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The Ground-Water Problem in Oregon

Oregon State System of Higher Education
Agricultural Experiment Station
Oregon State College
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The Ground-Water Problem in Oregon

Prepared by Oregon Agricultural Experiment Station
Department of Soils *

WATER is a daily need of almost every living thing. In arid sections water gives value to land. Ground water is less subject to contamination or heating than surface water and is much in demand for municipal and domestic use. In some areas the irrigation value is great. At the Harney Branch Experiment Station a demonstration farm has been irrigated from wells for ten years and has shown a profit throughout the depression. In the Fort Rock Valley, one of several pioneer irrigation wells yields about 1,250 gallons per minute with little draw-down.

Information as to occurrence and amount of ground water is needed in planning social, agricultural, and industrial development. Knowledge of ground water is important in economic development of watering places for stock in the utilization of range land. Information provided by ground-water surveys serves to guide economic devolopment by means of wells for domestic and irrigation purposes and to avoid much of the loss incurred by the construction of unproductive wells. It will guide the State Engineer in his administration of the ground-water law and may eliminate costly litigation.

To answer such questions as the following for any part of the state has only recently become possible. Are water supplies entirely dependable? If more water is needed, where can it be obtained? In what quantity and quality? Where are the promising ground-water basins, and how extensive are they? What is the extent in depth and water-yielding capacity of the pervious formations? How much water can be pumped from the respective basins year after year? These questions arise despite an Oregon statute that makes ground-water supplies in the region east of the Cascade Mountains subject to appropriation, with provision for ground-water rights based on beneficial use.

Strict limitations govern the use of ground water. Over a long term of years the dependable average water supply lies between the abundance of the '90's and the grim shortage of the last decade. Ultimate replenishment comes largely from rainfall, which fluctuates from year to year. Even large bodies of ground water may be so heavily pumped that the water level is depressed below limits of depth from which water may be profitably lifted. Usually the yield of wells is closely related to geological conditions which fix the extent of pervious formations and their capacity to transmit water.

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Ground-water levels and ground-water storage depend closely on the stage or height of the streams and may be influenced either beneficially or adversely for agriculture and for users of ground water through regulation of the streams. Some conditions make it possible to apportion ground water and surface water jointly to their most effective uses, with material reduction in conflict of interests.

PREVIOUS GROUND-WATER INVESTIGATIONS

State and Federal agencies have recognized these ground-water problems and have cooperated in recent years in studying them. In 1928 the State Agricultural Experiment Station began these studies as a phase of Oregon Soil and Soil-Water Investigations. The United States Geological

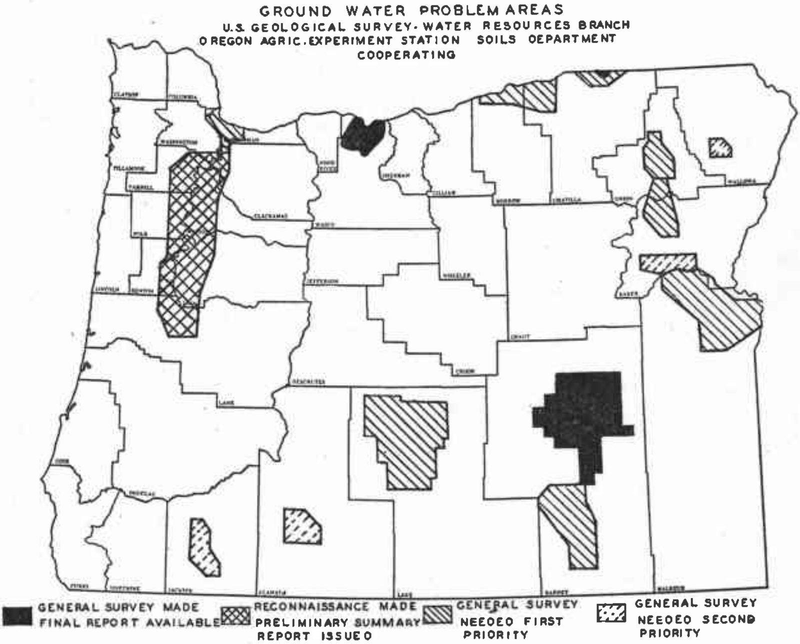

Figure 1.

Survey shared the cost of the ground-water investigations in the Willamette Valley, The Dalles region, and the Harney Basin. These cooperative investigations have been in immediate charge of A. M. Piper, Geologist of the United States Geological Survey. A brief preliminary statement on the Willamette Valley has been released,[3] and final reports are available for the other two areas.[1, 5]

In 1933 the foregoing two agencies investigated the Milton-Freewater district in Umatilla County, the Oregon State Engineer, Umatilla County, and the Washington Department of Conservation and Development cooperating. A report on the area has been released[2] and was stipulated in evidence in a recent action before the Supreme Court of the United States to determine interstate rights in the waters of the Walla Walla River Basin. A further report has been made in the Oregon section of a new bulletin dealing with the water levels and artesian pressure in observation wells in the United States in 1935.[4] Major ground-water problem areas of Oregon are shown in Figure 1.

These investigations are units of a program conceived by the Experiment Station ultimately to cover ground-water regions throughout the State. Since 1934, the Experiment Station has lacked funds to continue this cooperation with the Geological Survey. A small amount of field work has been done by the latter agency in cooperation with the State Engineer, in part through a WPA project.

The results already accomplished are presented in the brief summaries that follow. These are taken largely from the reports above cited.

WILLAMETTE VALLEY

The Willamette Valley is essentially a ground-water reservoir the bottom and sides of which are formed from sedimentary and volcanic rocks such as compose the inclosing mountains. The lowest part of the valley is floored with silt, sand, and gravel. Many of the sedimentary and volcanic rocks yield little water or only chemically inferior waters. The chief potential sources of ground water in sufficient quantity for practicable irrigation lie in the deposits of sand and gravel. Among the latter at least three distinct deposits are known: (1) stream deposits that form the flood plains of the Willamette River and its tributaries, (2) similar materials that form the extensive central valley plain, and (3) deposits of weathered gravel that cap benches or terraces about the margins of the central plain, the terraces commonly being bedrock shelves. Conditions of ground-water occurrence are distinctive for each of these deposits. (Figure 2.)

Recent stream deposits. The tongue of stream deposits that form the flood plain of the main Willamette River comprises mounds or lenses and tongue-shaped bodies of sand and gravel within a main body of finer material. The inferred thickness is a few tens of feet. Between the head of the valley at Eugene and the narrows above Oregon City, the width is commonly as much as a mile. In general, the coarsest members become progressively finer grained but better assorted downstream. Along three reaches the recent stream deposit or alluvial tongue is believed to rest commonly on the bedrock; namely: (1) along the three main headwater branches south and east of Eugene, (2) in the narrows between Corvallis and Salem, and (3) in the narrows that head near Canby and extend to and beyond Oregon City. Elsewhere the water-laid sediment or alluvium is believed to rest commonly on older stream deposits.

These stream deposits are generally moderately pervious with moderate water-yielding capacity, as has been shown by dug wells that have been pumped for irrigation in the vicinity of Coburg and elsewhere. The water table rises and falls in these wells in response to river stage. By autumn the water table, which is commonly less than 10 feet beneath the flood plain, may have declined 15 feet below the high stage of spring. Thus, because the deposits are relatively thin, the thickness of the saturated zone in its lower part ranges widely during the year. Obviously the capacity of the alluvial tongue to transmit water ranges somewhat in proportion to the thickness of the saturated zone and at some localities may become relatively small in the late autumn. The transmission capacity would be further reduced wherever the water table was depressed materially by pumping.

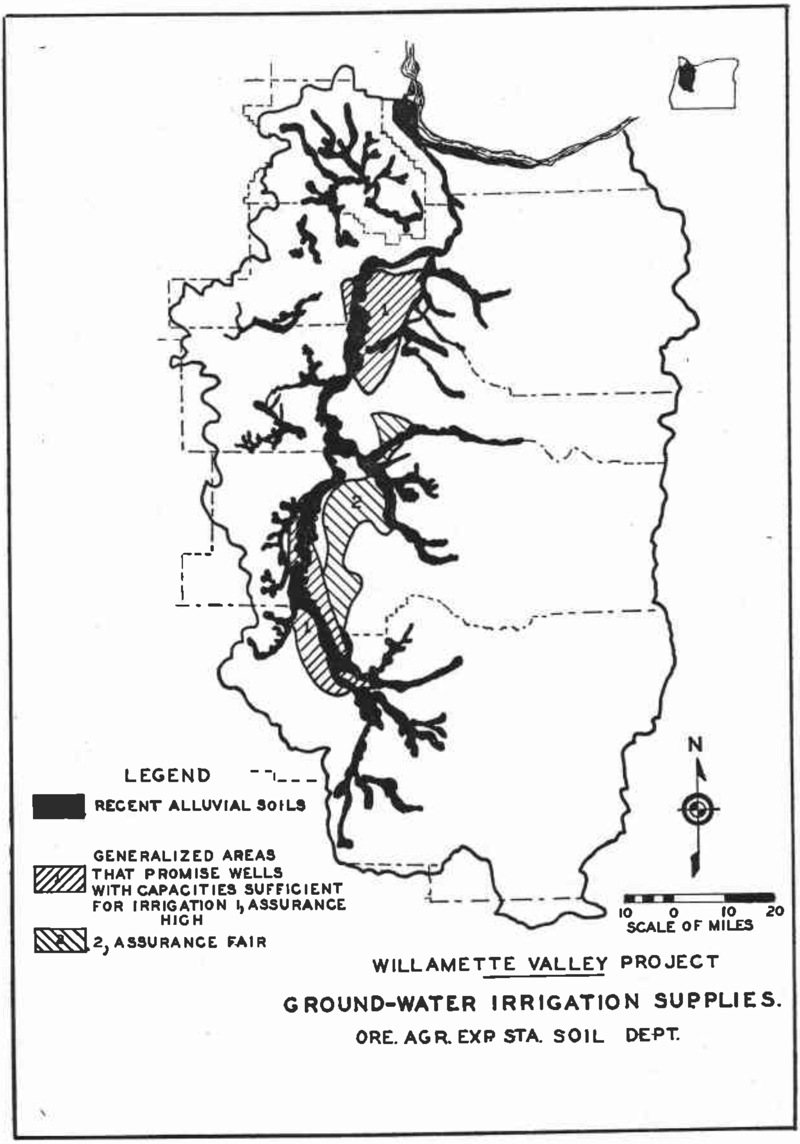

Figure 2.

Where the stream deposits rest on impervious bedrock the contour of the bedrock may in part control movement of ground water. Water pumped during the low-water season might well be drawn largely from storage in the deepest depressions of the bedrock surface. Extensive ground-water developments should be preceded by an adequate program of test drilling to locate the lowest course or thread of the bedrock drains and thus the thickest part of the water-yielding zone.

This description of ground-water occurrence in the alluvial tongue along the main Willamette River is thought to apply equally well along the lower reaches of three headwater branches south and east of Eugene (McKenzie River, Middle Fork, and Coast Fork), of the two forks of the Santiam River, and of the Molalla along the east side of the valley. On the other hand, it seems not to apply along the Long Tom, Mary's, and Yamhill rivers of the west side of the valley, along the Pudding River and Muddy Creek of the east side, nor along the numerous smaller tributaries. In the main, the deposits along the latter streams are probably composed of finer material which has much less capacity to transmit water.

Main valley floor. The central valley plain is the extensive surface on which are situated the cities of Eugene, Corvallis, Salem, and Woodburn. At the head of the valley near Eugene the surface stands but a few feet above the flood plain of the river, but at the northern end of the valley near Canby it stands nearly 100 feet above. There are two distinct sections; namely: a southern section that extends from Eugene to Albany, which is about 40 miles long by 12 to 20 miles wide, and a northern section that extends from Salem to Canby, which is 25 miles long by about 18 miles wide.

Occurrence of ground water in the southern section is somewhat like the flood plain of the river, for (1) the water-bearing material comprises tongues and lenses of gravel and sand within a main body of sand and silt; (2) the maximum thickness of the unconsolidated material is inferred to be less than 100 feet, so that its capacity to transmit water may be limited in some places by the thickness of the saturated zone between the water table and the bedrock; and (3) ground water is not confined.

In 1928-29 the water level fluctuated nearly 20 feet in certain wells of the section; the greatest observed depth below the land surface was nearly 30 feet. Beds of clean sand and gravel with relatively large water-yielding capacity are inferred to be relatively common within a subdistrict that covers the composite alluvial fan of the McKenzie River and the Middle Fork, and farther north, in the part of the central plain that lies west of Harrisburg. In the remaining or eastern part of the segment, beds of large water-yielding capacity are probably somewhat less numerous and less extensive. In the northern segment of the valley, conditions of ground-water occurrence are distinctly different. The material that underlies the central plain is composed largely of impervious fine sandy silt that incloses beds of moderately coarse clean sands. The latter confine water under pressure and have moderately large water-yielding capacity, as is shown by the performance of the municipal wells at Woodburn and Gervais, also of the irrigation well on the Brown property east of Gervais. (Figures 3 and 4.) In the municipal wells the static level was about 20 to 30 feet below the land surface in 1928-29. The well on the Brown property, drilled in 1930, was exploratory; its water is drawn chiefly from sand and gravel that compose most of the section at depths between 120 and 160 feet. From April to August, 1931, the well was pumped approximately 525 hours,

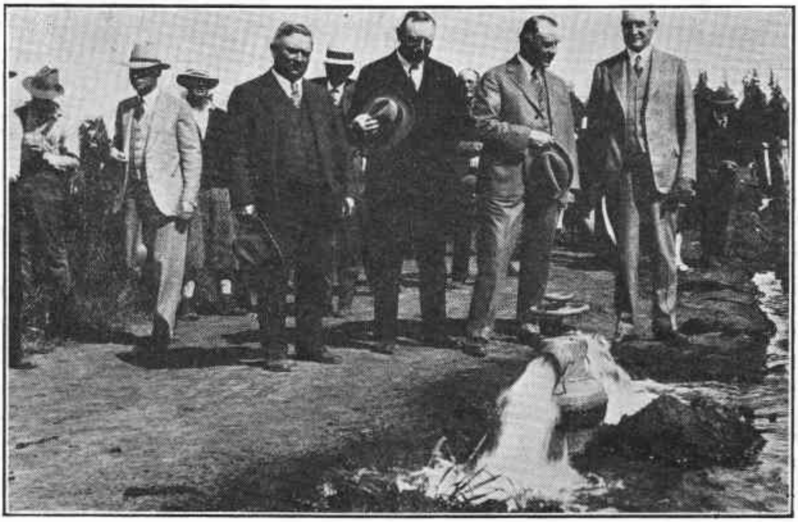

Figure 3. Well Irrigation on the Brown Farm, Gervais. *(Photograph by M. R. Lewis.)*

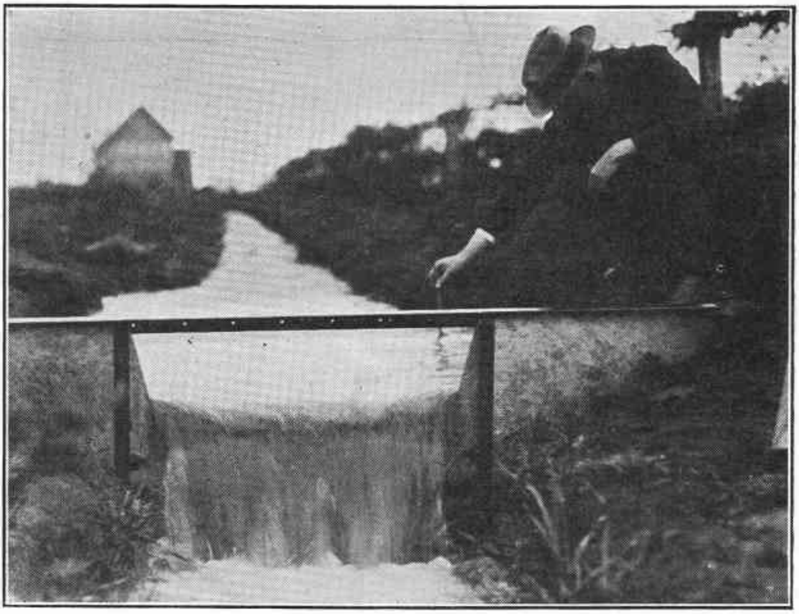

Figure 4. Weir measure showed up to 2 cubic feet per second. Discharge at the Brown Farm, Gervais, Oregon.

discharging about 2 second feet with the greatest observed pumping lift about 69 feet.

Wells are yet too few to trace the extent of this water-bearing zone. It is inferred to underlie most of the central plain except possibly along the margins where the valley fill thins out against the bedrock, also in the triangular alcove that extends eastward from the central plain to Molalla.

Higher bench or terrace deposits. The terrace deposits stand 20 to 100 feet above the central plain. Typical examples are Fern Ridge, west of Eugene, and Sand Ridge, a relatively low promontory along the west face of Peterson Butte southeast of Corvallis. Other remnants have been recognized along the margins of the valley as far north as the Yamhill River. In general these terrace deposits are deeply weathered, compact and clayey; hence they have little water-yielding capacity even when within the zone of saturation.

Adaptability to well irrigation. Irrigation from wells can be developed in small units adapted to individual farms. Some land may be served that will not be reached economically by gravity diversion. On the other hand, pumping from wells may prove more costly where gravity diversion can be accomplished through efficient works serving a relatively large district. In the southern part of the valley, pumping from wells seems best adapted to (1) irrigation at outlying localities or during the preliminary stages of developing a gravity system, and (2) possibly assisting drainage of depressions in cultivated land by lowering the water table. In the northern half of the valley, on the other hand, extensive tracts cannot be reached by gravity ditches except at relatively great cost. There, accordingly, pumping from wells would seem to afford an economic means of irrigation.

The feasibility of pumping from wells is determined chiefly by the safe yield, the purity or freedom from salinity of the water, and the cost of pumping. Owing to the scant development of ground-water supplies in the valley, the safe yield must be estimated, but it appears to afford a dependable moderate development. As more wells are drilled and pumped, data on the behavior of ground-water levels can accumulate and ultimately afford a trustworthy estimate of the long-term safe yield.

The water from the strata of sand and gravel that underline the flood plain and the central valley plain does not contain much dissolved mineral matter and is unlikely to have any detrimental effect on the physical character of the soil or to be toxic to common crop plants. Some of the water from the terrace gravel and from the volcanic bedrock might be slightly troublesome.

Some 1,400 determinations of ground-water level were made during 1928 to 1930, including periodic readings on 37 wells and continuous records on three wells for terms of 10 to 21 months.

During October 1935 the United States Engineering Department established 113 observation wells and took observations periodically for the year following.

THE DALLES REGION

The investigation in The Dalles region concerned the feasibility of pumping from wells to relieve a water deficiency for orchard tracts on a terrace high above the Columbia River and for produce tracts on low terraces near the river.

Two zones of flow. There are two possible sources of ground water for irrigating the existing orchards: the upper and the lower water-bearing zones of the Yakima basalt. The existing truck gardens can be irrigated from wells of moderate capacity in the stream deposits or from wells of larger capacity drawing from the lower water-bearing zone of the basalt. The formation that overlies the basalt generally has so small a water-yielding capacity that it is not a feasible source of water for irrigation.

Upper zone of flow. The water in the upper water-bearing zone of the basalt has a much higher head than that in the deeper zone and can be raised to a large part of the existing orchards by lifts between 150 and 450

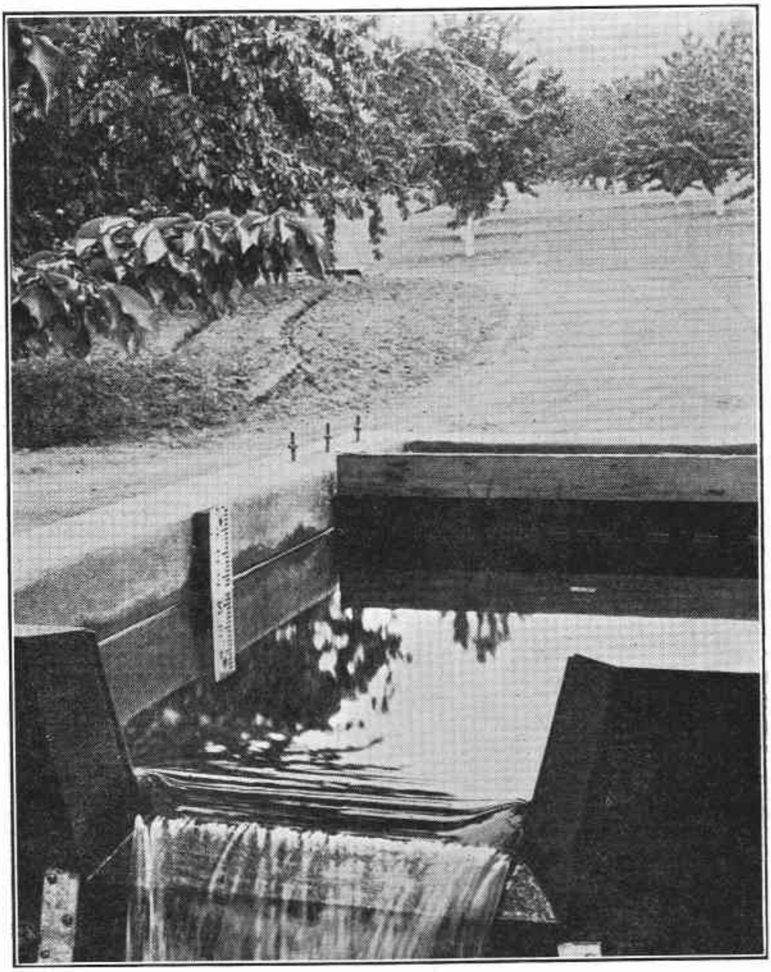

Figure 5. Ground water for irrigation; maximum lift 445 ft; discharge 175-230 gallons per minute. Cherry Hill Dist. Improvement Co., The Dalles. *(Photograph by A. M. P.)*

feet. Two irrigation wells were drawing water from this zone in 1930. The stronger of these two wells, operated by the Cherry Hill District Improvement Company, is 301 feet deep. (Figure 5.) It was first used in 1926; through 1930 it furnished 110 to 405 gallons a minute for 957 to 1,826 hours each season, the annual consumption ranging from 38 to 113 acre-feet. The greatest pumping head at this well, including both the lift to the surface of the ground at the well and that to the high point of the irrigated orchard, is approximately 350 feet.

The geologic and ground-water conditions and the performance of the existing wells indicate that the safe yield, or the quantity of water that can be pumped each year from this zone through a long period, is not very great and that the supply is insufficient to irrigate all of the existing orchard land. The supply in the vicinity of the present irrigation wells is probably sufficient for the land now under irrigation in that vicinity but not for a larger area therein. It is altogether unlikely, however, that the wells now in existence salvage all the water available in this permeable zone, so that drilling a moderate number of additional wells at a distance from the present wells seems feasible. When practicable such wells should be about a mile apart. A few wells in the valley of Threemile Creek both upstream and downstream from the present irrigation wells and in the lower part of the valley of Mill Creek probably would salvage practically all the water available in this zone.

Lower zones of flow. The lower water-bearing zone of the basalt yields water in much larger quantities than the upper zone, as is shown by the performance of the municipal well at The Dalles and by several wells along the Spokane, Portland & Seattle Railway on the north bank of the Columbia River. These wells yield from 45 to 450 gallons a minute for each foot of draw-down. The municipal well at The Dalles is pumped almost continuously for about three months each summer at the rate of 750 to perhaps 2,000 gallons a minute.

The level of standing water in the lower zone is nearly 400 feet below that of the water in the upper zone, and the cost of pumping from this zone to the orchards will be greater. This additional cost of pumping will be offset to some extent by economies that will result from larger yielding wells and less draw-down. Adequate pumping equipment may possibly raise water within permissible limits of cost from the lower zone to the orchards on the lowest lands, thereby supplementing the supply available from the upper zone. Certainly it is not practicable to pump from the lower zone to the orchards unless wells of large capacity are obtained. The most favorable sites for such wells are on the plains of Threemile and Mill creeks 2 to 3 miles south of The Dalles, where the top of the lower water-bearing zone is 350 to 500 feet below the land surface and where the lift to the lowest existing orchards is about 425 feet.

This zone is a feasible source of water for irrigating the existing truck gardens, most of which lie along a terrace of the Columbia River or on the plains of tributary creeks near The Dalles, 100 to 250 feet above the river. At these localities the top of the lower water-bearing zone is 200 to 300 feet below the land surface, with a pumping lift of about 75 to 200 feet. The safe annual yield of this zone is probably several times the quantity of water heretofore pumped from the city well each summer.

In describing the ground-water conditions of The Dalles region Piper gives water-level data for 46 wells.

HARNEY BASIN

The Harney Basin covers about 5,300 square miles on the relatively high and semiarid plateau of southeastern Oregon, in Harney and Grant counties. It constitutes the drainage area of the Malheur and Harney Lakes, which have no outlet to the sea. The average yearly rainfall is about 7.80 inches; the yearly mean temperature 44.6° F.

The Basin may be divided into (1) a low central district which comprises playas ("dry lakes"), extensive alluvial plains, cinder cones, and lava fields; and (2) a higher marginal district which attains a height of 9,600 feet above sea level at Strawberry Mountain to the north, and 9,400 feet at Steens Mountain to the southeast. The Harney, Malheur, and Mud playas occupy the lowest part of the central district; together they cover about 125 square miles and range in altitude from 4,080 to 4,095 feet above sea level. Alluvial plains cover fully 800 square miles in addition to the playas. These plains are underlain by the shallowest water-bearing beds and include the arable land that can be irrigated economically by pumping from wells.

The greater part of the Basin is drained by the Silvies River and the Donner und Blitzen River. These streams rise on the highest parts of the channel scarred upland to the north and south, respectively. Each ranges widely in discharge between a spring freshet of several thousand second-feet and small autumn ground-water run-off which, in the Silvies River, may fail altogether; also, each discharges into Malheur Lake, which in turn drains westward to Harney Lake. Since 1895, the aggregate area of these lakes has ranged repeatedly from about 125 square miles to about 2 square miles.

Along the principal streams at the outer margin of the central district the valley fill is largely clean sand and gravel but toward the center of the Basin these beds grade laterally, and finger and flatten into silt and clay. At least one thin layer of volcanic ash is found from 3 feet to 6 feet below the land surface.

It is believed that at one time the central part of the Basin was much lower and drained to the eastward through the Malheur Gap. This channel was dammed by a basalt flow and the Basin was then filled in by sediments brought in by the streams. These sediments are thickest, about 300 feet, along the northern edge of the Malheur Lake district.

The gravel and sand deposits in the valley fill are pervious. Those which are shallow hold unconfined water. Near the center of the Basin this shallow water contains considerable alkali. The deep permeable beds in the valley fill hold confined water and supply several irrigation wells on the northwestern part of the central alluvial plain. Pumpage from six of these wells for the five years, 1927 to 1931 inclusive, was 61.5, 205, 243, 495, and 502 acre-feet respectively. The depth of these wells ranges from 72 to 105 feet.

In connection with this investigation some 3,800 determinations of ground-water levels were made in Harney valley in 1930-32. In 1935-36 seven new permanent observation wells were constructed and twenty-four former observation wells were re-established.

Water classed by temperature in three groups. The water in the volcanic bedrock beneath the valley fill appears to fall into three distinct temperature ranges as follows: slightly warm water, 52° to 62° F.; water of intermediate temperature, 64° to 82° F.; and hot water, 90° to 154° F.

1. The slightly thermal water has been encountered in bedrock wells from 218 to 340 feet deep, in the northern part of the Basin. The safe yield of the water-bearing formations or aquifers appears to be at least equal to the safe yield of the valley fill. Yearly pumpage in acre-feet from four of these wells follows: 1927-29, 462; 1930, 534; 1931, 661; and 1932, 452 acre-feet. The major portions come from the Burns city wells.

2. The water of intermediate temperature issues from relatively large springs in three small districts in the western half of the Basin. The aggregate discharge by these springs in 1931 was about 40 second-feet. Water of intermediate temperature also issues from several flowing wells in the vicinity of the springs.

3. The hot water issues from a few springs that are widely scattered over the Basin. The aggregate yield in 1931 was about 5 second-feet. Hot water issues also from a deep flowing well on the southwestern part of the central alluvial plain. With few exceptions the warm springs and the warm flowing wells occur along or near faults.

Six wells more than 500 feet deep have been drilled on the central plain in search of flowing water. The single deep well that was flowing in 1931 suggests that the artesian head is not large.

MILTON-FREEWATER DISTRICT

The investigation in the Milton-Freewater district was concerned primarily with the relation between the flow in the Walla Walla River and the yield of numerous large springs and of pumped wells, both of which have been used for irrigation for a number of years. Altogether, the springs discharge about 50,000 acre-feet a year; the pumped wells about 9,000 acre-feet a year. The following conclusions were reached as to the source and movement of the ground water.

Form and movement of water table. From the apex of the alluvial fan at Milton downstream about to the McCoy bridge (which is on the boundary between Secs. 24 and 25, T. 6 N., R. 35 E.), the water table sloped away from the Walla Walla River toward the northeast and the northwest in both June and August, 1933. The river in this reach is therefore a losing stream at times. The major rise and decline of the water table which began in April and extended into July has been shown to reflect faithfully a corresponding fluctuation in the flow of the river. This rise and decline has been observed in wells as much as two miles away from the main channel of the river and three miles from the apex of the fan. Lesser fluctuations of the water table between December and March have been shown to reflect other fluctuations in the stream flow.

In May and June, 1933, the water surface of the river seems to have been essentially continuous with the water table while water was flowing through this reach of the stream channel. At that time the water in the river stood less than five feet above the water surface in wells that are less than a tenth of a mile away, and the apparent grade from one water surface to the other conformed approximately to the measured slope of the water table farther away. The younger alluvium, which forms the stream bed, is permeable. It seems obvious, therefore, that the major ground-water waves which have passed through the alluvium opposite this reach of the stream were supplied in large part by water lost from the river by seepage.

In August, 1933, when no water was flowing in the river channel from the railroad bridge at Freewater downstream nearly to the McCoy bridge, the form of the water table indicated that the ground water in the alluvium was still draining away from the river, even though the water table stood as much as 25 feet below the river bed in wells nearby. Clearly, the river is a losing stream in this reach. In August, 1933, water was flowing in the river channel from the McCoy bridge downstream to the interstate boundary and on to the confluence with the Columbia River. Hence this reach of the Walla Walla River was at that time a gaining stream. The form of the water table suggests that it gains perennially.

In respect to the form of the water table, the distributaries of the Walla Walla River are analogous to the main channel and might likewise be losing streams. Individually they have much less capacity than the main channel, and their beds appear to be less permeable because they are composed of gravel that contains much more fine material. The form of the water table is not known in sufficient detail, however, to indicate whether or not the Milton-Freewater segment receives water by seepage from any or all of the distributaries.

With the conical form of the water table defined by the contours of June and August, 1933, ground water in the Milton-Freewater segment would percolate northward and northwestward, away from the apex of the fan, and ultimately would reach the most remote parts of the segment in both Oregon and Washington unless it were sooner discharged. Down this cone would pass the successive recharge waves, their height decreasing as the length of the wave front increased in advancing outward from the apex. Beyond the spillway formed by the constriction of the younger alluvium, where each wave would presumably be dissipated in a measure by overflow among the springs of the inner zone, these waves would seem to become much less prominent than in the vicinity of Milton and Freewater.

The water table seems at times to fluctuate in response to irrigation on the alluvial soil and in response to protracted rainfall in the nongrowing season. Accordingly, it is presumed that a material quantity of groundwater may be derived from these sources. The water table throughout the Milton-Freewater segment, however, was so steep in 1933 that the quantity of water received by penetration of irrigation water or of rainfall was nowhere large enough to mask the conical form of the water table even locally. Accordingly it seems that the quality was nowhere sufficient to affect materially the direction or relative velocity of the percolating ground water.

Application to regional problems. These conclusions show the close relation between the flow in the Walla Walla River, the utilization of that stream for irrigation, and the ground-water supply. They were incorporated in the argument of special counsel that led to a recent decree from the Supreme Court (6) confirming the right of Oregon residents in their use of water.

In 1932-33 some 2,900 determinations of ground-water level were made in that part of the Walla Walla Basin.

BUTTER CREEK BASIN

Late in 1935 a reconnaissance survey of the Butter Creek area was made by the United States Geological Survey, in cooperation with the Oregon State Engineer, to determine the feasibility of relieving the water shortage by pumping from wells. The supply of shallow ground water under the valley plain was found to be contained in relatively thin and discontinuous layers of sand and gravel. These water-bearing layers underlie fine soil and overlie tight "blue"clay. They are recharged periodically when the creek is in freshet, but their storage capacity is so small that they do not equalize fluctuations in the recharge from year to year. This condition explains the common failure of shallow wells in the area during 1934 and 1935. It does not favor the recovery of water from shallow wells in quantities sufficient for irrigation.

The water-bearing formations in the bedrock were found several hundred feet below the land surface. These yield reliable supplies for domestic purposes and for watering stock, though it seems unlikely that they will yield water within practicable limits of cost in sufficient quantities for irrigation.

ACTIVITIES IN 1935-36

The United States Geological Survey, in cooperation with the State Engineer of Oregon, has measured ground-water levels occasionally in a few wells in six scattered areas in Eastern Oregon. This latter program was only a preliminary reconnaissance.

FURTHER INVESTIGATION NEEDED

In order that the study of ground-water resources in Oregon may have a firm and rational foundation, three things are highly desirable: (1) a preliminary reconnaissance of the whole state to compile information that is already available, to identify and evaluate the ground-water problems, to analyze the relative worth of the ground-water districts and to classify them according to their problems; (2) a net of selected key observation wells in all important ground-water districts in which systematic records of the fluctuations of the ground-water levels would be taken in order to determine the long-term average ground-water supply; and (3) a continuing program of comprehensive investigations in problem areas to evaluate the ground-water resources as to quantity, chemical quality, availability, and recovery; and to determine the maximum use reasonably safe with respect to the perennial yield of each district. (Figure 6.)

As the easily available surface supplies are appropriated and distant sources must be sought, or as instances arise where heavy expense must be incurred for storage, ground water will come into greater demand and increase in relative importance.

Water for domestic use is largely derived from below ground. With increased shortage of unappropriated surface water, and with ground-water regions more clearly defined, the proportion of domestic and municipal water supplied from below ground will no doubt be increased.

Water spreading in gravelly fans is a recent means of increasing the safe yield of ground-water basins worthy of further investigation. Tunneling for water also has possibilities in development of water supplies.

Figure 6. Well Irrigation, East of Fort Rock, Lake County.

An orderly program of fact finding as to ground-water resources is needed, and may well be continued cooperatively as in the work here reported.

A small State appropriation for Oregon soil and soil-water investigations by the Oregon Legislature in 1937 has permitted resumption of cooperative ground-water studies.

Appendix

SIX-YEAR PROGRAM FOR INVESTIGATION OF GROUND-WATER RESOURCES OF OREGON

An outline of the six-year investigational program to supply general data for the whole state and moderately detailed information on known problem areas is presented below. Other problem areas, equally worthy of study, doubtless would be disclosed by systematic reconnaissance. This outline is taken from recommendations by the Water Resources Advisory Committee of the State Planning Board for the recent series of drainage-basin reports that have been made by the Board for the National Resources Committee.

State-wide projects

Preliminary reconnaissance to outline the ground-water basins, to assemble the available hydrologic data, to classify the ground-water basins according to their problems and relative worth, and to determine an orderly plan of investigation.

Great Basin
Smith River Basin
Klamath, Lost River, and Goose Lake Basin
Snake River Basin
Middle Columbia Basin
Willamette River and Lower Columbia Basins
Pacific Coast Basins

Basic net of key observation wells for periodic measurement of ground-water levels irrespective of intensive studies in problem areas; selection, equipment, and maintenance of wells; study of records for seven watersheds listed above.

Reconnaissance survey of industrial utility and chemical character of public ground-water supplies: analyses by watersheds.

Comprehensive surveys in known problem areas *Priority**

Great Basin

1. Fort Rock–Christmas Lake area: To determine the extent and perennial safe yield of the ground-water basin for assured irrigation of land that is sub-marginal if not watered, the feasibility of irrigation having been demonstrated on several existing farms over a term of years; also to evaluate the possible effect of pumping ground water in the Fort Rock district on the discharge of the large springs at the head of Ana River to the south, the flow of which now irrigates considerable land I

* I: Immediate study justified and investigative program planned.
II: Deferred study practicable.

2. Catlow Valley: To determine extent and perennial safe yield of the ground-water basin for assured irrigation of land that is submarginal if not watered. A reconnaissance soil survey has indicated land of good quality, but surface-water supplies for irrigation are not available and the quantity of ground water is not known I

Smith River Basin

No urgent problems known .... ---

Klamath, Lost River, and Goose Lake Basin

3. For Klamath Basin and vicinity: To determine the safe ground-water yield for supplemental irrigation........ II

Snake River Basin

4. Grande Ronde Valley: To determine the extent and water-yielding capacity of pervious formations and the safe yield of the basin for supplemental irrigation supplies; also to determine the feasibility of draining certain land by pumping ground water I

5. Baker Valley: Scope and purpose as for Grande Ronde Valley I

6. Enterprise-Joseph area: To determine the imminence of a drainage problem and the safe yield of ground water for supplemental irrigation II

7. Willow Creek-Lower Malheur River area: To determine the most economical and dependable source of ground water for all-year household supplies on high land of the Owyhee project; to determine the feasibility of drainage by pumping; also, to determine the safe ground-water yield for additional irrigation supply in the Willow Creek Valley I

8. Upper Burnt River Valley: To determine the adequacy of ground water for supplemental irrigation II

Middle Columbia Basin

9. Lower Umatilla Basin: To evaluate ground water for supplemental irrigation supply and for household purposes I

10. Walla Walla Basin: To apportion ground water and surface water to their most effective joint use, to extend an investigation of limited scope made in 1933, to determine for the larger area the capacity of the ground-water basin to meet deficiencies in irrigation supplies, and to study the feasibility of increasing natural recharge by water spreading. (The Walla Walla Basin involves an inter-state water-supply problem between Oregon and Washington.) I

Willamette River and Lower Columbia Basins

11. Portland-Oregon City commercial district: To evaluate ground-water supplies for industrial uses and possibly for municipal use in outlying areas I

12. Willamette Valley south of Canby: To amplify somewhat a preliminary investigation made in 1928 and 1929, to continue the program for determining ground-water levels which the U. S. Engineer Department was carrying on, but terminated in October, 1936; ultimately, to determine the perennial safe yield of the ground-water basin for supplemental irrigation I

Pacific Coast Basins

13. Rogue River Valley: To determine the feasibility of pumping ground water for supplemental irrigation supply and to evaluate the safe ground-water yield II
14. Lower Columbia River Area: To find ground-water supplies suitable for domestic and industrial use in or near dyked lands ....

Total cost for six-year program in Oregon, all phases and sources, average per year $25,042

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