Problems of Utilizing Ground Water in the West-Side Business District of Portland, Oregon

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-O

Prepared in cooperation with
the Oregon State Engineer

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By S. G. BROWN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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PROBLEMS OF UTILIZING GROUND WATER IN THE WEST-SIDE BUSINESS DISTRICT OF PORTLAND, OREGON

By S. G. Brown

ABSTRACT

The withdrawal of ground water for industrial uses and for the heating and cooling of buildings in the west-side business district of Portland has increased greatly since 1955. As a result of this increased withdrawal, ground-water levels apparently are declining progressively, even though some of the water withdrawn is returned to the ground-water bodies by means of artificial recharge. Temperature and chemical quality of the ground water also are changing at places, due to the increased pumping and the practice of artificial recharging with water of different temperature and chemical composition from the natural ground waters.

The west-side business district is underlain, in downward succession, by alluvium of Recent age, fluviolacustrine deposits of late Pleistocene age, the Troutdale formation of early Pliocene age, the Sandy River mudstone, of early(?) Pliocene age, the Columbia River basalt of Miocene and Pliocene(?) age, and marine sedimentary rocks of early Tertiary age. Sand and gravel layers in the Troutdale formation and interflow zones in the Columbia River basalt are water bearing and yield water of good to fair chemical quality to several dozen industrial wells in the area. The underlying marine sedimentary rocks contain saline water, which apparently is migrating upward and mixing with water in the basalt aquifers.

The data presently available indicate that with continued uncoordinated increases in pumped withdrawal and artificial recharge the problems of declining levels and changes in the temperature and chemical quality of the ground water probably will increase. A comprehensive plan for the development and management of the ground-water resources is needed to insure maximum benefits from the ground water and to minimize the effects of the problems now developing. Additional information on the changes in temperature, chemical quality, and levels of the ground water, and on the amounts of ground water pumped and recharged artificially is needed to serve as a basis for such a comprehensive plan.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The withdrawal of ground water for industrial uses and for the heating and cooling of buildings in downtown Portland has increased greatly since 1955. As a result of this increased withdrawal, ground-water levels apparently are declining progressively, even though some of the water withdrawn is returned to the ground-water bodies by means of artificial recharge. The character of water withdrawn from some wells is changing noticeably. In view of the expected increase in the demand for ground water in the downtown district, it is anticipated that serious interference between wells will occur, and that the suitability of the ground water for some uses may be impaired, unless more orderly procedures are followed in the withdrawal and recharge of the ground water, and in development of additional ground-water supplies.

The purpose of this study is to consolidate and present available geologic and hydrologic information bearing on the occurrence and use of ground water in the area, to point out the developing and anticipated problems, and to suggest additional studies that are needed to form a basis for efficient administration and development of the ground-water resources.

Several classes of data are presented in this report: (1) records of wells in the area; (2) water-level data obtained during 19 years of regular monthly measurements at an index observation well in downtown Portland; (3) records of water withdrawn from the ground and discharged to the city sewers; (4) geologic information obtained from investigations made by the U.S. Geological Survey and from other sources; (5) stage records of the Willamette River; (6) chemical analyses of ground water sampled by the Geological Survey and others; (7) climatological data from the U.S. Weather Bureau. The analysis of these data provided the basis for the conclusions in this report.

The work was accomplished under the direct supervision of R.C. Newcomb, district geologist for Oregon. It was part of the continuing program of studies carried on by the Geological Survey in cooperation with the office of the Oregon State Engineer.

ACKNOWLEDGMENTS

Mr. W. T. Monahan and Mr. R. A. Carlson, engineers of the city of Portland, made available data on metered water discharged from wells to city sewers. The A. M. Jannsen Drilling Co., O. E. Jannsen Drilling Co., Steinman Bros., R. J. Strasser Drilling Co., and Mr. Lance Strayer contributed well logs and other information. The assistance of all is gratefully acknowledged.

LOCATION AND EXTENT OF THE AREA

The area of this study is the main business and industrial district on the west side of the Willamette River in the city of Portland (pl. 1). The area extends from the river across a narrow flood plain, stream-built terraces, and alluvial slopes, to the foot of the West Hills (part of the Tualatin Mountains), and along the Willamette

River downstream from the vicinity of the Ross Island Bridge to about 1 mile northwest of the Broadway Bridge. The area is roughly ovalshaped, about 3 miles long, 1¼ miles in maximum width, and totals slightly more than 3 square miles. Most of the area is built up in multiple-story commercial, warehouse, hotel, apartment, and office buildings.

CLIMATE

Portland has a temperate, moist, marine-type climate that is modified somewhat by the influence of the Coast Range, which lies between the city and the Pacific Ocean. The area is largely sheltered from the more extreme continental climate of eastern Oregon and eastern Washington by the Cascade Range to the east.

Climatological data have been recorded by the U.S. Weather Bureau at Portland since 1871. The mean monthly temperature and average monthly precipitation computed from those records are shown in figure 1. The mean annual temperature recorded at the Portland Weather Bureau Station is 54.6°F. The highest temperature recorded was 107°F in July 1942, and the lowest was 3°F in December 1919.

The average annual precipitation at Portland was 39.91 inches for the 88-year period ending in 1958; less than one-tenth of the total fell as snow. Average monthly precipitation ranged from 7.1 inches in December to 0.4 inch in July.

The relative humidity at Portland generally averages 85 to 95 percent in the early mornings. The relative humidity in the afternoons remains about 70 percent from November through February, but is as low as 47 percent during the summer. No evaporation data are available from the Portland station.

WELL-NUMBERING SYSTEM

Wells discussed in this report are designated by symbols that indicate their location according to the Federal rectangular system of land division. In the symbol 1N/1–34N1, 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. 34), and the letter (N) indicates a 40-acre subdivision of the section as shown in the accompanying diagram. The final digit is the serial number of the well within that 40-acre tract. Thus, well 1N/1-34N1 is in

SW¼SW¼ sec. 34, T. 1 N., R. 1 E., and is the first well in the tract to be listed.

D	C	B	A
E	F	G	H
M	L	K	J
N ●1	P	Q	R

CHARACTER AND RELATION OF THE ROCK UNITS

The Columbia River basalt, of Miocene and Pliocene(?) age, is the oldest rock unit exposed in the west Portland area. This formation comprises an accordantly layered series of lava flows and a few scattered interflow beds of tuff.

The basalt is exposed at places in the West Hills, where the basalt and underlying rocks have been upfolded in an anticline. The upper surface of the basalt slopes eastward about 300 feet per mile and passes beneath younger sedimentary rocks near the foot of the West Hills. At a well in the vicinity of N.E. 39th Avenue and Glisan Street, about 2 miles east of the Steel Bridge, the top of the basalt is believed to be 1,100 feet below sea level. The eastward inclination of the basalt is shown in the cross section in plate 1, and by contours on the upper surface of the basalt in figure 2.

Where unweathered, the basalt is mostly dense, hard, and dark gray to black. Beneath most of the West Hills, the upper part of the basalt has weathered to a red clayey soil to depths of 20 feet or more (Trimble, 1957). Along the steep eastern slope of the West Hills, where erosion is more active, the basalt is relatively unweathered.

Individual layers of the basalt range in thickness from 5 to about 100 feet and average about 50 feet. The layers commonly consist of a dense central part, moderately jointed as a result of contraction during cooling; a vesicular upper part, which commonly is more broken as a result of weathering and jointing; and a lower part that commonly is strongly jointed and sometimes rubbly.

Records of wells in the area suggest that the Columbia River basalt is at least 700 to 800 feet thick in the west Portland area. Shale and sand of Tertiary age underlie the basalt and have been reached

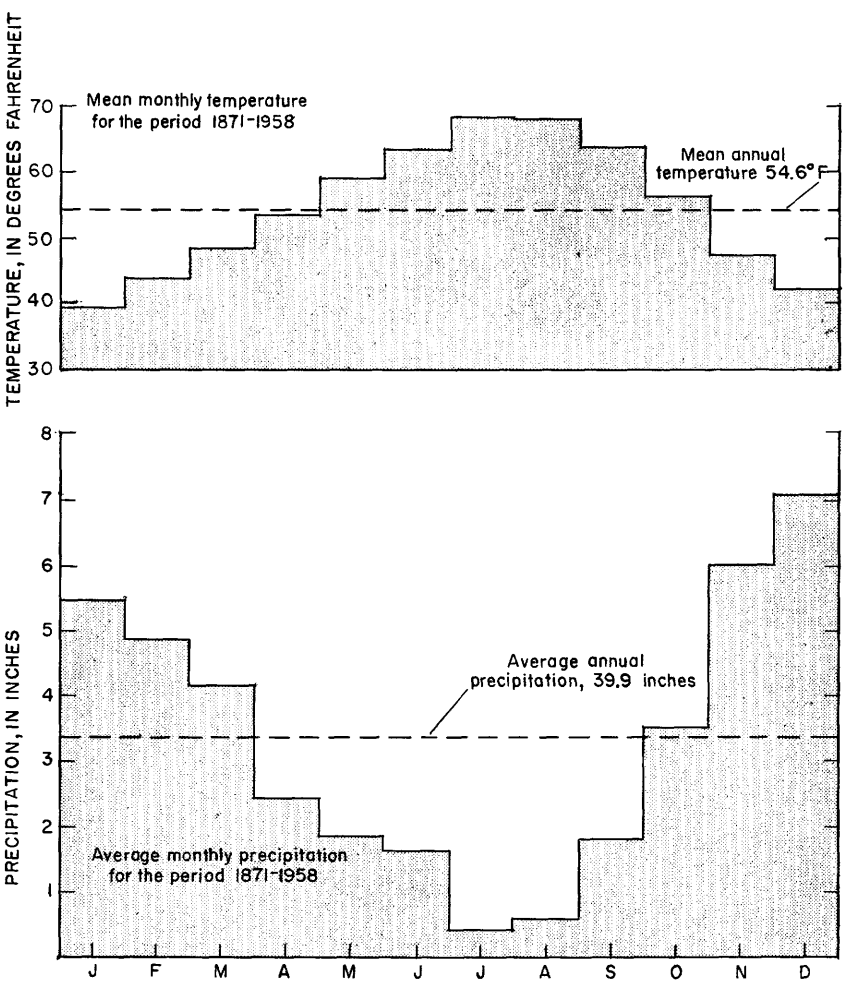
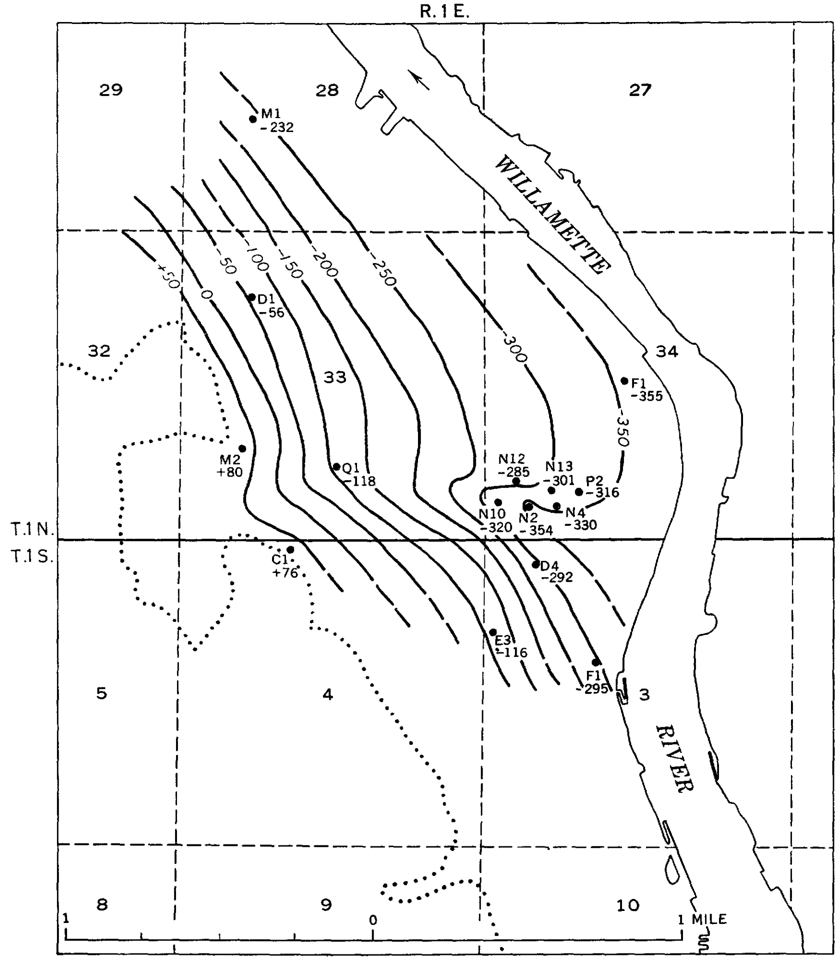


FIGURE 1.—Mean monthly temperature and average monthly precipitation in downtown Portland, Oreg. (from U.S. Weather Bureau data).

by drilling at Gladstone, about 9 miles southeast of this area, at a depth of 685 feet (615 ft below sea level), and in three wells in the West Hills. Of the three wells in West Hills, two are in sec. 23, T. 1 N., R. 1 W., where the basalt is about 700 feet thick, and the top of the older sedimentary material is about 200 feet above sea level. The third well is at the Riverside Cemetery, in sec. 27, T. 1 S., R. 1 E., where the underlying sedimentary rocks are 700 feet below the surface (250 ft below sea level).

Unconformably overlying the basalt is a series of consolidated and partly consolidated beds of mudstone, sandstone, and shale, formerly known as the lower member of the Troutdale formation,



Base from U. S. Geological Survey
Portland quadrangle, 1954

EXPLANATION

●M1
-118

Well penetrating Columbia River basalt

Number indicates altitude at which well entered the basalt

———–100— — —

Contours on the upper surface of the Columbia River basalt

Dashed where approximate or inferred. Contour interval 50 feet, datum is mean sea level

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Limit of area in which basalt is at or near the surface

FIGURE 2.—**Map showing the** altitude of the upper surface of the Columbia River basalt beneath a part of Portland, Oreg.

but recently named the Sandy River mudstone, of early(?) Pliocene age (Trimble, 1962). The Sandy River mudstone does not crop out here, but has been penetrated by wells in the eastern part of the area. Farther west, the Sandy River pinches out against the westward-rising surface of the Columbia River basalt (pl. 1, section *A–A′*). The maximum thickness penetrated was 228 feet in well 1N/1–34N2.

The Sandy River mudstone, where present, and the Columbia River basalt are overlain by the Troutdale formation, of early Pliocene age. The Troutdale formation, which is composed largely of pebble conglomerate and sandstone, underlies the entire west-side business district and extends to the east, north, and south beyond the limits of this area. Its known thickness ranges from a few feet on the slopes of the West Hills, to 235 feet at well 1N/1–33R2.

The gravel-size particles of the conglomerate consist mostly of Columbia River basalt and other volcanic rocks, but also contain much quartzite, granite, and metamorphic rocks typical of the upper Columbia River region. The sandstone is micaceous and is predominantly quartzose. The Troutdale apparently was deposited on an eroded surface of the Sandy River mudstone. Well logs indicate that the contact between the two units in this area ranges in altitude from about 120 to more than 200 feet below sea level (pl. 1, section *A–A′*).

Through most of the area the Troutdale formation is overlain by a relatively thin mantle of unconsolidated terrace deposits of late Pleistocene age, which are part of the deposits called "older alluvium" by Piper (1942, p. 28) and "Portland terrace gravels" by Treasher (1942). The deposits consist mostly of stratified and locally cross-bedded gravel and sand, and contain lesser amounts of silt and clay. The clay and silt, although comprising less than half of the total volume of the unit, occur in sizable bodies at a few places in the area, and indicate that this unit probably was laid down under alternating stream and quiet-water conditions, or by streams discharging into a lake. For that reason, the unit is herein referred to as fluviolacustrine deposits. The fluviolacustrine deposits underlie terraces that rise from an altitude of about 50 feet up to the foot of the West Hills at an altitude of about 200 feet, and generally are less than 100 feet thick.

Along the Willamette River below an altitude of about 50 feet, the terraces and flood plain are underlain by alluvium of Recent age and by artificial fill. These materials are predominantly unconsolidated sand and silt. They are commonly less than 50 feet thick where penetrated by wells in the area, but probably thicken closer to the Willamette River.

OCCURRENCE OF THE 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 material in which it occurs. The upper surface of such a zone of saturation, if unconfined, is called the water table, and its position is indicated by the level at which water will stand in a nondischarging well.

Because ground water occurs in the openings, or interstices, in the rock material, the amount of water contained and the rate at which water can move through the rocks depend largely upon the size and degree of interconnection of the interstices. The interstices differ greatly in size and character; they include minute pore spaces in clays and shales, large well-connected openings in coarse well-sorted gravel, and joints in basalt. The capacity of a rock material to transmit water is referred to as its permeability or transmissibility. A rock unit that is capable of transmitting and yielding appreciable amounts of water to a well is called an aquifer.

In addition to the unconfined, or water-table type of occurrence, at places ground water is confined. Confined ground water occurs where an aquifer is overlain by a less permeable layer that retards the upward movement of the water, and pressure is exerted by the head of water in the aquifer. Thus, the confined water is under pressure greater than that of the atmosphere and it rises above the base of the confining layer in wells. The two principal types of hydraulic conditions in which ground water occurs—confined and unconfined—can be gradational, and an area in which ground water is confined under a small hydrostatic head can occur close to an area of unconfined ground water.

Discharge of ground water in the area is mainly by seepage to the Willamette River and by withdrawal from wells. Under natural conditions, the water table was higher than the level of the river during most of the year and ground water moved toward the river and discharged into its channel. Conversely, during high stages, the river normally reached levels considerably above those of the water table, and water infiltrated from the stream channel to the ground-water body. During recent years, however, the water table has declined at places to the extent that it remains lower than the river level throughout the year (pl. 2).

Recharge, or replenishment of ground water occurs in the west Portland area chiefly by infiltration from precipitation and from streams. This natural recharge is augmented to some extent by artificial injection of water into wells. In addition, the amount of water available for discharge from a particular aquifer may be increased by water migrating from an adjacent aquifer.

WATER-BEARING CHARACTER OF THE ROCK UNITS

The principal aquifers underlying the west Portland business district are in the Columbia River basalt and in the Troutdale formation. Other less important aquifers are the fluviolacustrine deposits of late Pleistocene age and the alluvium of Recent age, where these units extend below the water table. The fine-grained sedimentary rocks of early Tertiary age beneath the Columbia River basalt are less permeable, and the small amount of water they yield is saline.

GROUND WATER IN THE OLDER SEDIMENTARY ROCKS

At least part of the fine-grained sedimentary rocks of early Tertiary age that underlie the Columbia River basalt in the west Portland area were deposited in a marine environment. In nearby areas where these rocks have been penetrated by wells they contain saline water. This saline water probably is connate—that is, the sediments probably still contain some of the sea water in which they originally were deposited. Where the overlying basalt has been flexed and ruptured by tectonic movement the saline water may migrate upward into the basalt from the marine sedimentary rocks (Hart and Newcomb, 1956, pl. 18).

GROUND WATER IN THE COLUMBIA RIVER BASALT

In the Columbia River basalt the fractured and scoriaceous zones in the upper parts of many of the flow layers are permeable and serve as aquifers when they are saturated. The dense central parts of the flows are relatively impermeable, except where they are jointed and fractured. In general, ground water can move freely through the tabular interflow zones parallel to the flow layers, but can move across the flows only in minor amounts. Where the basalt layers are tilted, the porous interflow zones farther downdip contain water confined by the dense, less permeable central parts of the lava flows.

The permeable interflow zones are not everywhere continuous. Each lava flow is limited in extent, and its water-bearing zone may be discontinuous or may merge with that of an adjacent flow. Faulting or intense folding of the basalt may have further interrupted the continuity of the permeable zones. Where faulting has occurred, the water-bearing strata may have been crushed to form impermeable material (gouge), or may be offset so that a permeable layer abuts an impermeable stratum. Folding of the basalt caused the layers to shift along the interflow zones, and in places the once-permeable material may have been crushed to form a finer, less permeable material.

Eighteen wells in the west-side business district are known to have been drilled into the Columbia River basalt, and 13 are finished in the baslt and obtain their water exclusively from it (table 1). Three wells draw water from both the basalt and the overlying Troutdale formation. The yields computed from test records for the 13 wells that tap the basalt average about 440 gpm (gallons per minute), and range from 50 to 1,000 gpm. Reported drawdowns of the water levels during pumping of these wells ranged from 28 to 260 feet at pumping rates of 600 and 650 gpm, respectively (table 1, wells 1N/1–34N4 and 34N10). The average of the reported drawdowns is about 130 feet. The maximum computed specific capacity[1] is about 21 gpm per ft; the minimum is 0.6 gpm per ft, and the average is 4.3 gpm per ft.

GROUND WATER IN THE SANDY RIVER MUDSTONE

The Sandy River mudstone is not important as an aquifer in the area; the fine-grained materials constituting this formation are relatively impermeable and yield little water to wells. Where present, the Sandy River mudstone forms an effective barrier to the vertical movement of water between permeable zones in the underlying basalt and those in the overlying Troutdale formation, and confines ground water in the upper part of the basalt. Most wells that are drilled into the Sandy River mudstone without having obtained a sufficient yield of water are extended through the formation into the underlying basalt.

GROUND WATER IN THE TROUTDALE FORMATION

The Troutdale formation is the most productive source of ground water in the area. Large yields are obtained from wells that tap unconsolidated gravel and coarse sand in the formation. The sand and gravel beds transmit water readily in any direction, but a few layers of clay and mudstone in the Troutdale limit the vertical movement of the water. Many of the sand and gravel layers are compacted, cemented, or have the interstices so filled with fine material that they do not transmit water readily. However, in most parts of the west Portland area the sand and gravel in the Troutdale formation act as a water-table type of aquifer.

In 1958, 14 wells were pumping water from the Troutdale formation for heating, cooling, and industrial use. This water was subsequently metered and discharged to the city sewers. Several other wells, including two at the Equitable Building, are believed to tap the Troutdale formation; however, water from these wells was not discharged to the sewers, but was injected underground through another well. The yields of the Equitable wells have been estimated from

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[1] Specific capacity of a well is a ratio of the discharge to the drawdown of water level produced by that discharge, and usually it is given in gallons per minute per foot of drawdown (gpm per ft).

data derived from commercial pumping tests and from the capacity ratings of the installed pumps. The maximum reported yield of a well in the Troutdale formation was 1,100 gpm of water with an 80-foot drawdown of the water level at well 1/1-3E1. The minimum reported yield was 3 gpm with a drawdown of 45 feet at well 1N/1-34P1. The average of the yields of the 14 wells was about 290 gpm. Specific capacities of the wells that tap the Troutdale formation were computed from the results of 14 commercial pumping tests. The maximum specific capacity was 40 gpm per ft for well 1N/1-34L3 and the average specific capacity was about 7 gpm per ft.

Pumped withdrawal probably constitutes the major form of ground-water discharge from the Troutdale formation in the area; infiltration from the Willamette River probably is the principal source of recharge to the formation. Infiltration of precipitation along the base of the West Hills probably is also an important source of recharge.

An additional source of recharge to the formation was suggested by Hart and Newcomb (1956, p. 66) who state that, along the axis of the anticline that forms the West Hills, the level of the ground water in the Columbia River basalt drops about 160 feet from the Tualatin Valley side on the west to the Portland side on the east, and that at places water probably is moving through the basalt from west to east across the structural divide. At the eastern base of the West Hills, where the basalt has been strongly deformed, it is possible that compression and tension have opened the joints in the basalt, and allowed some water to migrate across the flow layers into the Troutdale formation. To date, no effects of this possible interformational leakage have been recorded in the west Portland area.

THE WITHDRAWAL OF GROUND WATER

When a well that taps an unconfined aquifer is pumped, the water table in the vicinity of the well is drawn down in the shape of an inverted cone, called the cone of depression. Thus, a hydraulic gradient is established, and water from the surrounding parts of the aquifer moves toward the well. As pumping continues, the cone of depression expands, but at a progressively slower rate, until it reaches an impermeable body or a line source of recharge, or until the cone encompasses an area in which the recharge to the aquifer is equal to the discharge. The drawdown of ground-water levels within the cone of depression also increases until equilibrium is reached between recharge and discharge. Figure 3 shows the hydraulic conditions in the vicinity of a well pumping water from an unconfined aquifer.

The conditions in the vicinity of a well that discharges water from a confined aquifer are much the same as described above, except that the pressure surface (piezometric surface) of the confined ground

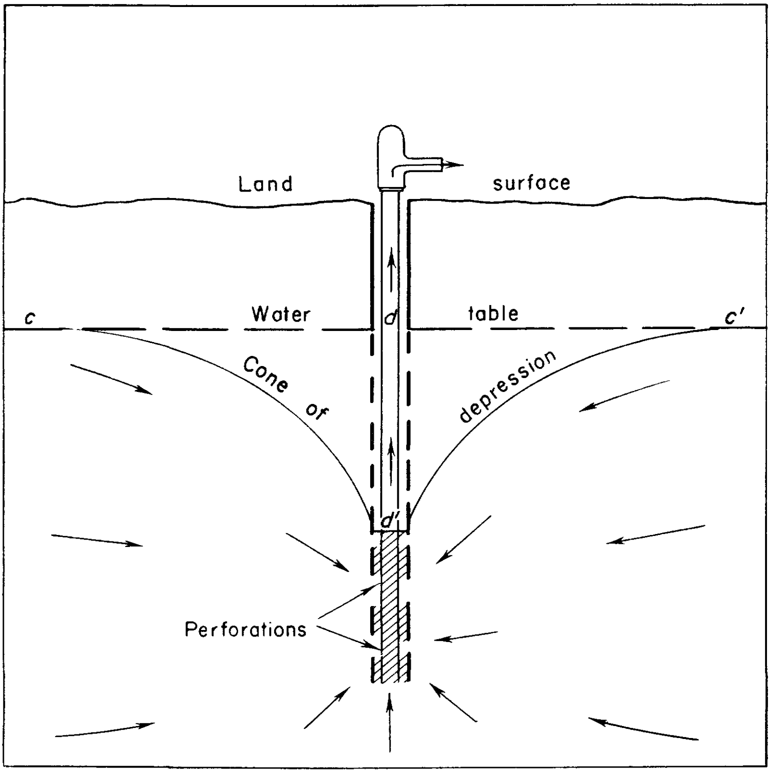

FIGURE 3.—Diagrammatic section through a discharging water-table well. Distance *d-d'* represents the drawdown from the static (nonpumping) water level. Section *cd'c'* shows the cone of water-table depression. Arrows indicate direction of water movement.

water, rather than the water table, is drawn down to form the cone of depression.

If no recharge occurs in the area of the cone of depression during discharge from a water-table well, the only water available for discharge is water that was previously stored in the aquifer. If the withdrawal from an aquifer exceeds the recharge for an extended period, a general lowering of the ground-water level occurs.

Where the cones of depression of adjacent wells overlap, there is competition for the ground water in that part of the aquifer between the wells. The amount of water moving toward each well is decreased, and the drawdown of water levels for a given discharge is greater than it would be if the cones of depression did not overlap.

The chief source of information on quantities of water withdrawn from wells has been the Water Bureau of the city of Portland. All well water that is wasted to the city sewers is metered by that bureau for sewer-use charges. The meter records are the source of the pumpage data presented in figure 4 and plate 2, and in table 3.

Between 1954 and 1958, 26 wells in the west-side business district were reported to be wasting water to the city sewers at one time or another. During 1958, 23 wells were metered. In addition, the water from two shallow wells that tap gravel (1N/1–34N3 and 34N5) is injected into a deep well that taps basalt (1N/1–34N4) after the water is used to heat the Equitable Building. Conversely, during periods when the heating wells are unused, the deeper well is pumped as a source of air conditioning water, and most of the water withdrawn is injected into the two shallow wells. Some water also is recharged interchangeably between wells in gravel and basalt at the Oregonian Building (wells 1/1–3E1, 3E2, and 3E3).

The water that is injected into wells is not metered, and thus the quantity is not known. The amount of ground water withdrawn for cooling or heating and wasted to the sewers from October 1954 to December 1958 is shown in table 3. The values given represent actual metered discharge, except for December 1958; the values for that month were estimated from previous records by use of temperature and relative humidity data.

It will be noted that the metered pumpage increased from about 780 acre-feet in 1955 to about 1,800 acre-feet in 1958, an average increase of about 340 acre-feet per year. If the volume of ground water that is wasted to the sewers continues to increase at the same average rate, it will amount to nearly 2,500 acre-feet in 1960. However, the city authorities of Portland have moved to restrict the disposal to the sewers of waste water from future air-conditioning and heating systems, as that practice has progressively taxed the capacity of the sewer system. This move has imposed upon well owners and those contemplating future installations the necessity to plan other methods of disposal, such as returning the water underground through wells.

Extensive artificial recharge by use of these waste waters may assist in maintaining ground-water levels, but it may also raise problems concerning the temperature of water in a given aquifer, local overpumping and over-recharging, and changes in the chemical quality of the ground waters.

WITHDRAWAL FROM THE TROUTDALE FORMATION

During 1955, the total metered pumpage from the Troutdale formation within this area was about 480 acre-feet. The metered pumpage from that formation has increased steadily every year since 1955 to about 1,300 acre-feet in 1958—an increase of about 170 percent. Although the withdrawal during some months may have been less than that for the same month in preceding years, the overall effect has been one of progressive increase of total yearly withdrawal.

The discharge from 19 wells was metered at some time during this period, but the records of discharge from some of these wells are incomplete.

WITHDRAWAL FROM THE COLUMBIA RIVER BASALT

Total metered pumpage from the Columbia River basalt was about 300 acre-feet in 1955, and about 510 acre-feet in 1958—an increase of about 70 percent. In early 1959, seven wells were yielding water from the basalt and additional wells were being drilled into it. Some of these wells may not be metered, as their waste water is planned for recharge to the Troutdale formation, provided that recharge wells in the gravel of the Troutdale will accept the desired amounts of water.

FACTORS INFLUENCING WITHDRAWAL

Many of the wells where water is metered are operated for air conditioning. The amount of water withdrawn from these wells is dependent upon many factors, among which are temperature, humidity, incoming solar radiation, length of daylight, and season of the year. Figure 4 shows the general relationship between monthly metered pumpage and the monthly mean temperature. It is apparent from the relationships shown in figure 4 that the total monthly pumpage increases greatly with rising monthly mean temperatures. This is partly because many air-conditioning wells are pumped only during the periods of warmest weather. The water that is withdrawn during months when mean temperatures are below about 45°F is used mainly for industrial purposes, for two reverse-cycle heating installations and for one direct-cycle heating system. During the cooler months the rate of ground-water withdrawal apparently approaches constant values (fig. 4) that probably are equivalent to the average industrial and heating demand.

ARTIFICIAL RECHARGE

At least 10 wells [2] in the area reportedly are or have been used for injection of water to recharge the aquifers. Other wells are planned for this use in the future. At present (1959), little information exists on the amount, temperature, or quality of the water injected, and there is no regulation of this artificial recharge. The amount of water recharged depends mostly on the amounts of water needed for air-conditioning and heating installations, as the waste water from these installations constitutes the only water so recharged at the present time.

Some operators of air-conditioning plants withdraw or plan to withdraw water from basalt and recharge the warmed waste water

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[2] 1N/1-33R2, First National Bank; 1N/1-34N3, 4, and 5, Equitable Building; 1N/1-34N11, Dierks Medical Center; 1/1-3D5, Ladd Building Co.; 1/1-3E1, 2, and 3, Oregonian Building; 1/1-4A3, Medical-Dental Building.

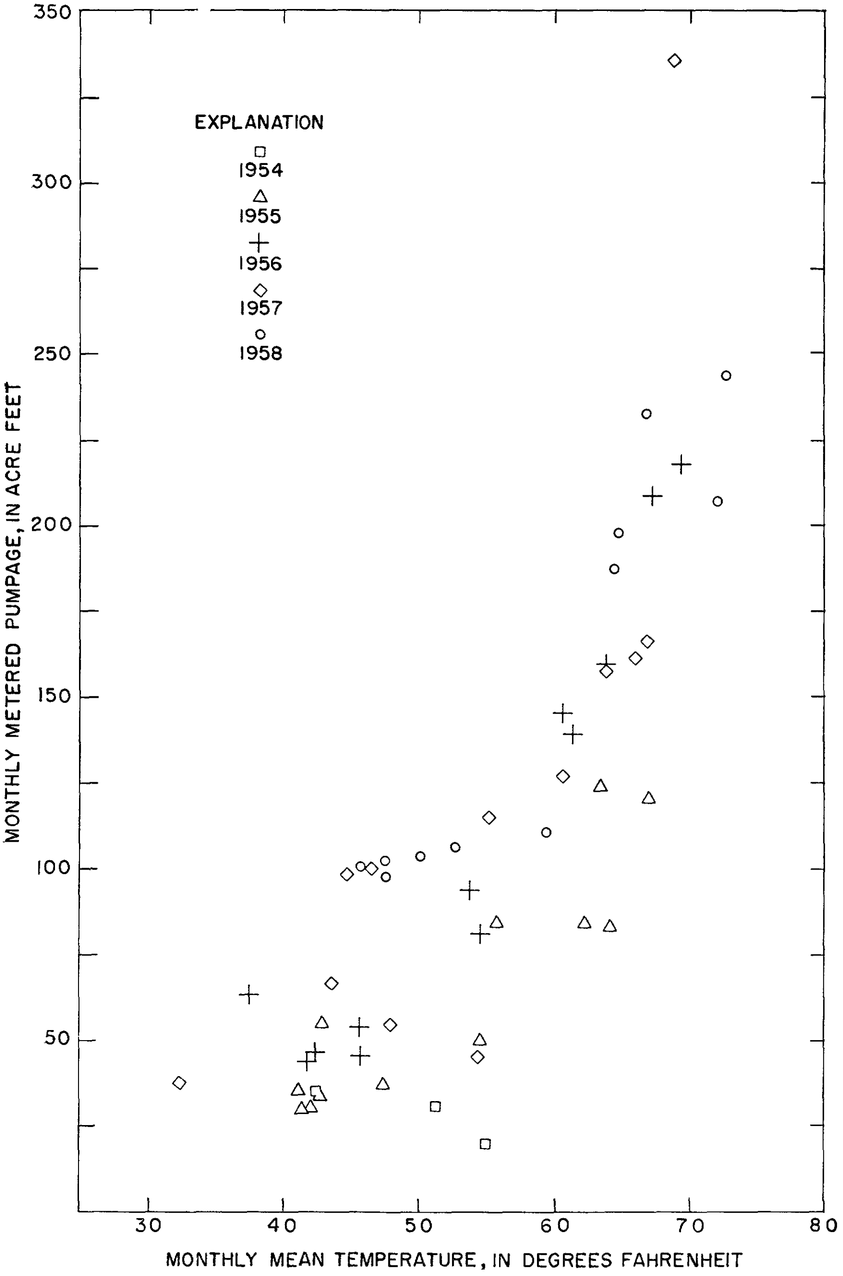

FIGURE 4.—Relationship of monthly metered pumpage to the monthly mean temperature from October 1954 to November 1958.

to the aquifers of the Troutdale formation. Others pump from the Troutdale and recharge to the basalt. Several operators are recharging, or plan to recharge, warmed water to the gravels of the Troutdale within about 100 feet of preexisting wells that withdraw water for cooling from the same aquifer. Thus, as water in the aquifer becomes warmer, many wells, especially those near wells that recharge warm water to the aquifer, will yield warm water that is less suitable for cooling.

GROUND-WATER LEVELS IN THE AREA

Under natural conditions an overall balance exists between the water an aquifer receives and the water it discharges; minor variations occur in the amount of water in storage within an aquifer, due to seasonal and long-term differences in the amount of water recharged and discharged and the rates and times at which these additions and losses take place. The differences in the rates of natural recharge to the aquifer and of natural discharge from the aquifer result in changes in the amount of water in storage, which are indicated by changes in the altitude of the water table or piezometric surface. Other natural changes in ground-water levels are caused principally by barometric pressure changes, tides, and earthquakes. Changes of ground-water levels also are induced artificially by such practices as (1) artificial recharge of the aquifers, (2) paving or artificially draining areas of natural infiltration (which decreases natural recharge), and (3) withdrawal from wells. These practices all affect ground-water levels in the downtown Portland area.

Since September 1940, measurements of the depth to water in well 1N/1–34N1 have been made monthly. The well is 155 feet deep and taps the Troutdale formation. It is at the southeast corner of SW. Sixth Avenue and Washington Street, near the approximate center of pumping from the Troutdale formation in the west-side business district.

Plate 2 shows the hydrograph of well 1N/1–34N1; graphs showing seasonal variations in pumpage from the observation well and from the Troutdale formation and Columbia River basalt; monthly average stage of the Willamette River at Portland; the monthly precipitation in downtown Portland; and the cumulative departure from average monthly precipitation. This assemblage of data allows visual comparison of the water-level variations in the well with some of the factors that influence the variations.

Comparison of the hydrograph of well 1N/1–34N1 and the pumpage graphs shows the effects of pumping on water levels in the well. During the summer months, when pumping is greatest, the water level in the well declines, but as pumping decreases during the fall and winter the water level recovers to near the level of the preceding spring. It is apparent that the year-to-year increase in the total quantity of water withdrawn from the Troutdale formation in this area is paralleled by a general decline in the summer month-end water levels in the index well. In every year that pumping from the Troutdale formation is known to have increased, the summer low water levels in the well have been lower than during the preceding years. From 1957 through the spring of 1959 an almost steady general decline of water levels occurred. The decline from 1956 to 1959 was about 4 feet in the winter high levels and 9 feet in the summer low levels in the observation well. Particularly notable is the drop in water levels from May through September 1958, when a large increase occurred in pumping from the Troutdale formation.

Comparison of the well and stream hydrographs show that from the beginning of the record, and especially before 1958, water levels in this well rose or fell more or less synchronously with the stage of the Willamette River at Portland. The highest stages in the Willamette River at Portland commonly occur as backwater from the annual high stage of the Columbia River in May, June, or July; secondary high stages occur in the winter due to precipitation in the Willamette basin. At times of low river stage the ground-water level formerly stood at or above the altitude of the river, whereas only at high or rising river stages was the altitude of water level in the index well below the monthly average river stage. Since the early part of 1957, this synchronism has in part persisted, but the level in the well has been consistently lower than the stage of the river. Thus, a greater than normal hydraulic gradient has been established from the Willamette River to the vicinity of the well, and the direction of this gradient is maintained throughout the year. As a result, recharge from the Willamette River to the aquifers in the Troutdale formation probably has increased substantially.

At the bottom of plate 2 is a bar graph showing the monthly precipitation measured at the U.S. Weather Bureau Portland (city) station; just above the bar graph is a line graph showing the cumulative departure of the monthly precipitation from the averages for 1940–58. Comparison of the month-end ground-water levels and the precipitation graphs indicates that precipitation has little direct or immediate effect upon the ground-water level in this well, and the long-term trends in precipitation bear no relation to the year-to-year decline in levels in the well from 1956 to 1959.

From 1940 to about November 1947 the cumulative departure curve for the precipitation and the curve for ground-water levels show a general similarity. However, the latter curve shows sharp declines that reflect the heavy pumping during the summer months, and rising trends that apparently coincided with the onset of the autumn rains, but doubtless were partly due to local recovery of the water table as pumping of water for air conditioning was reduced.

From 1948 to 1955 cumulative departure from the average precipitation showed an upward trend, whereas the month-end water levels remained near or slightly below average. From the autumn months of 1955 to January 1956 the cumulative precipitation curve shows a sharp upward trend and, except for minor variations, levels off after January 1956 and continues at a high level to December 1958. In contrast, the water-level curve has an overall downward trend, beginning in 1956 and continuing to the present (1959). Thus there are two unnatural declining trends in the water level in the well—one beginning in 1948 and the other in 1956—despite an increase in precipitation and a resultant increase in potential ground-water recharge.

The indicated lack of relationship between precipitation and ground-water levels agrees qualitatively with the factors governing the direct recharge to the Troutdale formation from precipitation. The west-side business district is largely paved or occupied by buildings, so that opportunity for surface infiltration is practically nonexistent in the area around well 1N/1–34N1.

Effective recharge from precipitation probably can occur only in a few distant places, such as at the base of the east slope of the West Hills. The interception of most of the precipitation by the pavement and buildings probably explains the lack of rise in water level in well 1N/1–34N1 after periods of heavy rainfall. However, it is difficult to identify any recharge from rain because changes in the pumping regimen and recharge from the river tend to mask other increments of recharge.

Within a radius of 1,000 feet of well 1N/1–34N1 are six wells that tap the Troutdale formation. Two are used for the heating phase of a reverse-cycle heating and cooling system, and although seldom pumped, frequently receive recharge water during the summer months. Together they accept as much as 280 gpm of water, which is recharged to the Troutdale formation. The other four nearby wells are capable of a combined yield as great as 1,200 gpm from the Troutdale formation during periods of peak demand.

Plate 2 indicates that the periods of low water levels in well 1N/1–34N1 are more directly related to periods of large withdrawal from the Troutdale formation than to any other factor. The periods of low level in the well are more closely related to total pumpage from the Troutdale formation than to pumping from the well itself. Therefore, it is concluded that the general downward trend in levels in the index well has been caused mostly by the year-to-year increase in pumpage from the aquifers of the Troutdale, and that the sharp declines in ground-water levels during recent summers are due mostly to the increasing use of ground water for air conditioning.

TEMPERATURE OF THE GROUND WATER

Water from the Troutdale formation normally is at temperatures ranging from 55° to 69°F, and water from the Columbia River basalt ranges from 54° to 70°F. Temperatures of water in both aquifers are unrelated to depth. Reverse-cycle heating and cooling systems utilizing these two aquifers have been installed in the Equitable and Oregonian Buildings and are planned for other buildings.

When the shallow wells that supply the Equitable Building system (1N/1–34N3 and 34N5) were drilled, the temperature of the water in the Troutdale formation was 63° to 66°F. Heated exhaust water from the system is recharged to these wells at temperatures of 75° to 85°F during the cooling phase of the operation. At the beginning of the heating phase each winter, the temperature of the water from the wells is at or near the temperature of the exhaust water that was recharged during the cooling phase. After about the first week of pumping, during the heating phase, the temperature of the water in the shallow wells is about 65°F. The chilled water exhausted during the heating phase is artificially recharged to the basalt through the deep well (1N/1–34N4) at a temperature of about 48°F. The water-bearing zone tapped by that well apparently is so permeable that this chilled water moves outward and mixes freely with the natural water in the aquifer. The chilled recharge water reportedly does not build up to form a substantial cone of elevation (the counterpart of the cone of depression of a discharging well) nor does its lower heat content appreciably lower the normal 54°F temperature of the natural water in the basalt aquifer.

The heating and cooling system used by the Oregonian Building is a three-well system consisting of two wells for cooling (1/1–3E1 and 3E2), which draw water at 55°F from the Troutdale formation and a deeper well for heating (1/1–3E3), which obtains water at 58°F from the Columbia River basalt. After the operation of the system had begun, it was found that water from the deeper well, 1/1–3E3, was less desirable because of its higher mineral content, and for this reason the well is largely unused. Also, the deeper well has a limited capacity for pumping and recharge. The two wells that tap the Troutdale formation are used for both the heating and cooling cycles, but a part of the exhaust water from the cooling system is injected at temperatures as high as 120°F into the deep well. When the deep well was pumped in January 1956, for the first time in 3 years, the water temperature was reported to be 96°F. This high temperature indicates that there is only limited movement of the water outward from the well into the basalt aquifer. Reportedly, the temperature of the water in the deep well normally is about 80°F after the warmed water from the cooling system has been injected throughout the summer, but the temperature drops to about 60°F after the well is pumped for 6 months.

Heated or cooled water that is recharged to an aquifer may move down the hydraulic gradient and adversely affect the temperature of water from down-gradient wells. If the warmed waste waters from several cooling systems are injected into the same aquifer, it is probable that the overall temperature of the ground water in that aquifer eventually will rise. Such a temperature rise would, of course, decrease the value of the ground water as a cooling supply and might limit its usefulness for other purposes as well.

In other parts of the country a general rise in the temperature of ground water in certain aquifers has been caused by using warmed water for artificial recharge. Concerning the use of warmed water for artificial recharge by one air-conditioning plant on Long Island, N.Y., Brashears (1941, p. 817–818) stated:

> * * * at an industrial plant in Kings County, which continuously recharges about 1 million gallons daily, the temperature of the water pumped from the supply well increased about 20 degrees after a few months of operation. The supply well and recharge well both end in the same formation and are about 200 feet apart. It is reported that this rise in temperature increased operating costs about 300 to 500 dollars a month.

A similar warming of the water withdrawn from a supply well at the Snohomish, Wash., substation of the Bonneville Power Administration was due to nearby artificial recharge with warmed water (Hart, 1958, p. 37).

CHEMICAL QUALITY OF THE GROUND WATER

Table 4 presents chemical analyses of water from three wells that tap the Troutdale formation, four wells that tap the Columbia River basalt, and one well that is reported to draw water from both formations. More than one analysis is listed for four of the wells that draw their supply solely from the Columbia River basalt. Samples from those wells were taken at different times and the analyses show that the chemical quality varies with time of sampling. The analysis of one sample from well 1/1–3E2, which taps the Troutdale formation, doubtless represents a mixture of the natural water in that formation with water that previously had been pumped from the basalt and injected into the well.

Water from the Troutdale formation is predominantly high in calcium bicarbonate and is generally of good quality. Its pH ranges from 6.5 to 6.7. This water is considered moderately hard or hard; the hardness, as $CaCO_3$, averaged 147 ppm (parts per million) for the 3 samples analyzed. Chloride content is low; the average was 23 ppm for 3 samples.

Analyses of two samples from each of four wells that tap the Columbia River basalt (1N/1–34N4 and N13, 34P2, and 1/1–3E3) are given in table 4. The analyses show that the water in the basalt contains much sodium and calcium and chloride, and is of generally poorer quality than water from the Troutdale formation. The hardness ranged from 119 ppm (moderately hard) to 650 ppm (very hard.) Chloride content ranged from 90 to 790 ppm. Comparison of the different analyses for each of the wells indicates that the chloride content increased consistently with time in all wells but 1/1–3E3, which received much recharge water pumped from the Troutdale formation. The most recent analysis for well 1/1–3E3 shows a decrease of 123 ppm in the chloride content since the previous analysis 7 years earlier. This decrease probably was caused by the injection into this well of water of lower chloride content from the Troutdale formation. The hardness also decreased by 12 ppm during the same time, and the pH dropped from 8.2 to 7.2. The injection of water from the Troutdale formation into this well, and the improvement in chemical quality that apparently resulted, reportedly were not accompanied by any noticeable change in temperature of the water in the aquifers recharged.

In well 1N/1–34N12, which taps aquifers in both the Troutdale formation and the Columbia River basalt, dissolved constituents increased between November 16, 1953, when the first sample was taken, and March 1, 1955, when the second sample was taken. The chloride content increased from 698 to 840 ppm, and the hardness from 540 to 665 ppm. Presumably, the increase in the mineral content of the water from that well is due principally to an increase in the salinity of water from the basalt aquifers tapped by the well. If so, the change in water quality in the basalt aquifers doubtless is even greater than indicated, because the water from those aquifers is diluted, to some extent, by water from the Troutdale formation before it is discharged from the well. Other possible conditions that may have influenced the measured increase in mineral content of the well water are: the water in the basalt aquifers may be under sufficient pressure to cause it to rise in the well and move outward into the Troutdale adjacent to the well, and thus to decrease the effectiveness of dilution by water from the Troutdale formation; or the basalt aquifers may be the more productive aquifers and may supply a progressively greater part of the water pumped from this well.

As previously stated, the mineral content of water from the basalt wells apparently is increasing as the wells are pumped. The increase in the calcium content (reflected by the hardness) and the chloride content of the water suggests that a different type of water is migrating upward from the underlying marine sedimentary rocks.

The saline water in the sedimentary rocks underlying the basalt is an unusual type, referred to as a calcium-sodium chloride water. Where the overlying basalt has been fractured or stretched during folding it possibly has more abundant and more open joints and fractures which allow this water of poorer quality to migrate upward (Hart and Newcomb, 1956, pl. 18). Where the basalt aquifer is tapped by a well in or near such a fractured zone, drawdown of the water table or reduction of artesian pressures due to pumping may cause larger amounts of the saline water to migrate upward into the basalt aquifer and thence to the well.

The belt of strongly folded basalt at the foot of the West Hills has always contained some saline water of this type. Well 1N/1–20N1, about 2 miles north of the area studied and owned by the Northern Pacific Terminal Co., yielded such a hard and mildly saline water as soon as it entered the basalt. The water from another well, 6 miles north of the west-side business district at the Pennsylvania Salt Co. plant, was too saline for plant use. Most of the wells in basalt beneath the west-side business district obtain water of this type, which has varying degrees of hardness and salinity. The mineral content was particularly troublesome in the deepest well, 1/1–3E3, at the Oregonian Building, and suggests that the salinity of water in the basalt may increase with depth.

The chemical quality of the water in an aquifer can be altered by recharge with water of a different type from another aquifer. For example, if aquifers in the Troutdale formation were recharged with the more saline water of the Columbia River basalt, the water in the Troutdale, especially near the recharge well, probably would have some of the undesirable characteristics of water from the basalt. Conversely, recharging the basalt aquifers with water from the Troutdale formation, or with other water of good quality, might improve the quality of the water in the basalt aquifers near the recharge well. The chemistry of the waters must be considered carefully in planning for the ultimate maximum utilization of the two main ground-water bodies beneath the downtown Portland area. It is reiterated that the water of good quality in the Troutdale formation, the upper aquifer, can be impaired or rendered unfit for certain industrial uses if water of poor quality is injected into the Troutdale in substantial amounts.

SUMMARY OF PROBLEMS

In view of the rapid and continuing increase in withdrawal of water from the Troutdale formation and the Columbia River basalt, the following problems in the west Portland area may be expected to increase unless a comprehensive plan is established to control withdrawal, artificial recharge, and the temperature and quality of the ground water.

Declining water levels.—The continuing increase in withdrawal for heating and cooling purposes probably will cause continuing declines in ground-water levels, both in wells that tap the Troutdale formation and in those that tap the Columbia River basalt. The declining trends will be offset to some extent by the current practice of artificially recharging in some of the wells. As previously stated, the decline of the water table in the Troutdale formation has established a steeper than normal hydraulic gradient from the Willamette River to aquifers in that formation, and may have induced substantially greater recharge from the river to those aquifers. This induced recharge also would tend to offset the continuing decline in levels in those aquifers. The degree of hydraulic connection between the Willamette River and aquifers in the basalt is not known; however, because the basalt aquifers are at considerable depths beneath the river, and are overlain by much material of low permeability, there appears to be little possibility of artificially inducing substantial recharge from the river to those aquifers.

Deterioration of chemical quality.—A lowering of artesian pressure in the basalt aquifers apparently has allowed the upward migration of saline water from the underlying marine sedimentary rocks. If these artesian pressures decline further because of continued intensive pumping, further deterioration in quality of the water in the basalt can be expected, at least locally. The saline water might also, contaminate aquifers in the Troutdale formation if the saline water is used to recharge those aquifers artificially, or if a well taps aquifers in both the Troutdale formation and the basalt and saline water in the basalt is under sufficient pressure to cause it to move upward in the well and outward into higher aquifers. Conversely, the quality of the water in the basalt aquifers might be improved substantially by increased artificial recharge with water of better quality, either from the Troutdale formation or from some other source.

Temperature changes.—The use of water in air-conditioning or heating systems produces radical changes in the water temperature—as much as 30°F or more. If the heated or cooled exhaust water from these systems is injected into wells, it will tend to change the temperatures of the natural water in aquifers tapped by those wells. The temperature changes produced by artificial recharge to aquifers with such water depends largely on the transmissibility of the aquifers—that is, the capacity of the aquifers to carry the water away from the well—and on the amount of heated or cooled water that is injected.

Any change in the temperature of ground water may radically effect the usefulness of the water for some purposes. For example, the warming produced by artificial recharge of an aquifer with warmed exhaust water from an air-conditioning plant may impair the value of the water in the aquifer for industrial processes that require water of a lower temperature, and improve it for those that want higher temperature water for heating.

Artificial recharge of the ground-water bodies in the west-side business district is likely to increase in the future, especially because of the reluctance of the city authorities to permit disposal of more heating and cooling water to the sewer system. There is, at present, little coordination between well operators in the withdrawal and recharge of ground water. Because of this lack of coordination, some well operators may, through artificial recharge, cause temperature charges in the ground water that are incompatible with the needs of other ground-water users.

Other problems.—The aforementioned changes in the character of the ground water and the lowering of levels in wells in the west Portland area probably will cause economic or legal problems. For example, the lowering of ground-water levels that would accompany the expected increases in withdrawal would increase the costs of pumping the ground water. Likewise, the operation of heating and cooling plants with water of unsuitable temperature would decrease the efficiency and increase the costs of such operations.

An unusual legal question not previously encountered in Oregon may arise as a result of the temperature changes induced by artificial recharge. That question is whether such temperature changes, which might impair the usefulness of the water for certain purposes, "adversely affect the public interest" should be considered a problem for administration under the water laws of Oregon (Office of the State Engineer, 1958, Chap. 537.170, p. 26).

An additional problem may develop at those buildings in the area that are founded on wooden pilings, if the water table declines below the tops of the pilings. Pilings thus exposed to aeration, or to repeated submergence and aeration probably would decay rapidly, especially if untreated.

ADDITIONAL STUDIES NEEDED

A comprehensive plan for the development and management of ground-water resources in the west Portland district would aid in insuring optimum use of this valuable resource and in minimizing the effects of the problems that are now developing. As a basis for such a comprehensive plan, the data now available allow only partial understanding of the hydrologic factors involved. Additional studies, outlined below, are needed to provide the information necessary for a better understanding of the changing hydrologic regimen of the area.

Measurement of ground-water levels.—The water levels in a large percentage of the wells in the west-side district should be measured periodically on a continuing basis to provide data for relating water-level changes to pumpage, changes in chemical quality and temperature, and possible changes in recharge from the Willamette River. In order to obtain the needed water-level data, it will be necessary to make an opening in the base of the pump or in the casing at many of the wells to permit the insertion of a steel tape or other measuring device.

Measurement of ground-water temperatures.—Periodic measurement of the temperature of water should be made at all wells during periods of pumping and artificial recharge. The temperature data thus obtained would allow evaluation of the seasonal and long-term effects of recharging the aquifers with waters of unnatural temperatures, and the areal extent of such effects. In order to obtain the temperature data, it would be necessary to provide a sampling tap in the discharge and injection pipes at the wells where such taps are not already installed. The sampling taps also would allow the collection of water samples for chemical analyses, discussed below.

Analysis of ground-water samples.—Systematic sampling and chemical analysis of the natural water in the aquifers, and the water introduced into the aquifers by artificial recharge, should be started as soon as possible. More data on the chemical composition of the waters are needed to predict any possible deleterious effects of the mixing of waters of different chemical composition, and to determine changes in the salinity of water in the aquifers. The quality-of-water data would serve to guide decisions concerning the areal distribution and intensity of withdrawal from the basalt aquifers. Those data also would provide a check on the effectiveness of any future program of artificial recharge aimed at improving the quality of water in the basalt.

Records of pumpage and artificial recharge.—To evaluate properly the effects of pumpage and artificial recharge, better records of the amounts of water withdrawn and injected are needed. At present, only incomplete records of pumpage exist, and very little information is available on the amounts of water recharged through wells. Adequate and reliable quantitative data probably could be obtained by the installation and periodic reading of totalizing water meters on the discharge and injection pipes at all large-capacity wells.

Possible improvement of water quality by artificial recharge.—The injection of water from the Troutdale formation into well 1/1–3E3 apparently improved, at least temporarily, the quality of water in the basalt aquifers in the vicinity of that well. This fact suggests the possibility of improving the quality of the water in the basalt aquifers throughout the area by a planned program of artificial recharge. However, before such a program could be undertaken, a preliminary appraisal would be needed to determine the feasibility and probable effectiveness of the recharge program. Such a study would involve the collection and interpretation of geochemical data obtained either during present recharge operations or by means of a recharge experiment.

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TABLES

TABLE 1.—*Records of representative wells in the west-side business district of Portland, Oreg.*

Altitude: Altitude of land-surface datum at well, in feet above mean sea level, interpolated from topographic maps and shown in round figures; one altitude, obtained by leveling, is given to nearest tenth of foot.
Type of well: Dg, dug; Dr, drilled.
Ground-water occurrence: C, confined or partly confined; U, unconfined.
Type of pump: C, centrifugal; S, submersible turbine; T, turbine.
Use (of the water or the well): A, air conditioning (mostly cooling); H, Heating; Ind, industrial; N, not used; R, disposal or recharge.
Remarks: C, Chemical analysis in table 4; dd, drawdown; gpm, gallons per minute; hr, hour or hours; L, log in table 2; pf, perforated or perforations; ppm, parts per million; Temp, temperature of water in degrees Fahrenheit. Remarks on the general quality of the water and the materials penetrated were reported by owners, tenants, drillers and others.

Well	Owner or tenant	Approximate altitude (ft)	Type of well (ft)	Depth of well (ft)	Diameter (in.)	Depth of casing (ft)	Water-bearing zone(s)			Ground-water occurrence	Water level		Type of pump	Yield (gpm)	Use	Remarks
							Depth to top (ft)	Thickness (ft)	Character of material		Feet below datum	Date				
T. 1 N., R. 1 E.																
28E1	Young & Son Iron Works.	48	Dr	77	4	------	------	------	Gravel	------	------	------	------	10	N	Water was formerly used for tempering steel.
28L1	Zehrung Chemicals	45	Dr	126	10	124	124	2	do	U	25	1957	------	------	Ind	Pumped 45 gpm, dd reported small. L.
28M1	Griffith Rubber Mills.	53	Dr	395	8 6	188 395	------	------	Basalt	C	32	August 1946	T	250	Ind	Pumped 50 gpm, dd reported small. L.
28Q1	Blitz Weinhard	47	------	------	------	------	------	------	Gravel	------	------	------	------	40	Ind	Cloride 286 ppm, hardness 67 ppm. Temp 58°.
28Q2	Portland Ice and Cold Storage Co.	38	Dr	------	8	------	------	------	do	------	------	------	T	150	Ind	
28R1	Portland Commission of Public Docks.	32	Dr	142	8	------	------	------	do	------	------	------	T	100	Ind	Temp 58°.
33C1	Ice Coliseum	------	------	------	------	------	------	------	do	------	------	------	------	75	N	
33D1	Good Samaritan Hospital.	100	Dr	400	10	169	351	49	Basalt	C	97	Jan. 17, 1958	------	385	N	Pumped 385 gpm for 2 hr, dd 209 ft. Temp 55°. L.
33K1	Fred Meyer Inc	110	Dr	195	12	------	------	------	Gravel	------	------	------	T	200	A	Temp 53°.
33M2	Henry Thiele	190	Dr	281	8	135.7	125	156	Basalt	C	30	May 1951	------	75	A	Pumped 75 gpm for 1 hr, dd 120 ft. L.
33Q1	U.S. National Bank, Stadium Branch.	110	Dr	563	8 6	203 428	455	108	do	C	100	July 1946	T	100	A	Pumped 65 gpm with 75-ft dd, and 100 gpm with 140-ft dd. L.
33R1	First National Bank, 14th and Morrison Branch.	100	Dr	460	10 8	300 460	------	------	Gravel(?) and basalt.	------	88	November 1955.	T	300	------	Pumped 300 gpm for 8 hr, dd 62 ft, 8-in. casing pf.

33R2	do	100	Dr	300	10	300	106	194	Gravel	U	91	1956			R	Used for disposal of water from air-conditioning plant. L.
33R3	Pacific Telephone & Telegraph Co.	105	Dr	255	8	255	210	45	do	U			T	200	A	Pumped 299 gpm, dd 200 ft. L.
34D1	Spokane, Portland & Seattle Railway Co.	30	Dr	166	18				do						N	Water too hard for use in boilers. Yield "high."
34F1	Terminal Ice & Cold Storage Co.	30	Dr	552	10 8	324 552	465	87	Basalt	C			T	125	Ind	Pumped 501 gpm, dd to "14 ft below top of casing." Temp 60°. L.
34F2	Swift & Co., Dairy & Poultry Plant.	30	Dr	60	5				Gravel				T	125	N	Temp 57°.
34K1	Former LaGrande Creamery.	25	Dr	61	6?		50	11	do	U					N	Quicksand to 30 ft, and cemented gravel and sand to 50 ft. Water left iron stain. Temp 52°.
34L1	Day Lite Meat Market.	30	Dr	180	6				do				C	15	N	Temp 50°.
34L2	Portland Fish Co.	30	Dr	86	8				Gravel						N	
34L3	Portland (Atlantic) Fish Co.	30	Dr	78	8		60	5	do	U	21	December 1942	T	200	Ind	Pumped 200 gpm, dd 5 ft. L.
34N1	Weisfield & Goldberg.	37.2	Dr	155	8	142	75	74	do	U	32	Sept. 28, 1940	T		A	Hydrograph on pl. 2. Bailed 53 gpm for 15 min, dd 27 ft. Temp 69°. L.
34N2	U.S. National Bank, formerly United Artists' Theater.	48	Dr	403	10 8 6	135 220 403	130	19	Gravel and sand.	U			T	500	N	Pumped 500 gpm for 14 days, dd 52 ft. Formerly supplied air-conditioning water to theater. Temp 56°. L.
34N3	Equitable Bldg	40	Dr	173	14	155	67	88	Gravel, slightly cemented.	U	30	October 1946	T	225	H	With casing pf from 60 ft, to 100 ft, pumped 150 gpm, dd about 80 ft. Then pf to 140 ft and pumped 225 gpm, dd about 117 ft. Temp 66°. C. L.
34N4	do	40	Dr	508	14 12	163 380	370	138	Basalt	C	36	December 1946.	T	600	A	Pumped 600 gpm for 1 hr, dd 28 ft. Temp 57°. C. L.
34N5	do	40	Dr	180	12	165	55	107	Sand and gravel.	U	30	February 1947	T	200	H	Pumped 200 gpm. Temp. 66°. L.
34N6	Northwest Electric Co.	55	Dr	97	12				Gravel				T	100	N	Temp 56°.
34N7	Benson Hotel	38	Dg	28	60				Sand and gravel.	U					N	Formerly used for air-conditioning.
34N8	Lipman Wolfe & Co.	40	Dg	40	72				Gravel				T	20	Ind	Supplies water for sanitary facilities. Temp 56°.

TABLE 1.—*Records of representative wells in the west-side business district of Portland, Oreg.*—Continued

Well	Owner or tenant	Approximate altitude (ft)	Type of well (ft)	Depth of well (ft)	Diameter (in.)	Depth of casing (ft)	Water-bearing zone(s)			Ground-water occurrence	Water level		Type of pump	Yield (gpm)	Use	Remarks
							Depth to top (ft)	Thickness (ft)	Character of material		Feet below datum	Date				
							T. 1 N., R. 1 E.—Continued									
34N9	Former Oregonian Bldg. (razed).	45	Dr	147	7				Gravel						N	Abandoned and apparently destroyed. Formerly supplied 400 gpm to air-conditioning system. Temp 58°.
34N10	Dierks Medical Center.	65	Dr	591	12	380	385	206	Basalt	C	59	Apr. 14, 1958			A	Well will supply reverse-cycle heating and cooling plant. Pumped 650 gpm for 12 hrs, dd 260 ft. L.
34N11	do	65	Dr	418	12	327	130	138	Gravel, cemented.	U					R	To be used as disposal well for reverse-cycle heating and cooling plant. L.
34N12	Federal Reserve Bank of San Francisco.	50	Dr	755	14	404	300	95	Sand, gravel and clay.		40	Feb. 22, 1952	T	500	A	Pumped 200 gpm, dd 11 ft; 500 gpm, dd 44 ft. C. L.
34N13	U.S. National Bank, Main Branch.	38	Dr	549	10 12 10 8	605 299 85 432	605 399 119	150 150 21	Basalt do Gravel	C	28	November 1947.	T		A, H	Pumped 200 gpm, dd 45 ft; 400 gpm, dd 105 ft. Temp initially 70°; after pumping 310 gpm for several hr temp drops to 68°. C. L.
34N14	First National Bank.	36	Dr	544	16	368	365	179	Basalt		45	Apr. 9, 1959			A	Pumped 1,000 gpm for 12 hr, dd 223 ft. Temp 54°. L.
34N15	do	37	Dr	161	14	148	65	95	Gravel		18	May 1, 1959			R	Pumped about 100 gpm. Temp 63°.
34P1	Pacific Telephone & Telegraph Co.	35	Dr	92	6	36			Sand and gravel(?).	U	37	September 1948.			N	Pumped 3 gpm for 1 hr, dd 45 ft. L.
34P2	do	35	Dr	697	14	324	351	346	Basalt	C	31	December 1950.	T		A	Pumped 250 gpm, dd 78 ft; 375 gpm, dd 134 ft. C. L.
34P3	Alder Market	28	Dr	75	3				Gravel				C		Ind	Temp 55°.

T. 1 S., R. 1 E.

3D1	Fox Theatre	70	Dr	225	8				Sand(?) and gravel.	U				200	A	Temp 54°. L.
3D2	Paramount Theatre.	88	Dr	147					Sand and gravel.				T	300	A	Pumps 280 gpm for 10 hr each day for 4 months.
3D3	Pacific Power & Light Co.	65	Dr	100	10				do				T	25	A	Temp 56°.
3D4	Pacific First Federal Savings & Loan Association.	60	Dr	368	14	264	230	7	do	U	48	1955	T	500	A	Pumped 500 gpm, dd 96 ft; 700 gpm, dd 140 ft. L.
3D5	Ladd Building Co	60	Dr	228	14	228	125 198	15 9	Sand and gravel.	U	55	May 15, 1959			R	Pumped 450 gpm for 20 hr, dd 53 ft; 765 gpm for 20 hr, dd 95 ft. Temp 60°. L.
3D6	Pacific Bldg	60	Dr	765	16	386	403	362	Basalt		53	1959			A	Pumped 750 gpm, dd 206 ft. Temp 59.5°. Chloride 376 ppm, hardness 333 ppm.
3D7	do	62	Dr	228	14	228	130 198	10 9	Gravel do		55	1959			R	Pumped 765 gpm, dd 95 ft. Temp 60°.
3E1	Oregonian Bldg. Co.	110	Dr	203	18	191	127 171	15 18	Sand and gravel. do	U	95	June 1942	T		A, R	Pumped 750 gpm for 24 hr, dd 49 ft; 1,100 gpm for 24 hr, dd 80 ft. Temp 55°. C. L.
3E2	do	110	Dr	216	14 10	189 216	128 191	12 19	do do	U	101	June 1947			A, R	Pumped 400 gpm for 24 hr, dd 30 ft; 500 gpm for 24 hr, dd 39 ft. Temp 54°. C. L.
3E3	do	110	Dr	930	16 12	198 390	226	704	Basalt	C	86	January 1948			H, R	Used only occasionally. Pumped 250 gpm for 1 hr, dd 67 ft; 500 gpm for 1 hr, dd 160 ft. Temp 58°. C. L.
3E4	Boiler Makers Union.	60	Dr	151	10		120	20	Sand and gravel.	U	56	July 1942		200	A	Pumped 200 gpm for 10 hr, dd 27 ft. Temp 57°. L.
3F1	Portland General Electric Co.	45	Dr	560	8	175	540 315	20 25	Basalt Gravel	C			T	130	Ind	Pumped 130 gpm, dd 4.6 ft. Temp 58°. L.
3L1	Western Condensing Co.	70	Dr	191	8				do				T	420	Ind	Temp 54°.
4A1	Portland Art Museum.	110	Dr	235	10	235	205 215	10 20	Sand, green, and loose gravel.	U	106	October 1938	T	175	A	Pumped 200 gpm for 1 hr, dd 149 ft. Temp 53° (1938); 56 (1945). L.
4A2	Medical Dental Bldg.	110	Dr	772	12–10	558	558	214	Basalt	C	100	1959			A	Pumped 723 gpm, dd 91 ft. Temp 60°.
4A3	do	115	Dr	193	12	193	150	25	Gravel	U	101	1959			R	Pumped 600 gpm, dd 32 ft. Temp 56°.
4C1	Rose City Bowl, Inc.	140	Dr	245	8 6	63 195	172	73	Basalt	C	51	June 1953			A	Pumped 90 gpm for 1 hr, dd 100 ft. L.

TABLE 2.—*Drillers' logs of representative wells*

[Tentative stratigraphic headings by S. G. Brown; word order changed to conform with U.S. Geol. Survey style]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
1N/1-28L1. Zehrung Chemical Co. [Drilled by A. M. Jannsen Drilling Co., 1957]					
Alluvium and Troutdale formation:			Alluvium and Troutdale formation—Continued		
Clay, brown	10	10	Sand, black	4	65
Sand, dry	10	20	Clay and gravel	59	124
Gravel, dry	41	61	Gravel, water-bearing	2	126
1N/1-28M1. Griffith Rubber Mills [Drilled by A. M. Jannsen Drilling Co., 1946]					
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation:		
			Gravel, cemented	4	145
			Gravel, loose	22	165
Rock, sandy	22	22	Sand and gravel	20	185
Gravel, large	10	32	Sandy River mudstone:		
Gravel	13	45	Sand	10	195
Sand and gravel	20	65	"Sand rock"	3	198
Gravel	29	94	Clay, red	87	285
Gravel, muddy	17	111	Columbia River basalt:		
Gravel	9	120	"Sand rock" (basalt?)	3	288
Gravel, loose	21	141	"Lava rock"	3	291
			Rock, hard	104	395
1N/1-33D1. Good Samaritan Hospital [Drilled by Steinman Bros., 1958]					
Fluviolacustrine deposits and artificial fill:			Columbia River basalt:		
			Rock, decomposed	57	213
"Fill"	6	6	Rock, gray, hard	31	244
Sand and silt, yellow	64	70	Rock, black	49	293
Troutdale formation:			Basalt, hard, gray	58	351
Gravel, brown, cemented	18	88	Rock, "seamy," gray	5	356
Gravel, loose	4	92	Rock, black and gray, honeycombed	6	362
Gravel, gray, cemented	54	146	Rock, black, "seamy"	38	400
Silt, yellow	10	156			
1N/1-33M2. Henry Thiele [Drilled by A. M. Jannsen Drilling Co., 1951]					
Slope wash, fluviolacustrine deposits, and Troutdale(?) formation:			Columbia River basalt:		
			Rock, lava	15	125
			Rock, brown and black	156	281
Rock, broken, and clay	110	110			

TABLE 2.—*Drillers' logs of representative wells*—Continued

1N/1–33Q1. U.S. National Bank, Stadium Branch

[Drilled by A.M. Jannsen Drilling Co., 1946]

Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:		
Sand	40	40
Gravel, loose	76	116
Troutdale formation:		
Gravel, cemented	12	128
Sand and gravel	20	148
Gravel, cemented	29	177
Sand	4	181
Gravel, cemented	47	228
Columbia River basalt:		
Rock, lava	72	300
"Lime rock"	17	317
Rock, black, hard	37	354
Rock, broken	36	390
Rock, some water	13	403
Sand, black	22	425
Rock and clay	30	455
Rock	108	563

1N/1–33R2. First National Bank, 14th and Morrison Branch

[Drilled by R. J. Strasser Drilling Co , 1956. Casing perforated, 150 to 300 ft.]

Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:		
Silt and sand	10	10
Sand, yellow	55	65
Troutdale formation:		
Gravel, cemented	41	106
Gravel, cemented, and sand, water-bearing	14	120
Gravel, cemented	18	138
Gravel and sand, water-bearing	15	153
Troutdale formation—Continued		
Gravel, large, cemented	61	214
Gravel and boulders, cemented	11	225
Gravel, cemented	21	246
Gravel, water-bearing	12	258
Gravel, cemented	9	267
"Conglomerate"	33	300

1N/1–33R3. Pacific Telephone & Telegraph Co.

[Drilled by A. M. Jannsen Drilling Co., 1947. Casing perforated, 203 to 255 ft.]

Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale formation:		
Gravel	210	210
Gravel, water-bearing	45	255

1N/1–34F1. Terminal Ice & Cold Storage Co.

[Drilled by Green(?) 1914(?). Log furnished by O. E. Jannsen]

Materials	Thickness (feet)	Depth (feet)
Unrecorded	31	31
Alluvium(?), Troutdale(?) Formation, and Sandy River mudstone:		
Gravel, cemented	149	180
Sand, hard, and clay, blue	65	245
Gravel and sand, cemented	64	309
Gravel, cemented, and clay, blue	15	324
Sandy River mudstone:		
Clay, yellow; overlying clay, red, blue, soft	61	385
Columbia River basalt:		
Basalt, hard	31½	416½
Basalt, alternate layers hard and soft, some water-bearing	135½	552

TABLE 2.—*Drillers' logs of representative wells*—Continued

1N/1-34L3. Portland (Atlantic) Fish Co.

[Drilled by R. J. Strasser Drilling Co., 1942. Casing perforated, 60 to 70 ft.]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Alluvium:			Troutdale(?) formation:		
Clay	30	30	Gravel, cemented	13	78
Gravel, cemented	30	60			
Gravel, loose, water-bearing	5	65			

1N/1-34N1. Weisfield & Goldberg

[Drilled by A. M. Jannsen Drilling Co., 1940]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Excavation	-----	10	Troutdale formation—Con.		
Alluvium and fluviolacustrine deposits:			Gravel, loose, water-bearing	20	105
Sand and gravel	26	36	Gravel	3	108
Gravel	9	45	Sand	3	111
Sand and gravel, water-bearing	15	60	Gravel	2	113
Gravel	20	80	Sand and gravel, water-bearing	24	137
Troutdale formation:					
Gravel, cemented	5	85	Sand, black, and rock, water-bearing	22	159

1N/1-34N2. U.S. National Bank

[Formerly United Artists' Theater. Drilled by A. M. Jannsen Drilling Co., 1943]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale formation:			Sandy River mudstone:		
			Clay	60	234
			"Sand rock"	2	236
No record, old well	150	150	Clay	166	402
Sand and gravel	7	157	Columbia River basalt:		
Gravel	17	174	Rock	1	403

1N/1-34N3. Equitable Building

[Drilled by A. M. Jannsen Drilling Co., 1946. Casing perforated, 60 to 140 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Alluvium, fluviolacustrine deposits, and Troutdale(?) formation:			Troutdale formation:		
			Gravel, slightly cemented, water-bearing	88	155
			Sandy River mudstone:		
			Clay, blue	18	173
Silt and sand with gravel lenses (excavation)	15	15			
Gravel and boulders	30	45			
Gravel	10	55			
Sand and gravel	12	67			

TABLE 2.—*Drillers' logs of representative wells*—Continued

1N/1-34N4. Equitable Building

[Drilled by A. M. Jannsen Drilling Co., 1946]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Alluvium, fluviolacustrine deposits, and Troutdale formation:			Columbia River basalt:		
Gravel	163	163	Rock	100	470
Sandy River mudstone:			Rock, porous	30	500
Clay	56	219	"Sand," coarse, water-bearing	8	508
Clay with sand	31	250			
Clay	120	370			

1N/1-34N5. Equitable Building

[Drilled by A. M. Jannsen Drilling Co., 1947. Casing perforated from 50 to 117 ft and from 127 to 165 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Alluvium, fluviolacustrine deposits, and Troutdale formation:			Sandy River mudstone:		
Gravel and boulders	35	35	Clay, blue	3	165
Gravel, cemented	20	55			
Sand and gravel, water-bearing	107	162			

1N/1-34N10. Dierks Medical Center

[Drilled by Lance Strayer, 1958]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Sandy River mudstone:		
Clay, sandy	20	20	Clay, yellow	132	385
Gravel	55	75	Columbia River basalt:		
Troutdale formation:			Rock, black	15	400
Gravel, cemented	75	150	Rock, hard, black	25	425
Gravel, bouldery	50	200	Basalt, softer	166	591
Gravel, cemented	53	253			

1N/1-34N11. Dierks Medical Center

[Drilled by Lance Strayer, 1958. Casing perforated, 135 to 320 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale formation:			Sandy River mudstone:		
Sand, yellow	15	15	Clay, yellow, and rock	59	327
Gravel, cemented	110	125	Columbia River basalt:		
Sand	5	130	Basalt	91	418
Gravel, cemented	138	268			

TABLE 2.—*Drillers' logs of representative wells*—Continued

1N/1-34N12. Federal Reserve Bank of San Francisco

[Drilled by R. J. Strasser Drilling Co., 1952. Casing perforated 300 to 395 ft.]

Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:		
No record (excavation)	11	11
Sand, "packed"	7	18
Gravel and boulders	18	36
Gravel and clay	21	57
Troutdale formation:		
Gravel, sand with "binder" (clay?), some water	12	69
Gravel, with "binder" (clay?)	47	116
Sand and gravel, loose, water-bearing	2	118
Gravel and clay	60	178
Sandy River mudstone:		
Clay, blue	2	180
Sand, "packed"	17	197
Gravel and clay	68	265
"Shale," green	40	305
Sand, water-bearing	15	320
Sandy River mudstone—Continued		
Clay, brown	15	335
Columbia River basalt (decomposed):		
Gravel and clay	67	402
Columbia River basalt:		
Rock, hard, green	10	412
"Conglomerate," hard	20	432
Rock, green	14	446
Rock, soft, black	40	486
Clay, yellow	9	495
Rock, black, hard and soft	139	634
Rock, gray, with seams	14	648
Rock, gray and red	6	654
Rock, soft, red and gray water-bearing	14	668
Rock, gray and black	57	725
Rock, black, water-bearing	13	738
Rock, hard, gray	17	755

1N/1-34N13. U.S. National Bank, Main Branch

[Drilled by R. J. Strasser Drilling Co., 1947]

Materials	Thickness (feet)	Depth (feet)
Alluvium and fluviolacustrine deposits:		
No record (open shaft)	17	17
Gravel and boulders, cemented	22	39
Silt, yellow	3	42
Troutdale formation:		
Gravel and boulders, cemented	20	62
Gravel and sand, clayey, some water	8	70
Gravel, cemented	5	75
Gravel and sand, loose, some water	22	97
Gravel, cemented	22	119
Gravel and sand	21	140
Gravel and sand with clay, blue	15	155
Sandy River mudstone:		
Clay, blue	52	207
Silt, fine, brown	6	213
Shale, brown	6	219
Sandstone, hard, gray	23	242
Shale, brown	17	259
Clay, reddish-brown	36	295
Rock, gray	1½	296½
Sandy River mudstone—Continued		
Clay, brown	8½	305
Silt and sand	22	327
Clay, brown	18	345
Columbia River basalt (decomposed?):		
Rock ledges in brown clay	48	393
Columbia River basalt:		
Rock, hard, gray	6	399
Rock, porous, black	3	402
Clay, brown	7	409
Rock, hard, black and gray	26	435
Rock, black, softer	15	450
Rock, black with clay in crevices	4	454
Rock, porous, black, no water	38	492
Rock, hard and creviced, black	41	533
Rock, porous, black water-bearing	12	545
Rock, hard, black	4	549

TABLE 2.—*Drillers' logs of representative wells*—Continued

1N/1-34N14. First National Bank

[Drilled by Barron and Strayer, 1959]

Materials	Thickness (feet)	Depth (feet)
Alluvium, fluviolacustrine deposits, and Troutdale(?) formation:		
Gravel	85	85
Gravel and sand	35	120
Troutdale formation:		
Gravel, coarse	45	165
Gravel, with cobbles and boulders	20	185
Clay, blue and green	5	190
Gravel, hard	30	220
Sandy River mudstone:		
Sand, hard	25	245
Sand and clay, blue	5	250
"Hard shell" (sandy bed, cemented?)	2	252
Sand and clay, blue—Continued		
Clay, layered brown, black, blue and yellow	73	325
Columbia River basalt:		
Rock, brown and black	115	440
Rock, porous, some water	53	493
Rock, hard, black, water level dropped 20 ft	15	508
Rock, black, "coarse cuttings"	20	528
Rock, porous, black	15	543
Rock, hard	1	544

1N/1-34P1. Pacific Telephone & Telephone Co.

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

Materials	Thickness (feet)	Depth (feet)
Alluvium and Troutdale(?) formation:		
Clay	4	4
Boulders and gravel	31	35
"Rock" (gravel?)	37	72
Sandy River mudstone:		
Clay, brown and blue	5	77
Sand	1	78
"Rock" (sandstone?)	14	92

1N/1-34P2. Pacific Telephone & Telegraph Co.

[Drilled by R. J. Strasser Drilling Co., 1950]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, yellow	15	15
Gravel, boulders and clay	14	29
Gravel and boulders, loose	4	33
Troutdale formation:		
Gravel and clay	92	125
Gravel, cemented	44	169
Clay, blue	3	172
Gravel and clay	11	183
Sandy River mudstone:		
Sand, silt, some gravel, dark	57	240
Clay, brown	86	326
Sand, green	2	328
Sandstone	23	351
Columbia River basalt:		
Basalt, black	21	372
Rock, gray	3	375
Columbia River basalt—Continued		
"Conglomerate," hard	16	391
Rock, hard, black	37	428
"Conglomerate," hard	12	440
Basalt, hard, black	8	448
Rock, yellow	17	465
"Conglomerate"	31	496
"Shale," hard, brown	30	526
Basalt, gray and black	31	557
Rock, porous, black, water-bearing	13	570
Basalt, hard, black and gray	55	625
"Shale," hard, dark	21	646
Rock, porous, black, water-bearing	32	678
Basalt, very hard, black	19	697

TABLE 2.—*Drillers' logs of representative wells*—Continued

1/1-3D1. Fox Theater

[Drilled by A. M. Jannsen Drilling Co., 1941]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:			Fluviolacustrine deposits, etc.—Continued		
Sand	47	47	Gravel, coarse, considerable water	12	137
Sand, coarse, and gravel	38	85	Gravel, cemented	21	158
Gravel, some water at 95 ft	20	105	Sand, coarse and gravel	29	187
Sand, coarse, and gravel, slightly cemented	20	125	Gravel, coarse	5	192
			Gravel, water-bearing	33	225

1/1-3D4. Pacific First Federal Savings & Loan

[Drilled by R. J. Strasser Drilling Co., 1955. Casing perforated, 230 to 237 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Sandy River mudstone:		
Soil and fill	10	10	Clay, blue, some gravel	30	267
Sand, brown	26	36	Clay, brown	33	300
Troutdale(?) formation:			Shale, hard, green	2	302
Gravel, cemented	26	62	Clay, brown, and some shale, green	28	330
Sand and gravel, water-bearing	21	83	Shale, hard, brown	3	333
Troutdale formation:			Clay, brown	13	346
Gravel, cemented	18	101	Sandstone, brown and gray	6	352
Clay, sandy, brown	12	113	Columbia River basalt (decomposed?):		
Sand, gravel and clay, blue, some water	27	140	Clay, brown, and some basalt	15	367
Gravel, cemented	15	155	Columbia River basalt:		
Sand, gravel and clay, blue	75	230	Basalt, gray	1	368
Sand and gravel, loose, water-bearing	7	237			

1/1-3D5. Ladd Building Co.

[Drilled by R. J. Strasser Drilling Co., 1959. Casing perforated from 130 to 140 ft and from 198 to 207 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale formation—Con.		
No record, excavation	12	12	Gravel and sand, loose, water-bearing	15	140
Sand	7	19	Gravel, cemented	58	198
Sand and boulders, large	7	26	Gravel, loose, and sand	9	207
Troutdale(?) formation:			Sandy River(?) mudstone:		
Gravel, cemented, large	57	83	Clay, blue	21	228
Troutdale formation:					
Clay, sand, and gravel	42	125			

TABLE 2.—*Drillers' logs of representative wells*—Continued

1/1-3E1. Oregonian Building Co.

[Drilled by R. J. Strasser Drilling Co., 1947. Casing perforated from 127 to 142 ft and from 171 to 188 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and artificial fill:			Troutdale formation—Con.		
Fill	9	9	Sand and gravel, loose, water-bearing	15	142
Sand, brown	63	72	Gravel, cemented	29	171
Troutdale formation:					
Gravel, cemented	41	113	Sand and gravel, loose, water-bearing	18	189
Gravel, sand and clay	14	127	Gravel, cemented	14	203

1/1-3E2. Oregonian Building Co.

[Drilled by R. J. Strasser Drilling Co., 1947. Casing perforated from 128 to 143 ft, 146 to 164 ft, 169 to 179 ft, 180 to 190 ft, and 191 to 206 ft. Gravel filled to 216 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Troutdale formation—Con.		
Sand, brown	91	91			
Troutdale formation:			Sand and gravel, water-bearing	19	210
Gravel, cemented	37	128	Gravel, cemented	18	228
			Clay, greenish-blue	3	231
Sand and gravel, loose, water-bearing	12	140	Columbia River basalt:		
Sand, gravel and clay	19	159	Rock, hard, black	4	235
Gravel, cemented	32	191			

1/1-3E3. Oregonian Building Co.

[Drilled by R. J. Strasser Drilling Co., 1947]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits:			Columbia River basalt—Continued		
Silt and clay, dry	83	83			
Troutdale formation:			Rock, soft, gray	28	503
Gravel, cemented	41	124	"Conglomerate," gray	6	509
			Rock, soft, gray	15	524
Sand, gravel, some water	13	137	Rock, hard, gray	16	540
Gravel, cemented	33	170			
			Rock, soft, porous, gray	36	576
			Rock, hard, gray	83	659
Sand and gravel, varicolored, water-bearing	21	191	Rock, soft, black	16	675
Sand, black	2	193	Rock, hard, gray	95	770
Gravel, cemented	5	198	Rock, soft, black	65	835
			Rock, hard, black	7	842
Sand and gravel, water-bearing	25	223	Rock, soft, black	12	854
Gravel and clay	3	226	Rock, hard, gray	8	862
Columbia River basalt:			Rock, soft, black	1	863
Rock, hard, gray	34	260	Rock, hard, gray	5	868
Rock, soft, yellow	27	287			
Rock, hard, gray	19	306	Rock, soft, red and black	17	885
Rock, soft, green	41	347	Rock, hard, red	13	898
Rock, hard, black	40	387			
"Conglomerate," some water	3	390	Rock, black, caving, with red deposits, water-bearing	27	925
Rock, hard, gray	85	475	Rock, hard, gray	5	930

TABLE 2.—*Drillers' logs of representative wells*—Continued

1/1-3E4. Boiler Makers Union

[Drilled by R. J. Strasser Drilling Co., 1942. Casing perforated from 120 to 126 ft and from 128 to 140 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation:		
Clay, sandy	43	43	Gravel, cemented	40	120
Gravel, cemented	18	61	Sand and gravel, water-bearing	20	140
Sand, some water	5	66	Gravel and sand, very fine	11	151
Clay and gravel	14	80			

1/1-3F1. Portland General Electric Co.

[Drilled by A. M. Jannsen Drilling Co., 1947]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation—Con.		
Sand	10	10	Sand and some gravel	40	157
Gravel and boulders	30	40	Gravel, water-bearing	18	175
Shale	2	42	Sand and gravel	45	220
Sand and gravel	18	60	Sandy River mudstone:		
Clay, yellow	5	65	Clay, blue	55	275
Troutdale formation:			Clay, yellow	40	315
Gravel, cemented	30	95	Sand and gravel, water-bearing	25	340
Gravel, loose	22	117	Columbia River basalt:		
			Rock	220	560

1/1-4A1. Portland Art Museum

[Drilled by A. M. Jannsen Drilling Co., 1938. Casing perforated, 218 to 233 ft]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale formation—Con.		
Sand, loose, and clay	90	90	Gravel, loose, water-bearing	4	170
Troutdale formation:			Sand and gravel, cemented	30	200
Sand and gravel, cemented	34	124	Sand, loose, and gravel	5	205
Gravel, cemented, and clay	42	166	Sand, loose, green	10	215
			Sand, green, and rock, loose, water-bearing	20	235

1/1-4C1. Rose City Bowl, Inc.

[Drilled by A. M. Jannsen Drilling Co., 1950]

Materials	Thickness (feet)	Depth (feet)	Materials	Thickness (feet)	Depth (feet)
Fluviolacustrine deposits and Troutdale(?) formation:			Troutdale(?) formation—Continued		
Gravel	26	26	Clay and "rock"	25	98
Boulder	9	35	Gravel and clay	64	162
Gravel	29	64	Clay and "rock"	10	172
Troutdale(?) formation:			Columbia River basalt:		
"Rock"	9	73	Rock	73	245

TABLE 3.—*Monthly metered pumpage for heating and cooling, in acre-feet, discharged to the city of Portland sewers from wells in the west-side business district*

[Tt, Troutdale formation; Tc, Columbia River basalt; e, estimated data; p, partial data only; totals rounded]

Year	Pumpage from	January	February	March	April	May	June	July	August	September	October	November	December	Totals
1954	Tt	------	------	------	------	------	------	------	------	------	^{p}1.2	23.0	27.7	------
	Tc	------	------	------	------	------	------	------	------	------	18.6	8.1	8.0	------
	Totals	------	------	------	------	------	------	------	------	------	20	31	36	------
1955	Tt	27.8	20.1	26.3	25.3	27.6	49.9	47.0	57.4	75.9	57.3	41.7	26.0	480
	Tc	8.9	10.6	9.1	12.2	22.6	35.0	37.1	63.7	49.2	28.0	14.1	4.3	300
	Totals	37	31	35	38	50	85	84	120	130	85	56	30	780
1956	Tt	37.4	60.5	41.8	65.5	108.9	100.6	128.6	124.4	94.0	71.1	48.8	39.7	920
	Tc	9.2	3.5	4.6	15.7	31.2	46.0	90.8	85.8	67.3	23.4	5.5	4.5	390
	Totals	47	64	46	81	140	150	220	210	160	94	54	44	1,300
1957	Tt	34.0	60.8	48.7	32.8	98.8	108.1	116.4	120.0	258.1	97.5	88.7	92.2	1,200
	Tc	4.5	6.6	6.8	13.6	28.4	50.7	52.0	42.1	78.2	18.0	11.7	7.0	300
	Totals	38	67	56	46	130	160	170	160	340	120	100	100	1,500
1958	Tt	92.2	93.9	93.9	88.2	138.0	166.2	148.0	138.5	133.3	80.9	57.8	^{e}57	1,300
	Tc	8.6	11.0	9.5	19.0	50.4	66.4	97.0	70.4	64.7	31.5	40.9	^{e}40	510
	Totals	100	100	100	110	190	230	250	210	200	110	100	100	1,800

TABLE 4.—*Chemical analyses of water from wells of the west-side business district, Portland, Oregon*

[In parts per million except the last 2 items. Tt, Troutdale formation; Tc, Columbia River basalt]

Well	1N/1-34N3	1N/1-34N4		1N/1-34N12		1N/1-34N13		1N/1-34P2		1/1-3E1	1/1-3E2		1/1-3E3	
Date of collection	Oct. 25, 1946 [1]	Jan. 9, 1947 [1]	Mar. 9, 1955 [2]	Nov. 16, 1953 [1]	Mar. 1, 1955 [2]	November 1955 [3]	Mar. 1, 1955 [2]	Apr. 3, 1951 [1]	Mar. 1, 1955 [2]	June 11, 1947 [1]	July 1, 1947 [1]	July 14, 1950 [1]	Jan. 7, 1948 [1]	Mar. 1, 1955 [2]
Aquifer (formation)	Tt	Tc	Tc	Tt & Tc	Tt & Tc	Tc	Tc	Tc	Tc	Tt	Tt	Tt & Tc [4]	Tc	Tc
Silica (SiO_2)	52	35		45				43		53	49	44	58	
Iron (Fe) (total)	[5] 14	.2		2.9				.19		.01	.03	.2	.4	
Manganese (Mn)				.03				.05		.06	.27	.6		
Calcium (Ca)	31	45		197		84		64		36	39	41	115	
Magnesium (Mg)	10	2		12				3.7		16	17	8	6	
Sodium (Na) Potassium (K)		174		218				189		4.7	8.3	42	154	
Bicarbonate (HCO_3)			116	73	107	95	85	117	118			169	125	154
Carbonate (CO_3)				12(?)				0				0	12	
Sulfate (SO_4)	18	13		12				9.8		9.1	14	15	7.1	
Chloride (Cl)	29	308	400	698	840	90	790	328	530	18	22	52	356	233
Fluoride (F)				.3				.6		.3	.05	.7		
Nitrate (NO_3)				4.8						1.6	2.3			
Dissolved solids:														
Sum				1,239				697				287		
Residue on evaporation	312												918	918
Hardness as $CaCO_3$	117	119	290	540	665	164	650	176	285	156	168	138	312	300
Noncarbonate	0	0								0	0			
Free CO_2	60	3						3		55	66	21	0	
Specific conductance			1,510		2,890		2,710		1,940					1,070
pH	6.5	7.8	7.1	7.6	7.4		6.8	7.9	7.5	6.7	6.7	7.2	8.2	7.2

[1] Analysis by Charlton Laboratories, Portland.
[2] Analysis by U.S. Geol. Survey.
[3] Analysis by the Flox Co., Inc.
[4] Water from Tc introduced by artificial recharge.
[5] Iron and aluminum oxide.