Ground-Water Resources of the Clatsop Plains Sand-Dune Area, Clatsop County, Oregon

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1899-A

Prepared in cooperation with Clatsop County

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By F. J. FRANK

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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GROUND-WATER RESOURCES OF THE CLATSOP PLAINS SAND-DUNE AREA, CLATSOP COUNTY, OREGON

By F. J. Frank

ABSTRACT

Although the average annual precipitation of the Clatsop Plains is 78.5 inches, the area is not without problems of water supply. The Clatsop Plains area is underlain by Tertiary bedrock of low permeability that stores and yields small quantities of ground water, which may be of poor chemical quality. This Tertiary bedrock furnishes only minor ground-water discharge to maintain the base flow of streams. The flow of rivers and creeks, normally abundant during the wet season, decreases greatly during the dry summer months.

The lowlands are overlain by extensive deposits of dune and beach sand. The dune sand is permeable and can absorb and store, as fresh water, a large percentage of the annual precipitation. In the central part of the dune area, the saturated thickness of the sand ranges from 95 to more than 150 feet. Most of the ground water in the sand discharges to the ocean through beach-line seeps and underflow. Much of the water now being discharged to the ocean could be recovered by pumping from properly located, designed, and constructed wells. Three test wells drilled as part of this study are capable of yielding 100 gallons per minute although they are equipped with only short lengths of well screen. It is estimated that 2,500 acre-feet of ground water per year per square mile of area may be available for withdrawal in the 10-square mile area that is most favorable for development.

The water from the dune sand is soft to moderately hard, has a low chloride concentration, and is of generally good chemical quality; however, at places it is weakly acidic and contains sufficient dissolved iron to make iron removal necessary for some uses. Ground water from shallow depths beneath a few swampy low-lying areas is brown and contains excessive concentrations of iron.

INTRODUCTION

Water to supply the needs of the Clatsop Plains might be obtained from the ground, streams, and manmade reservoirs. Streamflow, normally abundant during the wet seasons of the year, decreases greatly during summer, and the lack of suitable reservoir sites makes surface

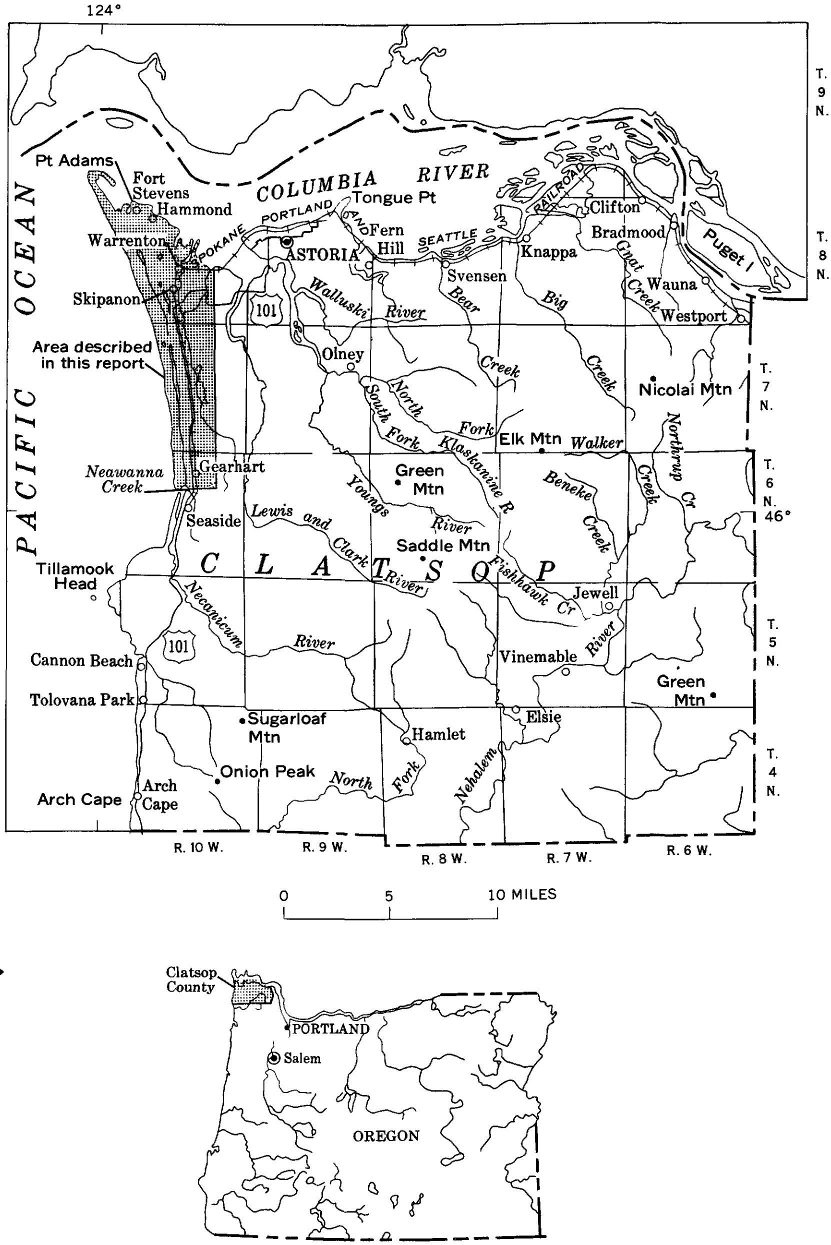

FIGURE 1.—Location of Clatsop County and project area.

storage of water difficult. Because economic growth is placing additional demands on water supplies, city and county officials of the area recognize the need to determine the ground-water resources of the Clatsop Plains sand-dune area.

Most of the Clatsop Plains water supply is imported by pipeline from a nearby drainage basin, but in late summer the supply is barely adequate. At present (1968), the only area where ground water is used as a main source of water supply is at the Surf Pines, a private development of beach properties near Gearhart consisting of about 40 homes, some of which are occupied on a seasonal basis.

This report explains the relation of the geologic environment to the occurrence of ground water and describes the hydrologic conditions, the chemical quality of ground water, and the potential ground-water supply for the Clatsop Plains sand-dune area.

Fieldwork was done during July 1966–October 1967. Existing geologic maps for the area were checked, and the contact between the Tertiary Astoria Formation and the Quaternary deposits was defined and modified. Thirty-four shallow observation wells were constructed for sampling and periodic measurement of water levels. Discharge measurements were made periodically on several streams. Staff gages were installed on five lakes and several small streams. The altitude of each well and staff gage was established by spirit leveling, and water samples were collected and analyzed for chemical quality. To determine the nature and depth of the sand and the yield of a properly screened well, three test wells were drilled. During the drilling of the test wells, sand samples were collected from various depths and analyzed for grain size and hydrologic properties. Each well was test pumped to determine the water-yielding properties of the sand.

The Clatsop Plains sand-dune area extends southward along the Oregon coast from the mouth of the Columbia River to Tillamook Head, and is in Clatsop County, Oreg. The dune area ranges in width from about half a mile near Tillamook Head to about 2 miles near Point Adams. The area comprises about 40 square miles, and the part studied most intensively is the central and widest part of the sand-dune area. This part, about 14 square miles (fig. 1), lies south of Fort Stevens, west of U.S. Highway 101, and north of Neawanna Creek and the mouth of the Necanicum River.

The present investigation was made by the U.S. Geological Survey in cooperation with Clatsop County. The study was made under the immediate supervision of D. D. Harris, chief of the Hydrologic Investigations Section, and under the general supervision of S. F. Kapustka, district chief in charge of water-resources investigations in Oregon. Assisting with the fieldwork were C. H. Swift III, E. A. Oster, P. M. Merrill, and E. R. Hampton, of the U.S. Geological Survey. The study

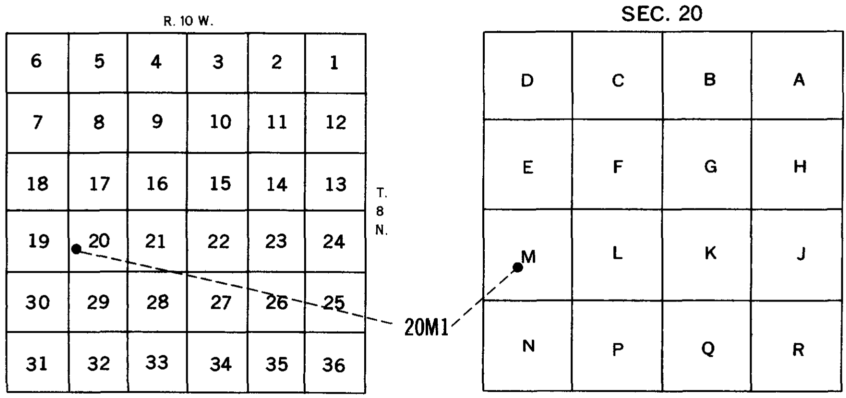

FIGURE 2.—Well-numbering system.

was facilitated by many of the local residents. The Clatsop County Board of Commissioners, Hiram C. Johnson, Verne Stratton, and Lyle G. Ordway, were very helpful at all times and gave splendid cooperation. The assistance of all is gratefully acknowledged.

The U.S. Geological Survey has made studies of ground-water resources in the sand dunes along the Oregon coast north of Coos Bay (Brown and Newcomb, 1963) and near Florence (Hampton, 1963). These studies and the experimental and developmental work done by Pacific Power & Light Co. in the Coos Bay, Oreg., area show that large volumes of potable water suitable for domestic and industrial uses can be obtained from the aquifers in the coastal dune sand.

The wells described in this report are designated by symbols that indicate their locations according to the official rectangular survey of public lands. In the symbol 8N/10W–20M1, the part preceding the hyphen indicates the township and range (T. 8 N., R. 10 W.) north and west of the Willamette base line and meridian. The first number after the hyphen indicates the section (sec. 20), and the letter M indicates a 40-acre subdivision, as shown in figure 2. The final digit is the serial number of the well within that 40-acre tract. In the example shown in figure 2, well number 8N/10W–20M1 designates the well as being in the NW¼SW¼ sec. 20, T. 8 N., R. 10 W.

Records of wells in the area are given in table 8.

GEOGRAPHIC SETTING

Except at the north end, the surface of the sand-dune area consists of a series of undulating ridges that slope upward from the ocean to the base of the bedrock foothills. Areas of swamp and bog forest are extensive and in places form strips between minor ridges, particularly at the north end and on the east side of the dune area. The highest points of the dune ridges, southwest of Warrenton, are at altitudes of more than 100 feet. The area has many fresh-water lakes, most of which lie in a north-south line through the center of the dunes. The major lakes, from north to south, are Coffenbury, Smith, Sunset, and Cullaby Lakes. The dune area is drained by a few streams. These are Neacoxie Creek, which is the outlet of Sunset Lake, and a small unnamed creek which drains to the Skipanon River. There is surface flow to Cullaby Creek from the bedrock hills to the east of the area.

Population figures for the area as a whole are not available, but the three towns in the study area—Warrenton, Gearhart, and Hammond—had 1965 populations of 1,800, 730, and 563, respectively. Many people, possibly 1,000 permanent residents, live outside these towns.

The economy of the region depends largely on tourist activities. The area includes Fort Stevens State Park, which is one of the most popular State parks in Oregon. Commercial fishing and the processing of fish are among the major industries, and the lumbering industry also employs many people in the area. The only agricultural crop in the area is cranberries, planted in about 40 acres of the lowland on the eastern edge of the dunes.

The climate of the area is cool and moist; an average annual precipitation of 78.5 inches was recorded during 36 years of record (1931–66) at the U.S. Weather Bureau station at Seaside. The annual precipitation at Seaside for the years 1931–66 is shown in figure 3. This figure also shows the cumulative departure, in percent, from the average annual precipitation—that is, the accumulative excesses and deficiencies of precipitation—for the 36-year period. Most of the precipitation occurs as rain during fall and winter (table 1). The prevailing winds blow from the northwest during summer and from the southwest during winter. The mean annual temperature is about 52°F.

Because of low summer temperatures and moist air from the ocean, the evaporation in the area is low. Evaporation data from the Astor Experiment Station near Astoria indicate that evaporation from open-water surfaces in the area is probably 20–21 inches per year (Kohler and others, 1959, pl. 2). The period of greatest evapotranspiration is from June through August, which coincides with the period of least rainfall.

GEOLOGIC SETTING

Ground-water conditions in any area are directly related to the geology of that area. The rate at which water recharges to and discharges from an aquifer is dependent on (1) the character and distribution of the geologic units, especially those near the surface, (2) the underlying geologic conditions, and (3) the climate and physiography of the area.

TABLE 1.—*Average monthly temperature and precipitation at Seaside, 1931–66*

[From records of U.S. Weather Bureau]

Month	Temperature (°F)	Precipitation (inches)
January	43.0	12.24
February	45.3	9.88
March	45.4	8.70
April	48.7	5.60
May	52.8	2.85
June	56.7	2.65
July	59.4	1.23
August	60.0	1.57
September	58.9	2.68
October	54.4	7.48
November	48.3	10.59
December	45.0	11.81

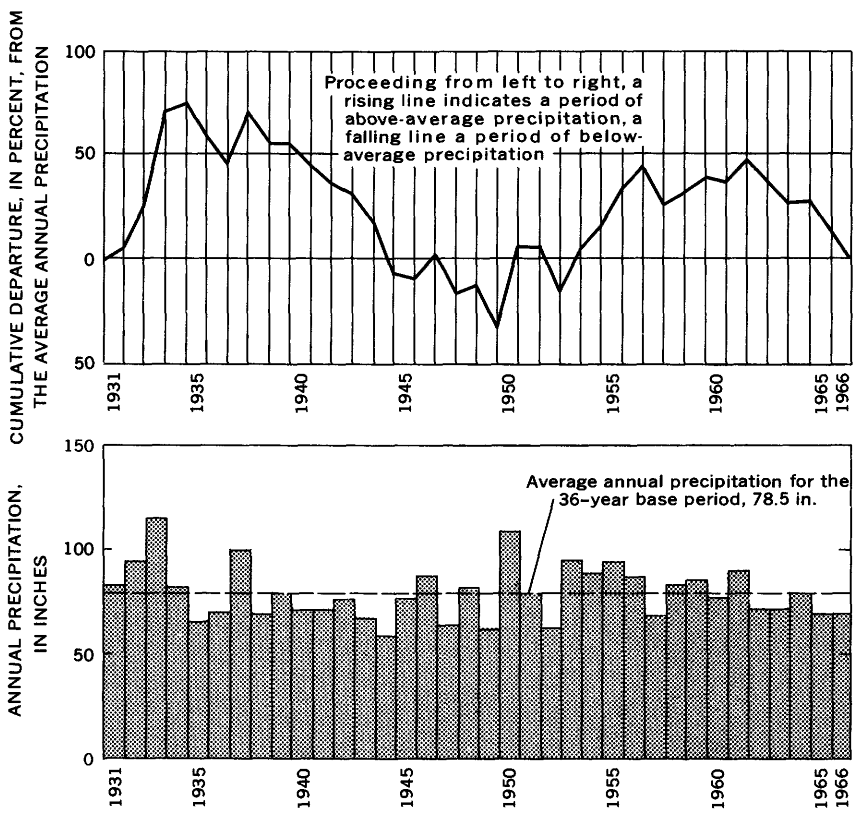

FIGURE 3.—Average annual precipitation and cumulative departure from average precipitation at Seaside, 1931–66.

For this area, the general geologic conditions were known from previous studies.

A study of the coastal sand dunes of Oregon and Washington, including the Clatsop Plains sand dunes, was made by Cooper (1958). His report includes a description of this dune area and a discussion of the history, origin, and configuration of the dunes.

The major geologic units in the Clatsop Plains sand-dune area were mapped by Warren, Grivetti, and Norbisrath (1945). Also, the broader aspects of the geology of the area are shown on the "Geologic Map of Oregon West of the 121st Meridian," compiled by Wells and Peck (1961). The distribution of the rock units, modified after the map of Wells and Peck, is shown on plate 1.

TERTIARY ROCKS

The major rock unit of Tertiary age in the area is the Astoria Formation, which consists of sandstone and shale with an estimated thickness of 1,400 feet (Warren and others, 1945). The Astoria Formation underlies the hills along the eastern edge of the dunes and constitutes the bedrock of the sand-dune area. The unit as a whole is fine grained, tightly compacted, and relatively impermeable. It supplies only minor ground-water discharge to maintain the base flow of streams and yields only small quantities of water, which may be of poor chemical quality.

QUATERNARY DEPOSITS

The Quaternary alluvium, which is of small extent, lies in the northern part of the area and consists mostly of clay, silt, and sand. The alluvium is outside the area of greatest ground-water potential and was not studied extensively during this investigation. Although no existing wells are known to tap the alluvium, the coarser parts of this unit may yield small to moderate quantities of water to wells.

Dune sand of Pleistocene and Holocene age overlies the eroded surface of the Astoria Formation and is the principal water-bearing material in the area. In the part of the area studied in most detail and in which the three test wells were drilled, the sand has a thickness exceeding 100 feet. (See drillers' logs, table 2.) The sections on plate 1 show the general shape of the base of the sand unit.

The sand grains are subangular to rounded, range in size from coarse to very fine, and are mostly quartz with lesser amounts of feldspar, magnetite, mica, and undetermined rock fragments. In sand samples collected from the three test wells, the particles ranged in size from clay and silt, <0.0625 mm (millimeters), to coarse sand, 0.5–1.0 mm, but were predominantly within the size classifications of fine sand, 0.125–

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

Materials	Thickness (ft)	Depth (ft)
7N/10W-22N1		
[C. H. Lewis. Drilled by A. M. Jannsen Drilling Co., 1962. Casing 6 in. 0–51 ft; 6-in. screen 50–55 ft]		
Quaternary deposits:		
Sand	8	8
Sand, water-bearing	17	25
Sand, heaving	37	62
7N/10W-33H2		
[U.S. Geological Survey. Drilled by A. M. Jannsen Drilling Co., 1967. Casing 6 in. 0–60 ft; 6-in. screen 60–75 ft]		
Quaternary deposits:		
Sand, light-brown, very fine, silty; perched water zone 5–20 ft	45	45
Sand, light-brown, very fine to medium-grained; plant remains and woodchips at 64 ft	19	64
Sand, gray, very fine to medium-grained, with plant remains; fossiliferous	18	82
Sand, grayish-black, very fine to fine-grained, with large amount of grayish-green silt; fossiliferous	38	120
Sand, very fine to medium-grained; some granule-sized pieces of basalt, with some grayish-green silt	7	127
Tertiary rocks		
Astoria(?) Formation:		
Silt and clay, black	13	140
8N/10W-9D1		
[Point Adams Cannery. Drilled by A. M. Jannsen Drilling Co., 1964. Well abandoned]		
Quaternary deposits:		
Sand and silt	12	12
Sand, heaving; some wood at 138 to 143 ft	131	143
Sand, coarse, and shells	2	145
Sand, heaving	50	195
Sand, gray, and wood and gravel	45	240
Sand and logs	22	262
Sand	23	285
Tertiary rocks		
Astoria(?) Formation:		
Clay, silty	3	288
Sand, silty	17	305
Astoria Formation:		
Clay, sandy	14	319
Sandstone, soft	1	320
Sandstone, hard	19	339
Sand, coarse, sharp	23	362
Sand, coarse, sharp, micaceous; salt water	7	369

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

Materials	Thickness (ft)	Depth (ft)
8N/10W-9K1		
[Spokane, Portland & Seattle Railway Co. Date drilled and driller unknown. Well abandoned]		
Quaternary deposits:		
Sand	240	240
Tertiary rocks		
Astoria(?) Formation:		
Clay, blue, soft; small log at 262 ft	22	262
Shale, moderately hard	7	269
Clay, soft	9	278
Sand, fine	38	316
Shale	11	327
Sand	62	389
Astoria Formation:		
Shale, very sticky	37	426
Sand, coarse	25	451
Shale, brown	43	494
Sand, coarse; salt water	2	496
Shale, blue	734	1,230
Shale, very hard	50	1,280
Shale	230	1,510
Shale, very hard	28	1,538

Materials	Thickness (ft)	Depth (ft)
8N/10W-7A1		
[Fort Stevens. Drilled in 1915; driller unknown. Well abandoned]		
Quaternary deposits:		
Sand, yellow	40	40
Sand, blue and gray, with some wood from 98 to 125 ft; log at 118 ft	130	170
Sand, blue, very fine, micaceous	93	263
Sand, blue, coarse	9	272
Tertiary rocks		
Astoria(?) Formation:		
Sandstone, brown	8	281
Sandstone, gray	13	294
Sand, blue	3	297
Sand, gray	2	299
Sand, blue	4	303
Sandstone, gray	2½	305½
Sand, blue	3	308½
Sandstone, gray	1½	310
Sand	90	400
Astoria Formation:		
Clay, blue, and sand	34	434
Sandstone, light-colored	29	463
Shale	34	497
Sandstone, gray	135	632
Shale, gray, with hard streaks of talc	168	800

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

Materials	Thickness (ft)	Depth (ft)
8N/10W-20M1		
[U.S. Geological Survey. Drilled by A. M. Jannsen Drilling Co., 1967. Casing 6 in. 0–105 ft; 6-in. screen 105–120 ft]		
Quaternary deposits:		
Sand, brown, fine-grained; plant remains at bottom of interval	23	23
Sand, gray; plant remains and small amount of mica	37	60
Sand, gray, fossiliferous	5	65
Sand, gray, very fine to medium-grained, micaceous	50	115
Sand, gray, fine- to medium-grained; a few scattered gravels and fossils	7	122
Sand, gray, fine- to medium-grained, with silt, wood chips, and a few small gravels; fossiliferous	10	132
Sand, gray, very fine grained, with thin lenses of silt	28	160
8N/10W-33N1		
[U.S. Geological Survey. Drilled by A. M. Jannsen Drilling Co., 1967. Casing 6 in. 0–73 ft; 6-in. screen 73–88 ft]		
Quaternary deposits:		
Sand, light-brown, very fine grained	40	40
Sand, light-brown, fine- to medium-grained, micaceous	10	50
Sand, light-brown, very fine to fine-grained; some silt	5	55
Sand, light-brown, fine- to medium-grained	18	73
Sand, gray, fine- to medium-grained; some silt and a few plant remains and wood chips	2	75
Sand, gray, fine- to medium-grained	13	88
Sand, gray, fine-grained	10	98
Sand, gray, tight, with some basaltic and quartzitic pebbles in a silty clay matrix	2	100
Sand, blackish-gray, very fine to medium-grained, with some silt	8	108
Tertiary rocks		
Astoria(?) Formation:		
Clay, greenish-blue, with streaks of shale	17	125
Shale, grayish-green, hard	10	135

0.25 mm, and medium sand, 0.25–0.5 mm. (See fig. 4.) Table 3 illustrates the range in distribution of the particles in the various size classifications, in percentage by weight of the total sample.

With few exceptions, the entire section of sand is loosely compacted and unconsolidated. The exceptions are thin discontinuous silty and

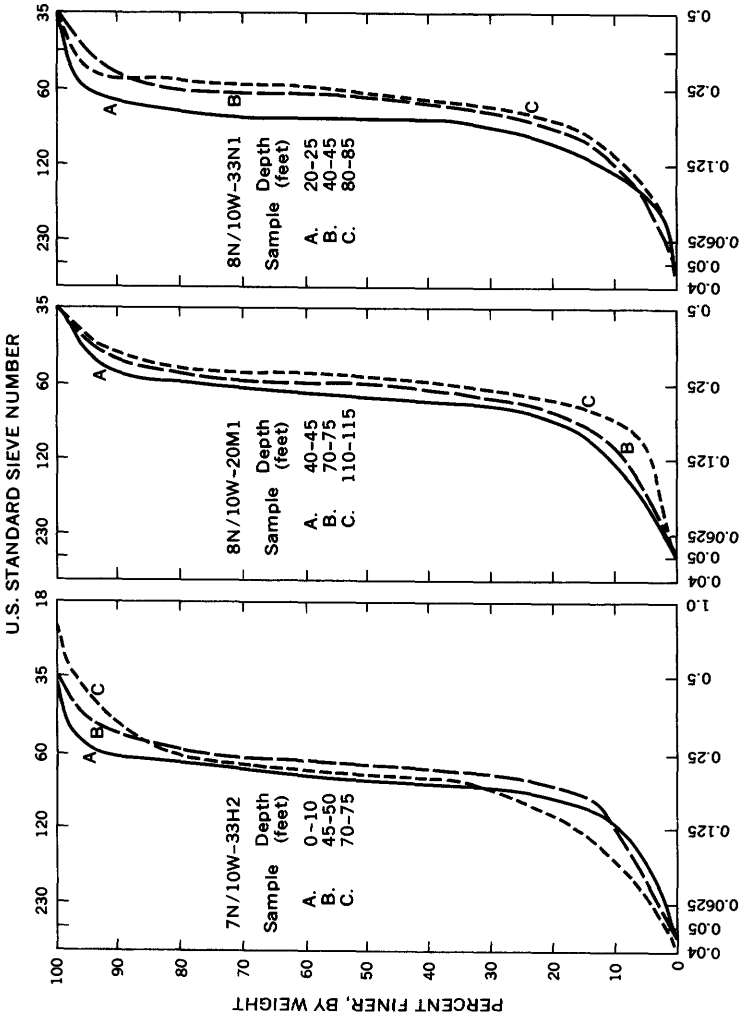

FIGURE 4.—Results of particle-size analyses of dune sand from test wells 7N/10W-33H2, 8N/10W-20M1, and 8N/10W-33N1.

TABLE 3.—*Weight percentage, by size, of particles in samples from wells*

[Particle diameters in millimeters]

Test well	Depth of sample (ft)	Clay and silt (<0.0625)	Sand			
			Very fine (0.0625–0.125)	Fine (0.125–0.25)	Medium (0.25–0.5)	Coarse (0.5–1.0)
8N/10W–20M1	40–45	2.1	12.9	65.2	18.6	1.2
	70–75	2.0	10.0	54.2	33.5	.3
	110–115	1.4	5.4	63.1	30.1	.0
8N/10W–33N1	20–25	1.6	20.5	74.3	3.8	.1
	40–45	2.5	11.9	61.0	24.3	.3
	80–85	1.7	11.3	68.1	18.3	.6
7N/10W–33H2	0–10	2.2	10.5	79.9	7.2	.2
	45–50	2.5	12.6	60.2	24.5	.2
	70–75	4.5	18.2	59.2	15.2	2.9

clayey layers that were penetrated during drilling of the test wells. The sand at and near the surface is all wind-deposited dune sand. At depth, the windblown sand probably is interbedded with sand that was deposited in the littoral zone at lower levels of the sea during Pleistocene time. However, because ground water in the dune sand and littoral or beach sand has hydraulic continuity, both sand deposits are considered in this report as a single unit.

HYDROLOGIC SETTING

Precipitation is the source of fresh water in the area. Unless the rate of precipitation exceeds the rate at which water can infiltrate and transfer downward, all the water is absorbed by the soil. The precipitation that does not infiltrate flows overland as runoff and may reach stream channels. Water that infiltrates the soil in excess of the ability of the soil to hold it by capillary attraction continues to move downward toward the zone of saturation. If a unit of saturated materials yields water in sufficient quantity to be used as a water supply, it is called an aquifer. Water moves downgradient through the aquifer and is discharged naturally to streams or the ocean, artificially to wells, or is lost to the atmosphere by evaporation and transpiration by vegetation.

The upper surface of a zone of saturation is a water table, and the water in the zone of saturation is ground water. In some places, a body of "perched" ground water lies above the main water table. Ground water is said to be perched if it is separated from an underlying body of ground water by unsaturated rock. Perched water belongs to a different zone of saturation from that of the underlying water table. Its water table is a perched water table and is distinct from that of the lower zone of saturation, which is called the main water table.

WATER TABLE

CONFIGURATION

Water-table contours depict the configuration of the water table (pl. 1) as topographic contours do that of the land surface. The surface defined by water-table contours roughly conforms to the land-surface topography, except that the slopes of the water table are gentler. Ground water moves in response to gravity—that is, down the slope of the water table.

The principal factors that control the shape and slope of the water table in the dune area are (1) the topography of the land surface, (2) the configuration of the underlying bedrock, (3) the permeability of the materials through which the ground water moves, (4) the relative location of areas of recharge to and discharge from the ground-water reservoir, and (5) the relative rates of recharge and discharge.

The generalized configurations of the water table in the dune area in October 1966 and January 1967 are shown on plate 1. In October 1966, the altitudes of the higher parts of the water table were about 15–20 feet above mean sea level—about 5 feet lower than those in January 1967. The map representing October conditions shows not only a lower water table but also a generally flatter gradient of the water table along the western edge of the dune area, where water is discharged by seeps and underflow to the ocean, and along other main areas of drainage, particularly south along Neacoxie Creek and north along the Skipanon River.

In general, the water table in the area is in the shape of a low ridge that coincides with the extent of the dune sand. This low ridge has minor ridges and troughs superimposed on it that correspond closely to the land-surface features. The water table is highest in the central part of the area and slopes downward to the Skipanon River, Cullaby Lake, and other surface-water bodies near the east margin, as well as to the ocean shoreline on the west. The elongate dune lakes represent above-surface areas of the ground-water body, and their margins intersect the water table.

FLUCTUATION

Data on the fluctuation of the water table were obtained by measuring water levels in a network of shallow observation wells constructed during the investigation and by periodically reading gages installed on lakes and streams of the area. To obtain a continuous record of water-level fluctuations, automatic water-level recorders were installed and operated at test wells 7N/10W–33H2 and 8N/10W–33N1 from June 1967 to June 1968.

The water table in the dune sand fluctuates principally in response to recharge or lack of recharge from precipitation. Precipitation in the area is least in July and August and greatest in December and January. The dune sand rapidly absorbs and stores water from precipitation, as shown by the quick response of the water table to periods of precipitation. (See hydrographs in fig. 5.) After a period of dry weather, the initial part of the infiltrated water enlarges the capillary film about each grain of sand until the moisture content of the surficial sand is replenished. As the moisture-holding capacity of the sand is reached, additional precipitation is rapidly transferred to the water table. The hydrographs show that the water levels in most of the wells decline from spring to October; as precipitation thereafter increases in quantity and intensity, the soil moisture is replenished, and the additional water rapidly percolates to the water table.

Fluctuations of the water table in the central part of the area are virtually unaffected by tidal movements. This is illustrated by the hydrographs of the water-level recorder operated to obtain a continuing record at test well 8N/10W–33N1 (fig. 6). However, water-level fluctuations due to tidal movement have been noted at the gage at the lower end of Neacoxie Creek near Gearhart and at observation well 6N/10W–4B1, which is near the beach (pl. 1).

PERCHED GROUND WATER

Many perched ground-water bodies in the study area are seasonal. During the rainy season they may become thick and extensive, but during the dry season they may shrink or disappear as the water drains away laterally (or vertically if the perching layer is slightly permeable).

A local body of perched ground water has been recognized in the vicinity of two wells in the dune area in a depression somewhat lower than the immediate surrounding topography. This perched water occurs at observation well 7N/10W–33H1 and also at test well 7N/10W–33H2, drilled about 100 feet south of the observation well. The bottom of well 7N/10W–33H1 is in silt and very fine sand, which retard the downward percolation of water and hold a thin saturated zone above the main water table. Figure 7 shows the relative position of the perched water table and the main water table in the two wells. The size of this perched zone is not known, but it is probably of small areal extent. Geologic conditions similar to those that contribute to this perched-water zone probably exist in other parts of the area. Poorly permeable materials that retard the vertical movement of water may be present beneath some of the major lakes.

SOURCE AND RECHARGE OF GROUND WATER

Because the dune sand allows infiltration of a high percentage of precipitation, surface runoff from the area is negligible. Evaporation of

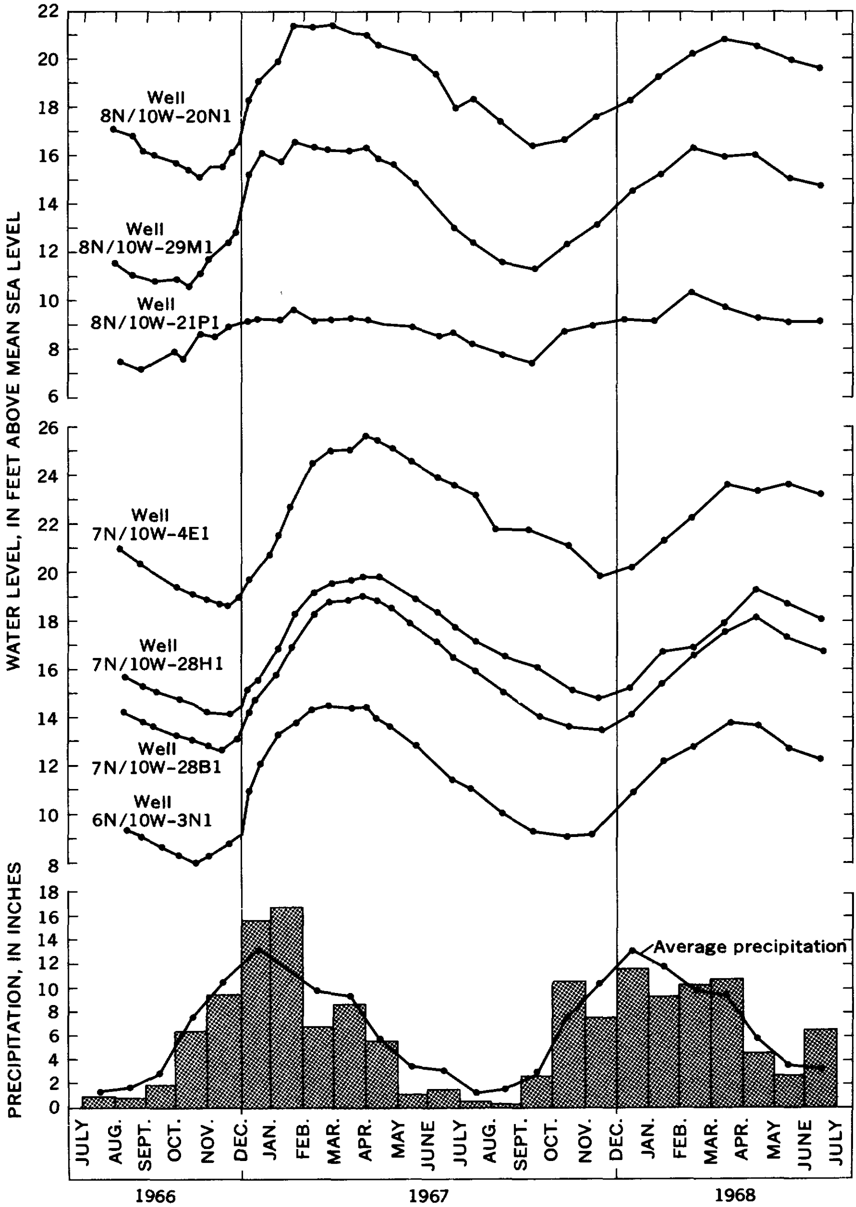

FIGURE 5.—Relation of precipitation to water-level fluctuations in selected wells.

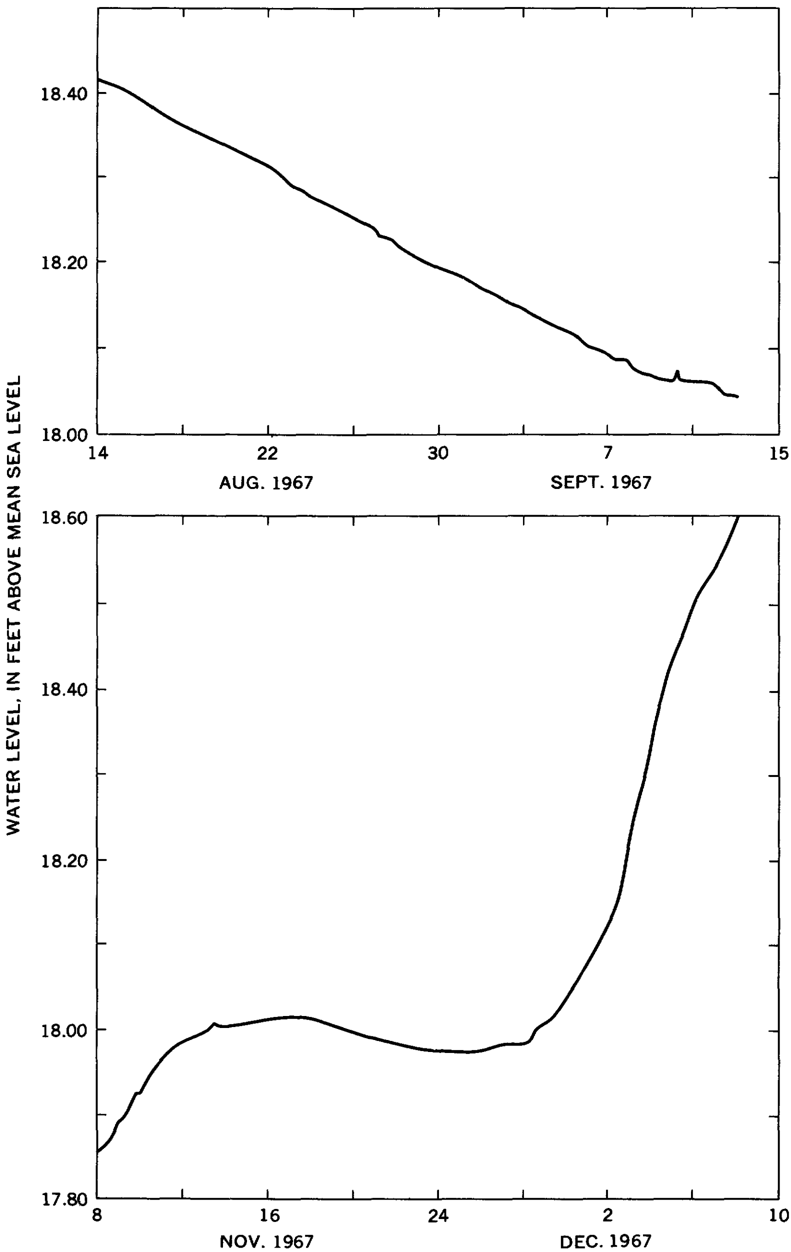

FIGURE 6.—Hydrographs of well 8N/10W–33N1.

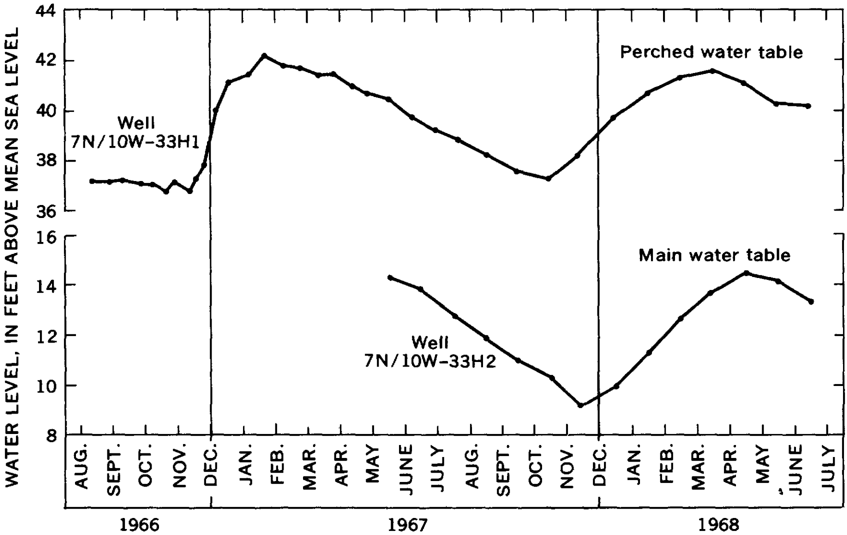

FIGURE 7.—Relation of altitudes of a perched water table to the main water table.

precipitation from land or vegetation surfaces and from the unsaturated zone above the water table is minor. Therefore, most of the precipitation recharges the ground-water body. Only a few small streams flow out of the dune area, and they function mainly as ground-water drains. (See p. A21.)

An estimate of the average annual recharge in the sand-dune area was made by comparing the change in water levels of 20 observation wells with the precipitation that occurred between water-level measurements (table 4). Comparison of these data indicates that about 5 inches

TABLE 4.—*Change in water levels of observation wells in relation to precipitation at Seaside*

Period	Change in water level[1] (ft)	Precipitation[2] (in)
1966		
Aug. 12–Sept. 8	−0.32	0.73
Sept. 9–Oct. 5	−.22	2.11
Oct. 6–Nov. 3	+.30	6.64
Nov. 4–Dec. 8	+2.12	16.68
Dec. 9–Jan. 4, 1967	+.77	9.12
1967		
Jan. 5–Feb. 8	+.87	15.83
Feb. 9–Mar. 15	+.03	10.21
Mar. 16–Apr. 12	−.20	4.56
Apr. 13–May 17	−.59	3.79
May 18–June 8	−.59	1.04
June 9–July 12	−.72	1.29
July 13–Aug. 10	−.68	.28

[1] Composite water-level change, derived from records of 20 wells.
[2] From daily precipitation records at Seaside.

of precipitation per month is necessary for the water levels in the observation wells to rise from their low stages. As the water table rises, the hydraulic gradients near the sides of the dune-sand aquifer steepen, and ground water moves more rapidly toward areas of discharge. Therefore, a greater volume of precipitation is required to maintain the water table at its highest level than is required to maintain the water table at its lowest stage.

MOVEMENT AND DISCHARGE OF GROUND WATER

Ground water beneath the Clatsop Plains is in constant motion and flows from areas of higher head to areas of lower head. The horizontal direction of ground-water movement can be deduced from water-table contour maps. (See pl. 1.) Most of the precipitation that falls on the area enters the sand and moves downgradient to points of discharge.

Recharge from precipitation probably is distributed rather evenly over the dune area, but discharge of the fresh ground water is more localized. Discharge of the ground water is principally through seeps and underflow to the Pacific Ocean, along the western edge of the dune sheet. Quicksand areas, which indicate rising or effluent ground water, extend along the beach from the northern end of the area near the mouth of the Columbia River to Gearhart and are present during even the driest parts of the year. Ground water is also discharged by several small streams, one of which drains part of the northern section of the dunes and is diverted to flow into the Skipanon River. Neacoxie Creek drains the southern part of the area and flows into Neawanna Creek and thence to the Necanicum River.

Ground water percolates southward from West Lake and is intercepted by a ditch system and conveyed to cranberry bogs in secs. 22 and 27, T. 7 N., R. 10 W. Water emerges from the dunes in the vicinity of Swash Lake, flows into the lake, and drains out with the ebb tide to the Columbia River.

The volume of ground water discharged from the area by evapotranspiration was not determined. Evaporation from the surface of lakes and streams, which constitute about 10 percent of the area, probably does not exceed 20–21 inches, according to evaporation data. As most of the area is covered with fairly dense stands of European beach grass, native grasses, Scotch-broom, and shore pine, probably most evapotranspiration losses are by transpiration—the process by which plants transfer water to the atmosphere from the soil or from the ground-water body. In the Coos Bay dune area, which has a climate and a vegetative cover similar to those of the Clatsop Plains dune area, Brown and Newcomb (1963, p. 22) estimated the average evapotranspiration discharge to be about 15 inches per year. This estimate is considered by the writer to be reasonable for the Clatsop Plains dune area as a whole. In parts of the area where the water table is near the surface and where there is more vegetative cover, evapotranspiration may be more than 15 inches. In other parts of the area, where the water table is at greater depths and the vegetative cover is less dense, evapotranspiration losses may be less than 15 inches.

The potential ground-water supply of the area is nearly undeveloped. The volume of ground water withdrawn from wells was not determined but is believed to be insignificant compared with the water being discharged naturally from the dune area. Most of the few existing wells are sand points driven deep enough to penetrate only a short distance below the water table. With few exceptions, these wells are used for auxiliary water supplies only. The primary source of water for domestic and other uses is surface water from nearby rivers and creeks.

The natural recharge to the Clatsop Plains sand-dune area is estimated to be about 60 inches per year. To maintain the water table within the range of levels observed during this investigation, an equal volume of water must be discharged. On the basis of the estimate of 15 inches per year of evapotranspiration, the natural ground-water discharge, excluding evapotranspiration, is expected to average about 45 inches per year for the area. (See p. A30.)

RELATION OF GROUND WATER TO LAKES AND STREAMS

Most of the major lakes are in parts of the area where the water table is at a relatively high altitude. The lake levels in the Clatsop Plains fluctuate in general accordance with fluctuations of the adjacent water table. However, the relative positions of the water table and lake levels differ from place to place and vary in response to seasonal variations in precipitation and recharge. In general, the lakes fluctuate less than does the water table. The relative positions of the lake levels and the water table in October 1966 and January 1967 are shown on plate 1.

The similarity of the fluctuation in lake and ground-water levels is shown by the hydrographs in figure 8. In that figure, the hydrographs of Sunset and Cullaby Lakes show fluctuations of approximately 1 to 2 feet per year, which is typical of most of the lakes. The levels of lakes with surface outlets are more nearly constant than are the ground-water levels in the adjacent dune sand, whereas the levels of lakes without good surface outlets fluctuate in closer agreement with the positions of the adjacent water table. This is illustrated by the hydrographs for Coffenbury and Sunset Lakes and observation wells 8N/10W–18G1 and 7N/10W–9R1. Coffenbury Lake, in a deep depression between dunes, lacks good drainage and fills to a high level during the wet season, whereas Sunset Lake discharges to Neacoxie Creek. The curves for

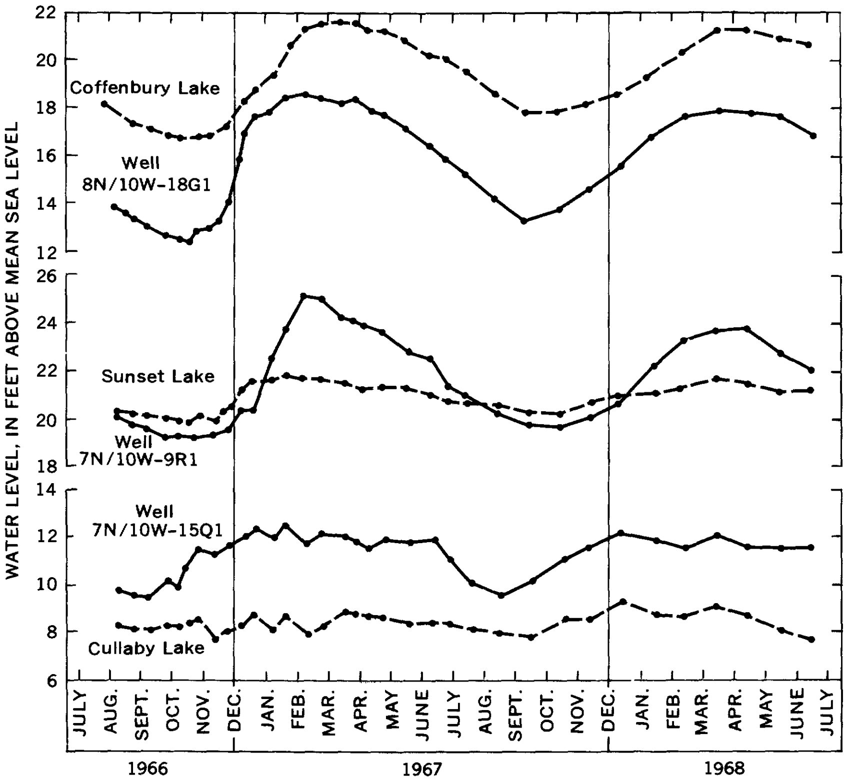

FIGURE 8.—Comparison of water-level fluctuations of wells with those of lakes.

Coffenbury Lake and well 8N/10W–18G1 have the same general trends, although they differ in magnitude. During the year, the water level in the observation well ranges from a few hundredths of a foot to 4½ feet lower than that of the lake level. The exact relationship of the lake level to the water table is not fully understood, but at times, particularly during the dry season, water from the lake may percolate to the water table. The rate of downward movement of water from the lake may be slow because the lakebed is probably sealed by silt. No surface outflow was observed from Coffenbury Lake during this investigation. Because evaporation discharge would account for only about 20 inches of the nearly 80 inches of precipitation on the lake, much of the water probably was discharged from the lake by vertical or lateral seepage.

The hydrographs for Sunset Lake and observation well 7N/10W–9R1 (fig. 8) show a seasonal interchange in the relative positions of lake levels and the water table at the well. During the summer and fall of 1966, the water level in the observation well was about half a foot below the level of the lake. In December 1966, the water level in the well rose a few hundredths of a foot above the level of the lake and reached its peak in February. The water level in the well remained several feet above the level of the lake until the next period of seasonal water-table decline.

Cullaby Lake is the only major lake in the area that receives surface runoff from the bedrock hills to the east. Most of this surface flow enters the lake from Cullaby Creek during the wet season. The level of the lake remains nearly constant because excess flow is discharged through a spillway at the north end of the lake. Inflowing ground water, particularly during the dry season of the year, helps to maintain the level of the lake. This is confirmed by flow measurements of Cullaby Creek and of Cullaby Lake at its outlet. Measurements made at the outlet of the lake on February 7, 1967, showed a flow of 28.1 cfs (cubic feet per second) from the lake; measurements made on September 21, 1967, during the dry season, showed a flow of 0.44 cfs. Measurements made of Cullaby Creek near Delmoor station, about 1 mile south of the inlet to Cullaby Lake, showed a flow of 12.8 cfs on February 7, 1967, and no flow on September 21, 1967. The hydrographs of Cullaby Lake and observation well 7N/10W-15Q1 show general conformance of fluctuations (fig. 8).

The levels of most of the lakes are maintained principally by ground-water discharge from the dune sand; therefore, large withdrawals of water close to most of the lakes could cause a fairly rapid lowering of lake levels. Some of the lakes are long and narrow, such as Sunset Lake, and water enters them from seeps and springs in many places along their banks. Although the level of Sunset Lake or a similar lake might be lowered by intensive pumping from a nearby well field, any such decline in level would be slowed by inflow of ground water near other parts of the lake. Maximum seasonal lowering of lake levels and of water tables near the lakes probably would occur during the relatively short dry season, when the greatest volumes of water are likely to be withdrawn and when the open surfaces of the lakes receive little rainfall. Before lake levels could be seriously lowered during any dry season, however, the heavy precipitation of the wet season would rapidly restore them.

To avoid adverse effects of ground-water development on lake levels would necessitate a water-management program whereby water would be withdrawn only to the extent that winter precipitation would restore the water table to its natural wintertime position. The net withdrawal would be limited to the volume of salvageable natural discharge. Long-term withdrawals in excess of that volume would begin to remove water from storage in the aquifer and the lakes, and would cause permanent lowering of the water table and lake levels.

Most streams in the area act as ground-water drains. The lack of well-defined channels tributary to the streams is evidence that very little precipitation leaves the dune area by direct runoff. Water runs off the surface of the sand only when rainfall exceeds the intake capacity of the sand or when the sand is saturated to the land surface. Normally, the water table stands higher than the stream levels, and water discharges from the ground-water body to the streams. Neacoxie Creek receives ground-water discharge throughout the year, and its flow increases progressively in a downstream direction. At various times during 1967, the flow of Neacoxie Creek was measured at a point about 1 mile south of the outlet of Sunset Lake and at a point 1½ miles farther downstream. Measurements made at these two points on February 7, 1967, show a 5.4 cfs increase in flow downstream—from 11.1 to 16.5 cfs. Measurements made at the same points on April 10, 1967, show an increase in flow downstream of 5.09 cfs, from 8.71 to 13.8 cfs.

HYDROLOGIC PROPERTIES OF AQUIFER

AQUIFER TESTS

Three pumping tests were made to determine the specific capacities of the wells (in gallons per minute per foot of drawdown) and the ability of the sand to transmit water. The tests were conducted on three test wells that were drilled as part of the study. Each well is 6 inches in diameter, is equipped with 15 feet of 6-inch well screen with slot openings of 0.01 inch, and penetrates only part of the aquifer. The data from the pumping tests were analyzed by the Theis recovery method (Theis, 1935) and the Theis nonequilibrium method as modified by Cooper and Jacob (1946). The results of the aquifer tests are shown in table 5.

The ability of an aquifer to transmit water may be expressed as its coefficient of transmissibility, defined as the volume of water, in gallons per day, that will pass through a vertical strip of aquifer having a width of 1 foot and a height equal to the saturated thickness of the aquifer under the hydraulic gradient of 1 foot per foot at the prevailing ground-water temperature.

The average value for coefficient of transmissibility obtained from the pumping tests on the test wells was 27,000 gpd per ft (gallons per day per foot) and is probably lower than the true value due to hydraulic effects caused by the wells penetrating and being open to less than the full saturated thickness of the aquifer. It is possible that transmissibility values could be as high as 50,000 for wells that nearly or completely penetrate the aquifer and are equipped with adequate lengths of well screen to reduce the effects of partial penetration.

The volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface is known as the coefficient of storage of an aquifer. Although the coefficient of storage was not determined, this coefficient for the sand aquifer could reasonably range in value from 0.10 to 0.30.

TABLE 5.—*Results of aquifer tests*

Well	Depth of well (ft)	Depth of casing (ft)	Screened interval (ft)	Character of water-bearing materials	Duration of pumping (hr)	Depth to water before start of pump test (ft)	Average pumping rate (gpm)	Drawdown (ft)	Specific capacity (gpm per ft)	Coefficient of trans-missibility (gpd per ft)
8N/10W-33N1	135	88	73–88	Dune sand	40	15.54	70	29.26	2.4	26,000
8N/10W-20M1	160	120	105–120	do	72	11.59	98	32.63	3.0	26,000
7N/10W-33H2	140	75	60–75	do	40	33.01	50	11.77	4.2	29,000

POSSIBLE MAGNITUDE OF DRAWDOWN EFFECTS

If the transmissibility and storage coefficients are known, values for these and other terms can be substituted in the nonequilibrium equation of Theis (1935, p. 520) to calculate the drawdown caused by a well pumping at any given rate in an aquifer having those coefficients. The results of such calculations using two different coefficients of transmissibility, three values of storage coefficient, two factors of time, three values of distance, and two pumping rates are shown in table 6. The table shows the theoretical relations of drawdown, time, and distance

TABLE 6.—*Calculated drawdown of water table at various distances from a hypothetical well pumping for selected rates and periods, using coefficients of transmissibility and storage assumed for the dune sand*

Coefficient of transmissibility (gpd per ft)	Time since pumping started (days)	Coefficient of storage	Distance from pumped well (ft)	Drawdown of water level (ft)[1] at indicated pumping rate	
				100 gpm	200 gpm
27,000	10	0.10	100	1.9	3.6
			500	.6	1.3
			1,000	.2	.4
		.20	100	1.6	3.2
			500	.4	.8
			1,000	.1	.2
		.30	100	1.4	2.9
			500	.3	.6
			1,000	.1	.2
	100	.10	100	2.9	5.7
			500	1.5	3.0
			1,000	.9	1.9
		.20	100	2.6	5.1
			500	1.2	2.4
			1,000	.7	1.3
		.30	100	2.4	4.8
			500	1.1	2.2
			1,000	.6	1.1
50,000	10	.10	100	1.2	2.3
			500	.4	.9
			1,000	.2	.3
		.20	100	1.0	2.0
			500	.3	.6
			1,000	.1	.2
		.30	100	.9	1.8
			500	.2	.5
			1,000	.1	.1
	100	.10	100	1.7	3.4
			500	1.0	1.9
			1,000	.6	1.3
		.20	100	1.5	3.0
			500	.8	1.6
			1,000	.5	1.0
		.30	100	1.4	2.8
			500	.7	1.4
			1,000	.4	.8

[1] Rounded to nearest tenth.

from the pumping well for reasonable well yields and for a range of aquifer coefficients that probably includes the true values for most or all the dune sand.

Through use of table 6, it is possible to estimate the approximate drawdown for a period of 100 consecutive days (July, August, and parts of June and September—a period of maximum water use). The drawdown is directly proportional to the pumping rate. For example, the maximum drawdown caused by a single well pumping 200 gpm (gallons per minute), assuming a transmissibility of 27,000 gpd per ft and a coefficient of storage of 0.10, is about 1.9 feet at a distance of 1,000 feet from the pumped well. Therefore, if wells were spaced fairly uniformly along one or two lines throughout a well field, large quantities of water could be withdrawn during the 100-day season without causing serious interference between wells, even though the wells were pumped simultaneously and each yielded 200 gpm.

Table 6 can also be used to estimate the distance well fields should be located from existing lakes to avoid seasonal lowering of lake levels. The above calculations indicate that if well fields are not constructed immediately adjacent to the lakes, a sizable volume of ground water can be pumped from the aquifer without causing desiccation of the existing lakes.

CHEMICAL QUALITY OF WATER

To determine the general chemical quality of the water in the dune-sand aquifer, 41 samples were collected from wells and lakes and analyzed by the U.S. Geological Survey. Nine of the samples were analyzed for all the major constituents usually included in a comprehensive water analysis; 32 of the samples were analyzed for iron, calcium, magnesium, sulfate, chloride, and hardness only. The results of chemical analysis of these water samples are shown in table 7 along with results of one analysis obtained from the Surf Pines development (wells 7N/10W–21G1, 2). The analyses indicate that the water is of generally good chemical quality for most domestic and industrial uses. Most of the ground water is odorless, has a satisfactory taste, and has a temperature about the same as the mean annual air temperature. Water from the lakes and some of the shallow wells in marshy areas is brown; otherwise, the water in the Clatsop Plains area is colorless. The brown color probably is caused by dissolved organic material which was not identified in the analyses.

Certain chemical and physical characteristics of natural waters must be considered in determining suitability for industrial or domestic use. The occurrence and importance of several critical properties and dissolved constituents of ground water in the Clatsop Plains sand dunes are discussed below.

TABLE 7.—*Chemical analyses of water from wells and lakes in the Clatsop Plains sand-dune area*

[Analyses by the U.S. Geol. Survey, Portland, Oreg., unless otherwise noted. Temperature of water in degrees Celsius (centigrade) is followed by temperature in degrees Fahrenheit within parentheses]

Well or lake	Date of collection	Temperature	Milligrams per liter												Dissolved solids		Hardness		Specific conductance (micromhos at 25°C)	pH	Color
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Calculated	Residue on evaporation at 180°C	As $CaCO_3$	Noncarbonate			
6N/10W-3C1	11-10-66	12 (53)		3.1	6.9	3.2					3.4	8.0					30		101		
3H1	11- 9-66	11 (52)		26	14	6.9					.0	20					64		246		
3N1	11-10-66	12 (53)		.22	2.9	1.0					5.6	10					11		81		
3R1	11- 9-66	12 (53)		4.9	2.4	1.8					2.8	9.5					14		66		
4A1	11-10-66	13 (55)		.55	8.7	6.5					8.8	57					48		239		
4B1	11-10-66	16 (61)		1.9	1.4	2.8					15	50					15		640		
7N/10W-3N1	11- 8-66	12 (53)		.09	5.7	2.8					1.8	23					26		153		
4E1	11- 8-66	11 (52)		.58	4.1	2.7					2.2	16					21		99		
5H1	11- 8-66	12 (53)		16	5.7	9.0					2.8	70					51		291		
Sunset Lake	7-20-67	21 (70)	16	.48	6.1	6.8	20	3.5	62	0	.4	29	0.1	0.2	113	106	43	0	194	7.5	20
7N/10W-5R1	11- 8-66	13 (55)		8.4	6.6	17					2.4	56					86		330		
9N1	11- 8-66	13 (55)		.60	5.5	11					11	74					58		310		
9P1	11- 8-66	12 (54)		.16	3.8	6					2.4	14					34		155		
9R1	11- 8-66	11 (51)		.49	2.0	1.0					2.2	14					9		74		
10N1	11- 8-66	11 (52)		1.7	6.7	4.0					11	13					33		120		
Cullaby Lake	7-14-67	22 (71)	6.9	1.5	3.3	2.4	14	1.2	24	0	4.8	18	.1	.9	64	69	18	0	113	6.7	100
7N/10W-15Q1	11- 8-66			53	9.4	5.6					33	20					46		214		
16H1	11- 9-66	13 (56)		.07	8.1	3.8					6.0	36					36		164		
21B1	11- 9-66	11 (52)	28	.08	4.2	6.5	34	3.3	52	0	6.4	47	.2	1.4	157	145	37	0	255	6.2	0
21G1-2[1]	4-27-59			.27					40	0	Trace	53				182	56			7.3	
7N/10W-27K1	11- 9-66	12 (54)		17	3.6	1.5					1.6	15					15		68		
28B1	11- 9-66	11 (52)		.17	4.4	8.2					10	46					44		259		
28H1	11- 9-66	13 (55)		.32	3.2	4.5					2.6	25					26		132		
33G1	11- 9-66	13 (55)		.41	3.3	6.3					5.8	36					34		211		
33H1	11- 9-66	11 (52)		5.5	4.3	6.2					2.6	24					36		147		
33H2	5-25-67	11 (52)	30	.30	17	12	19	10	122	0	4.4	27	.2	1.5	181	189	92	0	291	7.3	0
34E1	11- 9-66	11 (52)		.16	2.6	1.8					3.0	14					14		90		
34F1	11- 9-66	13 (55)		.05	2.8	.8					3.6	12					10		66		
34G1	11- 9-66	13 (55)		.49	3.4	1.9					2.4	9.0					16		64		
8N/10W-17D1	11- 8-66	12 (53)		1.5	5.3	4.0					6.6	26					30		146		

Coffenbury Lake	7-12-67	21 (70)	.2	.28	1.8	2.8	16	1.00	10	0	4.4	29	.1	.3	60	60	16	8	126	6.8	20
8N/10W-18F1	11- 7-66			.94	4.8	8.7					2.0	39					48		216		
18G1	11- 7-66	12 (54)	21	.65	4.8	6.1	14	4.60	44	0	3.6	25	.2	.8	102	100	37	0	163	6.3	5
20B1	11- 8-66			.6	5.2	3.1					3.0	13					26		105		
20M1	8-11-67	12 (53)	50	.11	6.3	16	25	14	119	2	.4	38	.2	.8	212	218	82	0	318	8.3	5
20N1	11- 8-66	13 (55)		.12	7.7	11					10	57					64		281		
20R1	11- 8-66	13 (55)		.11	2.1	1.9					3.4	7.0					13		70		
21P1	11- 8-66	12 (53)		25	5.7	5.0					.8	30					34		184		
8N/10W-29M1	11- 8-66	13 (55)		1.0	5.5	12					3.4	45					63		280		
32G1	11- 8-66	12 (54)		8.6	6.6	12					6.4	48					66		260		
33N1	5-28-67	11 (52)	31	.09	3.3	14	26	14	105	0	13.0	27	.2	.5	181	181	66	0	281	8.0	5
33R1	11- 7-66	12 (53)		4.9	3.7	3.0					.4	14					22		99		

[1] Analysis by Charlton Laboratories, Portland, Oreg.

IRON

Iron is not known to be injurious to health, but excessive amounts will produce certain undesirable effects. Excessive iron in drinking water imparts an unpleasant taste. Concentrations in excess of 0.3 mg/l (milligram per liter) may cause yellowish or reddish stains on plumbing fixtures, cooking utensils, and laundry. Many industrial processes cannot tolerate excessive iron in the water.

According to the U.S. Public Health Service (1962), a combined concentration of iron and manganese in excess of 0.3 mg/l is considered to be objectionable for domestic and public uses. Water from shallow wells in boggy or swampy areas in the Clatsop Plains contained dissolved-iron concentrations objectionable for most uses. The highest iron concentration was 53 mg/l in water from well 7N/10W–15Q1, which is in a low marshy area. The lowest iron concentration was 0.05 mg/l in water from well 7N/10W–28B1 in an area of open sand. As shown in table 7, the iron concentration is relatively low in the water from the deep 6-inch test wells that were drilled in areas of open sand. The presence of more than 0.3 mg/l of iron in many of the water samples analyzed indicates that future wells in the area may obtain water having amounts of this constituent that would be objectionable unless removed by treatment of the water.

Treatment of water for removal of iron is relatively simple. Iron removal in municipal and industrial supplies is generally accomplished by aeration, which oxidizes the dissolved iron and causes it to precipitate. Subsequent filtration removes the precipitate.

CHLORIDE

Chloride concentration in water samples analyzed ranged from 74 mg/l in water from well 7N/10W–9N1 to 7.0 mg/l in water from well 8N/10W–20R1. The chloride concentration in water from some of the shallow wells immediately adjacent to the ocean was somewhat higher than that in water from shallow wells farther inland; this may be due largely to precipitation which dissolves salts deposited by ocean spray and the subsequent percolation downward to the fresh ground-water body. The chloride concentration in water from the three 6-inch test wells averaged about 30 mg/l.

The upper limit recommended by the U.S. Public Health Service (1962) for chloride in drinking water is 250 mg/l. None of the water samples analyzed approached this limit.

HARDNESS

Certain constituents in water, especially calcium and magnesium, cause hardness, which affects the use of soaps and detergents. These constituents consume soap in laundry operations and, like silica, are the source of scale in boilers and cooking utensils. The degree of hardness can be evaluated by using the following classification:

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

Observed hardness values of the ground water from the dune area ranged from 11 to 92 mg/l, which indicates that the water is soft or only slightly hard.

ACIDITY

The acidity of the ground water represents the content of free carbon dioxide, other uncombined gases, certain organic acids, and salts of strong acids and weak bases that hydrolyze to give hydrogen ions.

The pH (hydrogen-ion concentration) of a water is a measure of its acidity or alkalinity and is related to the corrosive properties of water. A pH of 7.0 indicates that the water is neither acidic nor alkaline. A pH reading progressively lower than 7.0 denotes increasing acidity and indicates progressively higher corrosive conditions; conversely, a pH of more than 7.0 would be alkaline in reaction. Determinations of pH were made for nine of the samples listed in table 7. Of these, the pH of four samples is less than 7.0.

The average pH values for water from the three deep test wells was about 7.8 compared with an average pH value of 6.8 for water from shallow wells and lakes. As shown in table 7, water in the deeper wells in the dune sand has greater hardness and a higher pH value than does water in wells of shallow depth.

POTENTIAL GROUND-WATER SUPPLY

In the dune-sand aquifer beneath the Clatsop Plains, the total volume of deposits saturated with fresh water is more than 900,000 acre-feet. Even if the reservoir could be completely drained, the volume of fresh ground water that could be recovered would be considerably less than that in storage. The volume of water that could be derived from the sand aquifer by gravity drainage is commonly referred to as the "specific yield" and is expressed as a percentage of the volume of saturated material. The specific yield would be equal to the total quantity of water in storage minus the quantity that is retained in the deposits by capillary and other forces. The average specific yield of the ground-water reservoir of the Clatsop Plains is assumed to be about 20 percent, which represents the volume of ground water that can be recovered by pumping. Therefore, the estimated maximum volume of fresh ground water that could be pumped from the reservoir beneath the dune area is 180,000 acre-feet, or nearly 60 billion gallons.

It has been previously estimated that 60 inches of water, or nearly 80 percent of the average annual precipitation, infiltrates into the dune sand. About one-fourth of this amount is required to meet evapotranspiration losses, and the remainder (about 45 in.) is discharged to the ocean, mostly by seeps and underflow. On that basis, as much as 2,500 acre-feet of water per year per square mile of area may be available for withdrawal. This is an average of 2 mgd per sq mi (million gallons per day per square mile).

The most favorable area for development of this water covers about 10 square miles in the central part of the dune area, where the ground-water reservoir is thickest and absorbs and stores the most precipitation. This part of the sand-dune area has a water level sufficiently high above sea level to permit pumping below sea level locally and yet maintain the water table several feet above sea level along the beaches, thereby preventing the intrusion of sea water.

Because of economic and other factors, it is generally not feasible to withdraw the entire quantity of water available from a given area. In the Clatsop Plains dune area, withdrawal of all available water would require a large number of wells and could result in the depletion of existing lakes (p. A21). The optimum quantity of water that could be withdrawn, from the total quantity available, would depend on the economic factors involved and should be consistent with a water-management program based on the hydrologic regimen of the area.

This approximately 10-square-mile area does not include (1) a narrow strip of dune sand immediately adjacent to the Pacific Ocean and the mouth of the Necanicum River, where large withdrawals from wells might cause sufficient lowering of the water table to permit saline-water intrusion into the aquifer, (2) several square miles of the northward extension of the dune area, and (3) parts of the dune area east of U.S. Highway 101, where the dune aquifer probably does not have enough thickness to store the volume of precipitation necessary to support large and sustained withdrawals of water. Much of the dune area east of U.S. Highway 101 lies in low boggy areas that may contain water having an excessive iron content.

As the withdrawal of ground water from the dune sand increases in the future, the volume of water available might be increased by artificial recharge or by a general lowering of the water table.

The dune area might be recharged artificially by injection of water into wells, by collection of water into recharge basins, and by spreading of water over the surface. Water of good quality for artificial recharge can be pumped from nearby streams during high stages.

During winter periods of maximum precipitation, the sand becomes saturated to a relatively high level, the hydraulic gradient toward points of discharge increases, and ground-water discharge increases. If withdrawals of water were increased during summer so that the water table would be lowered at the onset of the rainy season, the natural ground-water discharge during winter would be reduced. The natural discharge salvaged could be considered as an increase in the fresh-water supply available for withdrawal.

CONSTRUCTION AND DEVELOPMENT OF WELLS

Results of this and other research on sand-dune aquifers (Brown and Newcomb, 1963; Hampton, 1963) have shown that the most practical method of extracting large volumes of water from the dune sand is by the use of properly screened and developed vertical wells. A properly designed well screen is the best water-inlet mechanism. It allows water to enter the well readily at low velocity and prevents sand from entering with the water. The optimum length of well screen should be chosen in relation to the anticipated drawdown and the thickness and stratification of the aquifer.

Results of tests indicate that at least half the saturated thickness of the aquifer should be screened. In most of the area, optimum screen length would be 50 to 75 feet. Each of the three test wells was equipped with 15 feet of screen adjacent to a selected section of the aquifer, and pumping-test results indicate that each of the wells was capable of yielding 100 gpm. Increased screen length would allow greater exposure of the water-bearing zones to these wells and would result in less drawdown, higher specific capacity, and greater well efficiency. Possibly, the yield of the test wells could be increased at least 50 percent by the use of a longer well screen.

Another common method of well construction that may prove to be feasible in the Clatsop Plains sand-dune area involves the use of an artificial envelope of coarse sand or gravel around the well screen. Where the natural water-bearing sand contains no relatively coarse material to permit development of a natural gravel pack, it may be desirable to place coarse material around the screen. A gravel pack permits the use of a screen with larger slots than otherwise could be used, and the increased slot size permits the water to enter the well with much reduced head loss. To be effective, an envelope of 3 to 6 inches of coarse sand or gravel is generally used. An artificially gravel packed well that is properly constructed in fine uniform sand generally has a higher yield per foot of drawdown than does one of the same diameter not surrounded by gravel.

The cost of an artificially gravel packed well is generally higher than that of a naturally developed well. The former necessitates drilling a hole of larger diameter, which usually costs more per foot and requires specially graded sand or gravel. However, increased production can more than justify the additional cost.

Upon completion of drilling, a properly constructed well should be developed to bring it to its maximum yield capacity and to obtain maximum economic well life. Such development tends to correct any damage or clogging of the water-bearing formation resulting from drilling, and increases porosity and permeability of the aquifer in the vicinity of the well. Water can then move through this zone toward the well with smaller loss of head, resulting in reduced drawdown and increased yield. Development should continue until the movement of fine material through the formation ceases and the well is sand free. Among methods commonly used are pumping at progressively higher rates and surging by intermittent pumping with surge blocks or with compressed air. Development methods are described in a publication by Edward E. Johnson, Inc. (1966), as well as in many other publications.

The three test wells demonstrate the importance and the results of adequate development. After development was completed, the wells were pumped continuously for periods of 24 to 72 hours. Throughout these periods, water pumped from the wells was sand free.

When a well is completed, it should be test pumped to determine its maximum yield and the drawdown at that yield. If additional wells are available for observation purposes, data on the depth to water in them can be used along with the test data from the pumped well to determine hydraulic characteristics of the aquifer and how large an area will be affected by pumping. The hydraulic characteristics of the aquifer can be used to calculate the drawdown caused by a well pumping at a given rate and to show the relation of drawdown to distance for various intervals of time. Such calculations were made for this study, and similar ones will be needed to provide other quantitative estimates for water-management purposes.

PROBLEMS OF SEA-WATER INTRUSION

In the Clatsop Plains sand-dune area, the sand aquifer is in contact with the ocean at, and possibly seaward of, the coastline. At the contact, fresh ground water from the sand-dune area mixes with and discharges into salty ground water in seaward extensions of the aquifer, or directly into the ocean at the shoreline. Because fresh and salty ground water have different densities, a boundary zone or interface is formed wherever they are in contact. The shape and position of the interface is governed by a hydrodynamic balance of the fresh and salt waters and is directly related to the ground-water discharge as submarine outflow. In the dune area, existence of fresh water to any appreciable depth requires that the average position of the water table must be above sea level and that there must be a fresh-water gradient toward the sea.

Future withdrawals of ground water from the Clatsop Plains dune aquifer should be carefully planned and monitored to prevent sea-water contamination of the aquifer. When the total inflow of fresh water to the ground-water reservoir is less than the total outflow permanently lost from the system by evapotranspiration and by discharge to the sea, an imbalance in the hydrologic system exists. A local imbalance in the hydrologic system may result from pumping water from the more permeable parts of the aquifer in excess of the rate of recharge. Such an imbalance would result in decreases in the volume of fresh water in storage and tend to cause concurrent landward movement of salty ground water. Also, provided vertical permeability is low compared with a high horizontal permeability, an imbalance might occur in a single zone even though the overall system is in general balance.

Because recharge to the dune sand a short distance inland from the beach is adequate to maintain the water table at least several feet above sea level throughout the year, the natural hydrodynamic pressure and seaward movement of the fresh water should be sufficient to hold back the sea water, even though withdrawals farther inland might lower the water table locally below sea level. With moderate ground-water development and maintenance of good infiltration conditions at land surface, the water table should remain sufficiently high near the beaches to prevent landward migration of sea water.

Any water-management program for the Clatsop Plains must be consistent with the water-budget equation: inflow = outflow ± change in storage. From this equation it is apparent that increased consumptive use of ground water must be balanced by increased inflow, such as artificial recharge, or by a reduction of natural outflow, such as ground-water discharge to streams, to avoid a continuing decrease in the volume of fresh water in storage and a consequent landward movement of salty ground water.

The volume of ground water that can be withdrawn from the dune area annually without producing an undesired result, such as sea-water intrusion, will depend mainly on future management decisions regarding the volume of natural ground-water discharge to be salvaged and the volume of additional ground-water recharge, natural or artificial, to be induced.

Any plans for development of ground water in the area should provide for (1) designing wells for minimum local and areawide drawdown (as discussed under "Construction and development of wells"); (2) spacing wells to minimize interference between wells and to prevent excessive drawdown in any one part of the area; (3) maintaining a high water table along the seaward edge of the dune sand, as described previously; and (4) constructing and maintaining a network of wells of various depths, especially near the seaward edge of the dune area, to monitor water levels and chloride concentration in the ground water.

POSSIBLE POLLUTION PROBLEMS

Ground water in the study area is presently of good quality and probably safe to drink. Where aquifers are composed of sand, great numbers of bacteria are effectively removed from the water as it percolates through the sand. This filtering action of the sand may eliminate the need for sterilization of the water; however, public water supplies from wells are usually chlorinated as a precautionary measure. During an extensive investigation of travel of pollution (California Water Pollution Control Board, 1954, p. 99), experiments showed that the maximum travel distance of bacteria through a fine-grained aquifer is about 100 feet and that travel occurred only briefly after the start of the experiments. However, sand is not capable of removing chemical contaminants and probably does not filter out viruses.

There are a number of septic tanks and other private sewage-disposal systems that discharge to the sand in the area and which are or may become sources of pollution of the aquifer. Because they are not filtered by the sand, chemical constituents in waste water may cause contamination. Such substances are difficult to remove by treatment and may remain unchanged by long movement underground. However, the concentration of these constituents can be reduced by dilution, and isolated toxic effluents can be treated for removal.

At present (1968), the parts of the area most favorable for the development of ground water are sparsely populated, and well fields could be located at considerable distances from possible sources of contamination.

SUMMARY AND CONCLUSIONS

The principal conclusions from this study are:

1. The bedrock of the Clatsop Plains dune area consists of shale and sandstone of Tertiary age. These rocks are nearly impermeable and yield only small quantities of water, which may be of poor chemical quality. The bedrock is overlain by deposits of dune and beach sand, locally more than 100 feet thick. These deposits contain the principal aquifers in the area.
2. The dune sand is permeable and absorbs and stores a high percentage of the 78.5 inches of annual precipitation. Most of the ground water in the sand is discharged to the ocean by seeps and under-

flow. In the area most favorable for development of ground water, about 45 inches of the estimated 60 inches of annual recharge discharges from the sand and may be available for withdrawal. Based on an assumed average specific yield of the ground-water reservoir of 20 percent, the estimated maximum volume that could be pumped from the reservoir is 180,000 acre-feet, or nearly 60 billion gallons. In the 10-square-mile area most favorable for ground-water development, about 24,000 acre-feet per year, or about 2 mgd per sq mi, is estimated to be available for withdrawal. However, only a part of the total could feasibly be withdrawn.

3. The most practical method of extracting water from the sand is by means of properly screened and developed vertical wells. Pumping tests on three 6-inch-diameter wells equipped with a short length of screen showed a yield of 100 gpm for each well. The yields of these wells could have been increased substantially by use of longer screens. The average value of aquifer transmissibility calculated from the three pumping tests was 27,000 gpd per ft. This value, because of the effects of partial penetration caused by the inadequate length of well screen in the wells, indicates the minimum range of transmissibility values that may be expected at the well sites.
4. The levels of most of the lakes in the area are maintained principally by ground-water discharge from the dune sand. Large withdrawals of water immediately adjacent to the lakes could cause a lowering of the lake levels. Provided well fields are located and constructed so that there would be minimum drawdown effects on the water table near the lakes, it should be possible to make large seasonal withdrawals of ground water without desiccating the lakes.
5. The water is soft to slightly hard, has a low chloride concentration, and is of generally good chemical quality. Water from the shallow observation wells is generally weakly acidic, contains objectionable concentrations of iron, and may require iron-removal treatment for certain uses. On the other hand, water from the three test wells, drilled to greater depths, has lower iron concentrations and higher pH values.
6. To avoid desiccation of the ground-water lakes and the encroachment of sea water, a water-management program for the Clatsop Plains must be consistent with the water-budget equation. To avoid perennial depletion of fresh ground water in storage, increased consumptive use of ground water must be balanced by increased inflow or reduced natural outflow. The sustained yield of the ground-water reservoir will depend on future water-management decisions regarding the quantity of natural discharge salvaged and the quantity of additional ground-water recharge induced.

7. Plans for development of ground water in the area should provide for the construction of deep wells near the seaward edge of the dune sand to monitor water levels and chloride concentration of the ground water. The production wells should be located and spaced (1) to minimize interference between wells, (2) to prevent excessive drawdown which might induce sea-water intrusion in any part of the area, (3) to avoid desiccating the sand-dune lakes, and (4) to ultimately withdraw the optimum water yield from the ground-water reservoir.

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TABLE 8

TABLE 8.—*Records of wells in the*

Type of well: Dr, drilled; Dv, driven.
Finish: B, open bottom (not perforated or screened); S, screened at depth shown.
Altitude: Altitude of land surface datum at well, in feet above mean sea level; altitude expressed in feet and decimals, obtained by spirit leveling; altitude expressed in whole numbers, interpolated from topographic maps.
Water level: Depths to water, given in feet and decimals, were measured by the U.S. Geological Survey; depths in whole feet were reported by others or estimated.
Datum is land surface.

Well	Owner or driller	Type of well	Year completed	Depth of well (ft)	Diameter of well (in.)	Depth of casing (ft)	Finish	Water-bearing zone(s)	
								Depth to top (ft)	Thickness (ft)
6N/10W-3C1	U.S. Geological Survey	Dv	1966	9.1	1¼	7.6	S, 7.6–9.1	3	6
3H1	do	Dv	1966	13.3	1¼	12.9	S, 11.8–13.3	6	7
3N1	do	Dv	1966	13.1	1¼	11.6	S, 13.1–11.6	9	4
3N2	City of Gearhart	Dr	1933	180	8	106	B	------	------
3R1	U.S. Geological Survey.	Dv	1966	8.7	1¼	7.2	S, 7.2–8.7	4	5
4A1	do	Dv	1966	18.9	1¼	17.4	S, 17.4–18.9	14	5
4B1	do	Dv	1966	11.5	1¼	10	S, 10–11.5	8	3
7N/10W-3N1	do	Dv	1966	8.7	1¼	7.2	S, 7.2–8.7	6	3
4E1	do	Dv	1966	21.3	1¼	19.8	S, 19.8–21.3	16	5
5H1	do	Dv	1966	9.4	1¼	7.9	S, 7.9–9.4	4	5
5R1	do	Dv	1966	8.5	1¼	7	S, 7–8.5	5	3
9N1	do	Dv	1966	10.2	1¼	8.7	S, 8.7–10.2	6	4
9P1	do	Dv	1966	9.3	1¼	7.8	S, 7.8–9.3	5	4
9R1	do	Dv	1966	15.0	1¼	13.5	S, 13.5–15	11	4
10N1	do	Dv	1966	9	1¼	7.5	S, 7.5–9	3	6
15Q1	do	Dv	1966	9.1	1¼	7.6	S, 7.6–9.1	3	6
16H1	do	Dv	1966	10	1¼	8.5	S, 8.5–10	4	6
7N/10W-21B1	U.S. Geological Survey.	Dv	1966	9.2	1¼	7.7	S, 7.7–9.2	4	5
21G1	Surf Pine Development	Dv	--------	34	2	31	S, 31–34	------	------
21G2	do	Dv	--------	34	2	31	S, 31–34	------	------
21G3	do	Dv	1967	17	2	14	S, 14–17	------	------
22N1	C. H. Lewis	Dr	1962	62	6	50	S, 50–55	8	54
27K1	U.S. Geological Survey.	Dv	1966	8.9	1¼	7.4	S, 7.4–8.9	2	5
28B1	do	Dv	1966	9.2	1¼	7.7	S, 7.7–9.2	4	4
28H1	do	Dv	1966	19.2	1¼	17.7	S, 17.7–19.2	14	4
33G1	do	Dv	1966	13.3	1¼	11.8	S, 11.8–13.3	10	3
33H1	do	Dv	1966	11.5	1¼	10	S, 10–11.5	9	3
33H2	do	Dr	1967	145	6	60	S, 60–85	33	94
33H3	do	Dv	1967	33.2	1¼	32.7	S, 32.7–34.2	32	1
34E1	do	Dv	1966	9.1	1¼	7.6	S, 7.6–9.1	3	6
34F1	do	Dv	1966	9.3	1¼	7.8	S, 7.8–9.3	5	4
34G1	do	Dv	1966	9.1	1¼	7.6	S, 7.6–9.1	5	4
8N/10W-7A1	Formerly U.S. Army	Dr	1915	800	------	------	------------	------	------
8N/10W-9D1	Point Adams Cannery	Dr	1964	369	------	------	------------	------	------

Clatsop Plains sand-dune area

Type of pump: C, centrifugal; J, jet; ---, none; hp, horsepower.
Well performance: Yield in gallons per minute, and drawdown in feet below nondischarging water level. All U.S. Geological Survey test and observation wells were pumped, and unless indicated by M (measured), yield and drawdown figures are estimated. Yields of other wells were reported by others.
Use: O, observation; T, test well; D, domestic; PS, public supply; N, none.
Remarks: Ca, chemical analysis of water in table 7; H, hydrograph included in this report; L, lithologic log of well in table 2.

Water-bearing zone(s)—Con.	Altitude (ft)	Water level		Type of pump and hp	Well performance		Use	Remarks
Character of material		Feet below datum	Date		Yield (gpm)	Drawdown (ft)		
Sand	11.3	3.07	8-12-66	---	10	---	O	Ca.
do	13.8	6	8-12-66	---	4	---	O	Ca.
do	17.9	9.18	8-12-66	---	12	---	O	Ca., H.
do	30	20	1-30-67	---	---	---	N	May have been drilled 74 ft into shale.
do	8.9	4.68	8-12-66	---	8	---	O	Ca.
do	24.9	14.31	8-12-66	---	8	---	O	Ca.
do	13.8	8.89	9-2-66	---	5	---	O	Ca.
do	17.5	6.05	8-4-66	---	4	---	O	Ca.
do	36.8	16.70	8-3-66	---	5	---	O	Ca, H.
do	20.2	4.73	8-4-66	---	20	---	O	Ca.
do	17.9	5.01	8-4-66	---	18	---	O	Ca.
do	19.5	6.11	8-5-66	---	10	---	O	Ca.
do	22.9	5.60	8-12-66	---	25	---	O	Ca.
do	31.43	11.99	8-5-66	---	5	---	O	Ca, H.
do	12.34	3.40	8-5-66	---	5	---	O	Ca.
do	12.52	3.39	8-10-66	---	5	---	O	Ca, H.
do	23.65	4.86	8-31-66	---	15	---	O	Ca.
Sand	20.16	4.25	8-10-66	---	18	---	O	Ca.
do	20	2	---	C, 5	40	---	PS	Four wells equipped with well points connected to one pump; Ca.
do	20	2	---	C, 5	85	---	PS	Do.
do	20	2	---	C, 5	---	---	PS	Eight wells equipped with well points connected to one pump. Not connected to water system at present. Designed to pump 400 gpm.
do	22	8	12-22-62	J, ½	25	21	D	L.
do	15.37	2.64	8-10-66	---	8	---	O	Ca.
do	18.82	4.60	8-10-66	---	8	---	O	Ca, H.
do	29.60	14.40	8-10-66	---	10	---	O	Ca, H.
do	19.67	10.82	8-11-66	---	15	---	O	Ca.
do	44.58	9.57	8-11-66	---	2	---	O	In perched-water zone; Ca, H.
do	46.27	32.01	5-23-67	---	50M	11.77	T	See table 5 for results of pumping tests; L, Ca, H.
do	46.76	32.83	5-23-67	---	---	---	O	Observation well for pump test.
do	11.55	3.69	8-10-66	---	10	---	O	Ca.
do	17.45	4.75	8-10-66	---	8	---	O	Ca.
do	17.23	4.86	8-10-66	---	5	---	O	Ca.
---	23	---	---	---	---	---	N	Abandoned; not found in field; location tentative; L.
---	10	---	---	---	---	---	N	Abandoned; reported saline water at 362-369-foot depth; L.

TABLE 8.—*Records of wells in the*

Well	Owner or driller	Type of well	Year completed	Depth of well (ft)	Diameter of well (in.)	Depth of casing (ft)	Finish	Water-bearing zone(s)	
								Depth to top (ft)	Thickness (ft)
8N/10W-9K1	Spokane Portland & Seattle Railway Co.	Dr	--------	1538	------	------	------------	------	------
17D1	U.S. Geological Survey	Dv	1966	16.5	1¼	15	S, 15-16.5	10	7
18F1	do	Dv	1966	10.2	1¼	8.7	S, 8.7-10.2	7	3
18G1	do	Dv	1966	17.3	1¼	15.8	S, 15.8-17.3	14	3
20B1	do	Dv	1966	9.9	1¼	8.4	S, 8.4-9.9	5	5
20M1	do	Dr	1967	160	6	105	S, 105-120	10	150
20M2	do	Dv	1967	19	1¼	18.5	S, 18.5-19	10	9
20M3	do	Dv	1967	15	1¼	14.5	S, 14.5-15	9	6
20M4	do	Dv	1967	16.9	1¼	15.4	S, 15.4-16.9	10	7
20M5	do	Dv	1967	15.9	1¼	14.4	S, 14.4-15.9	9	7
20N1	do	Dv	1966	10.5	1¼	9	S, 9-10.5	5	11
20R1	do	Dv	1966	10.3	1¼	8.8	S, 8.8-10.3	6	4
21P1	do	Dv	1966	10.1	1¼	8.6	S, 8.6-10.1	3	7
29M1	do	Dv	1966	9.7	1¼	8.2	S, 8.2-9.7	5	5
32G1	do	Dv	1966	8.3	1¼	6.8	S, 6.8-8.3	3	5
8N/10W-33R1	U.S. Geological Survey	Dv	1966	16.9	1¼	15.4	S, 15.4-16.9	4	13
33N1	do	Dr	1967	135	6	73	S, 73-88	14	88
33N2	do	Dv	1967	18	1¼	16.5	S, 16.5-18	13	5

Clatsop Plains sand-dune area—Continued

Water-bearing zone(s)—Con.	Alti-tude (ft)	Water level		Type of pump and hp	Well performance		Use	Remarks
Character of material		Feet below datum	Date		Yield (gpm)	Draw-down (ft)		
------------	10	-------	---------	----------	--------	--------	N	Abandoned; not found in field; location tentative; reported saline water at 494–496-foot depth; L.
Sand-------	22.33	10.12	7-29-66	----------	5	--------	O	Ca.
-----do------	15.20	6.69	7-29-66	----------	10	--------	O	Ca.
-----do------	27.29	13.61	8-2-66	----------	8	--------	O	Ca, H.
-----do------	23.74	5.10	8-2-66	----------	15	--------	O	Ca.
-----do------	25	10.59	8-9-67	----------	98M	32.63	T	See table 5 for results of pumping tests; Ca, L.
-----do------	25	10.45	8-9-67	----------	20M	--------	O	Observation well for pump test.
-----do------	23	9.03	8-9-67	----------	20M	--------	O	Observation well for pump test.
-----do------	25	10.31	8-9-67	----------	15	--------	O	Observation well for pump test.
-----do------	23	8.71	8-9-67	----------	15	--------	O	Observation well for pump test.
-----do------	21.16	4.79	7-27-66	----------	20	--------	O	Ca, H.
-----do------	20.59	5.90	8-2-66	----------	5	--------	O	Ca.
-----do------	11.22	3.38	8-2-66	----------	5	--------	O	Ca, H.
-----do------	15.73	5.10	7-29-66	----------	20	--------	O	Ca, H.
-----do------	15.15	2.66	8-30-66	----------	15	--------	O	Ca.
Sand-------	10.5	3.82	8-3-66	----------	8	--------	O	Ca.
-----do-----	34.63	14.54	5-26-67	----------	70M	28.26	T	See table 5 for results of pumping test; L, Ca, H.
-----do-----	32.79	13.06	5-26-67	----------	10M	--------	O	Observation well for pump test.

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