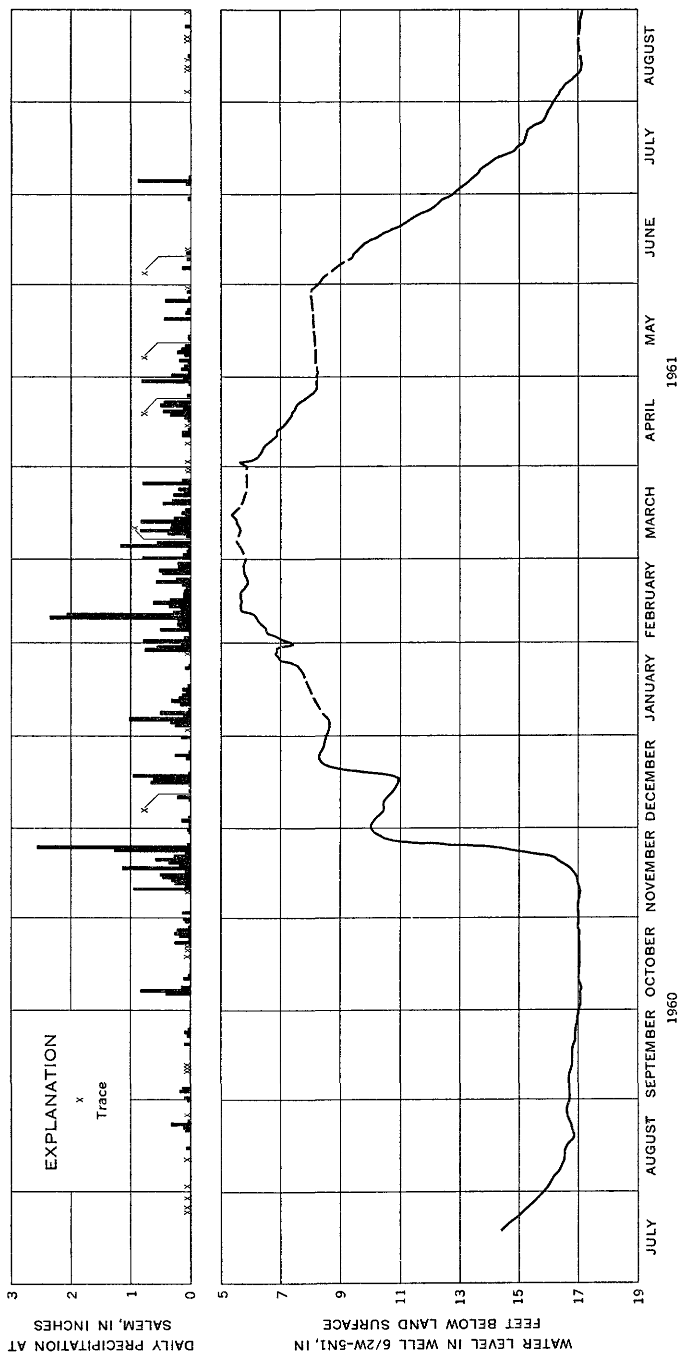

FIGURE 13.—Relationship between daily precipitation recorded at Salem, Oreg., and changes of water level in well 6/2W–5N1.

influent seepage from Mill Creek. The ground water moves generally northward to areas of natural discharge. Part of the ground water probably drains into the lower end of Mill Creek, and part drains into Little Pudding River. The rest continues northward beneath the southern boundary of the French Prairie area and drains into the Lake Labish Ditch.

If the coefficients of permeability of the sediments through which ground water moves are about the same as the coefficient of permeability for the sample collected from well 6/3W–26D2 (table 3, sample 7), as much as 3 million gpd may flow beneath the 4-mile-long south boundary of the study area. This amount is equivalent to about 3,400 acre-feet per year.

There is probably no underflow of unconfined ground water into the shallow nonmarine sedimentary deposits underlying the French Prairie area from any direction other than the south, because the water that recharges the nonmarine sedimentary rocks at the edges of the Willamette Valley is probably intercepted by the streams that bound the French Prairie area. There is, however, a possibility of upward leakage of ground water from confined aquifers in the Columbia River Group and marine sedimentary rocks. The chemical quality of water from Giesy Mineral Spring in the NE¼NE¼ sec. 15, T. 4 S., R. 1 W., indicates that the spring is fed by deep-seated water derived from marine sedimentary rocks. That water is under sufficient pressure to rise to the land surface. The water from well 3/1W–27R1, which taps basalt of the Columbia River Group, also contained unusually large concentrations of dissolved solids, which indicates that water was percolating upward under artesian pressure from the underlying marine sedimentary rocks into the basalt (p. 68). Information is too sparse to estimate the contribution from this source, but rock densities and observed pressures suggest that the amount is probably small compared to total recharge.

INFILTRATION OF IRRIGATION WATER AND OF FLUID WASTE

Ground-water seepage from irrigated lands and fluid disposal of waste may be considered as recharge, although they merely represent the return of the unconsumed part of water diverted from the hydrologic system. The amount of recharge depends largely on the amount of water used for irrigation (which in turn depends on the type of crops, weather conditions, and irrigation practices that affect consumption rates) and on the amount of water used in disposal of waste.

Recharge from irrigation is probably small compared with total natural recharge but is important because some of the water pumped for irrigation is recirculated to the ground-water body. If about 20 percent of the water applied for irrigation in 1960 (about 20,000 acre-ft, including irrigation water from streams) percolated to the water table, the amount of recharge from irrigated land would be about 4,000 acre-feet. The estimate seems conservative.

Little is known about the amount of water that actually reaches the ground-water body as seepage from septic tanks or from disposal of fluid waste upon the land surface. Perhaps the largest volume of water recharged by seepage is the return underground of water pumped to wash gravel (p. 58); the volume of water that returns may be nearly equal to the volume pumped for that purpose (less than 1,000 acre-ft in 1960). Similarly, the amount of seepage loss from septic tanks is expected to be less than the amount of water pumped for domestic and public supplies (about 600 acre-ft in 1960) and may be about 500 acre-feet per year.

GROUND-WATER MOVEMENT

Ground water in the zone of saturation generally moves radially outward from areas on French Prairie between streams, where the water table is highest, toward areas of discharge along the streams. The rate of movement varies considerably from place to place; it is governed mainly by the hydraulic gradient (slope of the water table) and the permeability of the rock materials through which the ground water percolates. In general, ground water moves more rapidly in areas where the rocks are most permeable and hydraulic gradients are steepest.

Although no direct measurement of the rate of ground-water movement was made in the French Prairie area during this study, the rate of movement locally can be approximated from the Darcy equation as adapted from Tolman (1937, p. 215).

$$v = \frac{(2.532 \times 10^{-5} \times Pf)\ (h)}{P}$$

where

v = velocity of the water in feet per day,

Pf = field coefficient of permability in gallons per day per square foot,

h = hydraulic gradient in feet per mile, and

P = porosity of the rocks expressed as a decimal fraction.

In Mission Bottom, for example, the average hydraulic gradient is about 20 feet per mile, and the porosity and coefficient of permeability of the alluvium are, respectively, 38.5 percent and 24,000 gpd per sq ft, as determined by laboratory methods (table 3). Substituting these values in the foregoing equation, the velocity of the ground-water flow is:

$$v = \frac{(2.5 \times 10^{-5})(24{,}000)(20)}{0.385} = 32 \text{ feet per day.}$$

Ground water probably moves most rapidly through the highly permeable alluvium underlying Mission Bottom and other segments of the Willamette River flood plain. In other parts of the study area, however, the rate of movement is probably much slower, owing mainly to the lower permeabilities of the older rock units in those parts. For example, the rate of movement through the most permeable gravels of the Troutdale Formation may be only a few feet per day, and through some zones in the Willamette Silt may be less than 1 inch per day.

GROUND-WATER DISCHARGE

SPRINGS AND SEEPS

Springs and seeps constitute one of the principal means of discharge of ground water from the French Prairie area. They occur mainly along streams which intersect the water table (fig. 7). The springs and seeps are not widely separated, nor are they at places where their individual flows can be measured; instead, they are closely spaced along the stream channels and occur at or beneath the water surface. Consequently, the discharge of springs and seeps in this study was estimated from streamflow records. Streamflow records of the Pudding River collected near Mount Angel and Aurora were used because (a) they afforded the most reliable estimate of the ground-water increment of the total streamflow, and (b) the rate of ground-water discharge, per unit area, into the Pudding River between Mount Angel and Aurora is believed to be the most representative measurement available of the rate of ground-water discharge, per unit area, into all streams draining the French Prairie area.

During the normal period of low flow in the study area (June–September), nearly all the gain in flow of the Pudding River between the Mount Angel and Aurora gaging stations is derived from seeps and springs. Consequently, the ground-water component of the measured streamflow between the stations can be determined accurately. From September to May, however, part of the gain in flow of the river between the Mount Angel and Aurora gaging stations is from direct surface runoff; the ground-water component of the gain in flow for that period must be estimated.

Two methods were used to estimate annual spring and seep outflow from the ground-water reservoir underlying the French Prairie area. The first method consisted of estimating the ground-water component for calendar year 1960 directly from a hydrograph of the gain in flow of the Pudding River between Mount Angel and Aurora according to the method described by Linsley, Kohler, and Paulhus (1949, p. 400). The hydrograph and estimated ground-water component are shown in figure 14. Using the foregoing method, the total volume

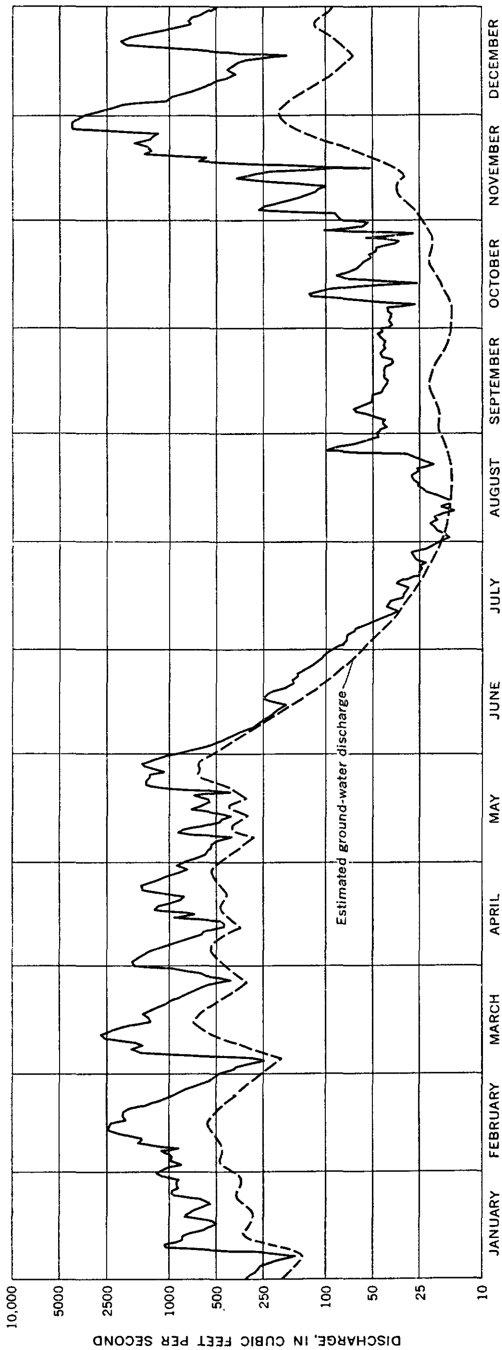

FIGURE 14.—Hydrograph of gain in flow of the Pudding River between Mount Angel and Aurora during calendar year 1960, and estimated ground-water component of the gain in flow.

of ground water discharged to the Pudding River between Mount Angel and Aurora in 1960 was about 150,800 acre-feet.

The second method for estimating ground-water discharge consisted of comparing ground-water discharge into the Pudding River with water-table fluctuations in French Prairie. Figure 15 shows the approximate relationship between the ground-water inflow to the Pudding River between Mount Angel and Aurora (determined from the summer base-flow recession curve) and the altitude of the water table in French Prairie at well 6/2W–5N1.

Using the graph shown in figure 15, winter rates of ground-water discharge to the Pudding River were estimated for various altitudes of the water table at well 6/2W–5N1. Actual ground-water discharge during the winter might be somewhat greater because the relation used was developed for a period when evapotranspiration was greater. From this method, the gain in flow of the Pudding River that could be attributed to ground-water seepage was determined to range from about 15 cfs (cubic feet per second) when the water table at well 6/2W–5N1 was lowest (161 ft altitude) to about 750 cfs when

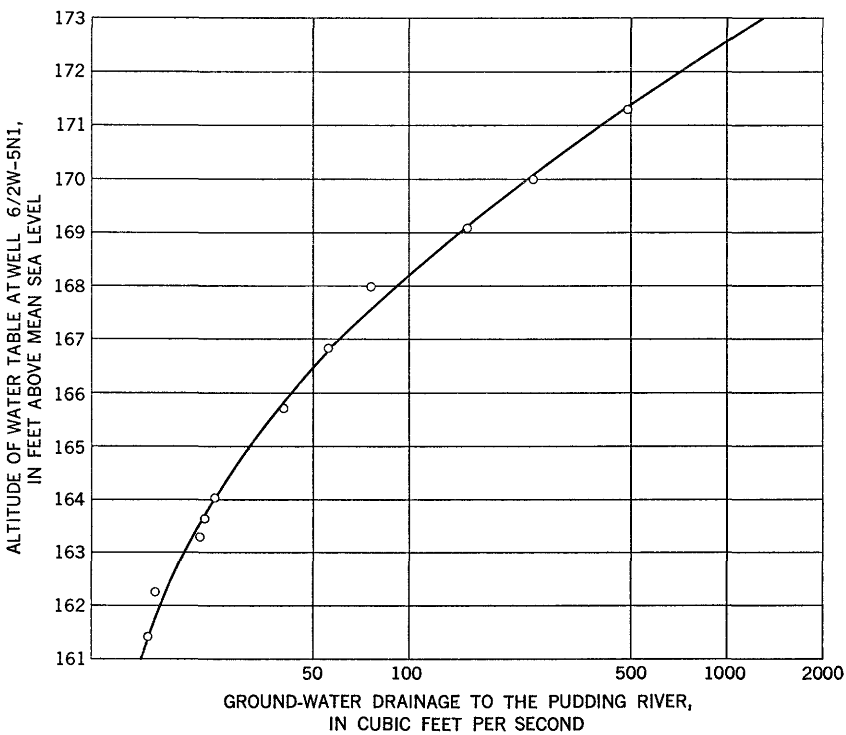

Figure 15.—Relation of the altitude of the water level in well 6/2W–5N1 and ground-water discharge to the Pudding River between Mount Angel and Aurora.

the water table was highest (173 ft altitude). Month-by month estimates of ground-water discharge were made, using figure 15 and the hydrograph of well 6/2W–5N1, and were found to total about 141,500 acre-feet in 1960. This compared favorably with the result obtained from the first method (150,800 acre-ft). A mean between the results of the two methods (146,000 acre-ft) seems to be a reasonable estimate for the volume of ground water discharged through seeps and springs into the Pudding River and its tributaries between Mount Angel and Aurora during 1960.

Obviously, not all the ground-water inflow to the Pudding River between Mount Angel and Aurora is derived from the French Prairie area. Most is derived from the area east of the river. Of the 275 square miles drained by that reach of the river, only about 65 square miles is in the French Prairie area. This is equal to about 24 percent of the total area drained. Therefore, for lack of a better criterion, it is estimated that about 24 percent of the ground-water inflow to the Pudding River between Mount Angel and Aurora was derived from the French Prairie area. In 1960, this was about 35,000 acre-feet, or about 540 acre-feet per square mile. If the average annual yield of ground water per square mile is about 540 acre-feet throughout the entire study area, then about 113,000 acre-feet of ground water was discharged from the 210-square-mile French Prairie area in 1960. Most drained directly into the Willamette River and its tributaries which head on French Prairie.

EVAPOTRANSPIRATION

Evapotranspiration is the return of water to the atmosphere by the combined processes of direct evaporation and transpiration through leaves of plants. Evapotranspiration is greatest during daylight hours in summer, when temperatures are highest, humidity is lowest, and vegetation growth is most active.

In areas where the water table is near the ground surface, considerable ground water can be discharged by evapotranspiration. However, the rate of evapotranspiration from ground water decreases rapidly as depth to the water table becomes greater. According to Houk (1951, p. 292), when the water table is at the ground surface, the rate of evaporation from sand or sandy loam may be equal to, or slightly greater than, the rate of evaporation from a standard Weather Bureau evaporation pan, but the evaporation becomes negligible when the water table falls to a depth greater than about 4 feet. Discharge of ground water by transpiration continues below the 4-foot level but decreases abruptly as the water table declines below the root zones of the plants.

Along the alluvial plains of the Willamette River and its tributaries, where the water table is at or near the ground surface, direct evaporation and loss of ground water by transpiration may nearly equal the rate of evaporation from open-water bodies, which is about 5 inches from October to March and 27 inches from April to September (p. 10).

On French Prairie, discharge of ground water by evapotranspiration is probably much less per unit area than on the adjacent alluvial plains, because on French Prairie the water table is generally several tens of feet below the land surface.

Evapotranspiration from all sources in the Willamette Valley, as estimated by the U.S. Army Corps of Engineers, is about 20 inches a year, or about 62.5 percent of the average potential evaporation as measured at Corvallis, Oreg. This value is believed by the writer to be low with respect to the French Prairie area because, as stated above, evapotranspiration along the alluvial plains of the Willamette River and its tributaries may nearly equal or exceed the potential evaporation (32 in. per yr) locally. Actual evapotranspiration from all sources in the area, therefore, is believed by the writer to be somewhat higher (possibly as high as 70 percent of the potential evapotranspiration). This would be about 22 inches, or about 250,000 acre-feet, for the area of study.

PUMPAGE FROM WELLS

The total volume of ground water withdrawn from wells in the French Prairie area in 1960 was about 20,000 acre-feet. Of this, about 85 percent (17,000 acre-ft) was pumped for irrigation and the rest was pumped for public, domestic and stock, and industrial supplies. The amount of water pumped for each type of use during 1960 is given in the following table. The sections in which withdrawals were greatest are shown in figure 16.

Type of supply	*Withdrawals (acre-ft)*
Irrigation	17, 000
Industry	1, 100
Public supply	1, 200
Domestic and stock	900
Total (rounded)	20, 000

Irrigation supplies

Irrigation supplies tabulated herein included water pumped to irrigate agricultural crops but did not include pumpage for watering of lawns and small gardens. The volume of water pumped for irrigation each year varies considerably, depending on the type of crops and the amount of rain during the growing season. Some

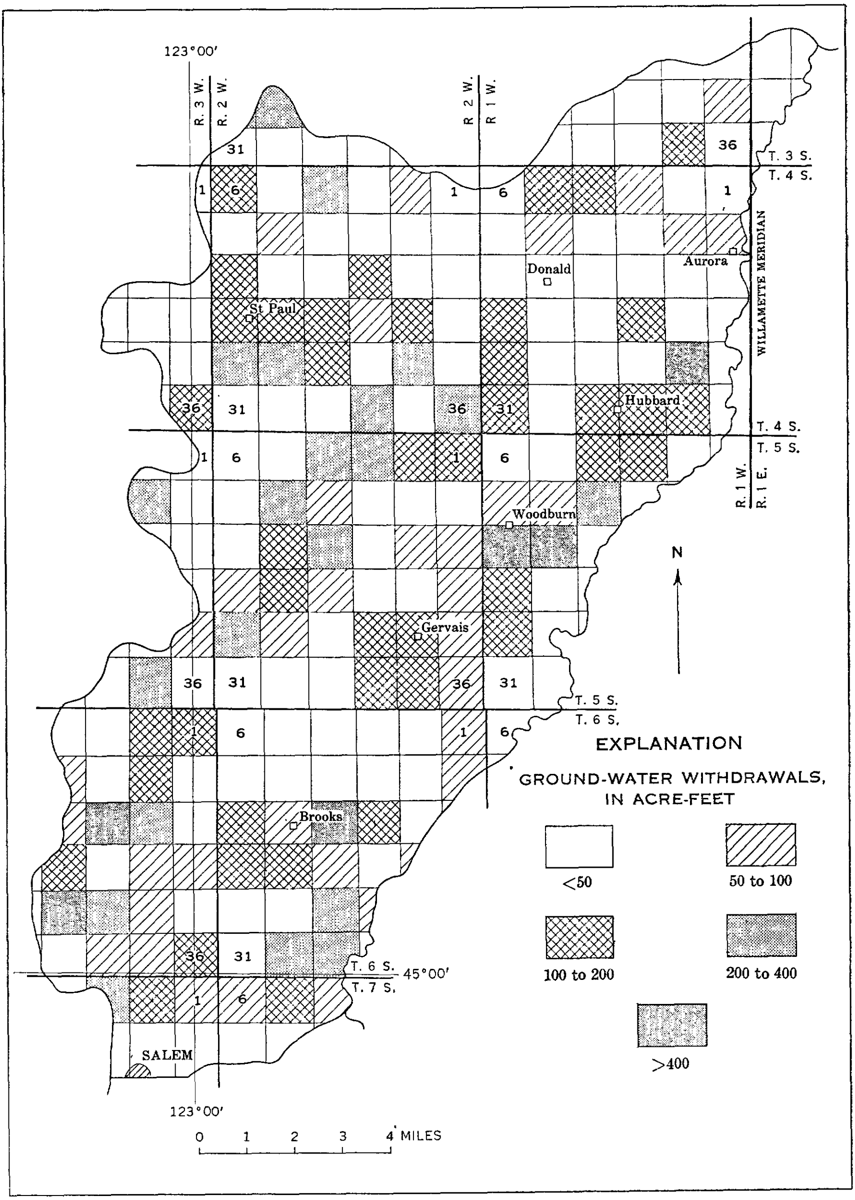

FIGURE 16.—Pumping withdrawals by section in the French Prairie area during 1960.

crops, such as pasture, require more than 2 feet of water each year, whereas most grains require little or no irrigation water. In 1960, applications were filed with the Oregon State Engineer to irrigate about 25,000 acres in the French Prairie area. However, not all this land was irrigated; part was not cultivated, and part was in grass or grain crops not requiring irrigation.

Estimates of the volume of water pumped for irrigation in 1960 were derived largely from electrical-power records. The kilowatt-hour consumption for the year was multiplied by the ratio of water pumped per kilowatt-hour. The ratio was developed assuming an average wire to water efficiency of 70 percent and pumping lift of 70 feet. Pumping rates were obtained from pump-test data and from measurements in the field. Not all pumps were rated. Pumpage from those that were not was estimated according to the type of crop and number of acres irrigated, and the estimates were applied to similar farms nearby.

On the basis of the foregoing methods, it was estimated that about 17,000 acre-feet of ground water was pumped from wells for irrigation in the study area in 1960. This figure does not include water pumped from streams fed by ground water, such as the Lake Labish Ditch and streams that drain the north end of French Prairie. (See p. 39.)

Public supplies

In this report, public water supplies include water used by cities and towns, residential water districts, schools, churches, parks, and other public facilities.

Virtually all water used for public supplies in the French Prairie area is obtained from ground water; in addition, the municipal supply for the city of Newberg (north of French Prairie) is augmented by water which is piped across the Willamette River from wells in the French Prairie area. Within the area, only one small part of the community of Keizer, served by the Keizer Water District, obtains its supply partly from surface water. That water is from the city of Salem supply, which is diverted from the North Santiam River.

Estimates of the volume of ground water pumped for public supplies were obtained from owners and operators of public-supply facilities. Reliability of the information differed widely—from rough estimates for some small towns and water districts to reliable records for the larger cities. However, because the pumpage for these larger cities is considerably greater than for the small towns and water districts, the overall estimate of pumpage for public supplies is believed to be reasonably accurate.

About 1,250 acre-feet of ground water was pumped for public supplies in the French Prairie area during 1960. This included about 300 acre-feet that was pumped for use by the city of Newberg. The largest volume of water pumped for a single public supply was for use by the city of Woodburn, the largest city wholly within the study area. During 1960, nearly 500 acre-feet (159.8 million gallons) of water was pumped from five wells to meet the city's requirements. The following table shows the annual pumpage from the five Woodburn wells during the period 1941–61 (data from city of Woodburn).

Year	Pumpage (millions of gallons)	Year	Pumpage (millions of gallons)	Year	Pumpage (millions of gallons)
1941	48.3	1948	84.4	1955	132.1
1942	48.3	1949	99.7	1956	162.5
1943	51.2	1950	102.0	1957	157.1
1944	58.8	1951	115.4	1958	167.4
1945	64.9	1952	116.4	1959	157.7
1946	74.3	1953	99.3	1960	159.8
1947	82.2	1954	117.6	1961	173.4

Industrial supplies

About 1,100 acre-feet of ground water was pumped in 1960 for industrial supplies, which included water for canning, packing, dairy operations, gravel washing, and fish rearing. There are six gravel-washing operations within the area that utilize ground water; for each of these, probably as much as 100 acre-feet of water is pumped each year, but most of the wash water infiltrates the floors of the gravel pits and percolates back to the ground-water body. Perhaps only about 5 percent of the water pumped is consumed. In 1960, about 800 acre-feet of water was pumped in the Woodburn area for packing and canning of food, and as much as 300 acre-feet was pumped for dairy operations and fish rearing.

Domestic and stock supplies

About 11,000 persons in rural and suburban districts of the French Prairie area depend on privately owned wells for water for household purposes, stock watering, and irrigation of lawns, shrubbery, and small gardens. Although precise data are lacking, the rural per capita requirements in the area are believed to be about 75 gpd. This is equivalent to the daily per capita requirements in similar areas served by water districts near Portland, where records are kept of pumpage and numbers of persons served; it takes into account water used for stock, lawn, and garden watering. Therefore, the volume of water pumped in 1960 for domestic supplies probably was about 825,000 gpd, or about 920 acre-feet for the year.

GROUND-WATER-RESERVOIR STORAGE CAPACITY

The storage capacity of a given ground-water reservoir may be defined as the volume of water that will drain by gravity from the saturated rocks which form that reservoir; the storage capacity is the total volume of ground water theoretically available for development and can be calculated by multiplying the total volume of saturated rocks by their estimated average specific yield. Practically, the amount available depends on the economics and is always less than the storage capacity.

For the purpose of this report, ground-water-storage capacity in the French Prairie area is computed for the 10–200-foot-depth zone only. There is considerable fresh water available below the 200-foot level, and dewatering below that level may be economically feasible. However, it was decided to limit the depth zone to the 200-foot level until more data are available concerning the type of rock and quality of water below that level. Furthermore, the amount in this zone seems more than adequate to serve the needs for many years to come.

In computing the ground-water-storage capacity, a procedure was followed similar to that used by Davis, Green, Olmsted, and Brown (1959, p. 199) to calculate storage capacity in the San Joaquin Valley, Calif. Briefly, this entailed (a) division of the area into ground-water-storage units, (b) selection of storage-depth zones, and (c) grouping of materials described in well logs into rock-type categories to which estimated values of specific yield could be assigned.

The storage units into which the area was divided consisted of townships, or parts thereof, that lie within the boundaries of the Salem-Aurora and St. Paul-Donald ground-water subareas and the flood plain of the Willamette River. Where only part of a township was within the area, it was combined with the adjacent township. The Willamette River flood plain was treated as a separate unit because of its different lithology and marked difference in altitude. The storage units are shown in figure 10.

Much more drilling data were available to a depth of 100 feet than between the depths of 100 and 200 feet. For this reason, capacity of each storage unit was estimated between those two depth ranges and later combined; the two depth ranges are from 10 to 100 feet and from 100 to 200 feet. This was done to provide flexibility for adjustments in the storage estimates for the lower 100 feet as more drilling information becomes available.

To assign specific-yield values to the water-bearing materials, the lithologic descriptions given in driller's logs were grouped into five categories, as shown in the following table.

Category	Drillers' description	Assigned specific yield (percent)
G	Gravel, cobbles, and boulders	25
S	Sand, sand and gravel	25
Cs	Sandy clay, silt and sand, clay with sand lenses, sand with clay lenses	20
Cg	Clay and gravel; gravel with clay binder; conglomerate; gravel, cemented; clay with gravel lenses	15
C	Clay, silt, silt and clay, shale, hard clay, sticky clay	5

The above values for specific yield were arrived at by comparing laboratory determinations of specific yield of aquifer materials in the French Prairie area (table 3) with published values for similar materials in other areas. The values given for the category C may seem low when compared with the values determined for the Willamette Silt (table 3); however, this category, although it includes silt, also includes hard clay, sticky clay, and shale, which probably have specific yields of less than 1 percent. These clays and shales make up the bulk of the category C.

Although basalt has been reported above the 200-foot level in several well logs, it was not considered in any category because very little of it occurs above that level.

The calculation of ground-water-storage capacity in the French Prairie area is summarized in table 4. By use of the most descriptive well logs in each township of the respective ground-water subareas, the footage of each lithologic category between the 10- to 100-foot and the 100- to 200-foot depth ranges was totaled, and an average specific yield was calculated. The average specific yield of the materials in the 10- to 100-foot depth interval ranged from 15.4 percent in the T. 4 S., Rs. 2–3 W., storage unit to 19.1 percent in the T. 3 S., Rs. 1 E. and 1 W., storage unit; the average specific yield of the materials in the 100- to 200-foot depth interval ranged from 13.2 percent in the T. 2 S., Rs. 2–3 W., storage unit to 23.8 percent in the T. 7 S., Rs. 2–3 W., storage unit. The overall average specific yield of the materials in the upper depth interval was 17.1 percent, and the overall average specific yield of the materials in the 100- to 200-foot depth interval was 16.9 percent; the average specific yield of both zones was 17 percent.

After the average specific yield of the water-bearing materials in each depth interval of each storage unit was determined, the surface area of each individual storage unit was planimetered; the area of those units, in acres, is shown in table 4. The volume of saturated rocks in each depth interval of each storage unit was then determined by multiplying the surface area of the storage unit by the thickness of each depth zone—that is, 90 and 100 feet, respectively. The volume of saturated rocks in each depth interval of each storage unit was then multiplied by the specific yields that were determined for the materials in each storage unit. The estimated storage capacity in each depth interval of each storage unit is given in the last column of table 4. The total ground-water storage capacity in the French Prairie area is the sum of these, or about 4 million acre-feet.

TABLE 4.—*Summary of ground-water-storage capacity in the French Prairie area*

Depth zone (feet)	Saturated sedimentary deposits							Total volume (acre-ft)	Storage volume (acre-ft)
	G	S	Cs	Cg	C	Total	Area (acres)		
SALEM-AURORA AND ST. PAUL-DONALD SUBAREAS									
T. 3 S., Rs. 1 E. and 1 W.									
10–100:									
Feet	6.50	454.50	147	0	202	810	5,375	483,750	92,400
Percent	1	56	18	0	25	100			
Average specific yield	.25	14.00	3.60	0	1.25	19.1			
100–200:									
Feet	33	122	12	0	213	380		537,000	73,000
Percent	9	32	3	0	56	100			
Average specific yield	2.25	8.00	.6	0	2.80	13.6			
T. 4 S., R. 1 W.									
10–100:									
Feet	58.50	306.50	583	0	497	1,445	20,380	1,834,200	296,000
Percent	4	21	41	0	34	100			
Average specific yield	1.00	5.25	8.20	0	1.70	16.2			
100–200:									
Feet	24.50	119	212	0	241	597		2,038,000	309,000
Percent	4	20	36	0	40	100			
Average specific yield	1.00	5.00	7.20	0	2.00	15.2			
T. 4 S., Rs. 2–3 W.									
10–100:									
Feet	0	288	656	13	573	1,530	21,400	1,923,000	296,200
Percent	1	19	43	0	37	100			
Average specific yield	.25	4.75	8.60	0	1.85	15.4			
100–200:									
Feet	6	259	531	0	850	1,659		2,140,000	282,000
Percent	1	16	32	0	51	100			
Average specific yield	.25	4.00	6.40	0	2.55	13.2			

TABLE 4.—*Summary of ground-water-storage capacity in the French Prairie area*—Continued

Depth zone (feet)	Saturated sedimentary deposits							Total volume (acre-ft)	Storage volume (acre-ft)
	G	S	Cs	Cg	C	Total	Area (acres)		
SALEM-AURORA AND ST. PAUL-DONALD SUBAREAS—Continued									
T. 5 S., R. 1 W.									
10–100:									
Feet	20	312	373	5	370	1,080			
Percent	2	29	35	0	34	100		900,000	147,800
Average specific yield	.50	7.25	7.00	0	1.70	16.4			
100–200:							10,000		
Feet	286	326	113	183	196	1,104			
Percent	26	29	10	17	18	100		1,000,000	192,000
Average specific yield	6.50	7.25	2.00	2.55	.90	19.2			
T. 5 S., Rs. 2–3 W.									
10–100:									
Feet	0	220	579	55	768	1,622			
Percent	0	14	36	3	47	100		2,241,000	394,000
Average specific yield	0	3.50	7.20	4.50	2.35	17.60			
100–200:							24,900		
Feet	56	195	77	67	305	700			
Percent	8	28	11	10	43	100		2,490,000	368,800
Average specific yield	1.92	7.00	2.20	1.5	2.15	14.8			

T. 6 S., R 2 W.

10–100:									
Feet	156.50	446.50	626	60	561	1,850			
Percent	9	24	34	3	30	100		1,944,000	330,000
Average specific yield	2.25	6.00	6.80	0.45	1.50	17.0			
100–200:							21,600		
Feet	78	279	82	67	140.50	647			
Percent	12	43	13	10	22	100		2,160,000	418,000
Average specific yield	3.00	10.75	2.60	1.5	1.10	18.9			

T. 7 S., Rs. 2–3 W.

10–100:									
Feet	123	238	153	375	373	1,262			
Percent	10	19	12	29	30	100		426,600	66,000
Average specific yield	2.50	4.75	2.40	4.35	1.50	15.5			
100–200:							4,740		
Feet	89	73	0	155	20	337			
Percent	26	22	0	46	6	100		474,000	93,000
Average specific yield	6.50	5.50	0	6.9	0.30	19.2			

WILLAMETTE RIVER FLOOD-PLAIN SUBAREA

10–100:									
Feet	69	166	111	144	140.50	630			
Percent	11	26	18	23	22	100		2,331,000	381,000
Average specific yield	2.75	6.50	3.60	2.44	1.10	16.4			
100–200:							25,900		
Feet	0	52	0	0	48	100			
Percent	0	52	0	0	48	100		2,590,000	400,000
Average specific yield	0	13.00	0	0	2.40	15.40			

SEASONAL CHANGE OF GROUND-WATER STORAGE

The seasonal change of ground-water storage is the volume of water that drains from the saturated rock materials when the water table declines from its annual high position in the spring to its annual low position in late summer (pl. 1). It is equal to the volume of dewatered rocks multiplied by the average specific yield of the rocks.

The volume of rocks that were dewatered in the French Prairie as the water table declined during the summer of 1960 was determined as follows: On a map of the area showing high and low water levels in 36 representative observation wells during 1960, lines were drawn through points of equal water-level change. The resulting map showed five concentric subareas in which the mean decline of water level ranged from about 2.5 to about 20 feet (pl. 2). Each subarea was planimetered to determine its areal extent, and the acreage of each was multiplied by the mean change of water level, in feet, in that subarea. The total volume of dewatered sediments in the area—the sum of the volumes of dewatered sediments in the five subareas—was found to be about 1,289,400 acre-feet. Of this amount, about 75,000 acre-feet consisted of Recent alluvium of the Willamette River, and 1,214,400 acre-feet consisted of Willamette Silt.

The specific yield of the Willamette Silt was determined from the results of laboratory analyses of five samples, as given in table 3, and from analyses of quantitative estimates or ground-water recharge. The average of the laboratory determinations of specific yields of those five samples was 27 percent. However, because the laboratory determinations are equivalent to 100 years of drainage, the results shown in the table, and the average derived therefrom, are undoubtedly too high for a single season's drainage. However, as much as 50 percent of the drainage could probably take place during the dry summer when the water table is declining. Therefore, the short-term specific yield of the Willamette Silt is estimated to be only about 13.5 percent. Using the 13.5 percent value for specific yield of the Willamette Silt, the volume of water drained from that unit was estimated to be 164,000 acre-feet (13.5 percent of 1,214,400 acre-ft).

The Recent alluvium of the Willamette River is much more permeable than the Willamette Silt. It seems reasonable, therefore, that the laboratory determinations of specific yield of the Recent alluvium are close to the field determinations of specific yield of those deposits. The specific yield of a sample was found to be about 24 percent by laboratory analysis. If the field specific yield of the Recent alluvium is about 24 percent, then the volume of water drained from that unit was about 18,000 acre-feet.

Using the above figures for the volumes of water drained from the Willamette Silt (164,000 acre-ft) and the Recent alluvium (18,000 acre-ft), the total change of ground-water storage in the French Prairie area in 1960 was found to be about 182,000 acre-feet—the equivalent of about 16 inches. Using the average value for the upper depth interval, as calculated in the previous section of this report (see p. 60), the storage would be somewhat greater—about 220,000 acre-feet. The smaller figure was chosen for the water budget on p. 46 more or less arbitrarily, although draining time was a consideration in making the estimate.

CHEMICAL QUALITY OF THE GROUND WATER

Table 7 includes the results of chemical analyses of 27 ground-water samples and 4 surface-water samples collected in the French Prairie area. All but three of the analyses were made by the U.S. Geological Survey.

Samples from wells that tap nonmarine sedimentary rocks were found generally to be of good quality for most uses. Almost all those samples contained about 200 ppm (parts per million) or less of dissolved solids and were found to be soft or only moderately hard (fig. 17 and table 7). In contrast, the quality of the water samples from the Columbia River Group and the marine sedimentary rocks was found to be only fair to poor for domestic and other uses. The sample from well 3/1W–27R1 (which taps the Columbia River Group) contained 742 ppm of dissolved solids, including 400 ppm chloride and 147 ppm sodium; the sample from Giesy Mineral Spring, which is believed to issue from the marine sedimentary rocks, contained more than 6,800 ppm of dissolved solids, including 4,190 ppm chloride and 1,060 ppm sodium. Furthermore, the water samples from both the well and spring were very hard.

Certain chemical and physical characteristics of natural water must be considered in determining suitability for agricultural, industrial, or domestic use. The occurrence and importance of several critical properties and dissolved constituents of ground water in the French Prairie area are discussed below. The reader is referred to Hem (1959) for a more detailed discussion of the chemical quality of natural waters.

SILICA

Most of the silica dissolved in natural waters is derived from the chemical breakdown of silicon-rich minerals and volcanic glass. The most important minerals are quartz and the silicates (such as the feldspars), which are abundant in many igneous and sedimentary rocks.

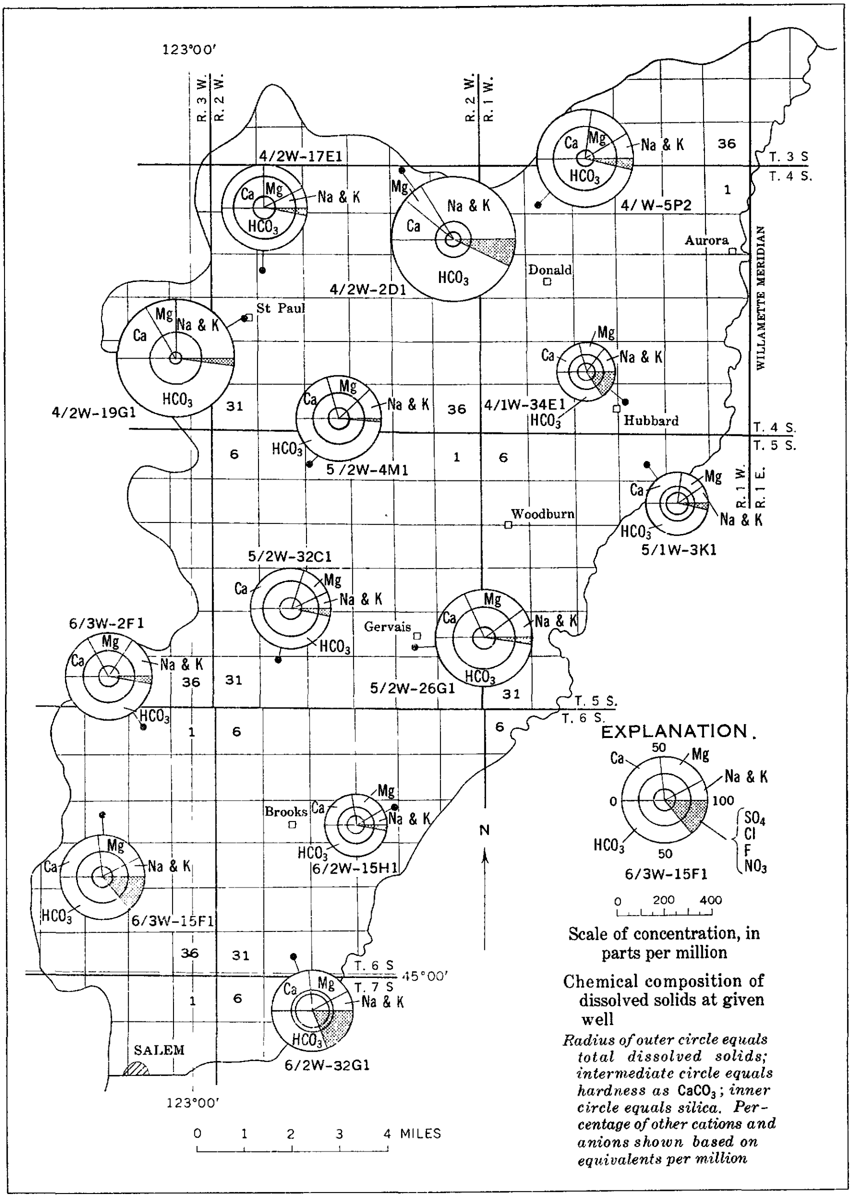

FIGURE 17.—Chemical quality of water from wells tapping the nonmarine sedimentary rocks in the French Prairie area.

Generally, silica is found in natural waters in concentrations that range from only a few parts per million to about 30 ppm, although some waters contain more than 100 ppm. The amount of silica in the ground-water samples collected in the French Prairie area ranged from 19 ppm (well 5/3W-13P1) to 64 ppm (well 6/2W-32G1). The average concentration in all samples was nearly 42 ppm. The relatively large amounts of dissolved silica are explained by the predominance of volcanic rock materials through which the water percolates.

The presence of silica in excessive concentrations in water is significant if the water is used in high-pressure boiler tanks. Under high pressure, some of the silica tends to precipitate and form scale on the boiler walls. The suggested limits for silica in boiler-feed water (after Moore, 1940) are given in the following table.

Pressure range (psi)	*Suggested allowable limits of silica (ppm)*
<150	40
151–250	20
251–400	5
>400	1

Excessive amounts of silica in water are also undesirable if the water is used to manufacture ice. It is desirable to have less than 10 ppm of silica in water used for that purpose. (See Hem, 1959, p. 253.)

IRON

Iron is derived from iron-bearing silicate minerals, particularly the amphiboles and the pyroxenes. However, the oxides and sulfides of iron, such as magnetite and pyrite, are also important sources of the iron found in natural waters.

Iron occurs in solution at two levels of oxidation—ferrous and ferric. Both forms can be present in the same solution under certain conditions. In the pH range of most ground water, however, significant amounts of dissolved iron are stable only in the ferrous form, within a reducing (oxygen-deficient) environment. Ferrous iron changes to the insoluble ferric form in the presence of oxygen, owing to oxidation. Thus, ground water within an aquifer can contain appreciable amounts (a few parts per million) of dissolved iron if the oxidation-reduction environment is proper, but the iron becomes unstable and precipitates as ferric hydroxide ("rust") when the water is brought to the land surface and exposed to the atmosphere.

Although water with several parts per million iron can be used for most purposes, concentrations in excess of about 0.3 ppm may stain plumbing fixtures, cooking utensils, and laundry, or it may impart an unpleasant taste. Iron exceeded 0.3 ppm in all but eight of the ground-water samples from the French Prairie area. The maximum was 5.3 ppm in the sample from well 4/2W–20G1.

CHLORIDE

Chloride was found to be only a minor constituent in most of the samples collected from wells tapping the nonmarine sedimentary rocks. It ranged from 1.7 to 83 ppm and averaged only about 5.4 ppm in those samples. In contrast, the marine sedimentary rocks,

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which underlie the area at depth, contain connate water (water entrapped in the interstices of the rocks at the time they were deposited), which is highly saline and chloride rich. For example, the sample collected from Giesy Mineral Spring contained 4,190 ppm chloride; that sample also contained 1,370 ppm calcium and 1,060 ppm sodium, which would classify it as a calcium-sodium chloride water—a type commonly found in marine sedimentary rocks in western Oregon.

The sample collected from well 3/1W–27R1, which taps the basalt of the Columbia River Group, contained 400 ppm chloride—an amount much higher than that normally found in waters from the Columbia River Group. The sample also contained comparatively high concentrations of calcium (92 ppm) and sodium (147 ppm), which suggest a slight contamination by upward leakage of the saline water from the underlying marine sedimentary rocks in that particular area.

The upper limit recommended by the U.S. Public Health Service (1962) for chloride in drinking water is 250 ppm. If the water contains more than this amount of chloride, it may taste salty; however, water containing more than 500 ppm of chloride is used for domestic supply in some areas.

FLUORIDE

Fluoride is generally present in natural waters in concentrations of less than 1 ppm; its presence in drinking waters is important because of its effects on teeth. Concentrations of fluoride in excess of about 2 ppm in water consumed by children during the formation of their permanent teeth may cause the enamel of the teeth to be mottled. On the other hand, controlled concentration of fluoride in drinking water reduces tooth decay. The highest fluoride concentration in the waters sampled in the French Prairie area was only 0.8 ppm—a safe limit by all suggested standards.

HARDNESS OF WATER

Hardness is a property of water that causes waste of soap. It is caused principally by dissolved calcium and magnesium. These constituents, like silica, are sources of scale in boilers and cooking utensils. The degree of water hardness can be evaluated using the following classification:

Hardness as $CaCO_3$ *(ppm)*	*Degree of hardness*
0–60	Soft
61–120	Slightly hard
121–200	Hard
>200	Very hard

Except for water from Giesy Mineral Spring, observed hardness values for ground water in the French Prairie area ranged from

37 to 276 ppm and averaged 107 ppm. In contrast, the spring flow contained 3,600 ppm of hardness when sampled in November 1961.

SUITABILITY OF THE GROUND WATER FOR IRRIGATION

Because ground water is used extensively for irrigation in the French Prairie area and will be used even more in the future, its suitability for irrigation is an important consideration. It has long been known that if sodium is the predominant cation in irrigation water, it tends to replace calcium and magnesium ions in the soils to which the water is applied. This causes the soil to deflocculate and become less permeable and, eventually, to be undesirable for cultivation. This phenomenon is called the sodium, or alkali, hazard. Total salinity also is an index of suitability of water for irrigation. A measure of this as dissolved solids or specific conductance is called the salinity hazard.

There are several methods by which the two hazards of irrigation waters can be evaluated. One method is to compute the percentage of sodium in the cations of the water and to compare that value with the specific conductance (Wilcox, 1948). If the percent sodium is less than 50 and the specific conductance is less than 500 micromhos, the hazard generally is not considered critical in irrigation waters.

Another method, considered by some to be more practical than the percent-sodium method, is to determine the sodium-adsorption-ratio (SAR) of the water and compare that value with the specific conductance. This method was devised by the U.S. Department of Agriculture, Salinity Laboratory Staff (1954, p. 80). Values of percent sodium and SAR were computed from the ground-water analyses and are presented along with the analytical data in table 3.

Figure 18 is a diagram, developed by the Salinity Laboratory, which is used to classify irrigation waters with respect to the sodium and salinity hazards. The computed SAR is plotted against the specific conductance of the water. In the diagram, waters can be classified into 1 of 16 categories, ranging from that having a low sodium, low-salinity hazard (C1–S1) to that having very high sodium, very high salinity hazard (C4–S4). Of 14 samples from wells tapping the nonmarine sedimentary rocks, 4 are classified as C1–S1 and 10 as C2–S1. The second class of SAR values indicates a medium-salinity, low-sodium hazard. Thus, water sampled from the nonmarine sedimentary rocks is of good quality for irrigation. However, the sample from well 3/1W–27R1, which taps the basalt of the Columbia River Group, fell in the C3–S1 class and was very close to the C3–S2 class, the latter indicating a high-salinity, medium-sodium hazard. Although the indicated hazard is relatively high, water from the basalt of the

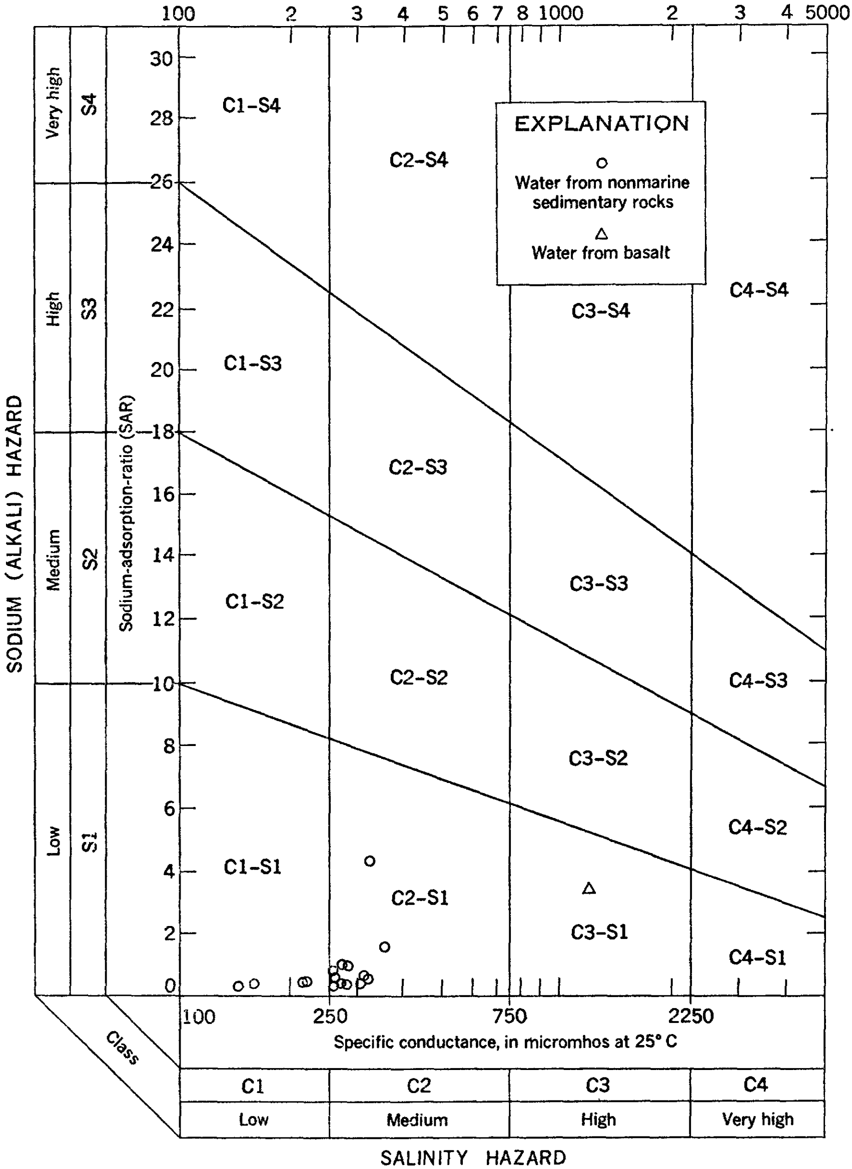

FIGURE 18.—Classification of irrigation waters. Adapted from U.S. Salinity Laboratory Staff (1954).

Columbia River Group still may be suitable because the classification does not rigidly apply except in warm, arid climates.

GROUND WATER AVAILABLE FOR FUTURE DEVELOPMENT

Much additional ground water can be developed in the French Prairie without seriously depleting ground-water storage. Records of water levels in wells, collected since 1929, indicate that storage has been replenished each year to about the same level despite a progressive increase in withdrawals. A look at various phases of the hydrologic cycle suggests that the ground-water reservoir could readily accommodate a fivefold increase in withdrawals. A fivefold increase, or a total of about 100,000 acre-feet, is the amount that would be needed to irrigate all arable land at the current rate of application.

Assurance that a particular sustained rate of withdrawal can be accommodated requires: (a) Evidence that the reservoir will be recharged at a rate at least equal to the proposed annual rate of withdrawal, and (b) evidence that sufficient ground-water storage is available to meet all foreseeable periods of shortage. Upon demonstration of these conditions, the remaining quantitative considerations are whether the lowering of water levels and intercepting of water from streams are acceptable and permissible conditions. Observed well yields indicate unquestionably that the withdrawal rate could be readily attained by a proportionate increase in the number of wells.

The water budget shown on page 46 shows that about 113,000 acre-feet of water is discharged from the ground-water reservoir through seeps and springs during a year of about-normal precipitation. This amount, and perhaps another amount (represented as the part of evapotranspiration that discharges from the ground-water reservoir) about equal to it, recharges the ground-water reservoir each year. Thus, it appears that the reservoir is amply able to be recharged at a rate of at least 100,000 acre-feet per year (five times the 1960 pumping rate). Furthermore, the 4 million acre-feet of ground water stored above a depth of 200 feet amply provides adequate storage to meet temporary demands during the most extreme droughts. It is, therefore, physically possible to develop 100,000 acre-feet of water annually.

Increasing the withdrawal rate would lower water levels during the pumping period to depths greater than they were lowered in 1960. As they lower, the discharge by seeps and springs would decrease and perhaps the discharge from the ground-water reservoir by evapotranspiration would decrease also. During winter, the reservoir would take longer to fill; when withdrawals increase above a certain annual rate, the reservoir would no longer fill to the same average yearly level. In effect, the level would adjust downward to each succeeding increase in withdrawal rate. So, although the ground-water reservoir level might be permanently altered and the discharge to the streams reduced, a fivefold increase in withdrawals could be accommodated without progressive losses of storage once the new equilibrium was established. Considering that each foot of material underlying the area contains about 20,000 acre-feet of water and that withdrawal concentrations would cause irregularities in the water table, it seems likely that the net seasonal effect on water levels would be a matter of only a few feet to a few tens of feet according to the distribution of new withdrawals.

PROBLEMS AFFECTING DEVELOPMENT OF GROUND WATER

Although additional ground water is available for withdrawal in the French Prairie area, increased withdrawals may result in certain problems. Other problems, associated with but not directly related to increased pumping, may result from disposal of wastes and use of chemicals on irrigated land. The most common problems that can be anticipated from past and present experience in developing ground-water supplies are (a) local interference between pumping wells, (b) undesirable changes in chemical and physical properties of the ground water, and (c) damaging effects of sand on wells and pumping equipment.

LOCAL INTERFERENCE BETWEEN PUMPING WELLS

Many of the earlier wells in the French Prairie area were shallow, and pump intakes were set only a few feet below the water table. These wells are generally reliable as long as there are only a few widely scattered wells in the vicinity. However, the addition of new wells and the subsequent increase of pumping withdrawals may cause the water levels to decline, perhaps below the original pump settings in the older wells. This may necessitate lowering of pumps and deepening some of the older wells if yields are to be sustained. This problem already exists in some parts of the area, particularly in the vicinity of Woodburn, where there is intensive localized pumping for municipal, industrial, and irrigation supplies from wells tapping virtually the same water-bearing zones.

Interference between wells cannot be avoided if the ground-water reservoir is to be utilized most efficiently. However, it can be minimized in areas of concentrated pumping by spacing wells as far apart as possible and by tapping more of the available water-bearing zones.

UNDESIRABLE CHANGES IN CHEMICAL AND PHYSICAL CHARACTER OF THE GROUND WATER

Contaminants may be introduced into the main ground-water body either by percolation from the land surface or by upward movement of saline water from the underlying marine sedimentary rocks. Throughout much of the French Prairie area, untreated household wastes are discharged to cesspools and septic tanks, whence they percolate into underlying rocks. The filtering action of the rocks, especially the fine-grained Willamette Silt, probably removes most organic contaminants, but certain household detergents remain unchanged in the percolating water for long periods of time. The detergents in small quantities are not detrimental to health, but concentrations of only a few parts per million can cause foaming of the water. Large amounts of detergents in the ground water could raise the dissolved-solids content of the water to undesirable levels and perhaps have other undesirable effects.

Contamination of water supplies through disposal of industrial wastes is a problem of growing concern in many populated areas. Such a problem was created in the vicinity of Keizer (pl. 1) during the middle 1940's, when ground water used extensively for domestic supplies was locally contaminated by industrial waste from an experimental alumina-reduction plant. (See table 7, sample from well 7/3W–11L1.) The waste, consisting of incompletely processed aluminum ore which had been treated with sulfuric acid and ammonium, was dumped into a borrow pit in the NW¼SE¼ sec. 11, T. 7 S., R. 3 W., where it percolated to the ground-water body. Aluminum, sulfate, and other ions were leached from the waste and migrated into adjacent aquifers.

Local residents using the ground water for domestic supply reported the contamination late in 1946. In 1947 a study was made by the Geological Survey, in cooperation with the Oregon State Engineer, to determine the cause and extent of the contamination. The findings and recommendations of that study were presented in an unpublished report by F. D. Trauger, U.S. Geological Survey (written commun., 1947). In accordance with recommendations in that report, the waste materials were removed from the gravel pit, and two large-yield wells were constructed nearby and pumped intensively for several months to remove as much of the contaminated water as possible. Water from the wells was discharged directly into the Willamette River through a large pipeline. Pumping alleviated the problem but did not remove all traces of the contaminated water from the aquifers.

Since 1947, samples from a number of selected wells in the contaminated locality have been collected and analyzed periodically. Between 1947 and 1954, samples were collected three or four times each year and analyzed by field methods to determine hardness only. The simple and inexpensive hardness determination was used as an indication of contamination because calcium and magnesium (which contribute to hardness of water) accompanied sulfate as a waste product. (See table 7, analysis of water from well 7/3W–11L1.)

After 1954, sampling was less frequent, and only one set of samples per year was collected in 1956, 1958, and 1962. These samples were analyzed in the laboratory for hardness, for specific conductance, and for concentrations of one or more additional constituents. Except for the analysis of water from well 7/3W-11L1 (table 7), the data for samples collected prior to 1962 are not included in this report but may be examined at the offices of the U.S. Geological Survey in Portland, Oreg. The analyses of samples collected on June 5, 1962, are given in the following table.

Analyses of water samples from 10 wells in the vicinity of Keizer, Oreg.

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

Approximate distance from borrow pit (feet)	Well	Depth (feet)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)
4,250	7/3W- 3R 1	42	34	10	149	347
2,900	11B 13	42	18	10	121	290
2,850	11C 11	25	19	6.0	84	212
2,150	11N 1	42	9.8	6.5	108	247
2,100	11M 6	?	30	6.2	138	314
1,950	11G 19	?	15	9.8	122	282
1,150	11F 1	41	99	6.0	227	501
800	10G 2	49	74	7.8	175	403
600	11G 1	44	66	8.5	193	448
600	11L 1	33	140	6.8	246	564

In general, the quality of water from wells nearest the borrow pit has progressively improved since the solid contaminants were removed from the pit and much of the contaminated water pumped from the aquifer. For example, the concentration of sulfate in water from well 7/3W-11L1 declined from 1,230 ppm on October 7, 1947 (table 7), to 140 ppm on June 5, 1962. Similarly, the hardness declined from 1,310 to 246 ppm during the same period. Nevertheless, traces of the contaminants still persist; the concentrations of sulfate in most of the water sampled June 5, 1962 (previous table) were still high in comparison with sulfate concentrations in samples from wells tapping the nonmarine sedimentary rocks elsewhere in the study area (table 7). However, the concentrations of sulfate in the samples collected June 5, 1962, were well within the maximum allowable limits (250 ppm) recommended by the U.S. Public Health Service. Concentrations should continue to decrease if more contaminants are not added to the ground water.

No other contamination of ground water by industrial wastes has been detected in the area, but contamination is possible wherever untreated industrial wastes are disposed of on the land surface. The hazard can be reduced by improved treatment of wastes and by better methods of disposal.

Excessive use of chemical fertilizers and insecticides may contaminate the ground-water supply. With increasing irrigation, the possibilities of contamination will increase, especially in Mission

Bottom and other parts of the Willamette River flood plain, where the water table is only a few feet below the land surface. If more fertilizer is applied than can be used by the plants or retained by the soil, some of the chemicals may reach the water table. The relatively high concentration of sulfate in the water samples from wells 6/2W–32G1 and 6/3W–15F1 (table 7) may have been derived from chemical fertilizers.

Certain insecticides consist of complex organic compounds, which, like some detergents, are not removed by normal filtration processes nor broken down by bacterial action. Consequently, the insecticides may reach the ground-water body.

Fresh-water aquifers could also become contaminated by saline water leaking upward from the marine sedimentary rocks which underlie the study area. Natural upward leakage through the younger rocks has occurred, and leakage through wells tapping both fresh- and salt-water aquifers is a possibility. A well penetrating a salt-water aquifer should be sealed above that aquifer. A faulty or ruptured seal may permit upward leakage of salt water through the well into overlying fresh-water aquifers.

Natural upward leakage has apparently occurred locally, as indicated by the unusually high mineral content (including sodium and chloride) of the sample from well 3/1W–27R1, which taps basalt of the Columbia River Group (table 7). The problem could become more widespread if pumping from deeper aquifers is increased. In the west-side business district of Portland, intensive pumping for air conditioning has reduced artesian pressure in the basalt aquifers and induced upward leakage of saline water from underlying marine sedimentary rocks (Brown, S. G., 1963, p. 23).

EFFECTS OF SAND ON WELLS AND WATER-SUPPLY SYSTEMS

One of the major problems affecting development of ground water in the French Prairie area is sand seepage into wells. The problem, which is acute in the St. Paul-Donald subarea where water-bearing materials are mostly fine sand, can affect future development of ground water elsewhere in the area unless appropriate precautions are taken. Sand that enters well bores along with the water reduces the life and efficiency of wells and equipment because of its abrasive action.

A method commonly used in well construction in areas where sand is a problem is to place an envelope of coarse sand or gravel (artificial gravel pack) around the perforated part of the well casing; the procedure is referred to as artificial gravel packing, although the pack material may consist entirely of sand. The gravel pack increases the effective diameter of the well and stabilizes the sand in the aquifers. In some wells, however, the gravel packs have not been entirely effective, and the wells continue to pump sand and lose their efficiency.

Fabricated well screens are another means of coping with the sand problem. The initial cost for a screened well is higher than for a gravel-pack well with perforated casing (the most common type in the area). However, some prefer the screened well which they claim is a better long-term investment because screens usually have a longer life than perforated casings. Screened wells also afford greater control over the slot-size opening and allow greater exposure of the aquifer to the well per unit depth penetrated. Thus, a maximum amount of sand-free water can be pumped with a minimum amount of drawdown provided a proper match of screen to sand size is selected.

SUMMARY AND CONCLUSIONS

The French Prairie area, a rich agricultural area in the northern Willamette Valley plain, is underlain to depths of as much as 650 feet by unconsolidated and partly consolidated nonmarine sedimentary rocks. The rocks range in age from early(?) Pliocene to Recent and overlie basalt of Miocene age and older marine sedimentary rocks.

The nonmarine sedimentary rocks form the principal ground-water reservoir in the French Prairie area. Wells tapping these rocks supply nearly all the water for irrigation and industrial use, and virtually all the water for municipal and domestic use in the area. About 20,000 acre-feet of water was pumped from wells in 1960; the most productive wells tap the early Pliocene Troutdale Formation and Recent alluvium of the Willamette River.

The ground-water reservoir acts as a regulator of the hydrologic system of the northern Willamette Valley. During the wet winters, much of the precipitation percolates to the water table and increases the ground-water storage. The reservoir continuously discharges through seeps and springs and by evapotranspiration. In 1960, about 113,000 acre-feet discharged through seeps and springs, and perhaps another 113,000 acre-feet of ground water discharged by evapotranspiration.

The maximum storage capacity of the reservoir between the depths of 10 and 200 feet is estimated to be about 4 million acre-feet. The seasonal change of ground-water storage was about 182,000 acre-feet in 1960. Long-term records of ground-water levels in the area indicate that the seasonal change in storage in past years may have been about the same as that estimated for 1960. Long-term water-level records also indicate that the water drained from the reservoir each summer was fully replaced by the following winter's rains and by other sources of recharge.

The ground-water reservoir is recharged mainly by infiltration of precipitation in the study area. Infiltration from about 28 inches of precipitation (about 70 percent of the average annual precipitation recorded at Salem) was required to refill the reservoir in 1960; this may be the minimum amount of precipitation needed to refill the reservoir under the present status of development.

The facts that (a) natural ground-water discharge far exceeds pumping withdrawals and (b) some of the water available for recharge is rejected when annual precipitation exceeds 28 inches, indicate that the reservoir was not fully utilized in 1960 and therefore could support greater pumping withdrawals. Increased pumping would intercept some of the water lost by natural discharge and, by lowering the water table, would provide additional storage space at lower levels in the reservoir for late-winter recharge.

Increasing pumping withdrawals fivefold (to 100,000 acre-ft per yr) would decrease streamflow slightly in the area. The decreased flow might be measurable in the smaller streams because their flow is relatively small and is obtained almost entirely from ground water during the normal low-flow periods. The reduction in flow of the Willamette River, however, would probably be negligible under any foreseeable level of development. For example, an annual pumpage withdrawal of about 100,000 acre-feet—enough water to irrigate most of the arable land in the area—would be less than 0.5 percent of the average annual flow of the Willamette River where it leaves the study area. This does not mean, however, that the flow of the river would decrease by about 0.5 percent owing to pumpage of 100,000 acre-feet, because much of the water pumped would percolate back to the ground-water body and eventually to the river.

An increase in withdrawals would probably be accompanied by a reduced operating level of the ground-water reservoir. The lowering would vary according to the distribution of withdrawals and would range from a few feet to a few tens of feet if the rate were increased to 100,000 acre-feet per year.

Several problems can be anticipated as ground-water withdrawals continue to increase in the area. These include (a) local interference between pumping wells, (b) undesirable changes in chemical and physical quality of the ground water, and (c) damaging effects of sand on wells and water-supply systems. Each of these problems has been or currently is being experienced locally in the area.

Interference between pumping wells occurs locally in the area and can be expected to become more widespread as more wells are drilled. Interference cannot be avoided if the reservoir is extensively developed, but it can be minimized by providing for the widest possible spacing between wells.

The chemical quality of water in the nonmarine sedimentary rocks is generally good for most uses. However, undesirable changes in quality of water in the lower part of the nonmarine section may occur in heavily pumped areas by upward leakage of saline water from the underlying marine sedimentary rocks. Contamination of ground water can also occur where contaminants percolate into aquifers from points of refuse disposal, as has occurred in the past (p. 73).

Another major problem affecting development of ground water in the area is the costly wear of sand on pumping equipment and water-supply systems. This problem could be virtually eliminated by careful design, construction, and logging of wells, and by more widespread use of properly designed and fabricated well screens.

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BASIC DATA

TABLE 5.—*Records of representative wells in the French Prairie area, Oregon*

Well number: See p. 5 for description of well-numbering system.
Type of well: Dg, dug; Dr, drilled.
Finish: B, open bottom (casing unperforated); G, gravel packed; P, casing perforated; Sc, screened. Depth interval of gravel pack, perforations, and screen given in feet below land surface at well.
Altitude: Altitude of land-surface datum at well, in feet above mean sea level, interpolated from topographic maps.
Water level: Depths to water given in feet and decimal fractions are measured; those given in whole feet are reported by the well owner or driller. F, flowing well whose static water level is not known.
Type of pump: C, centrifugal; J, jet; N, none; S, submersible; T, turbine.
Well performance: Yield and drawdown (below nondischarging water level) reported by owner, operator, driller, or pump company. b, bailing yields; f, flowing yields.
Use: D, domestic; Ind, industrial; Irr, irrigation; N, none; PS, public supply; S, stock.
Remarks: Ca, chemical analysis in table 7; H, hydrograph included in this report; L, driller's log of well in table 6; S, laboratory analyses of drill-cutting samples in tables 2 and 3; ppm, parts per million; Temp, temperature of water in degrees Fahrenheit; specific conductance in micromhos at 25° C. Remarks on the adequacy and dependability of water supply, general quality of water, and materials penetrated are reported by owners, tenants, drillers, or others.

Well	Owner	Type of well	Year completed	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Finish	Water-bearing zone(s)			Altitude (feet)	Water level		Type of pump and horsepower	Well performance		Use	Remarks
								Depth to top (feet)	Thickness (feet)	Character of material		Feet below datum	Date		Yield (gpm)	Drawdown (feet)		
CLACKAMAS COUNTY T. 3 S., R. 1 W.																		
25K1	Oregon State Univ.	Dr	1959	200	10	155	P, 115–130½	114	18	Sand, gravel, and clay.	165	42.28	2- 1-60	T, 25	270	9	Irr	Temp 54; L.
							P, 146–148	145	3	Sand and small gravel.					350	11		
27R1	Conrad Green.	Dr	1962	1,004	10, 8	682	B	862	10	Basalt	175	40	9-13-62	J	50	150	D	Ca, L.
								986	14	do								
35H1	J. E. Langdon.	Dr	1951	143	12	------	------	------	------	Gravel	185	58.11	2-29-60	T, 20	------	------	Irr	Unused in 1959–63; H.
35N1	Earl Barber	Dr	1950	180	10	170	P, 153–176	142	34	Sand and gravel.	190	33	9- -50	T, 30	325	105	Irr	Irrigates 40 acres.

MARION COUNTY

T. 3 S., R. 2 W.

29F1	City of Newberg.	Dr	1950	90	12	88	P, 78–88	77	11	Coarse gravel.	80	30	7– -50	S, 40	750	0	PS	Ca.
29F2	do	Dr	1951	100	12	95	P, 60–70	40	48	Gravel	80	32	12-10-51	S, 40	1,000	30	PS	L.

T. 4 S., R. 1 W.

5P2	J. P. Leavy.	Dr	1951	120	10	120	P, 80–120	110	10	Gravel	172	23.45	1-26-60	T, 40	490	85	Irr	Irrigates 143 acres; Ca.
14C2	Aurora Telephone Co.	Dr	1957	217	6	200	P, 107–115	107 217(?)	7 ------	do Sand	} 180	45	1– -57	J	40b	35	D	Hardness 101 ppm, specific conductance 274; S.
16P1	E. W. DeKoning.	Dr	1961	105	6	105	B	102	3	Gravel	182	23	1-19-61	S, 1½	70	60	D	L, S.
18C1	T. H. Yergen.	Dr	1958	102	6	96	B	98	4	Coarse sand and gravel.	170	23	11– -58	J	60b	15	D	
23A1	E. E. Bradtle.	Dr	1955	476	10, 6, 5	284	{P, 112–113 {P, 121–122	112 121	1 1+	Small gravel do	} 182	62	3– 7-60	T, 10	230	82	D, Irr	Casing: 10-in., 0–284 ft; 6-in., 0–62 ft; 5-in., 62–232 ft.
34E1	City of Hubbard.	Dr	1931	225	6	------	------	------	------	------	180	------	------	T, 5	150	------	PS	Originally 130 ft deep in 1918; temp 53.5; Ca.

T. 4 S., R. 2 W.

2G1	Oregon State Highway Dept. (Champoeg State Park).	Dr	1963	205	6	190	B	175	15	Clay, sand, and fine gravel.	98	8.29	1-22-63	N	------	------	N	Drilled to test aquifer materials; L.
2G2	do	Dr	1963	202	6	187	Sc, 187–202	187	15	Sand	98	10.83	8– 7-63	T, 3	64	28	Irr, PS	Rotary-drilled demonstration well; temp 56.
2M1	do	Dr	1960	243	6	220	B	238	5	Black sand	140	27	11-21-60	------	183	18	D	S.

TABLE 5.—*Records of representative wells in the French Prairie area, Oregon*—Continued

Well	Owner	Type of well	Year completed	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Finish	Water-bearing zone(s): Depth to top (feet)	Water-bearing zone(s): Thickness (feet)	Water-bearing zone(s): Character of material	Altitude (feet)	Water level: Feet below datum	Water level: Date	Type of pump and horsepower	Well performance: Yield (gpm)	Well performance: Drawdown (feet)	Use	Remarks
8F1	Nelson Tribbett.	Dr	1959	420	12, 8, 6	420	P, 265–268	260	9	Broken, hard sand, small gravel, and pumice.	172	65	12- -59	N	200	------	N	Casing: 12-in., 0–336 ft.; 8-in., 334–394 ft.; 6-in., 368–420 ft.; well silted in and replaced by G1.
							P, 316–318	316	5	Coarse sand and small gravel.								
8G1	do	Dr	1960	242	12, 8, 6	227	P, 55–60	55	5	Sand	175	27	4- -60	T, 15	200	100	Irr	Casing: 12-in., 0–140 ft.; 8-in., 0–227 ft.; 6-in., 0–84 ft.; temp 52.
17E1	Tressie Mullen.	Dr	1955	160	8	160	P, 100–160; G, 0–160	120	40	do	170	21.70	2-13-60	S	370	75	D	Temp 56; Ca, H.
18L1	F. L. Zielinski.	Dr	1956	781	10	510	P, 117–119	114	5	Sand and gravel.	171	47.30	8- 2-60	N	300 420	85 85	N	Deepened from former 119-ft. depth; produced "salt water" from below 510 ft.; abandoned; L.
19M1	M. H. Merton.	Dr	1957	137	16	132	P, 129–130	23	4	Sand	165	27.55	1-22-60	T, 30	620	69	Irr	
								59	2	Black sand								
								120	8	Coarse black sand.								
								128	4	Gravel								

20G1	William Gooding.	Dr	Prior to 1928.	147	6	147	B	147	------	Gravel and coarse sand.	170	20.25	1-22-60	T	------	------	D, S, Irr	Ca.
21H1	George Fick.	Dr	1960	126	20, 16, 12	126	P, 75-85	85	5	Black sand	165	F	1960	T, 40	400	25	Irr	
							P, 21-120	93	5	Brown sand					600	58		
							G, 0-126	101	4	do					1,000	85		
							------	105	11	Gravel								
							------	117	8	Black sand and gravel.								
34R1	Johnson School.	Dg	Prior to 1928.	20	18	------	------	------	------	------	173	17.72	9- 1-59	N	------	------	N	Ca, H.
T. 5 S., R. 1 W.																		
3K1	Julius Ramlo.	Dr	1959	102	6	102	B	95	7	Gravel	162	31.15	1-30-60	J	90	50	D	Ca, H.
4A1	Howard Hopkins.	Dr	1960	135+	8	------	------	------	------	------	180	------	------	T	------	------	Irr	S.
7E1	Senior Citizens of the West, Inc.	Dr	1960	157	18, 12	157	P, 115-150	119	33	Sand and gravel.	182	18	12-15-60	T	500	82	PS	S.
17M2	General Foods Corp. (Birds Eye Div.).	Dr	1946	200	12	170	P, 123-135	122	13	Gravel	180	23	6- 3-46	T, 60	750	40	Ind	
							P, 142-154	141	9	Cemented gravel.					1,000	50		
							P, 160-170	150	14	------								
17M4	do	Dr	1963	229	20, 12	228	Sc, 190-215	185	42	Sand and gravel.	180	31	5- -63	T	850	85	Ind	Temp 56.
T. 5 S., R. 2 W.																		
1J1	Donald Klute.	Dr	1958	260	8	200	P, 121-128	119	5	Brown sand and coarse gravel.	178	16.13	1-21-60	T, C	155	------	D, S, Irr	Temp 53; L.
22Q1	S. J. Payne.	Dr	1960	130	6	130	B	129	1	Sand and gravel.	188	30	8- -60	------	20b	15	D	L, S.
25M1	Agr. Research Found. (Sam H. Brown).	Dr	1930	255	18, 6	252¼	P, 117-147	112	31	do	180	33.18	9- 1-59	T, 20	620	40	Irr	Casing: 18-in., 0-155 ft; 6-in., 155-255 ft; irrigates 146 acres; H.
							P, 215-245	218	25	do					940	49		

TABLE 5.—*Records of representative wells in the French Prairie area, Oregon*—Continued

Well	Owner	Type of well	Year completed	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Finish	Water-bearing zone(s): Depth to top (feet)	Water-bearing zone(s): Thickness (feet)	Water-bearing zone(s): Character of material	Altitude (feet)	Water level: Feet below datum	Water level: Date	Type of pump and horsepower	Well performance: Yield (gpm)	Well performance: Drawdown (feet)	Use	Remarks
T. 5 S., R. 3 W.																		
13P1	C. Anderson (formerly S. F. Parker).	Dg	-------	29½	36	------	B	------	------	------	175	25.83	9-28-36	------	------	------	------	Temp 50; Ca.
T. 6 S., R. 2 W.																		
5N1	Fred Zielinski (formerly G. W. Lemery).	Dr	1922	115	8	123	------	123	------	Gravel	178	13.45	1-18-60	N	30	5	N	Well 299 in Water-Supply Paper 890; original depth 123 ft; H.
31L1	U.S. Bur. Indian Affairs, Chemawa Indian School.	Dr	1957	55	10	56	P, 44-55	36 42½	1½ 12½	Browngravel. Sand and gravel.	145	8.37	4-16-60	C	140 300	10 36	Irr, S	H.
32G1	Waldo Gilbert.	Dr	1959	101	10	101	P, 72-100	86	15	Sand and gravel.	180	36.88	3-5-60	T, 15	150 400	10 34	Irr	Temp 56; Ca.

T. 6 S., R. 3 W.

3A1	C. A. LaMar.	Dr		36	10			36		Gravel	105	14	1-14-60	C, 30	200		Irr	H.
26D2	Felix Reidel	Dr	1960	140	10	140	P, 100-140	92	48	Sand and gravel.	181	65	8- 5-60				PS	Supply for housing development.
33R1	G. E. Stolz	Dr	Prior to 1928.	57	8, 6	57		47	10	Coarse gravel.	133	10.85	2- 2-30		400	2½	Irr	Casing: 8-in., 0-47 ft; 6-in., 47-57 ft; H.
36Q1	U.S. Bur. Indian Affairs, Chemawa Indian School.	Dr	1944	130	12					Gravel	165	36	1944	T, 30	1,600	12	Irr	Used also for standby domestic supply; L.

T. 7 S., R. 2 W.

7E1	V. L. Cooley.	Dr	1959	206	10	206	P, 105-203			Sand and gravel.	180	16	5-16-58	T	500	70	PS	Supplies small housing development.

T. 7 S., R. 3 W.

11L11	C. E. Weese	Dr	1947	33	5		B			Sand and gravel.	147	23±	1947	J, ¼	20		Irr	Ca.
11P1	Salem Sand & Gravel Co.	Dr	1935	228	12, 8	228	P	36	4	Gravel	140	4	1935	T	750	4	Ind	L.
								50	1	do								
								90	2	do								
								135	2	do								
								180	2	do								
								220	8	do								

TABLE 6.—*Drillers' logs of representative wells*

3/1W-25K1

[Oregon State Univ. Alt 165 ft. Drilled by Robinson Drilling & Supply Co., 1959. Casing: 10-in., 0-155 ft.; perforated, 115-130½ ft., 146-148 ft., and 152½-154½ ft.]

Materials	Thickness (feet)	Depth (feet)
Willamette Silt:		
Top soil and silt, yellow	10	10
Sand, silty, firm	20	30
Sand, brown, fine	8½	38½
Gravel, pea-sized	1½	40
Clay, yellow	24	64
Sand, brown, dirty	31	95
Troutdale Formation:		
Gravel, fine; clay, yellow, compact	5	100
Clay, dark-gray; leaves	3	103
Sand, black, fine	5	108
Sand, brown, dirty	6	114
Sand, brown; gravel, fine; clay	15	129
Gravel, fine; clay, yellow	3	132
Sand, yellow-brown	10	142
Sand, brown, coarser	3	145
Sand, black, and gravel, fine	2	147
Sand, black, and wood fragments	4	151
Sand and gravel	2	153
Sandy River(?) Mudstone:		
Clay or shale, blue	27	180
Clay, yellow	10	190
Shale, blue	10	200

3/1W-27R1

[C. E. Green. Alt 175 ft. Drilled by Skyles Drilling & Supply Co., 1962. Casing: 10-in. 0-333 ft.; 8-in. 333-682 ft.; perforated]

Materials	Thickness (feet)	Depth (feet)
Willamette Silt:		
Top soil and silt	7	7
Silt and sand	74	81
Troutdale Formation:		
Sand, red, with clay	8	89
Sand, red, packed	22	111
Clay, tan	9	120
Gravel, fine, with clay	3	123
Gravel, coarse, with clay	5	128
Clay, blue	16	144
Sand, black, medium	13	157
Sand, black, fine	23	180
Sand, black, fine, with fine gravel	3	183
Sand, black, fine, with gray clay	16	199
Clay, green	8	207
Clay, blue	4	211
Clay, yellow	5	216

TABLE 6.—*Drillers' logs of representative wells*—Continued

3/1W-27R1—Continued

Materials	Thickness (feet)	Depth (feet)
Troutdale Formation—Continued		
Clay, brown and blue	7	223
Clay, yellow	22	245
Clay, brown	28	273
Clay, tan	57	330
Sand and medium gravel, cemented	8	338
Sandy River(?) Mudstone:		
Clay, gray	97	435
Shale, gray	10	445
Sand, blue, fine	7	452
Clay, gray	4	456
Sand, blue, fine	7	463
Clay, blue	45	508
Clay, gray	37	545
Clay, brown	15	560
Clay, brown, with medium sand	3	563
Clay, gray	7	570
Clay and gravel with wood	28	598
Clay, blue	11	609
Clay, gray	6	615
Clay, brown	36	651
Columbia River Basalt:		
Rock, gray, weathered	6	657
Clay, gray	12	669
Rock, brown, weathered	6	675
Rock, gray	13	688
Rock, red	7	695
Rock, gray, hard	61	756
Rock, gray, soft	8	764
Rock, red, soft	3	767
Rock, gray, weathered	39	806
Basalt	56	862
Rock, porous, water-bearing	10	872
Basalt	114	986
Rock, porous, water-bearing	18	1,004

TABLE 6.—*Drillers' logs of representative wells*—Continued

4/2W-2G1

[Oregon State Highway Dept. (Champoeg State Park). Alt 98 ft. Drilled by Hansen Drilling Co., 1963. Casing: Cased with 6 in.-diam plastic pipe to 190 ft]

Materials	Thickness (feet)	Depth (feet)
Recent alluvium:		
Soil, brown, silty	23	23
Clay, dark-gray, silty to sandy	45	68
Clay, dark blue-gray	5	73
Clay, dark blue-gray, sandy	7	80
Sand (lost drilling fluid)	2	82
Clay, dark-blue, silty; some sand	6	88
Troutdale Formation:		
Gravel, fine, cemented with clay	12	102
Clay, dark-gray, sandy	16	118
Gravel, black, cemented; some wood fragments	1	119
Clay, dark blue-gray, silty; some fine sand	3	122
Gravel, very fine, cemented	1	123
Clay, blue-gray; very fine sand	29	152
Clay, blue-gray; coarse sand to fine gravel	3	155
Clay, dark blue-gray, sandy	9	164
Clay and coarse sand	1	165
Clay, sandy, with pebbles and pieces of wood	16	181
Sand, coarse, cemented with clay	3	184
Clay, sandy	1	185
Sand, coarse, to gravel	5	190
Sandy River(?) Mudstone:		
Clay, dark blue-gray, tight	15	205

TABLE 6.—*Drillers' logs of representative wells*—Continued

4/2W-18L1

[F. L. Zielinski. Alt 171 ft. Drilled by J. T. Miller, 1956. Casing: 10-in. to 510 ft; perforated 117–119 ft]

Materials	Thickness (feet)	Depth (feet)
No record—old well	114	114
Troutdale Formation:		
Sand and gravel	5	119
Sandy River(?) Mudstone:		
Clay, black, red, and green	251	370
Clay, red and brown	28	398
Columbia River Basalt:		
"Conglomerate," red, brown, yellow, and green with 3 percent basalt in layers 1–2 in. thick	59	457
Clay, red	27	484
Sand, gray, hard, water-bearing	4	488
Shale, hard, red, with basalt	20	508
Clay, red	13	521
Rock, black, soft	3	524
Clay, red, brown	22	546
Clay, brown, soft	28	574
Clay, gray, brown, and blue	18	592
Clay, gray, with hard streaks	8	600
Rock, black	10	610
Marine sedimentary rocks(?):		
No log	171	781

TABLE 6.—*Drillers' logs of representative wells*—Continued

5/1W-17M2

[General Foods Corp., Birds Eye Div. Alt 180 ft. Drilled by R. J. Strasser, 1946. Casing: 12-in. to 170 ft.; perforated 123-135 ft., 142-154 ft., and 160-170 ft]

Materials	Thickness (feet)	Depth (feet)
Willamette Silt:		
Top soil	4	4
Silt, brown, sandy	42	46
Silt, blue, sandy	32	78
Sand	15	93
Troutdale Formation:		
Gravel with clay binder	5	98
Sand	20	118
Sand and gravel, tight	4	122
Gravel, water-bearing	13	135
Gravel, cemented, tight	6	141
Gravel, cemented, looser	9	150
Sand and gravel, water-bearing	14	164
Gravel, cemented	5	169
Sandy River(?) Mudstone:		
Shale	27	196
Sand	4	200

5/2W-1J1

[Donald Klute. Alt 178 ft. Drilled by J. W. Beck Well Drilling Co., 1958. Casing: 8-in. to 200 ft.; perforated 121-128 ft]

Materials	Thickness (feet)	Depth (feet)
Willamette Silt:		
Top soil	3	3
Silt, brown	24	27
Silt, blue	51	78
Clay, blue	10	88
Sand	21	109
Clay, brown	7	116
Sand, brown, fine	3	119
Troutdale Formation:		
Sand, brown, and gravel, coarse	5	124
Silt, brown	2	126
Sand, black	36	162
Clay, light-blue	6	168
Sand, greenish, fine	14	182
Sandy River(?) Mudstone:		
Silt, dark-blue	12	194
Clay, blue	12	206
Silt and sand, blue	20	226
Clay, dark-green	8	234
Shale, blue, broken	26	260

TABLE 6.—*Drillers' logs of representative wells*—Continued

7/3W-11P1

[Salem Sand & Gravel Co. Alt 140 ft. Drilled in 1935; driller unknown. Casing: 12-in. to 228 ft; perforated opposite all water-bearing zones]

Materials	Thickness (feet)	Depth (feet)
Recent alluvium:		
Gravel, cemented	36	36
Gravel, water-bearing	4	40
Troutdale Formation:		
Gravel (to 6-in. diam), cemented	10	50
Gravel, water-bearing	1	51
Gravel (to 6-in. diam), cemented	8	59
Clay, blue	7	66
Gravel and boulders, cemented	14	80
Sand, cemented	10	90
Gravel, water-bearing	2	92
Gravel (to 6-in. diam), cemented	43	135
Gravel, water-bearing	2	137
Gravel, cemented; small boulders	38	175
Sand, cemented	5	180
Gravel, water-bearing	2	182
Gravel and boulders, cemented	38	220
Gravel, water-bearing	8	228

TABLE 7.—*Chemical analyses of water from wells, springs, and streams in the French Prairie area*

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

	Source	Geologic formation [1]	Date of collection	Temperature (° F)	Silica (SiO_2)	Iron (Fe)[2]	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
	Ground water																					
	[Spring or water-bearing zone(s) (feet)]																					
3/1W-27R1	862–872, 986–1,004	Tcr	6–18–63	54	41	2.3	92	11	147	16	62	0	0.5	400	0.5	0.4	[3] 742	276	55	3.7	1,370	7.6
[4] 3/2W-29F1	77–88	Qal	12–31–47	----	54	4.0	18	12	----	----	105	0	6.8	2.5	.1	.0	----	93	----	----	----	6.6
3/2W-29F1	77–88	Qal	8–13–49	----	24	2.6	12	2.2	----	----	75	0	2.5	1.7	.1	.1	----	37	----	----	----	6.7
4/1W-5P2	80–120	Tt	6– 1–60	52	36	2.6T	39	12	11	3.4	192	0	5.2	5.0	.2	.1	207	146	14	.4	312	7.1
15Hs	Giesy Mineral Spring.	Tm	11– 9–61	56	49	1.9	1,370	44	1,060	64	51	0	3.1	4,190	.8	4.0	6,810	3,600	40	7.7	12,100	6.9
33Bs	Hubbard Mineral Spring.	Tt	11– 4–61	54	48	1.4	29	13	7.6	1.9	153	0	8.0	8.2	.1	.3	192	127	13	.3	276	7.3
34E1	----	Tt(?)	10–10–28	54	41	.50	17	6.3	5.6	1.4	88	0	4.9	2.6	----	.4	123	68	17	.3	----	----
4/2W-2D1	166	Tt	6– 1–60	55	31	.22	22	6.1	71	1.5	242	0	1.6	23	.1	.1	276	80	68	4.4	342	7.9
15N2	160	Tt	6– 1–60	55	48	.69	23	9.0	9.8	1.9	138	0	2.0	2.5	.3	.1	165	94	18	.4	217	7.6
17E1	100–160	Tt	6– 1–60	56	48	4.0T	28	12	7.7	1.5	157	0	2.8	2.2	.1	2.9	182	120	12	.3	254	7.8
19G1	160(?)	Tt	4–14–58	52	20	.20	30	9.7	39	1.0	240	0	2.7	3.0	.1	.0	224	115	42	1.6	368	8.0
20G1	147	Tt	10–10–28	52	43	5.3	27	11	12	1.7	165	0	3.3	2.5	----	.1	182	113	20	.5	----	----
34R1	20±	Qws	10–10–28	53	28	.15T	41	4.4	9.0	1.2	159	0	5.8	.0	----	1.0	172	121	15	.4	----	----

5/1W-3K1	95-102	Tt	6- 1-60	55	45	1.6	19	6.1	5.9	2.5	103	0	.4	3.0	.2	.1	135	72	15	.3	168	7.7
5/2W-4M1	70-90	Tt	6- 1-60	53	46	.43	24	11	15	1.7	167	0	.2	2.5	.2	.1	183	106	23	.6	255	7.8
26G1	120-140	Tt	10-20-28	56	48	1.2T	25	18	15	1.7	193	0	2.9	3.5	----	1.1	210	136	20	.6	---------	----
26G1	120-140	Tt	6-10-52	56	47	.62T	25	17	15	2.2	192	0	1.7	11	.1	2.0	216	132	19	.6	308	7.7
26G1	120-140	Tt	6- 1-60	55	49	1.2	24	18	15	2.2	195	0	.8	3.8	.4	.2	211	133	19	.6	300	7.6
32C1	96-103	Tt	6- 1-60	----	44	.62T	34	9.0	7.2	3.0	158	0	.8	5.0	.2	.1	181	122	11	.3	255	7.6
5/3W-13P1	29½	Qal	10-10-28	50	19	.46T	17	6.1	26	6.0	57	0	12	26	----	43	183	68	49	1.4	---------	----
6/2W-15H1	25-100, 125-130, 140-150	Tt	6- 1-60	57	46	.62	17	8.3	6.9	1.3	108	0	1.2	2.2	.3	.1	137	76	16	.3	172	7.7
32G1	72-100	Tt	6- 1-60	52	64	1.2	21	10	7.6	1.4	99	0	3.6	4.0	.2	24	186	94	15	.3	221	6.7
6/3W-2F1	40-45, 63-65, 190-230	Qal and Tt	6- 1-60	54	41	.29	21	13	21	2.2	180	0	1.6	5.5	.1	.2	195	107	29	.9	273	7.9
15F1	44	Qal	6- 1-60	----	41	.06	25	12	9.2	1.3	106	0	13	3.2	.1	29	186	112	16	.4	265	6.8
28R1	30	Qal	10-13-28	52	42	.15	16	10	3.5	.4	92	0	5.8	5.0	----	4.0	132	81	9	.2	---------	----
[5]7/3W-11L1	33	Qal	10- 7-47	----	46	.04	279	146	[6]47		116	0	1,230	9.5	.0	26	1,840	1,310	----	----	2,110	7.3
	Surface water																					
	Willamette River at Salem.	----------	7- 8-60	----	14	--------	5.5	2.0	3.7	.6	32	0	2.2	2.8	.0	.0	54	------	33	.3	64	7.1
	Willamette River at Wilsonville.	----------	4- 8-52	----	15	.04	4.3	1.7	3.2	.7	27	0	1.9	1.8	.2	.3	44	18	31	.3	44	7.3
	Pudding River at Aurora.	----------	2-20-51	44	17	--------	--------	------	5.5		28	0	4	2.9	----	2.1	------	21	----	----	57.7	----
	-----do---------	----------	4-21-54	52	16	.35T	6.6	.7	3.2	.8	27	0	1.5	1.8	.2	1.2	52	19	40	----	55.5	7.4

[1] Qal, alluvium; Qws, Willamette Silt; Tt, Troutdale Formation; Tcr, Columbia River Group; Tm, marine sedimentary rocks.
[2] All Geological Survey iron determinations except those followed by "T" represent iron in solution at the time of sample collection. "T" indicates a total iron value, which applies to samples that were turbid or contained sediment when collected.
[3] Includes 0.1 ppm manganese (Mn), 0.03 ppm orthophosphate (PO_4), and 0.12 ppm boron (B).
[4] Analysis by Charlton Laboratories, Portland, Oreg.
[5] Contaminated by industrial waste. (See p. 73.).
[6] Calculated sodium plus potassium, expressed as sodium.

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