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GEOLOGICAL SURVEY

# HYDROLOGY OF THE DUNES AREA NORTH OF COOS BAY, OREGON

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Prepared in cooperation with
COOS BAY-NORTH BEND WATER BOARD

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CONTENTS

CONTENTS

## ILLUSTRATIONS

[Plates are in pocket]

Page

## TABLES

# HYDROLOGY OF THE DUNES AREA NORTH OF COOS BAY, OREGON

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By J. H. Robison

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## ABSTRACT

Hydrology of a 20-square-mile area of dunes along the central Oregon coast was studied. The area is underlain by 80 to 150 feet of Quaternary dune and marine sand which overlies Tertiary marine clay and shale. Ground water for industrial and municipal use is being withdrawn at a rate of 4 million gallons per day. Original plans to withdraw as much as 30 million gallons per day are evidently limited by the prospect of excessive lowering of levels in shallow lakes near the wells, and possibly sea-water intrusion, if water-level gradients are reversed.

At the present stage of development there are 18 production wells, each capable of producing 200-300 gallons per minute from the lower part of the sand deposits. Except for thin layers of silt, clay, and organic matter, the deposits of sand are clean and uniform; horizontal permeability is two orders of magnitude times the vertical permeability. Because of the low vertical permeability, drawdown cones are not evident in the upper part of the aquifer adjacent to the wells. However, present pumping lowers general water levels in the lakes and the shallow ground-water zone as much as several feet.

A two-layer electric analog model was built to analyze effects of present and projected development as well as any alternate plans. Model results were used to develop curves for short-term prediction of water levels.

## INTRODUCTION

### Location and Extent of Area

The study area is a coastal strip 10 miles long and 1 to 3 miles wide between Coos Bay and Tenmile Creek, Coos County, in southwestern Oregon (fig. 1). This strip is underlain by dune sand and is part of a discontinuous dune area (50 square miles) recently established as the Oregon Dunes National Recreation Area, mostly from national forest lands.

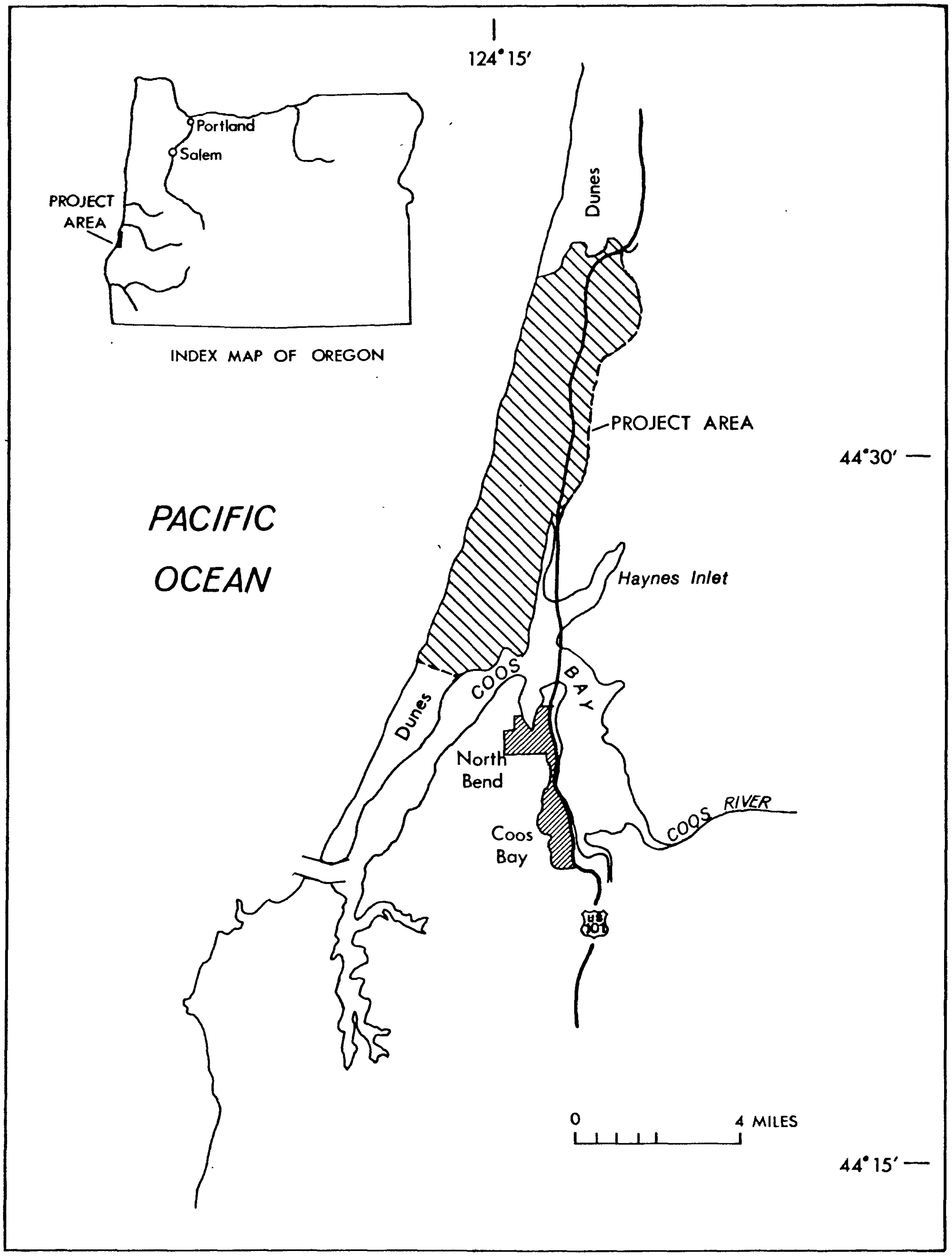


Figure 1. — Location of project area.

The study area is adjacent to the twin cities of Coos Bay and North Bend, which have a combined population of about 23,000. Total urban population is 35,000.

## Previous Investigations

Beginning in June 1954, a reconnaissance study of the occurrence of ground water in the sand-dune area was made by Brown and Newcomb (1963). In 1954 Pacific Power & Light Co. (P. P. & L.) began an extensive effort to locate, test, and develop water resources of the Coos Bay area for an industrial water supply. Because test wells drilled near Coos Bay and North Bend were unsuccessful, attention was directed to the dune area to the north.

A substantial amount of geological and hydrological information was obtained by P. P. & L. over a period of years, starting in the 1950's. Included were data from test drilling and pumping tests and from measurements of lake levels and water levels in wells. Three pilot production wells, now known as wells 47, 48, and 49 (tables 4, 5), were completed in 1957. The present investigation depended heavily on information obtained by P. P. & L., particularly the historical water-level measurements.

## History of Water Development

The first planned large-scale ground-water withdrawal was in 1957, when the pilot production wells of P. P. & L. were drilled and tested. P. P. & L. designed a plan for a well field, based on their test program and analysis, which provided for the gradual but complete development of ground water from the dunes, to be scheduled as the demand for water increased. Sixty-four well sites (pl. 1) were proposed, from which 30 mgd (million gallons per day) of water would be pumped.

In 1960, the Menasha Corporation built a pulpmill for the manufacture of paperboard near Jordan Cove. Wells 50, 51, and 52 were drilled by P. P. & L. in 1961, and were used with wells 47, 48, and 49 to supply 2 mgd of untreated water on an around-the-clock basis.

In 1968, P. P. & L. sold the well system and relinquished its interests in water supply and development to the Coos Bay-North Bend Water Board, which assumed operation of the well field and continued the original plan for development. Twelve more production wells (wells 41-46 and 53-58) were drilled in 1968, and wells 53-58 were put into production immediately. The pumps are operated automatically to maintain constant pressure during fluctuations in demand by the pulpmill; the system operates virtually without surface storage and has emergency storage for only several hours' use. Ordinarily, six wells will supply about 2 mgd, or 1,400 gpm (gallons per minute).

In the fall of 1970, wells 41-46 were made operational, and they presently supply the pulpmill, three wells at a time usually being adequate. A water-treatment plant was built by the Water Board on the east side of North Slough. This plant treats water from the east well field (wells 47-58), which is used to supplement the existing municipal supply for the Coos Bay-North Bend system.

## Need for Present Study

Recent and expected future increases in water demand in the Coos Bay area indicate that development plans for the dunes will have to be fully implemented in only a few years. The general objective of the Water Board is to develop optimum water yield from the dunes area consistent with hydrologic and economic considerations and in a manner compatible with recreational, esthetic, and other uses of the area.

To achieve its general objective, the Water Board has more specific objectives, as follows:

1. To minimize any adverse effects pumping may have on lakes or lake levels.

2. To prevent intrusion of saline water into the aquifers.

3. To minimize dissolved iron in water produced from the area so as to reduce treatment costs. Iron concentration varies among wells, and is high in most.

4. To take advantage of the most economical patterns for pumping at various rates, taking into account such factors as varying electric rates and rate structures. (Two utility companies serve the area.)

5. To prevent possible contamination of ground-water supply by seepage from a pond containing pulp-liquor wastes (secs. 6 and 7, T. 25 S., R. 13 W.).

6. To determine the extent to which any secondary benefits might be achieved from pumping water, such as draining desired areas or stabilizing lake levels.

Dr. John F. Mann, Jr., ground-water consultant retained in 1968 by the Water Board, recommended a quantitative evaluation of effects of pumping and proposed development, particularly regarding the possible lowering of lake levels. Evaluation of data from the well field would allow more precise determination of the ultimate yield of the area and of the probable extent of any adverse effects of pumping.

The objective of this study is to provide information for understanding the hydrologic system of the area and to interpret cause-effect relationships to help the Water Board achieve its objectives. One of the most important goals of this study is to determine quantitatively the water-level declines resulting from various patterns of pumping and to isolate those effects from natural causes.

## Investigational Methods and Approach

A substantial part of the information used in this study had already been collected by the Water Board and P. P. & L., but additional data were needed. Because no evaporation stations were in operation in this part of the State, the Water Board began maintaining an evaporation pan. The board resurveyed some reference-point elevations and began monitoring the water levels of Bluebill, Spirit, and Snag Lakes; levels of Clear, Saunders, Butterfield, Beale, and Horsfall Lakes were already being measured, as were the levels in many observation wells.

The Geological Survey analyzed quality of water, drilled additional test holes, and made various hydraulic tests. Graphs of typical aquifer tests are included in the appendix.

Lakebeds were examined at low stages to ascertain the hydraulic connection between the lakes and the underlying sand. Cores were obtained to determine permeability beneath Bluebill and Sandpoint Lakes and part of Horsfall Lake. Spirit Lake went dry in the fall of 1970; when well water was discharged directly into the lake, the hydraulic connection with underlying sand was noted by observing the rate of change of lake volume and comparing it with the well discharge.

Simple, steady-state electric analog models of conductive paper helped to develop and verify concepts of the hydrology. The Geological Survey, under the direction of E. P. Patten, Jr., constructed a two-layer, dynamic-state electric analog model using resistors and capacitors. The model design was based on maps similar to those shown on plate 2, which shows the distribution of transmissivity in the aquifers. Model design and calibration were tested by simulation of past or existing field conditions, as indicated by lake and ground-water levels.

## Acknowledgments

Special acknowledgment for advice and assistance is given to Mr. C. W. Heckard, manager of the Coos Bay-North Bend Water Board, and his staff, and to Dr. John F. Mann, Jr., ground-water consultant to the Water Board. The U.S. Forest Service extended permission and cooperation for the test drilling and other studies within national forest lands. Permission for testing on private land was given by the Spirit Lake Gun Club.

# GEOGRAPHY

The beach bordering the Pacific Ocean is sandy and nearly straight. Adjacent and parallel to the beach is a narrow ridge, 15 to 40 feet above sea level, which is a foredune produced by offshore winds. Locally it has sometimes been called "the sea wall." The foredune is partly covered by grass along the top and lee side.

East of the foredune is a plain a quarter to half a mile wide that is essentially continuous for the length of the area. Generally it is 5 to 10 feet above sea level; in places it is hummocky. Cooper (1958,

p. 56) considered the plain to be formed by wind erosion and called it a deflation plain (fig. 2). The deflation plain is covered by various types of grass, shrubs, low brush, and a few pine trees. Local observers say that vegetation has changed in types and expanded considerably in the past 50 years. Marram grass, imported by man (Cooper, p. 23), has stabilized the foredune ridge, and driftwood thrown up by storm waves has armored the ridge and allowed it to build up. Thus, the ocean now rarely breaches the ridge during storms.

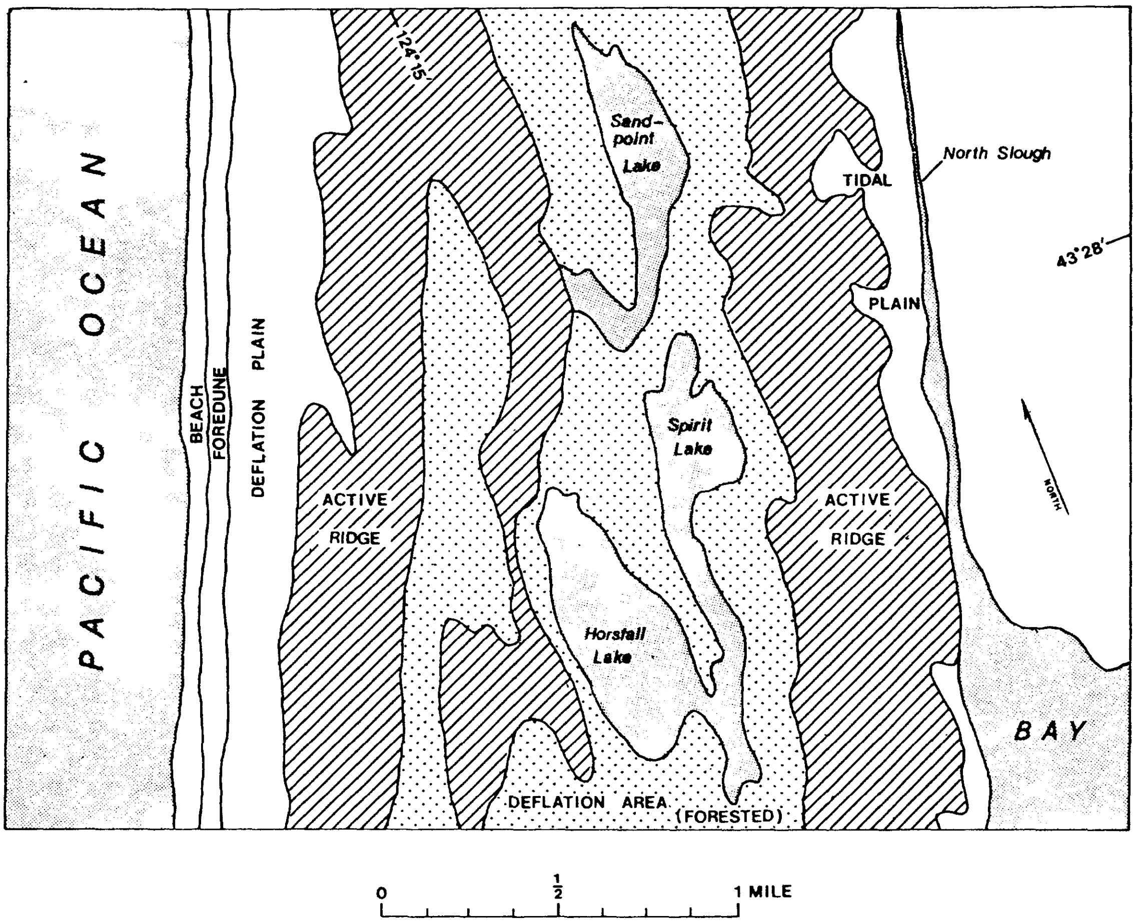


Figure 2. — Geomorphic subdivisions of part of the dunes.

East of the deflation plain is an irregular active ridge, composed of smaller ridges, which rises more than a hundred feet above sea level in places. The ridge is loose sand, has no vegetation, and is subject to shifting by winds.

East of the active ridge is a forested deflation plain (Cooper, p. 56) of irregular shape and as much as a mile wide. On the deflation plain the sand has been stabilized by a dense growth of shrubs and trees that include fir and pine. Typically, the plain lies 15 to 30 feet above sea level, and it includes Bluebill, Horsfall, Spirit, Sandpoint, Snag, and Beale Lakes. The lakes usually cover 6 to 8 percent of the project area, but at times they may cover more than 30 percent, because their area varies considerably with the seasons. There is surface outflow from the lakes only when they are at their highest levels.

Along the east side of the dunes, from Hauser south, is another active ridge of sand a quarter to half a mile wide and more than a hundred feet high.

Coos Bay, Haynes Inlet, and North Slough bound part of the east side of the project area. Salinity and tidal effects occur inland as far as the vicinity of Hauser on North Slough. North of Hauser the Southern Pacific Railway marks the approximate eastern limit of sand dunes; east of the railway, older consolidated formations underlie hills that rise abruptly to the edge of the drainage area.

Tenmile Creek, which lies along the north boundary of the project area, has an average discharge of about 320 cfs (cubic feet per second). Saunders Creek, between Clear Lake and Tenmile Creek, probably averages less than 3 cfs at the mouth. There are no perennial streams within the dune area, but during winter, when lake and ground-water levels are highest, considerable overland flow sometimes occurs in broad, undefined channels. The general direction and courses of this overland flow are shown on plate 2.

By far the greatest use of the area is recreational. A U.S. Forest Service campground near Bluebill Lake was completed recently, and there are day-use facilities at Horsfall Beach. There are some homes concentrated near U.S. Highway 101 between Hauser and Clear Lake, and also in the vicinity of Tenmile Creek. The only agriculture consists of 20 acres of cranberries in secs. 10 and 15, T. 24 S., R. 13 W.

## GEOLOGY

The oldest rocks exposed in the area are siltstones, mudstones, and sandstones deposited in a shallow marine environment. The rocks, which are shown as "older marine deposits" on plate 1, include the Coaledo Formation of late Eocene age (Baldwin, 1961). These deposits occur in the subsurface beneath the dunes and are exposed east of North Slough. They dip westward $15^{\circ}$ to $30^{\circ}$ in most places.

The Coaledo Formation may be overlain by the Bastendorff Shale beneath the dune area. Deeper wells within the dunes bottom in clay or shale, which is typical of the Bastendorff. (See table 15 in appendix for log of hole 200-C, 24S/13W-10cab3. Figure 21 in appendix shows well-numbering system.) The Bastendorff is of late Eocene and early Oligocene age and is exposed outside the project area, near the beach about 1 mile south of the mouth of Coos Bay, where it conformably overlies the Coaledo Formation (Allen and Baldwin, 1944).

The older marine deposits have relatively low permeability, although many wells tapping them provide enough water for household supplies. However, well yields sufficient for municipal or industrial supplies cannot be obtained from the deposits.

Marine deposits, probably of late Pleistocene age, are exposed in the Hauser area. They are littoral or strandline marine and terrace deposits of sand and silt. Most of the deposits lie below 120 feet altitude, but some exposures to the north are several hundred feet above sea level. The deposits are slightly compacted and cemented, and permeability is relatively low, but wells developed in them are usually adequate for domestic use.

During latest Pleistocene time, possibly in the period 25 to 30 thousand years ago, the sea cut a terrace in the Tertiary rocks at an altitude of 80 to 90 feet below present sea level. That bench is exemplified and preserved in the subsurface topography of the older marine deposits in the Sandpoint Lake area.

During the erosion of the 80- to 90-foot bench, the channel of the Coos River was near the center of Coos Bay (east of North Bend; see index map), but it continued northwestward beneath Horsfall Lake and then turned westward, 8 miles north of the present mouth. About 15,000 years ago, sea level was as much as 400 feet below present level (Milliman and Emery, 1968). The channel carved by the river at that time probably began filling with marine sand about 10,000 years ago, when sea level rose to 180 feet below its present level. This marine sand is not shown on the geologic map of plate 1 because it is not exposed, but it is indicated on the geologic sections on plate 1. The deposits are mostly well-sorted, fine to coarse sand, with a few thin layers of silt, clay, and organic material.

Until 5,000 to 7,000 years ago, sea level rose rapidly to 15 or 20 feet below present level and then continued to rise more slowly. During this period of slow rise the climate was drier and the sediment load in the rivers was less. Onshore winds, then able to keep pace with deposition, reworked the marine sands into dunes. The wind continues to rework dunes that have not been stabilized by vegetation.

## HYDROLOGY

### General

Precipitation on the dunes is the major source of ground water in the Coos Bay dunes aquifer system. Some of the precipitation within the drainage area (pl. 1) is almost immediately returned to the atmosphere by evaporation. In areas underlain by rocks of low permeability, a small amount of precipitation is collected by small streams and runs off into the sea or bay. The remainder of the precipitation falls into the lakes or infiltrates the sand and recharges the water table. Some water is evaporated from the lakes and wet sand areas, and some is transpired by plants living in water (hydrophytes) or whose roots obtain water from the ground-water reservoir (phreatophytes). The lakes are surface expressions of the water table and are continuous with the aquifers that underlie the lakes.

Water in the saturated zone is constantly moving through the permeable formations, and most of it eventually seeps into the ocean and bay (fig. 3). The dynamic action of infiltration, movement, and discharge maintains fresh water throughout the aquifer beneath the land. Because the system is dynamic and the aquifers are not deep enough, the Ghyben-Herzberg concept1/ does not appear to be applicable to the onshore parts of the Coos Bay dunes area.

## Modeling the Hydrology

An analog model can be used to simulate effects caused by changes in the real system, thus avoiding the time, expense, and possible adverse effects that might occur from experimenting with the real system. For these reasons, modeling was chosen to estimate and predict the effects of ground-water development.

An analog model simulates a hydrologic system quantitatively and is based on the principle of conservation of mass in the hydrologic cycle, where:

> Precipitation + stream inflow + ground-water inflow = stream outflow + ground-water outflow + evaporation and transpiration loss ± change in ground- and surface-water storage.

Each element in the equation that is known or can be estimated with reasonable precision improves the accuracy of any unknown elements that are calculated. Successful modeling depends on measurement or determination of as many of these elements as possible. Topics and degree of

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1/ The Ghyben-Herzberg concept (Todd, 1964, p. 13-48) assumes that in aquifers open to the ocean, fresh water floats on saline water because of the difference in specific gravity. The relation of the altitude of the water table (t) to the depth of the fresh-water zone below sea level (h) is

$$h = \frac{t}{g_{sw} - g_{fw}}$$

where $g_{sw}$ is the specific gravity of the saline water and $g_{fw}$ is the specific gravity of the fresh water. If the saline water is similar in density to sea water ($g_{sw}$ = 1.025), h is equal to about 40t.

The level of Spirit Lake is about 20 feet above sea level; the base of the aquifer would have to be at least 800 feet below sea level to allow flotation of the fresh water. The Ghyben-Herzberg concept would apply only if recharge were so low as to maintain the water table to no more than 1 or 2 feet above sea level.

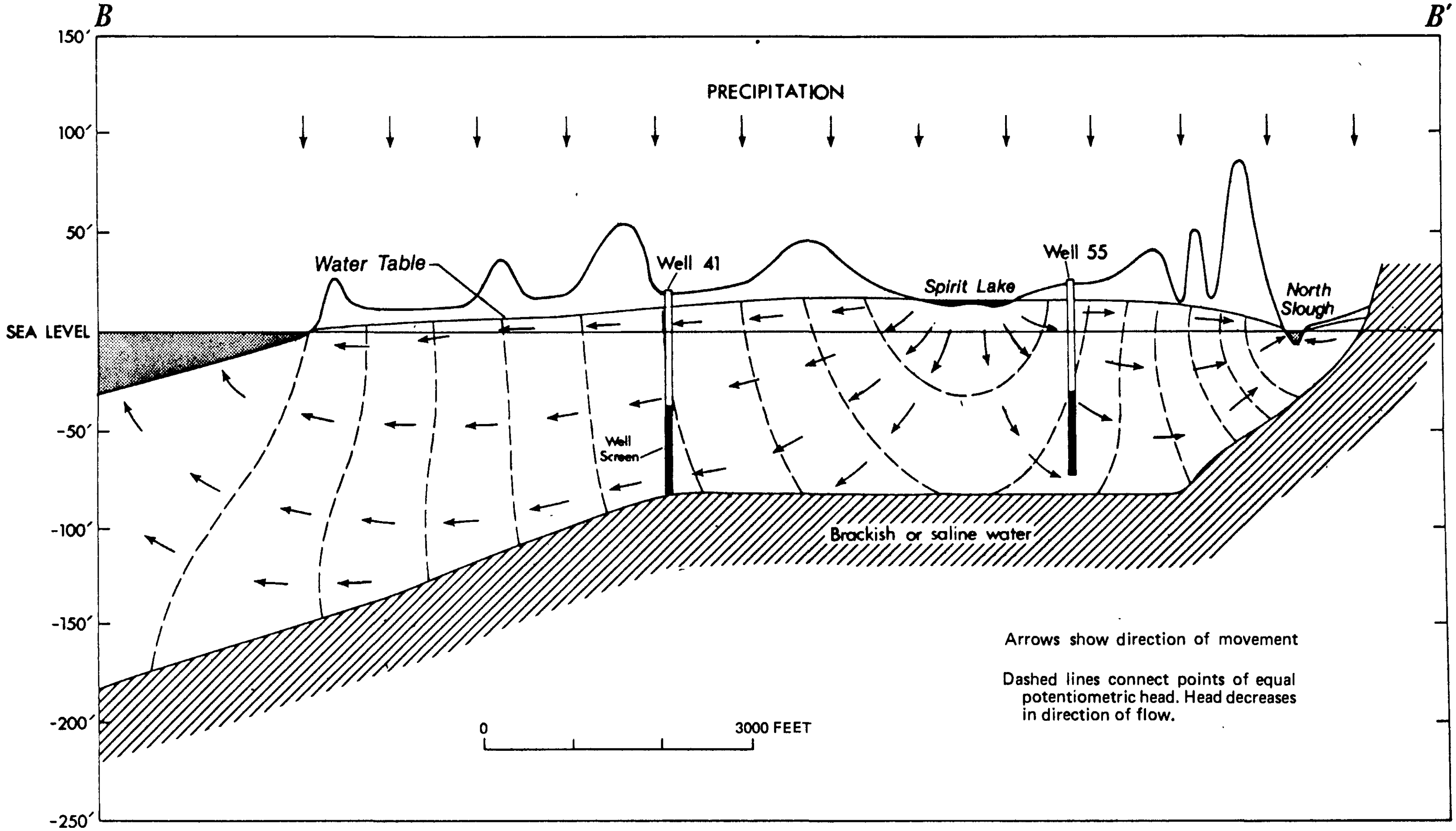


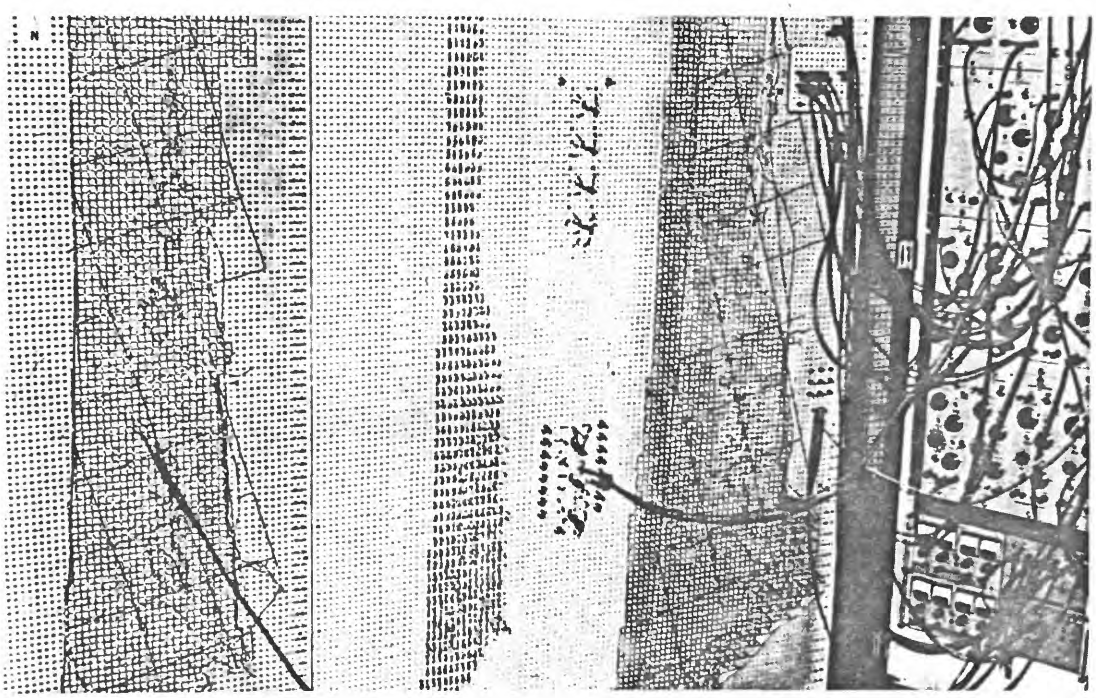

Figure 3. – Cross section through Spirit Lake, showing inferred movement of water.

detail in discussions of the hydrology on the following pages were dictated in part by the need for specific information for the construction of an electric analog model as well as for a better understanding of the system.

An electrical model is based on the similarity in behavior of electricity, which obeys Ohm's law, and of water in a porous medium, which obeys Darcy's law. Appropriate scale factors relate parameters of the model to the real system--volts to feet of hydraulic head and amperes to gallons per day. The electrical network has resistance (ohms) whose reciprocal (mhos) compares to transmissivity ($feet^2$ per day) and capacitance which is analogous to storage coefficient. (See glossary.) A scale factor also relates time in the electrical system (seconds, or fractions thereof) to that in the real system (days, months, or years).

Where feasible, project and model boundaries coincide with natural hydrologic boundaries, thus minimizing the need for measuring or estimating ground- or surface-water flow across arbitrary boundaries. Tenmile Creek on the north, the Pacific Ocean on the west, and Coos Bay-North Slough on the south and east are "constant-head" boundaries. North of Hauser the eastern boundary lies along the topographic divide, and the hydraulic head fluctuates in response to inflow or outflow from the system.

The upper boundary of the model is the water table. Hydraulic head at this boundary is controlled by net recharge, which was determined by subtracting evapotranspiration and runoff from precipitation. The base of the model is the surface of the older marine deposits, considered to be a "no-flow" boundary.



Electrical analog model.

## Climate

Climate of the study area is cool and moist--typical of the Oregon coast. Records of the National Weather Service show that at North Bend the average temperature is 45°F in January and 60°F in August; average annual temperature is 52°F. The maximum temperature that can be expected in a given year is about 84°F and the minimum is 25°F.

According to National Weather Service records, precipitation averages 62½ inches per year at the North Bend Airport (table 1); more than 80 percent occurs in the 6-month period of October through March (table 2).

Precipitation data obtained by P. P. & L. during the 1957 water year (October 1956 through September 1957) showed a slight increase northward--54.17 inches at North Bend, 56.99 inches at Saunders Lake, and 57.99 inches at Tenmile Lake, near the northeast boundary of the present study. A single value of precipitation was used to determine net recharge for modeling, however.

A class A evaporation pan was installed within the wire-fence enclosure at well 44, and personnel of the Water Board began operating the pan in June 1970. Previously, the closest evaporation station had been

Table 1.--Annual precipitation at North Bend FAA Airport

[Based on records of National Weather Service]

| Water year | Inches | Water year | Inches |
|---|---|---|---|
| 1945 | 58.53 | 1961 | 71.89 |
| 1946 | 68.23 | 1962 | 49.85 |
| 1947 | 59.60 | 1963 | 54.88 |
| 1948 | 72.73 | 1964 | 51.16 |
| 1949 | 47.80 | 1965 | 58.68 |
| 1950 | 64.38 | 1966 | 66.30 |
| 1951 | 68.18 | 1967 | 62.29 |
| 1952 | 56.33 | 1968 | 60.08 |
| 1953 | 65.17 | 1969 | 74.44 |
| 1954 | 69.98 | 1970 | 66.78 |
| | | 1971 | 72.17 |
| 1955 | 53.86 | 1961-71 average | 62.6 |
| 1956 | 77.52 | | |
| 1957 | 54.14 | | |
| 1958 | 67.99 | | |
| 1959 | 64.77 | 1945-71 average | 62.4 |
| 1960 | 47.88 | | |
| 1945-60 average | 62.3 | | |

Table 2.--Average monthly precipitation at North Bend FAA Airport, 1945-71

[Based on records of the National Weather Service]

| Month | Average (inches) | Cumulative average for water year (inches) |
|---|---|---|
| October | 5.27 | 5.27 |
| November | 9.18 | 14.45 |
| December | 10.14 | 24.59 |
| January | 11.25 | 35.84 |
| February | 7.69 | 43.53 |
| March | 7.62 | 51.15 |
| April | 4.10 | 55.25 |
| May | 2.64 | 57.89 |
| June | 1.49 | 59.38 |
| July | .42 | 59.80 |
| August | .75 | 60.55 |
| September | 1.85 | 62.40 |

near Astoria, at the northern tip of Oregon. Calculated evaporation from open-water surfaces near Coos Bay was 24 inches for the 1971 water year (table 3), which confirms an estimate by Brown and Newcomb (1963, p. D5).

Evapotranspiration in the study area was estimated using percentages of types of areas and the probable factors for relating evapotranspiration from each area type to that of open-water surfaces. The factors are based largely on empirical judgment of the author. During winter, open-water surface (1.0 factor) is about 20 percent of the total, vegetated area (0.5 factor) is 20 percent, and bare sand or soil (0.1 factor) is 60 percent. During summer, open-water surface is 5 percent (1.0 factor), vegetated area (0.6 factor) is 25 percent, and bare sand or soil (0.1 factor) is 70 percent. Evapotranspiration in winter is about one-third more than in summer because of the greater open-water surface during winter. Total evapotranspiration for 1971, probably a typical year, was 7 to 10 inches. The rates of precipitation and evapotranspiration are shown in figure 4, and estimated recharge is shown in

Table 3.--Evaporation and precipitation data

| Month | Precipitation (inches) | | | | | | | | Evaporation (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North Bend FAA Airport | | | | Well 44 | | | | Pan | | | | Lake[1/] (0.78 pan coefficient) | | | |
| | 1970 | 1971 | 1972 | 1973 | 1970 | 1971 | 1972 | 1973 | 1970 | 1971 | 1972 | 1973 | 1970 | 1971 | 1972 | 1973 |
| Jan.--------- | -- | 13.57 | 9.90 | 7.92 | -- | 10.47 | 9.36 | 6.89 | -- | -1.05 | -0.57 | -0.57 | -- | -0.82 | -0.44 | -0.44 |
| Feb.--------- | -- | 6.15 | 6.92 | 3.84 | -- | 5.79 | 6.50 | 1.96 | -- | 1.38 | -.02 | .92 | -- | 1.08 | -.02 | .72 |
| Mar.--------- | -- | 9.70 | 10.61 | 7.72 | -- | 8.31 | 7.81 | 5.34 | -- | 1.22 | -.27 | 2.22 | -- | .95 | -.21 | 1.73 |
| Apr.--------- | -- | 8.06 | 7.73 | 1.91 | -- | 6.83 | 6.22 | 2.26 | -- | 4.56 | 2.52 | 5.34 | -- | 3.56 | 1.97 | 4.17 |
| May---------- | -- | 1.84 | 1.13 | 1.65 | -- | 2.02 | 1.44 | 1.35 | -- | 3.77 | 3.61 | 4.68 | -- | 2.94 | 2.82 | 3.65 |
| June--------- | -- | 3.00 | .87 | 1.43 | -- | 2.71 | .96 | 1.26 | -- | 4.26 | 7.59 | 6.16 | -- | 3.32 | 5.92 | 4.80 |
| July--------- | 0.02 | .08 | .14 | T | 0.03 | .11 | .06 | .04 | 5.51 | 5.04 | 5.75 | 6.19 | 4.30 | 3.93 | 4.48 | 4.83 |
| Aug.--------- | .04 | 2.72 | 1.10 | .38 | .08 | 2.22 | 1.07 | .44 | 4.40 | 4.90 | 5.77 | 5.20 | 3.43 | 3.82 | 4.50 | 4.06 |
| Sept.-------- | 1.43 | 5.36 | 1.82 | 3.22 | 1.40 | 4.47 | 1.43 | 1.97 | 3.22 | 3.78 | 3.99 | 3.03 | 2.51 | 2.95 | 3.11 | 2.36 |
| Oct.--------- | 4.22 | 4.50 | 1.14 | -- | 3.27 | 4.21 | 1.10 | -- | 1.48 | 1.29 | 3.34 | 2.11 | 1.15 | 1.01 | 2.60 | -- |
| Nov.--------- | 8.10 | 9.50 | 5.85 | -- | 7.73 | 8.42 | 6.14 | -- | 2.73 | .40 | .94 | -- | 2.13 | .31 | .73 | -- |
| Dec.--------- | 11.98 | 15.00 | 11.91 | -- | 10.69 | 12.17 | 10.37 | -- | 1.78 | .94 | 1.92 | | 1.39 | .73 | 1.50 | -- |
| Total, calendar year | | 79.48 | 59.12 | | | 67.73 | 52.46 | | | 30.49 | 34.57 | | | 23.78 | 26.96 | |
| Total, water year | | 74.78 | 69.22 | 46.97 | | 64.62 | 59.65 | 39.12 | | 33.85 | 31.00 | 39.37 | | 26.40 | 24.18 | 30.71 |

1/ Kohler, Nordenson, and Baker (1959).

Reasons for some negative evaporation values not determined.

Evaporation pan

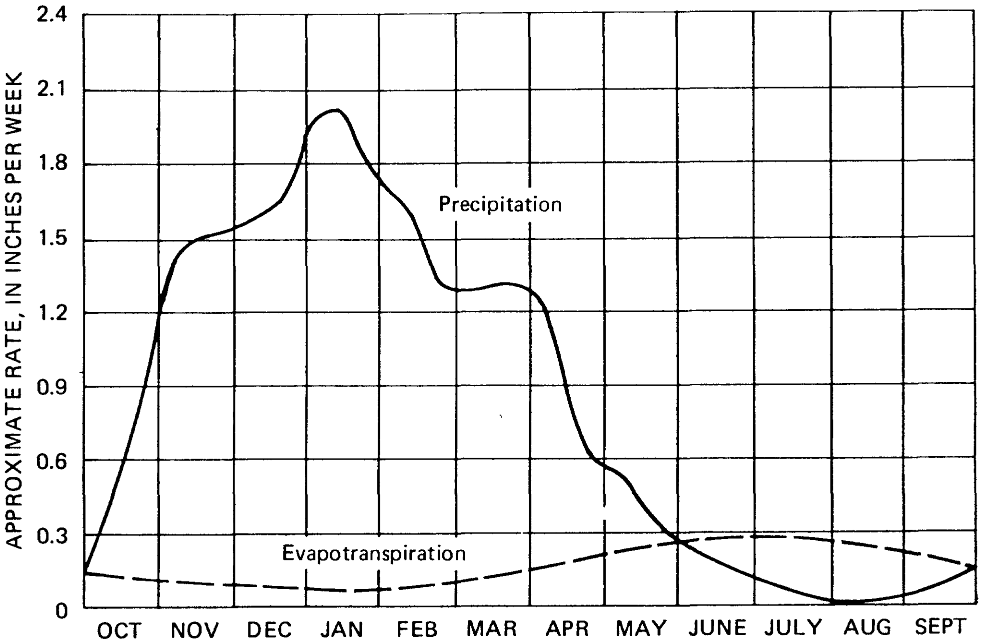



Figure 4. – Rate of precipitation and evapotranspiration.

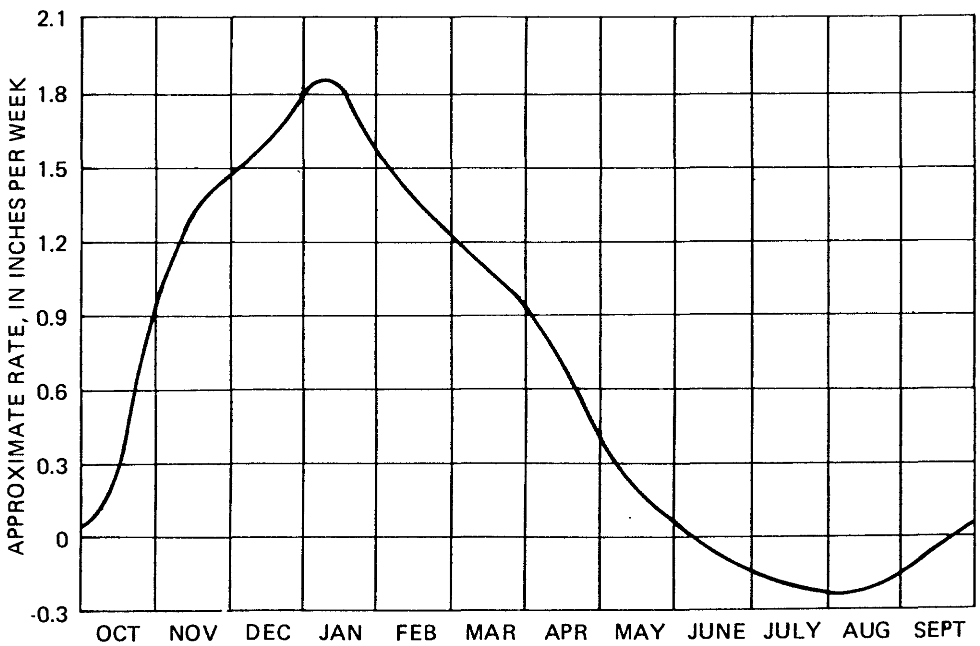



Figure 5. – Estimated rate of recharge, 1945-60, based on precipitation at North Bend FAA Airport minus average evapotranspiration and surface runoff of study area.

figure 5. When evapotranspiration exceeds precipitation, as it does during the summer, recharge is negative. In an unpublished report (1958) prepared for P. P. & L., A. C. Tester estimated evapotranspiration to be 8.7 inches per year.

Errors in estimating the above percentages and factors are not likely to result in differences of more than several inches, which could be less than local areal variations in precipitation. Areal differences in rate of evapotranspiration were not calculated; areal variations do not change the shape nor the level of the water locally to the extent that it is discernible in the existing observation network.

## Lakes and Lake Hydrographs

The major lakes, from north to south, are Clear, Saunders, Butterfield, Beale, Snag, Sandpoint, Spirit, Horsfall, and Bluebill.

Clear Lake is the deepest, having a maximum depth of about 38 feet in spring. On the map (pl. 1) it appears as four bodies of water, but the bodies are hydraulically joined. During periods of little or no precipitation, the lake stage declines at 1½ feet per month (fig. 6). At high stages the lake contributes water to Saunders Creek and is connected to Saunders Lake, but at low stages Clear Lake is as much as 2 feet lower than Saunders Lake.

Saunders has the highest lake level in the area and has a maximum depth of about 35 feet in spring. It has a natural recession rate of as much as 1 foot per month (fig. 6). At high stages, surface outflow is north to Clear Lake, and at maximum levels it may overflow to the west, also.

Butterfield Lake has a maximum seasonal depth of 33 feet. Overflow is south to Beale Lake. Butterfield (fig. 6), Saunders, and Clear Lakes are relatively steep sided; the area of each changes little as the stage changes. These lakes are underlain largely by indurated sand and silt shown as older marine deposits on the geologic map.

Beale Lake has a maximum seasonal depth of about 11 feet. Overflow is west, then south toward Snag Lake. The rate of natural decline during spring is 0.9 foot per month (fig. 6), slightly less than that of the lakes to the north. The bottom consists mostly of loose sand.

Few water-level data are available for Sandpoint Lake, but its maximum seasonal depth is about 10 feet. The bottom is underlain by dune sand.

Spirit and Horsfall Lakes are joined at high stages, and until 1971 only one water level was recorded for both lakes. Horsfall is 5 to 7 feet deep at maximum stage; Spirit is slightly shallower. Overflow is west and south, toward Bluebill Lake. The natural rate of recession is 0.8 foot per month (fig. 6), and seasonal range is about 3½ feet.

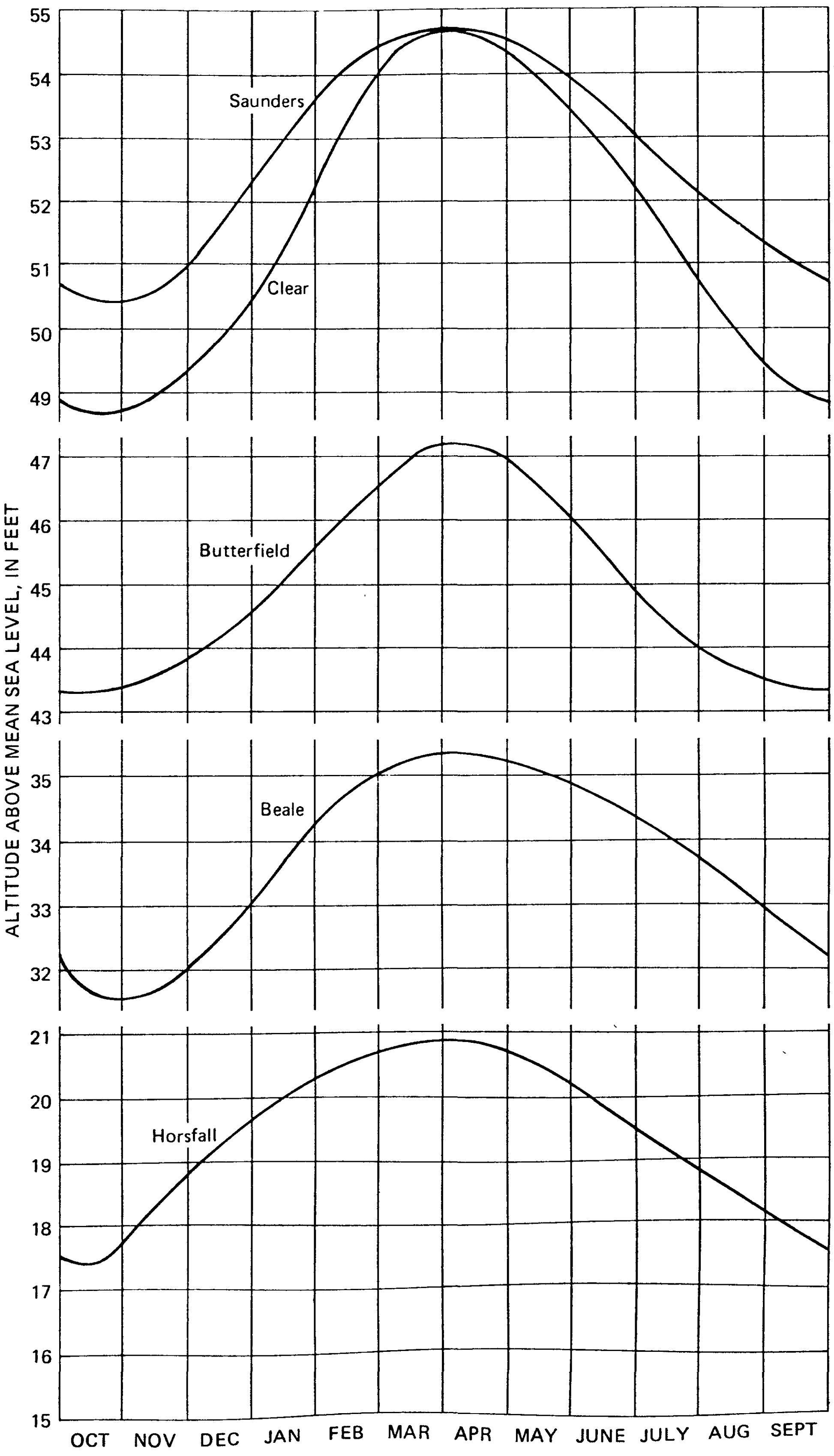



Figure 6. – Estimated average levels of Saunders, Clear, Butterfield, Beale, and Horsfall Lakes, 1945-60.

Until 1971 the levels of Bluebill and Snag Lakes had not been measured routinely. Bluebill is about 8 feet deep at maximum stage.

Under natural conditions, levels of all lakes appear to "recover" completely during fall and winter of most years, and levels show no residual effects from preceding seasons.

Figure 6 shows average levels of some of the lakes during a period prior to significant withdrawals of ground water. The graphs are based on levels actually recorded between 1945 and 1960; some were used in the process of model verification. Figures 7 and 8 show actual levels of Horsfall Lake after development began.

Precipitation and the level of Horsfall Lake are compared for 1959 (fig. 9), prior to development. The comparison is based on departures from averages for the base period 1945-60. As expected, lake level responds strongly to precipitation. Figure 10 shows a similar comparison for 1971, when 3.8 mgd was pumped from wells. General shape of the lake hydrograph was the same as before, but the average level was lower, relative to the precipitation curve, in 1971 than in 1959. The precipitation-departure curve was slightly negative for the first 3 months of the water year, connoting some carryover effect; in addition, the low lake level and its decline into November also suggest that pumping had a significant effect.

## Lake-Bottom Permeability

To determine effects of pumping on lake levels, it is important to know how freely water can move between the lakes and underlying aquifers. If the lake bottoms have significantly lower permeability than the underlying dune deposits, the model must be constructed to reflect these permeability differences. It was already believed there was a relatively free connection, because hydrographs for lakes and nearby observation wells (Brown and Newcomb, p. D12) did not show lags nor differences in water levels of more than several tenths of a foot at any time of the year. Direct evidence, however, would be helpful in confirming or refuting this preliminary conclusion; therefore, tests were made of materials underlying the lakes whose levels are most critical and potentially most affected by pumping. Details of these studies are included in the appendix.

Tests indicated the permeability of silty deposits in the lakes is low compared to that of the dune sand. However, the silty deposits are generally thin and may be absent; therefore, these deposits do not significantly hinder water movement. Half a foot of silt completely covering the bottom of a lake could cause a difference between water levels in the lake and in the dune sand of 0.1 or 0.2 foot, at the most, and this is no more than would be caused by an additional 3 or 4 feet of sand underlying the lake.

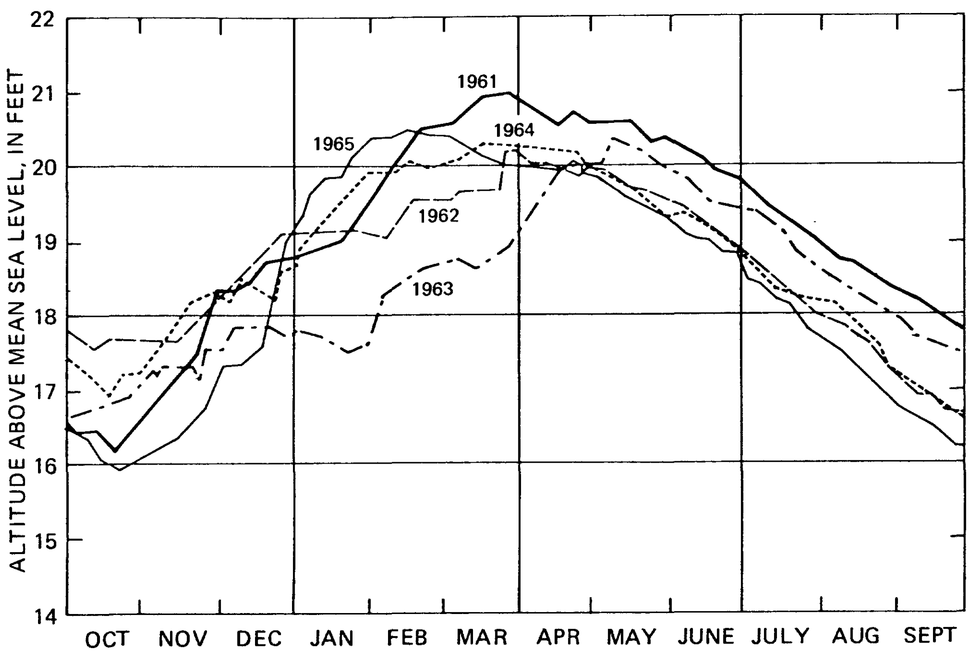



Figure 7. – Water level of Horsfall Lake, 1961-65.

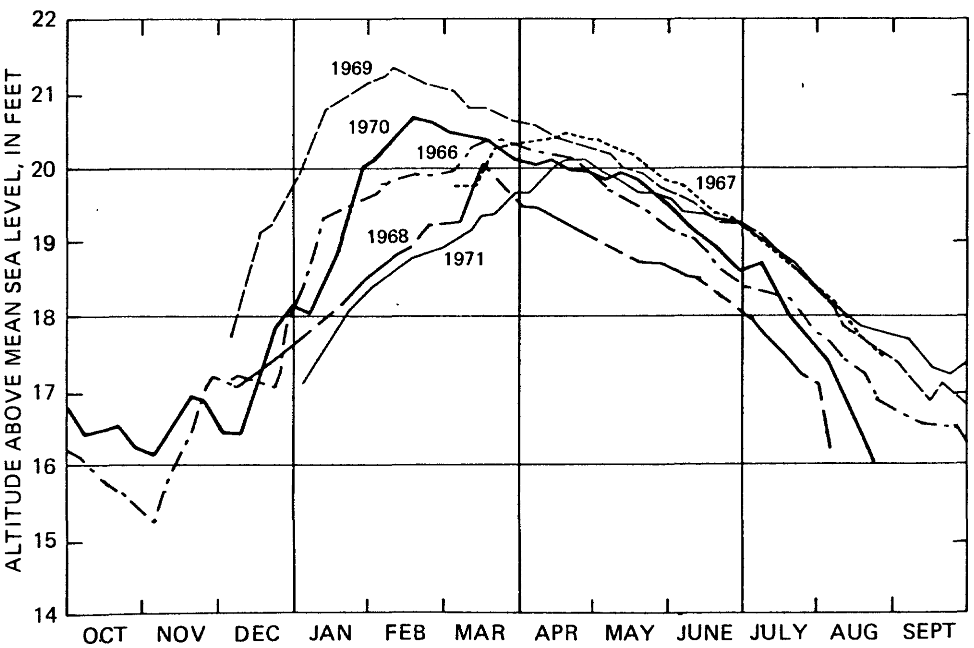



Figure 8. – Water level of Horsfall Lake, 1966-71.

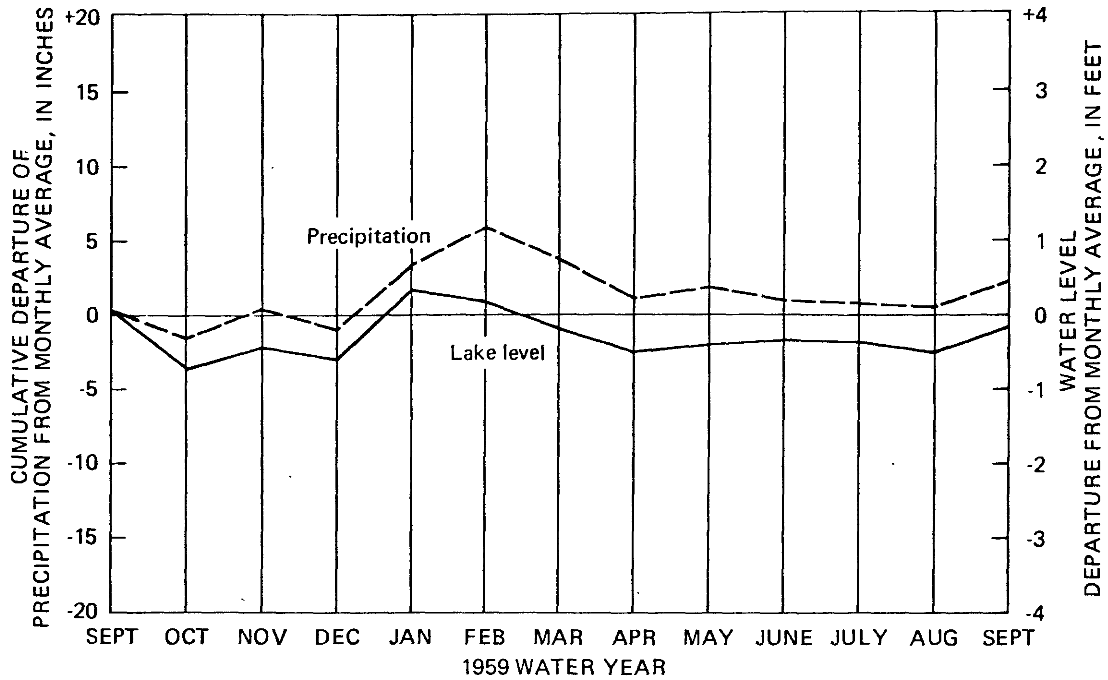



Figure 9. — Departures of average monthly precipitation at North Bend and level of Horsfall Lake, based on 1945-60 averages.

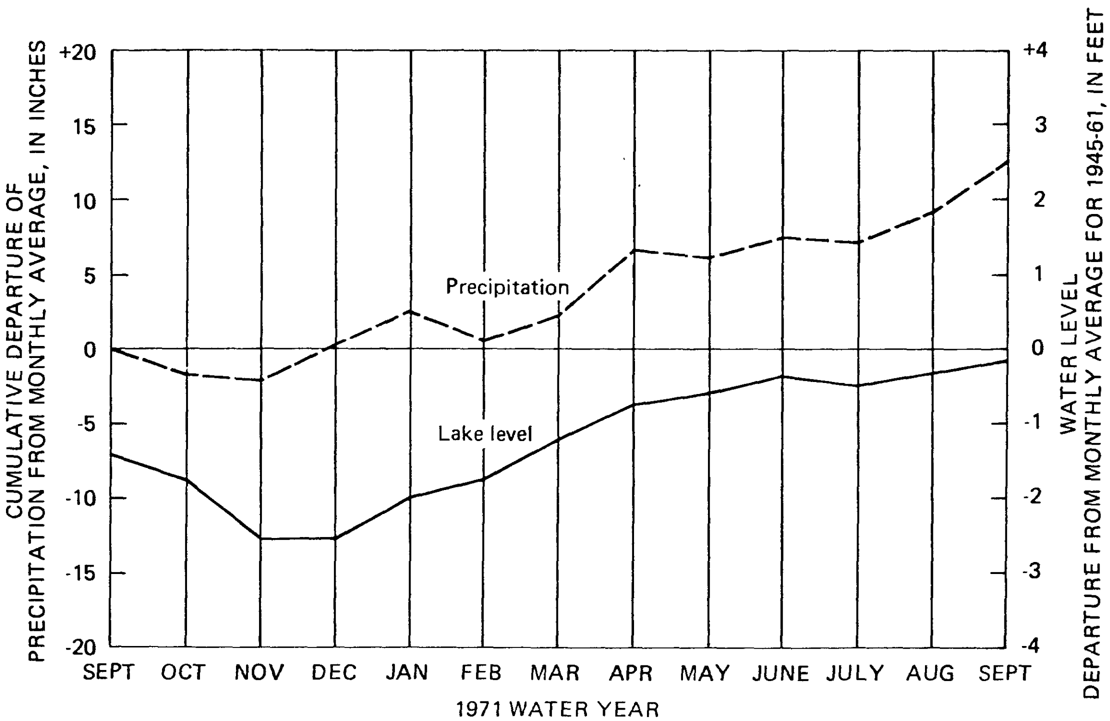



Figure 10. — Departures of average monthly precipitation at North Bend and level of Horsfall Lake, based on 1945-60 averages.

## Ground-Water Levels

Generalized water levels shown on plate 2 are average seasonal minimums. From Beale Lake north, the gradient is to the west at as much as 50 feet per mile. South of Beale Lake gradients are west to the ocean and east to North Slough, at 15 to 30 feet per mile. A ground-water divide trends south through Sandpoint, Spirit, and Horsfall Lakes.

Water-level fluctuations in shallow wells are similar to those in the lakes. Levels in the shallowest zones are always within several tenths of a foot of the levels in nearby lakes (Brown and Newcomb, p. D12).

Wells near the beach have a smaller seasonal range than those near the lakes, and some show a small response to tidal fluctuations (tidal range is about 7 feet); however, the response may not be systematic or predictable. A water-level recorder in one shallow well (SN-1) showed no response to daily tidal fluctuations, but showed longer term changes that apparently correspond to wind and sea-roughness conditions.

In most places where they have been measured, water levels in the deeper zones are lower than in the overlying zones. In a dynamic flow system there is a loss of head in the direction of flow, and the magnitude of the loss depends on the hydraulic conductivity of the porous material. Figure 3 shows the direction of flow and the distribution of head in a vertical section.

Because of thin layers of clay or silt and the preferred orientation of flat or platy minerals, hydraulic conductivity of the marine sand is much less in a vertical direction than it is in a horizontal direction. The head difference between piezometers 200-B (20 ft deep) and 200-C (80 ft deep) (fig. 11 and pl. 2, sec. 10, T. 24 S., R. 13 W.) is 7 feet, which yields a vertical gradient of 0.12. The hydraulic gradient in the horizontal direction is 30 feet per mile, or 0.006. The level in 200-B is lower than in Beale Lake because of both the vertical and the horizontal gradient; the well is about 200 feet west of the lake, so the vertical effect predominates. The level in 200-A is anomalous in that it is higher than in 200-C. Piezometer 200-A was completed in clay of the older marine deposits, and whether or not the hydraulic relationships of 200-A and 200-B is typical, low permeability precludes significant interchange of water in the clay with that in the aquifer.

Water levels of piezometers at SCP-4 (fig. 12) also show a decrease of head with increasing depth.

The pronounced vertical head gradients in the aquifer dictated that the model would have to take into account the vertical component of flow.

## Aquifer Coefficients

The aquifer system has no distinct or laterally continuous layers that are natural for modeling; it is essentially homogeneous, but anisotropic. A single-layer analog model of the production zone of the system would not be capable of simulating effects in the shallow zone of

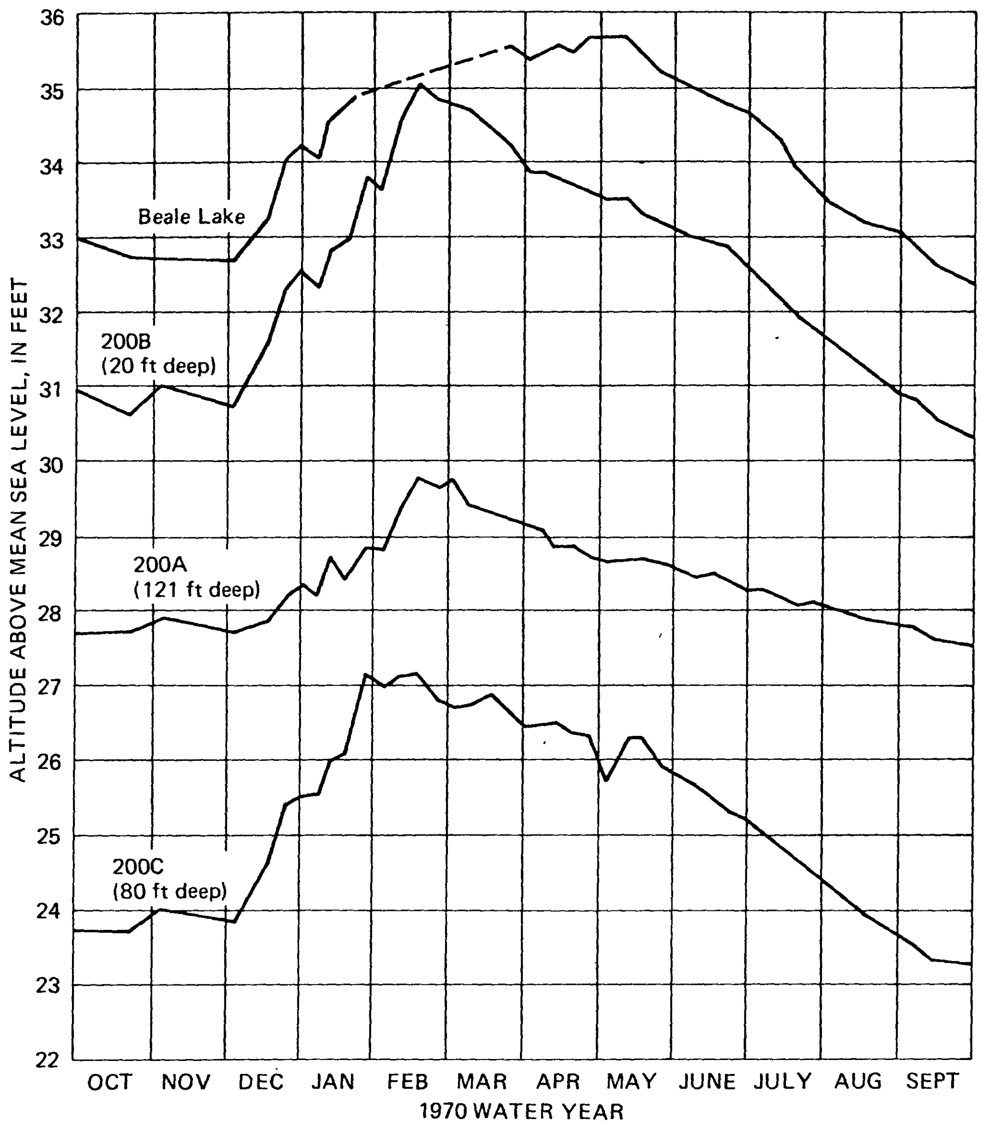



Figure 11. — Water levels in piezometer 200 and Beale Lake.

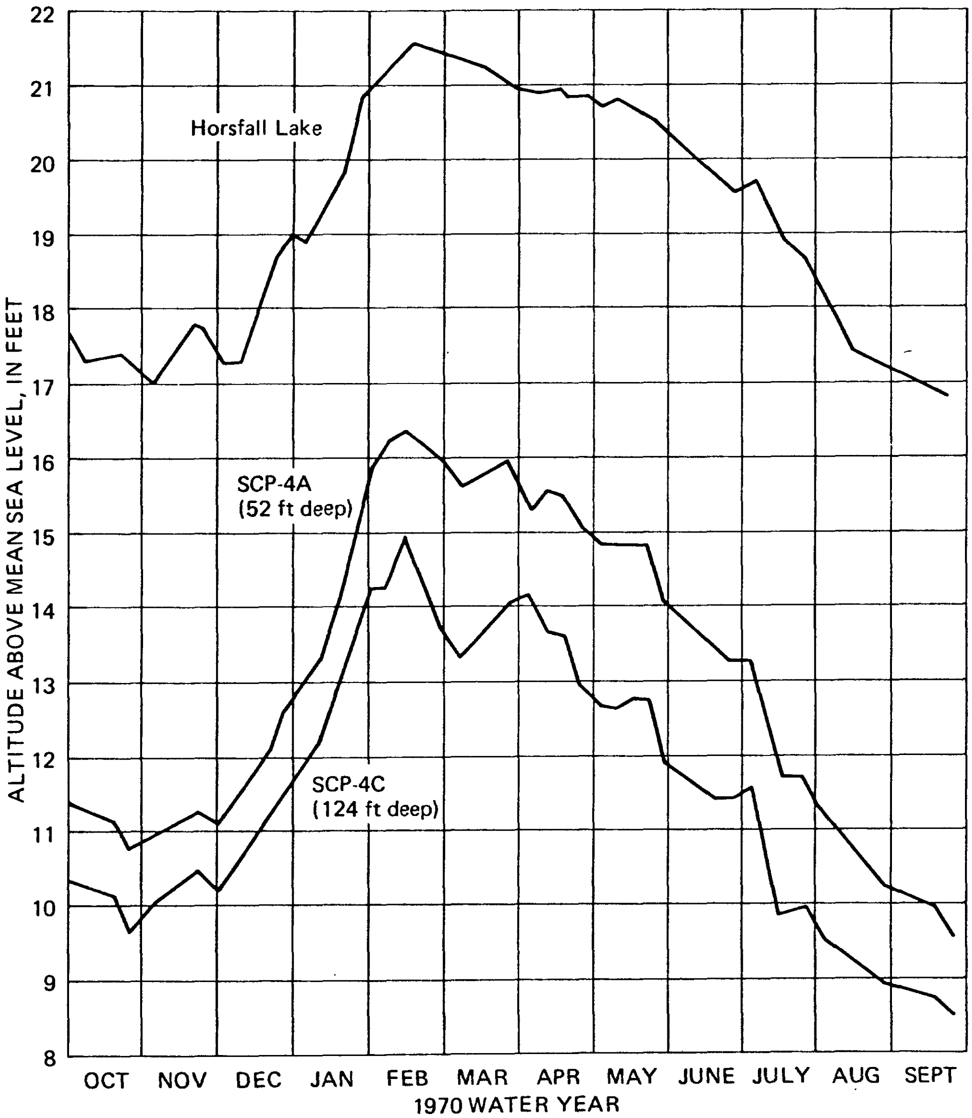



Figure 12. – Water levels in piezometer SCP-4 and Horsfall Lake.

which lakes are a part. A complete model of a homogeneous but anisotropic system would require an infinite number of layers. However, the objective is to determine what happens at the water table when water is pumped from an interval that may be considered as a single zone; two model layers are sufficient for that purpose if the aquifer coefficients are known, including the hydraulic connection between the layers.

Table 4 is a compilation of hydraulic tests and analyses to determine aquifer coefficients. Transmissivity tests at some sites were made or analyzed by several methods for comparison. The value believed to be most reliable in each case was used in making a map (pl. 2) which shows the distribution of transmissivity for the deeper or main aquifer. Transmissivity ranges from 5,000 to 17,400 $ft^2$ $day^{-1}$ and is approximately proportional to aquifer thickness. Use of seasonal water-level changes to calibrate the model showed that transmissivity is somewhat higher than was determined by the field tests.

Table 4.--Summary of aquifer tests of wells in the Coos Bay sand-dunes area

| Production well pumped or recovered | Well performance | | | Well used for data analysis | Transmissivity, in $ft^2$ $day^{-1}$ | | | | Vertical hydraulic conductivity ($ft$ $day^{-1}$) | Storage coefficient |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pumping rate (gpm) | Drawdown (ft) | Gpm/ft | | Recovery analysis | | Drawdown analysis | | | |
| | | | | | Semilog | Type curve | Semilog | Type curve | | |
| 41 | 485 | 20.9 | 23 | 41 | 5,600 | 5,900 | 6,400 | 5,100 | -- | -- |
| 43 | 340 | 11.0 | 31 | 43 | 10,000 | 8,000 | -- | -- | -- | -- |
| 43 | 340 | -- | -- | P-43 | -- | -- | -- | -- | -- | $2.3x10^{-4}$ |
| 44 | 482 | 14.5 | 33 | 44 | 17,400 | 9,800 | 16,400 | 9,900 | -- | -- |
| 44 | 482 | -- | -- | P-44 | -- | -- | -- | -- | -- | $1.4x10^{-4}$ |
| 44 | 482 | -- | -- | BB-1B | -- | -- | -- | -- | -- | $2.3x10^{-4}$ |
| 46 | 540 | 24.2 | 22 | 46 | 13,000 | 6,600 | 12,000 | 6,700 | -- | -- |
| 50 | 258 | -- | -- | P-50 | -- | -- | 6,200 | 6,200 | 2 | $7.7x10^{-5}$ |
| 52 | 200 | -- | -- | P-52 | 8,300 | 7,500 | -- | -- | .25 | $1.1x10^{-5}$ |
| 53 | 280 | 14.9 | 19 | 53 | 4,800 | 4,300 | 5,000 | 4,500 | -- | -- |
| 53 | 280 | -- | -- | P-54 | -- | -- | -- | -- | -- | $1.6x10^{-5}$ |
| 53 | 280 | -- | -- | SCP-11C | -- | -- | -- | -- | -- | $9x10^{-4}$ |
| 54 | 280 | 13.9 | 20 | 54 | 5,600 | 5,200 | 6,000 | 5,900 | -- | -- |
| 55 | 280 | 11.8 | 24 | 55 | 6,700 | 6,300 | 6,800 | 6,100 | -- | -- |
| 55 | 270 | -- | -- | SP-1 | -- | -- | -- | -- | -- | $2.3x10^{-4}$ |
| 56 | 280 | 14.8 | 19 | 56 | 5,500 | 5,400 | 7,000 | 5,400 | -- | -- |
| 56 | 280 | -- | -- | 1/ P-56 | -- | 9,600 | -- | 7,900 | .27 | $9.4x10^{-4}$ |
| 57 | 310 | 15.0 | 21 | 57 | 5,000 | 5,500 | -- | -- | -- | -- |

1/ Water-level response in piezometer probably reflects transmissivity in both deep and shallow zones.

Conducting pumping test.

Earlier attempts by others to determine transmissivity using shallow observation wells while pumping from the deep aquifer were largely unsuccessful because the anisotropy of the formation was not recognized; the levels in shallow wells respond only slightly to pumping and do not conform to most equilibrium and nonequilibrium formulas, which assume isotropy (Ferris and others, 1962, p. 91-93). In most cases, the response is not sufficient even for analysis by leaky-aquifer formulas. The lack of observation-well response can be seen in the tests of well 52 (appendix, figs. 25, 26). For this study, few production wells had nearby observation wells that penetrate the production zone, and most values were determined from the response of the production well itself.

Transmissivity of the shallow zone was initially assumed to be 2,000 $ft^2$ $day^{-1}$ for modeling. During calibration of the model the value was increased to 2,500 $ft^2$ $day^{-1}$, the equivalent of a zone 35 feet thick with an average hydraulic conductivity of 70 to 75 ft $day^{-1}$. This value of hydraulic conductivity for the shallow zone is within the range estimated for the deep zone.

Potentiometric changes in the deep zone are transmitted rapidly during testing, intercepting boundaries (sea, bay, or bedrock) within a few hours; then vertical leakage between the shallow and deep zones of the aquifer becomes important. Time-drawdown plots for the production wells start departing from the theoretical solution of Theis within 10 to 30 minutes, and the levels usually stabilize in less than 8 hours (figs. 24, 28, 30). When this occurs, it means that vertical leakage has been induced over an area large enough to supply all the water produced by the well.

Using leaky-aquifer curves of Hantush (1964), vertical hydraulic conductivities of 0.25 to 2 ft $day^{-1}$ were calculated from pumping tests of wells (table 4). The ratio of calculated horizontal to vertical hydraulic conductivities was as much as 300 to 1. Vertical hydraulic conductivity based on head differences in piezometers was estimated to be ¼ to ½ ft $day^{-1}$.

Storage coefficients of the deep zone were calculated using transmissivities from production wells and the projected time intercept for zero drawdown at an observation well (Ferris and others, 1962, p. 100). The values were small (table 4), approximately $10^{-3}$ to $10^{-5}$ (a single value of about $10^{-4}$ was used throughout the model).

A storage coefficient of about 0.1 for the shallow zone was calculated by Brown and Newcomb (1963, p. D15) from a pumping test, but a value of 0.25 was needed in the model to achieve satisfactory duplication of historical data.

The leakage coefficient (see glossary) is a function of thickness as well as of conductivity. Locally the thickness is the vertical distance between the effective midpoints of the upper and lower aquifer zones and is dependent on the depth to which the lower zone has been developed by wells, or is expected to be developed. Leakage coefficients were determined from the pumping or recovery data of production wells; the coefficient for well 50 was 20 to 100 $days^{-1}$, 300 $days^{-1}$ for well 52, and 330 $days^{-1}$ for well 55. The best model simulation was obtained by using a leakage coefficient corresponding to about double the rate of vertical movement determined from pumping tests.

Knowledge of the length of time required for water to circulate through the formation (fig. 3) was not needed for modeling; nevertheless, a general knowledge may be useful for considering problems such as might be associated with accidental contamination of the aquifer by water of an undesirable nature. The transit time is a function of the leakage coefficient. Included in table 5 is the expected maximum range of values for leakage coefficient and vertical gradients; values of the leakage coefficient compare with those used in the electric analog model, and 0.05 is the maximum observed vertical gradient. The minimum likely transit time for water moving (as a mass) from the water table to the middle of the deep, or production, zone is probably at least 10 years, and it may be considerably more. The horizontal rate of movement of water may be about 1 mile in 10 years in the shallow zone, less in the deep zone. Studies of contaminants, however, have shown first arrival of less concentrated contaminants may occur considerably sooner than indicated by calculations based on Darcy's law.

Table 5.--Time of transit from recharge at water table to deep aquifer

| Leakage coefficient | Vertical gradient | | | | | |
|---|---|---|---|---|---|---|
| | 0.10 | 0.05 | 0.04 | 0.03 | 0.02 | 0.01 |
| | Transit time, in years | | | | | |
| 1/2 $year^{-1}$ (182 $days^{-1}$) | 5 | 10 | 12 | 16 | 25 | 50 |
| 1 $year^{-1}$ (365 $days^{-1}$) | 10 | 20 | 25 | 33 | 50 | 100 |

## Water Withdrawals

### Well System

Performance, specifications, and drillers' logs of production wells owned by the Water Board are shown in tables 6 and 14. Each well is capable of producing 300 to 500 gpm. When operating against 40 psi (pounds per square inch) line pressure of the system, most produce 200 to 300 gpm, but automatic cycling to meet demands results in a lesser average yield. The wells are screened (0.010- and 0.012-inch slots) at depths ranging from 52 to 185 feet below land surface. Most wells are screened in one or two zones; well 45 is screened in three zones.

Table 6.--Selected data of production wells of the Coos Bay-North Bend Water Board

| Well number | Year | | Altitude (ft) | Well screens | | | Total aquifer thickness (feet) | Conducted or reported test | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Interval | | | | | | |
| | Drilled | Routine operation | | Depth (feet) | Altitude (ft below msl) | Total length (feet) | | Gpm | Drawdown (ft) | Gpm/ft |
| 41 | 1968 | 1970 | 21 | 57-104 | 36-83 | 47 | 98 | 485 | 20.9 | 23 |
| 42 | 1968 | -- | 22 | 52-100 | 30-78 | 48 | 125 | 350 | 19.2 | 18 |
| 43 | 1968 | 1970 | 20 | 71-108<br>150-171 | 51-88<br>130-151 | 58 | 170 | 400 | 13.7 | 29 |
| 44 | 1968 | -- | 22 | 87-119<br>159-185 | 65-97<br>137-163 | 58 | 170 | 482 | 14.5 | 33 |
| 45 | 1968 | -- | 18 | 69-84<br>108-130<br>154-176 | 51-66<br>90-112<br>136-158 | 59 | 175 | 390 | 9.9 | 40 |
| 46 | 1968 | 1970 | 17 | 80-111<br>159-180 | 63-94<br>142-163 | 52 | 175 | 540 | 24.2 | 22 |
| 47 | 1957 | 1961 | 24 | 56-135 | 32-111 | 79 | 125 | -- | -- | -- |
| 48 | 1957 | 1961 | 26 | 82-134 | 56-108 | 52 | 125 | -- | -- | -- |
| 49 | 1957 | 1961 | 23 | 78-130 | 55-107 | 52 | 125 | -- | -- | -- |
| 50 | 1960 | 1961 | 25 | 63-120 | 38-95 | 57 | 125 | 407 | 22.4 | 18 |
| 51 | 1960 | 1961 | 21 | 61-81<br>104-135 | 40-60<br>83-114 | 51 | 155 | 307 | 21.0 | 15 |
| 52 | 1960 | 1961 | 22 | 60-85<br>140-170 | 38-63<br>118-148 | 55 | 200 | 355 | 15.5 | 23 |
| 53 | 1968 | 1968 | 23 | 56-97 | 33-74 | 41 | 110 | 280 | 14.9 | 19 |
| 54 | 1968 | 1968 | 23 | 55-102 | 32-79 | 47 | 98 | 280 | 13.9 | 20 |
| 55 | 1968 | 1968 | 24 | 53-97 | 29-73 | 44 | 98 | 280 | 11.8 | 24 |
| 56 | 1968 | 1968 | 26 | 58-100 | 32-74 | 42 | 94 | 280 | 14.8 | 19 |
| 57 | 1968 | 1968 | 23 | 58-100 | 35-77 | 42 | 102 | 310 | 15.0 | 21 |
| 58 | 1968 | 1968 | 24 | 63-111 | 39-87 | 48 | 110 | 350 | 19.0 | 18 |

The wells are connected by pipeline, as shown on plate 1; the system was designed for expansion according to a plan originated by P. P. & L. Water production from the east well field may go to the Menasha pulpmill without being treated, or through a treatment plant on North Slough so that the water may be used to augment municipal supplies. Most water from the west well field goes to the pulpmill and is not treated, but an auxiliary treatment plant was installed in 1971 to serve the Forest Service campground at Bluebill Lake and restrooms at Horsfall Beach.

Electrical power for the pumps at wells 47 to 52 is supplied by P. P. & L., and power to wells 41 to 46 and 53 to 58 is supplied by Central Lincoln Public Utility District. Rates and rate structures of the two utilities have differed--an important factor in the economics of well-field operations.

The monitoring and control network for the well fields is necessarily complex because the system has little capacity for storage--a continuous supply is needed to prevent damage to boilers at the pulpmill. Each well is equipped with a meter capable of recording cumulative pumpage and a readout of discharge rate, as well as with controls for manual or automatic operation. A central control house is located near the pulpmill where automatic controls may be set to turn the required number of wells on and off in any predetermined order in response to demand. Total discharge of the well field is recorded continuously, and the rate of individual wells may be monitored at the Water Board headquarters in the city of Coos Bay. Warning of equipment failure is received automatically at the headquarters.

## Rates of Withdrawal

Wells 47 to 52 were put into production in 1961 and supplied 2 mgd (million gallons per day), an average of 230 gpm per well. (Table 13 in the appendix lists conversion factors.) When wells 53 to 58 were made operational in 1968, total production remained at 2 mgd, and average discharge per well was halved. Wells 47 to 49 were staged to pump only when the other wells could not meet the demand. In the fall of 1970, wells 41 to 46 were made operational, and the west field began to supply 1.9 mgd. Normally only three or four wells are needed to maintain this rate; therefore, wells 42, 44, and 45 have not been pumped routinely. Average production of the six wells is 0.32 mgd.

The original plan for development specified rated capacities of 220 gpm each for wells 47 to 64 (east field) and a nominal spacing of 1,200 feet. In the west field, rated capacities were planned for 370 gpm each, with a 760-foot spacing for wells 1 to 34 and a 2,000-foot spacing for wells 34 to 46 (pl. 1). A summary analysis (table 7) shows that implementation of the plan for ultimate development would result in greater withdrawals per unit area in the north than in the south, although the aquifer is thinner (pl. 1) and has a lower transmissivity (pl. 2) in the north.

Table 7.--Original plan for withdrawal by wells

| | Total (1-64) | West wells (1-46) | East wells (47-64) | North wells (1-34) | South wells (35-64) |
|---|---|---|---|---|---|
| Rate per well (gpm) | -- | 370 | 220 | 370 | -- |
| Total (gpm) | 21,000 | 17,000 | 4,000 | 12,600 | 8,400 |
| Total (mgd) | 30 | 24½ | 5½ | 18 | 12 |
| Mgd per sq mi | 1½ | -- | -- | 2 | 1¼ |
| Ft per year | 2½ | -- | -- | 3 | 2 |

## Analysis of the Flow System

A quantitative description of the hydrologic system provides a basis for predicting the effects of natural and artificial changes. For the model, precipitation was assumed to be 62 inches each year and uniformly distributed areally. A value of 8 inches of evapotranspiration per year was used, also uniformly distributed.

Essentially all surface runoff is spill from the lakes during winter, and it is 1 to 1½ feet per year based partly on lake hydrographs. The spill moves in broad channels or as sheetflow, alternately becoming ground water and then surface water again.

During testing of the model, simulation of recharge at a rate of 38-39 inches per year was found to duplicate most closely actual water-level hydrographs for natural or undeveloped conditions. Recharge was distributed seasonally about as shown in figure 8, and at constant rates is equivalent to 37 mgd over the entire area. Net recharge increases with development to the extent that evapotranspiration and runoff are captured by pumping; for some of the model runs this increase was estimated and the model adjusted accordingly.

## Effects of Pumping

The major effect of withdrawals is to diminish subsurface outflow to the sea and bay; reversal of the outflow by pumping in excess of net recharge will cause eventual onshore intrusion of saline water into the aquifer. Also, withdrawal of ground water at or near the maximum rate of net recharge will lower the lakes to levels that may be unacceptable to water managers who must consider the other intended uses of the area.

Transient tests of the aquifer system using the electric analog model were made to simulate the effects of pumping. The tests, equivalent to 6 months of real time, are believed to show the changes in water levels that would occur from short-term or seasonally managed withdrawals. During short periods, the rate of net recharge would be changed only slightly, especially if those periods were during seasons of little precipitation. Analyses 1 to 5 of table 8 are of the transient type.

Analyses 6 and 7 represent tests continued to equilibrium; they show the long-term effects of pumping after the system has stabilized and ground-water levels no longer decline with time. For analyses 6a and 7a, model runs were made with the simplifying assumption that pumping causes no change in the rate of recharge. Analyses 6b and 7b were adjusted for a 35 percent assumed increase in the rate of recharge during the pumping period, the most that could reasonably be expected. Analyses 6c and 7c are based on recharge equal to 100 percent of precipitation--the maximum possible. This would require the highly unlikely condition of recovery or capture of all the runoff and evapotranspiration.

Precipitation and the water levels of Horsfall Lake were compared for pumping and prepumping years. The graphs for 1959 (prepumping, fig. 9) and 1971 (pumping 3.8 mgd, fig. 10) suggest a lower water level of about 2 feet due to pumping; analysis 6b indicates the lowering would be 5 feet at equilibrium.

Lake-level effects that were predicted by P. P. & L. using an impermanent, conductive-paper analog are included in table 8. The predictions of some of the lake-level effects are not greatly dissimilar from analyses 6a or 6b, although the P. P. & L. model (1) simulated equilibrium conditions; (2) included a single layer; and (3) assumed a single, uniform value for transmissivity (6,700 $ft^2$ $day^{-1}$) throughout the area. The assumptions, including a uniform transmissivity and

Table 8.--Predicted effects of pumping on water levels, based on analyses using electric analog model

[See text for explanation and table 13 for additional data]

| Analysis no. | 1 | 2 | 3 | 4 | 5 | 6 | | | 7 | | | Analysis by P. P. & L. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | a | b | c | a | b | c | |
| Equilibrium (E), or 6 mos. draw-down (T) | T | T | T | T | T | E | | | E | | | E |
| Well numbers of pumping wells | 50-58 | 41, 43, 46, 50-58 | 41, 43, 46-53, 57, 58 | Odd nos. 1-43; 46, 50-58 | Odd nos. 1-39; 43, 46, 50-58 | 41, 43, 46, 50-58 | | | Odd nos. 1-39; 40-64 | | | -- |
| Total number of wells pumping | 9 | 12 | 12 | 38 | 38 | 12 | | | 45 | | | 13 |
| Total pumpage (mgd) | 1.9 | 3.8 | 3.8 | 10.2 | 16.2 | 3.8 | | | 15.3 | | | 4.0[1/] |
| | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd | in./yr mgd |
| Recharge before pumping | 38½ 37 | 38½ 37 | 38½ 37 | 38½ 37 | 43 41 | 38½ 37 | 38½ 37 | 38½ 37 | 38½ 37 | 38½ 37 | 38½ 37 | 44 42 |
| Recharge during pumping | 38½ 37 | 38½ 37 | 38½ 37 | 38½ 37 | 43 41 | 38½ 37 | 52 50 | 62 60 | 38½ 37 | 52 50 | 62 60 | 44 42 |
| Lake | Lowering of levels below natural conditions (feet) | | | | | | | | | | | |
| Clear | -- | -- | -- | 0.7 | 1.8 | -- | -- | -- | 13 | 9.5 | 8 | -- |
| Saunders | -- | -- | -- | .9 | 2.0 | -- | -- | -- | 13.5 | 10 | 8.5 | -- |
| Butterfield | -- | -- | -- | 1.0 | 1.5 | -- | -- | -- | 12.5 | 9.5 | 8 | -- |
| Beale | -- | -- | -- | 1.5 | 1.7 | -- | -- | -- | 13.5 | 10 | 8.5 | -- |
| Snag | 0.0 | 0.1 | -- | .9 | 2.0 | 3 | 2.5 | 2 | 12 | 9 | 7.5 | 2.0 |
| Sandpoint | .4 | .5 | 0.3 | 1.0 | 2.3 | 4 | 3 | 2.5 | 13 | 9.5 | 8 | 4.3 |
| Spirit | 1.0 | 1.3 | .6 | 1.5 | 1.7 | 6 | 4.5 | 3.5 | 11 | 8.5 | 7 | 4.8 |
| Horsfall | .6 | 1.0 | .6 | 1.1 | 2.0 | 7 | 5 | 4.5 | 10 | 7.5 | 6 | 6 |
| Bluebill | .2 | .8 | 1.2 | .8 | 1.5 | 3 | 2.5 | 2 | 6 | 4.5 | 3.5 | 3.3 |

1/ P. P. & L. plan for ultimate development (64 wells) assumes 30 mgd.

recharge by lateral inflow through the eastern boundary of the area, are factors that make a model of this type inadequate, however.

Graphs for predicting minimum seasonal lake levels under natural and selected pumping conditions have been constructed (figs. 13-19). The graphs are based on historical levels and analysis of the electric analog model. Predictions are made by entering the appropriate graph with a known water level for June or later, when the recession rate has stabilized. The known level is projected parallel to the family of curves on the graph. This projection indicates the minimum level that can be expected at a future date if there is no additional recharge from precipitation. Normally the recessions are reversed by October (fig. 6). Dashed lines on some of the graphs indicate uncertainty of recession characteristics at very low stages.

Recession rates of Clear and Butterfield Lakes (figs. 13, 15) diminish at lower stages, and those of Saunders Lake (fig. 14) may diminish slightly. These lakes have sides of permeable dune sand and bottoms of less permeable marine deposits, which may explain the dependence of recession rate on the stage.

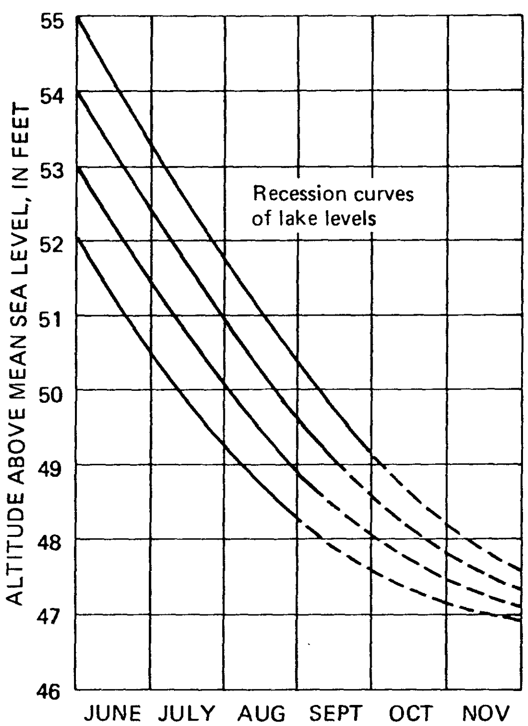



Figure 13. — Graph for predicting minimum level of Clear Lake (nonpumping conditions).

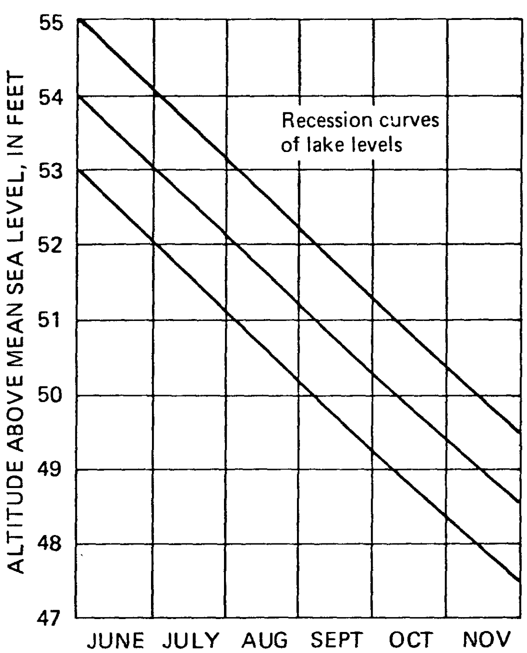



Figure 14. — Graph for predicting minimum level of Saunders Lake (nonpumping conditions).

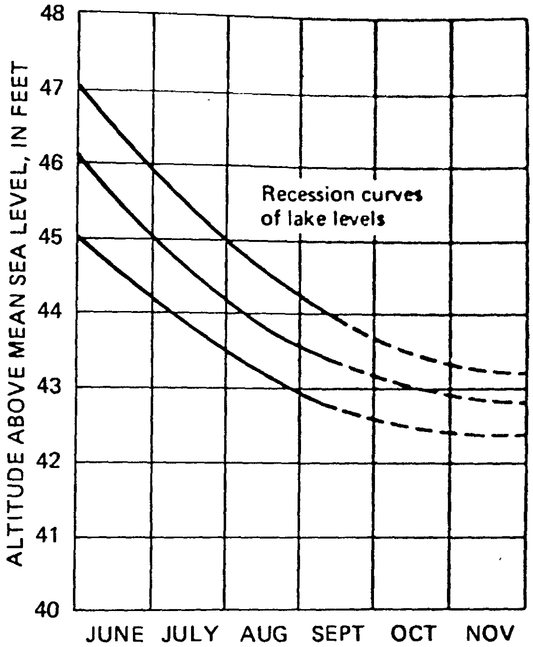



Figure 15. – Graph for predicting minimum level of Butterfield Lake (nonpumping conditions).

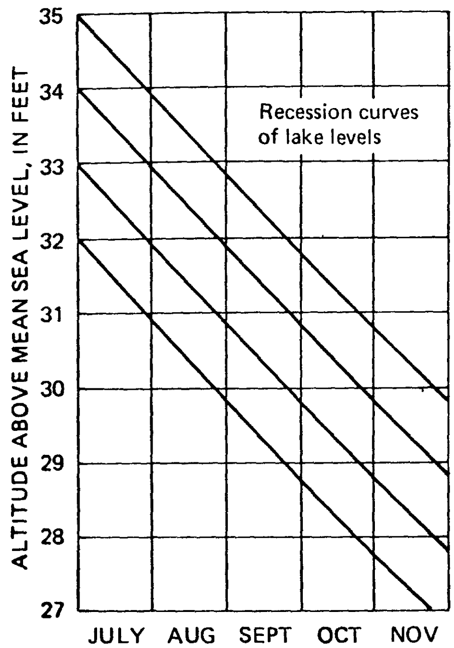



Figure 16. – Graph for predicting minimum level of Beale Lake (nonpumping conditions).

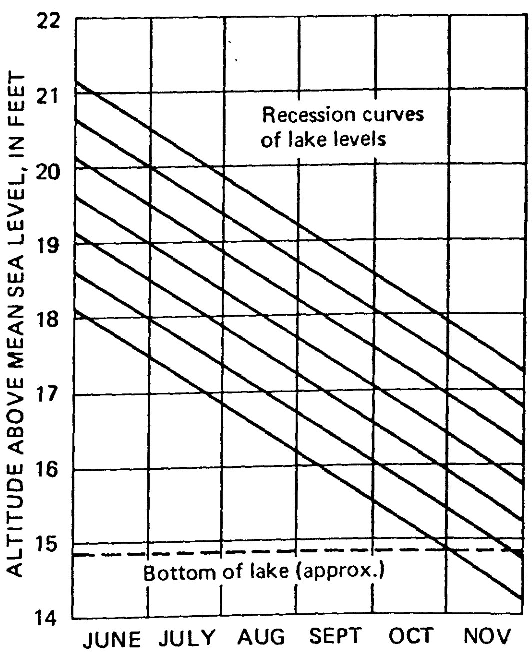



Figure 17. – Graph for predicting minimum levels of Horsfall and Spirit Lakes (nonpumping conditions).

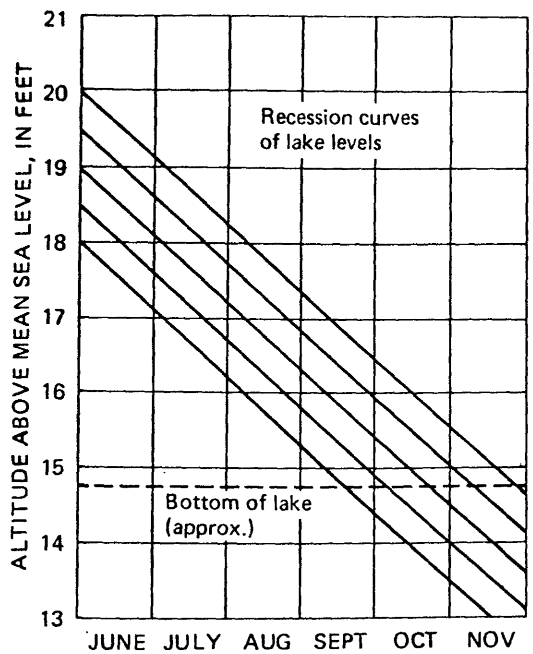



Figure 18. – Graph for predicting minimum levels of Horsfall and Spirit Lakes (pumping 3.8 mgd; wells 41, 43, 46, 50-58 on, as in analysis 2, table 10).

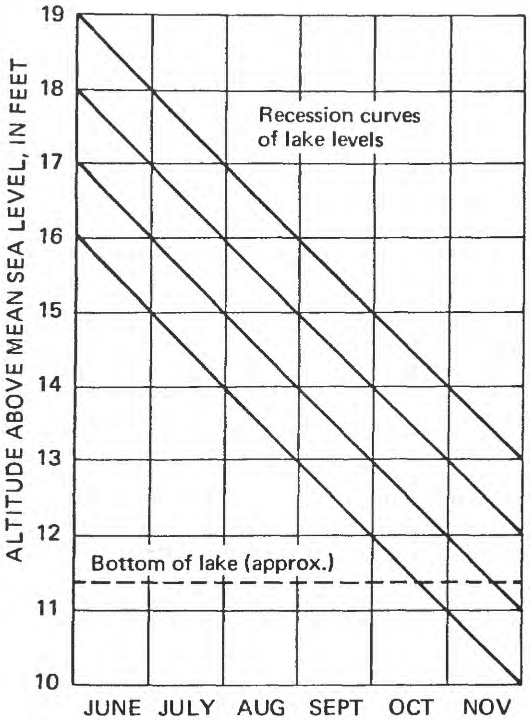
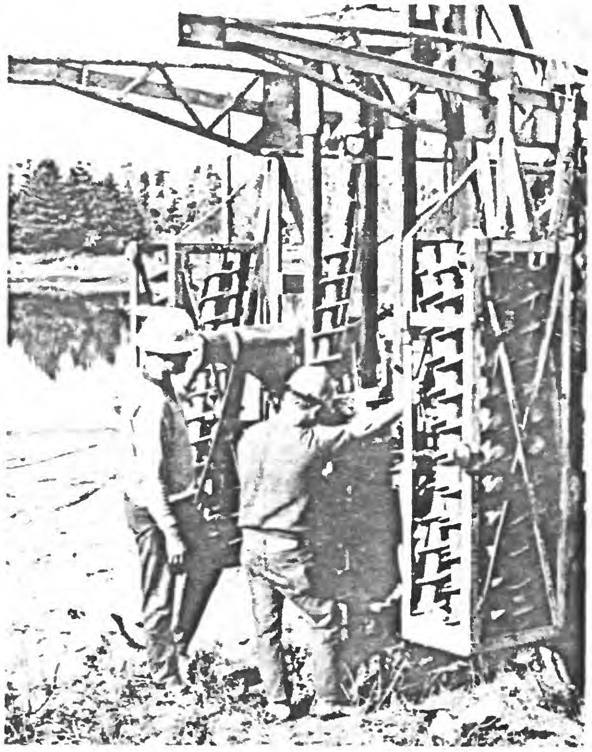



Figure 19. — Graph for predicting minimum level of Bluebill Lake (nonpumping conditions).



Drilling test hole.

## Outflow

As determined from the model, under natural conditions (no pumping), an average of about 29 mgd of the 37 mgd net recharge leaves the area as ground-water outflow from the shallow zone and 8 mgd from the deep zone. The rates vary seasonally; from the shallow zone the outflow is from 18 to 37 mgd, and from the deep zone it is 7 to 9 mgd.

At equilibrium conditions, assuming withdrawal of 10 mgd and recharge unchanged by pumping, average outflow from the shallow zone would be reduced to 22 mgd from 29 mgd. Outflow from the deep zone would be reduced to 5 mgd from 8 mgd. Thus, pumping 10 mgd would result in capture of 7 mgd of ground-water outflow from the shallow zone and 3 mgd from the deep zone. Analysis 5 shows that after 6 months of pumping at a rate of 16 mgd, 2 mgd would be captured from the shallow zone and 3½ mgd from the deep zone.

As the system approaches equilibrium, a greater proportion of the captured water comes from the shallow zone. Equilibrium is reached in several years or less in the southern and central areas, but takes at least 10 years in the northern area where deposits of low permeability would be drained. Pumping 15½ mgd until equilibrium is achieved (analysis 7a) would result in capturing 10 mgd from the shallow zone and 5½ mgd from the deep zone (if recharge is not increased by pumping). Inasmuch as 8 mgd in the deep zone is calculated to leave the system under natural conditions, withdrawals substantially greater than 15-16 mgd might cause local or general reversal of flow in the deep zone, accompanied by sea-water intrusion.

## Well Interference

One of the considerations in the design of a well field is the spacing of wells. The aim is to achieve a balance between maximum recovery of water and the lowest cost for development and operation of wells. Wells should not be so closely spaced that pumping lifts will be unduly increased because of mutual interference or overlapping of drawdown cones of wells.

In the Coos Bay dunes the transmissivity of the deep or production zone is high, the storage coefficient is low, and the ultimate source of water to wells is vertical leakage. In the deep zone, drawdown cones are quite flat, and in the shallow zone they are observable only as slight general declines of water levels. In the presently developed part of the dunes, a single well pumping 200-300 gpm would, at equilibrium, cause a drawdown of head in the production zone of only about 1 foot at a radius of 1,000 feet. Mutual interference is probably not significant where spacing of wells is more than several hundred feet and total withdrawals from the field do not exceed recoverable recharge. The number and spacing of wells can be based largely on operational convenience, as long as the wells are not placed so close to sources of saline water that they would induce a local reversal of the natural flow and thereby contaminate the aquifer.

The analog model was built to include only every other proposed well in the northern group (odd numbers 1 through 39). The model analyses did not indicate that perceptible drawdown cones would develop and, for a given volume of water withdrawn, fewer wells may be necessary than have been proposed.

## Salt-Water Intrusion

The chloride content of water in observation wells being monitored by the Water Board shows that fresh water extends the full depth of the aquifer along the Pacific shoreline and also along the bay. How far offshore the fresh water extends and the nature of the fresh water-salt water interface are not known. So long as the net flow of water is seaward (this can be determined by monitoring the head in the aquifer along the shoreline), there should be no <u>onshore</u> encroachment of salt water. Monitoring of quality of water in the shoreline observation wells provides early warning should intrusion occur.

Rate of migration of the fresh water-salt water interface can be estimated should the gradient be changed or reversed:

$$v_i = \frac{k\ dh/dl}{n_e}$$

where

$v_i$ = velocity, in feet per year,

$k$ = hydraulic conductivity, in feet per year,

$dh/dl$ = hydraulic gradient,

$n_e$ = effective porosity.

If $k = 20{,}000$ ft year$^{-1}$ (55 ft day$^{-1}$) and effective porosity = 0.25,

$$v_i = \frac{20{,}000 \, dh/dl}{0.25} = 80{,}000 \, dh/dl,$$

which simplifies to

$$v_i = 15 \text{ ft year}^{-1}, \text{ per ft per mile change in gradient.}$$

Thus, a one-time change in gradient of 10 feet per mile would induce a migration of the interface at an initial rate of 150 feet per year. For a one-time change, the initial rate would gradually decrease until the interface stabilizes at a new position of equilibrium.

## Water Management to Minimize Adverse Effects

One of the goals of water management is to withdraw the needed quantity of water while minimizing any adverse hydrologic effects. It was originally expected that the area might supply 30 mgd, but this investigation shows that pumping 15 to 16 mgd can lower the lakes to levels that may be considered undesirable or unacceptable for some uses. The greatest restraint on withdrawals may result from esthetic or recreational considerations rather than from solely hydrologic limitations. Development plans based on the constraints imposed by the natural hydrologic system will help to achieve the water-management goals.

Though well location does not usually have a large effect on nearby water levels, even small effects may be important at critical times and places. For example, a water-level decline of half a foot in a shallow lake may mean disappearance of the lake. Analyses 2 and 3 (table 8) show the effect of pumping the same total quantity from different wells. In analysis 3, wells 54, 55, and 56, adjacent to Spirit Lake, were considered to be replaced by wells 47, 48, and 49, which lie south of the lake. Compared to analysis 2, the level of Spirit Lake would be 0.7 foot higher after 6 months.

Well design can have a significant effect on local water levels. Production wells have been screened in the deep zone only (table 4, pl. 1). Were the wells screened through the entire aquifer, drawdown cones would develop in the shallow zone adjacent to the wells.

Varying the seasonal rate of ground-water withdrawal would help to minimize effects on lakes, and the analog model can be used to estimate the effects of changing the rates (table 8, analyses 1-5). Unfortunately, flexibility is limited because the demand for water is nearly constant and storage capacity is limited. However, conjunctive use of ground water and surface water could minimize the lowering of lake levels at critical times of the year.

Direct recharge into lake.

Another method that might be used to help sustain water levels within desired ranges involves pumping directly into lakes. Lakes favorably situated to receive water from presently active wells are Spirit and Bluebill Lakes and possibly Sandpoint and southeast Horsfall Lakes. During or before critical periods, part of the water from production wells could be discharged into lakes. A small area of water could be maintained even though there would be considerable seepage through the sides of the lakes.

Outlet areas, where lakes typically spill during the rainy season, could be raised artificially. In wet years this might cause the peak levels to be a foot or two higher than otherwise. Some of this extra water would be retained during the dry season, and this would tend to delay the time when the lake would reach its lowest level.

Deepening of the shallow lakes, as by dredging, could eliminate their drying up. Deepening would not help to maintain the altitude of the lake levels, but it would preserve a depth of water so that the lakes would remain usable bodies of water. The cost of dredging, frequency of maintenance, effects on aquatic life, and other factors would need to be considered.

The possibility of placing impermeable liners in lakes to prevent excessive loss of water might be studied. However, this might cause a number of problems, especially regarding ecological balance. Maintenance of liners could also be a problem; where ground-water levels tended to rise higher and faster than the level in a sealed lake, a liner might tend to float, even if covered with sand.

Another possibility is to reroute streamflow to recharge the aquifers. Local observers have noted that in late summer to early fall drifting sand may dam Tenmile Creek near its mouth when discharge of the creek is small. When this happens, ground-water levels are raised near the creek, causing ground water to move south from Tenmile lagoon (pl. 2). Artificially damming Tenmile Creek might raise water levels high enough to induce surface and ground water to move southward along the plain that lies a quarter to half a mile east of the shore, behind the foredune. Because this water would be downgradient from water levels of presently proposed wells, it would probably cause only small water-level rises near the wells or to lakes lying to the east. A number of shallow, small-capacity wells could be located along the plain to capture the additional recharge available from Tenmile Creek.

Whether or not recharge from Tenmile Creek is feasible, the placement of small-capacity wells relatively close to the coast might help in maximum development of the ground water. The analog model indicates that even though 10 mgd were withdrawn according to existing plans, 22 mgd would nevertheless leave as outflow through the shallow ground-water zone. Much of the outflow could be recovered using shallow wells arranged in a system similar to those commonly used for dewatering construction sites. The water-level gradient in the shallow zone would be steepened near the shore, but by reducing the volume pumped from wells at the originally proposed locations, lake levels would not be affected as much. As there would be little warning of salt-water intrusion, great care should be taken not to reverse hydraulic gradients along the shore.

## Water Quality

### General

Chemical quality of samples from Beale, Horsfall, and Bluebill Lakes is given in table 9 and plotted on the trilinear diagram of figure 20. Dissolved-solids concentrations are low--less than 100 mg/l (milligrams per liter). The lake water is of sodium chloride type, which is common in coastal areas where much of the precipitation is transported by onshore winds. Analyses of shallow ground water reported by Brown and Newcomb (1963, p. D28) are of similar type and concentration.

Compared to lake water and shallow ground water, water from the production zone of the aquifer has significantly more silica, calcium, magnesium, bicarbonate, and hardness (table 9). Ground water of the shallow zone is intermediate in chemical character between lake water and ground water from the production zone.

Table 9.--Chemical analyses of water from lakes and production wells

| Sample no. | Local designation | Well number | Total interval of screen or perforations (depth in (feet) | Date of collection | Milligrams per liter | | | | | | | | | | | | | | | Specific conductance, micromhos @ 25°C | pH | Temperature | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 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 ($NO_3$) | Boron (B) | Dissolved solids | Hardness, as $CaCO_3$ | | | °C | °F |
| 1 | Beale Lake | | | 12/15/55 | 1.6 | 0.06 | 1.2 | 1.2 | 9.6 | 0.9 | 7 | 0 | 1.3 | 15 | 0.1 | 0.1 | 0.01 | 37 | 8 | 66 | 6.5 | -- | -- |
| 2 | Horsfall Lake | | | 9/18/70 | .0 | .06 | 1.7 | 1.9 | 14 | 2.2 | 0 | 0 | 10 | 25 | .1 | 1.2 | -- | 56 | 12 | 126 | 7.2 | -- | -- |
| 3 | Bluebill Lake | | | 9/18/70 | 1 | .50 | 1.9 | 1.7 | 19 | 2.8 | 7 | 0 | 7.8 | 33 | .0 | .5 | -- | 70 | 12 | 135 | 7.1 | -- | -- |
| 4 | Well 44 | 24S/13W-32abd | 87-185 | 10/28/70 | 30 | 1.0 | 22 | 11 | 17 | 8.7 | 143 | 0 | 2.8 | 23 | .1 | .1 | -- | 190 | 100 | 292 | 7.6 | 13 | 55 |
| 5 | 46 | 24S/13W-32dcb | 80-180 | 10/31/70 | 24 | .02 | 27 | 20 | 18 | -- | 189 | 0 | 7.5 | 28 | .1 | .3 | -- | 220 | 150 | 373 | 7.9 | 12 | 53 |
| 6 | (47, 48, 49) | | | 8/ 8/58 | 23 | 2.5 | 33 | 3.4 | 9.7 | 4.9 | 110 | 0 | 2.9 | 16 | .0 | .1 | -- | 150 | 95 | -- | 7.6 | -- | -- |
| 7 | 48 | 24S/13W-33dbc | 82-134 | 4/ 7/59 | 20 | 2.4 | 31 | 4.9 | 12 | 6.0 | 120 | 0 | 3.0 | 18 | .0 | .0 | -- | 160 | 97 | -- | 7.8 | -- | -- |
| 8 | 49 | 24S/13W-33acd | 78-130 | 7/17/70 | 22 | 2.6 | 23 | 3.4 | 9.6 | 3.5 | 90 | 0 | 4.2 | 14 | .1 | .8 | -- | 130 | 72 | 190 | 7.7 | 13 | 55 |
| 9 | 55 | 24S/13W-27bbd | 53-97 | 10/ 4/70 | 31 | .05 | 26 | 6.8 | 19 | -- | 124 | 0 | 1.0 | 27 | -- | .3 | -- | 170 | 93 | 280 | 7.8 | 14 | 57 |
| 10 | 56 | 24S/13W-22ccd | 58-100 | 7/16/70 | -- | 4.1 | -- | -- | -- | -- | -- | -- | -- | 27 | -- | -- | -- | -- | -- | 324 | -- | -- | -- |
| 11 | 57 | 24S/13W-22cac | 58-100 | 6/18/70 | 36 | .90 | 40 | 7.7 | 21 | 5.7 | 164 | 0 | .0 | 34 | .1 | 3.0 | -- | 230 | 130 | 360 | 7.9 | 14 | 57 |
| 12 | 58 | 24S/13W-22bdc | 63-111 | 6/18/70 | 30 | 6.6 | 36 | 5.0 | 22 | 4.3 | 142 | 0 | .0 | 33 | .1 | 2.9 | -- | 210 | 110 | 323 | 7.7 | 13 | 55 |

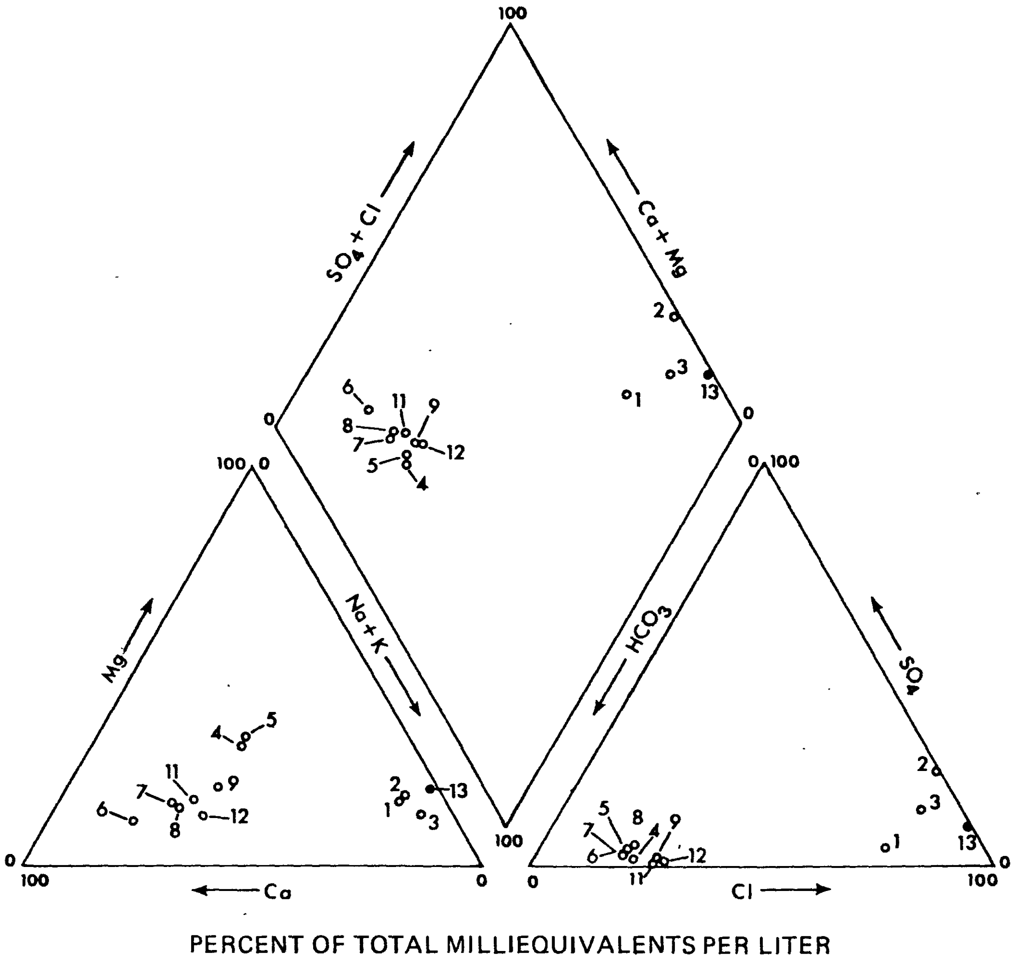



Figure 20. – Trilinear diagram of selected chemical analyses of water (number 13 represents normal sea water).

Many piezometers from which samples were obtained (table 10) are screened near the base of the aquifer, just above silt and clay containing brackish water; 200A is screened slightly below the base of the aquifer. Production wells, on the other hand, draw much of their water from the middle of the aquifer. Thus, specific conductance of samples collected from many of the piezometers is higher than is typical of water from production wells.

## Dissolved Iron

Dissolved iron, which has been reported to be as high as 9.0 mg/l in individual wells, is a problem for municipal use--the recommended limit of iron for public supplies is 0.3 mg/l (Federal Water Pollution Adm., 1968, p. 20). Where iron concentration is in excess of the limit, staining is generally a problem. The water from the well field that is used to supplement municipal supplies is softened and fluoridated, and the iron is removed.

Table 10.--Iron concentration in water from piezometers

| No. | Alt of screen (feet) | Date of collection (1971) | Iron (mg/l) | Spec. conduc. (micromhos at 25°C | Field pH | Temperature °C | Temperature °F |
|---|---|---|---|---|---|---|---|
| 200B | +16 | 7/15 | 0.23 | 130 | -- | 15.5 | 60 |
| C | -44 | 7/15 | .93 | 170 | -- | 15.0 | 59 |
| C | -44 | 12/1 | -- | -- | 9.5 | -- | -- |
| A | -84 | 7/15 | .30 | 2,600 | -- | 15.0 | 59 |
| A | -84 | 12/1 | .02 | -- | 11.0 | -- | -- |
| BA-1A | +5 | 7/15 | 2.0 | 140 | -- | -- | -- |
| B | -90 | 7/15 | .41 | 210 | -- | -- | -- |
| HF-1A | ~ 0 | 12/1 | 8.5 | 280 | 6.9 | 12.0 | 53 |
| B | ~ -80 | 12/1 | .18 | 120 | 8.2 | 12.5 | 54 |
| P-41 | -108 | 7/15 | .12 | 300 | -- | 12.5 | 54 |
| 41A | -132 | 7/15 | -- | 650 | -- | -- | -- |
| P-42 | -117 | 11/30 | .96 | 2,100 | 8.8 | 12.5 | 54 |
| P-43 | -157 | 11/30 | .51 | 440 | 9.3 | 12.5 | 54 |
| P-44 | -141 | 7/15 | .03 | 1,300 | -- | 12.5 | 54 |
| P-45 | -141 | 11/30 | .41 | 280 | 9.6 | 12.5 | 54 |
| P-46 | -130 | 7/15 | .14 | 260 | -- | 12.5 | 54 |
| 46A | -178 | 7/15 | -- | 400 | -- | 12.5 | 54 |
| P-54 | -69 | 11/30 | 1.0 | 520 | 8.3 | 13.5 | 56 |
| P-55 | -83 | 11/30 | 1.2 | 750 | 8.1 | 13.0 | 55 |
| P-56 | -88 | 11/30 | .96 | 1,700 | 7.7 | 13.5 | 56 |
| P-58 | ~-100 | 11/30 | .84 | 650 | 8.6 | 12.5 | 54 |
| SCP-4A | -26 | 11/30 | 1.2 | 85 | 6.4 | 12.5 | 54 |
| B | -60 | 11/30 | .99 | 230 | 7.9 | 12.5 | 54 |
| C | -98 | 11/30 | 4.2 | 330 | 8.3 | 13.0 | 55 |
| SCP-11A | -8 | 11/30 | 2.6 | 70 | 6.6 | 13.5 | 56 |
| | -60 | 11/30 | .07 | 210 | 8.3 | 13.5 | 56 |
| | -83 | 11/30 | .61 | 540 | 7.9 | 13.5 | 56 |
| TM-2A | ~ 0 | 12/1 | 5.8 | 110 | 6.1 | 13.0 | 55 |
| B | ~-105 | 12/1 | 3.7 | 180 | 8.1 | 13.0 | 55 |

Areal distribution of high concentrations of iron (see tables 9, 10) is highly variable, although the average iron content in water from the west well field is less than that in water from the east well field. Concentrations also vary with depth and with the seasons. Concentration of iron in the water from the east well field is about 4.0 mg/l and has decreased since pumping began.

Water samples obtained from piezometers showed that pH measured in the field generally increases with depth (table 10). There appears to be no direct, simple relation of pH and iron concentration, although the Coos Bay results are compatible with Eh-pH stability-field diagrams (Back and Barnes, p. C3).

Possibly the highest concentrations of iron in the ground water are to be found in areas where time and distance since oxygenation of the water are shortest; however, present data are not complete nor consistent enough to verify this hypothesis for the dunes area.

## CONCLUSIONS

Plans for developing significant quantities of water from the dunes have been successful to date, and development has progressed without excessive adverse effects. However, maintenance of water levels in lakes has become important, even critical, as ultimate development is approached.

The electric analog model has helped to show that pumping can lower lake levels several feet or more. Unless appropriate management practices are employed, lake levels may be the most restrictive factor determining the limit on quantities of water that may be withdrawn. Withdrawal of water at optimum times, places, and depths should allow recovery of a high percentage of recharge to the dunes while keeping adverse effects within allowable limits. The electric analog model of the area has already helped to determine some of these optimum conditions and also to determine graphs for use in seasonal prediction of water levels. The model should be equally helpful as development proceeds, as knowledge of the hydrology is refined, and as new management and development ideas are conceived and tested.

## RECOMMENDATIONS

### Data Collection

Monitoring of water levels of lakes and observation wells should be continued. Static and pumping levels of production wells should be measured at least twice a year. To warn of possible clogging of the well screens or aquifer, production rate and drawdown should be measured at least once a year.

Chloride content or specific electrical conductance of water should be determined at least quarterly in piezometers located between production wells and the shore. Chloride and conductance should be measured in both intermediate and deep wells. More complete chemical analysis should be made of water that shows a high or substantial increase in values.

Continued operation of an evaporation pan may be desirable but is not essential. If operation of a pan is continued, the rain gage that is used with it should be calibrated against a standard gage of the National Weather Service.

## Management

No attempt should be made to develop ground water in quantities that equal or exceed net recharge.

Individual wells should not be pumped at a rate at which the water level will be drawn to or below the shallowest screen openings; otherwise, air may be entrapped in the water or in the formation adjacent to the screen and cause operational problems. In the northern section, wells can probably be constructed to yield 15 gpm or more per foot of drawdown; a well producing 450 gpm would have 30 feet or less of drawdown. Saturated aquifer thickness is about 90 feet (pls. 1, 2), so if the deepest screen opening is 10 feet above the base of the aquifer and the shallowest opening is 10 feet below the expected pumping level, 40 feet of aquifer could be screened. Attempting to pump more water would result in a diminishing return; the greater drawdown would limit the length of the screen, because the top of the screen should remain below the pumping level.

Continuing effort to refine or modify the concepts, values, and predictive methods that have been developed would assist in predicting and assessing the effects due to development. To the extent possible, new development programs would be best if begun as pilot programs so that the methods can be modified, if necessary, to be most effective and to achieve basic objectives.

Magnitude and scheduling of future needs for additional water in the Coos Bay area should be anticipated as far in advance as possible. The adequacy of various possible sources of water in the region can then be evaluated and plans made for the most efficient development.

## GLOSSARY OF SELECTED TERMS

Anisotropic.--Having different properties or values of a property in different directions. Applied to an aquifer that has greater permeability or hydraulic conductivity in some directions than in others.

Aquifer.--A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells.

Drawdown.--In a well, the extent of lowering of the water level during pumping. The difference, in feet, between the static water level and the pumping level.

Evapotranspiration.--Water withdrawn from an area by evaporation from water surfaces and soil, and by transpiration (water used by plant tissue.)

Hydraulic conductivity.--The rate at which a porous medium will transmit water under a hydraulic gradient of 1; expressed as ft $day^{-1}$ (feet per day). Replaces the term coefficient of permeability; to convert from the previous units of gallons per day per square foot, divide by 7.5. (See Lohman and others, 1972.)

Leakage coefficient (leakance).--The ratio of vertical hydraulic conductivity to confining-bed thickness ($K_z/b'$); it is therefore a function of both permeability and thickness. May be reported in $days^{-1}$ (may be written 1/days); a small number (of $days^{-1}$) indicates a high potential for vertical leakage.

Static level.--The level at which water stands in a well that has not been affected by recent pumping of that well. The level is reported in feet below land surface.

Storage coefficient.--The volume of water released or taken into storage by an aquifer per unit surface area of the aquifer per unit change in head. Expressed as a decimal fraction.

Transmissivity.--The rate at which water is transmitted through a unit width (1 foot) of the aquifer under a hydraulic gradient of 1, expressed as $ft^2$ $day^{-1}$ ($feet^2$ per day = cubic feet per day per foot of gradient). Replaces the term "coefficient of transmissibility"; to convert from the previous units of gallons per day per foot, divide by 7.5. (See Lohman and others, 1972.)

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# APPENDIX

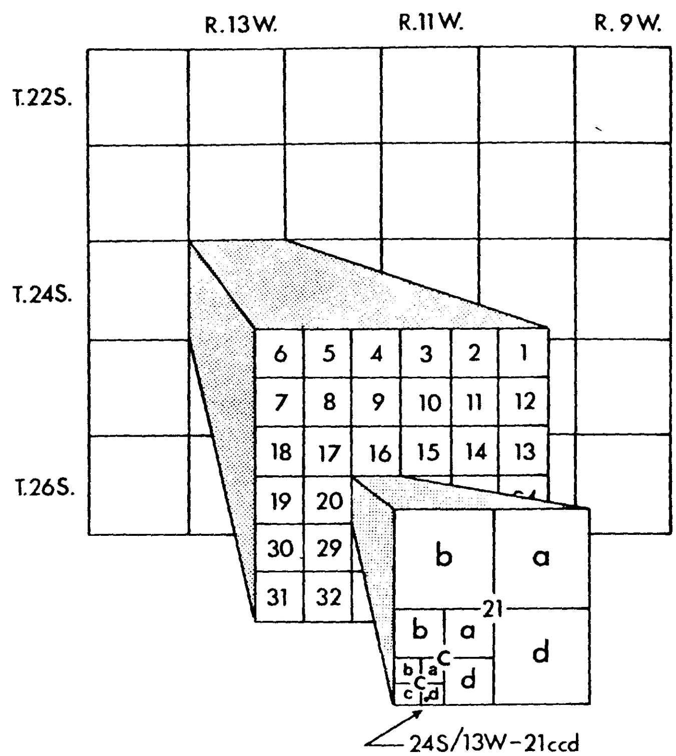


Figure 21. — Geological Survey well-numbering system for Oregon.

Lake-Bottom Permeability (See text, p. 18)

Bluebill Lake

In August 1970 there was no measurable difference between the lake level and the water level in a piezometer placed immediately below the organic, silty bottom deposits. Thus, the lake was not perched, nor was it being fed from below.

Cores were taken in a clear plastic tube (fig. 22) to determine thickness, permeability, and type of lake-bottom deposits overlying the sand. The lake-bottom deposits, consisting of organic silt and muck containing some woody plant fibers, were partly suspended to unconsolidated and were easily compressed by the coring tube. In most places the entire thickness of lake deposits was easily penetrated by a light rod. Thickness of lake deposits recovered was about 80 percent of the thickness of undisturbed deposits--average recovered thickness was 0.6 foot (table 11). The contact with underlying dune sand was usually sharp, but in places silt and sand were mixed or interlayered with the lake-bottom deposits.

Permeability of selected cores was measured at the site (table 11); because of the partly suspended nature of the deposits, cores could not be transported without undue disturbance. The greatest calculated vertical hydraulic conductivity for any sample was a quarter of a foot per day. (See glossary for discussion of units.) Compression of the samples during the coring process collapses some of the pore space in the deposits, with the possibility of reducing permeability by as much as an order of magnitude; therefore, the calculated results should be considered minimum, not actual, values.

A reference core (site 22) containing only dune sand yielded a vertical conductivity of 0.87 foot per day. Horizontal hydraulic conductivity of dune sand determined in the laboratory (Brown and Newcomb, p. D15) or calculated from pumping tests is 40 to 60 feet per day.

## Sandpoint Lake

A survey of Sandpoint Lake (fig. 23, table 12) shows that lake-bottom deposits averaged 0.2 foot thick. Along the west side, where there are many reeds, lilies, and other hydrophytes, the deposits were as much as 1½ feet thick, but the southern part of the lake was nearly bare of silt. Deposits that are typical of the lake were too thin to measure their hydraulic conductivity.

## Horsfall Lake

Lake-bottom deposits were less than 0.2 foot thick in cores from an arm of Horsfall Lake that lies northwest of well 50 (pl. 1). In October 1970 the size of the lake was unusually small, and its maximum depth of less than 1½ feet permitted visual inspection. The bottom appeared to be free of significant thicknesses of silt.

## Spirit Lake

Spirit Lake dried completely in September 1970, exposing a bottom of mostly clean sand; in the lowest areas silt was as much as several tenths of a foot thick.

In October 1970, water from production wells was discharged into the lake, west of well 55, at an initial rate of 410 gpm. The lake began to re-form, and the water rose to a depth of 1½ feet in 1 day. After 3 days of pumping, the rate was increased to 680 gpm, but a maximum depth of 2 feet and a surface area of about 20 acres was not achieved until the sixth day of pumping. The estimated volume of the lake was substantially less than the total discharge into the lake, indicating that the water was moving easily through the bottom and nearly flat sides of the lake.

Table 11.--Data from survey of bottom deposits of Bluebill Lake

| Site no. | Depth of water[1/] (feet) | Recovered thickness of lake-bottom deposits (feet) | Vertical hydraulic conductivity (ft day$^{-1}$) |
|---|---|---|---|
| 1 | 2.7 | 0.8 | 0.25 |
| 2 | 2.7 | .8 | -- |
| 3 | 2.1 | .6 | -- |
| 4 | 1.1 | .6 | -- |
| 5 | 1.7 | .5 | -- |
| 6 | 2.3 | .4 | -- |
| 7 | 2.7 | .8 | -- |
| 8 | 2.6 | .8 | -- |
| 9 | 2.4 | .7 | -- |
| 10 | 1.8 | .3 | -- |
| 11 | 1.7 | .1 | -- |
| 12 | 2.2 | .4 | -- |
| 13 | 1.7 | .2 | -- |
| 14 | 2.2 | .2 | -- |
| 15 | 2.9 | .6 | .1 |
| 16 | 2.6 | .5 | -- |
| 17 | 2.4 | .6 | Near zero |
| 18 | 2.2 | .4 | .13 |
| 19 | 2.1 | .8 | .08 |
| 20 | 1.6 | .8 | -- |
| 21 | 1.3 | 1.0 | -- |
| 22 | .5 | 2/ | .87 |

1/ Stage gage reading 14.1 feet above mean sea level during survey, August 25-26, 1970.
2/ Reference test of dune sand only.

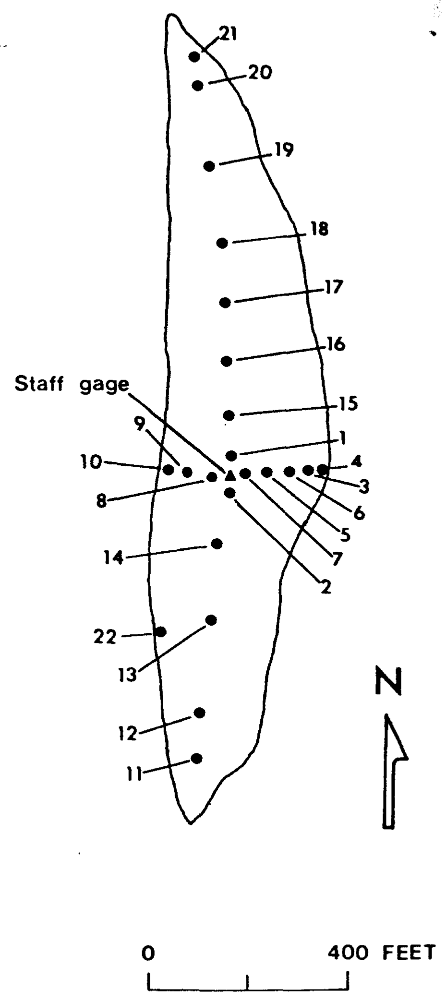


Figure 22. — Map of Bluebill Lake showing locations of core sites.

Table 12.--Data from survey of bottom deposits of Sandpoint Lake

| Site no. | Depth of water 1/ (feet) | Recovered thickness of lake-bottom deposits (feet) |
|---|---|---|
| 1 | 2.9 | 0.15 |
| 2 | 3.3 | .2 |
| 3 | 3.3 | .15 |
| 4 | 2.9 | .1 |
| 5 | 2.2 | .05 |
| 6 | 3.4 | -- |
| 7 | 2.3 | .05 |
| 8 | 2.5 | 0 |
| 9 | 2.2 | .1 |
| 10 | .5 | .5 |
| 11 | 3.5 | -- |
| 12 | 2/ | 2/ |
| 13 | 2.7 | .3 |
| 14 | 2.5 | .1 |
| 15 | 1.9 | .2 |
| 16 | 2.2 | .1 |
| 17 | 1.5 | 0 |
| 18 | 3.2 | .2 |
| 19 | 3.0 | .3 |
| 20 | 2.4 | .7 |
| 21 | 2.5 | 1.0 |
| 22 | 2.7 | 1.0 |
| 23 | 2.8 | .9 |
| 24 | 2.1 | 1.6 |
| 25 | 3.4 | .1 |
| 26 | 2.6 | .3 |

1/ Staff gage near McKeown landing read 4.3 feet during survey, August 27, 1970.

2/ Site of unsuccessful attempt to install piezometer.

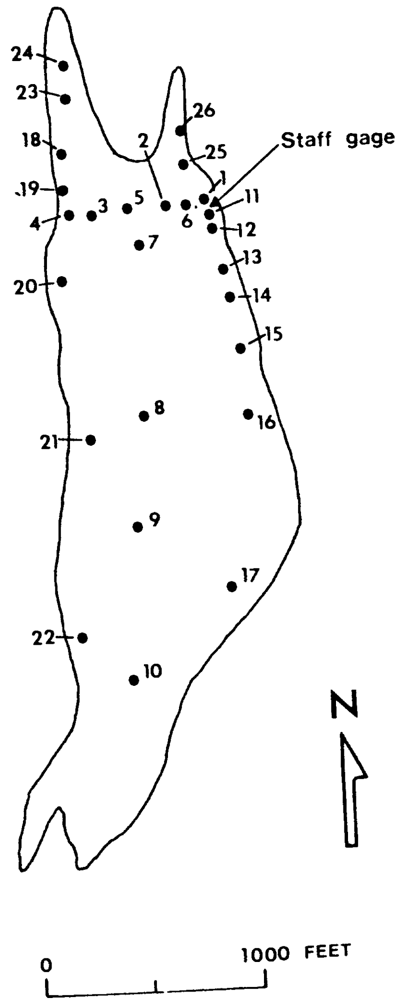


Figure 23. – Map of Sandpoint Lake showing locations of core sites.

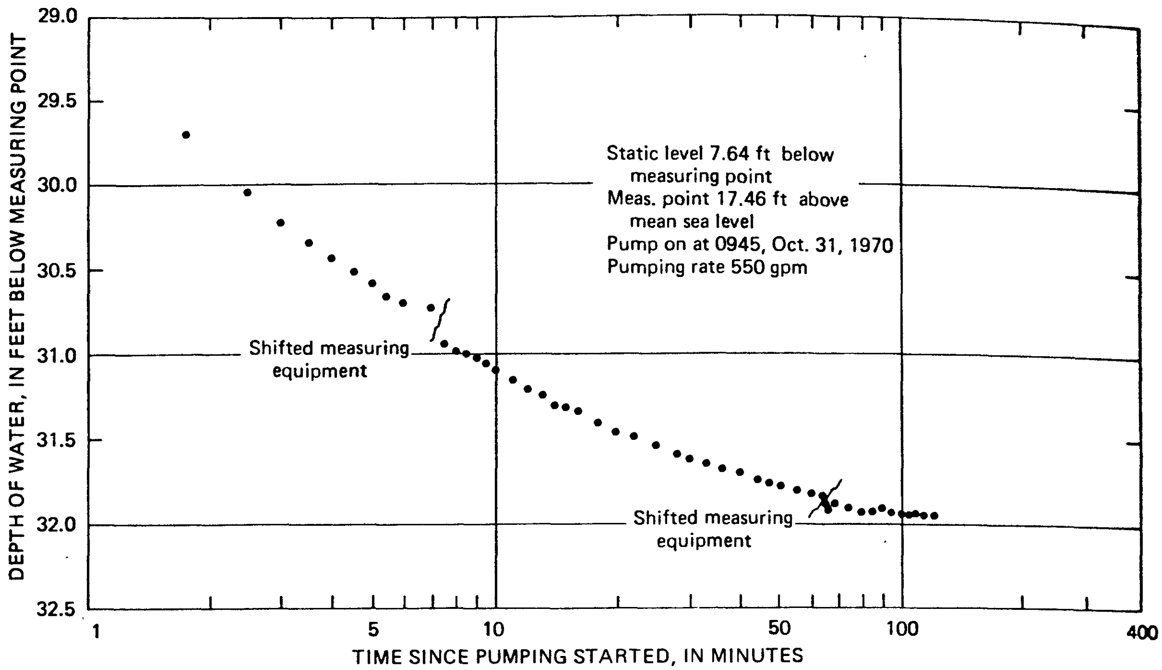


Figure 24. — Water level in well 46 during a drawdown test.

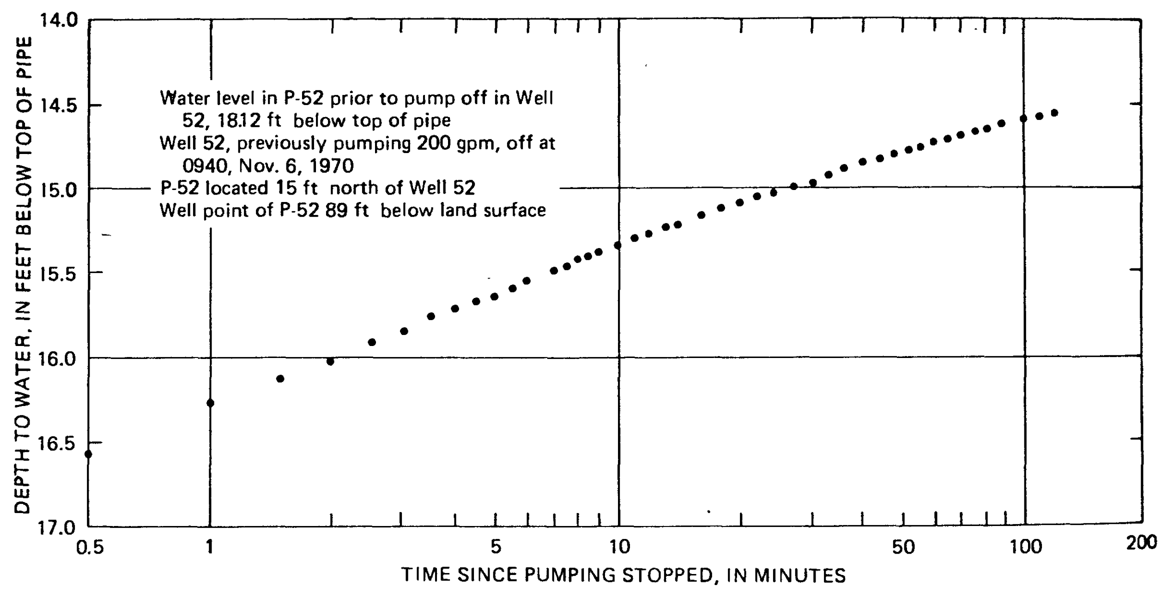


Figure 25. — Water level in piezometer P-52 during a recovery test of well 52 (24S/13W-28dda).

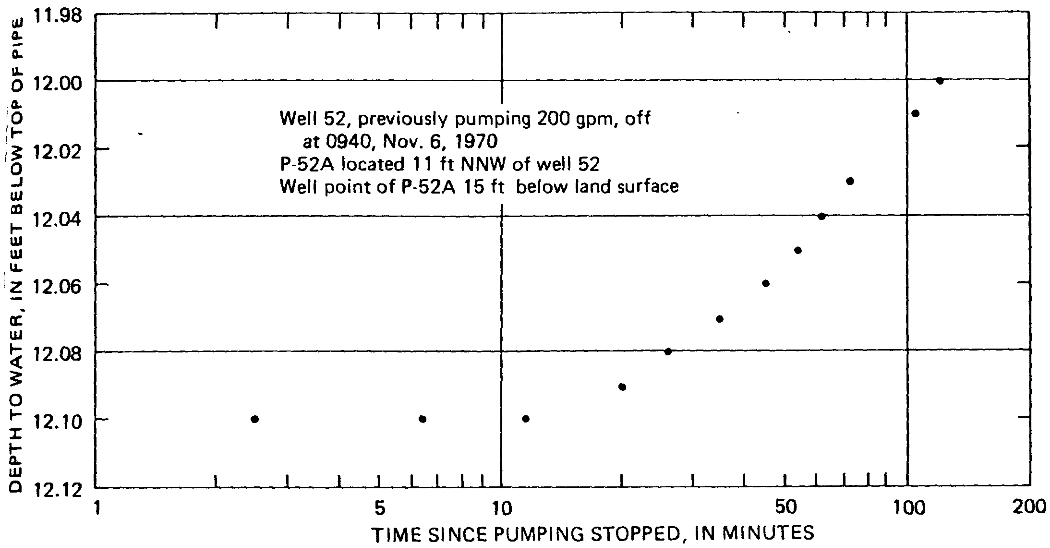


Figure 26. – Water level in piezometer P-52A during a recovery test of well 52 (24S/13W-28dda).

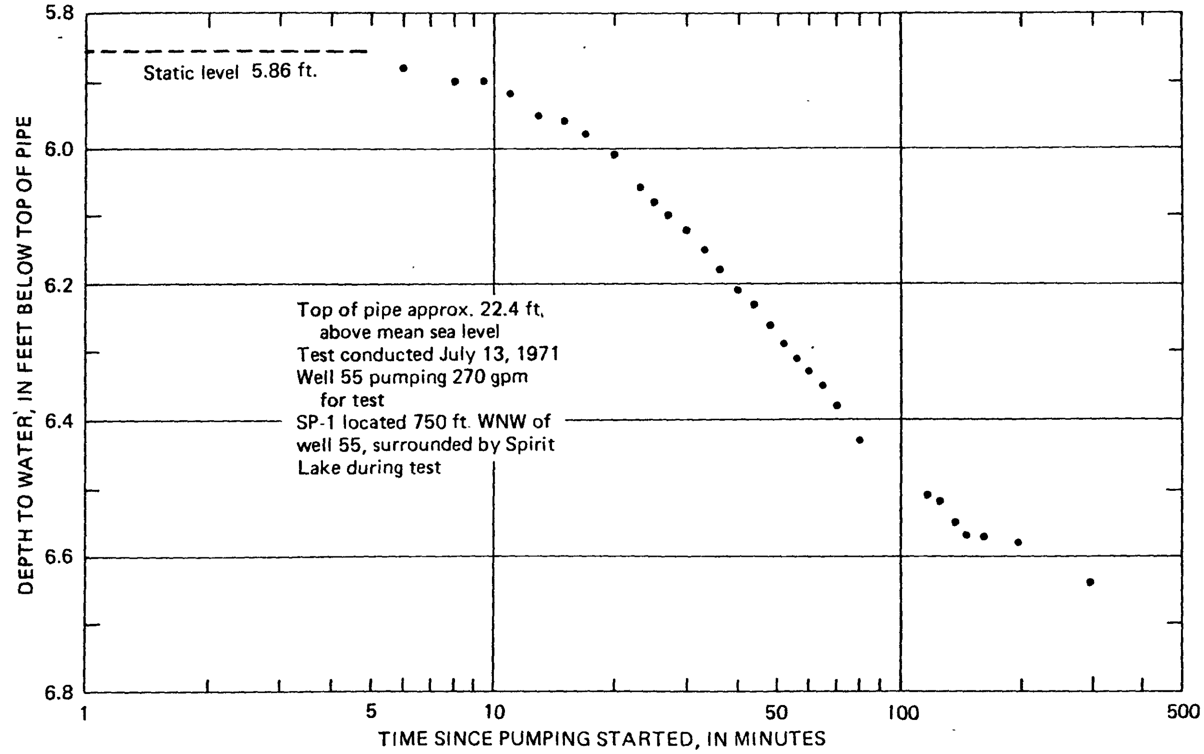


Figure 27. – Water level in piezometer SP-1 (24S/13W-28aaa) during a drawdown test of well 55 (24S/13W-27bbd) (semilog).

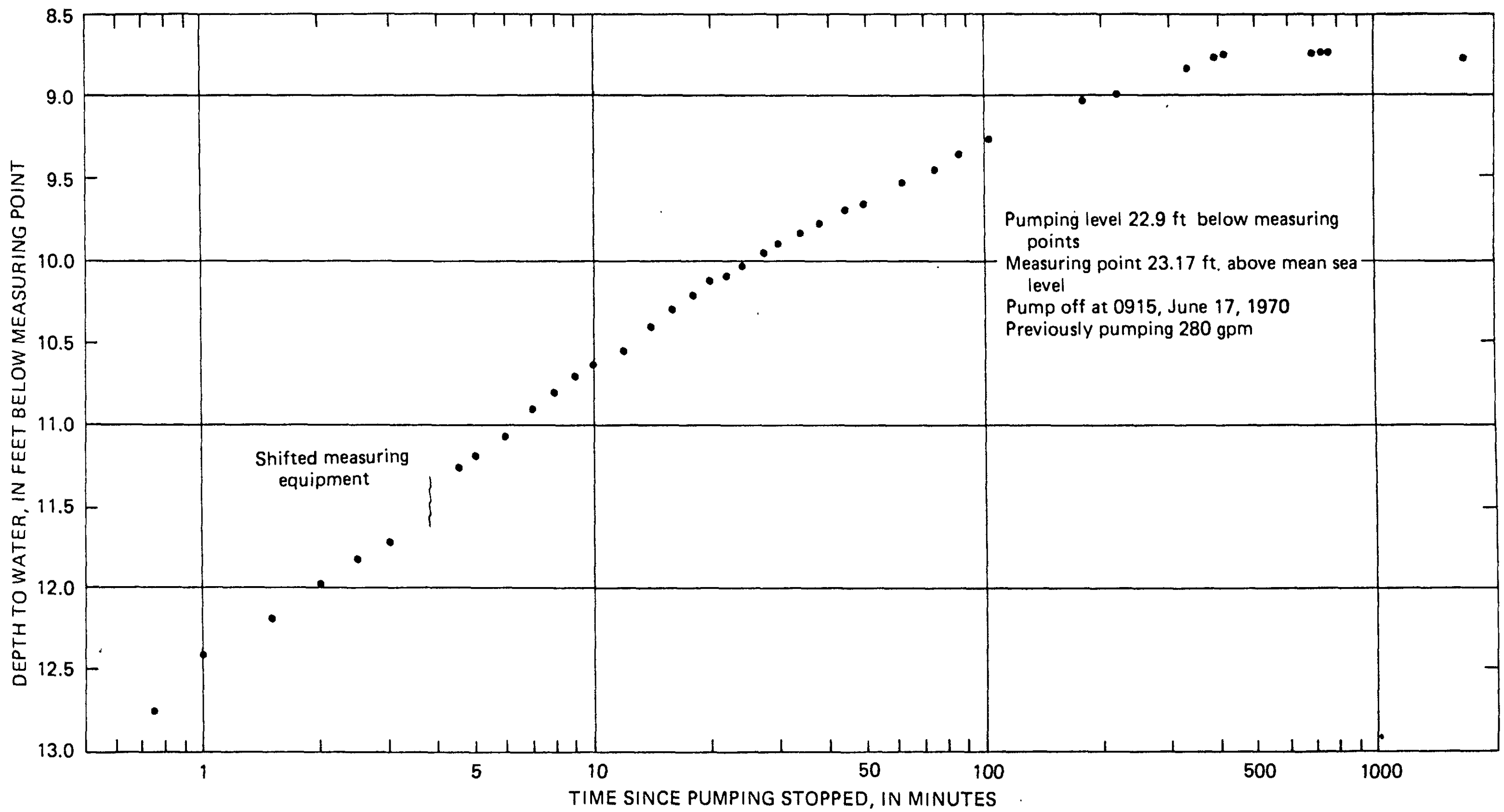


Figure 28. — Water level in well 54 during a recovery test.

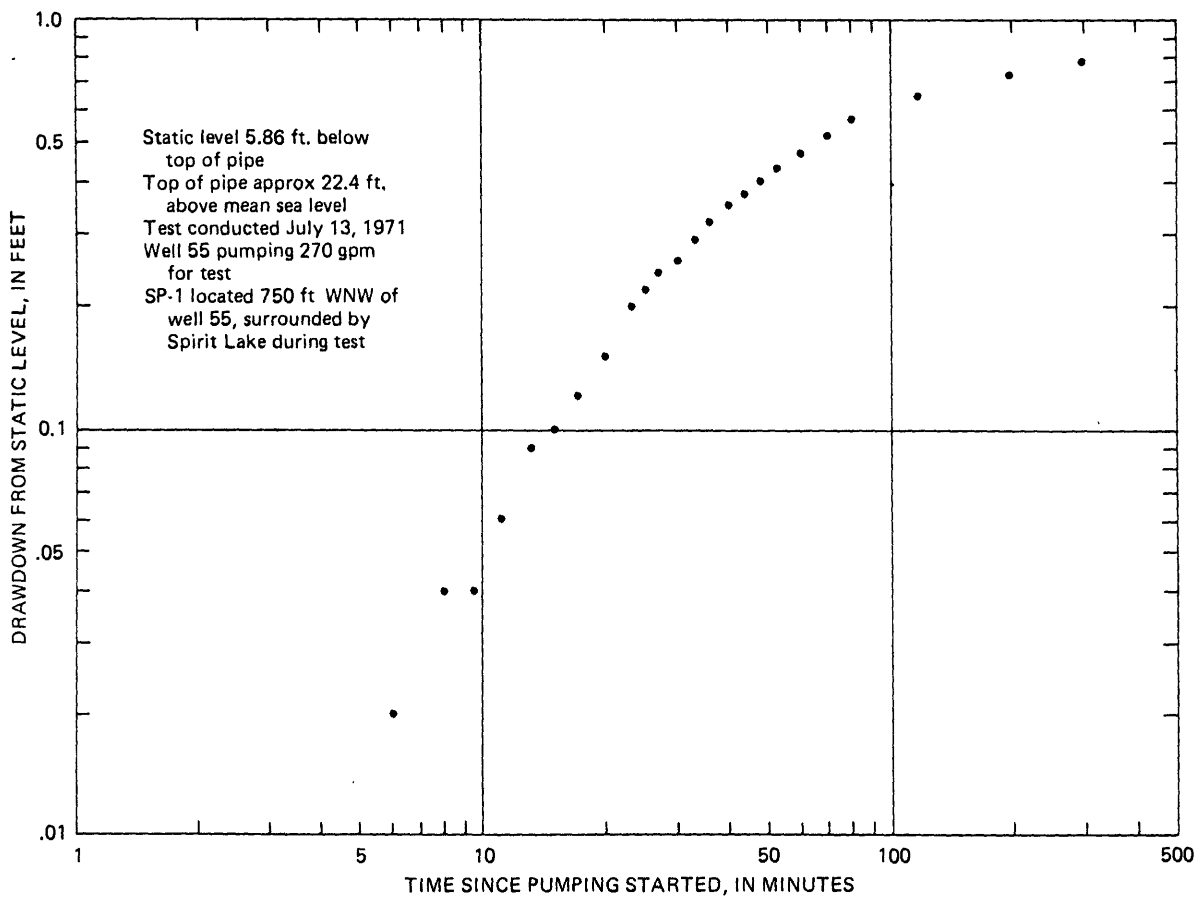


Figure 29. — Water level in piezometer SP-1 (24S/13W-28aaa) during a drawdown test of well 55 (24S/13W-27bbd) (log).

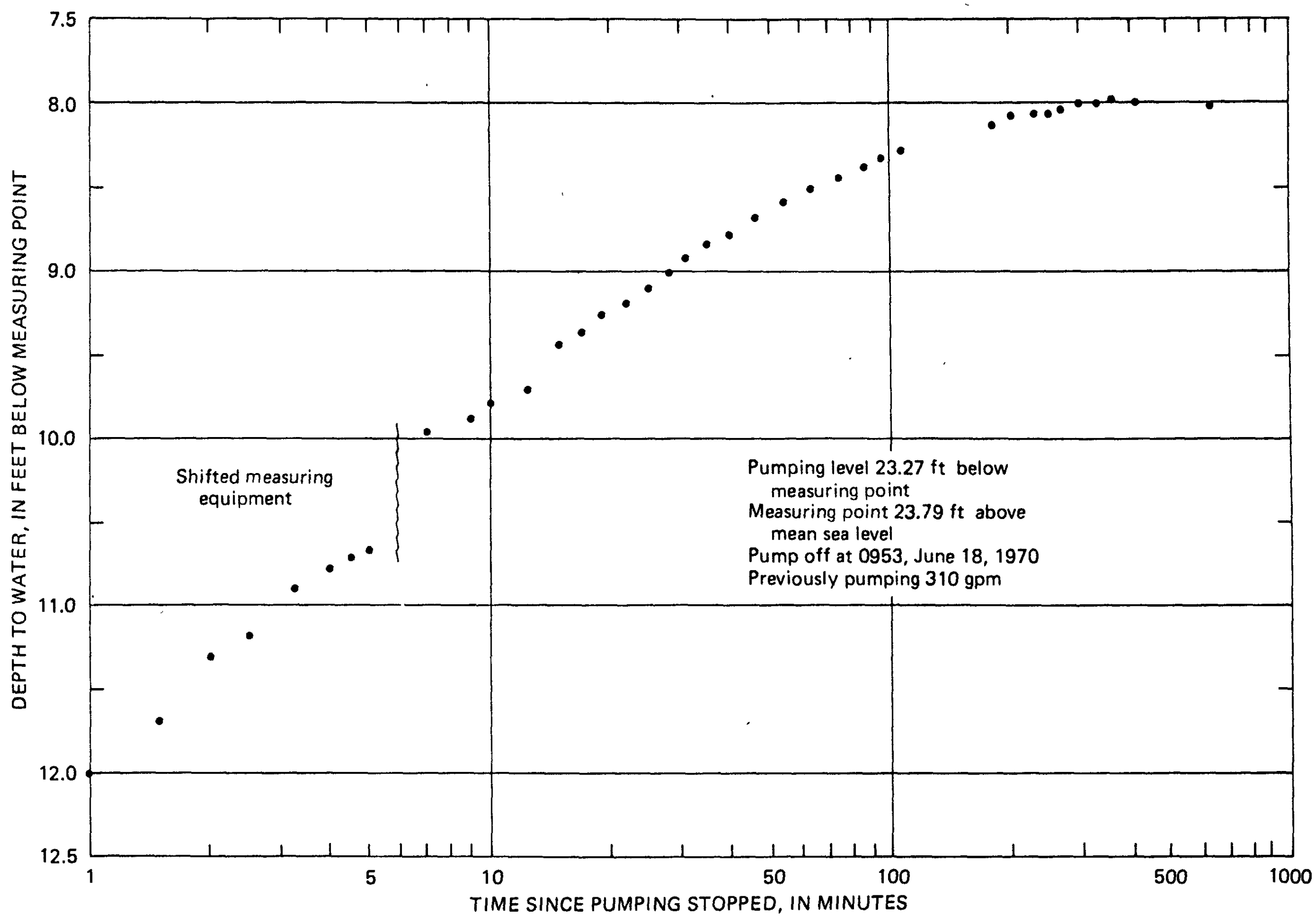


Figure 30. — Water level in well 57 during a recovery test.

Table 13.--Selected values and conversion factors for model analysis

Modeled area subject to recharge:

$$20.5\ mi^2 = 13{,}000\ acres = 5.7 \times 10^8\ ft^2$$

$1\ mi^2 = 640\ acres = 27.8 \times 10^6\ ft^2$

$1\ ft^3 = 7.48\ gallons$

1 mgd = 695 gpm = 1.55 cfs = 3.07 af $day^{-1}$ = 1,120 af $yr^{-1}$

1,000 gpm = 1.44 mgd = 2.23 cfs = 4.42 af $day^{-1}$ = 1,613 af $yr^{-1}$

1 cfs = 449 gpm = 0.646 mgd = 1.98 af $day^{-1}$ = 724 af $yr^{-1}$

Assumed average precipitation:

| | | Per $mile^2$ | Per 20.5 $mi^2$ |
|---|---|---|---|
| 62.5 inches or | | 2,050 gpm | 42,000 gpm |
| 5.2 ft per year | = | 3.0 mgd | 61 mgd |
| | | 3,300 af $yr^{-1}$ | 68,000 af $yr^{-1}$ |

Assumed average pumping rate per well; individual analyses in table 8 specify which wells considered operational:

| | | | |
|---|---|---|---|
| Analyses 1-4, 6 | Wells 1-46 | 0.310 mgd | 215 gpm |
| | 47-64 | .206 | 143 |
| Analyses 5, 7 | Wells 1-46 (29 wells) | .435 | 302 |
| | 47-64 (18 wells) | .289 | 201 |
| P. P. & L. | Wells 1-46 (46 wells) | .535 | 370 |
| | 47-64 (18 wells) | .316 | 220 |

Table 14.--Drillers' logs of production wells of the Coos Bay-North Bend Water Board

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| **Well 41.** 24S/13W-21ccd. Alt 21 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in diam to 57 ft, 8-in. diam 51-115 ft; screened 57-104 ft | | | |
| Sand, blue | 20 | 20 | +1 |
| Sand, gray | 5 | 25 | -4 |
| Sand, gray, with shells | 21 | 46 | -25 |
| Sand, very dark gray | 7 | 53 | -32 |
| Sand, gray, coarse | 8 | 61 | -40 |
| Sand, light-gray | 19 | 80 | -59 |
| Sand, gray | 4 | 84 | -63 |
| Sand, dark-gray | 6 | 90 | -69 |
| Sand, dark-gray, shells and wood | 8 | 98 | -77 |
| Sandstone, gray | 7 | 105 | -84 |
| Shale, brown, hard | 5 | 110 | -89 |
| Shale, dark-brown, hard | 5 | 115 | -94 |
| **Well 42.** 24S/13W-28bcc. Alt 22 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in diam to 52 ft, 8-in diam 48-140 ft; screened 52-100 ft | | | |
| Sand, brown, with wood | 26 | 26 | -4 |
| Sand, blue, fine | 44 | 70 | -48 |
| Sand, brownish-gray, medium | 22 | 92 | -70 |
| Sand, coarse, with wood and shells | 25 | 117 | -95 |
| Sand, dark bluish-gray, with wood and peat | 2 | 119 | -97 |
| Sand, dark bluish-gray | 15 | 134 | -112 |
| Sandstone, gray, hard | 6 | 140 | -118 |
| **Well 43.** 24S/13W-29dda. Alt 20 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 70 ft, 8-in. diam 66-183 ft; screened 71-108 ft, 150-171 ft | | | |
| Sand, yellow, fine | 6 | 6 | +14 |
| Sand, yellow, fine, with vegetation | 6 | 12 | +8 |
| Sand, yellow, fine | 13 | 25 | -5 |
| Sand, light-green, fine, and silt | 42 | 67 | -47 |
| Sand, dark-gray, medium | 31 | 98 | -78 |
| Sand, dark-gray, medium, and shells | 10 | 108 | -88 |
| Sand, dark-gray, medium | 27 | 135 | -115 |
| Sand, dark-gray, medium, with clay and gravel | 42 | 177 | -157 |
| Clay, blue, soft, sticky, and shells | 6 | 183 | -163 |
| **Well 44.** 24S/13W-32abd. Alt 22 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 86 ft, 8-in. diam 81-196 ft; screened 87-119 ft, 159-185 ft | | | |
| Sand, brown, fine | 15 | 15 | +7 |
| Wood, bark, and fine brown sand | 8 | 23 | -1 |
| Sand, brown, coarse, and silt | 17 | 40 | -18 |
| Sand, light blue-gray, coarse | 151 | 191 | -169 |
| Clay, blue, soft, sticky | 5 | 196 | -174 |
| **Well 45.** 24S/13W-32acc. Alt 18 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 69 ft, 8-in. diam 63-190 ft; screened 69-84 ft, 108-130 ft, 154-176 ft | | | |
| Sand, yellow, fine | 25 | 25 | -7 |
| Sand, light-green, fine | 10 | 35 | -17 |
| Sand, brown, medium | 15 | 50 | -32 |
| Sand, brown, medium, and shells | 22 | 72 | -54 |
| Sand, brown, medium | 11 | 83 | -65 |
| Sand, brown, medium, and shells | 5 | 88 | -70 |
| Sand, brown, medium | 22 | 110 | -92 |
| Sand, gray, medium, and some small gravel | 60 | 170 | -152 |
| Sand, gray, medium, gravel and shells | 15 | 185 | -167 |
| Clay, dark-gray, sticky | 5 | 190 | -172 |
| **Well 46.** 24S/13W-32dcb. Alt 17 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 78 ft, 8-in. diam 73-190 ft; screened 80-111 ft, 159-180 ft | | | |
| Sand, fine | 20 | 20 | -3 |
| Sand, light-blue and gray, fine | 22 | 42 | -25 |
| Sand, light-gray | 5 | 47 | -30 |
| Sand, very light gray, coarse | 16 | 63 | -46 |
| Sand, light-brown, coarse | 17 | 80 | -63 |
| **Well 46.**--Continued | | | |
| Sand, coarse; clay and shells | 14 | 94 | -77 |
| Sandstone and shells | 24 | 118 | -101 |
| Sandstone, gravel, and shells | 7 | 125 | -108 |
| Sand, gray | 6 | 131 | -114 |
| Clay; sand, coarse, and shells | 4 | 135 | -118 |
| Sand, very coarse, with small gravel and shells | 3 | 138 | -121 |
| Sand, gray, coarse | 7 | 145 | -128 |
| Sand, dark-gray, coarse, with shells; shale | 15 | 160 | -143 |
| Sand, with wood, shells, and clay | 13 | 173 | -156 |
| Sand, very coarse, and small gravel | 2 | 175 | -158 |
| Clay and coarse sand; wood and shells | 9 | 184 | -167 |
| Shale and clay | 6 | 190 | -173 |
| **Well 47** (formerly Pacific Power & Light Co. pilot well 2). 24S/13W-33acc (formerly 24/13W-33L1). Alt 24 ft. Drilled in 1957. Casing: 12-in diam; screened 56-135 ft | | | |
| No sample | 20 | 20 | +4 |
| Sand, fine, with thin bands of clay | 35 | 55 | -31 |
| Sand, coarse, fossiliferous | 5 | 60 | -36 |
| Sand, medium to coarse | 15 | 75 | -51 |
| Sand, medium to coarse, fossiliferous | 10 | 85 | -61 |
| Sand, coarse, fossiliferous | 10 | 95 | -71 |
| Sand, medium to fine, fossiliferous | 25 | 120 | -96 |
| Sand, medium to fine, fossiliferous, with thin clay layers | 15 | 135 | -111 |
| Sand, coarse; shale and rock fragments | 3 | 138 | -114 |
| Clay, shale, or siltstone | 7 | 145 | -121 |
| **Well 48** (formerly Pacific Power & Light Co. pilot well 4). 24S/13W-33dbc (formerly 24/13W-33Q1). Alt 26 ft. Drilled in 1957. Casing: 10-in. diam; screened 82-134 ft | | | |
| Sand, fine, with thin bands of clay | 45 | 45 | -19 |
| Sand, coarse, fossiliferous | 20 | 65 | -39 |
| Sand, medium to coarse, fossiliferous | 25 | 90 | -64 |
| Sand, coarse, fossiliferous | 10 | 100 | -74 |
| No sample | 5 | 105 | -79 |
| Sand, coarse, fossiliferous | 15 | 120 | -94 |
| Sand, medium to fine, fossiliferous | 5 | 125 | -99 |
| Sand, medium to fine, with thin clay layers | 13 | 138 | -112 |
| Clay, shale, or siltstone | 4 | 142 | -116 |
| **Well 49** (formerly Pacific Power & Light Co. pilot well 3). 24S/13W-33adc (formerly 24/13W-33K2). Alt 23 ft. Drilled in 1957. Casing: 10-in. diam; screened 78-130 ft | | | |
| Sand, fine, with thin bands of clay | 35 | 35 | -12 |
| Sand, fine, fossiliferous | 20 | 55 | -32 |
| Sand, coarse; few thin clay bands near top | 15 | 70 | -47 |
| Sand, medium,to coarse, fossiliferous | 25 | 95 | -72 |
| Sand, coarse, fossiliferous | 5 | 100 | -77 |
| Sand, medium to fine, fossiliferous | 5 | 105 | -82 |
| Sand, medium to fine, fossiliferous; with thin clay layers | 25 | 130 | -107 |
| Sand, coarse; shell and rock fragments | 6 | 136 | -113 |
| Clay, shale, or siltstone | 4 | 140 | -117 |
| **Well 50.** 24S/13W-33adbl. Alt 25 ft. Drilled by L. R. Gaudio Drilling Co., 1960. Casing: 10-in. diam to 66 ft, 8-in. diam 63-141 ft; screened 63-120 ft | | | |
| Sand, medium, with ½-in. clay bed at 45 ft and 50 ft, shell fragments at 70 ft and 95 ft | 102 | 102 | -77 |
| Sand, fine, and shell fragments, with 1-in. clay layer at 109 ft | 7 | 109 | -84 |
| Sand, medium, with shells at 124 ft and 130 ft | 31 | 140 | -115 |
| Siltstone, poorly consolidated | 2 | 142 | -117 |
| Rock, soft | 8 | 150 | -125 |

Table 14.--Drillers' logs of production wells of the Coos Bay-North Bend Water Board--Continued

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| ell 51. 24S/13W-28ddd. Alt 21 ft. Drilled by L. R. Gaudio Drilling Co., 1960. Casing: 10-in. diam to 61 ft, 8-in. diam 61-135 ft; screen 61-81 ft, 104-135 ft | | | |
| and, medium, with ½-in. clay layer at 40 ft, and shell fragments at 45 ft | 55 | 55 | -34 |
| and, with shells | 5 | 60 | -39 |
| and, medium | 20 | 80 | -59 |
| and, with shells | 7 | 87 | -66 |
| and, shells, and clay | 6 | 93 | -72 |
| and, fine, with some shells | 27 | 120 | -99 |
| and, medium, with some shells | 10 | 130 | -109 |
| and, fine | 5 | 135 | -114 |
| and, medium, and shells | 21 | 156 | -135 |
| and, medium; clay, shells, and wood | 8 | 164 | -143 |
| ock, soft | 11 | 175 | -154 |
| ell 52. 24S/13W-28ddal. Alt 22 ft. Drilled by L. R. Gaudio Drilling Co., 1960. Casing: 10-in. diam to 60 ft, 8-in. diam 60-170 ft; screened 60-85 ft, 140-170 ft | | | |
| and, medium | 78 | 78 | -56 |
| and, medium, with shells | 14 | 92 | -70 |
| lay | 6 | 98 | -76 |
| and, fine, and some shells, with clay and wood at 140 ft | 42 | 140 | -118 |
| and, medium | 7 | 147 | -125 |
| and, medium; shells and wood | 40 | 187 | -165 |
| and, clay, shells, and wood | 24 | 211 | -189 |
| ock, soft | 1 | 212 | -190 |
| ell 53. 24S/13W-27cbbl. Alt 23 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 50 ft, 8-in. diam 46-127 ft; screened 56-97 ft | | | |
| and, yellow, fine | 20 | 20 | +3 |
| and, green, fine | 19 | 39 | -16 |
| and, brown, coarse, and silt | 3 | 42 | -19 |
| and, fine, and silt, blue | 3 | 45 | -22 |
| and, coarse, and shells | 5 | 50 | -27 |
| hells and blue sand | 2 | 52 | -29 |
| and, blue, coarse, and shells | 13 | 65 | -42 |
| and, blue, coarse | 10 | 75 | -52 |
| and, blue, coarse, and shells | 20 | 95 | -72 |
| and, coarse; shells and pebbles | 6 | 101 | -78 |
| lay, dark-blue; sand, wood, and bark | 3 | 104 | -81 |
| og | 3 | 107 | -84 |
| lay, dark-blue; sand and soft boulders | 5 | 112 | -89 |
| and, silt, rotten bark, and wood | 8 | 120 | -97 |
| lay, blue, soft, sticky | 8 | 128 | -105 |
| ell 54. 24S/13W-27bcc. Alt 23 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 54 ft, 8-in. diam 49-113 ft; screened 55-102 ft | | | |
| egetation, decomposed | 1 | 1 | +22 |
| and, brown and yellow | 28 | 29 | -6 |
| and, blue, and silt | 17 | 46 | -23 |
| and, blue, and shells | 5 | 51 | -28 |
| and, blue-gray | 9 | 60 | -37 |
| and, gray, coarse; with shells | 30 | 90 | -67 |
| and, gray, and wood | 2 | 92 | -69 |
| and, gray, and shells | 13 | 105 | -82 |
| nd and clay | 1 | 106 | -83 |
| laystone, blue | 7 | 113 | -90 |
| Well 55. 24S/13W-27bbdl. Alt 24 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 53 ft, 8-in. diam 46-115 ft; screened 53-97 ft | | | |
| Sand, yellow and brown | 33 | 33 | -9 |
| Sand, brown and blue | 4 | 37 | -13 |
| Sand, blue, medium to fine | 13 | 50 | -26 |
| Sand, blue, with clay | 3 | 53 | -29 |
| Sand, blue, coarse | 25 | 78 | -54 |
| Sand, blue, fine | 9 | 87 | -63 |
| Sand, blue; shells and small gravel | 20 | 107 | -83 |
| Claystone, blue | 8 | 115 | -91 |
| Well 56. 24S/13W-22ccc. Alt 26 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 58 ft, 8-in. diam 54-114 ft; screened 58-100 ft | | | |
| Sand, fine | 20 | 20 | +6 |
| Sand, light-blue, with thin layer of vegetation | 2 | 22 | +4 |
| Sand, light-blue | 24 | 46 | -20 |
| Sand, blue | 14 | 60 | -34 |
| Sand, gray | 20 | 80 | -54 |
| Sand, gray, coarse, and shells | 15 | 95 | -69 |
| Sand, gray, and shells | 9 | 104 | -78 |
| Shells, clay, and mud | 1 | 105 | -79 |
| Clay | 11 | 116 | -90 |
| Well 57. 24S/13W-22cbd. Alt 23 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 54 ft, 8-in. diam 53-119 ft; screened 58-100 ft | | | |
| Sand, brown and yellow, fine | 29 | 29 | -6 |
| Peat | ½ | 29½ | -6½ |
| Sand, brown and blue | 3½ | 33 | -10 |
| Sand, blue, medium to fine | 17 | 50 | -27 |
| Sand, blue, fine, and clay | 1 | 51 | -28 |
| Sand, blue, coarse | 14 | 65 | -42 |
| Sand, blue, coarse, with shells | 3 | 68 | -45 |
| Sand, blue, medium | 32 | 100 | -77 |
| Sand, blue, with wood and shells | 2 | 102 | -79 |
| Sand, blue, coarse | 7 | 109 | -86 |
| Claystone | 10 | 119 | -96 |
| Well 58. 24S/13W-22bdc. Alt 24 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 10-in. diam to 63 ft, 8-in. diam 58-125 ft; screened 63-111 ft | | | |
| Sand, brown, fine | 19 | 19 | +5 |
| Sand, brown, fine, and vegetation | 6 | 25 | -1 |
| Sand, brown, fine | 10 | 35 | -11 |
| Sand, blue, coarse, with a little silt | 15 | 50 | -26 |
| Sand, blue, medium | 11 | 61 | -37 |
| Sand, gray | 9 | 70 | -46 |
| Shells and coarse sand | 1 | 71 | -47 |
| Sand, gray, coarse, and shells; trace of silt | 14 | 85 | -61 |
| Sand, coarse; small amount of gravel | 4 | 89 | -65 |
| Sand with small shells | 5 | 94 | -70 |
| Sand, gray, with wood | 2 | 96 | -72 |
| Sand, light-gray, with many shells | 4 | 100 | -76 |
| Sand, gray, coarse, and some shells | 10 | 110 | -86 |
| Sand, light-blue, and shells | 5 | 115 | -91 |
| Sand, coarse, and clam shells with wood | 2 | 117 | -93 |
| Claystone | 8 | 125 | -101 |

Table 15.--Drillers' logs of miscellaneous wells, piezometers, and test holes

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| **Test hole Booster Access 1 (BA-1B).** 24S/13W-33cca2. Alt about 24 ft. Augered by U.S. Geological Survey, 1970. Casing: 1¼-in. diam pipe and well point; bottom of well point 115 ft below land surface | | | |
| Sand, gray, medium and fine | 122 | 122 | -98 |
| **Test hole Tenmile 2 (TM-2B).** 23S/13W-22dac2. Alt about 10 ft. Augered by U.S. Geological Survey, 1970. Casing: 1¼-in. pipe and well point; bottom of well point 115 ft below land surface | | | |
| Sand, gray, medium and fine, well-rounded, well-sorted | 90 | 90 | -80 |
| Sand, yellow, fine, subangular, with clay pebbles | 5 | 95 | -85 |
| Sand, dark-gray, fine, subrounded, with silt | 27 | 122 | -112 |
| **Test hole Spirit Lake 1 (SP-1).** 24S/13W-28aaa. Alt about 18 ft. Augered by U.S. Geological Survey, 1970. Casing: 1¼-in. diam pipe and well point; bottom of well point 95 ft below land surface | | | |
| Sand, fine to medium | 84 | 84 | -66 |
| Clay, silty | 1 | 85 | -67 |
| Sand, gray, silty | 7 | 92 | -74 |
| Clay | 5 | 97 | -79 |
| Sand, silty | 5 | 102 | -84 |
| Sand, silty, with layers of clay | 5 | 107 | -89 |
| Sand, silty | 10 | 117 | -99 |
| **Test hole Bluebill 1 (BB-1).** 24S/13W-32add. Alt about 19 ft. Augered by U.S. Geological Survey, 1970. Casing: 1¼-in. diam pipe and well point; bottom of well point 105 ft below land surface | | | |
| Sand, beige, fine to medium | 2 | 2 | +17 |
| Sand, gray, fine to medium | 6 | 8 | +11 |
| Sand, brown and gray, fine to medium; some silt | 5 | 13 | +6 |
| Sand, gray, fine to medium | 92 | 105 | -86 |
| **Test hole Horsfall 1 (HF-1B).** 24S/13W-33bad2. Alt about 20 ft. Augered by U.S. Geological Survey, 1970. Casing: 1¼-in. pipe and well point; bottom of well point 105 ft below land surface | | | |
| Sand, brown, fine to medium | 7 | 7 | +13 |
| Sand, beige, fine to medium | 5 | 12 | +8 |
| Sand, gray, fine to medium | 113 | 125 | -105 |
| **Piezometers P-41 and P-41A.** 24S/13W-20dcb1 and 2. Alt 18 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: P-41: 2-in. diam pipe and well point; altitude bottom of well point -108 ft. P-41A: 2-in. diam pipe and well point; altitude bottom of well point -132 ft | | | |
| Sand, fine | 61 | 61 | -43 |
| Sand, gray | 18 | 79 | -61 |
| Sand, dark-gray | 8 | 87 | -69 |
| Sand, gray | 11 | 98 | -80 |
| Sand, dark-gray | 12 | 110 | -92 |
| Sand, gray, and shells | 20 | 130 | -112 |
| Sand, gray, coarse, and shells | 8 | 138 | -120 |
| Sand, silt, wood, and shells | 9 | 147 | -129 |
| Sand, gray, silt, and shells | 14 | 161 | -143 |
| Shale | 7 | 168 | -150 |
| **Piezometer P-42.** 24S/13W-29adb. Alt 18 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point at altitude -117 ft | | | |
| Sand, fine | 15 | 15 | +3 |
| Sand, blue | 20 | 35 | -17 |
| Sand, gray | 8 | 43 | -25 |
| Sand, dark-gray, coarse | 7 | 50 | -32 |
| Sand, dark-gray; and shells | 28 | 78 | -60 |
| Sand, dark-gray, coarse | 12 | 90 | -72 |
| **Piezometer P-42.**--Continued | | | |
| Sand, black, coarse, and shells | 8 | 98 | -80 |
| Sand, dark-gray; shale and sandstone | 4 | 102 | -84 |
| Shale, gray; sand and clay | 24 | 126 | -108 |
| Sand, blue, very coarse | 1 | 127 | -109 |
| Shale and clay | 17 | 144 | -126 |
| **Piezometer P-43.** 24S/13W-29dbd. Alt 17 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude -157 ft | | | |
| Sand, fine | 19 | 19 | -2 |
| Sand, blue | 3 | 22 | -5 |
| Sand, gray, and shells | 28 | 50 | -33 |
| Sand, gray | 10 | 60 | -43 |
| Sand, dark-gray, coarse | 15 | 75 | -58 |
| Sand, gray, coarse, and shells | 20 | 95 | -78 |
| Sand, gray, with gravel and shells | 10 | 105 | -88 |
| Sand, gray, and silt | 40 | 145 | -128 |
| Sand, light-gray, coarse | 10 | 155 | -138 |
| Sand, gray, coarse | 7 | 162 | -145 |
| Sand, gray, very coarse | 19 | 181 | -164 |
| **Piezometer P-44.** 24S/13W-32baa1. Alt 12 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude -141 ft | | | |
| Sand, yellow, fine | 29 | 29 | -17 |
| Sand, gray-brown, medium | 46 | 75 | -63 |
| Sand, gray, fine; shells and silt | 45 | 120 | -108 |
| Sand, gray, medium | 35 | 155 | -143 |
| Clay, green, sticky | 4 | 159 | -147 |
| **Piezometer P-45.** 24S/13W-32bdc. Alt 13 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude -141 ft | | | |
| Sand, fine | 37 | 37 | -24 |
| Sand, gray, with a little rock | 10 | 47 | -34 |
| Sand, gray | 10 | 57 | -44 |
| Sand, gray, and shells | 15 | 72 | -59 |
| Sand, brown, coarse | 15 | 87 | -74 |
| Sand, brown | 10 | 97 | -84 |
| Sand, brown, and shells | 30 | 127 | -114 |
| Sand, gray, and shells | 33 | 160 | -147 |
| Clay, dark-brown | 10 | 170 | -157 |
| **Piezometers P-46 and P-46A.** 24S/13W-32cca1 and 2. Alt 9 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: P-46: 2-in. diam pipe and well point; bottom of well point altitude -130 ft. P-46A: 2-in. diam pipe and well point; bottom of well point altitude -178 ft. | | | |
| Sand, fine | 29 | 29 | -20 |
| Sand, blue and gray | 24 | 53 | -44 |
| Sand, light-gray | 13 | 66 | -57 |
| Sand, gray, with shells | 26 | 92 | -83 |
| Sand, blue, coarse | 11 | 103 | -94 |
| Sand, gray, coarse, with shells | 39 | 142 | -133 |
| Sand, gray, medium to coarse | 9 | 151 | -142 |
| Sand, gray, fine, packed, and very fine silt | 37 | 188 | -179 |
| Clay, blue-black, sticky | 3 | 191 | -182 |
| **Piezometer P-54.** 24S/13W-27bdb. Alt 18 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude -69 ft | | | |
| Sand, brown | 19 | 19 | -1 |
| Clay and silt | 1 | 20 | -2 |
| Sand, brown and blue | 8 | 28 | -10 |
| Sand, blue, with silt | 59 | 87 | -69 |
| Shale, blue | 5 | 92 | -74 |

Table 15.--Drillers' logs of miscellaneous wells, piezometers, and test holes--Continued

zometer P-55. 24S/13W-27bab. Alt 24 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and ell point; bottom of well point altitude -83 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| d, yellow, fine | 14 | 14 | +10 |
| d, yellow and gray | 7 | 21 | +3 |
| d, brown | 10 | 31 | -7 |
| d, clay, and silt, blue | 14 | 45 | -21 |
| y, brown, and vegetation | 3 | 48 | -24 |
| d, blue, coarse | 23 | 71 | -47 |
| d, gray, coarse, with shells | 13 | 84 | -60 |
| d, gray, very coarse, with shells | 23 | 107 | -83 |
| y and shale | 15 | 122 | -98 |

ezometer P-56. 24S/13W-22cdd. Alt 20 ft. Drilled by Casey Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude -88 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| d, brown | 27 | 27 | -7 |
| , black | 2 | 29 | -9 |
| d, blue, with silt | 13 | 42 | -22 |
| d, blue, fine | 56 | 98 | -78 |
| d, blue, coarse | 10 | 108 | -88 |
| le | 17 | 125 | -105 |

ezometer P-58. 24S/13W-22bdc. Alt about 20 ft. Drilled by Casay Jones Well Drilling, 1968. Casing: 2-in. diam pipe and well point; bottom of well point altitude about -110 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| d | 21 | 21 | -1 |
| getation | 1 | 22 | -2 |
| d, dark-brown | 1 | 23 | -3 |
| d, light-blue | 7 | 30 | -10 |
| d and clay | 5 | 35 | -15 |
| d and silt, dark-gray | 8 | 43 | -23 |
| d, black and white | 17 | 60 | -40 |
| d, black, with some white | 5 | 65 | -45 |
| d, gray, coarse | 25 | 80 | -60 |
| d, gray, very coarse, with shells | 10 | 90 | -70 |
| d and shells | 10 | 100 | -80 |
| d, gray, coarse | 14 | 114 | -94 |
| s and fine gray sand | 4 | 118 | -98 |
| d, gray, and shells | 12 | 130 | -110 |
| y and shale | 6 | 136 | -116 |

le 200C. 24S/13W-10cab3 (formerly 24/13W-10L1). Alt 35 ft. Drilled for Pacific Power & Light Co., 1957. Casing: 2-in. pipe and well point; bottom of well point at alt -84 ft, top of pipe at +37.46 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| d, consolidated and slightly consolidated | 49 | 49 | -14 |
| d, consolidated and slightly consolidated; thin clay lenses to ½-in. thick | 4 | 53 | -18 |
| d | 4 | 57 | -22 |
| d, with clay fragments to ½-in. diam | 2 | 59 | -24 |
| d and dark gray-green clay | 3 | 62 | -27 |
| d, with clay fragments to 3/4-in. diam | 2 | 64 | -29 |
| d, with many clay fragments to ½-in. diam | 3 | 67 | -32 |
| d, with few small clay fragments | 3 | 70 | -35 |
| d | 6 | 76 | -41 |
| d, with trace of mica; few fossils | 4 | 80 | -45 |
| d | 14 | 94 | -59 |
| d; trace of clay and claystone fragments | 3 | 97 | -62 |
| d, with mudstone fragments | 9 | 106 | -71 |
| d, with pebbles of sandstone, siltstone, and chert | 1 | 107 | -72 |
| y and mudstone, dark-brown | 14 | 121 | -86 |
| aystone, dark-gray, firm | 19 | 140 | -105 |
| aystone, gray, interbedded, firm | 10 | 150 | -115 |
| aystone, dark-gray, firm to well compacted, somewhat crumbly | 10 | 160 | -125 |
| aystone, dark-gray; interbeds of soft green clay | 30 | 190 | -155 |
| aystone with thin streaks of sandy siltstone | 10 | 200 | -165 |

Hole 200C.--Continued

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Claystone with some interbeds of soft olive-green clay; apparent dip 30° | 10 | 210 | -175 |
| Claystone, dark-gray to brown; hard drilling at 237 ft may be chert | 27 | 237 | -202 |
| Claystone, light gray-blue | 13 | 250 | -215 |
| Claystone, gray-green, silty to sandy, fossils; zones of fractured claystone | 10 | 260 | -225 |
| Claystone, well-indurated | 22 | 282 | -247 |
| Chert(?) | 2 | 284 | -249 |
| Claystone, well-indurated; interbedded soft streaks | 16 | 300 | -265 |
| Claystone, well-indurated; 6-in. bed of silty blue claystone; apparent dip 15° to 20° | 10 | 310 | -275 |
| Claystone and clay, oliva-drab, interbedded | 35 | 345 | -310 |
| Claystone, well-indurated, fossils; chert streaks | 5 | 350 | -315 |
| Claystone, light-gray to gray-green, well-indurated; apparent dip 15°-20° | 10 | 360 | -325 |
| Claystone, hard and soft interbedded; 3-in. chert streak at 352 ft | 27 | 387 | -352 |
| Claystone, hard, with fossils; chert streaks | 13 | 400 | -365 |
| Claystone, various colors, well-indurated; dip 15° to 20° | 10 | 410 | -375 |
| Clay and claystone, interbedded | 40 | 450 | -415 |
| Claystone, well-indurated; dip 20° to 30° | 10 | 460 | -425 |
| Claystone, well-indurated with soft beds of olive-drab claystone | 40 | 500 | -465 |
| Claystone, well-compacted; soft olive-drab claystone | 5 | 505 | -470 |

Hole 201. 24S/13W-9cab (formerly 24/13W-9L1). Alt 10 ft. Drilled for Pacific Power & Light Co., 1957. Casing: 2-diam pipe and well point; bottom of well point at altitude -108 ft, top of pipe at +9.60 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, unconsolidated | 40 | 40 | -30 |
| Sand, unconsolidated and semi-consolidated | 30 | 70 | -60 |
| Sand with trace of clay | 5 | 75 | -65 |
| Sand | 10 | 85 | -75 |
| Sand with shell fragments | 3 | 88 | -78 |
| Sand with claystone fragments | 2 | 90 | -80 |
| Sand | 14 | 104 | -94 |
| Sand with few tiny, rounded shale fragments | 13 | 117 | -107 |
| Sand with traces of mica and shells | 16 | 133 | -123 |
| Siltstone and mudstone, consolidated | 22 | 155 | -145 |

Hole 202. 23S/13W-34aca. Alt 37 ft. Drilled for Pacific Power & Light Co., 1957. Casing: 2-in. diam pipe and well point; bottom of well point at altituda -66 ft, top of pipe at +41.08 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, unconsolidated | 20 | 20 | +17 |
| Sand, gray, unconsolidated | 55 | 75 | -38 |
| Sand, gray, unconsolidated, with trace of gray clay | 5 | 80 | -43 |
| Sand, unconsolidated | 15 | 95 | -58 |
| Sand, unconsolidated, with trace of clay | 9 | 104 | -67 |
| Siltstone and mudstone, consolidated | 33 | 137 | -100 |

Hole 203. 23S/13W-34cbb. Alt 11 ft. Drilled for Pacific Power & Light Co., 1957. Casing: None

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, unconsolidated | 40 | 40 | -29 |
| Sand, gray, unconsolidated | 50 | 90 | -79 |
| Sand, with few claystone fragments | 5 | 95 | -84 |
| Sand | 5 | 100 | -89 |
| Sand, with shells and some claystone fragments | 5 | 105 | -94 |
| Sand, with shells and some mica | 13 | 118 | -107 |
| Claystone, hard, and some interbedded siltstone | 9 | 127 | -116 |

Hole 204. 24S/13W-28cdc (formerly 24/13W-28P1). Alt 22 ft. Drilled for Pacific Power & Light Co., 1957. Casing: 10-in. diam to 175 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, buff, unconsolidated | 6 | 6 | +16 |
| Sand, gray, unconsolidated | 14 | 20 | +2 |
| Sand, gray, unconsolidated; some woody material | 3 | 23 | -1 |
| Sand, unconsolidated; much decayed plant material | 8 | 31 | -9 |
| Sand, dark-gray | 9 | 40 | -18 |
| Sand, dark-gray; several small clay fragments | 2 | 42 | -20 |
| Sand, dark-gray | 4 | 46 | -24 |
| Sand, dark-gray; few small clay particles | 4 | 50 | -28 |
| Sand, dark-gray | 25 | 75 | -53 |
| Sand, dark-gray; few claystone pebbles | 5 | 80 | -58 |
| Sand, dark-gray; few small sandy, clayey fragments | 29 | 109 | -87 |
| Sand, dark-gray; few clay fragments | 15 | 124 | -102 |
| Sand, gray-black; few fossils | 3 | 127 | -105 |
| Sand, gray-black; woody material and mica | 5 | 132 | -110 |
| Sand, gray-black; some mica | 4 | 136 | -114 |
| Sand, gray-black; several fragments of brown clay | 4 | 140 | -118 |
| Sand, gray-black; some mica | 4 | 144 | -122 |
| Sand, gray-black; some organic material | 4 | 148 | -126 |
| Sand, gray-black; very small clay fragments | 5 | 153 | -131 |
| Sand, gray-black, fossiliferous | 3 | 156 | -134 |
| Sand, gray-black, fossiliferous; clay particles containing shell fragments | 2 | 158 | -136 |
| Sand, gray-black; clay fragments | 3 | 161 | -139 |
| Sand, gray-black, fossiliferous; few small to medium pebbles | 3 | 164 | -142 |
| Sand, gray-black, fossiliferous; organic material and clay fragments | 4 | 168 | -146 |
| Sand, gray-black; gray-green clay fragments | 4 | 172 | -150 |
| Claystone, gray-green | 7 | 179 | -157 |

Hole 205. 24S/13W-29cdb (formerly 24/13W-32D1). Alt 7 ft. Drilled for Pacific Power & Light Co., 1957. Casing: 2-in. diam pipe and well point; bottom of well point at altitude -141 ft, top of pipe at +11.67 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, unconsolidated | 160 | 160 | -153 |
| Sand, unconsolidated; interbedded pebbles | 8 | 168 | -161 |
| Clay, soft, gray | 14 | 182 | -175 |

Falk No. 3 hole. 24S/13W-2bbb. Alt 62 ft. Jetted for Pacific Power & Light Co., 1957. Casing: None

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Soil and sand | 2 | 2 | +60 |
| Sand | 1 | 3 | +59 |
| Clay, light-gray, sandy | 3 | 6 | +56 |
| Sand, light yellow-brown | 2 | 8 | +54 |
| Sand, light yellow-green | 2 | 10 | +52 |
| Sand, light yellow-brown | 4 | 14 | +48 |
| Sand, light yellow-gray | 5 | 19 | +43 |
| Sand, light-gray | 3 | 22 | +40 |
| Sand, light gray-green | 6 | 28 | +34 |
| Sand, light-gray | 9 | 37 | +25 |
| Sand, light gray-green | 13 | 50 | +12 |
| Sand, light yellow-gray | 11 | 61 | +1 |

Radar Cluster well 15G9. 24S/13W-15acd (formerly 24/13W-15G8). Alt 23 ft. Augered for Pacific Power & Light Co., 1957. Casing: 2-in. diam pipe and well point to 41 ft

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Soil and sand | 2 | 2 | +21 |
| Sand, gray | 18 | 20 | +3 |
| Sand, brown and gray; hard silt streak at 22 ft | 10 | 30 | -7 |
| Sand, blue-gray; hard streaks at 62, 68, and 75 ft | 48 | 78 | -55 |
| Clay, sandy | 5 | 83 | -60 |
| Clay, having dark, shalelike partings | 2 | 85 | -62 |

Saunders Lake hole. 23S/13W-35cac. Alt 64 ft. Augered for Pacific Power & Light Co., 1957. Casing: None

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Claystone, red, crumbly | 1 | 1 | +63 |
| Claystone, light-brown | 2 | 3 | +61 |
| Clay, white, hard | 1 | 4 | +60 |
| Sandstone, light-brown, fine, unconsolidated | 5 | 9 | +55 |
| Sand, dark-brown | 2 | 11 | +53 |
| Sand, light-brown | 30 | 41 | +23 |
| Clay, dark-gray, hard | 39 | 80 | -16 |

Hauser No. 1 hole. 24S/13W-10ddd. Alt 35 ft. Drilled for Pacific Power & Light Co., 1957. Casing: None

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Sand, light-gray to tan, fine to medium; some iron staining | 65 | 65 | -30 |
| Sand, dark blue-gray, carbonaceous | 13 | 78 | -43 |
| Clay, black, with lignite | 3 | 81 | -46 |
| Clay and red-brown micaceous sandstone with chlorite and limonite | 3 | 84 | -49 |
| Shale, gray-black, hard-fossiliferous | 4 | 88 | -53 |
| Clay | 10 | 98 | -63 |
| Clay and gray, hard micaceous sandstone | 6 | 104 | -69 |
| Clay | 38 | 142 | -107 |

McKeown No. 1 hole. 24S/13W-10aaa. Alt 98 ft. Jetted for Pacific Power & Light Co., 1957. Casing: None

| Materials | Thickness (feet) | Depth (feet) | Altitude (feet) |
|---|---|---|---|
| Soil and sand | 3 | 3 | +95 |
| Sand, light-yellow, medium | 15 | 18 | +80 |
| Sand, white, silty | 5 | 23 | +75 |
| Sand, light-gray | 2 | 25 | +73 |
| Sand, yellow-gray | 2 | 27 | +71 |
| Sand, light-gray | 3 | 30 | +68 |
| Sand, light-yellow, with fragments of iron oxide | 2 | 32 | +66 |
| Sand, light-gray | 8 | 40 | +58 |
| Sand, light-gray; fragments of iron oxide | 2 | 42 | +56 |
| Sand, light-gray | 10 | 52 | +46 |
| Sand, light-yellow | 8 | 60 | +38 |
| Sand, light-yellow; fragments of iron oxide | 2 | 62 | +36 |
| Sand, light-gray | 20 | 82 | +16 |