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GEOLOGICAL SURVEY

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GROUND WATER IN THE EAST PORTLAND AREA, OREGON

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ABSTRACT

The eastern part of the city of Portland, Oreg., and the suburban and rural districts extending north to the Columbia River, south to the Clackamas River, and from the Willamette River on the west to the Sandy River on the east constitute an area of rapid population growth in which progressively greater amounts of ground water are being sought for industrial, irrigation, and public supplies. It is also an area of diverse geologic and hydrologic conditions.

The area occupies part of a broad downwarp of pre-Pliocene rocks between the Cascade Mountains and the Coast Range. The principal water-bearing rock units in the area are the Troutdale Formation of early Pliocene age, fluviolacustrine deposits of late Pleistocene age, and alluvium of Recent age. At places, each of these water-bearing units is tapped by wells that yield moderate to large amounts of water of good chemical quality. Locally, the Columbia River Basalt of Miocene age and the Boring Lava of late Pliocene to late (?) Pleistocene age also yield substantial amounts of water. Other sedimentary rocks that are younger than the Columbia River Basalt are saturated at places but are generally fine grained and relatively impermeable and do not readily yield water to wells; these include the Sandy River Mudstone of early (?) Pliocene age, piedmont deposits of early (?) Pleistocene age, and terrace deposits, probably of late Pleistocene age. Rocks underlying the basalt are poorly permeable and yield only small amounts of water, which is commonly of poor chemical quality.

The ground-water bodies are chiefly recharged by infiltration of the abundant precipitation during the autumn, winter, and spring. The general movement of the ground water is toward the large streams that border the area. Discharge of the ground water occurs mainly as seepage to the perennial streams, spring flow and seepage at the land surface, evapotranspiration, and withdrawal from wells.

Many domestic and stock water supplies are obtained at relatively shallow depths from local bodies of ground water perched above the regional water table. The larger supplies are generally obtained from confined or unconfined zones below the regional water table. Those confined and unconfined aquifers are generally dependable perennial sources, but the perched aquifers are locally subject to depletion during the autumn and winter months.

The amount of ground water used in the area during 1960 was nearly 50,000 acre-feet—only a small part of the amount that is replenished naturally each year. Present trends of economic development and population growth in the area, as well as other factors, indicate that future withdrawals will be substantially greater, especially for industrial, irrigation, and public supplies.

Existing problems pertaining to ground water in the area are mostly local in extent and their comprehension is within the scope of available information. Problems that are more serious and extensive, however, are likely to grow with increased use of the ground water and with current waste-disposal practices. The available information is adequate for evaluating some of the factors pertinent to the foreseeable problems, but additional information, which can be obtained through continuing and systematic study, will be needed to meet some of the problems effectively.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The eastern part of the city of Portland, Oreg., and the suburban and rural districts lying north and east of the city constitute an area of rapid population growth, in which progressively greater amounts of ground water are being sought for industrial, irrigation, and public supplies. It is also an area of diverse geologic and hydrologic conditions, which make the success and cost of ground-water development widely different from place to place. Throughout the area, but particularly in the rapidly growing suburban districts, information is needed to aid in the orderly development and effective management of the ground-water resources.

The objective of this investigation is to provide the needed technical guidance by (1) collecting and evaluating sufficient geologic and hydrologic data to permit the reasonable prediction of the ground-water conditions in various parts of the area, (2) determining the present uses of ground water, the outlook for future demands, and the adequacy of the ground-water resources for meeting those demands, (3) outlining the ground-water problems that are likely to arise under present or expected future conditions, and the types of information that are needed to meet those problems.

To obtain the necessary data, representative wells and springs in the area were inventoried, and their locations were plotted on a compiled base map. Geologic information was obtained from the records of various preceding studies but especially from a report by Trimble (1963) and from field reconnaissance. Water levels in selected wells were measured periodically, and chemical analyses were made of samples of water collected from representative wells and springs tapping the various water-bearing units. Data on the climate, the surface-water bodies, and the uses of water were obtained from various published and unpublished sources.

Water for the cities of Portland and Gresham and for some suburban areas is supplied by the Portland Municipal Water Bureau from the Bull Run River. In the parts of the area not supplied from the Bull

Run River, ground water is the principal source of supply. Consequently, the most pressing need for ground-water information exists in those districts. This investigation was mostly concerned with those districts of greatest need, although a considerable amount of information on ground-water occurrence within the city of Portland was collected and is included in this report.

The investigation was conducted by the U.S. Geological Survey as part of a continuing program of water-resource investigations in cooperation with the Oregon State Engineer.

LOCATION AND EXTENT OF THE AREA

This investigation includes those parts of western Multnomah County and northern Clackamas County, in northwestern Oregon, extending from the Columbia River on the north to the Clackamas River on the south and from the Willamette River on the west to the Sandy River on the east (fig. 1).

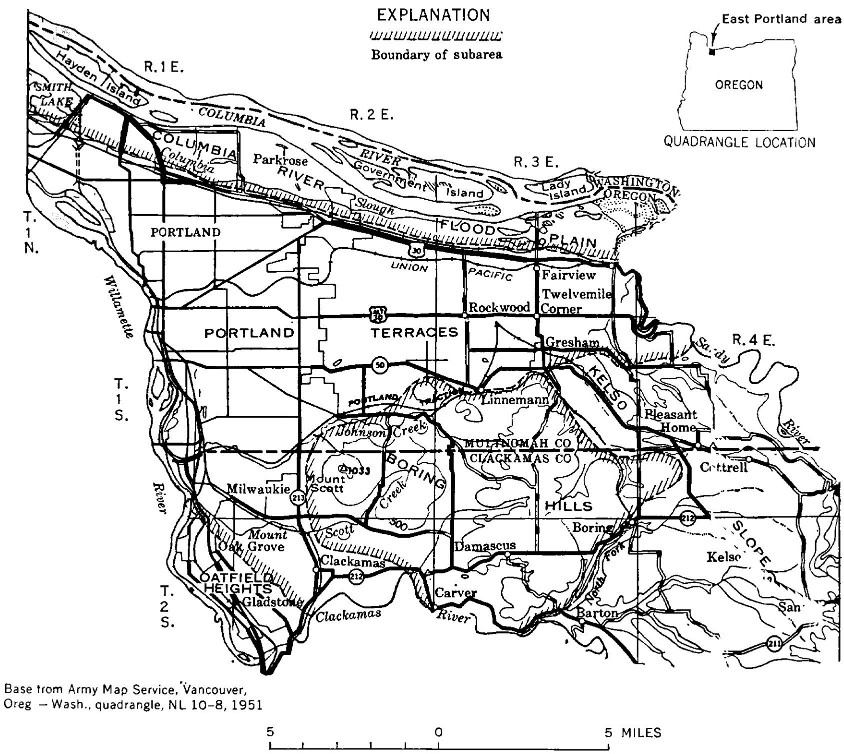

FIGURE 1.—Major physiographic subareas of the East Portland area, Oregon.

The area is roughly diamond shaped; it is about 30 miles long (northwest to southeast) and about 15 miles wide. It covers about 230 square miles and ranges in altitude from about 10 feet on the flood plain of the Columbia River to 1,083 feet at the top of Mount Scott.

The East Portland area constitutes the northeastern part of the extensive Willamette Valley lowland, which lies between the Cascade Range on the east and the Coast Range on the west. It is within the Puget Trough section of the Pacific Border physiographic province (Fenneman, 1931, p. 443–454).

PREVIOUS INVESTIGATIONS

The East Portland area has been included or briefly described in several previous investigations, most of which dealt principally with the geology. The reports of these investigations are included in the list of references cited (p. 74).

The older works include a reconnaissance geologic map covering part of the East Portland area in a report by Darton (1909), and a popular description of Portland and vicinity in a report by Diller (1915, p. 25–33). A popular account of the geology of the Portland area is also included in a report by Williams (1916, p. 14–20) that deals mostly with the geologic history of the Columbia River gorge upstream from Portland.

Bretz (1925, p. 252–256, and 1928, p. 697–700), in two articles describing the physiographic development of the Columbia River valley, briefly discussed the Portland area. Allison (1933, p. 715–718) also cited some geologic evidence in and near the East Portland area in a report proposing an alternative explanation for some of the geologic phenomena described by Bretz.

A reconnaissance geologic map of the area was prepared by Treasher (1942) to accompany a popular account of the geologic history of the Portland area. The area was also discussed by Lowry and Baldwin (1952, p. 1–24) in a paper describing the Cenozoic history of the lower Columbia River valley.

Part of the East Portland area is included in a geologic map of the Portland quadrangle, Oregon-Washington, by Trimble (1957). The mapping of Trimble, begun in 1951, was subsequently extended through several quadrangles adjacent to the Portland quadrangle, including the rest of the East Portland area (Trimble, 1963). The geologic map accompanying this report (pl. 1) is largely based on his work.

Parts of the East Portland area are included in two previous water-resources investigations, and ground-water studies have been made in three adjacent areas. The East Portland area is part of a larger area described by Griffin, Watkins, and Swenson (1956) in a report on the water resources of the Portland, Oreg., and Vancouver, Wash., area. That report includes brief descriptions of the principal streams, the major rock units and their water-bearing character, and a few of the wells in the East Portland area. The western part of the area was included in an investigation of the ground-water resources of the Willamette Valley (Piper, 1942). The report of that study includes a brief discussion of the availability of ground water in the "Portland Delta" and records of a few wells in that part of the area.

A comprehensive study of the occurrence, availability, and chemical quality of the ground water in the Tualatin Valley, which adjoins the southwestern part of the East Portland area, was made by Hart and Newcomb (1965). Mundorff (1964) made a similar study in Clark County, Wash., which is on the north side of the Columbia River opposite the East Portland area. A brief report on the occurrence and problems of utilizing ground water in the west-side business district of Portland (across the Willamette River from the west-central part of the area of this study) was prepared by Brown (1963) concurrently with the present investigation.

ACKNOWLEDGMENTS

The basic data for this investigation were largely supplied by well owners and operators, well drillers, and by pump companies and their representatives. Officials and operating personnel of municipal and suburban water-supply systems contributed valuable information concerning sources and use of water. The courtesy and cooperation of these people are gratefully acknowledged.

The writer was assisted in the collection and compilation of the field data by E. R. Hampton.

Special thanks are due Mr. D. E. Trimble for furnishing preliminary copies of his maps and manuscript for use during this study.

WELL- AND SPRING-NUMBERING SYSTEM

Wells discussed in this report are designated by serial numbers that indicate their location according to the Federal rectangular system of land division. In 1N/1–35N1, for example, the part preceding the hyphen indicates respectively the township and range (T. 1 N., R. 1 E.) north and east of the Willamette base line and meridian. Because most of the State lies south of the Willamette base line and east of the Willamette meridian, the letters indicating the directions south and east are omitted, but the letters "W" and "N" are included for wells lying west of the meridian and north of the base line. The first number after the hyphen indicates the section (sec. 35), and the letter (N) indicates a 40-acre subdivision of the section as shown in figure 2. The final digit is the serial number of the well within that 40-acre tract. Thus, well 1N/1–35N1 is in SW¼SW¼ sec. 35, T. 1 N., R. 1 E., and is the first well in the tract to be listed.

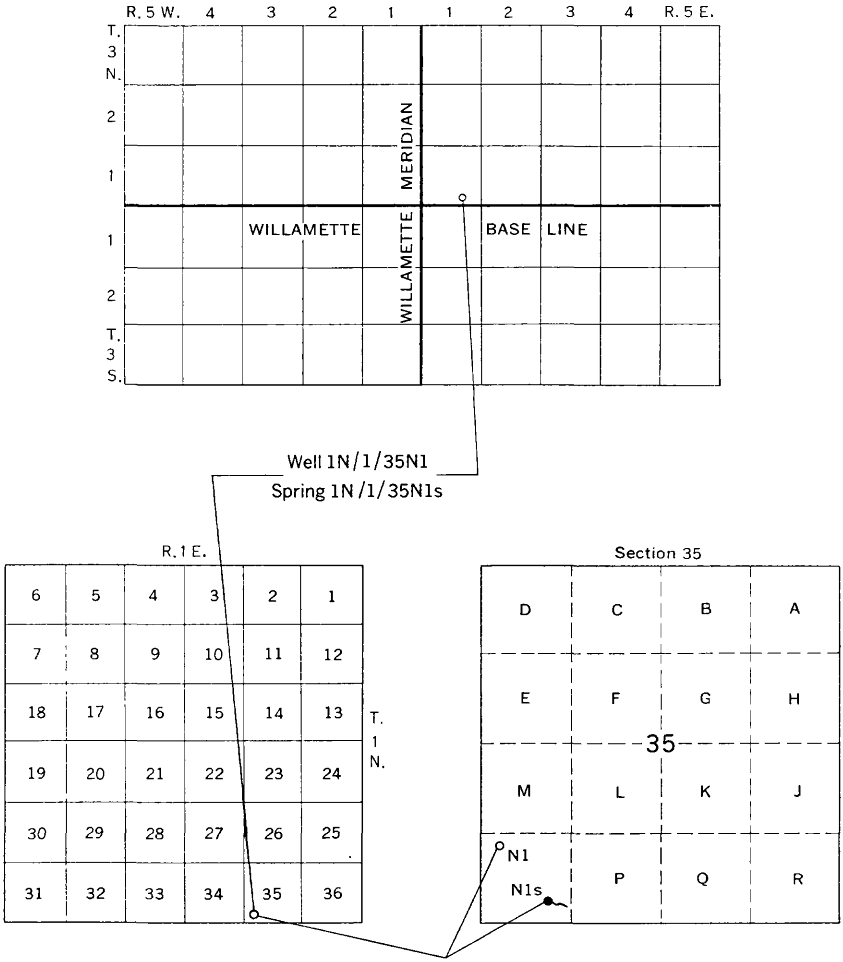

FIGURE 2.—Well- and spring-numbering system.

Springs are numbered in the same manner except that the letter "s" is added following the final digit. Thus, the first spring recorded in SW¼SW¼ sec. 35, T. 1 N., R. 1 E. would have the number 1N/1–35N1s.

In the tables of well and spring records (tables 1 and 4, respectively) the well and spring numbers are not given in full. Only the parts of the numbers following the hyphen are shown (35N1, for example) grouped under subheads that indicate the appropriate township and range. On the map showing locations of representative wells and springs, only the letters indicating location within the section and the serial numbers (as N1, N1s) are shown.

CLIMATE

The East Portland area has a temperate, moderately humid climate. It is separated from the milder, wetter marine climate of the coastal region by the Coast Range and from the drier, continental-type climate of eastern Oregon by the Cascade Range. Airmasses generally enter the area from the west, after passing across the Pacific Ocean. As a result, the ocean exerts a strong moderating influence on the temperatures during both summer and winter.

Climatological data have been collected by the U.S. Weather Bureau at Portland since 1871. Those data indicate that the mean annual temperature at Portland is about 55°F. The highest temperature ever recorded at Portland was 107°F in July 1942, and the lowest was −2°F in January 1888.

Most of the yearly precipitation in the area occurs in the 6-month period from October through March and very little occurs during July and August. The average annual precipitation at Portland during the period 1872–1957 was 42.7 inches. The greatest annual precipitation during that period was 67.2 inches in 1882, and the least was 26.1 in 1929.

The relative humidity at Portland is generally high or moderately high. It generally ranges from about 85 to 93 percent in the early morning (4:00 a.m.) during all months. Later in the day (4:00 p.m.), the relative humidity averages about 70 percent during November through February but is often less than 50 percent during the summer months.

Winds in the East Portland area are commonly gentle. Mean monthly wind velocities range from 6 mph (miles per hour) in October to about 10 mph in December and January. The highest wind velocity recorded at Portland was 88 mph on October 12, 1962. Although the general direction of air movement is from the west, east winds are common, especially along the north fringe of the area, in front of the funnellike opening provided by the Columbia River gorge.

U.S. Weather Bureau records show that the average growing season at Portland is 257 days. Killing frosts have been recorded as late as May 2 and as early as October 13.

CULTURE

The East Portland area includes urban, suburban, and rural districts. The northwestern part is mainly urban and suburban; the southeastern part is rural except for a few communities.

The eastern, and largest, part of metropolitan Portland is on the terraces east of the Willamette River and south of the Columbia River flood plain. Suburbs of Portland extend southward along the east bank of the Willamette to the mouth of the Clackamas River and include the cities of Milwaukie and Gladstone. Other suburban districts extend eastward along the Columbia River almost to the city of Fairview. The remainder of the area is mostly rural, served by the towns and villages of Fairview, Troutdale, Gresham, Wood Village, and Sandy and by hamlets such as Damascus, Boring, Barton, Kelso, and Orient.

The population of Portland in 1960 was 372,680. Much of this population resides in the eastern part of metropolitan Portland. The 1960 census figures for population of other incorporated cities and towns in the area were: Milwaukie, 9,100; Gresham, 3,940; Troutdale, 520; Sandy, 1,150; Wood Village, 820; Gladstone, 3,850; and Fairview, 580.

In 1957, the U.S. Post Office served about 4,070 rural mail boxes in about 150 square miles of the area. If each of these mailboxes represents one rural family of four, the rural population density is about 110 persons per square mile.

Portland is the main center of industry and of international and interstate commerce for a large part of the Pacific Northwest. Its industry is diversified, but consists largely of the manufacture and export of wood and food products and of machinery and equipment.

Outside of metropolitan Portland, the urban centers are mainly commercial, serving the needs of the suburban and rural population and supplying a market for local produce. The principal industries in this part of the area are lumbering, agriculture, and the reduction of alumina ore at a large plant near Troutdale. Important agricultural products of the area include produce from truck gardens, fruits, nuts, berries, dairy products, and ornamental plants.

LANDFORMS AND DRAINAGE

MAJOR TOPOGRAPHIC SUBAREAS

The area of this investigation is almost completely bounded by four large streams—the Columbia River on the north, the Willamette River on the west, the Clackamas River on the south, and the Sandy River on the east. The area includes the following major subareas of distinctive topography: The Boring Hills, the Kelso slope, the Portland terraces, the Oatfield Heights ridge, and the flood plain of the Columbia River (fig. 1). Lesser topographic features are the terraces and small flood plains of the Willamette, Clackamas, and Sandy Rivers and the small hills and buttes scattered within the Portland terraces subarea.

BORING HILLS

The Boring Hills subarea is a generally circular area of rolling hills that occupies about 52 square miles of the south-central part of the East Portland area. This subarea includes about 25 hills and buttes and associated benches and highlands. The individual hills are mostly steep sided and conical or dome shaped, although some have relatively flat or gently rounded tops. The hills are of both volcanic and erosional origin. Several of the hills reach altitudes of about 1,000 feet. The highest is Mount Scott (alt 1,083 ft), which is about 800 feet higher than the terrace to the west and north.

The Boring Hills subarea is divided into three main parts by Pleasant Valley and a similar valley extending from Kunitake station past Hillsview School to the vicinity of Union School. These valleys, which are broad and gently rolling, appear to be upland remnants of a former drainage system that now is largely unoccupied by perennial streams.

KELSO SLOPE

The Kelso slope is a dissected northwestward-sloping surface west of the canyon of the Sandy River, northeast of the Clackamas River canyon, and east of the Boring Hills. It extends northward nearly to Gresham and occupies about 44 square miles. It slopes northwestward from a general altitude of about 1,000 feet near Sandy to about 400 feet east of Gresham, and, in this area, constitutes the lowest part of the foothills of the Cascade Range.

East of Gresham, the Kelso slope terminates in a series of bluffs which apparently originated from erosion, during a former higher level of the Columbia River, at about the time of the formation of the Portland terraces.

Pleasant Valley and the other large valley that dissects the Boring Hills subarea contain surfaces that are generally concordant with the Kelso slope and are underlain by the same type of alluvial deposits. Therefore, these valleys probably were formed contemporaneously with the Kelso slope.

A thick clayey soil underlies most of the Kelso slope. The relatively impermeable soil and the sloping land surface cause a rather rapid runoff of surface water. As a result, a well-developed system of small streams is entrenching itself into the slope. The small streams are fed by local precipitation, and as a result, their rate of downcutting has not kept pace with that of the Sandy and Clackamas Rivers, which are fed by precipitation and snowmelt from the Cascade Range. The tributaries of Deep Creek receive most of the runoff from the Kelso slope. The major branches of this stream leave the slope through several deep, narrow ravines that carry the runoff toward the Clackamas River canyon.

PORTLAND TERRACES

The Portland terraces compose the largest physiographic subunit in the East Portland area. Collectively, they occupy an area of about 100 square miles. They form most of the western, northwestern, and northern parts of the area lying south of the Columbia River flood plain.

The highest terraces, at altitudes of about 300 and 350 feet, respectively, are near Russellville and in the Troutdale-Gresham district. North and west from these highest terraces, the land surface descends across successively lower terraces to the flood plains of the Columbia and Willamette Rivers. These two high terraces are separated by a broad abandoned former channelway trending southwestward from Fairview, past Rockwood, to Lents Junction, where Johnson Creek enters this channelway from the east. At that point, the bottom of this channelway is at an altitude of about 225 feet, decreasing generally toward the southwest. Several shallow undrained depressions are alined along the bottom of the channelway. Southwest of Lents Junction, the erosion by Johnson Creek has lowered the bottom of the channelway to altitudes of less than 200 feet.

Three isolated hills—Rocky Butte, Mount Tabor, and Kelly Butte—rise about 200 to 400 feet above the surrounding terraces. These hills are composed of Boring Lava (p. 23) and associated remnants of the Troutdale Formation (p. 23) and were left as "islands" when the streams were forming the terraces.

The Portland terraces were formed by the ancestral Columbia and Willamette Rivers during a time when the rivers were flowing at higher levels than at present. Abandoned channels and elongated undrained depressions and bars on the terraces are alined in a manner that indicates that the former streams flowed southwestward over most of the terrace area. In the vicinity of the present course of the Willamette River, however, the predominant direction of flow during the formation of the terraces was at times northwestward.

A major feature of the Portland terraces subarea is a broad abandoned stream channel that extends for about 12 miles near the southwestern boundary of the area. This ancient channelway trends northwest at an altitude of about 100 feet from near Clackamas, where it is nearly 2 miles wide, to Milwaukie. There, the abandoned channel turns northward and continues at an altitude of about 50 feet along the east side of the Sellwood district. It merges with the channel of the present Willamette River 1 to 2 miles downstream from Ross Island. This channelway probably once carried the flow of the Clackamas River and perhaps, at times, all or part of the flow of the Willamette River. It is now drained in part by Crystal Springs, Kellogg, lower Johnson, and Mount Scott Creeks.

The Portland terraces do not have a well-developed stream system in all places; the surface features related to drainage largely date back to the period of, and are associated with, terrace formation. The terraces are underlain mostly by permeable sand and gravel, and although the precipitation is fairly abundant, most of it percolates down to the ground-water body and leaves the area by underground migration. Also, at places on the terraces, the precipitation is held at the surface in ponds by relatively impermeable soils and leaves the area by evaporation rather than as surface runoff. Only three fairly large creeks—Johnson, Kellogg, and Beaver Creeks—cross parts of the Portland terrace area. All three have their headwaters either in the Boring Hills or on the Kelso slope.

At places in the vicinity of Fairview, Troutdale, Parkrose, and the Sellwood district of Portland, springs issue at the foot of steep terrace scarps. Some of those near Fairview, Troutdale, and Parkrose are the sources of small streams that flow intermittently to the Columbia River flood plain; those near Sellwood discharge to the lower reaches of Johnson Creek. These springs are the outflow of ground water which occurs at depth beneath the higher terraces.

OATFIELD HEIGHTS RIDGE

Between the Willamette River and the abandoned stream channel previously described is a broad-crested ridge that extends southeastward from the vicinity of Milwaukie to near Gladstone. The ridge seems to have no formal name, but is called Oatfield Heights in this report, in accordance with local usage. The ridge is the southeastward continuation of Palatine Hill, which is north of Oswego on the west side of the Willamette River. Oatfield Heights ridge rises as much as 300 feet above adjacent parts of the Portland terraces. Its northeastern part is drained by small tributaries of Kellogg Creek, and its southwestern part is drained by minor streams flowing to the Willamette River.

Although it is the smallest physiographic subunit, comprising only about 4 square miles, Oatfield Heights ridge is unique in this area with regard both to origin and to the rock materials underlying it. The geology of the subunit is described subsequently in this report.

COLUMBIA RIVER FLOOD PLAIN

The flood plain south of the Columbia River ranges in width from about 1 to 2 miles and is about 25 square miles in total area. It ranges in altitude from about 10 to 30 feet. The flood plain contains several marshes, shallow lakes, and sloughs, in many of which the water levels are kept low by artificial drainage. Most of the flood plain is protected by artificial dikes and is flooded only partly during years of exceptionally heavy rainfall or of very high water in the Columbia River. Under natural conditions, however, the flood plain was partly or completely flooded during normal high-water periods and was naturally drained through a system of sloughs and minor streams.

MINOR FLOOD PLAINS AND TERRACES

Minor flood plains in the valleys of the Sandy, Clackamas, and Willamette Rivers occupy a total area of less than 5 square miles. These flood plains are commonly only a few feet above the mean low stream levels, and parts of them are subject to annual flooding.

Several minor terraces are present in the canyons of the Sandy and Clackamas Rivers. The terraces are small in extent, nearly flat in profile, and slope gently toward the adjacent streams. Most of them are bounded by steep bluffs plunging to the river and rising to the adjacent uplands.

MAJOR STREAMS THAT BORDER THE AREA

The four major streams that border the East Portland area—the Columbia, Willamette, Clackamas, and Sandy Rivers—all descend from remote headwater areas. The channels of the Columbia and Willamette Rivers extend below sea level, and those rivers are affected by tides.

The Columbia River is the master stream of the region. It enters the Portland-Vancouver lowland from the east and flows west-northwestward, its south shore forming the north boundary of the East Portland area. Its annual flood stage generally occurs in the period May to July, and its annual low stage is in the fall or winter months. The range between the annual low and high levels of the Columbia River is usually about 20 feet.

The Willamette River flows north from its headwaters area in west-central Oregon and enters the East Portland area near Gladstone, where it is joined by the Clackamas River. From Gladstone the Willamette flows northwestward between lava bluffs nearly to Sellwood and thence continues northward and northwestward between alluvial terrace scarps. The east shore of the Willamette River forms the west boundary of the area studied.

The Clackamas River forms part of the southern boundary of the East Portland area. It rises in the Cascade Range, from whence it flows westward to join the Willamette River at Gladstone. It is deeply entrenched but occupies a generally broad terraced canyon.

The Sandy River, like the Clackamas, is a mountain stream whose headwaters are in the Cascade Range. It flows into the East Portland area from the southeast and forms part of the east boundary of the area. Through most of its course past the East Portland area, it is deeply entrenched within a narrow canyon. It debouches on the Columbia River flood plain at Troutdale, where it turns sharply northeastward and flows through its own sandy delta to join the Columbia River.

These four major streams receive only small amounts of surface runoff from the few minor streams draining the East Portland area; however, they all, especially the Columbia and Willamette Rivers, receive considerable amounts of ground-water discharge from the East Portland area.

SMALL STREAMS THAT DRAIN THE AREA

Five small streams and their tributaries drain parts of the East Portland area. These are Beaver, Johnson, Kellogg, Rock, and Deep Creeks. All except Kellogg Creek have their headwaters in the Boring Hills and the Kelso slope subareas, from which they derive most of their runoff.

Beaver Creek drains about 11 square miles, about 10 of which are on the northern part of the Kelso slope. Its tributaries are several small streams that flow generally northwestward down the slope. Near the north edge of the Kelso slope, those tributaries merge, and Beaver Creek turns northeastward and flows through a shallow steep-walled gorge to where it joins the Sandy River at Troutdale.

Johnson Creek drains most of the northern part of the Kelso slope and the north side of the Boring Hills. It flows westward across the Portland terraces through a shallow valley to its confluence with Crystal Springs Creek and thence turns southward to join the Willamette River at Milwaukie. Johnson Creek has no substantial tributaries except Crystal Springs Creek, which is fed by ground water discharging from the gravels beneath the Portland terraces.

A gaging station is maintained by the U.S. Geological Survey on Johnson Creek in the SW¼ sec. 13, T. 1 S., R. 2 E., near Sycamore. Records of the creek's discharge are published annually by the U.S. Geological Survey (1940–60) in a series of water-supply papers entitled "Surface-Water Supply of the United States, Part 14, Pacific Slope Basins in Oregon and Lower Columbia River Basin." Above the gaging station, Johnson Creek drains about 28 square miles of the Boring Hills and the Kelso slope. The average runoff at the gaging station for the period 1941–59 was 39,180 acre-feet, or about 1,390 acre-feet per square mile, and the average discharge rate was 54 cfs (cubic feet per second). This runoff, which is equivalent to an average depth

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of 26 inches of water per year throughout the drainage basin, probably is fairly representative of the Kelso slope and the Boring Hills subareas. During 1956, the maximum recorded flow of Johnson Creek at the gaging station was 1,320 cfs on January 4, and the minimum was 0.4 cfs during August 21–23. This wide range indicates the flashy nature of the runoff from the drainage basin of that stream.

Crystal Springs Creek, the principal tributary to Johnson Creek, is fed by springs that issue from near the base of a terrace scarp where the regional water table is intercepted by the land surface. Total annual runoff of Crystal Springs Creek is estimated at about 4,000 acre-feet per year, most of which is ground-water discharge.

Kellogg Creek begins as spring outflow but also drains a surface area of about 13 square miles in the southwestern part of the Boring Hills, on the northeast slope of Oatfield Heights, and in the abandoned stream channel between Clackamas and Milwaukie. It flows generally northwestward and joins the Willamette River at Milwaukie.

Rock Creek drains about 10 square miles of the southern part of the Boring Hills. Its main branch flows southeastward through a steep, narrow ravine to the Clackamas River, which it joins about 1½ miles downstream from Carver.

Deep Creek and its tributaries drain an area of about 36 square miles, most of which is in the southern part of the Kelso slope. Its drainage pattern is dendritic and it is in a youthful stage of erosion. Its two major branches flow southwestward and northwestward, respectively, through deep, steep-sided ravines to the canyon of the Clackamas River. The creek joins that river about a mile west of Barton.

GEOLOGY

GENERAL CHARACTER AND RELATION OF THE ROCK UNITS

The general relations of the rock units in the East Portland area are represented in the diagrammatic cross sections in plate 1.

The oldest rock unit exposed in the East Portland area is the Columbia River Basalt, of Miocene age (pl. 1). Older rocks underlie the basalt but are not exposed in the East Portland area. These older rocks, however, are important to this ground-water study, either because they do not yield appreciable amounts of ground water or because some water of inferior chemical quality may at places move from them into the overlying basalt, as is subsequently discussed.

The rocks underlying the Columbia River Basalt are best known in areas east and west of the East Portland area but occur also to the northeast and south. To the west and south of the area, the Columbia River Basalt is underlain by sedimentary rocks of both marine and continental origin. East of the area, the basalt is underlain by a series of continental sedimentary and volcanic rocks which, though not exposed in the East Portland area, crop out at Camas, Wash., just across the Columbia River from the northeast corner of this area.

The Columbia River Basalt, which unconformably overlies the older rocks, comprises a thick series of accordantly layered lava flows with a few scattered intercalated beds of tuff or sedimentary materials of continental origin.

The Columbia River Basalt and the older rocks have been warped so that the upper surface of the basalt forms a broad basin. The top of the basalt is gently sloping in general but is probably displaced at places by buried faults. (See NW.–SE. section, pl. 1.) In the deepest part of this basin under the East Portland area, the basalt is at least 1,200 feet below sea level. The basalt rims of the basin are exposed in the anticlinal ridge forming the West (Portland) Hills (officially a part of the Tualatin Mountains) and in the foothills of the Cascade Range near Corbett, about 5 miles east of Troutdale. East from Corbett, the basalt rises in the Cascade Range.

This structural basin is partly filled with sedimentary deposits. The oldest of these deposits consists of several hundred feet of mudstone and claystone containing scattered lenses of sandstone and conglomerate, named the Sandy River Mudstone (of early(?) Pliocene age) by Trimble (1963) but formerly known as the lower member of the Troutdale Formation. Overlying the Sandy River Mudstone is the Troutdale Formation (redefined by Trimble, 1963), of early Pliocene age. The Troutdale comprises a thick series of conglomerate, gravel, and sandstone and minor beds of sand and clay. This unit, which was formerly referred to as the upper part of the Troutdale Formation, is as thick as several hundred feet.

The Boring Lava, ranging in age from late Pliocene to late(?) Pleistocene, rests unconformably upon an eroded surface of the Troutdale Formation. The Boring Lava is an irregularly distributed sequence of basaltic lava flows. Within the East Portland area it is largely confined to the Boring Hills, but it also occurs at places beyond the area to the east, west, north, and south.

Throughout most of the area, the Boring Lava and older rocks are overlain by surficial materials. The oldest of these is a widespread relatively thin layer of predominantly fine-grained sediments, mostly of fluvial origin, that mantles the Kelso slope and extends eastward and southward from Gresham and beyond the canyons of the Sandy and Clackamas Rivers. This unit is herein called the piedmont deposits.

In the northern and western parts of the area, some of the Boring Lava and Troutdale Formation has been removed by erosion, and a widespread fairly thick deposit of fluviolacustrine gravel, sand, and clay has been deposited upon this eroded surface. These are the deposits that underlie and form the Portland terraces.

The Sandy and Clackamas Rivers have cut through the Boring Lava and are deeply entrenched in the Troutdale Formation and Sandy River Mudstone. Scattered along the walls of the stream canyons are several terraces underlain by a thin veneer of alluvium.

The youngest of the rock units is the alluvium of Recent age that underlies the flood plains of the streams. An extensive body of this material lies south of the Columbia River. Lesser deposits underlie the small flood plains along the Willamette, Clackamas, and Sandy Rivers.

A thick layer of soil mantles nearly all the rocks in this area. This soil cover and the luxuriant vegetation native to the district make geologic mapping difficult. For this reason, most of the contacts between rock units shown on the geologic map are approximately, rather than precisely, located.

The principal aquifers, or water-bearing zones, that underlie the East Portland area are within the Columbia River Basalt, the Troutdale Formation, the Boring Lava, the fluviolacustrine deposits, and the younger alluvium. The other rock units that are younger than the Columbia River Basalt may be saturated at places but are generally fine grained and relatively impermeable and thus do not readily yield water to wells. As previously stated, the older rocks underlying the basalt are poorly permeable and yield only small amounts of water, which is commonly of poor quality. A more detailed description of the rock units and their water-bearing character follows.

THE ROCK UNITS AND THEIR WATER-BEARING CHARACTER

OLDER ROCKS

In virtually all directions from the East Portland area, the Columbia River Basalt is known to be underlain by earlier Tertiary formations that include both volcanic and sedimentary rocks. These older rocks range in age from Eocene to early Miocene. South and west of the area the older sedimentary rocks are mostly fine-grained marine deposits (Warren and others, 1945; Warren and Norbisrath, 1946; Thayer, 1939); the older volcanic rocks are mostly of basaltic composition and are probably of both submarine and continental extrusion.

Northeast of Portland, in the Columbia River gorge, the Columbia River Basalt unconformably overlies the Eagle Creek Formation, of Miocene age. The Eagle Creek Formation consists of continental deposits—mainly gray bouldery tuff agglomerate of andesitic composition—containing numerous ash beds.

Just across the Columbia River from the northeast corner of the East Portland area, near Camas, Wash., is a group of low hills made up of andesitic lava flows older than the Columbia River Basalt. These older lava rocks have been correlated by Mundorff (1964, p. 32) with the Skamania Andesite Series of Felts (1939). The position and extent of the older lava suggest that it had been deformed prior to the extrusion of the Columbia River Basalt and was not completely covered by that extrusion.

The old marine sedimentary rocks that underlie the Columbia River Basalt west and south of the East Portland area are generally fine grained and poorly permeable. At places, they contain connate saline water—that is, sea water that was trapped in the sediments when they were deposited. This saline water is unusable for most purposes and wells tapping it must generally be modified to exclude it or must be abandoned. At places, the saline water has mixed with and contaminated fresh water in overlying aquifers. (See p. 45 this report; also Hart and Newcomb, 1965, p. 29 and pl. 3; Brown, 1963, p. O23.)

The Skamania Andesite Series of Felts and the materials of the Eagle Creek Formation, which underlie the Columbia River Basalt in the Columbia River gorge east of Troutdale, are dense and compact and generally lack permeable zones. Hence, neither rock unit yields appreciable quantities of water to wells. Only one well (1N/3–27M1) in the East Portland area has been drilled into these older rocks. That well apparently derived little, if any, water from the older rocks.

COLUMBIA RIVER BASALT

During Miocene time, a vast amount of basaltic lava was extruded, layer upon layer. By the time this volcanic activity ceased, the sequence of lava flows, which is known as the Columbia River Basalt, covered most of southern Washington and northern Oregon. The lava extended from the Rocky Mountains across the low ancestral Cascade Range and through the East Portland area to the Pacific Ocean.

In the East Portland area, the Columbia River Basalt is exposed only in the Oatfield Heights ridge and in the Willamette River channel north of the mouth of the Clackamas River, in the vicinities of Gladstone, Milwaukie, and Sellwood. It is well exposed, however, in the Portland Hills to the west and in the Columbia River gorge to the east of the area.

Wherever seen, the Columbia River Basalt is a remarkably consistent sequence of accordantly layered basaltic lava flows. Individual flows range in thickness from about 10 feet to about 150 feet. The most extensive flows can be traced laterally for distances ranging from less than 1 to as much as 3 miles.

The bottom few inches of most lava flows consist of fine-grained glassy, fractured rock grading upward into a coarser grained but dense rock. Roughly vertical cooling joints commonly separate the rock into polygonal vertical columns. These columns range from a few inches to several feet in diameter in the bottom half of the flow but become progressively smaller and less perfectly formed in the upper part of most flows. The basalt in the upper few feet of a flow is commonly finer grained and vesicular or scoriaceous. Variations of this structure are common, dependent upon the chemical composition of the lava, the temperature at which lava was extruded, the rate of cooling, and the physical environment in which the lava cooled. Some flows are composed almost entirely of blocky, columnar basalt, whereas others have in their upper parts thick zones of greatly inflated "honeycomb" lava.

In addition to the columnar jointing, just mentioned, two other kinds of jointing are fairly common. These are cubic, or "brickbat," and platy jointing. In cubic jointing, the rock is divided into roughly cubic fragments from 2 to 12 inches in diameter. In the platy jointing the rock is divided into roughly horizontal plates ranging from less than 1 inch to as much as several inches in thickness. The plates are more common and well formed near the tops and bottoms of the flows and are generally parallel to flow surfaces. All three types of jointing may be present in a single flow, but in most flows one type is dominant.

Beneath most of the East Portland area, the thickness of the basalt is unknown. The lowermost flows covered the hills and valleys of an irregular surface on the older rocks, and at places, parts of the uppermost flows were removed by erosion before subsequent deposition. The basalt is known to be about 700 feet thick in the vicinity of St. Helens, northwest of Portland (Wilkinson and others, 1946, p. 19). West of Portland, the basalt ranges in thickness from 0 at the northern part of the Tualatin Valley to about 1,000 feet in the central and southern parts of the valley (Hart and Newcomb, 1964, p. 17). East of the East Portland area, where the Columbia River gorge crosses the axis of the Cascade Range, the basalt is about 2,500 feet thick. At Gladstone, in the southwest corner of the East Portland area, the log of well 2/2–20F1 indicates a thickness of about 600 feet for the basalt.

The log of well IN/3–27M1 at Fairview indicates that the basalt there is only 120 feet thick. Apparently the older rocks in that vicinity formed an irregular surface, the highest parts of which were covered by only a relatively thin layer of Columbia River Basalt. Across the Columbia River, near Camas, Wash., the older rocks crop out in a range of low hills. The older rocks in these hills may never have been completely covered by the basalt. These lower hills may be a continuation of a buried ridge or highland of older rocks, which is thinly covered by basalt at Fairview.

The basalt weathers rapidly and deeply in the climate of this area. Fresh, unweathered basalt is found at the surface only at manmade excavations and on the most precipitous slopes of the valleys of actively eroding streams. Elsewhere, the basalt is intensely weathered to depths as great as 200 feet below the surface. The residual weathering product is a red or reddish-brown clayey and lateritic soil, some of which contains low-grade concentrations of residual aluminum ore (Libby and others, 1945, p. 7–21).

The Columbia River Basalt in eastern Oregon probably ranges in age from Miocene to early Pliocene. Closer to Portland, however, the extrusion of the basalt may have ceased before Pliocene time. The Columbia River Basalt is considered to be of Miocene age in the St. Helens area by Wilkinson, Lowry, and Baldwin (1946, p. 19 and 24). Trimble (1957 and 1963) considers the Columbia River Basalt at Portland to be of early or middle Miocene age.

When the extrustion of the Columbia River Basalt ceased, the upper surface of the lava presumably was a broad, nearly level plain. Since then, the basalt has been warped into a series of broad, gentle folds. The East Portland area occupies part of a broad downwarped, or synclinal, basin. On the west rim of the basin, the basalt surface is at an altitude of about 1,000 feet at Council Crest, in the West Hills about 2 miles west of Ross Island. From the foot of the West Hills, the basalt slopes abruptly to the east and disappears beneath the younger sedimentary deposits. The top of the basalt was penetrated at about 1,100 feet below sea level during drilling of well 1N/1–36H1 (log in table 2), but throughout most of the central part of the area its altitude is unknown. The basalt reaches altitudes above sea level in the east edge of the area (pl. 1). Eastward its base reaches an altitude of about 3,000 feet in the Columbia River gorge at the axis of the Cascade Range.

The Oatfield Heights ridge is formed by an upfold, or anticline, involving the Columbia River Basalt and the older rocks. This folding may have been accompanied by faulting on the northeast side of the ridge. The ridge lies en echelon with, or perhaps is a continuation of, a similar anticlinal ridge (Palatine Hill) on the west side of the Willamette River. The basalt occurs at shallow depths at most places on top of Oatfield Heights ridge; thus, it probably reaches altitudes of nearly 400 feet. It is exposed at several places on the flanks and ends of the ridge. None of the wells on the ridge have completely penetrated the Columbia River Basalt.

The fractured and scoriaceous zones between and at the tops of many flows of the Columbia River Basalt are porous and permeable, but the more compact center parts of most flows are relatively impermeable. The main permeable zones are (1) tabular interflow zones consisting of scoriaceous and fractured material near the tops of some lava flows, and (2) joints and other fractures of irregular form within some of the lava flows.

The interflow zones often are discontinuous and vary in permeability from place to place. Also, many lava flows do not have permeable zones; in some flows the zones were never formed, and in others they were removed by erosion or rendered less permeable by weathering prior to inundation by subsequent flows. A lava flow may pinch out between the overlying and underlying flows and, consequently, its water-bearing zone may end or may merge with that of an adjacent flow. Where faulting has occurred, water-bearing interflow zones may have been displaced opposite dense less permeable lava or may butt against an impermeable fault gouge. The permeability of an interflow zone may be reduced by sharp folding, which at places causes slippage between adjacent flow layers that often is accompanied by grinding and compression of the weaker interflow zones. Conversely, a lesser amount of faulting and folding may actually increase the permeability of the basalt by opening joints or causing fractures that serve as conduits for the ground water.

Water is present in the Columbia River Basalt under all three general conditions of ground-water occurrence—confined, unconfined, and perched. (See p. 35.) The water can move relatively freely through the tabular interflow zones parallel to the flows, but does not readily pass across the denser parts of the lava flows unless those parts are strongly jointed or fractured. Therefore, the water in the permeable zones is commonly confined to some extent by the denser parts of adjacent flow layers. Well 1/4–10D1, owned by the Young Men's Christian Association, obtains confined water from the basalt. Water flows from the well at a rate of about 40 gpm (gallons per minute) under a head about 30 feet above land surface, or about 110 feet above sea level. The basalt aquifers tapped by well 2/2–19E1 probably contain unconfined water. The static water level in that well is about 30 feet above sea level, only slightly higher than the surfaces of the nearby Clackamas and Willamette Rivers.

Most wells obtain the required amount of water when they are drilled to sufficient depth in the Columbia River Basalt. Newcomb (1959, p. 14) has found that on the average, the basalt will yield about 1 gpm of water per foot of well penetration below the water table. This average is for wells that are about 12 inches in diameter, penetrate at least 300 feet of basalt below the water table, and are pumped with a drawdown of about 50 feet.

SANDY RIVER MUDSTONE

The Columbia River Basalt is unconformably overlain by the Sandy River Mudstone of early(?) Pliocene age. The Sandy River Mudstone is exposed in the canyons of the Sandy and Clackamas Rivers near the east margin of the East Portland area and is reported in the drillers' logs of several wells located toward the center of the basin. It probably extends at depth throughout all or most of the area.

The Sandy River Mudstone consists mostly of indurated clay and silt, probably of lacustrine origin, but includes minor amounts of sand and fine gravel. Its maximum known thickness in this area is shown by the log of well 1N/1–36H1, which indicates a sequence of about 900 feet of mostly fine-grained material extending from an altitude of about 185 feet below sea level to about 1,080 feet below sea level, where the Columbia River Basalt was first penetrated. The lower 300 feet of that section contains significant amounts of sandstone and gravel, which may represent alluvial-fan, delta, or channel-fill materials deposited early during the filling of the bedrock basin.

The deformation that warped the Columbia River Basalt and older rocks into the structural basin underlying the East Portland area continued after the deposition of the Sandy River Mudstone, for the top of this formation slopes westward from an altitude of about 600 feet near the town of Sandy to about 185 feet below sea level at well 1N/1–36H1. All this westward slope, however, may not be due to warping, for the Sandy River Mudstone is known to have been eroded prior to its burial by younger deposits, and its upper surface at places may have been substantially lowered by that erosion.

Chaney (1944, p. 339) established the Pliocene age of the formation on the basis of fossil leaves found in its uppermost part at Buck Creek, 7 miles southeast of Troutdale. The Pliocene age was later confirmed by R. W. Brown (Trimble, 1957) on the basis of flora collected from the same locality.

Through much of the East Portland area the materials that constitute the Sandy River Mudstone are saturated with ground water; however, most of those materials are relatively impermeable and do not yield water readily to wells. A few wells obtain small amounts of water from the minor sandy or gravelly layers within the finer grained material. Well records suggest that these slightly permeable beds may be somewhat more abundant in the eastern part of the area than they are in the western part. The logs of wells 1/1–2E2 and

11D1, 2/2–11K1, and 2/3–23B1 (table 2) indicate materials that are typical of the aquifers of this formation. In each of those wells, the water-bearing zones within the Sandy River Mudstone are relatively thin layers of sand or gravel that make up only a small part of the formation and that yield amounts of water adequte only for domestic or stock supply. Large quantities of water—such as are needed for industrial, irrigation, or public supplies—ordinarily are not available from this formation.

A number of drillers' records report "quicksand" beds within the Sandy River Mudstone. Most such reports refer to fine-grained or very fine grained sand that "heaves," or moves into the well along with the water during drilling operations. In this area, fine sand is shut out of a well by means of casing, and an attempt is made to develop a supply of sand-free water by the local practice of using perforated casing opposite coarser grained material. However, the beds of loose fine sand are commonly capable of yielding moderate quantities of water, and sand-free supplies might be obtained from such beds if well screens having the proper openings are used and if the wells are adequately developed.

TROUTDALE FORMATION

The Sandy River Mudstone is unconformably overlain by the Troutdale Formation, of early Pliocene age. The Troutdale Formation is exposed in the canyons of the Sandy and Clackamas Rivers, in the Boring Hills, in the vicinities of Troutdale and Fairview, and on the hills scattered about the Portland terraces subarea. It also extends in all directions beyond the East Portland area.

The Troutdale Formation consists mostly of well-indurated sandy conglomerate containing pebbles, cobbles, and scattered boulders. Locally, it contains layers of stratified claystone and siltstone as thick as 50 feet. Most of the coarser particles are basalt, but at places well-rounded pebbles and cobbles of quartzite constitute as much as 30 percent of the gravel particles. The coarser fragments are generally in a matrix of clay, siltstone, or micaceous sandstone. At exposures in the walls of the Sandy River canyon, the formation contains much tuffaceous sandstone. Most of the conglomerate and sandstone is well indurated and is capable of standing in nearly vertical cliffs. Some of the looser gravels, however, slump readily at surface exposures and are recorded as loose gravel (much of which is water bearing) in drillers' logs.

The original thickness of the Troutdale Formation is not known but at places was probably more than 1,000 feet. The present thickness is about 150 feet near Sandy, more than 200 feet at well

1N/1–36H1, and about 360 feet thick at well 1N/3–27M1 (table 2). At all these places, the upper part of the formation has been removed by erosion. In well 1N/1–36H1 the base of this unit was found at an altitude of about 185 feet below sea level, and at the crest of Mount Tabor, less than 2 miles southeast, a higher stratum of the unit reaches an altitude of 645 feet. Thus, the thickness of the remaining Troutdale is at least 830 feet. An even greater apparent thickness—about 1,100 feet—is indicated from a comparison of the altitude of the base of the unit as logged at well 1N/3–27M1 (230 ft below sea level) and with the altitude of materials of the unit at the crest of a hill (868 ft above sea level) south of Gresham in NE¼ sec. 16, T. 1 S., R. 3 E. The well and the hill are less than 4 miles apart.

The Troutdale Formation in the area was mainly deposited by westward-flowing streams, presumably parts of the ancestral Columbia River drainage system, which imparted to the deposits a slight initial westward dip. In the eastern part of the area, this initial dip apparently was slightly steepened by subsequent tilting—a continuation of the deformation that formed the Portland structural basin. The resultant dip of the beds of the Troutdale Formation is everywhere small but locally affects the movement and availability of ground water in this unit, as is discussed subsequently.

Many wells in the East Portland area obtain small to large quantities of water from poorly indurated beds of sand and gravel in the Troutdale Formation. These permeable strata are interbedded with less permeable beds of clay, mudstone, and partly indurated materials of mixed grain size, which impede the crossbed movement of the ground water. Thus, ground water in the formation moves more readily within the nearly horizontal beds of permeable sand and gravel than between these beds, and it often is perched on, and at places confined by, adjacent less permeable strata.

Large amounts of ground water discharge naturally from the Troutdale Formation through many seeps and springs. The springs that drain this formation have flows ranging from less than 1 gpm to several hundred gallons per minute. The greatest measured flow from a single spring issuing from the Troutdale was 335 gpm from spring 1N/3–26H2s (table 4).

BORING LAVA

The Troutdale Formation is at places overlain or intruded by basaltic lava, tuff, and volcanic cinders constituting the Boring Lava, of late Pliocene to late(?) Pleistocene age. This lava unit forms the Boring Hills and is exposed in isolated hills—such as Kelly Butte, Rocky Butte, and Mount Tabor—and in small patches in the canyon of Sandy River. The Boring Lava rests on an undulating erosional surface that at places is the top of an old thick soil zone on the underlying Troutdale Formation. This old soil zone and the uneven base of the lava indicate that the Boring Lava was extruded upon a surface having considerable local relief. At most places the base of the Boring lies more than 100 feet above sea level.

The Boring Lava has been strongly weathered, and a thick mantle of residual soil causes it to be poorly exposed. Drillers' logs and a few good exposures, however, indicate that it has many of the structural and textural characteristics common to basaltic lavas, as described in the previous section on the Columbia River Basalt. The petrologic features of these lavas were described by Treasher (1942) and Trimble (1957, and 1963).

At most places in the Boring Hills, the unit consists of a thick sequence of massive flows of gray lava and a few intercalated beds of pyroclastic materials. Locally, individual flows were weathered, and possibly eroded, prior to the extrusion of later flows. At Kelly Butte, a feeder dike and a single flow of Boring Lava rest on an ancient hillside of conglomerate of the Troutdale Formation. At Mount Tabor, a cinder cone and a single flow of Boring Lava are exposed. Rocky Butte is composed almost entirely of light-gray Boring Lava. Mount Scott is a conical pile of Boring Lava resting on an eroded surface of the Troutdale Formation. Several isolated bodies of Boring Lava, most of which are too small to be shown on the geologic map, also are exposed in the west side of the canyon of the Sandy River overlying materials of the Troutdale Formation and underlying younger alluvial deposits.

Some bodies of Boring Lava occur buried beneath younger alluvial and fluviolacustrine deposits at places where they are remote from outcrops of the lava. For example, well 1/1–1Q1, more than 1 mile west of the nearest outcrop of lava on Mount Tabor, apparently penetrated Boring Lava at depths ranging from 85 to 110 feet below the land surface (table 2). Such buried masses of the Boring, together with isolated remnants that are exposed in the Sandy River canyon, suggest that this unit was originally much more extensive but has been largely removed by erosion. Some of these isolated bodies of the Boring, however, may represent sills that extended outward from the feeder dikes of the lava. Such is probably the situation at well 2/3–15D1, where lava believed to be Boring was penetrated below about 325 feet of Troutdale and Sandy River materials and about 660 feet above the level where Columbia River Basalt was penetrated in a well about 1 mile distant (2/3–14L1).

Because the Boring Lava poured out upon an uneven surface, it has a low or moderate initial dip at places. No evidence of subsequent deformation of this unit was found during the present study.

The Boring Lava is almost entirely above the regional water table; consequently, any ground water it contains is perched. This perched ground water may be either confined or unconfined, depending upon local conditions. The perching strata are old soil zones between lava flows, dense and impermeable central parts of individual flows, and clayey soil zones that underlie the base of the lava.

Ground water moves within the Boring Lava in much the same manner as in the Columbia River Basalt (p. 20), although the highly permeable water-bearing interflow zones found at places in the Columbia River Basalt are apparently lacking in the Boring Lava. Because of the lesser permeability of individual aquifers and the lesser extent and thickness of the bodies of Boring Lava, wells tapping the Boring generally have smaller yields than those tapping the Columbia River Basalt. At most places within the Boring Hills subarea, wells that tap aquifiers in the Boring Lava yield water in quantities adequate for domestic use; a few, such as well 2/3–6Q1, yield enough for small amounts of irrigation.

Many springs issue from the Boring Lava, but the flow of most is small (table 4). Springs draining the Boring commonly decrease in yield during late summer or early autumn, and some flow only intermittently.

At places where impermeable perching layers are not present, the Boring Lava is unsaturated, and wells must be drilled into the underlying Troutdale Formation to obtain water. At Rocky Butte, Kelly Butte, and Mount Tabor, the Boring Lava is not known to contain usable amounts of ground water.

PIEDMONT DEPOSITS

A body of mostly clay, but including some silt, sand, gravel, and mudflow deposits, underlies the Kelso slope west of the Sandy River and south and east of the towns of Gresham and Boring. These materials, herein called piedmont deposits, also underlie the surface of two broad valleys in the Boring Hills subarea—Pleasant Valley and a similar southward-trending valley that extends roughly between Hillsview and Union Schools. In the eastern, higher part of the area of its occurrence, this unit doubtless consists largely of true piedmont deposits; however, at lower levels it consists chiefly of fluviatile and mudflow deposits of a drainage system that was ancestral to the present Sandy and Clackamas Rivers.

East of about the longitude of Gresham, in the Kelso slope subarea, the materials of this unit are identical with those mapped and designated the Springwater Formation, of early(?) Pleistocene age, by Trimble (1963, p. 46). Farther west, however, the distribution of this unit as shown in plate 1 of this report differs from that shown for the

Springwater by Trimble. For example, Trimble considers the materials that form the floor of Pleasant Valley to be part of a younger unit (Gresham Formation), whereas these writers believe them to be equivalent to the materials that directly underlie the Kelso slope because of similarities in lithology and altitude.

The materials composing the piedmont deposits consist mostly of clay- or silt-size particles, owing largely to the deep weathering that has occurred in the upper part of the unit. Even where sand and gravel particles constitute an appreciable part of the beds, they are commonly in a matrix of clay or silt. Drillers' logs of wells penetrating these deposits commonly report them as "clay," "sandy clay," "clay and gravel," or "cemented gravel." (See table 2, wells 1/3–14R1 and 24E1, and 1/4–16H1.) The thickness of these deposits is commonly less than 100 feet but at places is nearly 200 feet. These materials generally overlie the conglomerate of the Troutdale Formation but at places rest upon patches of Boring Lava.

Because the materials comprising this unit are predominantly fine grained and relatively impermeable, much of the precipitation that falls upon areas underlain by the piedmont deposits drains directly to streams, and leaves the area without reaching the ground-water body. Only a small amount of the precipitation infiltrates the piedmont deposits and percolates downward to a saturated zone. The piedmont deposits themselves generally do not yield water readily to wells; however, a few dug wells of large diameter obtain adequate domestic or stock-water supplies from this unit.

FLUVIOLACUSTRINE DEPOSITS

The Portland terraces subarea is underlain by unconsolidated gravel, sand, silt, and clay that was deposited by the ancestral Columbia River and its tributaries during a time when the streams were eroding the previous sedimentary fill of the Portland basin. These deposits rest upon the eroded surfaces of the more indurated gravel of the Troutdale Formation and, at places, upon the Boring Lava and the Columbia River Basalt.

The deposits are relatively coarse grained in the northeastern part of the area; bouldery gravels make up much of the material in the vicinity of Troutdale and Fairview. Farther west, near the Willamette River, the deposits are finer grained; there they consist mostly of clay, silt, and sand and include relatively few layers of gravel. The gravel is poorly sorted and at many places has a fine-grained matrix. The deposits are slightly indurated—enough to stand for several years in nearly vertical cliffs. Induration is mostly by compaction of the finer grained materials, although in some beds the gravels are slightly cemented with carbonate or limonite.

The pebbles, cobbles, and boulders of this unit are mostly basaltic; however, some are quartzite and crystalline igneous and metamorphic rocks that are foreign to western Oregon. These foreign gravels were transported from the upper part of the Columbia River drainage basin. Many large erratic boulders, apparently rafted to their present position by floating ice, occur throughout the extent of this unit.

The fluviolacustrine deposits have been variously called delta deposits (Salisbury and Atwood, 1908, p. 38), terrace deposits (Darton, 1909, p. 9), terrace gravels (Treasher, 1942), Portland gravels (Lowry and Baldwin, 1952, p. 17), Portland sand (Baldwin, 1957, p. 115), and lacustrine deposits (Trimble, 1957, and 1963, p. 58). They were deposited by the Columbia and Willamette Rivers during and after those rivers were impounded to a level several hundred feet above their present channels. Even when the streams were impounded, a forceful current apparently passed through the lake—an action resulting in gravelly layers being spread intermittently over parts of the basin, especially in the eastern part of the Portland area. Thus, the deposits are more characteristic of alluvium rather than lake deposits, and the term "fluviolacustrine" is more appropriate.

The water surface in the ponded river at one time rose above an altitude of 400 feet, and the fluviolacustrine materials were deposited to altitudes above 350 feet. As the water declined, much of the sedimentary fill deposited from it was removed and the remainder was left in the form of several prominent terraces.

The fluviolacustrine deposits are commonly assigned to late Pleistocene time, when glacial ice occupied upstream regions of the Columbia River basin.

The fluviolacustrine deposits are generally moderately permeable, and where they extend below the water table they are capable of yielding small to large amounts of water to wells. In the western part of the Portland terraces subarea, near the Willamette River, the fluviolacustrine deposits extend below the regional water table and are tapped by several wells that supply water for air-conditioning and industrial uses. In this part of the area, yields from this unit to properly constructed wells range from several hundred to more than a thousand gallons per minute. (See table 1, wells 1N/1–8B1 and 11N2.)

In much of the eastern part of the Portland terraces subarea the base of the fluviolacustrine deposits lies above the regional water table, and the deposits are generally unsaturated. Locally, however, as near Twelvemile Corner, wells tapping the fluviolacustrine deposits obtain small to moderate quantities of water that is perched on relatively impermeable layers within these deposits or on the less permeable beds of the underlying Troutdale Formation.

The fluviolacustrine deposits greatly facilitate the recharge of ground-water reservoirs in parts of the area. The materials are generally porous and permeable, and precipitation that falls upon surfaces underlain by them readily percolates downward, rather than escaping as surface runoff. Except for a few minor streams, there is no surface drainage from the Portland terraces, although this area receives adequate precipitation, mostly during the winter months when evaporation losses are low. In this part of the area, much of the precipitation that infiltrates the surface materials percolates downward into the gravels of the Troutdale Formation.

ALLUVIUM OF AN ABANDONED RIVER CHANNEL

The abandoned stream channel at the southwest margin of the Portland terraces subarea is mantled by alluvium that consists mostly of clay and silt but that contains some sand and relatively small amounts of gravel. At various places, the alluvium of the abandoned channel rests upon parts of the Troutdale Formation, the Columbia River Basalt, and the fluviolacustrine deposits. The erosion of the channel in which the alluvium was deposited, however, postdated the deposition of the main fluviolacustrine deposits of the Portland terraces and must have been largely postglacial in age. Therefore, the alluvium in this ancient channel is regarded as either late Pleistocene or Recent in age.

The part of the channel between the Clackamas River and Milwaukie probably carried only the flow of the Clackamas River. The alluvium there consists of a relatively thin layer of clay and silt. This fine-grained material is about 29 feet thick at well 2/2–5M1, 5 feet at 2/2–9B1, and 4 feet at 2/2–16B1. These wells apparently failed to produce sufficient water from the alluvium of the abandoned channel, for all were drilled into the underlying Troutdale Formation.

The abandoned channel in the stretch from Milwaukie north to its end probably once contained all or a large part of the flow of the Willamette River, at a time when the Clackamas River discharged into the Willamette at the present site of Milwaukie. In that stretch of the abandoned channel, the alluvium ranges in thickness from a few feet near the margins of the ancient flood plain to about 100 feet near the center of the former channelway. The alluvial materials were penetrated to a depth of about 90 feet in well 1/1–25M1, and to about 125 feet in well 1/1–3A3 (table 2).

Because the alluvium of the abandoned channel consists principally of fine-grained materials, or of gravel mixed with fine-grained materials, it does not yield appreciable amounts of water to wells. No well in the area is known to derive its principal supply of water from materials of this unit.

YOUNGER TERRACE DEPOSITS

At least two terrace systems were formed within the canyons of the Sandy and Clackamas Rivers, probably during late Pleistocene time, when these streams were downcutting in the Troutdale Formation and Sandy River Mudstone. These terraces are underlain by a mantle of alluvium that is generally less than 50 feet thick.

Ground water in the younger terrace deposits is mostly ephemeral. The base of the deposits commonly slopes outward toward the canyon, as do any impermeable perching layers within the deposits. Consequently, water that infiltrates the younger terrace deposits can readily drain into the canyon or into any permeable underlying rocks. Most ground water that is present is temporarily perched on impermeable layers within the terrace deposits or in the underlying rock unit. On many of the small terraces, small bodies of perched ground water build up during periods of abundant precipitation and drain away rapidly soon after the high rate of recharge ceases.

In the Clackamas River valley, the terrace deposits consist mostly of loose poorly sorted bouldery gravel, containing fine-grained interstitial material and irregular lenses and layers of sand, silt, and clay. One of the largest terraces in this valley—the one on which the hamlet of Barton is built—was cut from the Sandy River Mudstone by the Clackamas River and is mantled by a deposit of poorly sorted gravel, sand, and clay about 30 feet thick. The terrace deposits in this valley contain ground water that is perched on less permeable materials of the underlying Sandy River Mudstone and yield enough water for domestic purposes to several drilled wells. (See table 1, well 2/3-24E1.)

In the valley of Sandy River, the terrace deposits consist mostly of poorly sorted fine-grained tuffaceous material containing scattered boulders and bodies of gravel. These deposits in the Sandy River canyon have been described as glacial outwash (Treasher, 1942) but are considered by Trimble (1957 and 1963, p. 53) and by this writer to be mostly mudflow deposits. On the higher terraces there is a well-developed soil profile, but weathering has not produced a deep soil on the lower, younger terraces.

Most wells that tap the terrace deposits in the Sandy River valley are large-diameter wells that yield small amounts of water for domestic or stock uses. Some of those wells are inadequate or barely adequate for domestic supply, especially during the summer months. Examples of wells that withdraw water from these terrace deposits are 1/4-10N1, 23P1, and 25P1.

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YOUNGER ALLUVIUM

The bars and narrow, intermittent flood plains in the valleys of the Willamette, Sandy, and Clackamas Rivers and the broad flood plains along the Columbia River are underlain by alluvium of Recent age.

The alluvium in the Sandy and Clackamas River canyons is generally less than 20 or 30 feet deep. It is predominantly gravel and sand containing lenses of finer grained material. Although at some places the gravel has a matrix of silt and clay, the alluvium is mostly loose, porous, and permeable. The ground water in the alluvium is unconfined, is generally in hydraulic continuity with the adjacent stream, and is recharged, at least in part, by infiltration of surface water during high stream stages. The water table approximates the level of the river surface and rises and falls rapidly in response to changes in stream levels.

The alluvium along the Willamette River occurs in bars and narrow patches bordering the river bank. Near the river's mouth the alluvium may be as thick as 125 feet, but it becomes progressively thinner upstream toward Milwaukie. At places, the alluvium is mainly composed of clay and silt in the upper part and sand and gravel in the lower part, as shown by the log of well 1N/1–7N1. At this well the alluvium extends to a depth of about 105 feet, or about 75 feet below sea level. Presumably, the channel was deeper during a late Pleistocene lowering of sea level, and the gradient of the stream was greater than at present. During that time the bottom, coarse-grained material was deposited. Subsequently, as the sea level rose to its present altitude and the gradient lessened, the upper, fine-grained material was deposited. At some places no gravel was deposited in the lower part, and the alluvium consists mostly of fine-grained materials (see table 2, well 1N/1–21L1.) Where the coarser grained layers are present in the alluvium of the Willamette River, they are capable of yielding large quantities of ground water to wells. Well 1N/1–7N1 reportedly yields 1,600 gpm; most of that water is obtained from the alluvium but some is probably from the underlying gravels of the Troutdale Formation.

The alluvium underlying the broad flood plain of the Columbia River is thicker than that beneath the flood plains of the tributary streams. Wells drilled at old Vanport in sec. 4, T. 1 N., R. 1 E., reached depths as great as 150 feet, or about 140 feet below sea level, apparently without reaching the bottom of the alluvium. There, the alluvium is composed mainly of sand, silt, and clay but contains some gravelly layers, especially in the deeper parts (table 2, well 1N/1–4K1). As in the lower part of the Willamette River channel, the channel presumably was deepened, and the lower gravelly layers were deposited during late Pleistocene time, when the sea level may have been as much as 200 feet below its present position. As the sea level later rose to about its present level, the channel became estuarian, and the fine-grained materials were deposited. The total thickness of the alluvium here is not known, but it is probably not more than about 200 feet.

The character of the alluvium underlying the Columbia River flood plain farther east is shown by records of several wells that have been drilled in sec. 23, T. 1 N., R. 3 E. Although the drillers' logs of only a few of these differentiate between loose and cemented gravels (this distinction is one criterion for distinguishing the gravels of the Recent alluvium from those of the Troutdale Formation), the log of well 1N/3–23B1 indicates that the unconsolidated alluvium there is about 174 feet deep. The Troutdale Formation is exposed at places in the eastern part of the flood plain, and a reef of older volcanic rock (Lone Reef) is present in the channel of the Columbia River. These outcrops of the older rocks and the well logs indicate that the alluvium is generally thinner in this part of the subarea than it is farther west.

Shallow wells that tap only the upper fine-grained material in the alluvium of the Columbia River yield small to moderate quantities of water, but some wells that tap the deeper, and generally coarser, strata yield larger quantities. The wells that once supplied water for the wartime community of Vanport (in sec. 4, T. 1 N., R. 1 E.) derived their main yield from water-bearing gravel and sand below depths of about 100 feet. Those wells were reportedly pumped at rates of 1,100 to 1,400 gpm, resulting in a drawdown of water levels of less than 10 feet.

An alumina reduction plant of the Reynolds Metals Co. in sec. 23, T. 1 N., R. 3 E., obtains its industrial supply from about 15 wells, many of which draw water from Recent alluvium. The drillers' logs of those wells indicate that about 150 feet of younger alluvium overlies the gravels of the Troutdale Formation. The alluvium was logged as clay, silt, and sand in the upper part and as sand or sand and gravel in the lower part. Each of the wells has a pumping yield of several hundred gallons per minute, resulting in a drawdown of a few tens of feet. Some of the deeper wells also draw water from the underlying Troutdale Formation, and one of the wells (1N/3–23G4) obtains its entire supply from that formation.

At most places the ground water in the alluvium of the Columbia River is in direct hydraulic balance with the water in the river. The ground water discharges to the river during periods of low flow and is recharged by the river during flood stages. The higher ground-water levels in the alluvium during flood stages of the river causes increased flow in the drainage channels behind the dikes that border the river. It also causes "boils," or upwellings, of sand at places in the low areas.

At some places, however, ground water in the deeper parts of the alluvium is not in direct hydraulic continuity with the water in the Columbia River. Such an example was observed when the area around well 1N/2-9D1, which taps the deeper zones of the alluvium, was inundated by a flood in 1948. At a time when the floodwater was receding and was standing at about 5 feet below the top of the well casing, the static level of water in the well was about at its normal depth of 30 feet below the top of the casing.

SUMMARY OF GEOLOGIC HISTORY

The succession of known geologic events which shaped the present East Portland area began during Oligocene time. Then, the shore of the Pacific Ocean must have been somewhere near the East Portland area because sedimentary rocks that were deposited in salt water during Oligocene time are now exposed to the west of Portland, whereas sedimentary rocks deposited in fresh water and volcanic rocks (the Eagle Creek Formation) are exposed east of Portland in the Columbia River gorge. A range of hills that is composed of still older volcanic rocks (Skamania(?) Andesite Series of Felts, 1939) trended northward from near Fairview and Troutdale past Camas, Wash. This range may have been a spur of a larger mountain range to the northeast.

Late in Oligocene time or early in Miocene time, the East Portland area was uplifted slightly, and the ocean shoreline receded to the West. During Miocene time, a vast flood of basaltic lava flows, now called the Columbia River Basalt, was extruded. In the Portland area it flowed out upon an erosional surface of moderate relief. By the time this phase of volcanism had ceased, the lava had accumulated to a depth of possibly 1,000 feet at places in the East Portland area; thus a broad, nearly featureless lava plain, having islandlike hills of older rock near its edges, was created.

In late Miocene or early(?) Pliocene time, movements of the earth's crust slightly deformed the lava plain. A structural basin was created in the East Portland area between upwarped areas to the west (the ancestral West Hills) and to the east (the ancestral Cascade Range). A lake, fed by streams carrying detritus from the surounding higher lands, formed in this basin. As the basin deepened during early(?) Pliocene time, several hundred feet of lacustrine sediments (Sandy River Mudstone) were deposited.

About the middle of Pliocene time, the basin had filled sufficiently, and the outlet to the northwest of the basin had been eroded so deeply that strong river currents swept completely through the basin. Deformation continued; the basin was deepened and the Cascade Range was further uplifted as also were the West Hills and similar smaller upwarps such as the Oatfield Heights ridge. The ancestral Columbia River traversed the basin from the northeast, bringing into the area basaltic gravel from northeastern Oregon and southeastern Washington and quartzitic gravel from farther upstream. These gravels, as well as basaltic gravels brought in by other streams, were deposited in the area as alluvial fans and delta and channel deposits. When this deposition ceased early in the Pliocene Epoch, as much as 1,000 feet of the Troutdale Formation covered parts of the fine-grained Sandy River Mudstone, and the formation lapped upon the basalt ridges to the east and west.

Late in the Pliocene Epoch, either the sea level was further lowered or the East Portland region was uplifted slightly. The Columbia River and its tributaries further entrenched themselves and an erosion surface was established upon the Troutdale Formation. At this time began another period of volcanism, which continued intermittently to late(?) Pleistocene time. The Boring Lava flows and ash beds accumulated and cinder cones of the lava were built up locally upon the hilly surface that had formed upon the Troutdale Formation.

Erosion continued during this period, and a well-integrated drainage system was established on the Boring Lava, on the Troutdale Formation, and on exposed parts of the Columbia River Basalt. Lateral planation by the ancestral Sandy River, which was a low-gradient stream at a higher position than the present Sandy River, eroded the Boring Lava and Troutdale Formation and formed a broad plain between the present Boring Hills and the hills east of the present Sandy River canyon. During this lateral planation, alluvial materials—herein called the piedmont deposits—generally as thick as about 100 feet were deposited on the broad plain and in valleys between the hills of Boring Lava.

During the beginning of the Pleistocene Epoch, the Columbia River was at or near its present altitude, and hills containing Boring Lava—including Rocky Butte, Mount Tabor, and Kelly Butte—extended northward nearly to the Columbia River. The general sea level fluctuated several times during the "Ice Ages" of Pleistocene time; it lowered when large amounts of water were removed from the oceans and were held in the continental glaciers, and it raised when the continental glaciers melted. Also, during Pleistocene time at least one major uplift occurred in the Cascade Range.

During late Pleistocene time, the Portland basin received a large volume of glacial melt water and water-laid detritus from melting continental glaciers upstream in the Columbia River basin. The melt waters, at times, were apparently impounded in the Portland basin to a maximum altitude of more than 400 feet above present sea level owing to obstructions in the west outlet of the Columbia River basin. As the obstructions were breached by erosion and as the load of glacial debris lessened, the Columbia River and its tributaries eroded away much of the melt-water deposits from the basin. They eroded the Boring Lava back to the present position of the Boring Hills and also removed much of the Troutdale Formation. After each erosive sweep, the rivers partly backfilled the basin with the fluviolacustrine deposits that now underlie the steplike Portland terraces. As the glacial melt waters diminished, the Willamette River followed its present course south of Waverly Heights, where it was joined by the Clackamas River flowing through the abandoned channel past Clackamas and Milwaukie. North of Waverly Heights, the river has successively followed two channels. The first channel trended northward along the east side of Waverly Heights, past Sellwood, and joined the main channel north of Ross Island; the second channel is the present course of the river.

For a time after the melt waters had subsided, sea level remained lower than at present. The Columbia River and the lower part of the Willamette River eroded their channels deeper, possibly to nearly 200 feet below present sea level. The lower part of the Clackamas River was diverted westward through a low interstream swale near Gladstone, presumably by headward erosion of a small former tributary of the Willamette. The courses of the Willamette, Clackamas, and Sandy Rivers, especially those of the latter two streams, became deeply entrenched. During this entrenchment there were at least two stages when concordant terraces were formed along the walls of the Sandy and Clackamas River canyons.

Toward the end of Pleistocene time, the sea level rose to about its present level, drowning the deeply eroded channels of the Columbia and lower Willamette Rivers. Those deep channels were gradually filled with detritus carried by the stream until flood plains were constructed.

Deposition and erosion continues at present, but the topography of the northern and western parts of the East Portland area resulted largely from deposition and erosion by the glacial melt waters.

GROUND WATER

GENERAL FEATURES OF OCCURRENCE

Ground water may be defined as water that occurs under hydrostatic pressure below the land surface and completely saturates or fills all pore spaces of the rock materials in which it occurs. Ground water occurs under three main hydraulic conditions—unconfined, confined, or perched. Each of these types of ground-water occurrence is represented at places within the East Portland area.

The upper surface of a body of unconfined ground water is called the water table, and its position is represented by the level at which water will stand in a well that taps the unconfined water. The water table is free to rise and decline in response to recharge to, and discharge from, the ground-water body.

Confined, or artesian, ground water occurs where water moving in a saturated permeable stratum, such as sand or gravel, passes beneath a less permeable stratum, such as clay, and is under pressure due to the head of water in the unconfined part of the aquifer. In a well that taps such a body of confined ground water, the water will rise above the bottom of the confining bed. The imaginary surface coinciding with the level to which confined water will rise in wells is called the piezometric surface. If the piezometric surface is higher than the land surface at a well tapping the confined aquifer, water will flow naturally from the top of the well.

Perched ground water occurs where a saturated zone is held above an unsaturated zone by a relatively impermeable stratum, such as a clay layer. The upper surface of an unconfined body of perched ground water is higher than the true or regional water table and is called a perched water table. If the perching stratum is penetrated by a well, the perched water may drain through the well to a deeper saturated zone or zones.

Perched ground water that is also confined may occur where the perched ground-water body is overlain by a relatively impermeable rock stratum.

In general, a water table or a piezometric surface is a sloping surface. It is highest in areas of recharge, where water is added to the ground-water body, and slopes downward to areas of discharge, where water leaves or is removed from the ground-water body. Ground water moves chiefly in response to gravity—that is, it moves down the hydraulic gradient.

The ground-water bodies receive natural replenishment (recharge) chiefly by downward seepage from the surface, either from rain and melting snow or from streams and lakes which themselves are recharged by precipitation. Irrigation may be considered a form of artificial recharge, in that part of the water that is spread over the land surface commonly seeps downward to a zone of saturation. Recharge in the East Portland area occurs mainly as infiltration from rainfall in the area.

Where a permeable zone is completely saturated, the rate of recharge cannot exceed the rate of discharge from the zone. Any water available for recharge that is in excess of the amount of discharge will be rejected and will flow off as direct runoff. Generally, the ground-water system tends toward a state of equilibrium wherein annual recharge equals annual discharge.

Ground water in the East Portland area is largely discharged as follows: Naturally through springs and seeps that issue either at the land surface or into streams and by evaporation or transpiration and artificially by withdrawal from wells or drains. Water, however, may also discharge from one aquifer or ground-water body to another, as for example, by seepage across the beds or by the downward draining of perched ground water to a deeper saturated zone.

WATER-LEVEL FLUCTUATIONS

The water table or piezometric surface of a ground-water body fluctuates chiefly in response to variations in recharge and discharge. These fluctuations are reflected by water-level changes in wells, which provide a source for information on the seasonal distribution of recharge and discharge and on the changes in ground-water storage.

The main water table in most of the East Portland area stands slightly above the level of the nearest major stream, but many local perched water bodies stand above the regional water table. In the southeastern part of the area, in the Kelso slope and Boring Hills subareas, the water levels recorded in many wells are 200 or more feet above the regional water table. Most of these relatively high water levels represent the water tables of perched ground-water bodies. In these topographic subareas, especially in the Boring Hills, perched ground water stands at many different levels, and the level at which water will first be found during drilling of a well is not closely predictable.

In the western and northwestern parts of the area, water levels in the wells generally stand at a common water surface (the regional water table) that gently slopes toward the major streams, and the aquifers tapped by most of the wells are unconfined. In these parts of the area, static (nonpumping) water levels in representative wells can be used to predict, at least within a few tens of feet, the water levels to be expected in new wells of similar depth.

Water levels in 12 wells in the East Portland area were measured periodically during the period August 1955 to September 1957. Hydrographs, along with a graph of the monthly precipitation at Portland Airport, are shown for eight of these wells in plate 2.

As shown by plate 2, the highest annual water levels in most of the observation wells were measured during the spring of 1956 and 1957. The high water levels in most of the wells during 1956 and 1957 occurred from 1 to 3 months after the months of greatest precipitation (January and March, respectively). Likewise, the lowest annual levels in most wells occurred during autumn or winter considerably later than the summertime period of least precipitation and greatest withdrawals from wells. Apparently, after the water from precipitation infiltrates the surface materials, a period of as much as several months may be required for the water to percolate down to the zones of saturation and thus recharge the ground-water bodies.

The overall fluctuation of water levels in the 12 observation wells during the period of measurement ranged from about 1 foot in well 1/4–17F2 (hydrograph not included) to 17 feet in well 1/3–12D1 (pl. 2). For two wells tapping the fluviolacustrine deposits, the average of the maximum observed range in levels was about 9 feet; for five wells tapping unconfined aquifers in the Troutdale Formation this average was about 5 feet; and for four wells tapping perched aquifers in that formation, about 11 feet.

The levels measured in well 1/3–8C2 are probably fairly representative of water-level fluctuations in unconfined aquifers beneath much of the east-central part of the East Portland area. That well, which is 120 feet deep and taps unconfined aquifers in the Troutdale Formation, is not used and is remote from wells that are heavily pumped. During 1956, the level in that well declined about 5.7 feet between May and December—from 57.8 feet to 63.5 feet below the land surface—before rising to its high level during spring of 1957.

Changes of water level amounting to only a few feet may represent substantial changes in ground-water storage. For example, if the aquifer materials that were dewatered in the vicinity of well 1/3–8C2 during the aforementioned period of decline yielded a volume of ground water amounting to only 10 percent of their total volume, the water-level decline would represent a discharge from the ground-water body of more than one-half acre-foot of water per acre throughout the area of the decline.

In the spring of 1957, the water level in well 1/3–8C2 did not return to its high position of the previous year; in April 1957, the level was more than 2 feet below levels during the previous April. Of 10 other wells at which comparable measurements were made, the highest observed water level in 1957 was below that for 1956 at 6 wells, was higher at 1 well, and was about the same in the rest of the wells.

The relatively high water levels at most of the wells during the spring of 1956 may have been due to above-normal precipitation during the previous recharge period—autumn of 1955 and winter of 1955–56. As shown by the graph of monthly precipitation (pl. 2), the total precipitation at the Portland Airport during the 6-month period September 1955 to February 1956 was nearly 42 inches, or about 1 inch less than the long-term average for an entire year (p. 7).

During 1956, the water levels in two of the wells that tap perched aquifers in the Troutdale Formation did not follow the general pattern of seasonal fluctuations that was observed at the other wells. At wells 1/3–12D1 and 2/3–10C1, which are 140 and 300 feet deep, respectively, the lowest water levels for 1956 were measured during late spring, while levels at most of the other wells were high. Levels in well 2/3–10C1 remained low throughout the winter and spring of 1956, even though the precipitation during and preceding that period was above normal, and the conditions for recharge were unusually favorable. During 1957, however, the levels measured in both wells followed the pattern typical for the majority—that is, the levels were highest during April of that year and declined during the following few months. The reasons for the anomalous fluctuations in those wells during 1956 cannot be determined from the available water-level data; however, these fluctuations were probably due to local influences, such as seasonal variations in the withdrawal from nearby wells.

The period of water-level measurements shown in pl. 2 is too short to indicate any long-term trends in water levels which could, for example, be used to predict a long-term change in ground-water storage. However, even multiple measurements made at a few wells over periods of several years do not suggest any such long-term trends.

OCCURRENCE IN THE SUBAREAS

The availability of ground water for use within any given area is controlled by the nature and distribution of the rocks underlying the area and the position of those rock units relative to the zone or zones of saturation, as well as by the procession of the water that recharges, and discharges from, the ground-water reservoirs.

The hydrologic characteristics of the various rock units in the East Portland area have been described in previous sections of this report. As shown on the geologic map and cross sections, these rock units are not uniformly distributed through the area. For this reason and because the hydrologic setting varies widely from district to district, the ground-water situation is described separately for each of the physiographic subareas.

BORING HILLS

The Boring Hills subarea, which constitutes the south-central part of the East Portland area, is underlain in descending order by the piedmont deposits, Boring Lava, Troutdale Formation, Sandy River Mudstone, Columbia River Basalt, and, at depth, by the older rocks.

Beneath much of the Boring Hills subarea, the regional water table is 400 feet or more below the land surface, but beds of low permeability in the Boring Lava and Troutdale Formation cause ground water to be perched at fairly shallow depths. Consequently, in most of the area small to moderate quantities of perched ground water, adequate for domestic, stock, and some irrigation uses, are obtained from wells less than 300 feet deep. Several springs on the steeper hillsides and valley walls also discharge water from these perched ground-water bodies.

The perching layers and the perched ground-water bodies are discontinuous and irregularly distributed. At places, wells are drilled to depths of several hundred feet before reaching usable amounts of perched ground water. At well 1/2–27B1, which was drilled near the crest of Mount Scott at an altitude of about 730 feet, the driller's record indicates that an unsaturated interval of 576 feet of the Boring Lava and the Troutdale Formation was penetrated before water was found in a sandy zone of the Troutdale from 576 to 589 feet below the surface. The water level in that well (243 ft above sea level when the well was completed in 1950) probably represents the regional water table at that place. Drilling was continued to a depth of 967 feet, but no other water-bearing zones were reported. The well reportedly yielded 100 gpm, and drawdown was 73 feet, after 3 hours of pumping.

The Troutdale Formation is sufficiently thick to extend below the regional water table in the western and northern parts of the Boring Hills. Wells 1/3–7N1, 18R1, and 32E1 are representative of those that obtain water from the Troutdale Formation and have water levels at or near the regional water table in those parts of the subarea.

KELSO SLOPE

Wells on the Kelso slope penetrate successively piedmont deposits, Troutdale Formation, Sandy River Mudstone, and Columbia River Basalt. In general, the beds of these rock units are nearly horizontal or dip gently northwestward.

The Troutdale Formation is the main water-yielding rock unit beneath the Kelso slope. The piedmont deposits which overlie the Troutdale Formation and the Sandy River Mudstone which underlies the Troutdale are fine grained and relatively impermeable and yield only small quantities of water to wells. The Columbia River Basalt beneath most of the subarea is at depth, and therefore its water-yielding potential has not been extensively explored.

The ground water that supplies most of the wells on the Kelso slope is perched within the gravelly Troutdale Formation, either upon less permeable beds within that formation or upon the Sandy River Mudstone. Some wells obtain small amounts of water from perched aquifers of sand or fine gravel in the piedmont deposits or from the Sandy River Mudstone, and at least three wells in the southern part of the subarea tap the Columbia River Basalt.

Beneath much of the Kelso slope, the movement of the ground water is generally westward, although along the edges of the area, adjacent to the canyons of the Sandy and Clackamas Rivers, the ground water moves toward the canyons. Ground water that occurs at relatively shallow depths adjacent to the canyons is perched on poorly permeable beds in the Troutdale Formation or in the Sandy River Mudstone.

Some dug and drilled wells, generally less than 80 feet deep, obtain small amounts of water, adequate only for domestic or stock supplies, from perched aquifers in the piedmont deposits; other wells that tap these deposits fail to obtain quantities that are adequate even for these uses. Most wells that have been drilled to depths of 200 or 300 feet in order to penetrate a substantial thickness of the Troutdale Formation have obtained enough water for domestic or stock supplies, and some wells yield sufficient water for small-scale irrigation. A few of the wells in this subarea have produced enough water from the Troutdale Formation for extensive irrigation; however, some of these were drilled as deep as 500 or 600 feet in order to obtain yields of 100 gpm or more.

At least three wells in the southern part of the subarea, near the canyons of the Clackamas River and its tributaries, failed to obtain sufficient water from the Troutdale Formation and Sandy River Mudstone and so were drilled into the underlying Columbia River Basalt. Well 2/3–14L1, owned by the Salvation Army near Norris, is 600 feet deep. It entered the Columbia River Basalt at a depth of 575 feet (about 275 ft below sea level). Well 2/4–18R1, owned by Schedeen Bros., is 904 feet deep and entered the basalt at a depth of 708 feet (about 43 ft below sea level). Both wells obtain small amounts of water from the upper part of the basalt. Well 2/4–21J1, owned by Hudson-Duncan Co., entered the basalt at a depth of 885 feet (about 95 ft below sea level) and penetrated it to a total depth of 1,330 feet. That well reportedly yields about 100 gpm from the basalt aquifers. Well 2/3–14L1 flowed slightly in 1951; the water levels in wells 2/4–18R1 and 21J1 were about 115 and 200 feet, respectively, above sea level when the wells were completed. The water levels in these two wells probably represent approximately the altitude of the regional water table at those places.

PORTLAND TERRACES

The Portland terraces subarea includes most of the northeastern, northwestern, and southwestern parts of the area. The rock units underlying this subarea are, in descending order, the fluviolacustrine deposits, Troutdale Formation, Sandy River Mudstone, and Columbia River Basalt. A few residual hills and knolls of Boring Lava and Troutdale Formation rise above the general level of the subarea.

In the part of the subarea that extends eastward from Rocky Butte and Kelly Butte to Troutdale, the Troutdale Formation is the main water-bearing rock unit. The overlying mantle of fluviolacustrine deposit is generally thin and lies above the regional water table, although some wells, such as 1N/3–34N1, obtain perched ground water from gravel beds within the fluviolacustrine deposits. Also, a few wells obtain water from sand or gravel lenses in the Sandy River Mudstone beneath the Troutdale Formation. Because the Columbia River Basalt is at great depth, it has probably been reached by only one well in this part of the subarea; that well is 1N/3–27M1, owned by the city of Fairview. The basalt penetrated by this well is relatively thin (120 ft thick) and reportedly did not yield an appreciable amount of water.

In most of the eastern part of the subarea, the regional water table is within the Troutdale Formation and slopes generally northward, toward the Columbia River. At places, bodies of perched ground water also occur within the Troutdale—held up above the regional water table by poorly permeable beds in the formation. Well 1N/2–25C3 taps such as perched zone as well as a gravel aquifer in the Troutdale below the regional water table. In that well, water cascades down the well from perforations in the casing opposite the perched zone and flows out into a deeper unconfined aquifer in which the water level is about 30 feet below the base of the perched aquifer.

South of Troutdale, and at other places near the east end of the subarea, the beds of the Troutdale Formation dip slightly to the west; at places, ground water in sand and gravel beds of this formation is both perched on, and confined by, finer grained beds. Well 1N/3–36F1, which is 46 feet deep, taps gravel that presumably is in the upper part of the Troutdale Formation. The land surface at that well is more than 100 feet higher than the level of Beaver Creek at a point about a quarter of a mile to the east. Inasmuch as the well is so close to the creek, which doubtless is near the local level of the water table, the water in the shallow zone tapped by the well must be perched; because the well flows at the land surface, the ground water there is confined as well as perched.

Wells in the eastern part of the subarea are generally less than 400 feet deep and have yields ranging from a few tens to several hundred gallons per minute. Throughout this part of the subarea, yields of several hundred gallons per minute may be reasonably expected from properly constructed wells that completely penetrate the Troutdale Formation.

In the western part of the Portland terraces subarea—that is, in the part of the subarea generally west of Rocky Butte, Kelly Butte, and Mount Scott, and north of Kellogg Creek—the fluviolacustrine deposits (where they extend below the regional water table) and the Troutdale Formation are the main water-bearing rocks. Gravel or sand beds in the underlying Sandy River Mudstone yield only small quantities of water to some wells. The Columbia River Basalt extends continuously beneath this part of the area, but, except near the southwest corner, it is at such great depth that its water-bearing potential has not been explored by wells.

The water table in this part of the area slopes gently westward and northward toward the Willamette and Columbia Rivers. It is at an altitude of about 125 feet in the district west of Mount Scott, but is about 10 feet above sea level in the northwestern part of the area.

Although it is generally less permeable than the overlying fluviolacustrine deposits, the Troutdale Formation at places in the western part of the subarea yields more than 1,000 gpm to properly constructed wells that penetrate a substantial saturated thickness of the formation. (See table 1, wells 1N/1–35C1 and 1/1–11D1.) Nearly everywhere in this part of the area, the top of the Troutdale Formation lies below or only slightly above the regional water table, and locally the base extends to depths of more than 200 feet below sea level. Here impermeable beds within the Troutdale do not cause pronounced perching or confinement of the ground water, and water in this formation may generally be considered as unconfined ground water under water-table conditions.

The fluviolacustrine deposits extend below the water table in the western and northern parts of the Portland terraces subarea, and locally gravel and sand layers of these deposits yield several hundred to a thousand gallons per minute to properly constructed wells (table 1, wells 1N/8B1 and 11N2).

OATFIELD HEIGHTS

In the Oatfield Heights subarea, the Columbia River Basalt is the principal water-bearing rock unit. The basalt, which underlies the prominent ridge that extends northwestward from Gladstone to near Milwaukie, also continues at shallow depth northward along the Willamette River to the Sellwood district of Portland. The log of well 2/2–20F1 (table 2) shows the basalt to be more than 600 feet thick at Gladstone. It is underlain by older sedimentary rocks that contain water so saline as to be unsuitable for most purposes.

The basalt is deeply weathered to a clayey soil at the ridgetop and is overlain at places by younger materials, including fluviolacustrine and terrace deposits and Boring Lava. The younger deposits, however, lie mostly above the water table, and they, as well as the weathered material, are generally too thin to hold appreciable amounts of perched water. Hence, the materials overlying the basalt do not constitute productive or dependable sources of ground water.

Most of the existing wells in the subarea obtain small yields of perched ground water at relatively shallow depths in the basalt. Beneath the regional water table, which is somewhat above the levels of the adjacent Willamette and Clackamas Rivers, permeable zones in the basalt are saturated and are capable of yielding at least moderate quantities of water to wells.

The inclined basalt layers along the flanks of the Oatfield Heights ridge probably contain confined ground water. If wells were drilled far enough into those inclined beds to tap saturated permeable zones, the water in those wells would probably rise to levels considerably higher than levels of the water-yielding zones. The head at some of those wells might even be sufficient to cause the wells to flow.

COLUMBIA RIVER FLOOD PLAIN

The main aquifers beneath the Columbia River flood plain are sand and gravel layers within the younger alluvium and in the underlying Troutdale Formation.

The younger alluvium of the Columbia River flood plain is not thicker than about 200 feet. The upper part is mostly fine sand, silt, and clay, which generally do not yield large amounts of water to wells, but also includes some isolated lenses of sand and fine gravel that yield moderate to large amounts of water. The lower parts of the alluvium—below depth of about 100 feet—contain more abundant and continuous layers of sand and gravel that are capable of yielding large quantities of water to wells.

At places in the subarea, as near Fairview Lake and Blue Lake, the younger alluvium is comparatively thin, and some wells enter the Troutdale Formation at depths of less than 100 feet. At these places, however, the upper part of the Troutdale is apparently capable of yielding at least moderate quantities of water, and so wells tapping it may be as productive as those that tap the thicker alluvium beneath other parts of the flood plain.

The water table beneath the flood plain is nearly horizontal and is at about the level of the Columbia River, except during high stages of the river. Artificial dikes have been built along the river's edge to contain the river when it is in flood stage. During high stages of the river, some of the wells flow and "boils," or upwellings, of ground water are common in parts of the flood plain.

Few wells on the flood plain are more than 300 feet deep. The exceptions include wells 1N/3–23G4 and 23K1, which supply the Reynolds Metal Co. plant, where the maximum possible yield was needed. Those wells are 625 and 615 feet deep, respectively. Wells extending less than 100 feet into the alluvium commonly yield water adequate for domestic, stock, and small irrigation supplies. Wells that are more than about 100 feet deep and enter the gravelly lower part of the younger alluvium or the Troutdale Formation commonly yield from several hundred to more than 1,000 gpm.

CHEMICAL QUALITY

The ground water in the East Portland area is generally of good quality. Typically, it ranges in hardness from soft to moderately hard, has a moderate concentration of dissolved minerals, and lacks significant amounts of objectionable constituents.

Table 3 presents 20 chemical analyses of waters from 17 wells in the East Portland area. Other determinations of hardness, chloride content, and specific conductance, made under field conditions without laboratory control, are listed in the "Remarks" column of table 1.

HARDNESS

Hardness of water is caused mostly by compounds of calcium and magnesium. It is commonly recognized by the increased quantity of soap required to produce lather. Hardness in water is also objectionable because it contributes to the formation of scale when heated and because it affects the use of dyes. Hardness is classified by the U.S. Geological Survey as follows:

Hardness as $CaCO_3$ (ppm)	*Class*
0–60	Soft.
61–120	Moderately hard.
121–180	Hard.
>180	Very hard.

The hardness determinations listed in table 3 range from 14 ppm (parts per million) in well 1/4–10D1 to 195 ppm in well 2/2–20K1. All the field determinations of hardness that are listed in table 1 also are within this range. The average for all 17 wells listed in table 3 is 91 ppm. Thus, the ground waters range from soft to very hard, and the average hardness is in the moderately hard category.

CHLORIDE

The chloride content of most of the sampled ground water was negligible. The upper limit of chloride concentration in water for domestic use that is recommended by the U.S. Public Health Service (1962, p. 2154) is 250 ppm, and a concentration of 300 ppm or more is necessary before the water tastes noticeably salty.

Waters from the 17 wells listed in table 3 ranged in chloride from 2 ppm at wells 1N/2-26R1 and 1N/3-34D1 to 225 ppm at well 2/2-20K1, and had an average concentration of 38 ppm. More than two-thirds of all the samples analyzed contained less than 25 ppm chloride.

Two wells in the East Portland area, 2/2-20F1 and 20K1, owned by the city of Gladstone, produced water that was judged too saline for municipal use. Well 2/2-20F1 was drilled through the Columbia River Basalt and, from depths of 685 to 692 feet, penetrated a blue shale underneath the basalt. The principal water-bearing zone was the lower 10 feet of basalt, ranging in depth from about 675 to 685 feet and containing saline water that apparently migrated into it from the underlying shale (p. 17). A secondary water-bearing zone in the basalt was at a depth of about 200 feet and yielded fresh water. Before the well was put into service, the fresh water stood at a relatively high level and kept the saline water from entering the well. According to Mr. Wellman, water superintendent for the city (oral communication, Dec. 1950), the water from the well initially had a hardness of 114 ppm and a chloride content of 144 ppm based on analyses by a commercial laboratory (not included herein). Pumping lowered the head on the fresh water and thus allowed the saline water to enter the well. Mr. Wellman stated that, after the well was pumped for some time, water having a hardness and a chloride content of about 250 and 430 ppm, respectively, was pumped. Subsequently, the permeable zone near the base of the basalt was plugged with cement, and the hardness and chloride content of the water then decreased to about the value initially determined (table 3[1]).

Well 2/2-20K1 yielded water that reportedly increased in chloride content from 136 ppm in March 1952 to 225 ppm in June 1953 (table 3). It is about 1,500 feet southeast of well 2/2-20L1 and was drilled in 1951, the year after the saline-water zone in well 20L1 had been sealed out. Well 2/2-20K1 penetrated basalt—much of which was reportedly fractured—to a depth of 250 feet, or to a level about 420 feet higher than the top of the contaminated lowermost aquifer tapped by well 2/2-20L1. Apparently, the pumping of well 2/2-20K1 reduced the artesian pressures in the shallow basalt aquifers tapped by that well and thereby allowed the upward migration of saline water from below. Possibly the fractured rock penetrated by that well represents a general zone of fracturing that extends across several of

[1] The three analyses shown for this well are of water from the less saline basalt aquifers and were collected after the saline water had been sealed out.

the basalt layers and serves as a conduit for the upward-leaking saline water.

BORON

In certain small amounts, boron is essential to the growth of nearly all plants. In only slightly greater amounts, however, it is detrimental to plant growth. Wilcox (1948, p. 5 and table 2) rated plants as sensitive, semitolerant, and tolerant, according to their ability to withstand boron concentrations; irrigation waters were rated in five classifications—from "excellent" through "unsuitable"—for each of these classes of plants. Water containing boron concentrations of less than 0.33 ppm is regarded as excellent for the sensitive plants, and water containing more than 3.75 ppm of boron is regarded as unsuitable even for the tolerant plants.

Boron concentrations were determined for samples from five wells in the East Portland area. All but one sample had boron concentrations no greater than 0.2 ppm, and that one (from well 1/4–10D1) had 0.38 ppm. Thus, with respect to boron concentration, the waters sampled would be excellent or near excellent for irrigation of even the most sensitive plants.

FLUORIDE

A concentration of fluoride of about 1.0 ppm in drinking water is considered beneficial in decreasing decay to children's teeth (Dean, 1936). In higher concentrations, however, fluoride may cause a dental defect known as mottled enamel. Accordingly, the Public Health Service (1962, p. 2154) recommended a maximum limit of 1.7 ppm of fluoride in water that is to be used for cooking and drinking.

Determinations of fluoride for 17 samples of water from 15 wells in the East Portland area are shown in table 3. In 16 of the samples, the fluoride concentrations ranged from 0 to 0.6 ppm, indicating that none of those waters would have a detrimental effect on teeth; waters having concentrations in the upper part of that range might be slightly beneficial. In one sample, from well 1/4–10D1, the fluoride content was 3.2 ppm; however, the water from that well is not used for cooking or drinking.

IRON

Water containing more than about 0.3 ppm of iron, or of iron and manganese together, can stain utensils, plumbing fixtures, and laundry and may require treatment for iron removal to be suitable for some purposes. Of 18 samples tested for this constituent (table 3), only those from wells 1N/3–34D1, 2/2–20F1 (latest sample), and 2/2–20K1 (latest sample) had concentrations in excess of 0.3 ppm. A test well in the NE¼SW¼ sec. 16, T. 2 S., R. 2 E. (not listed in the tables) obtained water having an iron content of 37 ppm from the younger alluvium along the Clackamas River.

TEMPERATURE

The temperature of water in shallow aquifers is controlled largely by the mean annual temperature, which ranges from about 50° to 54°F in the East Portland area. Water from deeper aquifers is usually warmer, chiefly in response to the geothermal gradient, which corresponds roughly to a temperature rise of about 1.8°F for each 100 feet of depth below the first 100 feet.

Most of the wells in the area yield water at temperatures ranging from about 50° to 60°F; however, waters from a few wells have temperatures as low as 47°F and water from one well, as high as 76°F. Presumably, the lower temperatures occur where the ground water is recharged rapidly by precipitation, most of which falls in the winter months at temperatures below the mean annual air temperature. Well 1/4–10D1, a flowing artesian well only 310 feet deep that taps aquifers in the Columbia River Basalt, yields water having temperatures of 74° to 76°F. The warm water yielded by that well has a distinctive chemical character (see analysis in table 3), which suggests that it may be percolating upward from deeper, warmer artesian zones in or below the basalt. However, it probably derives its abnormal temperature mostly from residual heat in adjacent bodies of Boring Lava or from heat produced in enclosing rocks by mechanical friction during deformation.

UTILIZATION OF THE GROUND WATER

Ground water in the East Portland area has been developed for domestic, stock, and public water supplies, for irrigation, for industrial uses (including heating and air-conditioning of buildings), and for water supplies at recreation sites. Except in urban and suburban districts that are supplied from the Portland Water Bureau system, ground water is at present (1960) the principal source of water for community and cooperative water systems and for individual household supplies. Ground water is used for most of the irrigation in the area and probably also for most of the industrial water needs.

RURAL WATER SUPPLIES

Most of the wells in the East Portland area are used principally for rural-domestic and stock-water supplies, although water from many of these wells is also used to irrigate lawns and small gardens. The estimated population in about 100 square miles of the area that is not served by the Portland Water Bureau system or by smaller water-supply districts is 14,000 persons. They rely mostly on wells and springs for their water supply. Per capita water use for the rural population is probably about the same as in the suburban water districts in the area—that is, about 75 gallons per day. Thus, the average use of ground water for rural supplies in the area probably amounts to about 1 mgd (million gallons per day), or nearly 1,200 acre-feet per year.

IRRIGATION SUPPLIES

In the urban districts in and near Portland, most of the ground water that is used for irrigation is applied on cemeteries and golf courses; in the rural areas, most is used on agricultural lands.

From electrical power-use data supplied by the Portland General Electric Co., it is estimated that in 1957 about 28,000 acre-feet, or about 9.2 billion gallons, of ground water was withdrawn for irrigation use. Most of this withdrawal was from wells on the Portland terraces, where the water table stands close enough to the surface to allow economical pumping lifts.

Although some additional irrigation wells were drilled in the area during the period 1957–60, sizable tracts of agricultural land were taken out of production during that period as a result of suburban housing construction. The reduced acreage offsets, to some extent, the acreage irrigated by the additional wells; so, the amount of ground water used in 1960 is probably about the same as, or only slightly more than, the amount estimated for 1957.

PUBLIC SUPPLIES

Several small towns and water districts pump ground water from wells or springs for distribution to parts of the urban and suburban population. In some of these districts, the ground-water supply is supplemental to surface water purchased from the Portland Water Bureau. The names of the distribution systems and the reported amounts of ground water withdrawn in 1957 and 1960 are as follows:

Public-water-supply system	*Ground-water withdrawal (million gallons per year)*	
	1957	*1960*
Fairview	15	18
Milwaukie	206	308
Parkrose Water District	32	69
Richland Water District	48	59
Troutdale	12	13
Wood Village	30	15
Totals (rounded)	340	480

A few other water districts have wells for standby supply, but the pumpage is small and the use so infrequent that the withdrawal from those wells was not included in the foregoing table.

INDUSTRIAL SUPPLIES

At a few places in the area, large quantities of ground water are used by industries. Major industrial uses of ground water are for aluminum production, heating and air-conditioning of buildings, food processing, ice making, cooling of compressors at cold-storage plants, and manufacture of lumber and paper products. In 1960 about 5,800 million gallons, or 18,000 acre-feet, of water was used for all industrial purposes in the area. This estimate is based upon records of the city of Portland and the Oregon State Engineer and upon statements of officials of individual industrial firms.

The alumina reduction plant operated by Reynolds Metals Co. on the Columbia River flood plain north of Troutdale is by far the largest single industrial user of ground water. This plant uses an estimated 13,700 acre-feet of water per year from wells tapping the younger alluvium and the Troutdale Formation.

One concrete-pipe company in the area has injected excess water from their plant underground through a well. This operation constitutes the only artificial recharge of ground water that has been practiced in the area; however, in the adjacent west-side business district of Portland, west of the Willamette River, discharge water from several reverse-cycle heating and air-conditioning installations has been returned underground through wells (Brown, 1963).

SUMMARY OF PRESENT USE

For all uses, about 16 billion gallons, or nearly 50,000 acre-feet of ground water was withdrawn in the East Portland area during 1960. The amount withdrawn for each major use is shown in the following table. Nearly half of the ground water used for public supplies, and virtually all that used for irrigation, was withdrawn during the summer and early autumn—in the period June to September.

Principal uses of ground water	*Estimated amount, 1960* (*million gallons per year*)	(*acre-feet per year*)
Rural domestic and stock supplies	380	1, 200
Irrigation supplies	9, 200	28, 000
Public supplies	480	1, 500
Industrial supplies	5, 800	18, 000
Totals (rounded)	16, 000	50, 000

In all, comparatively little use has been made of the ground-water resources in the area. Only a small part of the amount replenished each year by natural recharge has been used; most of it leaves the area by evapotranspiration or flows to the bordering rivers without having been put to beneficial use. Thus, for the area as a whole, additional large amounts of ground water are available for withdrawal.

OUTLOOK FOR FUTURE USE

Present trends in the growth of population and industry in the area and the general increase in the per capita demand for water indicate that increased use of water from all sources is inevitable in the East Portland area. A combination of several factors suggests that the use of ground water in the future not only will increase along with the total water use but will probably constitute a larger percentage of the total than in 1960.

Where sufficient ground water of a suitable quality is available, it has certain advantages over water from surface sources. For example, because it is normally free of sediment and pollution, ground water can usually be used for human consumption without costly filtration and treatment. Thus, the initial cost of installing a public supply system using ground water is commonly much less than that for a system using available surface water. Also, because the water occurs in natural storage underground, it requires less elaborate surface storage facilities and is more amenable to automatic control of withdrawal works. Ground water is preferable for sprinkler irrigation because it is free of weed seeds and other foreign matter and also for some industrial processes and in fish rearing owing to its more constant temperature and chemical character. An increasing public recognition of these advantages is expected to encourage the search for and development of additional large supplies of ground water in the area.

Although additional farmland doubtless will be taken out of production as suburban growth continues, the use of ground water for irrigation is expected to increase for the area as a whole. The major reasons for this probable increase are (1) the need for greater financial returns from the land remaining in agricultural production, and (2) irrigation of additional land that will be brought under cultivation. Irrigation from wells during the dry summer months has certain advantages: it is one means of increasing the yields of some of the crops presently grown without irrigation, and it allows production of some crops having a high financial return but requiring more moisture during the main part of the growing season than is usually available from rainfall alone.

Increased use of ground water for all purposes is expected to be stimulated by improvement in techniques for constructing and developing wells to obtain maximum yields from the water-bearing materials in the area. The search for and development of available supplies of ground water have been retarded by reports of wells that failed to yield the desired amounts of water, or that yielded water containing excessive sand or silt. Many of the unsatisfactory wells, however, were not properly constructed or adequately developed to obtain the maximum or best supplies from the types of saturated materials that were penetrated. For example, wells in this area are commonly constructed to tap water entirely from beds of loose or cemented gravel, and only a few are adequately developed by surging and pumping to remove fine-grained aquifer materials or the drill cuttings that are forced into the aquifer during drilling. Layers of "heaving" sand or "quicksand" that are penetrated during drilling are usually sealed out by cement or solid casing, although supplies of sand-free water in moderate quantities could be obtained at some places from these beds by the proper use of well screens and well-development methods. Also, during the drilling of many wells in the area, insufficient data were obtained on the water-yielding capacities of the various saturated beds that were penetrated; consequently, any perforations that were later made in the casing were not always at the horizons of the best aquifers. Clearly then, proper methods of well construction and development will result in a higher percentage of satisfactory wells and will thereby encourage other drilling.

The largest increases in withdrawal will probably be for industrial, irrigation, and public supplies. The relatively small amount used for rural domestic and stock supplies will probably not increase appreciably for the area as a whole and is expected to decrease in districts that become urbanized.

FUTURE GROUND-WATER PROBLEMS AND NEEDS FOR INFORMATION

Increased ground-water use in the area will doubtless be accompanied by problems. Problems might also result from current practices of underground disposal of household sewage and of water used for the heating and cooling of buildings. The data in this report and elsewhere (p. 54) constitute a basis for evaluating some of the factors pertinent to the foreseeable problems but allow only tentative conclusions to be drawn about other factors. Additional information, which can be obtained through continuing and systematic study, will be needed to understand and combat effectively the following foreseeable problems.

WELL INTERFERENCE AND LOCAL OVERDRAFT

No problems of overdraft on the aquifers or of serious interference (mutual drawdown) between discharging wells are known to exist in the East Portland area, but these problems can be expected to arise locally as ground-water withdrawals increase in the future. Well interference can become an economic problem in areas of closely spaced wells of moderate to large yield that tap the same or hydraulically connected aquifers; therefore, future wells should be spaced as far as practical from existing wells of substantial yield. Also, in some districts of intensive pumping, the withdrawal may eventually exceed the rate of natural recharge; such a situation might cause water levels to decline perennially. Any such long-term declines that may occur in the area, however, are expected to be of local rather than widespread extent. Water levels are most likely to decline seriously in areas where large withdrawals are made from aquifers whose recharge is naturally small or has diminished as a result of widespread building, paving, and construction of storm drains in natural infiltration areas.

Water-use data that are now available and additional data that will become available as more wells are drilled will probably be adequate to allow determination and prediction of the areal distribution of ground-water withdrawals in the area. Those data should be periodically analyzed to delineate districts in which pumpage is greatest. In the districts where withdrawals are now or are likely to become intensive, observation wells should be established and measured periodically to provide early warning of impending overdraft.

LOCAL CHANGES IN PHYSICAL AND CHEMICAL CHARACTER OF THE GROUND WATER

The use of ground water for reverse-cycle heating and cooling of buildings is increasing in the Portland area. In the downtown district of Portland, west of the Willamette River and the area of this study, artificial recharge using large amounts of exhaust water from the air-conditioning installations has caused serious deterioration of the quality and temperature of the ground water with respect to the requirements for other uses (Brown, 1963, p. O23). The practice of returning the exhaust water undeground has so far been restricted to the west-side business district of Portland but will probably be extended into urban districts of the East Portland area. The inauguration of such a practice in the East Portland area should be preceded by a thorough quantitative analysis of the hydrologic conditions in the affected districts to determine the probable effects of such artificial recharge. Such a study would aid in the effective management and optimum development of the ground-water resources with a minimum of hardship resulting from competitive water demands. It would require the collection and interpretation of comprehensive data on levels, temperatures, chemical quality, pumpage and use of the ground water, and hydraulic characteristics of the aquifers.

CONTAMINATION OF GROUND WATER

During the well inventory for this investigation, only a few wells were found to be contaminated, and most of those were shallow wells that had been contaminated by pollutants from the immediate vicinities of the wells. One exception was at Gladstone, where large withdrawals from aquifers of the Columbia River Basalt apparently induced the migration of saline water from older rocks into those aquifers (pp. 17 and 45). Such problems are but the beginning of greater problems that can be expected to arise as the population density of the area increases, as new industries bring additional waste-disposal problems, and as the use of ground water becomes greater and more competitive.

Contamination by saline water from marine sedimentary rocks underlying the Columbia River Basalt has occurred not only in the Gladstone district but also in the Tualatin Valley (Hart and Newcomb, 1965, p. 29 and pl. 3) and in the west-side business district of Portland (Brown, 1963, p. O23). This problem may therefore be expected to arise at other places in the East Portland area where localized large withdrawals are made from deep aquifers in the Columbia River Basalt. The only parts of the area where that rock unit is shallow enough so that substantial yields of water are likely to be developed from it in the foreseeable future are the east-central, southeastern, and southwestern parts; therefore, any contamination of this kind that may occur in the future will probably be restricted to those parts of the area.

In much of the area, including some densely populated suburban districts of Portland, household and other wastes are discharged into cesspools and septic tanks. Contamination of ground water from these sources may become a serious problem in the future, especially in districts where the underlying rock materials are relatively permeable and are tapped by wells used for domestic and public supplies. The danger of contamination from these and other sources at or near the land surface may be increased in districts where precipitation, which otherwise would percolate downward and dilute the wastes is largely intercepted by buildings, paving, and storm drains.

The presence of household detergents in the waste water intensifies the problem, for some substances in synthetic detergents are difficult to remove by treatment, are normally unchanged by long movement underground, and are troublesome even in concentrations as small as 1 ppm.

Two relatively recent practices in the region tend to increase the danger of contamination of the groud water. One is the disposal of virtually all garbage in pits or sanitary fills owing to the restriction on the burning of rubbish in western Oregon. The other is the increasing use of ponds, or "lagoons," to hold untreated sewage from small municipal systems. Serious contamination of underlying ground-water bodies can result from downward percolation of pollutants from these sources.

Studies should be begun as soon as possible to (1) determine the areas of potential contamination of ground-water supplies from sewage and other wastes, (2) determine the probable courses and rates of movement of the contaminants underground, (3) work out a monitor program of periodic sampling and analysis to trace the contaminants or to provide early warning of possible pollution, and (4) determine methods or develop techniques for controlling or alleviating contamination before it becomes serious.

BASIC GROUND-WATER DATA

The remainder of this report comprises summary tables of records of representative wells (table 1) and springs (table 4), logs of representative wells (table 2), and chemical analyses of well water (table 3). Except for chemical analyses provided by commercial laboratories, nearly all these data represent observations by personnel of the U.S. Geological Survey or reports by well drillers or the owners or users of the wells and springs. Interpretations of the geologic source of the water from wells and springs (tables 1 and 4) and the stratigraphic units penetrated by the wells (table 2) are by the writers.

Most of the information presented in table 2 (logs of representative wells) was obtained from records made by well drillers at the time the wells were constructed, although some information was supplied from memory by drillers and well owners. A few of the wells were visited during construction, and samples were examined by the writers. The records were edited for consistency of terminology and presentation and for conformance with the stratigraphic units described in the text, but were not changed otherwise. For clarity, the writers' interpretations have been added in parentheses after some of the drillers' designations.

The locations of wells and springs listed in the tables are shown on plate 1; also shown on that figure are the locations of other wells, the records of which have been published in State of Oregon Ground Water Report Number 3. In addition to the data in the following tables and those published by the State of Oregon, other ground-water data from the East Portland area are on file at offices of the Geological Survey, Portland, Oreg., and the office of the Oregon State Engineer, Salem, Oreg.

Table 1.—*Records of representative wells in the East Portland area, Oregon*

Well number: See p. 5 for description of well-numbering system.
Approximate altitude: Land-surface datum at well, in feet above mean sea level interpolated from topographic maps.
Type of well: Dg, dug; Dr, drilled.
Character of materials: B, basalt; C, clay; Cg, cemented gravel; G, gravel; Ms, mudstone; S, sand; Si, silt; Ss, sandstone. Letters within parentheses: Tc, Columbia River Basalt; Ts, Sandy River Mudstone; Tt, Troutdale Formation; QTv, Boring Lava; Qfl, fluviolacustrine deposits; Qt, younger terrace deposits; Qal, younger alluvium.
Ground-water occurrence: C, confined; P, perched; U, unconfined.
Water level: Depths to water given in feet and decimal fractions were measured by the U.S. Geol. Survey; those given in whole feet were reported by the well owner or driller. F, flowing well whose static water level is not known. Datum is land surface at the well.

Type of pump: B, bucket; C, centrifugal; J, jet; N, none; P, piston; T, turbine St, submersible.
Use: D, domestic; Ind, industrial; Irr, irrigation; N, none; PS, public supply; S, stock.
Remarks: Ca, chemical analysis in table 3; Cl, chloride; dd, drawdown; gpm, gallons per minute; H, hydrograph included in this report; Hn, hardness as $CaCO_3$; L, driller's log in table 2; Mgd, million gallons per day; Pf, perforated casing (followed by depth interval, in feet); ppm, parts per million; Temp, temperature of water in ° Fahrenheit; SC, 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 or occupant	Approximate altitude (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s): Depth to top (feet)	Water-bearing zone(s): Thickness (feet)	Water-bearing zone(s): Character of materials	Ground-water occurrence	Water level: Feet below datum	Water level: Date	Type of pump and yield (gallons per minute)	Use	Remarks
							T. 1 N., R. 1 E.								
4K1	U.S. Govt	10	Dr	148	12	148	115	22	S, G (Qal)	U	13	1942	N	N	Vanport well 2. Pumped 1,400 gpm, dd 8 ft; Ca, L.
7N1	McCormick & Baxter Co.	30	Dr	130	12	130	60 118	24 5	S (Qal) G (Tt)	U	23	9- -45	T	Ind	Pumped 1,600 gpm, dd 26 ft. Pf 65-84, 94-104, and 116-124 ft; L.
8B1	Western States Rendering Co.	80	Dr	96	10	96	48	48	S, G (Qfl)	U	--------	--------	T, 500	Ind	Pf 55-96 ft; L.
11N2	American Pipe & Construction Co.	40	Dr	91	12	92	40	52	G (Qfl)	U	25-30	1957	--------	Ind	Pumped 1,100 gpm, slight dd.
21L1	Continental Grain Co.	20	Dr	189	16	189	136	47	S, G (Tt)	U	30	10-13-57	T	Ind	Pumped 1,000 gpm, dd 48 ft after 8 hr. Pf 135-183 ft; L.
35C1	Lloyd Corp., Ltd	130	Dr	272	13	272	177 238	27 12	S, G (Tt) S, G (Tt)	U	121	12- 3-57	T	Ind	Pumped 1,050 gpm, dd 3 ft after 3 hr; Temp 53. Pf 189-204, 240-250 ft; L.
36H1	Ladd Estate	220	Dr	1,700	8-5	--------	--------	--------	--------	--------	340(?)	1885	N	N	Well drilled about 1885; long abandoned; L.

TABLE 1.—*Records of representative wells in the East Portland area, Oregon*—Continued

Well	Owner or occupant	Approximate altitude (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s): Depth to top (feet)	Water-bearing zone(s): Thickness (feet)	Water-bearing zone(s): Character of materials	Ground-water occurrence	Water level: Feet below datum	Water level: Date	Type of pump and yield (gallons per minute)	Use	Remarks
T. 1 N., R. 2 E.															
9D1	S. J. Mason	30	Dr	115	6	-------	107	8	G	U	30	8- -56	J	D	Driller reported only sand was penetrated from surface to aquifer.
22Q1	Parkrose Water Dist.	210	Dr	265	12	265	215	16	G (Tt)	U	198	4- -52	T	PS	Standby supply for Parkrose; pumped 1,000 gpm, dd 9 in. after 1 hr; Ca. Pf 217-247 ft; L.
25C3	Blair Holcomb	75	Dr	133	8	100+	53 119	7 6	G (Tt) G (Tt)	P U	92	5- 8-49	T	Irr	Pf 47-60 and 79-88 ft; perched water cascades into well from water-bearing zone opposite upper perforations.
26R1	Richland Water Dist.	260	Dr	490	12	335	200	103	S, G (Tt)	U	145	9- -56	T	PS	Pumped 220 gpm, dd 94 ft after 4 hr; Ca. Pf below 145 ft; L.
T. 1 N., R. 3 E.															
21G1	Church of Latter Day Saints.	20	Dr	52	12	2		50	G (Qal)	U			T	Irr	Pumped 1,050 gpm, dd 7 ft; flows during high stages of Columbia River; Ca.
23B1	Bonneville Power Adm.	25	Dr	183	10	183	175	8	G, S (Tt)	U	10.3	3-15-46	T	Ind	Pumped 142 gpm, dd 142 ft after 20 hr; Ca, L.
23G4	Reynolds Metals Co. 10.	28	Dr	625	20-12	590	472 520 536	10 12 23	S, G (Tt) S, G (Tt) S, G (Tt)	U	78	1955	T, 1,000	Ind	Pf 440-482, 522-530, and 538-558 ft; L.
23H1	Reynolds Metals Co. 4.	28	Dr	190	12	190	164	13	G (Tt)	U	16	8- 3-42	T, 980	Ind	Pumped 1,300 gpm, dd 24 ft; Ca; Temp 54. Pf 170-180 ft.
23K1	Reynolds Metals Co. 12.	28	Dr	615	20-12	590	156 230 507	31 4 70	S, G (Tt) S (Tt) S, G (Tt)	U	23	9- -49	T, 1,200	Ind	Pf 512-518, 522-538, 544-555, and 563-578 ft; Ca, L.
26N1	Multnomah County Farm.	135	Dr	228	10	-------	195	33	Cg (Tt)	U	65	1943	T	PS, Irr	Drilled to 257 ft, backfilled to 228 ft. Pumped 500 gpm, dd 100 ft; Ca.

27M1	City of Fairview	130	Dr	1,060	12	830	265 967	80 8	G (Tt) Ss		92.7	7-30-58		PS	Pumped 400 gpm. Pf 320–340 ft; L.
29A2	Gresham Sewage Plant.	80	Dr	103	6				G (Tt)	U	50.5	9-12-55	St	D	Pumped 44 gpm, dd 2 ft after 48 hr; Hn 108 ppm, Cl 7 ppm, Sc 254; H.
34D1	Multnomah Kennel Club.	180	Dr	405	12				G	U	103	5- -56	T		Pumped 350 gpm, dd 73 ft; Ca.
34N1	Carl Zimmerman	325	Dr	132	8	126	55 85	 45	G (Qfl) G, S (Tt)		85		T	D, Ind	Pumped 30 gpm, slight dd after 1 hr; L.
36F1	Y. Mishima	215	Dr	46	10				G (Tt?)	C, P	F	1-15-54		Irr	Flows about 15 gpm; pumped 60 gpm, dd 45+ ft after 2 hr.

T. 1 S., R. 1 E.

1Q1	Sunnybrook Farm	145	Dr	156	10-8	156	110		G, S (Tt)	U	83	9- -55		Ind	Pumped 44 gpm for 1hr, dd slight; L.
2E2	Arden Farms Co	55	Dr	385	14	307	170 281	5 11	G (Tt) S, G(Ts)				T	Ind	Pumped 1,200 gpm, dd 27 ft after 1 hr. Pf 45–50, 168–175, and 285–295 ft; L.
3A3	Northwestern Ice & Cold Storage Co.	35	Dr	265	12	241	240	25	S (Ts)	U	14.5	1928	T, 500	Ind	Supplies about 0.5 mgd for cooling; L. Temp 54.
11D1	Dairy Coop. Assoc.	40	Dr	490	16	433	119 194 415	3 24 8	S (Tt) S (Tt) S, G (Ts)	U	49	1- -46	T	Ind	Pumped 1,200 gpm, dd 108 ft after 48 hr. Pf 105–115, 221–230, 245–255, and 419–425 ft; L.
11H1	Libby, McNeill, & Libby.	65	Dr	330	12-10	330	215 282	25 48	G (Tt) S, G (Tt)	U	20.5	1929	T	Ind	Pumped 800 gpm, dd 50 ft; Ca. Pf 215–240, 282–297, and 301–330 ft; L.
25M1	Kellogg Park Housing Proj.	40	Dr	430	12-8	368	120 402	48 18	B (Tc) B (Tc)	C	24	6- -45		PS	Pumped 180 gpm, dd 125 ft after 1 hr; L.

T. 1 S., R. 2 E.

3E1	C. H. Withers	290	Dr	165	8	165	155	10	G (Tt)	U	110	1951	St, 60	Irr	Pumped 50 gpm, dd 2 ft after 2 hr; Ca; Temp 52. Pf 157–164 ft.
12E1	J. Henderson	230	Dr	125	6				G (Qfl)	U	39.0	9-13-55	J	D	Supplies domestic heating plant; H.
14J2	M. Raab	250	Dr	110	6				(Tt)	U	45.8	9-21-55	J	Irr	Supplies water for garden; H.
27B1	U.S. Veterans Adm.	730	Dr	967	10	769	576	13	S (Tt)		487	1950	T	Irr	Pumped 100 gpm, dd 73 ft after 3 hr. Pf 540–550 and 650–573 ft; L.
28P1	M. E. Thomas	375	Dr	225	6	99			(Tt)	P	109.0	9-19-55	St	D	H.

TABLE 1.—*Records of representative wells in the East Portland area, Oregon*—Continued

Well	Owner or occupant	Approximate altitude (feet)	Type of well	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s)			Ground-water occurrence	Water level		Type of pump and yield (gallons per minute)	Use	Remarks
							Depth to top (feet)	Thickness (feet)	Character of materials		Feet below datum	Date			
							T. 1 S., R, 3, E.								
7N1	H. Andregg	305	Dr	260	12				(Tt)	U	139.8	9- 9-55	T, 500	Irr	
8C2	Rockwood Water Dist.	348	Dr	120	12	120	82 104	10 16	G (Tt) G (Tt)	U	62	12- -55	N	N	Formerly used for public supply; pumped 100 gpm, dd 12 ft. Pf 87-97 and 104-116 ft; H.
10B1	Gresham Berry Growers.	335	Dr	400					S, G (Tt)	U				Ind	Ca.
12D1	F. A. Arrington	400	Dr	140	6				(Tt)	P	115.5	8-15-55	P	D	Water contains iron; H.
14R1	James Gordon	450	Dr	197	8	196	155 172	10 23	S, G (Tt) G (Tt)	P	88	1953			Pumped 300 gpm, dd 57 ft after 7 hr. Pf 174-192 ft; L. Temp 54.
18R1	J. Vohs	510	Dr	480	6				(Tt)	U	350	8- -55	St	D	
22J2	R. Shiiki	600	Dr	510	12-8	509	265 331 499	5 10 9	G (Tt) G (Tt) B (Tc)		199.1	8-18-55	T	Irr	Pumped 600 gpm, dd 75 ft after 1 hr. Pf 265-270 and 331-510 ft; L. Temp 54.
24E1	R. D. Monnie	440	Dr	177	6	86	170	5	B (QTv)		50		J	D	Pumped 15 gpm, dd 5 ft; L.
29F1	F. DeLano	550	Dr	265			200	65	B (QTv)	P	170		10	D	Ca, L.
29M1	Mr. Eggenberger	335	Dr	180	8	120	115	43	B (QTv)	P	55	1948	50	D	Pf 85-100 ft; L.
32E1	R. M. Williams	425	Dr	169	8				(Tt)	U	149.9	8-26-55	J	D	
33A1	O. H. Yeager	550	Dr	130	6				G, C (Tt)	U	118.5	8-19-55	J	D	Pumped 15 gpm, dd 1 ft after 1 hr; H.
							T. 1 S., R. 4 E								
10D1	Young Men's Christian Assoc.	80	Dr	310		310	310		B (Tc)	C	F	8-10-55		PS	Flows 40 gpm; has shut-in pressure of 12 lb. Supplies swimming pool. Ca; Temp 76.
10N1	A. Thompson	375	Dg	20.8	11				(Qt)	P	14.7	8-10-55	C	D	
16H1	A. W. Sherwood	650	Dr	480	8	383	380	30	Ss (Tt)	U	375	6-30-56	T	Irr	Pumped 150 gpm, dd 15 ft after 6 hr; L.
17F2	J. E. Nelson	600	Dr	198	6	180			(Tt)	P	157.1	8-10-55	P	Irr	Supplies small garden.
23P1	Ida Nordene	500	Dg	19.8	48	20			(Qt)	P	14.1	8- 5-55	B	D	Temp 50.
25P1	A. I. Geetz	585	Dg	10	108	10			Cg (Qt)	P	4.9	4- 4-55	C. 150	Irr	Hn 14 ppm, Cl 3 ppm, Sc 52.
							T. 2 S., R. 1 E.								
1L1	D. M. Steeves	190	Dr	397	6	23	264		B (Tc)	U	150	10- -56		D	Bailed 25 gpm, dd 25 ft; L.

T. 2 S., R. 2 E.

5M1	Union High School, Dist. 5.	95	Dr	203	8-6	203	147 187	33 1	Cg (Tt) G, S (Tt)	U	8±	11- 2-57	T	Irr	Pumped 135 gpm for 30 hr, dd 58 ft. Pf 101-108, 124-131, 146-181, and 186-197 ft;L. Temp 52.
9B1	A. L. Alexander	110	Dr	80	6	80	50	22	G, S (Tt)	U	8	1929	P, 10	S	Casing not perforated; L.
11K1	F. T. Williams	140	Dr	185	6	165	133	10	S (Ts)	C	7	5- 5-27	P, 50	Irr	Pumped 50 gpm, dd 8 ft. Pf 122-150 ft; L.
16B1	F. J. Mooney	95	Dr	51	8	34	15		G (Tt)	P	3.5	1-22-58	N	N	Bailed 10 gpm, dd 32 ft; L.
19E1	N. F. Bixby	75	Dr	124	6	124	96	28	B (Tc)	U	44	10-29-57		D	Pumped 26 gpm, dd 60 ft after 4 hr. Pf 85-95 and 105-120 ft; L.
20F1	City of Gladstone	65	Dr	692	12	169	200 675	 10	B (Tc) B (Tc)	C	42.1	1-27-51	T	N	Large yield at 675 ft near bottom of basalt; water saline and was sealed off. Pumped 200 gpm from upper fresh-water part of basalt; Ca, L.
20K1	do	50	Dr	250	12				B (Tc)	C				N	Yielded 250 gpm. Drilled in basalt entire depth; Ca.

T. 2 S., R. 3 E.

5N1	Mr. Josefson	550	Dr	60	6				B (QTv)	P			J	D	Well reportedly entered rock at 40 ft; Ca.
6Q1	J. W. Aylett	430	Dr	105	6	105	90	15	B (QTv)	P	88	7- -56	St, 35	D, Irr	Bailed 20 gpm, dd 5 ft after 1 hr. Pf 95-105 ft; L. Temp 52.
10C1	M. Fujimoto	640	Dr	300	10		225		S (Tt)	P	166.7	8-23-55	T, 300	Irr	Pumped 300 gpm, dd 125 ft; H.
14L1	Salvation Army	300	Dr	600	8	571	575	25	B (Tc)	C	F	1951		PS	Pumped 30 gpm, dd 200 ft after 1 hr; L.
15D1	Abraham Bialostosky.	755	Dr	400	12-6	370	400		B (QTv?)	P	205	6-20-57	St, 25	D	L.
23B1	Barton Baptist Church.	270	Dr	135	6	120	129	1	S (Ts)	P	70	3- -56		D	Pumped 10 gmp, dd 45 ft; L.
24E1	E. Odell	270	Dr	37	6	34	30	4	G (Qt)	P	7	1951	S, 11	D	L.

T. 2 S., R. 4 E.

4R1	M. K. Smith	700	Dr	400	8				G (Tt)	U	93.5	3-13-58	St	Irr	Irrigates 30 acres.
8C1	G. Schaeffer	610	Dr	450					B (Tc)	C	160	1952	T, 500	Irr	Irrigates 40 acres.
18R1	Schedeen Bros	665	Dr	904	8-6	743	750	10±	B (Tc)	U	550	1947		D	Pumped 7 gpm, slight dd; L.
21J1	Hudson-Duncan Co.	790	Dr	1,330	16-6	476	165 885	2 445	G (Tt) B (Tc)	U	585	6- 7-52	T, 100	Irr	L.

TABLE 2.—*Driller's logs of representative wells in the East Portland area, Oregon*

[Abbreviations: dd, drawdown in feet of the water level during pumping; ft, feet; gpm, gallons per minute; swl, static water level, in feet below land surface]

1N/1–4K1

[U.S. Govt. (Vanport well 2). Drilled by R. J. Strasser Drilling Co., 1942]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Younger alluvium:			Younger alluvium—Continued		
Clay	5	5	Sand and gravel, water-bearing	22	137
Silt and sand	90	95	Unreported	11	148
Gravel and clay	20	115			

1N/1–7N1

[McCormick & Baxter Co. Drilled by R. J. Strasser Drilling Co., 1945]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Artificial fill:			Troutdale Formation:		
"Dredged sand"	12	12	Gravel, cemented	13	118
Younger alluvium:			Gravel, water-bearing	5	123
Silt, clay, and very fine sand	48	60	Gravel, cemented	7	130
Sand, coarse, water-bearing	24	84			
Gravel and clay	21	105			

1N/1–8B1

[Western States Rendering Co. Drilled by Steinman Bros. Drilling Co., 1946]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Fluviolacustrine deposits—Con.		
Hardpan	6	6	Sand and gravel	12	60
Clay, sandy	11	17	Gravel, coarse	5	65
Sand, brown	31	48	Sand and coarse gravel	31	96

1N/1–21L1

[Continental Grain Co. Drilled by R. J. Strasser Drilling Co., 1957]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Artificial fill:			Troutdale Formation:		
Soil	5	5	Gravel, cemented	9	136
Concrete footing	10	15	Sand and gravel, loose, water-bearing	32	168
Younger alluvium:			Gravel, loose, water-bearing	15	183
Boulders, loose	5	20	Gravel, sandy, cemented	6	189
Silt, blue	58	78			
"Rock," brown, soft	2	80			
Clay, blue	47	127			

1N/1–35C1

[Lloyd Corp., Ltd. Drilled by R. J. Strasser Drilling Co., 1957]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale Formation—Con.		
Soil	4	4	Gravel and sand, loose, water-bearing	27	204
Silt, sandy	45	49	Gravel and sand; some boulders'	11	215
Sand and gravel, coarse	18	67	Gravel, sand, and clay, containing boulders	23	238
Sand, silty	22	89	Sand and gravel, water-bearing	12	250
Sand, silty; some gravel	27	116	Gravel, cemented	22	272
Troutdale Formation:					
Gravel and sand, bouldery	17	133			
Gravel and sand, loose	11	144			
Gravel and sand; some boulders	33	177			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1N/1–36H1

[Ladd Estate. Drilled about 1885]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Sandy River Mudstone—Con.		
Sand and clay	100	100	Sand, fine, and gravel	10	730
Sand, clay, and gravel	20	120	"Marl" and clay, some layers of fine, soft sandstone	120	850
Troutdale(?) Formation:					
Sand, containing boulders	20	140	Shale and "marl," some layers of sand; much fossilized plant debris	150	1,000
Gravel, containing boulders and "veins" of white sand	40	180	Sandstone, white and gray, partly micaceous	80	1,080
Gravel, sandy	20	200	Conglomerate, fine; some shale and "marl"; some fossil plants	120	1,200
"Boulders and grit"	20	220	Gravel and coarse grit	50	1,250
Gravel, containing "veins" of white sand	60	280	"Marl" and clay; some gravel and plant fossils	50	1,300
Troutdale Formation:			Columbia River Basalt:		
Conglomerate, sandy	50	330	"Granite" (basalt)	400	1,700
Sand, fine, and gravel	30	360			
Clay, sand, and gravel in alternating layers	45	405			
Sandy River Mudstone:					
"Marl," olive-colored, and shale with some basaltic grit and sand. Some fossilized plant remains	315	720			

1N/2–22Q1

[Parkrose Water Dist. Drilled by Haakon I. Bottner Drilling Co., 1952]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale Formation—Con.		
Soil(?)	51	51	Gravel	12	205
Troutdale Formation:			Sand	10	215
Gravel, cemented	43	94	Gravel, water-bearing	16	231
Gravel, loose	44	138	Unreported	7	238
Sand	40	178	Gravel and clay	23	261
Sand and gravel	15	193	Unreported	4	265

1N/2-26R1

[Richland Water Dist. Drilled by Haakon I. Bottner Drilling Co., 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale Formation—Con.		
Clay, yellow	6	6	Gravel and sand, water-bearing	11	211
Gravel and boulders	26	32	Gravel, cemented, water-bearing	92	303
Gravel, loose	34	66	Sand, coarse, and gravel	9	312
Troutdale Formation:			Gravel, cemented	98	410
Gravel, cemented	19	85	Sandy River Mudstone:		
Gravel and yellow clay	15	100	Clay, gray	42	452
Sand, water-bearing (approx. 26 gpm)	30	130	Clay, blue	38	490
Gravel and yellow clay	15	145			
Gravel, cemented	55	200			

1N/3–23B1

[Bonneville Power Adm. Drilled by R. J. Strasser Drilling Co., 1946]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Younger alluvium:			Troutdale Formation:		
Sand	10	10	Gravel, cemented	1	175
Clay	15	25	Gravel and sand	8	183
Sand	143	168			
Clay	6	174			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1N/3-23G4

[Reynolds Metals Co. Drilled by R. J. Strasser Drilling Co., 1949]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Old well, no record	190	190	Troutdale Formation—Con.		
Troutdale Formation:			Sand, hard-packed	11	432
Silt, sandy, blue	16	206	Clay, sandy, containing some gravel	29	461
Sand, hard-packed	21	227	Gravel, cemented	11	472
Silt, sandy	11	238	Sand and gravel, water-bearing	10	482
Sand, coarse, and gravel	6	244	Gravel, cemented	31	513
Clay, blue	8	252	Sand, clay, and small gravel	7	520
Sand, hard-packed; some gravel	85	337	Sand and gravel, water-bearing	12	532
Silt, sand and gravel layers	35	372	Silt, blue	4	536
Clay, sandy	5	377	Sand and gravel, water-bearing	23	559
Sand, hard-packed, and gravel	8	385	Silt and clay; some gravel	28	587
Clay and silt, sandy	16	401	Shale, hard	38	625
Sand, hard-packed	15	416			
Clay	5	421			

1N/3-23K1

[Reynolds Metals Co. Drilled by R. J. Strasser Drilling Co., 1949 and 1954]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Artificial fill and younger alluvium:			Troutdale Formation—Con.		
Fill and soil	24	24	Sand and clay, gray	9	361
Younger alluvium:			Shale and sand, black	23	384
Silt and clay	18	42	Clay, brown	12	396
Sand, brown	12	54	Sandstone	13	409
Sand, fine, gray	89	143	Sand and clay, containing some gravel	11	420
Sand, coarse, gray; some clay	13	156	Sand, hard-packed, containing some clay	26	446
Troutdale Formation:			Clay and gravel	28	474
Sand, coarse, some gravel, water-bearing	31	187	Clay, sandy	13	487
Sand and clay, gray	43	230	Sandstone	20	507
Sand; in part water-bearing	4	234	Sand and gravel, loose, water-bearing	70	577
Sand and clay, blue	31	265	Gravel, cemented	20	597
Shale, blue	16	281	Sand and silt	9	606
Clay and sand	24	305	Clay, blue, hard	9	615
Sand, fine, containing scattered gravel	47	352			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1N/3-27M1

[City of Fairview. Drilled by Barron & Strayer, 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Troutdale Formation:			Sandy River(?) Mudstone—Con.		
Clay	5	5	Sand, fine	20	735
Boulders and gravel	15	20	Gravel, small, sandy, caving	10	745
Gravel	39	59	Clay, gray, sandy	10	755
Gravel, cemented	24	83	Clay, yellow; bottom of 10-in. casing at 800-ft depth	45	800
Clay, blue	22	105	Columbia River Basalt:		
Silt	20	125	Rock, gray, hard; open 10-in. hole below 800-ft depth	10	810
Gravel, sandy, water-bearing	15	140	Rock, broken	16	826
Gravel, cemented; bottom of 12-in. casing at 182 ft	63	203	Clay	1	827
Silt	62	265	Rock, black, hard	23	850
Gravel, clean	55	320	Rock, hard; some blue clay	25	875
Gravel, muddy	25	345	Rock, black	25	900
Gravel, cemented; swl 110 ft	15	360	Clay, blue	15	915
Sandy River(?) Mudstone:			Rock, gray	5	920
Clay, yellow, sandy	20	380	Older rocks:		
Sand, fine, "heaving"	40	420	Clay, blue; swl 90 ft	15	935
"Rock" (gravel?), coarse	25	445	"Shell," hard	2	937
Silt, sandy	50	495	Clay	13	950
Sand, heaving	40	535	"Sand rock," (tuffaceous(?) sandstone), hard, gray	15	965
Shale, blue	5	540	Clay, blue	2	967
Sand, black	20	560	Sandstone, gray, hard, water-bearing	8	975
Sand; some gravel	15	575	Rock, hard, black	23	998
Sand, fine, white; swl dropped to 120 ft at 585-ft depth	50	625	Clay, red and pink	4	1,002
Gravel, water-bearing	1	626	Rock, broken, hard; drilled muddy	28	1,030
Sand, fine, white	44	670	Rock, broken, and blue clay	15	1,045
Sand, fine, and gravel	20	690	Sand, gray, and clay	15	1,060
Sandstone, hard, "sharp"	15	705			
Shale, blue	10	715			

1N/3-34N1

[Carl Zimmerman. Drilled by Steinman Bros. Drilling Co., 1944]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale Formation:		
Gravel and boulders	11	11	Gravel, cemented, water bearing	35	120
Gravel	26	37	Gravel, fine, and coarse sand	10	130
Gravel and boulders	8	45	Clay, sandy, yellow	2	132
Gravel; water bearing at 55 ft	25	70			
Clay, sandy	15	85			

1/1-1Q1

[Sunnybrook Farm. Drilled by A.M. Jannsen Drilling Co., 1945]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Boring(?) Lava—Continued		
Sand	80	80	Rock(?)	10	110
Sand and gravel	5	85	Troutdale Formation:		
Boring(?) Lava:			Sand and gravel	33	143
Black lava rock(?)	13	98	Sand, brown; some clay	9	152
Sand	2	100	Sand and gravel	4	156

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1/1-2E2

[Arden Farms Co. Drilled by R. J. Strasser Drilling Co., 1944]

Materials	Thickness (feet)	Depth (feet)
Younger terrace deposits:		
Clay	6	6
Gravel	8	14
Boulders	6	20
Fluviolacustrine deposits and Troutdale Formation:		
Gravel, containing clay binder	25	45
Gravel, loose, water-bearing	7	52
Sand, yellow	2	54
Gravel, containing clay binder	59	113
Silt and sand, blue	4	117
Clay	6	123
Troutdale Formation:		
Gravel, cemented	47	170
Gravel, water-bearing	5	175
Gravel, containing sand and clay	54	229
Sandy River Mudstone:		
Shale	52	281
Sand and gravel, water-bearing	11	292
Clay	18	310
Clay and silt, scattered gravel	63	373
Sandstone	12	385

1/1-3A3

[Northwestern Ice & Cold Storage Co. Drilled by R. J. Strasser Drilling Co., 1928]

Materials	Thickness (feet)	Depth (feet)
Younger alluvium:		
Clay and gravel fill	19	19
Alluvium of abandoned river channel:		
"Muck," dark	14	33
Clay, "solid"	3	36
"Muck," dark	17	53
"Wood" (buried log?)	2	55
"Muck," dark	57	112
"Muck," sandy	13	125
Troutdale Formation:		
Gravel; some boulders	15	140
Sand	19	159
Gravel, cemented	5	164
Shale and gravel	15	179
Sandy River Mudstone:		
Clay, blue	54	233
Clay, blue; some yellow sand	7	240
Sand, yellow, and clay	15	255
Sand, clean	10	265

1/1-11D1

[Dairy Coop. Assoc. Drilled by R. J. Strasser Drilling Co., 1946]

Materials	Thickness (feet)	Depth (feet)
Artificial fill:		
Fill	12	12
Fluviolacustrine deposits:		
Gravel, loose	15	27
Gravel, bouldery	16	43
Troutdale Formation:		
Gravel, cemented	76	119
Sand, fine, water-bearing	3	122
Gravel, cemented	72	194
Sand, water-bearing	24	218
Gravel	2	220
Gravel, cemented	38	258
Sandy River Mudstone:		
Clay and fine sand	5	263
Clay, blue	50	313
Clay, brown	3	316
Sand	8	324
"Soapstone," green	7	331
Sand	3	334
Clay, blue and brown	6	340
Sand	39	379
Clay, brown; some gravel below 391 ft	17	396
Clay, sandy	14	410
Sand, gray	5	415
Gravel and sand, water-bearing	8	423
Shale	67	490

1/1-11H1

[Libby, McNiell & Libby. Drilled by R. J. Strasser Drilling Co., 192[illegible]]

Materials	Thickness (feet)	Depth (feet)
Alluvium of an abandoned river channel:		
Soil and clay	18	18
Gravel, loose, water-bearing	7	25
Gravel, cemented	13	38
Silt, sandy	24	62
Troutdale Formation:		
Gravel, cemented	45	107
Clay, yellow	3	110
Troutdate Formation—Con.		
Gravel, cemented	37	147
Gravel, containing sand and clay	43	190
Gravel, cemented	25	215
Gravel, water-bearing	25	240
Gravel, cemented	42	282
Sand and gravel, water-bearing	48	330

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1/1–25M1

[Kellogg Park Housing Proj. Drilled by R. J. Strasser Drilling Co., 1945]

Materials	Thickness (feet)	Depth (feet)
Alluvium of abandoned river channel:		
Soil	4	4
Clay and silt, blue	86	90
Columbia River Basalt, weathered:		
Shale, red	11	101
Clay, blue	19	120
Columbia River Basalt:		
Rock, black, water-bearing (about 50 gpm)	48	168
Clay, blue	17	185
Rock, gray	25	210
Shale, blue and red (weathered basalt?)	25	235
Rock	10	245
Columbia River Basalt—Con.		
Shale, red (weathered basalt?)	12	257
Rock	30	287
Shale, red (weathered basalt?)	5	292
Rock	56	348
Clay, blue	12	360
Shale, red	5	365
Rock, brown	7	372
Rock, black	30	402
Rock, black, fractured, water-bearing	18	420
Rock, black, hard	10	430

1/2–27B1

[U. S. Veterans Adm. Drilled by R. J. Strasser Drilling Co., 1950]

Materials	Thickness (feet)	Depth (feet)
Boring Lava, weathered:		
Soil	3	3
Clay	26	29
Boring Lava:		
Rock, decomposed	10	39
Rock, gray, hard; red seams at 125–131 and 144–167 ft	157	196
Rock, gray; hard layers alternating with red, brown, and yellow soft layers	250	446
Rock, gray, hard, containing red seams	89	535
Troutdale Formation:		
Sand, coarse, and tight gravel	41	576
Sand and silt, water-bearing; test bailed at 70 gpm	13	589
Troutdale Formation—Con.		
Sand and gravel	50	639
Shale	11	650
Gravel and clay	7	657
Sand and clay	26	683
Shale	33	716
Sand and clay	45	761
Conglomerate	78	839
Conglomerate, sand, and shale	6	845
Conglomerate and loose sand	6	851
Conglomerate	42	893
Conglomerate, containing quartz sand	52	945
Conglomerate	22	967

1/3–14R1

[James Gordon. Drilled by Haakon I. Bottner Drilling Co.]

Materials	Thickness (feet)	Depth (feet)
Piedmont deposits:		
Clay, yellow	55	55
Clay, white	8	63
Troutdale Formation:		
Gravel, cemented	21	84
Clay, sandy	5	89
Gravel, cemented	36	125
Troutdale Formation—Con.		
Sand, fine	5	130
Gravel, cemented	25	155
Sand and gravel, water-bearing	10	165
Gravel and sand	7	172
Gravel, water-bearing	23	195
Gravel, cemented	2	197

1/3–22J2

[R. Shiiki. Drilled by Haakon I. Bottner Drilling Co., 1954]

Materials	Thickness (feet)	Depth (feet)
Boring(?) Lava, weathered:		
Clay, yellow	64	64
Boring Lava:		
Rock	90	154
Rock and yellow clay	24	178
Rock	16	194
Troutdale Formation:		
Clay, yellow	6	200
Gravel, cemented	15	215
Clay, yellow	4	219
Gravel, cemented	46	265
Gravel, water-bearing (est. 40 gpm)	5	270
Troutdale Formation—Con.		
Gravel, cemented	61	331
Gravel, water-bearing (est. 60 gpm)	10	341
Gravel, cemented	19	360
Sandy River Mudstone:		
Clay, blue	100	460
Clay, green	10	470
Columbia River Basalt:		
Rock	29	499
Rock, soft, water-bearing	9	508
Rock, hard	2	510

756–496—65——6

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

1/3-24E1

[R. D. Monnie. Drilled by O. E. Jannsen, 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Piedmont deposits:			Boring Lava:		
Clay, sticky, red; some boulders	35	35	Lava, gray-black, hard and soft; water bearing at 170–175 ft	91	177
Gravel, partially cemented	51	86			

1/3-29F1

[F. DeLano]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Boring Lava:			Boring Lava—Continued		
Clay	40	40	Basalt	40	200
Basalt	90	130	Basalt, vesicular	65	265
"Red volcanic ash"	30	160			

1/3-29M1

[Mr. Eggenberger. Drilled A. O. Olsen, 1948]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Piedmont deposits and Boring Lava, weathered:			Boring Lava:		
Clay	82	82	"Honeycomb rock"	20	102
			Clay	13	115
			Rock, vesicular streaks	43	158
			Clay, blue	22	180

1/4-16H1

[A. W. Sherwood. Drilled by A. O. Olsen, 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Piedmont deposits:			Troutdale Formation:		
Clay and silt	75	75	Gravel, cemented	37	255
Clay and gravel	10	85	Clay and sand	50	305
Clay and silt	20	105	Sandstone	25	330
Clay and gravel	50	155	"Loam," sandy	30	360
Clay, blue	25	180	Gravel, cemented	20	380
Clay and gravel	5	185	Sandstone, water-bearing	30	410
Clay, blue, sandy	3	188	Sandy River Mudstone:		
Boring Lava:			Clay, red	5	415
Rock, hard	11	199	Sandstone and clay layers	65	480
Rock, red, soft	4	203			
Sand and clay (weathered lava?)	12	215			
Rock, hard	3	218			

2/1-1L1

[D. M. Steeves. Drilled by Steinman Bros. Drilling Co., 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Columbia River Basalt:			Columbia River Basalt—Con.		
Clay	4	4	Rock, gray, soft	8	288
Rock, broken, and clay	10	14	Rock, gray, hard; test bailed 18 gpm; dd 35 ft; swl 150 ft	62	350
Rock, broken	6	20	Rock, gray and black, hard	38	388
Rock, hard; some crevices	14	34	Rock, black, containing red seams	8	396
Rock, softer	7	41	Rock, gray, hard; test bailed 25 gpm; dd 25 ft; swl 150 ft	1	397
Rock, black and gray, hard	223	264			
Rock, black; test bailed 7 gpm; swl 150 ft	16	280			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
2/2-5M1					
[Union High School Dist. 5. Drilled by O. E. Jannsen, 1957]					
Alluvium of abandoned river channel:			Troutdale Formation—Con.		
Clay, sandy, brown	29	29	Gravel, cemented, gray	24	130
Troutdale Formation:			Shale, gray	17	147
Gravel, cemented, gray	14	43	Gravel, cemented, gray, water-bearing	33	180
Sand, fine, brown, water-bearing	3	46	Shale, blue-gray	7	187
Gravel, cemented, gray	17	63	Sand and gravel, loose, water-bearing	1	188
Sand, fine, gray	2	65	Gravel, cemented, gray	10	198
Gravel, cemented, gray	27	92	Columbia River Basalt:		
Shale, blue and gray	14	106	Lava, gray	5	203
2/2-9B1					
[A. L. Alexander. Drilled by O. E. Jannsen, 1927]					
Alluvium of abandoned river channel:			Troutdale Formation—Con.		
Soil and clay	5	5	Gravel, cemented	5	38
Troutdale Formation:			Sand	10	48
Gravel, cemented	11	16	Gravel, cemented, sandy	7	55
Sand	2	18	Sand	6	61
Gravel, cemented	10	28	Sand, cemented	4	65
Gravel, cemented, and sand	5	33	Sand, fine	13	78
			Gravel, cemented	2	80
2/2-11K1					
[F. T. Williams. Drilled by O. E. Jannsen, 1927]					
Alluvium of abandoned river channel:			Sandy River Mudstone—Con.		
No record	20	20	Shale, blue	8	95
Sand and gravel	8	28	Shale, sandy	33	128
Troutdale Formation:			Quicksand	5	133
Gravel, cemented	13	41	Sand, water-bearing; swl rose to 7 ft; well tested 24 gpm; dd 17 ft	10	143
Sand	14	55	Sand and blue shale	16	159
Gravel, cemented	11	66	Shale, blue	21	180
Sandy River Mudstone:			Shale, green	5	185
Clay, green	6	72			
Shale, brown	15	87			
2/2-16B1					
[F. J. Mooney. Drilled by O. E. Jannsen, 1958]					
Alluvium of abandoned river channel:			Troutdale Formation—Con.		
Clay, gravelly, brown	4	4	Gravel, cemented, containing layers of brown clay	12	31
Troutdale Formation:			Gravel, cemented; water-bearing at 39 ft	8	39
Gravel, lightly cemented	11	15	Shale, gray	6	45
Gravel, loose, water-bearing	1	16	Gravel, cemented	6	51
Gravel, lightly cemented	3	19			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

2/2–19E1

[N. F. Bixby. Drilled by J. W. Beck Drilling Co., 1957]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
No record; old drilled well	96	96	Columbia River Basin—Con.		
Columbia River Basalt:			Clay, blue	8	119
Basalt, weathered	5	101	Basalt, weathered	2	121
Basalt, solid	5	106	Basalt, solid	3	124
Clay, brown	5	111			

2/2–20F1

[City of Gladstone. Drilled by Haakon I. Bottner Drilling Co., 1949]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Younger terrace deposits:			Columbia River Basalt—Con.		
Clay and boulders	11	11	Clay and shale (weathered zone in the basalt?)	13	130
Clay, blue and yellow	29	40	Rock, soft	5	135
Clay and sand	15	55	Basalt, black	40	175
Shale, brown, sandy	20	75	Basalt; water bearing at 200 ft	500	675
Columbia River Basalt:			Basalt, water-bearing (saline water)	10	685
"Shale rock" (weathered basalt?)	12	87	Older rocks:		
Rock, gray, solid	1	88	Shale, blne, water-bearing (saline water)	7	692
Rock, blue, hard	7	95			
Rock, hard, fractured	15	110			
Rock, solid	7	117			

2/3–6Q1

[J. W. Aylett. Drilled by A. O. Olsen, 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Boring Lava:			Boring Lava—Continued		
Clay	28	28	Rock, "honeycomb," red	15	105
Rock, gray, hard	62	90			

2/3–14L1

[Salvation Army. Drilled by A. M. Jannsen Drilling Co., 1948]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Soil	3	3	Sandy River Mudstone—Con.		
Gravel and boulders	6	9	Clay, blue	377	537
Sandy River Mudstone:			Clay, brown, layers of shale	38	575
Shale, blue	71	80	Columbia River Basalt:		
Shale, brown	40	120	Rock, water-bearing	25	600
Quicksand	40	160			

2/3–15D1

[Abraham Bialostosky. Drilled by Haakon I. Bottner Drilling Co., 1954]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Boring Lava:			Sandy River Mudstone:		
Soil	21	21	Clay	105	370
Basalt	24	45	Boring Lava (sill?):		
Troutdale Formation:			Basalt, water bearing at 400 ft	30	400
Sandstone	205	250			
Gravel	15	265			

TABLE 2.—*Drillers' logs of representative wells in the East Portland area, Oregon*—Continued

2/3-23B1

[Barton Baptist Church. Drilled by O. E. Jannsen, 1956]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Younger terrace deposits:			Sandy River Mudstone—Con.		
Gravel and clay	5	5	Shale, blue, sticky	6	99
Gravel, coarse	22	27	Shale, green, sandy	10	109
Gravel and sand	5	32	Shale, dark-gray, sandy	7	116
Sandy River Mudstone:			Shale, blue-green, sticky	13	129
Shale, blue-green	58	90	Sand, fine, water-bearing	1	130
Sand, fine, water-bearing	3	93	Shale, gray, sandy	5	135

2/3-24E1

[E. Odell. Drilled by Steinman Bros. Drilling Co., 1951]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Younger terrace deposits:			Sandy River Mudstone:		
Soil	3	3	Clay	3	37
Gravel	27	30			
Gravel, water-bearing	4	34			

2/4-18R1

[Schedeen Bros. Drilled by Steinman Bros. Drilling Co., 1947]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Troutdale Formation:			Sandy River(?) Mudstone—Con.		
Gravel and boulders	18	18	Clay, yellow	23	703
Sandy River Mudstone:			Rock, gray	3	706
Clay, sandy, yellow	80	98	Clay, gritty, blue	2	708
Clay, blue	7	105	Columbia River Basalt:		
Clay, sandy, yellow	50	155	Rock, gray; cubic fracture	20	728
Clay, soft, blue and brown	275	430	Rock, red, soft	12	740
Sandy River(?) Mudstone:			Rock, soft, black	5	745
Rock, soft, chocolate-colored	30	460	Rock, gray, hard and soft; water bearing at 750 ft	69	814
Rock, red; water bearing at 555–558 ft	130	590	Rock, black, "honeycomb"	50	864
Clay, brown and yellow	77	667	Shale, soft, green	2	866
Clay, red	13	680	Rock, blue, "honeycomb"	38	904

2/4-21J1

[Hudson-Duncan Co. Drilled by A. M. Jannsen Drilling Co., 1952]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Piedmont deposits and Troutdale Formation, undifferentiated:			Sandy River Mudstone:		
Gravel and sand	160	160	Claystone	718	885
"Claystone"	5	165	Columbia River Basalt:		
Gravel, water-bearing (10 gpm±); swl at 162 ft	2	167	Basalt, water-bearing	445	1,330

TABLE 3.—*Chemical analyses of water from*

Water-bearing material: See table 1 for unit designation. Laboratory: CL, Charlton Laboratories, USGS, U.S. Geol. Survey. Remarks: For consistency of presentation, analytical results from

Well	Water-bearing material	Date of collection	Laboratory	Temperature (°F)	Constituents in parts per million (ppm)				
					Silica (SiO_2)	Iron (Fe) total	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)
1N/1-4K1	Sand, gravel	5-10-43	CL	---	43	0.05	----	34	12
1N/2-22Q1	Gravel	3-9-55	OBH	---	45	.10	0.00	19	8.6
26R1	Sand, gravel	4-22-58	USGS	52	64	.09	.00	16	7.8
1N/3-21G1	Gravel	6-7-54	USGS	---	54	.01	.00	39	16
23B1	Gravel, sand	6-7-54	USGS	63	57	.08	.00	56	4.4
23H1	Gravel	6-7-54	USGS	54	59	.03	.14	21	3.5
23K1	Sand, gravel	9-2-52	RM	---	---	----	----	----	----
26N1	Gravel, cemented.	2-2-58	USGS	54	40	.02	.01	15	10
34D1	Gravel	5-5-58	USGS	60	40	1.8	.10	11	11
1/1-11H1	Sand, gravel	11-28-29	USGS	56	45	.06	----	15	10
1/2-3E1	Gravel	6-11-54	USGS	52	58	.06	----	18	7.3
1/3-10B1	Sand, gravel	6-11-54	USGS	55	41	.07	.01	18	12
29F1	Basalt	5-5-58	USGS	54	52	.14	----	16	14
1/4-10D1	do	2-9-56	USGS	74	60	.06	----	5.2	.2
2/2-20F1	do	2-28-50	CL	62	53	----	----	42	----
Do	do	7-26-50	CL	---	53	.07	.05	35	6.2
Do	do	6-23-53	CL	---	49	.40	.01	37	12
2/2-20K1	do	3-17-52	CL	---	24	.13	.0	34	5.3
Do	do	6-9-53	CL	---	50	.43	.05	54	15
2/3-5N1	do	5-5-58	USGS	54	60	.10	----	9.5	6.4

wells in the East Portland area, Oregon

Portland, Oreg.; OBH, Oregon State Board of Health; RM, Reynolds Metals Co., Troutdale, Oreg. other laboratories have been rounded to conform with reporting standards of the U.S. Geo'. Survey.

Constituents in parts per million (ppm)—Continued														
Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Total dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°F)	pH
11		117	----	15	14	0. 3	----	----	272	135	39	----	----	----
8	2	----	----	8. 5	7	0	----	----	195	83	----	----	----	7. 1
7. 2	1. 2	101	0	4. 1	2	. 1	0. 0	----	151	72	0	18	167	7. 2
26	5. 2	231	0	20	9	. 5	1. 2	----	281	163	0	25	423	7. 4
79	7. 2	132	0	7. 8	156	. 3	. 4	----	454	158	50	----	726	7. 8
11	2. 2	87	0	4. 8	11	. 2	1. 0	0. 03	152	67	0	25	184	----
----	----	----	----	----	6	----	----	----	153	34	----	----	----	8. 0
7	2. 0	106	0	1. 6	2. 2	. 1	3. 3	. 02	130	78	0	----	182	7. 9
11	2. 2	115	0	3. 3	2	. 1	. 0	----	155	73	0	24	182	7. 9
8. 2	3. 0	118	0	4. 4	2. 2	----	. 0	----	141	78	----	----	----	----
4. 4	3. 4	54	0	14	7	. 1	15	----	159	75	31	11	168	6. 5
9. 2	2. 1	122	0	4. 4	4	. 1	. 0	. 15	149	94	0	17	201	7. 2
9. 5	1. 3	136	0	1. 2	3. 2	. 1	. 0	----	155	98	0	17	196	7. 8
10	9. 6	114	5	1. 2	92	3. 2	. 5	. 38	326	14	0	----	517	8. 6
----	----	116	----	----	144	----	----	----	452	106	----	----	----	7. 6
87		122	----	. 3	149	. 6	----	----	480	114	----	----	----	7. 8
63		114	----	4. 0	137	. 4	----	----	409	144	----	----	----	7. 8
82		116	----	. 4	136	. 4	----	----	418	107	----	----	----	7. 7
96		116	----	4. 6	225	. 4	----	----	589	195	----	----	----	7. 7
7. 0	. 7	70	0	. 6	4. 0	. 1	3. 5	. 20	126	50	0	23	124	7. 7

TABLE 4.—*Representative springs in the East Portland area, Oregon*

Topographic situation and altitude: cm, canyon of minor stream; cw, canyon wall; hs, hillside; s, slope; sc, spring cirque; te, terrace escarpment. Altitudes are in feet above mean sea level.

Geologic source: Tt, Troutpale Formation; QTv, Boring Lava; Qp, piedmont deposits; Qal, younger alluvium.
Use of water: D, domestic; Irr, irrigation; N, none; PS, public supply; S, stock.

Spring	Owner	Topographic situation and altitude	Geologic source	Mode of discharge	Use of water	Remarks
T. 1 N., R. 2 E.						
23D1s		te, 25	Qal	Issues from gravel beds at the water table.	N	Flowed 700 gpm in 1959: reportedly varies with river stage. Hardness of water reportedly 63 ppm. One of several springs that flow into river sloughs.
T. 1 N., R. 3 E.						
20N1s	T. V. Parkin	sc, 25	Qal		D	Water retained in concrete cistern.
26G1s	Mr. Stromboli	s, 60	Tt	Issues from soil overlying Troutdale Formation on gentle slope.	D, S	Water retained by covered concrete cistern over spring opening, and piped to three homes. Flowed 135 gpm Feb. 12, 1957.
26H2s	Spence Estate	sc, te, 50	Tt	Flows from bouldery rubble at bottom of spring cirque.	Irr	Concrete curbing and covered box divert part of flow into 6-in pipe. Flowed 335 gpm Feb. 12, 1957. Typical of many springs on edge of flood plain.
26H3s	Mr. Wilson	sc, te, 50	Tt	do	D	Water impounded by concrete dam about 3 ft high; overflow spills into a concrete stilling basin about 5 ft square, from which part is pumped; remainder spills into natural surface channels. Flowed 220 gpm Feb. 12, 1957.
26H4s		sc, te, 50	Tt	Issues from culvert driven into head of cirque-shaped depression.	N	Flowed 5 gpm Feb. 12, 1957.
26H5s		sc, te, 50	Tt	Issues from and around culvert pipe under railroad fill.	Irr	Railroad fill covers spring orifice. Flowed 60 gpm Feb. 12, 1957.
34A2s	Wood Village (Arata Spring).	te, 250	Tt	Issues from soil near base of terrace scarp.	P, S	Water retained in 32×13 ft concrete reservoir.
35D1s	Multnomah County	te, 250	Tt	Flows from gravel bed through 3 outlets along 1,000-ft length of terrace scarp.	D, Irr	Flowed 50 gpm in 1937. Water temperature 58°F.
T. 1 S., R. 2 E.						
25P1s	A. Guidi	hs, 650	QTv	Issues from soil mantle	D	Water retained in concrete cistern; supplies 10 families.

			T. 1 S., R. 3 E.			
12C1s	Lawrence Plum	cm, 275	Tt	Issues from rubbly mantle on canyon wall.	D	Spring is enlarged by a dug hole 4×4×12 ft, enclosed in small concrete building. Flows about 3 gpm.
21B1s	C. VanZyl	cm, 690	QTv	Issues from soil and rubble overlying basalt.	D	Water retained in small reservoir; supplies two families.
21G1s	R. R. Sherwood	cm, 700	QTv		D	Water retained in cistern.
21M1s	Mr. Imel	hs, 575	QTv		D	Water flows up into concrete cistern and is stored in two tanks having a combined capacity of 5,000 gal. Flows 6–10 gpm; supplies nine families.
28C1s	John Furst	hs, 775	QTv	Issues from platey joint openings	D	Water retained in concrete cistern; ½-in. pipe flows full continuously.
28L1s	Fred Borges	hs, 750	QTv	Issues from soil mantle	D, S	
35L1s	R. Taylor	hs, 630	Colluvium and Qp.	Seeps from soil on mantle slope	D	Improved by dug hole, 4 ft in diameter and 19 ft deep. Water hardness 54 ppm, chloride 5 ppm, and specific conductance 140.
			T. 1 S., R. 4 E.			
6Q1s	W. Wilson	te, 288	Tt	Seeps from soil	D	Water retained in brick cistern. Flowed 3 gpm Aug. 12 1955.
22E1s		sc, 658	Qp		N	This spring is the source of a small stream.
22J1s		cw, 675	Qp	Seeps from soil on slope	S	Flowed 2± gpm Aug. 12, 1955.
25D1s		cw, 510	Qp	Issues from bouldery clay	N	Flowed 5 gpm Aug. 12, 1955.
36C1s	J. V. Carlson	te, 625	Qp		D	Water retained in 5,000-gal concrete tank.
			T. 2 S., R. 2 E.			
3N1s	Andrew Teener	hs, 325	QTv		D	
11H1s	Sam Ackley	te, 210	QTv	Issues from rocky soil overlying Boring Lava.	D, Irr	Enclosed by spring house.
			T. 2 S., R. 3 E.			
10P2s	W. G. Wiley	hs, 680	QTv		D	Water retained in 6×6×4 ft cistern. Yield is sometimes inadequate for domestic supply.
18H1s	Mrs. Heald	cw, 280	QTv		D	Water retained in concrete cistern of about 5,000-gal capacity; supplies two families.
			T. 2 S., R. 4 E.			
1C1s	H. A. Bess	cw, 380	Tt	Seeps from gravelly soil mantle	D	Water is drawn from 34-in. tile sunk in hillside. Flows about 5 gpm, sufficient to keep ½-in. pipe full continuously.

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