Ground Water in the Prineville Area Crook County, Oregon

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-P

Prepared in cooperation with the Office of the Oregon State Engineer

Robinson and Price—GROUND WATER IN THE PRINEVILLE AREA, CROOK COUNTY, OREG.—Geological Survey Water-Supply Paper 1619-P

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By J. W. ROBINSON *and* DON PRICE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GROUND WATER IN THE PRINEVILLE AREA CROOK COUNTY, OREGON

By J. W. Robinson and Don Price

ABSTRACT

The area studied includes about 60 square miles of the valleys of Ochoco Creek and Crooked River in semiarid central Oregon, the city of Prineville, and the surrounding agricultural district. The principal source of ground water in the area is a single artesian aquifer of sand and gravel locally more than 30 feet thick, which occurs at the base of the unconsolidated valley fill deposits. This artesian aquifer yields as much as 1,000 gallons per minute to wells in the area, and at places contains water under sufficient pressure to rise 50 feet or more above the land surface. Shallower aquifers, which contain unconfined water, generally yield less than 20 gpm; the bedrock underlying the artesian aquifer does not yield appreciable amounts of water to wells. The ground water is of generally good chemical quality, although that from some wells is harder than desirable or contains iron in amounts that are troublesome for some uses.

Since the artesian aquifer was first tapped by wells in 1912, there has been both a progressive increase in the number of wells producing water from it and a general lowering of artesian pressures in the aquifer. Sharp declines of the pressures at some wells in the summer of 1944 caused local concern about the continued availability of the artesian water, and led to the present study. Between October 1944 and November 1953, the decline in artesian pressure was less than 20 feet throughout most of the area, but was more than 30 feet in localities of intensive pumping. At Prineville, the relatively great drawdown is caused largely by mutual interference between large-capacity wells.

The long-term decline of artesian pressures was caused by the progressively greater withdrawals from wells. It represents chiefly an increase in the rate at which ground water moves through the aquifer from the principal recharge area to points of discharge rather than the permanent removal of water stored in the aquifer. Increased withdrawal from the artesian aquifer would tend to cause further decline of artesian pressures, but it also might result in some increase in recharge to the aquifer, salvage of some water presently discharging from the aquifer by leakage to shallower zones, and possibly, some local increase in the concentrations of dissolved minerals in the artesian water in districts of greatest decline of artesian levels. The additional water that might be available for withdrawal, owing to increased recharge and decreased natural discharge from the aquifer, would tend to counteract the decline of artesian levels owing to the increased withdrawal. In 1953, the recharge to the aquifer may have been about 2,000 acre-feet.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The principal source of ground water in the Prineville area is a single artesian aquifer or water-bearing zone that underlies the valley floor in the vicinity of, and downstream from, Prineville. Since it was first tapped by wells in 1912, there has been a progressive increase in the number of wells producing water from this aquifer. In the summer of 1944, owners and operators of wells in the area became concerned when large withdrawals from the aquifer caused the water levels in some of the artesian wells to decline rapidly to new low levels. Thus, it became apparent that a better understanding of the extent and water-bearing properties of the aquifer would be necessary in order to guide future development and management of ground water in the area.

The principal purposes of this investigation were to determine the extent of the aquifer, the source and the approximate amount of water that moves through the aquifer, and the possible effects of increased withdrawals from the aquifer.

This investigation was made in cooperation with the Oregon State Engineer as part of a continuing program of appraisal of the ground-water resources of Oregon. Most of the fieldwork for this report was done from October 1944 to November 1946 by the senior author. The fieldwork during that period included reconnaissance geologic mapping and collection of basic ground-water data. Additional information on wells, ground-water levels, and chemical quality of the ground water have since been obtained, mostly during fieldwork in the area in November 1953 and November 1959. In May 1960, the earlier geologic mapping was checked and revised in the field by the junior author and E. R. Hampton.

A preliminary version of the report, based on data collected through 1946, was prepared by the senior author and was released to the open file for public inspection in April 1947.

LOCATION AND EXTENT OF THE AREA

The area of this study is in Crook County in central Oregon (fig. 1). It lies between lat 44°15′ and 44°22′ N., and long 120°43′ and 120°58′ W., and it covers about 60 square miles. The area is about 15 miles long (in a northwest direction), and about 7 miles at its widest point. It comprises the valleys of Ochoco Creek downstream from the Ochoco Reservoir, and of Crooked River from the vicinity of Prineville downstream for about 7 miles (pl. 1).

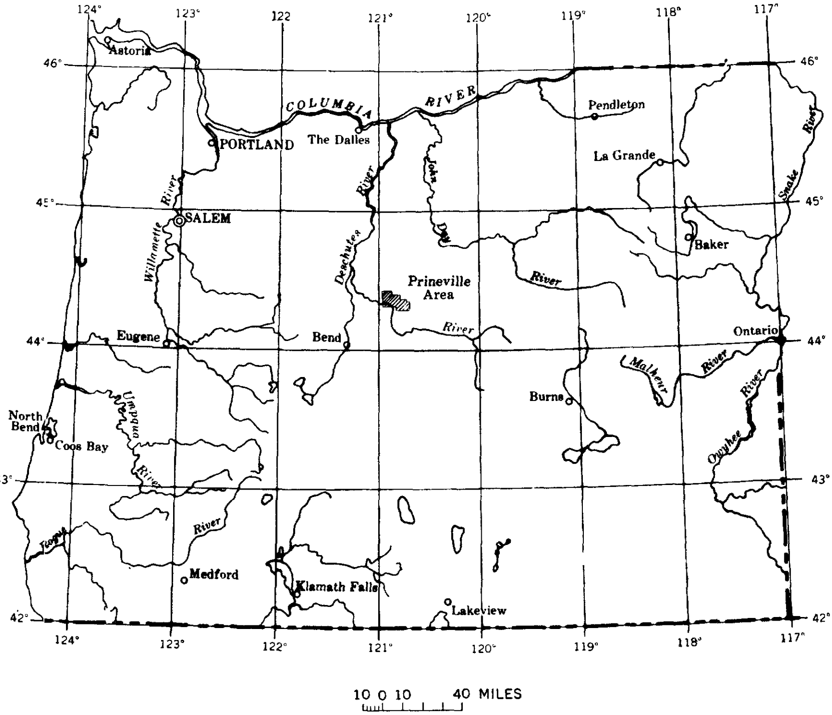


FIGURE 1.—Map of Oregon showing the location of the Prineville area.

PREVIOUS INVESTIGATIONS

Although the Prineville area has been included in larger areas of general geologic studies, no detailed investigation of the ground-water resources of the area was made prior to this study.

The geology and water resources of the Prineville area were mentioned briefly in a report by I. C. Russell (1905, p. 82–86) that describes a reconnaissance trip through central Oregon.

In 1925, H. T. Stearns made a geologic study of the middle Deschutes River basin, which includes a part of the Crooked River valley downstream from the Prineville area. In his report (1931, p. 132–152), Stearns described the rock units that are exposed in the canyon of Crooked River downstream from Prineville, and the geologic history of the region. During his investigation Stearns also wrote a brief memorandum report regarding artesian water at Prineville (Stearns, 1925).

In a report on the geology of north-central Oregon, Hodge (1942) included a generalized geologic map showing the major rock units in the Prineville area.

The geology of the Round Mountain quadrangle, which includes parts of the drainage basins of the Crooked River and Ochoco Creek upstream from the Prineville area, was mapped by Wilkinson (1939). The west edge of that quadrangle is 16 miles east of Prineville.

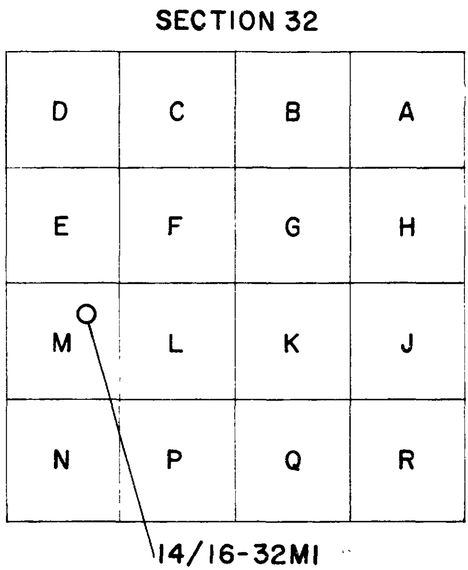
In a memorandum report on the availability of ground water for irrigation of valley land south of the Crooked River and downstream from Prineville, R. C. Newcomb (1950), described the geologic setting in the valley of Crooked River and the occurrence of ground water in the valley alluvium.

ACKNOWLEDGMENTS

The writers are indebted to the officials of the Pacific Power & Light Co. at Prineville for the many courtesies extended during the investigation and for pumpage and water-level records that were furnished. Two well drillers, Ernest Wagoner and George E. Scott, supplied well records and information concerning ground water in the area. The owners of wells in the area also furnished valuable information; special thanks is due Messrs. M. E. Gerow, William McKay, and Claude Williams for periodically measuring water levels in their wells.

WELL-NUMBERING SYSTEM

In this report, wells are designated by symbols that indicate their locations according to the official rectangular division of public lands as shown in diagram below. For example, in the symbol for well 14/16–32M1, the part that precedes the hyphen indicates respectively the township and range (T. 14 S., R. 16 E.) south and east of the Willamette base line and meridian. The number following the hyphen indicates the section (sec. 32) and the letter indicates the 40-acre subdivision of that section, according to the following diagram. The final digit is the serial number for that particular well. Thus, well 14/16–32M1 is in the NW¼SW¼ sec. 32, T. 14 S., R. 16 E., and was the first well in that tract to be listed.



GEOGRAPHY

SURFACE FEATURES AND DRAINAGE

The valley area in which Prineville is situated is part of a small structural basin that extends along the southwest side of the Ochoco Mountains, which constitute an outlier of the Blue Mountains section of the Columbia Plateaus physiographic province (Fenneman, 1931, p. 248–251). The valley is roughly rectangular in outline and trends northwestward.

The center of population, where ground water is most heavily used, is on the valley floor, which includes the narrow alluvial plains along the present stream channels and remnants of a low terrace that lie mostly along the north side of the valley. Several isolated bedrock outliers, a few tens to several hundreds of feet high, interrupt the general uniformity of the terrace. The largest of these outliers is Barnes Butte, about 2 miles northeast of Prineville. At most places, the most conspicuous features of the valley floor are the escarpments that separate the terrace remnants from the lower alluvial plain. These escarpments range in height from a few to as much as 50 feet. The valley floor is bordered on the north by the moderately steep slopes of the Ochoco Mountains and on the south by steep erosional escarpments, 200 to 500 feet high, that rise to an extensive lava plateau south of the Prineville area.

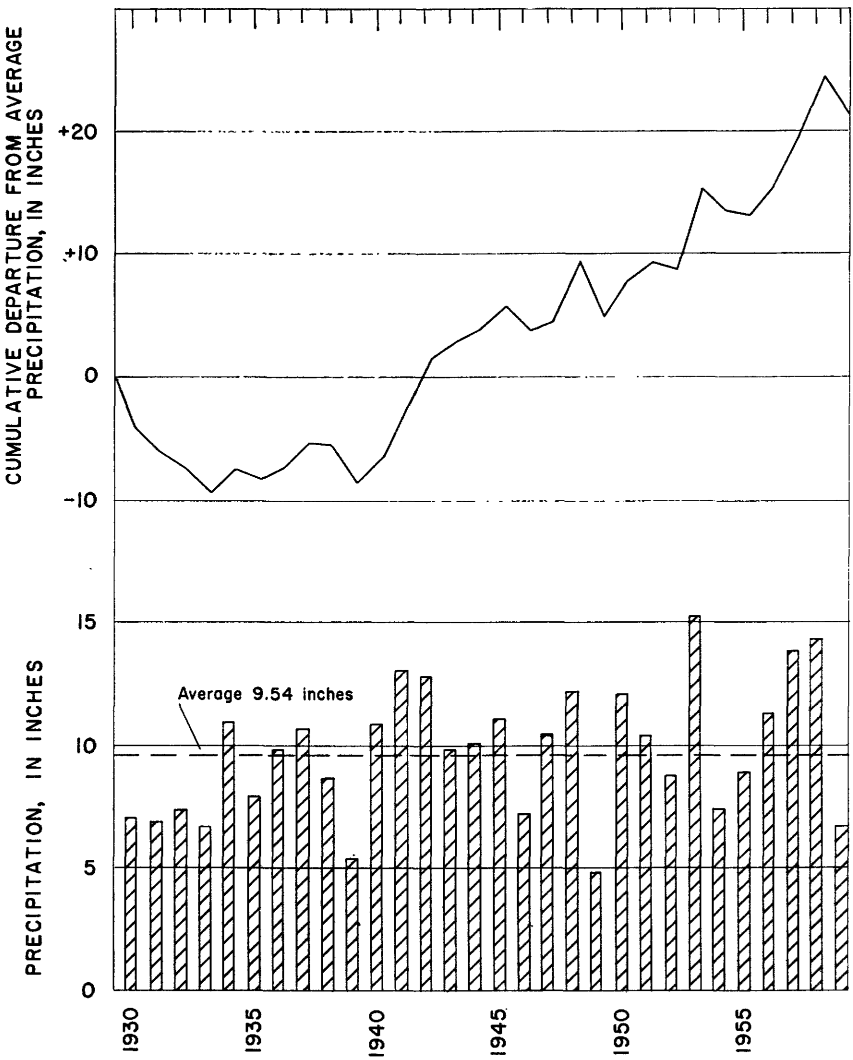


FIGURE 2.—Annual precipitation and cumulative departure from average at Prineville, Oreg. (Data from U.S. Weather Bureau).

The total relief in the mapped area is about 1,000 feet, from an altitude of about 3,800 feet on the slopes of the Ochoco Mountains near the northeast corner of sec. 6, T. 14 S., R. 16 E., to about 2,800 feet on the flood plain of Crooked River at the west edge of the area.

The Crooked River, which is the master stream in the area, drains the valley downstream (northwest) from Prineville. The tributaries to the Crooked River within the mapped area are the Ochoco, Johnson, McKay, and Lytle Creeks. They drain the terrain north and east of Prineville. At present, most of the flow from Ochoco Creek is impounded in Ochoco Reservoir and is used for irrigation within the area.

CLIMATE

The climate of the Prineville area is temperate and semiarid. The average annual precipitation at Prineville during the period 1897 to 1959 was 9.54 inches. November, December, and January are usually the wettest months, but a secondary wet period commonly occurs during May and June. Precipitation is consistently low in July and August. The annual precipitation and cumulative departure from average at Prineville during the period 1930–59 are shown in figure 2.

The mean monthly temperature during the period of record (1897–1959) ranged from 30.3°F in January to 63.2°F in July. The following table gives the mean monthly temperatures at Prineville:

Mean monthly temperatures at Prineville, Oregon (1897 to 1959), in degrees Fahrenheit

[From records of the U.S. Weather Bureau]

	Temperature (°F)		*Temperature (°F)*
January	30.3	July	63.2
February	32.7	August	61.2
March	39.2	September	55.7
April	45.5	October	47.7
May	51.6	November	38.7
June	56.8	December	33.3

CULTURE AND INDUSTRY

Agriculture is the principal industry of the Prineville area. The water that irrigates much of the valley northeast of the Crooked River is stored in Ochoco Reservoir and is distributed through the Main Canal (pl. 1), which follows approximately the northeastern margin of the valley floor. Water was first stored in the reservoir in 1918. Several irrigation wells have been drilled in the area north and west of Prineville to supplement this surface-water supply, but the acreage irrigated with ground water is relatively small. The land southeast of the Crooked River is irrigated by means of upstream diversions from the Crooked River. The principal crops grown in the area are small grains and hay.

The only city in the area is Prineville. It is the county seat and principal commerical center for Crook County; its economy also is based largely upon important lumber-milling industries and on tourist trade. In 1959 the city had a population of about 3,700.

GEOLOGIC SETTING

The occurrence and availability of ground water in the Prineville area depend not only upon the existence and extent of aquifers, but also upon the relation of the aquifers to the other rock units. Therefore, brief descriptions of each of the rock units, the stratigraphic relations, and the geologic history of the area are included in this report.

SUMMARY OF STRATIGRAPHY

The formations exposed in the Prineville area range in age from Eocene to Recent and consist of tuff and lava of felsic to mafic composition, ash beds, and alluvial and lacustrine deposits derived from volcanic rocks. The stratigraphic relationships of these formations are summarized in table 1, which is in part modified after Stearns (1931, p. 133) and Wilkinson (1939). The areas of outcrop of the units are shown in plate 1.

The oldest rock unit that crops out in the Prineville area is the Clarno formation, of Eocene age, which was described from exposures in the John Day River basin, about 50 miles northeast of Prineville, by Merriam (1901, p. 285). Rocks of the Clarno formation underlie the entire area and form both the uplands northeast of the valley floor and the isolated bedrock outliers within the valley. Where they are exposed in the Prineville area, the materials of the Clarno formation consist principally of dark-green, gray, buff, reddish-brown welded tuffs and andesitic lava.

The John Day formation, of middle and late Oligocene and early Miocene age, overlies the Clarno formation with apparent unconformity. The John Day formation was described in the John Day River basin by Merriam (1901, p. 278-314), and in the Round Mountain quadrangle, about 30 miles east of Prineville, by Wilkinson (1939). It was deposited in a number of apparently isolated basins in central Oregon by streams, in lakes, and as ash falls directly from the air.

Materials of the John Day formation are exposed at several places along the south margin of the Prineville area (secs. 1, 2, 3, and 4, T. 15 S., R. 16 E., and secs. 20 and 21, T. 14 S., R. 15 E.) and in Round Butte, near the west end of the valley (secs. 8, 16, 17, and 20, T. 14 S., R. 15 E.). At these places the formation consists principally of massive to well-bedded, tan and buff volcanic ash.

TABLE 1.—*Summary of geologic units exposed in the Prineville area, Oregon*

[In part modified from Stearns, 1931, and Wilkinson, 1939]

Age		Rock unit	Thickness (feet)	Physical character	Water-yielding character
Quaternary	Recent	Landslide debris	As much as 100.	Jumbled masses of materials derived from the Madras and older formations.	Water-yielding properties largely unknown; probably poor.
Quaternary	Recent	Younger alluvium or alluvium.	Less than 40.	Unconsolidated gravel, sand, and silt.	Generally yields small to moderate amounts of water to shallow wells.
		—Unconformity—			
Quaternary	Pleistocene	Fluviolacustrine deposits.	As much as 300.	Thick beds of clay and silt alternating with thinner beds of sand and fine gravel; forms the bulk of the uuconsolidated valley fill in the area.	Contains water under both confined and unconfined conditions. Unconfined aquifers generally yield small amounts of water to wells and seeps; an artesian aquifer at the base of the unit yields moderate to large amounts to wells and furnishes most of the ground water used in the area.
		—Unconformity—			
Tertiary	Pliocene	Madras formation	1,000+	Horizontal beds of yellow, brown, and black, partly consolidated sand, silt, gravel, and volcanic detritus, mostly mafic in composition; includes one or two basalt flows about 50 ft thick at the top of the unit.	May be capable of yielding small or moderate amounts of water from sand and gravel strata where saturated; not known to yield appreciable amounts to wells in the area.
		—Unconformity—			
Tertiary	Miocene	Columbia River basalt.	As much as 50.	One or possibly two flow layers of dark-gray to black fine-grained basalt; moderately weathered.	Apparently does not occur below the water table in the area.
		—Unconformity—			
Tertiary	Oligocene	John Day formation.	More than 100.	Massive to well-bedded tan, buff, and light-green ash and tuff; water-laid in part; fossiliferous; weathers rapidly.	Not known to be penetrated by wells in the area.
		—Unconformity?—			
Tertiary	Eocene	Clarno formation	More than 1,000.	Felsic to mafic lavas, tuffs, and welded tuffs; green, dark-gray, reddish-brown, or nearly black. Lavas and welded tuffs are resistant to weathering.	At places in the area, yields small amounts of water to seeps and wells.

The Columbia River basalt, of Miocene and possibly early Pliocene age, unconformably overlies the John Day formation at exposures in the southwestern part of the mapped area. Although the Columbia River basalt underlies vast areas of northern Oregon and eastern Washington, where it comprises a sequence of lava flows several thousands of feet thick, it apparently is represented in the Prineville area by one, or possibly two, flow layers whose total thickness is only about 50 feet. In this area, the basalt is dark gray to black, fine-grained, and moderately weathered.

The Madras formation,[1] of Pliocene age, unconformably overlies the

[1] The Madras formation was formerly know as the Deschutes. The name Deschutes was abandoned in 1957, and the name Madras, which includes the former Deschutes and an equivalent to the Dalles formation, was adopted.

Columbia River basalt, where present, and the older rock units in the southern and western parts of the mapped area. Rocks of the Madras formation form the steep walls of the southern, southwestern, and northwestern sides of the Prineville valley. They also cap Round Butte, and extend beneath the valley-fill deposits that form the valley floor (pl. 1). In the Prineville area, the Madras formation comprises a sequence of horizontal beds of yellow, brown, and black, partly consolidated silt, sand, gravel, and pyroclastic materials, which are capped by one or two shelf-forming basalt flows about 50 feet thick—the rimrock basalt of Stearns (1931, p. 140–141). Elsewhere in the middle Deschutes River basin, other basalt flows are intercalated with the sedimentary materials of the Madras formation (Stearns, 1931, p. 137), but in this area no lavas were found in the formation below the rimrock flows.

Underlying the terrace north of the valley floor and comprising the bulk of the valley fill, is a sequence of mixed and interlayered stream and quiet-water deposits herein termed "fluviolacustrine deposits." These deposits are as much as 300 feet thick and consist principally of thick beds of silt and clay alternating with thin beds of sand and fine gravel. A stratum of sand and gravel, ranging in thickness from less than 10 to more than 30 feet, occurs at places at the base of this unit and constitutes the most productive aquifer in the area—the artesian aquifer that is described more fully in a subsequent part of this report. The fluviolacustrine materials were deposited on an eroded surface of the Madras formation and are probably Pleistocene in age. Because of the lithologic similarities of the fluviolacustrine deposits and the underlying Madras formation, the contact between these two units is very difficult to ascertain from well logs.

Alluvial deposits of Recent age underlie the present flood plains of the Crooked River and its tributaries. The alluvium consists of unconsolidated gravel, sand, and silt, and is generally less than 40 feet thick. The gravel and sand in the alluvium yield small to moderate amounts of water to wells in the area.

Sizable landslides have occurred on the slope immediately north of Ochoco Dam, at several places along the southern wall of the valley near Prineville, and around the margin of Round Butte. The landslides involved rocks of the Madras and older formations, and occurred after the deposition of the fluviolacustrine terrace deposits, probably during Recent time.

GEOLOGIC HISTORY

The regional geologic history that is pertinent to this study began during Pliocene time with a downwarping, perhaps accompanied by faulting, that was centered in the middle Deschutes River basin. The deformation involved the Clarno formation of Eocene age and, where present, the overlying John Day formation and Columbia River basalt. It produced a broad, deep basin in the middle Deschutes region (Stearns, 1931, p. 150), and extended into the Prineville area, which lay at the eastern extremity of that basin.

Sediments of the Madras formation began to accumulate in the basin late in Pliocene time and continued to accumulate until the end of the epoch. As much as 1,000 feet of gravel, sand, silt, and volcanic detritus, at places intercalated with basalt flows, was deposited during that period. The deposition of the Madras formation concluded with the extrusion of the basalt that caps the sedimentary rocks of that formation along the south side of the Prineville area.

A period of erosion followed the deposition of the Madras formation. This period may have been initiated by a regional uplift, but apparently was not accompanied by strong local deformation, for the beds of the Madras formation are virtually horizontal. During this period of erosion, most of the deposits of the Madras were removed from the valley in which Prineville is situated, and the underlying Clarno formation was left with a relief of several hundred feet.

Erosion in the Prineville area was abruptly terminated when a local flood of lava poured into the canyon of the Crooked River about 8 miles downstream from Prineville. The lava flowed down the canyon for several miles, damming the river and causing a lake to form in what is now the Prineville area. This event probably took place in late Pleistocene time. In this lake thick layers of clay and silt were deposited alternately with thinner beds of sand and gravel that were carried into the lake by Crooked River and the smaller streams.

The crest of the lava dam was at least 3,000 feet above sea level; the highest remnant of fluviolacustrine deposits in the area stands about 2,995 feet above sea level.

The Recent epoch has been largely a time of erosion. Downcutting by the Crooked River and its tributaries has left the surface of the fluviolacustrine deposits standing as terrace remnants 20 to 100 feet above the present flood plains of the streams.

GROUND WATER

OCCURRENCE

GENERAL FEATURES

Ground water may be defined as water that occurs under hydrostatic pressure below the land surface and completely saturates or fills all pore spaces of the rock materials in which it occurs. The upper surface of such a zone of saturation, if unconfined, is called the water table, and its position is indicated by the level at which water will stand in a nondischarging well tapping that zone.

Where the cones of depression of two or more discharging wells overlap, the drawdown in each well may be substantially greater than it would be if the other wells were not discharging. In such a case, it may be said that there is "interference" between those wells. For any given rates and periods of discharge, the amount of drawdown caused by mutual interference is greater for wells that are closely grouped than for wells that are spaced at greater distances.

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

In addition to the unconfined, or water-table type of occurrence, at places ground water occurs under confined conditions. Confined ground water occurs where an aquifer underlies a less permeable layer that retards the upward movement of the water, and a pressure is exerted by the water in the intake area of the aquifer. Thus, the confined water is under pressure greater than that of the atmosphere and it rises above the base of the confining layer. The imaginary surface coinciding with the level to which confined water will rise in wells is called the "piezometric surface."

The piezometric surface of an artesian aquifer and the water table of an unconfined aquifer, are usually sloping, irregular, fluctuating surfaces. They are highest in areas of ground-water recharge and lowest in areas of discharge. Fluctuations and irregularities in the piezometric surface or in the water table are caused by variations in recharge to, and discharge from, the aquifer, and by differences in permeability within the aquifer. The two principal types of hydraulic conditions in which ground water occurs—confined and unconfined—can be gradational one to the other, and an area in which ground water is confined under a small hydrostatic head can occur close to an area having unconfined ground water. Both confined and unconfined waters are tapped by wells in the Prineville area.

As soon as a well begins discharging water, the water table (or piezometric surface) around the well is drawn down in a shape similar to an inverted cone, which is called the "cone of depression." Thus, a hydraulic gradient is established, and water moves downgradient into the well. As the pumping of the well continues, the cone of depression expands, but more and more slowly, and water moves toward the well from greater distances. The drawdown in the well also continues at a decreasing rate. Eventually, the cone of depression may become large enough that the aquifer receives recharge at the rate at which the well is being pumped. The cone of depression then remains virtually stable so long as all conditions remain unchanged.

BEDROCK UNITS

The existing well records and the character of the materials at surface exposures suggest that the bedrock materials underlying the Prineville area—that is, the materials of the Clarno, John Day, Columbia River basalt, and Madras formations—are generally incapable of yielding appreciable quantities of water to wells.

Eight wells in the area are known to have passed through the valley fill and tapped bedrock, and only one of these wells is reported to have a yield of more than a few gallons per minute. That is well 14/16–32D1, which was drilled to a depth of 690 feet (see tables 2 and 3). At a depth of 253 feet, the well entered "tight clay and gravel" which probably represents the top of the Madras formation at that place. At a depth of 352 feet, the well entered "shalelike material," probably of the Clarno formation, in which the driller reported thin water-bearing lenses at depths of 517, 596, and 651 feet. The well was cased to a depth of 414 feet, and the casing was perforated from 217 to 253 feet, opposite an artesian sand aquifer at the base of the fluviolacustrine deposits (see table 3). According to the driller, the well had a pumping yield of 1,000 gpm (gallons per minute), and a minor amount of the water was derived from the water-bearing lenses in the Clarno(?) formation.

Wells 14/15–12Q1, 14/16–29B1 and 30A1 also tapped materials of the Clarno formation, and each yields water sufficient only for small domestic supplies. In each of these wells the static water level stands at about the same altitude as the local water table.

Well 14/16–32M1 reportedly tapped mostly clay from 254 to 1,002 feet below land surface without obtaining any water below the base of the fluviolacustrine deposits at a depth of 254 feet (table 3). The clay, doubtless, is mostly of the Clarno formation, but the upper part of the clay section may include part of the Madras formation. Well 15/16–5D16 tapped "dry bedrock" (probably materials of the Madras and Clarno formations) from the base of the fluviolacustrine deposits, at 184 feet, to a depth of 510 feet below land surface. Similarly, well 14/15–24M2 penetrated fine silt and tuff of the Clarno(?) formation from 225 to 560 feet below the surface without obtaining an appreciable amount of water from those materials.

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The John Day formation is not known to be penetrated by wells in the area; however, the appearance of materials of this formation at exposures within the area indicate that the formation is relatively impermeable. The Columbia River basalt, although known to yield large amounts of water in other parts of Oregon and in Washington, apparently does not occur below the water table in the Prineville area. In this area, virtually all of the ground water that is available for use occurs in the valley fill—that is, in the alluvial and fluviolacustrine deposits.

FLUVIOLACUSTRINE DEPOSITS

Ground water occurs in materials of the fluviolacustrine deposits under both confined and unconfined conditions.

UNCONFINED AQUIFERS

At least 6 wells on the terrace northeast of the Crooked River probably obtain water from unconfined gravel and sand aquifers of the fluviolacustrine deposits at depths ranging from 12 to more than 60 feet. These aquifers are interbedded with finer grained materials (variously described by the well drillers of the area as hardpan, sand and mud, shale, silt, and clay) or with cemented gravel. The unconfined aquifers in the fluviolacustrine deposits probably are irregular and discontinuous; their combined thickness generally constitutes less than one-fifth of the total thickness of the unit.

The reported yields of the wells that tap unconfined aquifers in the fluviolacustrine deposits range from about 5 to 15 gpm. However, well 14/15–13D1, which apparently taps a very productive zone in these deposits, had a pumping yield of 346 gpm in 1955. That well is 200 feet deep, but probably derives water entirely from water-bearing sand and gravel that extend from about 12 to 22 feet below land surface. It is possible that the aquifer supplying this well is the northward, unconfined extension of the principal artesian aquifer that supplies flowing wells to the south and southwest.

Driven and drilled public-supply wells in sec. 5, T. 15 S., R. 16 E. obtained unconfined water from sand strata in the fluviolacustrine deposits at depths ranging from 40 to 80 feet. A group of 15 driven wells was used as the only source of municipal water supply for the city of Prineville before 1943. The combined yield of these wells was about 200 to 300 gpm, and they were pumped for many years without a noticeable long-term decline of water levels. These wells have since been replaced by larger, more widely spaced municipal wells, most of which tap a deeper confined aquifer. However, several small-diameter domestic wells in this same part of the area still obtain water from unconfined aquifers in the fluviolacustrine deposits.

Recharge to the unconfined aquifers of the fluviolacustrine plain occurs as infiltration from precipitation, irrigation water, streamflow, and as upward leakage from the underlying artesian aquifer. Recharge to the unconfined aquifers beneath the alluvial deposits of Crooked River and Ochoco Creek doubtless takes place locally as downward migration of water from the alluvium, but it probably occurs mostly as upward leakage from the underlying artesian aquifer. (See pp. P16–P17.) Infiltration of irrigation water probably is the principal form of recharge for the aquifers that underlie the terrace on the north side of the valley. Locally in that part of the area, some water also may infiltrate to the unconfined aquifers from McKay Creek and the intermittent streams.

Water in the unconfined aquifers of the fluviolacustrine deposits moves generally toward Ochoco Creek and the Crooked River. Discharge from these aquifers is mostly by withdrawal from wells or through springs and seeps. Some wells that tap aquifers of the fluviolacustrine deposits are grouped in and near Prineville; others are widely spread across the terrace on the north side of the valley. Along the scarp bordering the north side of the alluvial plain, some of the aquifers are exposed and at places discharge water through seeps and small springs on the scarp.

Because of insufficient data, no estimates were made of the water that recharges or discharges from the unconfined aquifers of the fluviolacustrine deposits.

THE ARTESIAN AQUIFER

The most productive source of ground water in the Prineville area is an artesian aquifer which occurs at or near the base of the fluviolacustrine deposits and extends throughout much of the valley floor. This artesian aquifer is known to extend from well 15/16–5E1, in the southeastern part of Prineville, to well 14/15–16J1, about 6 miles downstream from Prineville, and from the vicinity of the Crooked River northeastward for at least 2 miles. Thus, it underlies an area of at least 12 square miles.

The artesian aquifer, where it has been completely penetrated by wells, is a moderately to highly permeable zone of sand, or gravel and sand, that directly overlies materials of the Madras, Clarno, or, possibly in places, the John Day formations. The thickness of the artesian aquifer ranges from less than 10 to more than 30 feet. The aquifer apparently is at the lowest altitude beneath the flood plain of Ochoco Creek and the Crooked River, and slopes upward to the northeast, beneath the terrace bordering the Ochoco Mountains. The water-bearing materials are irregular in thickness and may be missing entirely at places within the known extent of the aquifer. The approximate position and configuration of the aquifer in the vicinity of Prineville are shown in plate 1.

At least 40 wells in the Prineville area derive most of or all their supply from the artesian aquifer; about 30 of those now flow or did flow at one time. Reported yields of the wells range from less than 10 to as much as 1,000 gpm (in well 15/16–5E1). For 6 of the wells the maximum reported yield ranged from 100 to 500 gpm; for 4 of the wells it was greater than 500 gpm. A few of the wells that penetrated the zone in which artesian water would be expected were abandoned because of insufficient yield.

The exclusion of fine sand from the wells has been a troublesome problem in the construction and use of wells that tap the artesian aquifer, and "sanding up" has been listed as a cause for abandoning a few of the wells. Most of the more productive wells that tap the artesian aquifer have been constructed with well screen or perforated casing opposite the water-bearing zone. Of these two methods of construction, the one utilizing well screen affords better control of the entrance of sand and also provides a larger total area of openings opposite the aquifer.

Most of the recharge to the artesian aquifer probably occurs in the northeastern part of the terrace, near the base of the Ochoco Mountains, where the permeable aquifer materials probably occur at relatively shallow depth and are unconfined. Here water is available for recharge to the aquifer in the form of infiltration from precipitation, from the flow of McKay Creek and the smaller, intermittent streams that drain the slopes of the Ochoco Mountains, and from irrigation water. For the recharge area as a whole, the relative importance of these potential sources of recharge is not known.

From this recharge area, the ground water moves generally south toward the Crooked River and Ochoco Creek. In its southward course, the water in the aquifer passes beneath a progressively thicker section of relatively impermeable materials of the fluviolacustrine deposits, which impede the upward movement of the water. Thus, in the southern part of the area the water in the aquifer is confined, and is under a pressure exerted by the water upslope in the aquifer.

At localities where the piezometric surface of the artesian aquifer has declined below the altitude of the water table, as at wells 14/16–31Q1 and –32M1 in Prineville, some recharge to the artesian aquifer doubtless occurs by downward leakage from the overlying water-table aquifers in the fluviolacustrine deposits and in the alluvium. At present, because those areas of low artesian pressure are relatively small, the amount of recharge by downward leakage to the artesian aquifers probably is also small.

Most discharge of water from the artesian aquifer probably is by withdrawals from wells. However, a considerable amount of water discharges from the artesian aquifer by leakage through the overlying deposits and thence into Ochoco Creek and the Crooked River. Because the water in the artesian aquifer is under pressure sufficient to raise it 10 feet or more above the land surface throughout much of the lower part of the valley floor, it can migrate upward through the confining beds to shallower aquifers. Even though the confining beds in the fluviolacustrine deposits have a low permeability and at places have an aggregate thickness of more than 200 feet, it is believed that hundreds of acre-feet of ground water leaks upward each year from the artesian aquifer.

Some water in the artesian aquifer may discharge from the area by underflow downvalley, but if such discharge occurs, the amount of water is small. As previously described (p. P11), a lava flow lies across and partially blocks the channel of Crooked River just west of the mapped area. It is not known whether the artesian aquifer extends that far west, but if so, the lava dam may act as an effective barrier to down-valley migration of ground water. Even if the artesian aquifer passes beneath the lava dam, the amount of water moving through it at that place probably is relatively small, because the bedrock channel there is relatively narrow, and much of the available water in the aquifer apparently is moving toward the areas of greatest pumping.

In November 1946, aquifer tests were made at six well to determine the transmissibility of the artesian aquifer. The data from the tests were analyzed according to the Thies nonequilibrium and recovery methods for determining coefficient of transmissibility (Thies, 1935, p. 519–524). The coefficient of transmissibility may be defined as the amount of water, in gallons per day, that will flow through each 1-mile segment of the aquifer (measured normal to the direction of flow) under a hydraulic gradient of 1 foot per mile at prevailing water temperatures. The coefficients of transmissibility computed for the artesian aquifer in the vicinity of the test wells are given in the following table:

Well	Date of test	Coefficient of transmissibility (gpd per ft)
	1946	
14/15–15Q1	November 21	7, 200
22B1	November 21	7, 900
36H1	November 19	11, 000
14/16–31P1	November 15	9, 500
31Q1	September 14–November 19	11, 000
32N1	November 14	5, 500

The coefficients of transmissibility obtained range from 5,500 to 11,000, a rather small range considering the irregular thickness of the aquifer. The tests indicated higher coefficients for the three wells near the center of the alluvial plain (14/15–36H1, 14/16–31P1 and Q1) than for those near the edge of the terrace. Also, the yield of individual wells per foot of drawdown is greater for the artesian wells on the alluvial plain than for wells of similar construction on or near the terrace.

The differences mentioned above indicate that the aquifer is either thicker or more permeable where it occurs beneath the alluvial plain than it is beneath the terrace. Therefore, to estimate the amount of water moving through the aquifer along the south edge of the terrace, the average transmissibilities obtained for wells 14/15–15Q1, –22B1, and 14/16–32N1, and the hydraulic gradients along the edge of the terrace were used. The average transmissibility from the tests at those three wells is about 7,000 gpd per ft (gallons per day per foot) and the average hydraulic gradient along the terrace edge was about 50 feet per mile in 1953, as estimated from plate 1. Consequently, for each mile-long segment of the aquifer, the amount of underflow was 7,000 gpd per ft times 50 feet per mile, or only about 350,000 gpd or 300 to 400 acre-feet per year. Similarly, in the 6-mile distance through which the artesian aquifer is known to extend, about 2 mgd (million gallons per day) or 2,000 acre-feet a year was moving southward through the artesian aquifer toward the Crooked River and Ochoco Creek. This is the best estimate presently available for the annual recharge to the artesian aquifer.

ALLUVIUM

The alluvial plain of Ochoco Creek and the Crooked River is underlain by a body of unconsolidated gravel and sand that is generally covered by only a few feet of soil. The alluvium ranges in thickness from about 10 to 40 feet and directly overlies the fluviolacustrine materials. The alluvial gravel is, at many places, saturated through nearly its entire thickness, and is the principal source of unconfined ground water in the Prineville area.

Nearly all of the wells that tap the alluvium are small-diameter driven wells that furnish domestic and stock supplies to homes in and near the city of Prineville. The yields of these wells range from about 5 to 20 gpm. Only two wells that tap the alluvium are reported to have yields that greatly exceed that average. Well 14/15–20R1, a dug well about 20 feet deep that is used for irrigation, reportedly pumped 500 gpm (table 2). Another irrigation well, 15/16–4B1, which is a driven well 4 inches in diameter and 24 feet deep, reportedly pumped 120 gpm.

Recharge to the alluvium occurs principally as infiltration from the streams, from irrigation and precipitation on the alluvial plain, and as upward leakage from the deeper aquifers. As previously discussed, where the piezometric surface of the artesian aquifer stands above the water table, a considerable amount of water doubtless leaks upward from the artesian aquifer to the unconfined aquifers, and this upward leakage may constitute the principal mode of recharge of the alluvium. Conversely, where the artesian pressure has been reduced below the water table, as it has at places in Prineville, the recharge to the alluvium occurs as infiltration from the surface or from the streams.

Discharge of ground water from the alluvium is chiefly by seepage discharge to the major streams, transpiration by vegetation, and withdrawal from wells. Available data do not permit quantitative estimates of the recharge to, or discharge from, the alluvium.

LANDSLIDE DEBRIS

Little is known of the possible occurrence of ground water in the landslide debris. In most cases, however, the materials making up the slide blocks stand above the water table and are, therefore, unsaturated. Also, the landslides involve mostly rocks of the Clarno, John Day, or Madras formations, which, unless strongly shattered during movement, would be expected to be relatively impermeable.

Landslide debris derived from the Clarno formation lies north of Ochoco Reservoir and extends southward onto the valley floor beneath the dam. Leakage from the reservoir has been troublesome since the dam was constructed, and most of that leakage doubtless is through the landslide debris, which at that place consists of large jumbled blocks of welded rhyolitic tuff and rhyolite.

WATER-LEVEL FLUCTUATIONS AND LONG-TERM TRENDS

Water levels in wells fluctuate chiefly in response to changes in recharge to, and discharge from the aquifers tapped by the wells. Analysis of these water-level fluctuations may indicate many characteristics of the ground-water regimen, such as the sources of recharge, the principal mode of ground-water discharge, and the relationship between pumpage and recharge.

During this investigation, water levels were measured periodically in 23 wells, most of which tap the artesian aquifer. Measurements were begun in October 1944, and by November 1946, the number of wells, considered representative for the area was reduced to four. Wells 14/15–15Q1, 14/16–32N1, and 15/16–6A1 tap the artesian aquifer in the fluviolacustrine deposits, and well 14/16–19H1 taps unconfined water in the fluviolacustrine deposits. The hydrographs of those four wells are shown in figures 3 and 4.

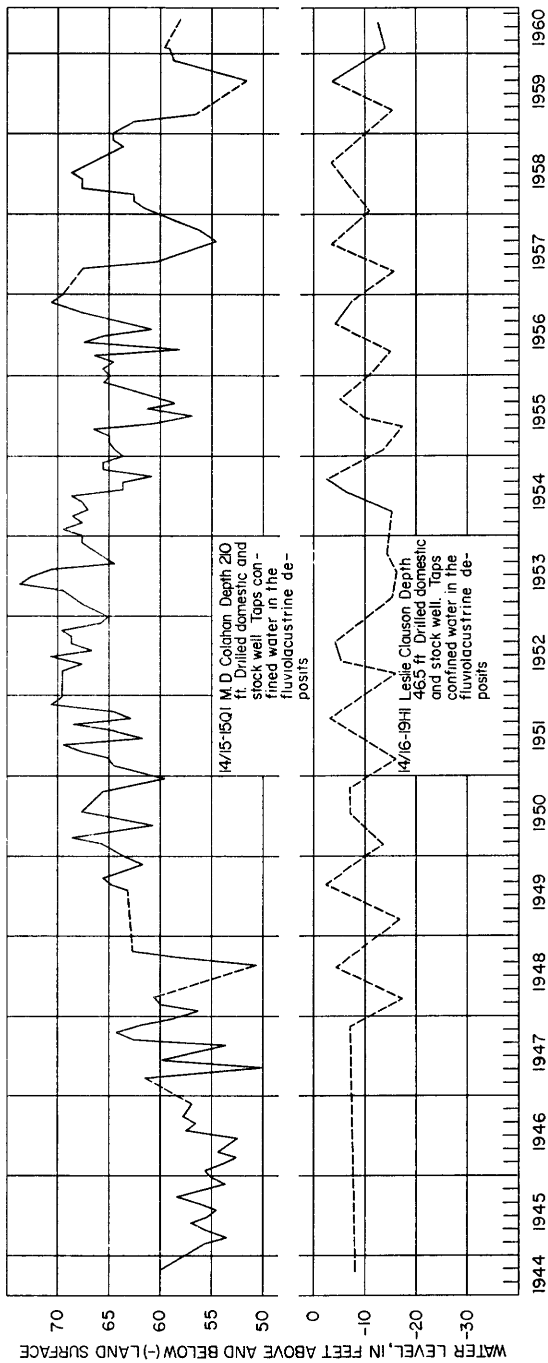

FIGURE 3.—Hydrographs of wells in the Prineville area, Oregon.

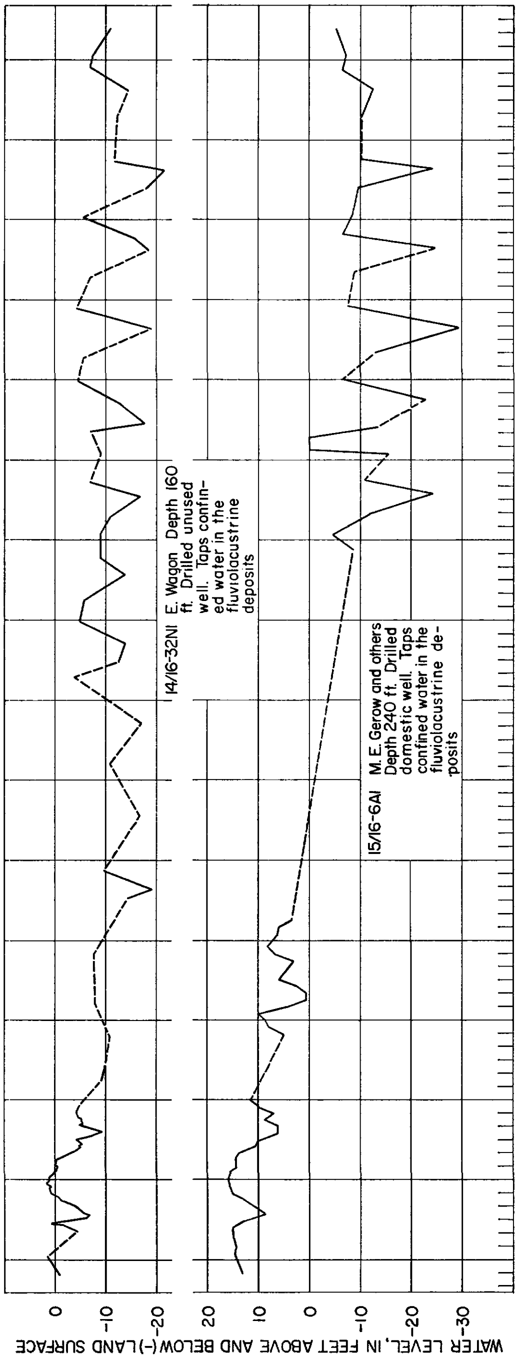

FIGURE 4.—Hydrographs of wells in the Prineville area, Oregon.

The water-level measurements were made by the wetted-tape method, by airline and water-pressure gages, and by means of a water-level recorder. The recorder was installed on well 14/16–32N1 in June 1945, and was removed from that well and installed temporarily in well 14/16–31H1 in November 1947.

The hydrographs of the three wells that tap the artesian aquifer indicate that seasonal changes in artesian pressure in that aquifer are chiefly in response to variations in withdrawal from the aquifer. In wells 14/16–32N1 and 15/16–6A1, for example, the water levels are normally lowest during the summer period of large-pumping withdrawals; levels are highest during the late autumn, winter, or early spring, when the pumping is at a low rate and recharge from precipitation is greatest. Seasonal fluctuations in well 14/15–15Q1 apparently are due mainly to withdrawals from the well itself, although the withdrawals from other wells that tap the artesian aquifer probably exert a strong secondary influence. The response of the artesian pressures to pumping is so pronounced that any increasing trend in pressure that may be caused by recharge from irrigation is completely masked by pressure reductions owing to the large withdrawals during the same season.

The hydrograph of well 14/16–19H1 (fig.3), which taps unconfined water in the fluviolacustrine deposits, shows that the water levels in that well usually are highest during August or September, during or shortly after the peak period of water application for irrigation. Levels in that well are usually lowest during March, April, or May, before the beginning of the irrigation season. The close correlation of the water-level rise to the application of irrigation water strongly indicates that the recharge to the unconfined aquifers tapped by that well occurs chiefly as infiltration of irrigation water. Because most of the area that is underlain by the fluviolacustrine deposits is irrigated, infiltration from this source probably is the principal mode of recharge of the unconfined aquifers of that deposit, as previously mentioned.

Contours on the piezometric surface of the artesian aquifer as of November 1953 are shown on plate 1. As those contours show, the altitudes of water levels in wells that tap that aquifer ranged from above 2,900 feet at 2 wells near the north edge of the alluvial plain in the western part of the area, to below 2,810 feet at 2 wells in Prineville. The lowest pressures were in the vicinities of three wells—14/15–23R1, which supplies the Pine Products Lumber Co. sawmill, and 14/16–31Q1 and 32M1, which are owned by the Pacific Power & Light Co. and are the source of part of the water supply for the city of Prineville. Those three wells were being pumped when they were measured in November 1953, and the contours shown near those wells (pl. 1) are based largely on the pumping levels in those wells. Because some of the large-yield wells, especially those that supply the city, are pumped almost continuously, drawdown of the magnitude indicated on plate 1 is nearly continuous. Thus, the contours shown in the figure are believed to depict with fair accuracy the normal configuration of the piezometric surface during late autumn.

As the measurements upon which the contours are based were made in November, which is after the end of the normal irrigation season, the artesian pressures probably had nearly or completely recovered from the drawdown due to irrigation pumping. Only one of the artesian irrigation wells measured during that month had a level suggestive of residual drawdown from pumping during the previous irrigation season. That is well 14/15–36G1, in which the water level on November 18, 1953, stood at 2,844 feet above sea level, or 17.5 feet below the level in nearby well 36H1 (see table 2).

Little information is available concerning the position of the piezometric surface when the first artesian wells were drilled in 1912; however, the pressure head in most of the early wells reportedly was sufficient to permit use of the water for domestic purposes without pumping.

Well 14/15–15P1, drilled in 1912, had sufficient head to flow into stock troughs which were about 33 feet above the land surface at the well, and in October 1944 the head in that well was measured at 42 feet above the land surface at the well. Obviously, no large permanent decline of head had taken place at that location by 1944. In November 1953, however, the head at that well was 29 feet above land surface, or 13 feet lower than in 1944.

Well 14/15–10Q1, which was drilled before 1918, originally did not flow. After 1919, when irrigation was begun on the terrace in the northern part of the Prineville area, the well began to flow at a gradually increasing rate. By October 1944, the pressure head at the well was 4 or 5 feet above the land surface; thus, it seems that in 1944 the pressure head in the vicinity of the group of artesian wells in the northwestern part of the area, downstream from Prineville, was as high or higher than it was when the wells were drilled. Also, the history of levels in well 10Q1 suggests that recharge to the artesian aquifer occurs largely as infiltration of irrigation water.

Well 14/15–24M1, drilled in 1914 and deepened in 1942, originally flowed, but continued withdrawal likewise has lowered the average water level in that well below the land surface. Drawdown caused by withdrawal from nearby well 14/15–23R1 may be a major reason that well 24M1 ceased to flow. A hydraulic connection between those two wells is indicated by water levels measured in well 24M1 in September and December, 1945. On September 25 the water level in the well was 7.18 feet below land surface—within the normal range of water levels that had been recorded at that well since periodic measurements began in July 1944. During and before the measurement in September 1945, the nearby well 23R1 had been pumped regularly. During the first part of October, however, pumping was stopped at well 23R1, and was not resumed until early in 1946. On December 5, 1945, after well 23R1 had been unused for more than 2 months, the water level in well 24M1 had risen to within 3.85 feet below land surface. That was the highest water level that has been recorded for that well, and represents a rise of 3.33 feet above the level measured during the previous September.

The long-term changes in the artesian aquifer may be determined from the hydrographs of wells 14/15–15Q1, 14/16–32N1, and 15/16–6A1 (figs. 3 and 4), and by comparing the water levels measured in wells during November 1953 with those measured in the same wells earlier during this investigation (table 2).

The hydrographs show that the nature and magnitude of the change in artesian pressures varies considerably from place to place within the area. The hydrograph of well 14/15–15Q1, a domestic and stock well about 4½ miles northwest of Prineville, shows a generally rising trend in the artesian pressure during the period from 1944 to 1953, and a declining trend since that time. The hydrograph further shows that as recently as January 1960 the artesian pressure was greater than the highest pressure measured at the well in 1945. Conversely, the hydrograph of the other two artesian wells (fig. 4), both in Prineville, show generally declining trends since 1945. At well 14/16–32N1 the overall decline, figured as the difference between annual measured high-water levels, amounted to about 8.8 feet, from about 1.8 feet above land surface in December 1945 to 7.0 feet below land surface in November 1959. The overall decline at well 15/16–6A1 during the same period amounted to about 22.5 feet.

The general pattern of changes in pressures in the artesian aquifer from October 1944 to November 1953 is shown in figure 5. That figure is based upon a comparison of the water-level measurements made in October 1944 with those made at 13 of the same wells in November 1953.[2] As the figure shows, a general decline of artesian pressure occurred during that 10-year period. Throughout much of the valley floor, the decline amounted to 20 feet or less, but in the vicinity of large-yield wells that are pumped nearly continuously, as in Prineville, the decline was greater than 30 feet. Thus, the decline was relatively great near the localities of intensive withdrawal, and was only moderate elsewhere in the area. It is concluded, therefore,

[2] *See* table 2, wells 14/15–15P1 and Q1, -16J1, -21H1, -22B1, -36G1 and H1; 14/16–31J1, M1, and Q1, -32M1 and N1; 15/16–6A1.

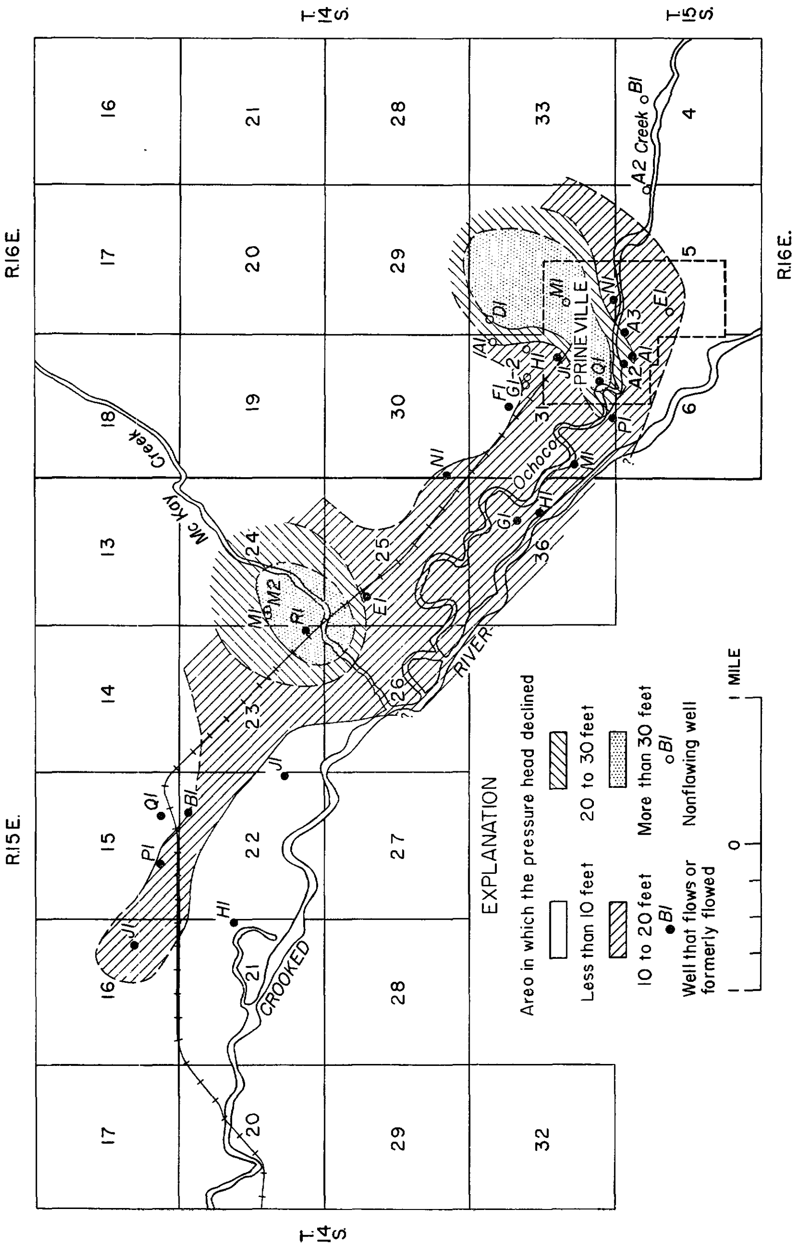

FIGURE 5.—Map of part of the Prineville area showing decline of pressure head in the artesian aquifer from October 1944 to November 1953.

that the relatively great decline of artesian pressures that has been troublesome at Prineville is caused largely by mutual interference between the pumped wells that are concentrated in that part of the area.

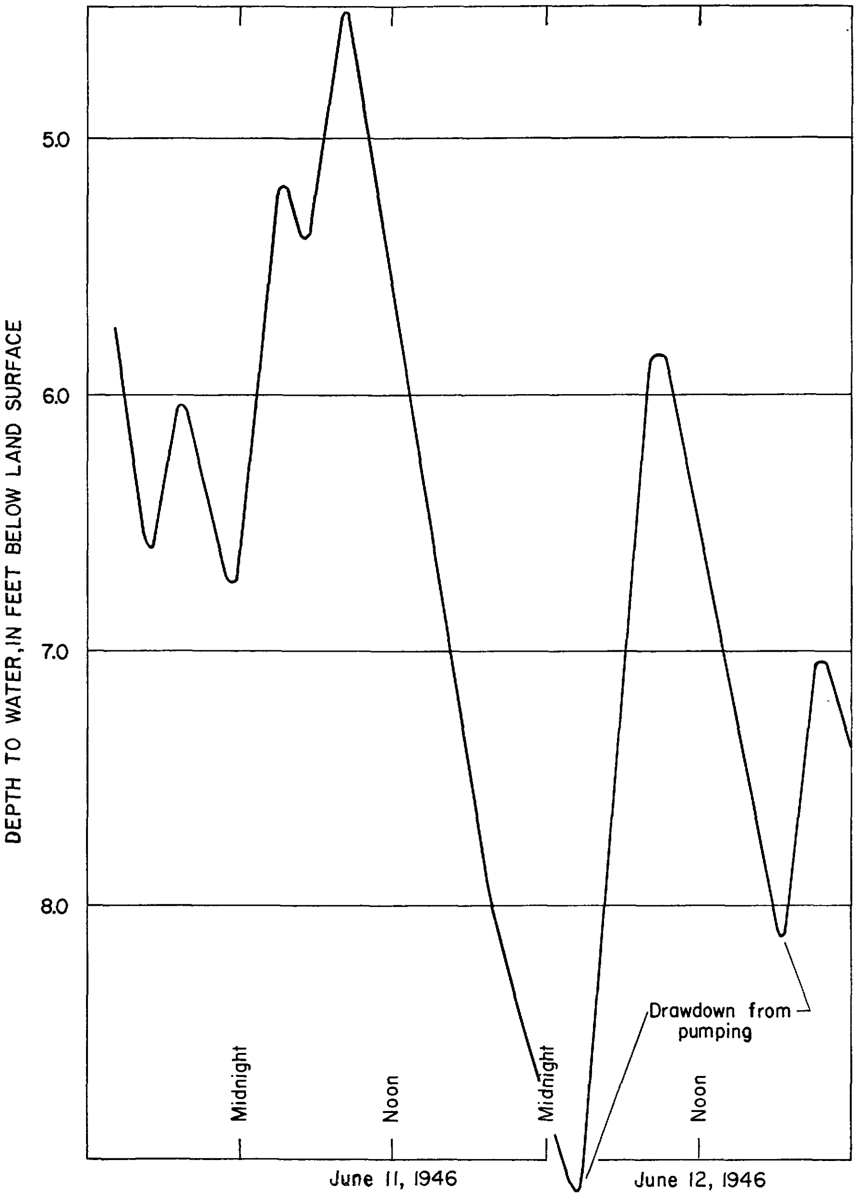

FIGURE 6.—Hydrograph of well 14/16-32N1 showing fluctuations of water level caused by variation in rates of pumping of nearby wells.

Short-term fluctuations caused by intermittent pumping of wells in Prineville are shown in figure 6, which is a copy of part of an original chart from the recording gage on well 14/16–32N1. That well was not pumped during the period represented by the figure, and the fluctuations doubtless were due almost entirely to variations of pumping from nearby wells. The greatest declines shown, which occurred from 8:15 a.m. June 11 to 2:20 a.m. June 12, and from 9:15 a.m. to 6:50 p.m. June 12, and which amounted to 4.6 and 2.3 feet respectively, were caused by the pumping of well 32M1, about 1800 feet north of the observation well. The fluctuations of smaller magnitude probably reflect the combined effects of variations in withdrawals from well 32M1 and from other nearby wells.

CHEMICAL CHARACTER OF THE GROUND WATER

Chemical analyses of waters from 18 wells in the Prineville area are shown in table 4, together with the temperatures of some of the waters at the time of sampling. Also included in the table, for purposes of comparison, are two analyses from surface-water sources. Of the wells for which analyses are listed, wells 14/15–36J1 and 15/16–5F1 tap unconfined water in the alluvium, and well 14/16–32D1 reportedly obtains most of its yield from the artesian aquifer and a small part from bedrock; the other wells obtain their entire supply from the artesian aquifer.

The analyses indicate that the ground water is of good chemical quality for most uses, although the water from some of the wells is harder than desirable or contains iron in amounts that are troublesome for some uses. The temperatures of the ground waters sampled ranged from 54° to 64° F.

The hardness of water is caused principally by dissolved calcium and magnesium compounds. Hard water tends to deposit scale in pipes and receptacles when the water is heated, effects the use of dyestuffs, and causes relatively great consumption of soap and synthetic detergents in washing operations. The following table shows the hardness scale that is generally used by the Geological Survey in determining relative hardness of water.

Hardness scale in use by the U.S. Geological Survey

Hardness as $CaCO_3$ *(PPM)*	*Degree of hardness*
0– 60	Soft
61–120	Slightly hard
121–180	Hard
> 180	Very hard

Hardness of all ground-water samples analyzed ranged from 61 ppm (slightly hard) in well 14/16–31H2 which taps the artesian aquifer, to 238 ppm (very hard) in well 14/15–36J1 which taps the alluvium.

Water that contains iron in amounts greater than about 0.3 ppm is likely to stain plumbing fixtures, utensils, and fabrics laundered in the water (U.S. Public Health Service, 1946, p. 383); in even smaller concentrations, iron is troublesome in waters used in some manufacturing processes. The concentration of dissolved iron in all the ground-water samples analyzed ranged from 0 in well 14/16–31Q1 to 0.57 ppm in well 14/15–36J1. Only the sample from well 14/15–36J1 which taps the alluvium, and that collected in 1950 from well 15/16–5E1, which taps the fluviolacustrine deposits, contained dissolved iron in concentrations greater than 0.3 ppm. The sample from well 14/16–32D1 contained 7.8 ppm iron but included a considerable amount of precipitated iron which may have been introduced into the well from pipes or pumping equipment.

Most samples of water from the artesian aquifer of the fluviolacustrine deposits had substantially lower concentrations of dissolved solids than did the samples from the alluvium (wells 14/15–36J1 and 15/16–5F1), from the irrigation waste-water ditch (in NW¼SE¼ sec. 31, or from the mixed water from the artesian aquifer and the bedrock (well 14/16–32D1). The water from the artesian aquifer is of a sodium-calcium-bicarbonate[3] type and is generally similar in total dissolved solids and proportions of the chemical constituents, to the water of the Crooked River near Prineville, as analyzed by Van Winkle (1914, p. 80).

The samples of artesian water analyzed in 1946 were moderately hard, ranging in hardness from 61 to 121 ppm (parts per million). The iron content of those samples, with the exception of the sample from well 14/16–31H2, was less than 0.15 ppm, which is too small to be troublesome for most uses. The hardness of two samples of water from the alluvium was considerably higher and the concentrations of calcium, magnesium, bicarbonate, and total dissolved solids were much greater than the samples of artesian water that were tested for for those constituents in 1946.

Six partial and one complete chemical analyses of water are available for three of the heavily pumped drilled wells that obtain their supply entirely from the artesian aquifer. Partial analyses were made of water from well 14/16–31Q1 in 1946 and 1959, from well 14/16–32M1 in 1943 and 1959, and from well 15/16–5E1 in 1950 and 1959. The complete chemical analysis was of a sample taken from well 32M1 in 1946. The three wells are in Prineville and furnish most of the water

[3] Sodium and calcium together constitute more than 50 percent of the bases, and bicarbonate constitutes more than 50 percent of the acids.

supply for that city. Comparative chemical data also are available from the two partial analyses of the water from well 14/16-32D1, which apparently obtains most of its yield from the artesian aquifer and a small part from the bedrock of the Clarno(?) formation. Comparison of the analyses for those wells suggests that, locally, the hardness and mineral content of the water in the artesian aquifer may be increasing progressively. For example, for each of those wells, the value for hardness was greater in the later samples than in earlier ones. Also, the analyses of samples from wells 31Q1 and 32M1 show a general increasing trend in concentrations of total dissolved solids and of each of the constituents for which the samples were analyzed more than once. The two partial analyses of water from well 15/16-5E1 show significant changes in the chemical character of the water, but not all of those changes represent increases in concentration. The analyses for that well show a slight to moderate decline in concentrations of total dissolved solids, iron, bicarbonate, and chloride, as well as a moderate increase in sulphate and hardness. Similarly, the analyses of water from well 14/16-32D1 show an increase in hardness and bicarbonate but a decrease in sulfate and chloride content.

It is significant that, of the wells obtaining their entire supply from the artesian aquifer, the greatest increase in mineral content was in water from well 14/16-32M1, which is in the district of greatest pumping withdrawal. In that district, as previously stated, there has been a gradual expansion of the area in which the piezometric surface stands below the water table, and in which recharge to the artesian aquifer can occur as downward leakage from the shallower aquifers. The increase in mineral content of the water from well 32M1 probably is caused by a mixing of water that infiltrates to the artesian aquifer in the principal recharge area along the north side of the valley floor, with water of greater mineral content that drains downward from the shallow aquifers. The latest (1959) analysis for well 32M1 showed that the water from that well was generally similar in chemical character to water from the two wells that tap the alluvium (14/15-36J1 and 15/16-5F1), and suggests that recharge to the artesian aquifer in the vicinity of well 32M1 occurs largely as downward leakage from the shallow aquifers.

The chemical data are too few to show the extent of the area in which the mineral content of the artesian water has increased, or to indicate the degree of chemical change other than at the three wells previously cited. Presumably, little or no change in chemical character of the artesian water would be found outside of the areas where the piezometric surface has declined below the water table, for except in those areas no downward leakage of water from the shallow aquifers can occur.

The classification of water as to suitability for irrigation usually is based on the concentration of boron, the total concentration of soluble salts, and the "percent sodium."

Boron was found in measurable amounts in only 2 of the 6 samples of ground water from the Prineville area. The two samples each contained 0.4 ppm of boron, a concentration that would be harmful to only the most sensitive crops.

Plants cannot tolerate water high in mineral content, and unfavorable soil conditions are likely to develop when sodium is the predominant cation in irrigation water. Figure 7 is a diagram for classifying irrigation water on the basis of total concentration of soluble salts, expressed in terms of specific conductance, and "percent sodium," which is the ratio of the concentration of sodium to the total concentration of calcium, magnesium, and sodium. This diagram, developed by Wilcox (1948), sets limits for waters applied to crops that have a moderate tolerance for dissolved salts, and growing under average conditions of soil texture and drainage. Of eight samples for which the "percent sodium" and specific conductance were determined, all fell within the classification of "excellent to good."

WITHDRAWAL FROM THE ARTESIAN AQUIFER

The greatest amount of ground water used in the Prineville area is obtained from wells that tap the artesian aquifer. Except for those artesian wells, only one well that taps an unconfined aquifer in the fluviolacustrine deposits (14/15–13D1) and two wells that tap the alluvium (14/15–20R1 and 15/16–4B1) are known to yield more than 100 gpm.

The first wells to penetrate the artesian aquifer were drilled in 1912, and by 1917 there were about 13 wells tapping that aquifer. Few additional wells were drilled before 1940, but during the period 1940–59 at least 25 more wells were drilled into the artesian aquifer. The earliest wells originally discharged entirely by artesian flow, but owing to the gradually increasing demands for water and the decline of artesian pressures over the years, pumps have been installed on most of the older wells that are still in use, as well as on the newer wells.

PRESENT DEVELOPMENT

In the Prineville area, ground water is used principally for municipal, industrial, irrigation, and domestic and stock supplies, listed in order of quantities used. The Pacific Power & Light Co. maintains the municipal water supply for the city of Prineville and obtains most of the water from four wells that tap the artesian aquifer. Several lumber mills pump water from the artesian aquifer for milling operations and fire protection. Less than a dozen wells produce water

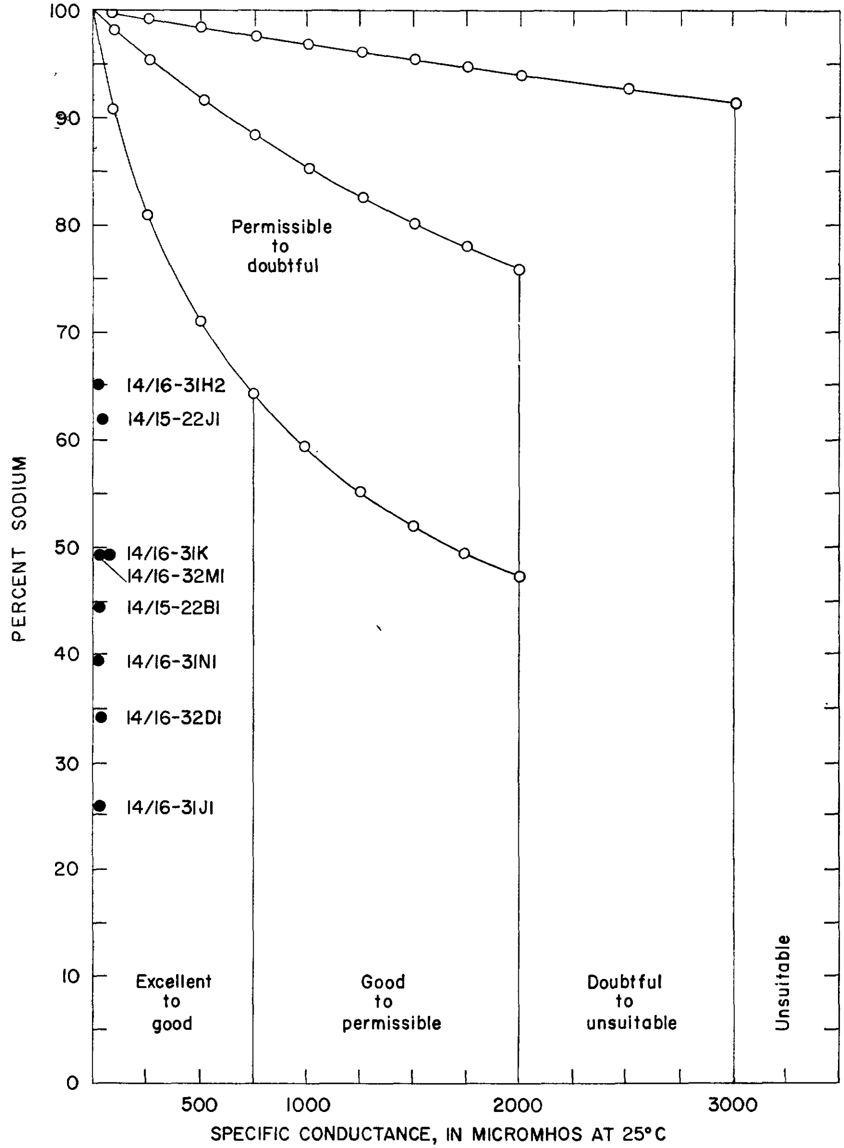

FIGURE 7.—Diagram for the classification of irrigation waters (after Wilcox, 1948).

from the artesian aquifer principally for irrigation use. Many wells that supply household requirements for the rural homes in the area tap the artesian aquifer, and some of those wells also are used for stock supplies and for watering lawns and small gardens.

In 1959, the average daily pumpage for municipal supplies was estimated to be about 0.7 mgd and that for industrial supplies was about 0.4 mgd. Very few data are available on the quantity of water withdrawn from irrigation, domestic, and stock wells that tap the artesian aquifer; however, the average combined withdrawal from these wells is almost certainly less than 0.2 mgd. Hence the total discharge from the artesian aquifer (through wells) is estimated to be no more than 1.3 mgd, or 1,500 acre-feet per year.

EFFECTS OF PRESENT WITHDRAWALS

As previously stated, during the period of this study there has been a moderate, general decline of artesian pressures throughout the alluvial plain, and localized declines of greater magnitude near the centers of large withdrawals (fig. 5). No probable cause for the decline of the piezometric surface, other than withdrawals from wells, can be postulated. Under other circumstances, such a general declining trend might be attributed to meager recharge during a period of deficient precipitation. However, the period of declining pressures measured during this study apparently has been one of above normal precipitation (fig. 2).

The long-term decline of artesian pressures in the Prineville area represents primarily a change in the rate at which water is moving through the artesian aquifer, rather than the permanent removal of appreciable amounts of water stored in the aquifer. As the pressure surface of the aquifer declines in areas of discharge, the hydraulic gradient from recharge areas steepens, and water can move more rapidly toward the centers of large withdrawal, as in Prineville. Because the drawdown of the pressure surface has not been sufficient to cause actual dewatering, or draining, of the artesian aquifer, even in the vicinity of Prineville, the overall decrease in the amount of water stored in the aquifer has been small, resulting only from a slight compaction of the aquifer materials owing to the decrease of pressures within the aquifer. However, dewatering may be occurring in the recharge area.

The withdrawal of water from artesian wells in the valley has caused other interrelated changes in the preexisting water regimen in addition to the lowering of the artesian pressure. The other important changes are: a decrease in the amount of natural ground-water discharge; an increase in the amount and, locally, a change in the mode of recharge to the aquifer; an increase, at places, in the concentration of dissolved mineral constituents in the artesian water.

As previously discussed, the reduction of artesian pressures in the aquifer, manifested as a lowering of the piezometric surface, has decreased the differential upward pressure exerted upon the confining beds between the artesian and water-table aquifers, and thus has caused a decrease in the amount of water lost from the artesian aquifer by natural upward leakage. Locally, where the piezometric surface has declined below the water table, the natural pressure differential has been reversed, and the water can now percolate downward from the unconfined aquifers to the artesian aquifer, thus providing additional recharge to the artesian aquifer. The water from the shallower aquifers apparently has a greater amount of dissolved minerals than other waters that recharge the artesian aquifer; where downward percolation from those shallow aquifers occurs, the concentraton of dissolved solids in the artesian aquifer has increased.

Besides allowing additional recharge to the artesian aquifer in areas of greatest drawdown, the reduction of artesian pressure may also have caused an increase in the recharge in the principal intake area of the confined water body. This intake area is along the upper side of the terrace on the north side of the valley floor. Because the steepened hydraulic gradient causes water in the artesian aquifer to move more rapidly away from the intake area toward the points of discharge, the aquifer probably can now accept more water in the intake area. Thus, the artesian aquifer probably now receives some potential recharge that in the past may have been rejected because the aquifer was full.

POSSIBLE EFFECTS OF INCREASED WITHDRAWALS

Additional large withdrawals of water from the artesian aquifer in the Prineville area may be expected to intensify the effects previously described. That is substantially greater withdrawal would tend to cause (1) additional decline of the piezometric surface, (2) further decrease of the natural discharge occurring as upward leakage from the aquifer, (3) dewatering in the recharge area, (4) increase in the recharge to the aquifer, and possibly (5) locally greater increase in the concentration of dissolved minerals in the artesian water. These possible effects would be greatest if the additional withdrawals were from wells grouped in a relatively small part of the area or located near the present centers of large withdrawal. Conversely, the effects would be less noticeable or, in the case of possible changes in chemical quality of the artesian water, might not develop so rapidly, if the increased withdrawals were from widely seperated wells.

Because the artesian aquifer apparently is a hydraulically continuous unit, additional withdrawal from a well tapping that aquifer in any part of the area would eventually cause a decline of the piezometric surface, not only in the vicinity of that well, but also at other wells in the area. Thus, the cone of depression caused by that withdrawal might expand to other wells that tap the artesian aquifer, and troublesome interference between wells might result. As previously stated the amount of drawdown caused by mutual interference is greater for wells that are closely grouped than for wells that are more widely spaced. Mutual interference, caused largely by the relatively close spacing of the large-capacity wells in Prineville, is the principal reason for the excessive drawdowns in those wells and for the accompanying problems of high-pumping lifts and possible increase of mineral content of the well water. It is apparent, therefore, that any additional large-yield wells that tap the artesian aquifer should be spaced as far as possible from existing wells and from each other.

Any further lowering of the piezometric surface as a result of increased withdrawal from the artesian aquifer could be expected to cause, indirectly, an increase in the recharge to the artesian aquifer. Further decline of the piezometric surface in the southern part of the valley floor would tend to increase the hydraulic gradient from the principal recharge area to the artesian aquifer, and thus by dewatering in the recharge area, would create additional storage space for recharge in that area, as previously described. In parts of the area where the piezometric surface now stands above the water table, the lowering of the piezometric surface also would salvage some water that now discharges naturally from the artesian aquifer by upward leakage. If the piezometric surface were drawn down below the water table throughout a larger part of the area, additional recharge could also take place as downward leakage from the shallower aquifers. Thus, the availability of additional water, owing to increased recharge and decreased natural discharge, would tend to counteract the larger withdrawal and its resultant drawdown.

Some increase of dissolved solids in the artesian water could be expected in any additional areas where the piezometric surface declines below the the water table. Available data do not allow prediction of the degree or extent of any future changes in chemical character of the artesian water; however, such changes probably would be greatest at places where the piezometric surface declines to its lowest levels. The concentration of dissolved solids in the artesian aquifer could never be greater than that of the most mineralized water recharging the aquifer. Therefore, even if the recharge to the artesian aquifer locally was entirely by downward percolation from the shallow aquifers, the chemical quality of the artesian water at that place could be no higher in mineral content than the shallow unconfined waters.

Substantially greater withdrawals from the artesian aquifer possibly would have some indirect influences on the flow of the streams in the area, but the available data do not permit evaluation of those factors. Presumably, the effects on streamflow would be greatest if the additional withdrawals were large enough to cause a lowering of the piezometric surface throughout the area to a position below the water table. Under such conditions, some ground water that now discharges from the alluvium to the streams during periods of low stream stages, and seepage from the streams themselves, would migrate downward to the deeper aquifers. At the same time, however, much of the ground water constituting the increased withdrawal doubtless would be allowed to return to the alluvium or to the streams following its use. Thus, the general effect on streamflow of increased withdrawal of artesian water on streamflow probably would depend mostly on the uses to which the additional ground water were put—that is, seasonal variation in the amounts used, and the amount of water that would actually be consumptively used, as by transpiration by crops.

CONCLUSIONS

The most important source of ground water in the Prineville area is a single artesian aquifer consisting of a layer of sand and gravel that ranges in thickness from less than 10 to more than 30 feet. This permeable layer, which yields large supplies of water to wells, underlies the valley floor at depths ranging from less than 100 to about 300 feet and is known to extend through an area of at least 12 square miles. The bedrock materials that underlie the aquifer apparently are not capable of yielding appreciable quantities of water to wells, and shallower aquifers generally yield only small supplies.

Recharge to the artesian aquifer is mostly by infiltration from precipitation, from the flow of small streams, and from irrigation water, and occurs principally along the north side of the valley floor on the terrace that abuts the lower slopes of the Ochoco Mountains. An additional and probably small amount of recharge occurs as downward leakage from the overlying unconfined aquifers at places where the piezometric surface stands below the water table.

Movement of water in the artesian aquifer is from the principal recharge area, described above, southward toward the alluvial plain. Under conditions that prevailed in November 1953, roughly 2 mgd, or about 2,000 acre-feet a year, moved through the aquifer. The latter amount is the best estimate presently available for the annual recharge to the artesian aquifer.

Discharge of water from the artesian aquifer is chiefly through wells; in 1959, as much as 1.3 mgd, or about 1,500 acre-feet per year probably was withdrawn through wells. A substantial but unknown amount of water also discharges from the artesian aquifer as upward leakage to shallower zones and possibly by underflow down-valley.

The withdrawal of artesian water during the period October 1944–November 1953 caused a general decline of the piezometric surface of the artesian aquifer less than 20 feet throughout most of the area, but more than 30 feet in districts of intensive pumping, as at Prineville. The long-term decline of the piezometric surface has not dewatered the artesian aquifer, but it may have caused some depletion in the recharge area.

The chemical quality of the ground water is generally good, although the water from some of the wells is harder than desirable or may contain iron in amounts that are troublesome for some uses. The available data suggest that in areas of intensive pumping, the concentration of dissolved minerals of the artesian water may be increasing locally.

Increased withdrawal from the artesian aquifer would tend to cause additional decline of the piezometric surface, an increase in the recharge to the artesian aquifer, a decrease in the natural groundwater discharge from the aquifer, and possibly, local increases in the concentration of dissolved minerals in the artesian water. The additional water that might be available for withdrawal, by reason of the increased recharge and decreased natural discharge from the aquifer, would tend to counteract the decline of the piezometric surface owing to the increased withdrawal.

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TABLE 2.—*Records of selected wells in the Prineville area, Oregon*

Well number: See p. P4 for description of well-numbering system.
Topography and altitude: Uk, upland bedrock knoll; Up, upland plain; Vp, valley plain; Vt, valley terrace slope. Altitude of land-surface datum at well, in feet above mean sea level; determined by leveling (*), barometric surveys, and interpolation from topographic maps (†).
Type of well: Dn, driven; Dr, drilled; Dg, dug.
Ground-water occurrence: C, confined; U, unconfined.
Water level: All water levels are referred to land-surface datum at well; R, reported; D, discharging when measured.
Type of pump: C, centrifugal; J, jet; N, none; P, piston or plunger; T, turbine.
Use: D, domestic; Ind, industrial; Irr, irrigation; N, none; Ps, public supply; RR, railroad; S, stock.
Remarks: Ca, chemical analysis in table 4; dd, drawdown; ft, feet or foot; gpm, gallons per minute; H, hydrograph in figure 3 or 4; L, log in table 3; temp, temperature of water in °F.

Well	Owner or occupant	Topography and altitude (feet)	Type of well	Year completed	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s): Depth to top (feet)	Water-bearing zone(s): Thickness (feet)	Water-bearing zone(s): Character of materials	Ground-water occurrence	Water level: Feet above (+) or below datum	Water level: Date	Type of pump and yield (gallons per minute)	Use	Remarks
T. 14 S., R. 15 E.																
1N1	E. P. Hunspurger.	Up, 2,995	Dr	-------	195	6	60	-----	-----	-------------	U	20R	Spring 1944	P, 5	D, S	Temp 58°.
10Q1	Ervie Grimes	Up, 2,915	Dr	-------	300±	---------	-----	-----	-----	-------------	C	+4 to +5R	10-28-44	N	D, S	Well started to flow after irrigation began in 1919; flowed 7 gpm, Oct. 1944; temp 61°.
11B1	Earl Forest	Up, 2,985	Dr	1945	110	8	-----	-----	-----	Gravel	U	23.8	3-20-47	J, 15	D, S	
12Q1	Foy Hibbard	Up, 2,950	Dr	-------	275	6	-----	264	11	Sandstone	C	20R	---------	---------	D, S	Well originally 198 ft deep; yields 5 gpm, dd 5 ft.
13D1	J. C. Windham	Up, 2,960†	Dr	1955	200	10-6	200	12	10	Gravel and sand.	U	3.5R	1955	T, 346	Irr	Pumped 346 gpm for 6 hr, dd 7 ft; L, temp 48°.
15P1	G. W. Slayton	Up, 2,852	Dr	1912	215	6	196.5	196	30	Sand(?)	C	+42 +29	10-25-44 11-18-53	N	D, S Irr	Measured depth, 215.3 ft, silt at bottom; flows less than 10 gpm; temp 60°.
15Q1	M. D. Colahan	Up, 2,847*	Dr	1915	210	4	-----	-----	-----	-------------	C	+60 +61	10-25-44 11-18-53	N	D, S Irr	Temp 60°, Ca.
16J1	George Russell, Jr.	Up, 2,850	Dr	1918	-------	---------	-----	-----	-----	-------------	C	+74 +55	10-25-44 11-18-53	N	D, S	Temp 60°, Ca.
20R1	Mr. Slavin	-----------	Dg	1949	20±	240×300	-----	-----	-----	-------------	U	14	4-4-50	T, 500 43	Irr	
21H1	James Small	Vp, 2,829	Dr	1914	260±	6	-----	-----	-----	-------------	C	+29 +29 +24	7-24-44 10-25-44 11-18-53	N, 20	D, S	Flows about 20 gpm; temp 59°.

22B1	Josiah Williams	Vp, 2,840*	Dr	1913	210±	6					C	+61 +50	10-25-44 11-18-53	N	D, S Irr	Flowed 150 gpm for 6½ hr 35 ft dd; temp 58°, Ca.
22J1	Claude Williams	Vp, 2,850	Dr	1946	264	6					C	+32 +24.5	11-20-46 11-18-53	N, 100	D, S Irr	Reportedly flows 100 gpm; temp 54°, Ca.
23G1	Earnest E. Fortner.	Vp, 2,900†	Dr	1956	80	6	79.5	30	50	Sand	U	27R	1956			Temp 55°, L.
23R1	Pine Products Lbr. Co.	Vp, 2,860	Dr	1943	216	6	206	213	3	Fine gravel	C	29.19D	4-15-54	C, 75	Ind	Well originally flowed; temp 58°.
24M1	Foy Hibbard	Vt, 2,885	Dr	1914-16	266	6					C	9.31	7-24-44	C, 10	D, Irr	Flowed in 1916.
24M2	do	Vt, 2,890	Dr	1947	560	4	220			Fine sand	C	17.1	9-5-46	N	N	Fine silt (tuff?) from 225 to 364 ft; green tuff to 560 ft.
25E1	R. M. Doty	Vp, 2,861	Dr	1920	215±	6					C	14.6	10-24-44		D, Irr	Formerly flowed.
27J1	Myron Hager	Vp	Dr	1945	300±	4		48±	4±	Quicksand					D	
35H1	Joe Martin	Vp	Dn	1950	22	3	22	18	4	Gravel	U	6.4	4-4-50	50-75	Irr	L.
36G1	H. G. Eldridge	Vp, 2,844*	Dr	1944	227	6	226	226	1	Gravel and sand.	C	+25 +17 0.0	Early 1944. 10-26-44 11-18-53	C, 5	D, Irr	Originally flowed about 15 gpm; temp 56°, L.
36H1	Alton Basey	Vp, 2,844*	Dr	1944	220	6	214	214	6	Sand and gravel.	C	+32 +17.5	10-26-44 11-18-53	N, 120	D, Irr	Flowed 120 gpm for 8 hr; dd 13.5 ft; L, Ca.
36H2	Charlie Loftin	Vp, 2,850†	Dr	1958	238	4	238	178	60	Fine black sand.	C	+11	4-30-58	N, 40	D	Temp 51°, L.
36J1	Unknown	Vp, 2,850			15-20	1¼				Gravel	U			P	D	Ca.
36R1	Mr. Davis	Vp, 2,850†	Dn	1950	23	1½		17	4	Sandy gravel.	U	9 to 10R	Mar. 50		D, S	

T. 14 S., R. 16 E.

7M1	Van Moore	Uk, 3,050†	Dr	1958	277	6	4	237	40	Tuff	U	115	10-12-58	N		L.
17N1	Mr. Bowman	Up, 2,985	Dr		115±	6				Sandy silt	U	15R	Oct. 44	P, 10	D, S	
19H1	Leslie Clauson	Up, 2,970	Dr		46.5	6					U	8.0	10-28-44	J, 10	D, S	Water level rises during irrigation season.
29B1	Mr. Endicott	Up, 2,970	Dr	1944	300	6		270	30	Sandstone(?)	C	30R	Sept. 44	J, 5	D	A few feet of alluvium overlies bedrock (Clarno? formation).
30A1	E. Wagoner	Uk, 2,960	Dr		60+	6				Tuff	U	30R		L, 5	D, S	Drilled nearly full depth in bedrock (Clarno formation).
30N1	Orville Yancey	Vp, 2,856	Dr	1915	212	6	203	210	2	Sand and gravel.	C	+25	10-25-44	C, 15	D, S, Ind, Irr.	Temp 58°.
31A1	Midstate Lbr. & Supply Co.	Up, 2,955†	Dr	1949	228			128	100(?)	Sand	C	35.30	4-15-54	J, 200+	Ind	
31D1	Pacific Power & Light Co.	Vp, 2,850	Dr	1957	256	24-12	228	231	21	Sand and gravel.	C	+2R	9-27-57	T, 800	P, S	Pumped 550 gpm for 8 hr dd 84 ft; L.
31F1	Mrs. Lon Smith	Vp, 2,866	Dr	1915		6					C	+14.9	10-24-44	P, 5	D, S	Temp 64,° Ca.

TABLE 2.—*Records of selected wells in the Prineville area, Oregon*—Continued

Well	Owner or occupant	Topography and altitude (feet)	Type of well	Year completed	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s)			Groundwater occurrence	Water level		Type of pump and yield (gallons per minute)	Use	Remarks
								Depth to top (feet)	Thickness (feet)	Character of materials		Feet above (+) or below datum	Date			
								T. 14 S., R. 16 E.—Continued								
31G1	Hudspeth Co., Inc.	Up, 2,940†	Dr	1948	288	10	286.5	281	7	Sand and gravel.	C	45R 55.86	1-30-48 4-15-54	T, 185	Ind	L.
31G2	do	Up, 2,940†	Dr	1948	400	8	315.5	150 284	20 11	Sand(?) Gravel	C	50R 57.68	3-31-48 4-15-54	T, 525	Ind	L.
31H1	Pioneer Cemetery Association.	Up, 2,942*	Dr	1946	244	6				Coarse sand	C	70.40	7- 9-46	N	Irr	
31H2	Hudspeth Sawmills Co.	Up, 2,927*	Dr	1946	265	6	250	250	15	Sand	C	54.60	7- 9-46	T, 20	Ind	Temp 59, Ca.
31J1	City of Prineville R.R.	Up, 2,868*	Dr	1940	223	6⅝	222	222	1	Gravel	C	+20R +4.8 10.61	 10-26-44 11-18-53	C, 15	RR	Originally flowed about 110 gpm; temp 61.
31M1	O. C. Hawk	Vp, 2,850*	Dr	1944	212	6	208	208	4	Sand	C	 +23 +8.2	 10-25-44 11-18-53	N	D, Irr.	Originally flowed about 50 gpm; L.
31N1	Packard and Thorpe.	Vp, 2,850*	Dr	1946	214.5	4					C	+14	9- 5-46	C, 20	Ps	Supplies auto court, Ca.
31P1	Grover C Barron.	Vp, 2,853*	Dr	1944	223	4	220	220	3	Sand and gravel.	C	+21R +18	1944 10-25-44	N	D, Irr.	Flowed 45 gpm for 6 hrs, dd 7.5 ft; originally flowed 100 gpm; temp 57, L, Ca.
31Q1	Pacific Power & Light Co.	Vp, 2,857	Dr	1915		8					C	+16 .51D	10-26-44 11-18-53	272	Ps	Temp 56°, Ca.
32D1	Alexander-Yawkey Lumber Co.	Up, 2,955	Dr	1942	690	12-8	414	217	36	Sand	C	35R	About 1942	T, 500	Ind	Pumped 700 gpm for 6 days, dd 33 ft; temp 63°, Ca, L.
								517 596 651		Previous lenses in shale.		64.99	4-15-54			1,000 gpm, dd unknown.
32M1	Pacific Power & Light Co.	Up, 2,933*	Dr	1943	300	12	300±	237 241	2 13	Sand and gravel. do	C	50R 66 149D	Mar. 43 10-28-44 11-18-53	T, 400	Ps	Originally 1,002 ft deep; pumped 130 gpm for 2 hr, dd 27 ft; temp 59°, Ca, L.

32N1	E. E. Wagoner	Vp, 2,866*	Dr	1912	160	4⅝					C	.90 9.4	10-27-44 11-18-53	N	N	Formerly flowed.
35N1	E. Slayton	Vp, 2,945	Dr	1912	600±	6					U	50R		L, 15	D, S	Alluvial material to a depth of 100 ft; varicolored bedrock below 100 ft.
								T. 15 S., R. 16 E.								
4B1	William Endicott.		Dn	1956	24	4	24	18	6		U	9R	9-10-52	120	Irr	
5A1	O. M. Young	Vp, 2,885	Dn	1937	32	2	32			Gravel	U	4R		P, 10	Ps	Typical of wells in shallow gravel zone along lower plain.
5A2	do	Vp, 2,885	Dr	1941	96	6	63	63		Fine sand	U	6.20	10-23-44	N		Well sanded up to 64 ft.
5D1-15	Pacific Power & Light Co.	Vp, 2,865	Dn		40-60	2		40	20±	Sand	U	6.74	9-13-43	P, 400	Ps	Series of driven wells connected to two pumps—auxiliary supply.
5D16	Crook County	Vp, 2,869	Dr	1915	510±			60	20±	Sand	U?	4 to 5,R			Ps	Alluvial material to a depth 184 ft, "dry" bedrock below.
5D17	do	Vp, 2,869	Dr	1915	70	5⅝	64	64	6	Sandy silt	U	4 to 5,R			Ps	
5D18	Pacific Power & Light Co.	Vp, 2,865	Dr	1950	160	12		147	1	Fine gravel and sand.	C	10R			N	Well abandoned, casing pulled. L.
5D19	do	Vp, 2,865	Dr	1950	252	12		220	10	Gravel	C	22R	1950	T, 620	Ps	Water reportedly contains silt; Ca.
5E1	do	Vp, 2,862	Dr	1950	252	10	241	220	22	Gravel and sand.	C	0 to 7, R		T, 1,000	Ps	L, Ca.
5F1	do	Vp, 2,865†	Dr	1956	400			162	22	do					N	Abandoned and plugged at about 40 ft; L, Ca.
6A1	M. E. Gerow, and others.	Vp, 2,860*	Dr	1914	240	4					C	+13.05 7.01	10-26-44 11-18-53	C, 15	D	Serves four families; Ca.
6A2	Thomas Smith	Vp, 2,858*	Dr			6					C	+12.60	10-26-44	P, 10	D, S	Temp 58°.
6A3	George Whiteman.	Vp, 2,864*	Dr	1942	228	5	225	225	3	Fine gravel	C	+25	Spring 1943	C, 10	Ind	Used for laundry; original flow reportedly 50 gpm; L, temp 57°.
6A4	William McKay.	Vp, 2,865*	Dr	1938	240	6⅝	216	216	24	Sand	C	+24 +6.60	Mar. 38 10-26-44	P, 10	Ps	Used for apartment building; Ca.
6D1	George Noble	Vp, 2,850	Dr	1915	300±						C				D	Drill passed from valley fill to bedrock at 175 to 180 ft; no water in bedrock.

TABLE 3.—*Logs of wells in the Prineville area*

[Tentative stratigraphic designations by J. W. Robinson]

Materials	Thickness (feet)	Depth (feet)
14/15-13D1		
[J. C. Windham. Drilled by Bert Abrams, 1955. Casing: 10-in to 69 ft, 6-in to 200 ft; perforated from 12 to 21 ft; gravel-packed from 2 to 23 ft]		
Fluviolacustrine deposits:		
Top soil	4	4
Hardpan, brown	8	12
Sand, brown, water-bearing	6	18
Gravel and sand	4	22
Sand, black, and mud	36	58
Clarno formation:		
Hardpan, black	124	182
Tuff rubble, green	18	200
14/15-23G1		
[E. E. Fortner. Drilled by Lee Grimes, 1956. Casing: 6-in to 79½ ft; perforated from 45 to 60 ft]		
Fluviolacustrine deposits:		
Top soil	2	2
Gravel	8	10
Hardpan, brown	20	30
Sand, light	50	80
14/15-35H1		
[Joe Martin. Driven by Mr. Martin, 1950. Casing: 3-in to 22 ft; perforated 20 to 22 ft]		
Alluvium:		
Silt and fine sand	8	8
Gravel, hard	2	10
Sand	4	14
Gravel, hard	2	16
Sand	2	18
Gravel, loose	4	22
14/15-36G1		
[H. G. Eldridge. Drilled by George E. Scott, 1944. Casing: 6-in to 226 ft; open bottom]		
Alluvium:		
Gravel	21	21
Fluviolacustrine deposits:		
Silt, sandy, and clay	205	226
Gravel and sand, water-bearing	1	227

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
14/15-36H1		
[Alton Basey. Drilled by George E. Scott, 1944. Casing: 6-in to 214 ft; open bottom]		
Alluvium:		
Soil	8	8
Gravel	10	18
Fluviolacustrine deposits:		
Silt and sand; with some seams of sticky clay below 120 feet	196	214
Sand and gravel, water-bearing	6	220
14/15-36H2		
[Charlie Loftin. Drilled by Lloyd Mathers, 1958. Casing: 4-in to 238 ft; not perforated]		
Alluvium:		
Top soil	4	4
Gravel	20	24
Fluviolacustrine deposits:		
Fine sand and gravel mixed	121	145
Clay, blue, hard	33	178
Sand, black, fine	60	238
14/16-7M1		
[Van Moore. Drilled by Bert Abrams, 1958. Casing: 6-in to 4 ft]		
Clarno formation:		
Top soil	1	1
Tuff	127	128
Hardpan, black	109	237
Tuff, broken	40	277
14/16-31D1		
[Pacific Power & Light Co. Drilled by R. J. Strasser, 1957. Cacing: 24-in. to unreported depth, 12-in to 228 ft; 12-in. screen from 228 to 253 ft]		
Alluvium:		
Sand, soft	2	2
Sandstone, water-bearing	10	12
Clay	7	19
Gravel, clay binder	12	31

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
14/16-31D1—Continued		
Fluviolacustrine deposits:		
Silt, sandy	21	52
Silt, sandy; gravel	5	57
Silt, sandy	44	101
Silt, sandy; some gravel	21	122
Silt	72	194
Shale, sticky	29	223
Silt, yellow	5	228
Gravel, cemented	3	231
Sand and gravel, water-bearing	21	252
Clay, yellow	4	256
14/16-31G1		
[Hudspeth Pine Co., Inc. Drilled by A. M. Jannsen, 1948. Casing: 10-in to 286.5 ft]		
Fluviolacustrine deposits:		
Sand and gravel	5	5
Sand and clay	45	50
Sand	128	178
Clay, sandy	53	231
Clay	48	279
Sandstone, hard	2	281
Sand and gravel	6	287
Gravel, cemented	1	288
14/16-31G2		
[Hudspeth Pine Co., Inc. Drilled by A. M. Jannsen, 1948. Casing: 8-in to 315½ ft; perforated from 150 to 170 ft and 285 to 295 ft]		
Fluviolacustrine deposits:		
Sand and clay	170	170
Clay	114	284
Gravel	11	295
Clarino(?) formation:		
Clay	25	320
Shale, hard	35	355
Shale, blue-green	45	400

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
14/16-31M1		
[O. C. Hawk. Drilled by George E. Scott, 1944. Casing: 6-in to 208 ft, open bottom]		
Alluvium:		
Soil	11	11
Gravel	11	22
Fluviolacustrine deposits:		
Clay	16	38
Silt, sandy; finer at bottom	170	208
Sand	4	212
14/16-31P1		
[Grover C. Barron. Drilled by George E. Scott, 1944. Casing: 4-in to 220 ft, open bottom]		
Alluvium:		
Soil	6	6
Gravel	16	22
Fluviolacustrine deposits:		
Clay, blue-gray, silty, and sandy silt	93	115
Silt, sandy	105	220
Sand, coarse, and some gravel	3	223
14/16-32D1		
[Alexander-Yawkey Lumber Co. Drilled by George E. Scott, 1942. Casing: 12-in to 217 ft, 8-in to 414 ft; open bottom; perforated from 217 to 253 ft]		
Alluvium:		
Soil	2	2
Fluviolacustrine deposits:		
Gravel	28	30
Sand, yellow	25	55
Sand, silty, and clay	162	217
Sand, water-bearing	36	253
Madras(?) formation:		
Clay and gravel, tight	79	332
Gravel, tight	20	352
Clarno(?) formation:		
Shalelike material, tight; thin water-bearing lenses at 517, 596, and 651 ft	316	668
Rock, hard	15	683
Shale, bluish-green	3	686
Rock	4	690

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
14/16-32M1		
[Pacific Power & Light Co. Drilled by George E. Scott, 1943. Casing: 12-in to 300± ft, plugged below 300 ft; perforated from 236 to 247 ft, and from 248 to 264 ft]		
Fluviolacustrine deposits:		
Gravel	18	18
Sand, yellow	21	39
Silt and sand, with streaks of clay	49	88
Sand, dark, dirty, water-bearing	6	94
Clay, dark, silty	125	219
Clay, blue	18	237
Gravel, dirty, water-bearing	2	239
Clay, sticky	2	241
Gravel, dirty, water-bearing	13	254
Clarno(?) formation:		
Clay, greenish	8	262
Clay, muddy, yellow	10	272
Clay, gray	35	307
Gravel(?)	½	307½
Clay, gray, with slight variations	694½	1,002
15/16-5D18		
[Pacific Power & Light Co. Drilled 1950. Casing: pulled, well abandoned]		
Alluvium:		
Soil	3	3
Gravel, light	1	4
Silt and gravel	6	10
Gravel, sandy, water-bearing	4	14
Fluviolacustrine deposits:		
Clay	2	16
Silt, sandy	10	26
Clay, blue	4	30
Sand, dark	25	55
Clay, dark	35	90
Sand, gray, fine	20	110
Clay	37	147
Gravel, fine (⅜-in), and sand, water-bearing	1	148
Clay	12	160

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
15/16-5E1		
[Pacific Power & Light Co. Drilled by Pacific Drilling Co. 1950. Casing: 10-in to 241 ft; perforated from 220 to 230 ft]		
Alluvium:		
Clay and silt	6	6
Gravel, coarse	5	11
Gravel, cemented	2	13
Gravel, coarse, water-bearing	15	28
Fluviolacustrine deposits:		
Sand, brown	10	38
Sand, black	27	65
Clay	10	75
Sand, black	35	110
Gravel	2	112
Sand, black	8	120
Sand and silt	70	190
Clay	30	220
Gravel, coarse, water-bearing	2	222
Gravel, fine	8	230
Sand, coarse; fine gravel	12	242
Madras(?) formation:		
Clay	10	252
15/16-5F1		
[Pacific Power & Light Co. Drilled 1956. Well abandoned]		
Alluvium:		
Top soil	5	5
Sand and gravel	5	10
Gravel	10	20
Gravel, cemented	19	39
Fluviolacustrine deposits:		
Sand	111	150
Clay	12	162
Sand, coarse, and gravel	22	184
Madras(?) formation:		
Rock and clay	36	220
Cinders, red	116	336
Clay	17	353
Shale, black	27	380
Clay, green	20	400

TABLE 3.—*Logs of wells in the Prineville area*—Continued

Materials	Thickness (feet)	Depth (feet)
15/16-6A3		
[George Whiteman. Drilled by George E. Scott, 1942. Casing: 5-in to 225 ft]		
Alluvium:		
Gravel	25	25
Fluviolacustrine deposits:		
Silt, sandy; sticky last 60 to 70 ft	200	225
Gravel, fine, water-bearing	3	228

TABLE 4.—*Chemical analyses of typical waters from the Prineville area, Oregon*

[Analyses are by the U.S. Geological Survey unless otherwise indicated]

Well	Source	Date of collection	Temperature (°F)	Parts per million: Dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Boron (BO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ (calculated)	Non-carbonate hardness	Percent sodium	Specific conductance (micromhos at 25°C)	pH
14/15-15Q1	Well taps confined water in fluviolacustrine deposits.	11-21-46	60			0.14				0.4			3.5			87			29.3	
16J1	do	11-18-46	60			.02							3.2			100			29.3	
22B1	do	11-18-46	59	171		.02	21	9.7	34	0	180	12	2.8	0.1	2.4	92	0	44	28.9	
22J1	do	11-20-46	54	170		.01	13	7.5	47		187	5.8	4.0	.3	.1	64	0	62	29.2	
36H1	do	11-19-46				.03							4.2			93			19.7	
36J1	Well taps unconfined water in alluvium.	11-22-46		360	37	.57	51	27	39		341	23	14	.1	.2	238	0	26	58.8	
14/16-31F1	Well taps confined water in fluviolacustrine deposits.	11-22-46	64			.03							4.2			86			24.1	
31H2	do	11-18-46	59	249	51	.23	12	8.7	56	0	195	4.0	11	.4	10	61		65	33.5	7.6
	Irrigation return flow in ditch (NW¼SE¼ sec. 31).	11-22-46		412		.03	42	23	89	0	366	48	29	.6	.4	200	0	49	69.2	
31N1	Well taps confined water in fluviolacustrine deposits.	11-18-46	57	136		.04	18	9.2	24	0	143	9.9	4.2	.3	.5	83	0	39	23.1	
31P1	do	11-18-46	57			.02							4.2			105			23.6	
31Q1	do	11-14-46	56			.0							4.0			80			23.2	
		Oct. 59[1]		218		.05					126	20	8.5			125				
32D1	Well taps confined water in fluviolacustrine deposits and water in bedrock.	11-20-46	63	328	56	.07	36	19	40		200	49	28	.2	.9	168	4	34	49.1	7.5
		Oct. 59		[3]1,091		[3]7.8					311	35	5.0			213				7.4
14/16-32M1	Well taps confined water in fluviolacustrine deposits.	5-5-43[1]		287							140	15	7.4			64				7.1
		11-14-46	59	254		.02	27	13	54	0.4	215	35	17	.3	1.5	121		49	43.4	
		Oct. 59[1]		358		.21					202	55	20			153				7.6
15/16-5D19	do	Oct. 59[1]		260		.16					137	25	11			140				7.3
5E1	do	9-13-50[1]		260		.4					147	5	5.6			70				7.95
		Oct. 59[1]		210		.16					127	15	3.5			90				8.0
5F1	Well taps unconfined water in alluvium.	Oct. 59[1]		371		.15					216	45	6.5			155				7.5
6A1	Well taps confined water in fluviolacustrine deposits.	11-22-46	56			.02							3.0			84				
6A4	do	11-22-46	58			.02							3.5			68				
	Crooked River near Prineville.[2]	1911-1912		246	34	.09	26	11	52		199	17	11		.4	110				

[1] Analysis by Charlton Laboratories, Portland, Oreg.
[2] Mean of 29 Chemical analyses made in 1911 and 1912 (Van Winkle, 1914).
[3] "Sample contained considerable amount of precipitated iron, which is included in the analysis figures."