Ground-Water Resources of Cow Valley Malheur County, Oregon

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By S. G. BROWN *and* R. C. NEWCOMB

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-M

*Prepared in cooperation with the office
of the Oregon State Engineer*

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GROUND-WATER RESOURCES OF COW VALLEY MALHEUR COUNTY, OREGON

By S. G. Brown and R. C. Newcomb

ABSTRACT

Cow Valley is a small upland basin in a semiarid region of eastern Oregon. The withdrawal of ground water for irrigation in the area increased rapidly from 1949, when the first irrigation well was drilled, until 1955, when nearly 7,000 acre-feet of ground water was pumped from 14 wells. The basin is isolated hydraulically from adjacent areas by its relatively high topographic position as well as by hills and buried ridges of impermeable bedrocks of Triassic and Jurassic (?) age, which surround the valley. The principal aquifers are alluvial sand and gravel of Pleistocene and Recent age, and lava flows and associated pyroclastic rocks of Pliocene or Pleistocene age, that overlie the impermeable bedrock.

Precipitation within the basin is the only source of water for the area; evapotranspiration and outflow through Cow Creek are the only modes of discharge from the basin. The recharge was less than the total ground-water discharge during 1951–59, even though the potential recharge from precipitation was generally above average during that period. The withdrawal of about 50,000 acre-feet of ground water during 1951–59 caused a decline of the water table, ranging from about 10 to 15 feet, which indicates that an appreciable part of the water pumped wss removed from ground water in storage. The amount of recharge that normally replaces the ground water pumped from storage now is, and probably will continue to be, considerably less than 5,500 acre-feet per year.

Chemical analyses indicate that the ground water is of generally good quality, not only for irrigation, but for most other purposes as well. However, the water from some of the wells is harder than is desirable for domestic use.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The exploitation of ground-water supplies for irrigation in Cow Valley increased rapidly from 1949, when the first irrigation well was drilled, until 1955, when nearly 7,000 acre-feet of water was pumped from 14 wells. Because there was some concern as early as 1950 about the quantity of ground water available in the valley, the Geological Survey began to measure water levels in two of the irrigation wells, and to collect records of the new wells as they were drilled.

In 1954, after it had become apparent that the ground-water levels were declining progressively, the Geological Survey was requested to make the investigation described in this report.   The objectives were to determine the source and occurrence of the ground water, the nature and extent of the water-yielding rock materials, and the relation of ground-water withdrawal to the decline of water levels.   This information was necessary for the future development and management of the water resources of the area.

During the investigation, all of the wells in the area were inventoried, and data were gathered on pumpage and acreage irrigated. The program of water-level measurements was expanded to include 19 wells in 1955.   A barometric traverse was made to establish the altitude of the wells, and some of those altitudes were later established more precisely by spirit leveling.   A geologic reconnaissance was made, and data were collected from short aquifer tests at two wells. The compilation and analysis of the resulting data form the basis for this report.

The investigation was made in financial and technical cooperation with the Oregon State Engineer.   In 1956, at the request of the State
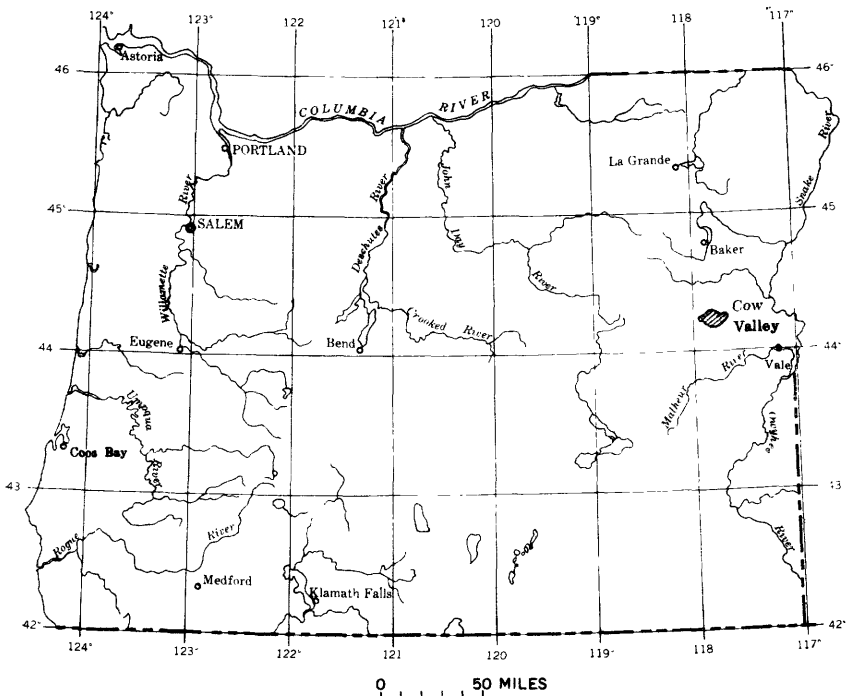
FIGURE 1.—Map of Oregon showing area of investigation.

Engineer, a preliminary version of the report was released so as to be available to interested parties during a public hearing on possible controls on the ground-water withdrawal in the area.   In 1959, largely as a result of information contained in the preliminary version of this report, the State Engineer declared Cow Valley to be a critical ground-water area, closed the area to further ground-water appropriation, and fixed maximum limits for withdrawals from the existing wells.

LOCATION AND EXTENT OF THE AREA

Cow Valley, as the name is used in this report, lies in the upper part of the drainage basin of Cow Creek, in the northern part of Malheur County, eastern Oregon (figs. 1 and 2).   The drainage area to this part of Cow Creek is an upland basin of about 60 square miles; it has a maximum length of about 14 miles in a general east-west direction and a maximum width of about 9 miles.   It lies about midway between the towns of Ironside and Brogan.
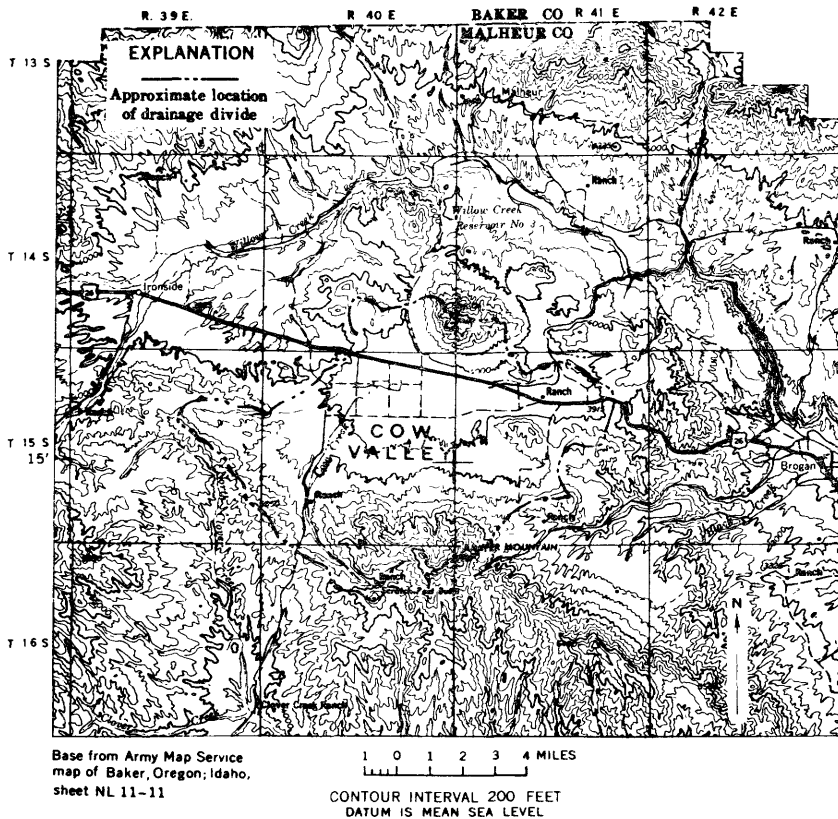
FIGURE 2.—Map of northern Malheur County, Oreg., showing location and general features of Cow Valley.

WELL DESIGNATIONS

In this report, wells are designated both by the local system utilizing the name of the owners and the consecutive order in which their wells were drilled (as Crow No. 8, Holloway No. 3, and Davis No. 4) and by the Geological Survey system (as 15/40–2Q1).

In the Geological Survey system, each well is designated by a symbol that indicates its location according to the rectangular system of land division. In the symbol 15/40–2Q1, for example, the part preceding the hyphen indicates respectively the township and range (T. 15 S., R. 40 E.) south and east of the Willamette base line and meridian. The first number after the hyphen indicates the section (sec. 2), and the letter (Q) indicates a 40-acre subdivision of the section as shown in the diagram below. The final digit is the serial number of the well within that 40-acre tract. Thus, well 15/40–2Q1 is in the SW¼SE¼ sec. 2, T. 15 S., R. 40 E., and is the first well in the tract to be listed.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R
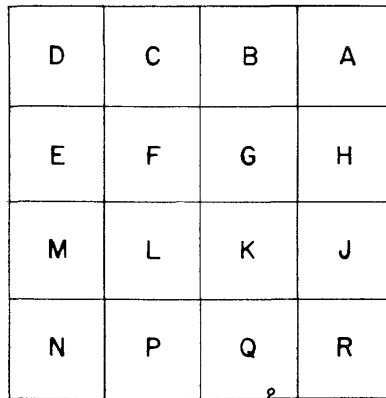
Q1

Well-numbering system.

PHYSIOGRAPHY

Cow Valley is typical of many small upland basins that owe their shape to folding and faulting of the bedrock, and subsequent erosion of the uplifted areas and deposition in the downwarped part.

The valley floor consists of a central alluvial plain and the adjoining alluvial slopes. The alluvial plain is a generally smooth and gentle surface underlain by fine-grained soils. The alluvial slopes are characterized by stony soils and gullied surfaces. On the east and west sides of the valley the alluvial slopes extend up to the bedrock exposures on the adjoining hills; on the north and south sides the alluvial slopes merge with the surface of colluvium that mantles the bedrock slopes.

Above the alluvial slopes the eroded bedrock slopes continue to the drainage divide. The hills that constitute the drainage divide stand 50 to 400 feet above the valley floor on the west, 50 to 1,000 feet on the north, 500 to 2,000 feet on the south, and 100 to 500 feet on the east.

The alluvial plain of Cow Valley lies north of the center of the drainage basin. In most places it is within a mile of the northern divide but lies mostly from 3 to 4 miles from the southern divide. It slopes gently from the south and north to a central east-west axis. The central axis of the plain ranges in altitude from about 4,000 feet near the west end to about 3,850 feet at the east end.

The uplands on the north and west sides of the valley consist of one generally continuous slope up to the drainage divide; the uplands on the south are more extensive and include several fault-block mountains. Some of these mountains are steep and pointed, but most are even topped, mesalike bodies. The highest, Juniper Mountain, reaches an altitude of 6,480 feet.

The area is drained by the upper reaches of Cow Creek, an intermittent tributary of Willow Creek (fig. 2). Cow Creek discharges water into the rock materials of the lower slope near the former site of Bonita (now destroyed), and only during periods of unusually heavy runoff does the creek flow entirely through the valley. During the winter and spring, its distributary channels seldom carry water as far downvalley as sections 10 and 11 of T. 15 S., R. 40 E. During the drier parts of most years upper Cow Creek carries less than 50 gpm (gallons per minute) and does not flow beyond old Bonita. Numerous other arroyos (not shown on pl. 1) in the southwestern and southern parts of the basin carry spring runoff to the lower slopes, but in most years that water sinks into the ground without reaching the valley plain.

Downstream from the highway crossing in section 5, T. 15 S., R. 41 E., Cow Creek carries some water throughout most years. It

flows along the north edge of the narrow eastern segment of the valley floor, passes through a gap in an old earthen dam at a bedrock constriction in NW¼ section 3, T. 15 S., R. 41 E., and flows northward through a narrow canyon toward Willow Creek. During the summer of 1961, for the first time in many years, there was no spring flow in the streambed just below the highway crossing and the channel was dry in the lower part of the valley. At a few times in recent years the creek below the highway bridge has carried several cubic feet per second of waste water from irrigation. Unpublished records in the office of the State Engineer, for a gaging station near the mouth of Cow Creek, show that the discharge totaled 390 acre-feet during 1912 and about 372 acre-feet in 1913.

CLIMATE

The valley lies in a semiarid region whose climate is characterized by dry, warm summers; more humid, cool winters and precipitation that increases with higher altitude.

Cow Valley has had no weather-observation station, but some short-term records of precipitation at Ironside have been collected. Precipitation and temperature data have been recorded at Vale, which is about 35 miles southeast of, and 1,640 feet lower in altitude than Cow Valley. A comparison of the monthly precipitation records from those stations is shown on figure 3. For the period July 1909 to December 1915 the average annual precipitation at Ironside was 13.49 inches. That amount probably is indicative of the precipitation received on the floor of Cow Valley during that period. Figure 3 shows that an average of 9 inches, or about 67 percent of the annual average, fell during the months October through April, and that about 1.7 inches, on the average, fell during the months July through September at Ironside.

Figure 4 shows annual precipitation and cumulative departure from average at Vale for water years 1921–59. The average annual precipitation at Vale for the water years 1891–1959 was 8.4 inches. The cumulative-departure curve shows that the periods 1928–37 and 1946–49 were periods of relatively low precipitation and, therefore, of less than average opportunity for recharge of the ground-water body. Conversely, 1938–45 and 1950–59 were periods of generally greater than average precipitation and good opportunity for recharge.

As is discussed subsequently in this report, the only natural source of recharge of the ground-water reservoir is the precipitation that falls within the basin. The return of some irrigation water by deep percolation augments the natural recharge from precipitation.

AVERAGE MONTHLY PRECIPITATION AT IRONSIDE AND VALE,
OREG., COMPARED FOR THE PERIOD OF RECORD
AT IRONSIDE, JULY 1909 TO DECEMBER 1915

AVERAGE MONTHLY PRECIPITATION AT VALE, OREG., FOR
THE PERIOD DECEMBER 1891 TO SEPTEMBER 1954
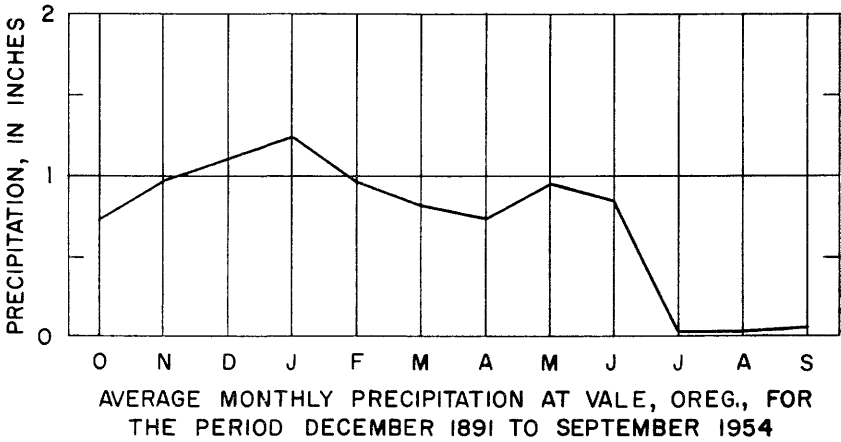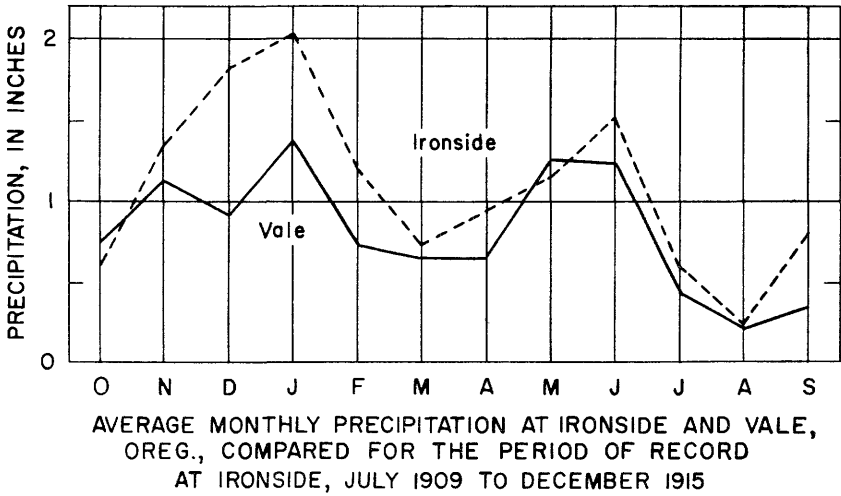
FIGURE 3.—Graphs showing average monthly precipitation at Ironside and Vale, Oreg.

GEOLOGIC SETTING

The region around Cow Valley is underlain largely by partly meta-
morphosed rocks of sedimentary and igneous origin. They are shown
as "Triassic and Jurassic rocks of Blue Mountains, Oregon" on the
Geologic Map of the United States (Stose, 1932).[1] They crop out in
the hill slopes and road cuts on all sides of Cow Valley. Plate 1 shows
the extent of the main exposures of these older rocks. Also, they crop
crop out in a few other places where the volcanic caprock is lacking
on the valley slopes. Shear planes, faults, and displacements not
present in the overlying rocks are common in the older bedrock. The
base of these older rocks is not exposed near Cow Valley. The rocks

[1] Stose, George W., 1932, Geologic Map of the United States: U.S. Geol. Survey (4 sheets).
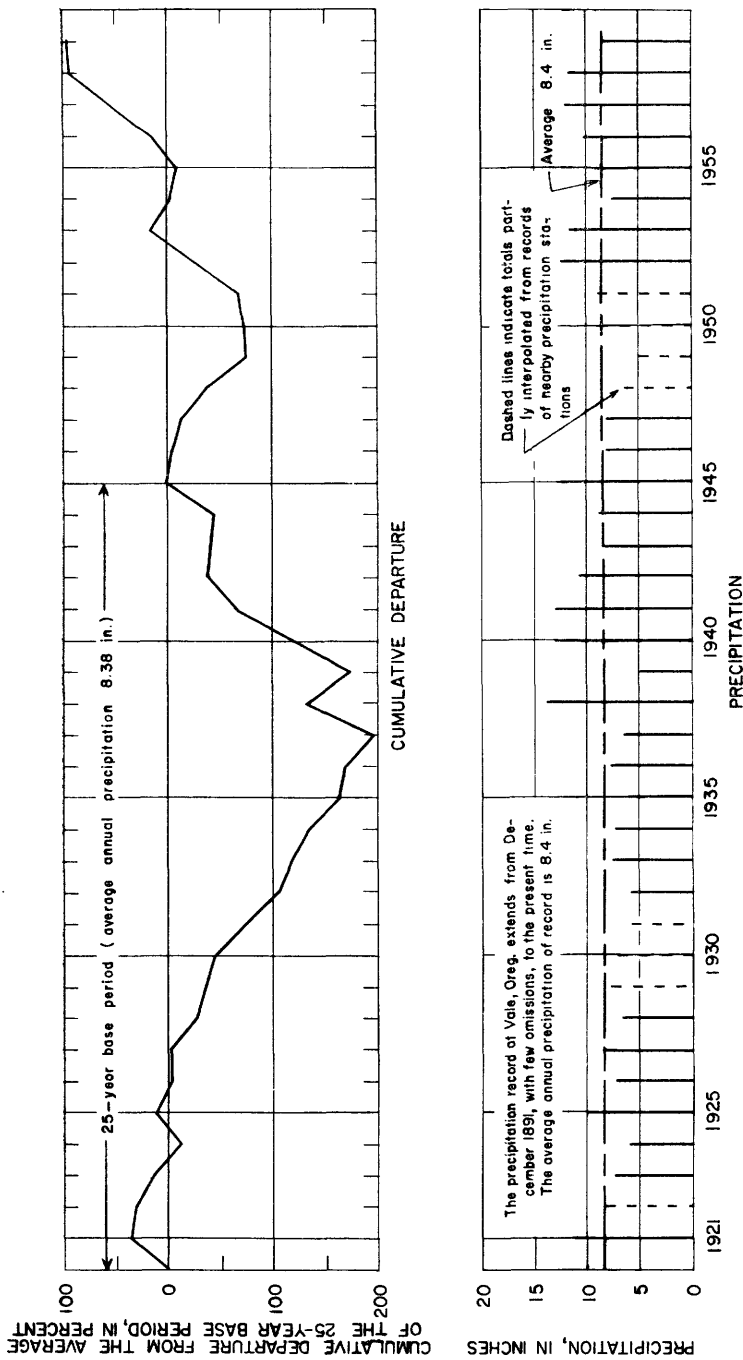
FIGURE 4.—Graphs showing precipitation at Vale, Oreg. during water years (ending September 30) 1921–59 inclusive, and cumulative departure from a 25-year average (1921–45). This graph shows the accumulated excesses or deficiencies in precipitation. A line rising from left to right indicates a period of above-average precipitation and above-average contribution to ground-water storage. A falling line indicates a period of below-average contribution to ground-water storage.

of Triassic and Jurassic(?) age include shale, argillite, slaty shale, sandstone, and quartzite of poor permeability.   In well 15/40–10K1 (Crow No. 9), about 785 feet of these older rocks were penetrated and found to contain only a little water-bearing material.   The water in them was much warmer than that in the overlying volcanic rocks and alluvium.

Overlying the older rocks is an extensive stratum of lava rock and pyroclastic materials (tuff and agglomerate) of Pliocene or Pleistocene age.   This stratum attains a thickness of more than 400 feet at places and overlies the older rocks on all sides of Cow Valley.   The lava occurs in dark, distinctly layered flows.   Where the unit is thickest, it contains much basaltic agglomerate in the basal part.   The volcanic rocks originally formed an extensive cap over the older rocks.

On the sides of the valley the lava strata dip toward the valley floor and are concealed by the colluvial and alluvial materials that underlie the central plain and the lower slopes of the valley.

The volcanic rocks and the older rocks were folded and faulted during the earth movements that formed Cow Valley.

The lava rock and associated pyroclastic materials contain pervious zones.   Most of the wells that have penetrated these materials beneath the valley alluvium, have obtained large yields of water from the volcanic rocks.

The youngest rocks, of Quaternary age, consist of colluvium that mantles the lower slopes, and alluvium that underlies the valley floor. The colluvium, where exposed in the ravines of the lower slopes, consists of unconsolidated rock rubble, rubbly sand and gravel, and silt. It apparently merges with the alluvium which underlies the valley floor.

The alluvium, where exposed on the valley floor, consists largely of silt and subrounded gravel and sand.   In secs. 5 and 6, T. 15 S., R. 41 E., near the highway crossing over Cow Creek, the alluvium immediately below the surface is silt and clay and appears to be of lower permeability than the colluvium and the alluvium in higher parts of the valley floor.   Drillers' logs of wells show that the alluvium beneath the valley floor contains irregular layers of sand and rubbly gravel some of which yield water to wells.

GROUND WATER

The drillers' records (table 2) show that the wells in Cow Valley derive water from the saturated parts of the valley alluvium and the volcanic rocks that overlie the older rocks of Triassic and Jurassic(?) age.   All of the wells in the area obtain water from one or both of those rocks units.   One well, 15/40–10K1 (Crow No. 9), penetrated about 785 feet into the older rocks and was not believed by the driller to

have obtained any appreciable amount of water below the volcanic rocks.

Available data on the subsurface materials and the water-level fluctuations indicate that the body of ground water beneath the valley is a single and hydraulically continuous unit in the alluvial and volcanic rock materials. The ground water apparently is mostly unconfined—that is, its upper surface is free to move up and down in response to variations in recharge to or discharge from the ground-water body.

GROUND-WATER LEVELS

The upper surface of a body of unconfined ground water is called the water table, and its position is represented by the level at which water will stand in wells that tap the ground-water body. Variations in the altitude of the water table in Cow Valley, as observed by periodic measurement of the levels in the wells, disclose several features of the natural ground-water regimen and indicate the effects of withdrawal by pumping.

Records of water levels in 17 wells in Cow Valley are listed in table 4; additional water-level data also are included with the records of wells (table 1). The belief that the ground water is mostly unconfined was substantiated by other water-level data (not included herein) that were obtained by the drillers. Those data did not indicate substantial changes in water level during the drilling of the wells that penetrate the valley alluvium and the lava rock; they likewise showed no water-level change during drilling of the well that penetrates deeply into the older rocks (well 15/40–10K1, Crow No. 9).

The water table stands at a relatively uniform level beneath the valley floor (fig. 5, also sections, pl. 1). It slopes gently downstream in the western or upper part of the valley and is graded to Cow Creek in the lower part of the valley. As is true of most bodies of unconfined ground water moving to a surface exit, the deeper water rises in wells a few feet above the level of the shallower water (table 1, wells 2Q1 and Q2).

The hydrographs of wells 15/40–2J1 and –2N1 (figs. 6 and 7) show that the ground-water levels decline during the late spring and summer—the period of large pumping withdrawal and of least rainfall—and rise during the autumn, winter, and early spring. The yearly rise of water levels measured in those wells probably represents the combined effects of a general recovery of the water table from levels drawn down by pumping throughout the valley, recovery from pumping levels at the wells themselves, and recharge of the ground-water body by infiltration from precipitation, which is greatest during the autumn, winter, and early spring (fig. 3).
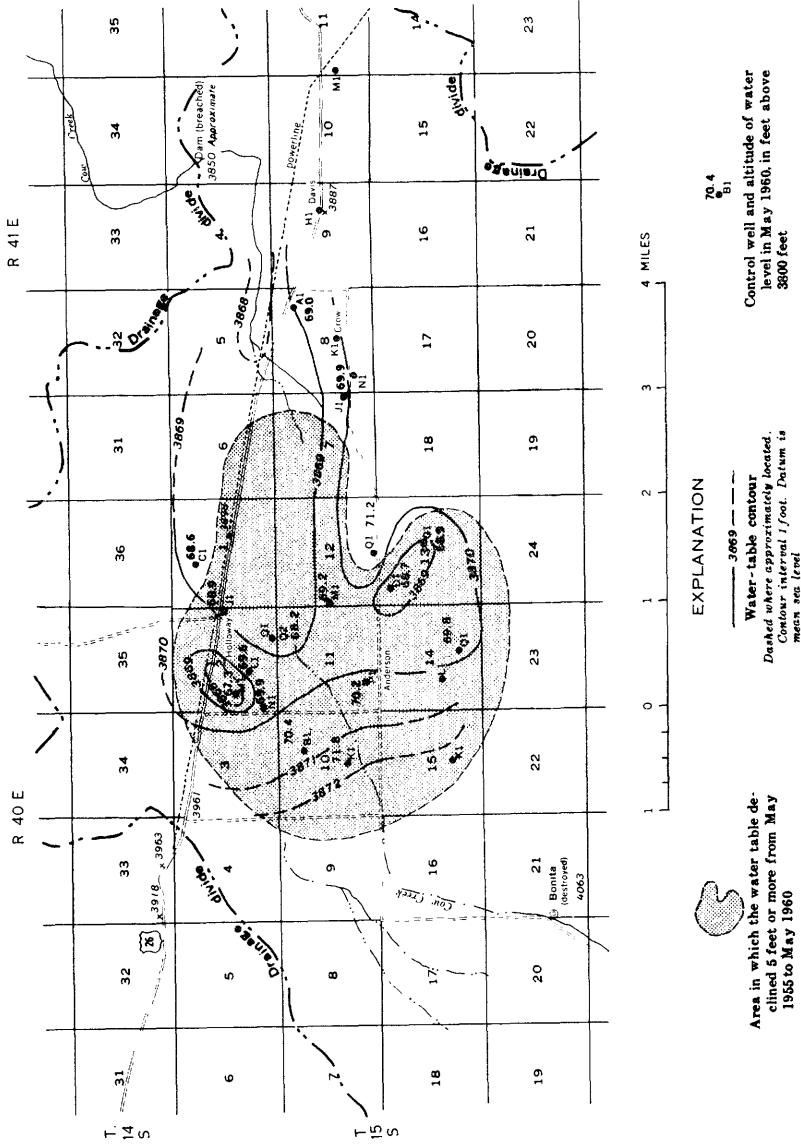
FIGURE 5.—Map of part of Cow Valley, showing water-table contours as of May 1960, and area in which water levels declined 5 feet or more during the period May 1955–May 1960.
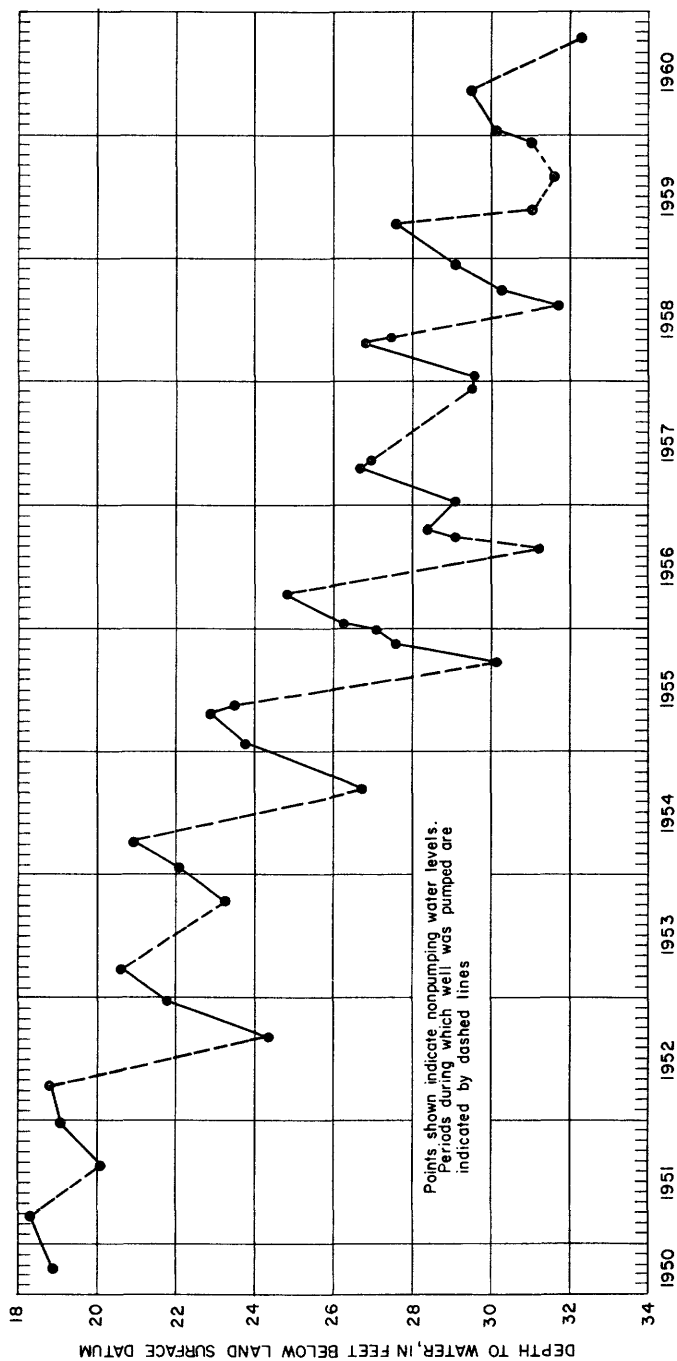
FIGURE 6.—Hydrograph of well 15/40-2J1 (Holloway No. 1).
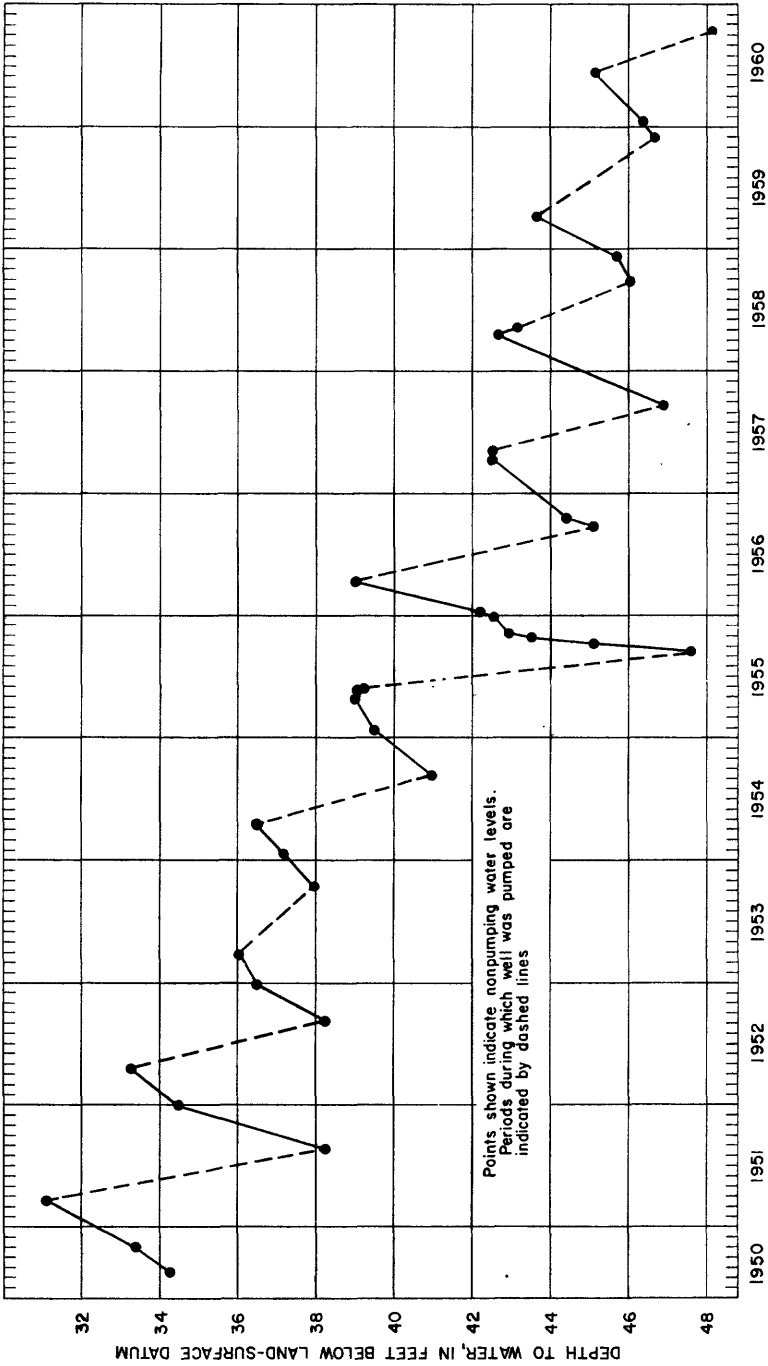
FIGURE 7.—Hydrograph of well 15/40-2N1 (Crow No. 2).

Points shown indicate nonpumping water levels.
Periods during which well was pumped are
indicated by dashed lines

DEPTH TO WATER, IN FEET BELOW LAND-SURFACE DATUM

The hydrographs also show that the yearly high-water levels measured in wells 15/40–2J1 and –2N1 declined progressively from 1951 through 1960. Such an overall decline occurred at all other wells in the area for which comparable water-level measurements were made during that period; however, the decline was neither continuous nor equal in amount at all of those wells. For example, of 19 wells at which high-water levels were measured in 1955 and again in 1956, 5 had the higher levels in 1956. Similarly, high levels rose above those of the previous year at 4 wells in 1958, and at 6 wells in 1960. All other comparable high-water level measurements during the period 1951–60 indicated a progressive year-to-year decline.

The overall decline during the 1951–60 period was greatest in the central part of the valley floor, in the district of greatest pumping withdrawal; in that part of the area the decline was generally 5 feet or more (fig. 5). The decline at individual wells during that period ranged from about 1.8 feet at well 15/41–8A1 to more than 7 feet at well 15/40–2M1 (table 4).

The average water-level change by years from May 1955 through May 1960, obtained by averaging the difference in water levels at each of the wells during successive spring measurements, is shown in the following table:

Period between measurements [1]	Number of wells at which comparative measurements were made	Average water-level decline (feet)
May 1955 to April 1956	19	1. 2
April 1956 to May 1957	17	1. 8
May 1957 to May 1958	17	. 2
May 1958 to May 1959	12	[2] 2. 0
May 1959 to May 1960	12	[2] . 0
Total (rounded)		5

[1] Measurements for all but 4 of the wells used in this calculation are listed in table 4 or shown on figs. 6 and 7.
[2] Amount questionable; measurements for May 1959 may not show yearly high position of water table. (See fig. 6.)

The average decline in levels for 16 wells during the period May 1955 to May 1960 amounted to about 5 feet. The data in the foregoing table indicate that the greatest average decline, about 2 feet, occurred between May 1958 and May 1959, and that the average water level did not change appreciably from May 1959 to May 1960. However, the water levels measured in May 1959 may not represent the yearly high-water level at all of the wells. (See fig. 6.) If not, the indicated relationships between the high levels for 1959 and those for 1958 and 1960 would not be entirely comparable—that is, the

average decline from 1958 to 1959 levels would be less than shown, and the change from 1959 to 1960 would be an appreciable decline.

RECHARGE

The rise of the water in the wells during autumn is largely a response to the cessation of pumping; however, the continuation of the rise during the winter and spring, which are the seasons of greatest precipitation and of runoff from snowmelt, indicates that the natural source of the ground-water replenishment, or recharge, is the precipitation.   This conclusion is substantiated by other evidence.   The altitude of the water level in Cow Valley, which is considerably higher than the water levels in the adjoining stream valleys, the basinlike shape of the valley, and the low permeability of the older rocks that surround the valley, all preclude the possibility of appreciable underground transfers of water from or into Cow Valley.   No evidence was found to indicate any natural recharge to the ground-water body of the valley other than from the infiltration of precipitation and runoff. However, part of the well water that is applied to the fields doubtless percolates to the water table, and this infiltration may be considered a form of artificial recharge.   The total recharge comprises the natural recharge plus the infiltration from irrigation.

Some recharge to the ground-water body takes place as infiltration from precipitation on all the slopes of the valley; however, much of the recharge occurs in the southwestern part of the valley floor, where the distributaries of Cow Creek and the intermittent streams lose their flow by infiltration into the alluvium.

The recharge is observed as a rise of the water table; the pumping withdrawals and the natural discharge are reflected by a lowering of the water table.   At present, neither the rise nor the decline of the water table can be converted directly to an exact measure of the quantities of recharge to the ground-water body in Cow Valley, because related factors such as effective porosity of the water-bearing materials, the natural discharge, and the amount and effect of the infiltration from irrigation are not adequately known.

In the spring of 1956, unusually great surface runoff provided sufficient water to fill two large farm ponds previously constructed by Mr. Rankin Crow in sec. 10, T. 15 S., R. 40 E.   The impounded water was derived from Cow Creek and an unnamed intermittent tributary northwest of Cow Creek.   That year, the high levels in four wells northeast or east of those ponds (wells 15/40–1C1, –2L1, –2N1, and –2Q2) rose slightly above the high levels measured during the previous year.   In contrast, high levels in most other wells in the area showed substantial declines below those of 1955, owing to greater pumpage that year than in any previous year.   The rise in

those four wells probably was caused by increased recharge from water impounded in the farm ponds. This rise suggests that recharge in the area possibly could be increased to the limits of the small surface runoff of Cow Creek if sufficient storage capacity were available on the gravelly upper part of the valley floor. This storage could delay the outflow of natural runoff and irrigation waste water, to allow more opportunity for infiltration.

AQUIFER CHARACTERISTICS

By analysis of data obtained from suitable regulated pumping tests on wells, values can be derived to indicate the hydraulic characteristics of the water-bearing zone, or aquifer. Aquifer tests were made at wells 15/40–2Q1 (Crow No. 1) and 15/41–7J1 (Crow No. 7) on May 21–24, 1955. During those tests, the wells were pumped at a measured, almost steady rate, and the water levels in the pumped well and nearby wells were measured at regular intervals throughout, and following, the period of pumping. The water-level data obtained from those tests are shown graphically in figures 8 and 9.

The data obtained from the pumping tests were analyzed by the nonequilibrium formula of Theis (1935, p. 520) [2] for determination of coefficients of transmissibility (T) and storage (S). The coefficient of transmissibility is defined as the flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a unit hydraulic gradient at the prevailing water temperature. The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Values of T and S obtained from analyses of the pumping test data were as follows:

Pumping 15/40–2Q1 (Crow No. 1)—T (average)$=85,000$ gpd per ft
S (average)$=2.4 \times 10^{-3}$
Pumping 15/41–7J1 (Crow No. 7)—$T=295,000$ gpd per ft
$S=1.4 \times 10^{-3}$

Well 15/40–2Q1 obtains water from the sand and gravel layers of the valley alluvium; well 15/41–7J1 apparently draws water only from the volcanic rocks underlying the valley alluvium. The small coefficients of storage indicate that the water entering each well is locally confined. However, if the tests were extended for several months, it is believed that the aquifer tests would demonstrate water-table conditions.

The corresponding trends of the water-level fluctuations in the wells (figs. 6 and 7), the drawdown of water levels in nearby wells due

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[2] Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., p. 519–524.
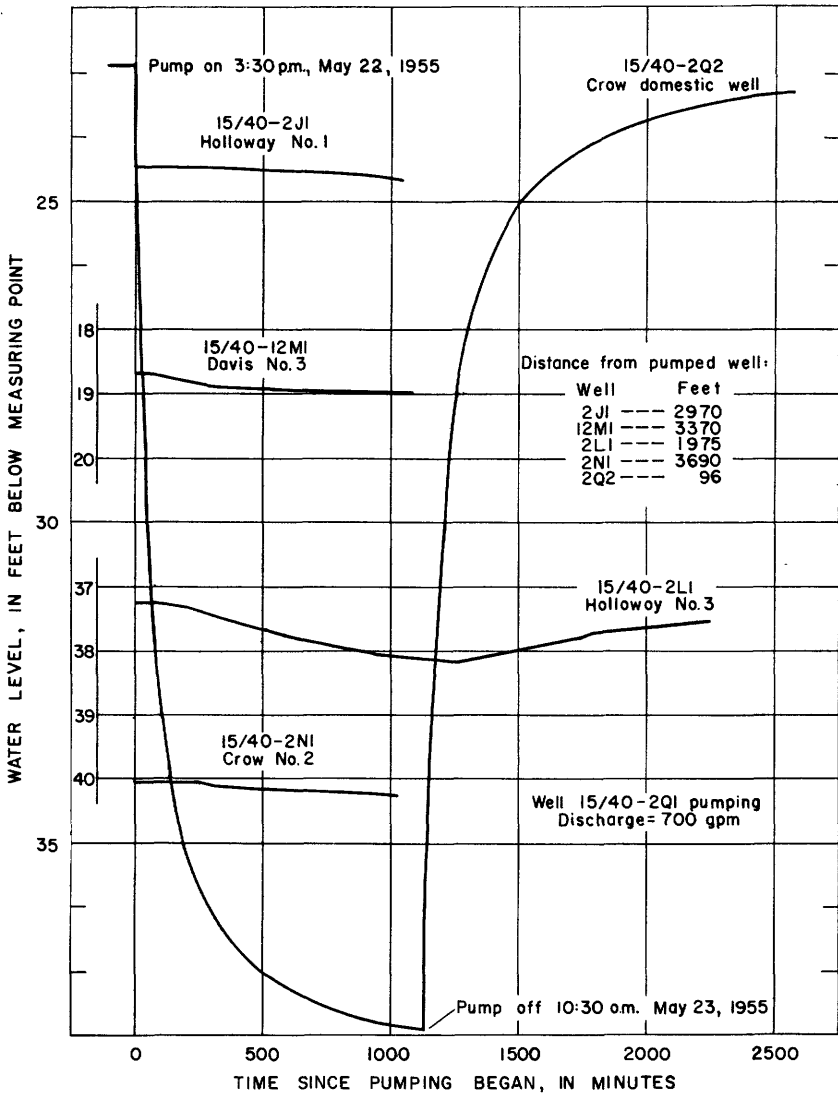
FIGURE 8.—Water levels in observation wells during aquifer test at well 15/40-2Q1 in Cow Valley, Oreg.

to pumping (figs. 8 and 9), and the physical and chemical similarity of the water from most of the wells (table 3), indicate that the water-bearing materials penetrated by the wells are hydraulically inter-connected. In effect, these features indicate that the aquifers in Cow Valley are a single hydraulic unit and that any differences in well performance are due primarily to conditions that may extend only a short distance from any one well, or are due to differences in the manner of constructing, finishing, and using the wells.
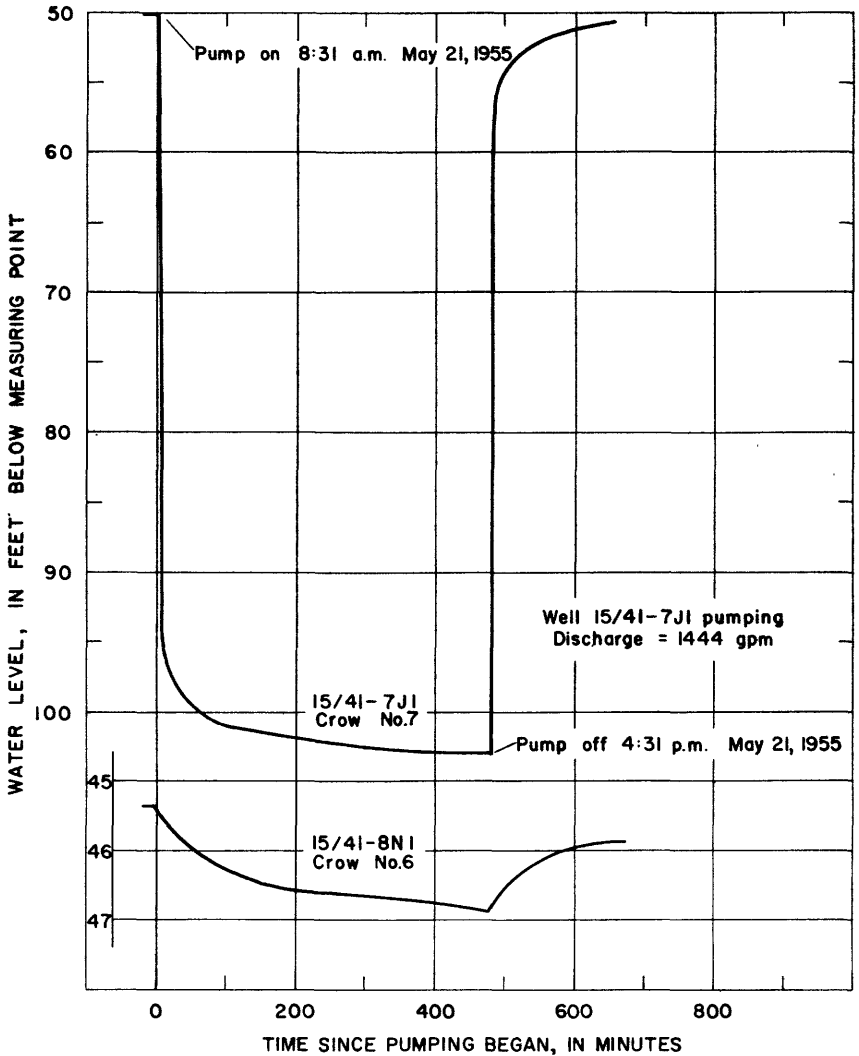
FIGURE 9.—Water levels in wells during aquifer test at well 15/41-7J1 in Cow Valley, Oreg.

WITHDRAWAL FROM WELLS

Under natural conditions, discharge of ground water in Cow Valley occurred by seepage to Cow Creek and by evapotranspiration. As previously stated, the basinlike shape of the valley and the relative impermeability of the older rocks that surround the valley preclude the possibility of appreciable quantities of ground water migrating from the valley underground. Pumping withdrawal from wells has added an artificial means of discharge, or diversion. At present, the withdrawal from wells constitutes the major form of discharge.

Evapotranspiration and discharge to Cow Creek—the natural ground-water discharge that formerly must have approximately balanced the recharge—must become progressively smaller as the water table in the area declines. The pumping withdrawal is the only form of discharge for which quantities can be assigned with the data now available.

The amount of water pumped from 14 irrigation wells in the valley was calculated by determining the electrical power consumed by the pump motors during each irrigation season and applying to those data the power-discharge factors. In 1955, the discharge of each of nine wells was measured by means of a weir placed in the discharge ditch. The discharge of each of the other five wells was estimated. The kilowatt-hour meter at each pump was read before the beginning of the irrigation season and again on July 11, 1955, after a known period of pumping, The calculated pumpage during this period was related to the electrical consumption, and a ratio of kilowatt-hours per acre-foot of water pumped was established for each pump. Records of power consumption by irrigation pumps during the years preceding 1955 were obtained from the power company serving the area, and those data were converted to acre-feet of water pumped. Power-consumption data for the years 1957 to 1959 were collected by personnel of the State Engineer's office.

The annual pumpage from the irrigation wells in Cow Valley, as determined by the method described here, is summarized in the following table:

Irrigation season (May–September)	Number of wells operating	Pumpage, in acre-feet
1951	6	2,020
1952	10	3,850
1953	11	3,030
1954	12	6,420
1955	14	6,940
1956	14	6,800
1957	14	7,300
1958	14	6,270
1959	14	6,820
Total (rounded)		50,000

The 14 irrigation wells supply all but a few acre-feet of the ground water withdrawn from Cow Valley. They normally operate almost continuously for about 4 months per year, usually starting in May and continuing into September. Minor variations in the discharge from the wells, which might result from variations of pumping levels in the wells or from wear on the pumps, probably were not great enough

during the period of study to cause significant year-to-year differences in the power-discharge relationship.

EFFECTS OF WITHDRAWAL

The withdrawal of ground water for irrigation in Cow Valley has caused the progressive decline of the water table beneath the valley floor. This indicates that the withdrawal has exceeded the recharge to the ground-water body, and that a part of the water withdrawn was stored in the aquifers during periods of recharge in previous years.

No probable cause for the progressive water-level decline, other than pumping withdrawals, can be postulated. Under other circumstances, part of such a general decline in water levels might be attributed to meager recharge during a period of deficient precipitation; however, the period of declining water levels in the valley apparently has been one of generally above-average precipitation, as shown by figure 4.

From May 1955 to May 1960, the average decline in water levels (about 5 feet) resulted directly from the withdrawal, during the irrigation seasons of 1955–59, of about 34,000 acre-feet of ground water. However, the apparent relationship between the pumpage and the water-level change varied widely from year to year. For example, the withdrawal of about 6,940 acre-feet during 1955, a year of about average precipitation, apparently caused an average net decline in water level of about 1.2 feet. Conversely, a withdrawal of about 7,300 acre-feet apparently caused a decline of only about 0.2 foot during the period May 1957 to May 1958, a period of above-average precipitation. It is concluded, therefore, that the precise relationship between pumpage and water-level change in the valley at times may be masked by variations in other factors, such as the amount of precipitation and the efficiency with which precipitation produces recharge to the ground-water body. Of course, if measurements other than peak water levels are used to derive year-to-year changes in level, an erroneous relationship between pumpage and water-level change would be indicated. (See p. M14.)

Because the aquifers beneath the valley floor are hydraulically interconnected, pumping withdrawal from a well in one part of the area eventually causes a decline of the water table in other parts of the area, as shown by the hydrographs in figures 8 and 9. By using the values previously obtained from the analyses of the aquifer test data (p. M16), it is possible to predict the amount of drawdown (s) that would be expected after a specific period of steady pumping (t) at any distance (r) from the discharging well. Figure 10 presents a series of graphs showing the computed amounts of drawdown under conditions that prevailed during the tests on wells 15/40-2Q1 and
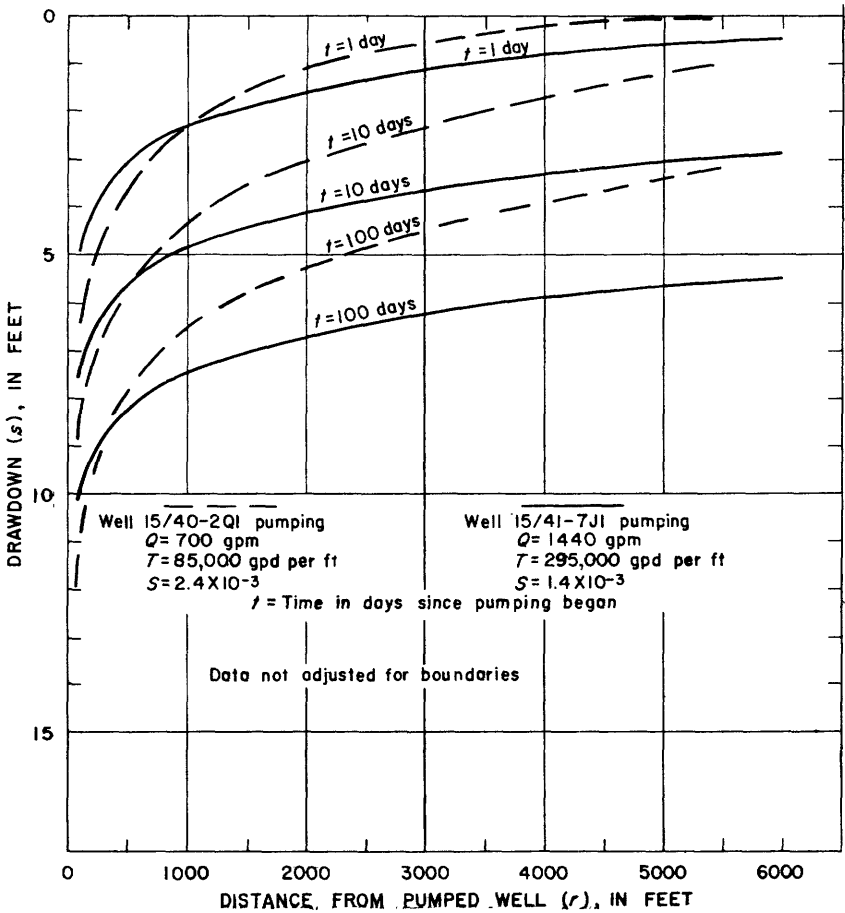
FIGURE 10.—Mathematical projection of aquifer-test data showing expected relation of drawdown to distance from pumped wells in aquifers underlying part of Cow Valley, Oreg.

15/41–7J1. These computed amounts of drawdown are given for places at various distances from the pumped wells, after various periods of pumping. Two sets of curves are shown—each set based on the data derived from one test—in order to depict the general amount and the range of drawdown under probable conditions of withdrawal and with aquifer properties that might be expected within the area. The figure shows, for example, that after 100 days of pumping of either well 15/40-2Q1 at a rate of 700 gpm, or well 15/41-7J1 at a rate of 1,440 gpm, the drawdown at a distance of 4,000 feet from the discharging well (and caused only by pumping of the one well) would be moderate—in the order of 4 to 6 feet. Similarly, after 10 days of pumping, the drawdown of levels at a point 2,000 feet from the pumped well probably would be 3 or 4 feet.

The withdrawal of water from wells in the valley and the use of that water for irrigation probably has caused several interrelated changes in the preexisting water regimen other than the lowering of the water table and the increase in ground-water discharge. The other changes are: (1) a decrease in the amount of natural ground-water discharge, (2) an increase in the amount of ground-water recharge, (3) a probable change in the amount or the seasonal distribution of the outflow in Cow Creek, and (4) an increase in the total discharge of water from the basin.

As previously stated, ground water in the valley discharges naturally as seepage to lower Cow Creek and as evapotranspiration from the ground-water body. With a lowering of the water table, both the evapotranspiration and seepage would be expected to decrease. Also, the natural draft on the ground water by vegetation probably has decreased as deep-rooted plants have been replaced by shallow-rooted crops. However, the water lost from the basin as consumptive use by the crops and as evaporation during the application of irrigation water, is much greater than the water salvaged through decreased natural discharge. The loss by natural evapotranspiration, consumptive use by crops, and evaporation during irrigation, constitutes the principal discharge of water from the basin, and amounts to many times the outflow in lower Cow Creek.

Not all of the water pumped from the wells is lost through evaporation and consumptive use by crops. Part of the irrigation water infiltrates and percolates to the water table; at times, part also has flowed into Cow Creek as irrigation waste water. Thus, since irrigation began, the natural recharge has been augmented by infiltration of irrigation water, and the flow of lower Cow Creek at times has been supplemented by waste runoff.

The lowering of the water table may also have caused, indirectly, an increase in the natural recharge to the ground-water body. Now that a large volume of the aquifer materials beneath the valley floor has been dewatered, there is more storage space for additional recharge, which in the natural state might have been rejected because the aquifers were full at some places.

Salvage of a small amount of ground water, now lost as discharge to lower Cow Creek, could be expected with a further decline of the water table. Despite the water-level decline, at times prior to the summer of 1961 the water table near the creek in the lower part of the valley, and probably throughout the reach from the highway bridge (sec. 5) to the point where the creek leaves the valley (sec. 3, T. 15 S., R. 41 E.), was higher than the channel of the creek. The seepage discharge to the creek can be expected to decrease still further as the water table adjacent to the stream declines. It may not stop entirely unless the

water table is held continuously below the altitude of the stream at its valley outlet which is about 3,850 feet.

REPLACED PUMPAGE

Of principal concern in the management of the ground-water re-sources of Cow Valley is the amount of ground water that can be pumped perennially without depleting unduly the ground water in storage in the valley. The limiting element is the total ground-water recharge; however, only a part of that total recharge goes to replace the water pumped from wells, because the natural ground-water discharge also exerts a constant draft on the ground-water body.

The important increment of the total recharge, which represents the amount of ground water that can be pumped without causing a long-term change in ground-water levels or in the amount of ground water in storage, is herein referred to as the "replaced pumpage." The replaced pumpage in an area varies from year to year with changes in total recharge, pumpage, and natural ground-water discharge. Although the data now available do not allow a precise quantitative determination of the replaced pumpage in Cow Valley, some general conclusions may be made from the data on it during 1951–60.

If, after a season of intensive pumping, the water table throughout the valley were to recover to its highest level of the previous year, the replaced pumpage could be said to equal the actual withdrawal. Conversely, if the highest position of the water table after the period of pumping were to occur at an altitude below that of the previous year, the replaced pumpage would have been less than the amount pumped, and there would have been a depletion of ground-water storage. During the period May 1955–April 1956, the replaced pump-age was considerably less than the 6,940 acre-feet pumped, because at the end of that period the water table was about 1.2 feet lower than it had been at the beginning. In contrast, the replaced pumpage during the period May 1957–May 1958 nearly equaled the 7,300 acre-feet withdrawn, because there was only about 0.2 foot of difference in the highest measured positions of the water table at the end as compared to the beginning of that period.

The difference in the amounts of replaced pumpage during the 2 years cited above was due mostly to differences in the recharge from precipitation. The difference in precipitation, hence, in the water available for recharge, was substantial; precipitation at Vale was about average from May 1955 to April 1956, but was about 26 percent above average during the year ending in May 1958.

If the pumping of ground water in Cow Valley continues to exceed the replaced pumpage, the water table will continue to decline. A continued decline in levels would result in a small additional salvage

of water that is not now being put to beneficial use, and this saving, in turn, would tend to slow the decline. However, it appears unlikely that the long-term average replaced pumpage would reach 5,500 acre-feet per year, which was the average annual withdrawal during the period 1951–59. The reasons for this conclusion are:

1. The average withdrawal of 5,500 acre-feet per year for the 9-year period produced a decline of the water table amounting to about 10 to 15 feet (figs. 6 and 7), which indicates that the recharge was substantially less than the withdrawal.

2. The period 1951–59 apparently was one of generally above-average precipitation (fig. 4); thus the opportunity for recharge during those years was greater than the average that could be expected over a long period of time.

3. Under the limits that have been imposed upon the withdrawal of ground water in the area, annual pumpage in the future probably will be substantially less than the average during the period 1954–59. Consequently, the recharge by infiltration from irrigation can be expected to be somewhat less, and the replaced pumpage proportionally smaller, than during that period.

CHEMICAL QUALITY

To determine the general chemical quality of the ground water in the area and to detect any possible differences in the composition of the water obtained by different wells, samples from 8 irrigation wells, 1 stock well, and 1 unused well were collected and analyzed. The results of these analyses are presented in table 3 together with the temperature of the water at the time of collection.

The analyses indicate that the ground water is of generally good chemical quality not only for irrigation but also for most other uses. The water is of a siliceous, calcium sodium bicarbonate type, and is rather alkaline; the pH ranging from 8.2 to 8.8. Silica was present in the greatest concentration, except bicarbonate, of any constituent in all the samples. The hardness ranged from 69 ppm (parts per million), which may be considered "moderately hard," to 210 ppm, which is "very hard."

Only one water showed a significant difference in general chemical composition from the other ground waters. The water from well 15/40–10K1 had the highest proportion of sodium concentration to the total cation concentration (percent sodium, 58), the highest temperature (76°), and the lowest hardness (69 ppm); these properties doubtlessly were caused by a mixing in that well of the shallower ground water in the alluvium and the volcanic rocks with warmer, more sodic water from the older rocks. (See table 2.)

NEED FOR ADDITIONAL STUDY

A better understanding of the local hydrologic regimen is needed to guide the conservation and management of the water resources of Cow Valley if the optimum use is to be made of the water, and if future periods of drought are to be met with a minimum of hardships due to water shortage. For some elements of the hydrologic regimen, the existing data allow only a partial understanding. Additional reliable data are needed on precipitation, ground-water levels, pumpage, types of crops and acreage irrigated from wells, and outflow in lower Cow Creek. These data will be necessary to establish and maintain a reliable water budget for the area.

With reliable data on the annual precipitation and continuing records of the pumpage, runoff, and ground-water levels, a relationship can be established between pumpage, water-level change, and recharge from precipitation. Such a relationship, once established, could be used to determine the annual supply of ground water expected to be available for pumping. It would be a vital basis for management of this water resource.

CONCLUSIONS

The principal conclusions resulting from this investigation are as follows:

1. The ground water of the upland basin known as Cow Valley is hydraulically isolated from adjoining areas by its high topographic position and by the nearly impervious rocks that underlie it and surround the valley.

2. Precipitation within the basin is the only natural source of water to recharge the ground water; discharge of water apparently is entirely by evapotranspiration and by runoff in Cow Creek. The ground-water body discharges naturally into the lower part of Cow Creek, which flowed permanently until the summer of 1961.

3. The principal aquifers consist of alluvial deposits of gravel and sand and the underlying lava flows and associated pyroclastic rocks. The ground water probably is mostly unconfined, but may occur under confined conditions locally. The aquifers apparently are hydraulically connected; therefore, pumping from an aquifer in one part of the valley affects water levels in other parts of the area as well.

4. The withdrawal of about 50,000 acre-feet of ground water during the period 1951–59 caused a decline of the water table amounting to about 10 to 15 feet. Thus, a substantially greater quantity of ground water has been removed from storage than has been replenished through recharge during that period.

5. Besides producing a progressive decline of the water table, the increased withdrawal of ground water for irrigation probably also has resulted in a decrease in the amount of ground water discharging naturally as evapotranspiration and as seepage to lower Cow Creek and has increased slightly the opportunity for ground-water recharge in parts of the valley floor.

6. The period of this study was one of generally above-average precipitation. Consequently, the depletion of the ground water in storage produced by pumping during this period was less severe than would be caused by the same withdrawals during a period of below-average precipitation.

7. Available data are inadequate to allow precise quantitative determination of the total recharge to the ground-water body; however, the average annual recharge that replaces the ground water pumped for irrigation is, and probably will continue to be, less than 5,500 acre-feet per year.

8. Additional data will be needed on precipitation and evapotranspiration, and continued records will be needed on ground-water levels, pumpage, types of crops and acreages irrigated from wells, and outflow in Cow Creek. Analyses of such data over a longer period of record should provide a basis for refining the estimates of the amount of water that can be pumped perennially, and hence furnish the guidelines for the management and conservation of the water resources.

TABLE 1.—*Records of representative wells in Cow Valley, Oreg.*

[Well number: See p. M4 for description of well-numbering system. Topography and altitude: Vs, valley slope; V, valley. Altitude of land-surface datum at well, in feet above mean sea level, determined by barometric surveys and spirit leveling. Type of well: All wells listed are drilled. Water level: Depths given in feet and decimal fractions were measured; those in whole feet were reported by well owners or drillers. All water levels are related to land-surface datum at well. Type of pump: J, jet; N, none; T, turbine. Yield: Letter in parenthesis indicates source of data; (e), estimated sustained discharge of pump; (m), measured during discharge test by Geological Survey; (r), reported by driller or owner. Additional reported yield data are presented with drillers' logs in table 2. Use of water: D, domestic; Irr, irrigation; Nu, not used; S, stock. Remarks: Ca, chemical analysis in table 3; H, hydrograph included in this report; L, log in table 2; W, water-level record in table 4]

Well	Owner or occupant	Topography and altitude (feet)	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s)			Water level		Type of pump and yield (gallons per minute)	Use	Remarks
						Depth to top (feet)	Thickness (feet)	Character of material	Feet below datum	Date			
						T. 15 S., R. 40 E.							
1C1	Mrs. W. E. Anderson.	Vs, 3,972.8--	330	14	300	120	95	Sand and gravel--	90	1953	T, 1,200 (e)--	Irr	Known as Locey No. 1; L, W.
						245	55	--do--					
						312	18	Volcanic rock--					
2f1	Max Holloway----	V, 3,898.3--	421	12	55	97	3	Gravel--------	19	1949	T, 500 (e)---	Irr	Holloway No. 1; H, Ca, L.
						180	3	Volcanic rock--					
						320	6	--do--					
						415	6	--do--					
2L1	-----do-----	V, 3,910.7--	535	12	250	83	17	Sand and gravel-	35.6	5-18-55	N, 600 (r)---	Nu	Holloway No. 3; W.
						393	142	Volcanic rock--					
2M1	-----do-----	V, 3,916.3--							40	1952(?)	T, 800 (e)---	Irr	Holloway No. 2; L, W.
2N1	Rankin Crow-----	V, 3,915.0--	310	10	170	48	2	Sand and gravel-	37.5	1949-50	T, 251 (m)---	Irr	Crow No. 2. Filled to 128 ft by sand Aug. 1950; Ca, H, L.
						140	25	--do--					
						285	25	--do--					
2Q1	-----do-----	V, 3,897±--	362	10	121	114	4	--do--	17	5-?-49	T, 700 (m)	Irr	Crow No. 1; Ca, L.
						305	3	Sand, cindery---					
2Q2	-----do-----	V, 3,897.4--	74	6	62	62	12	Sand---------	22.5	5-18-55	J, 20 (r)----	D,S	W.
10B1	-----do-----	V, 3,922.9--	255	12	130	50	4	Sand and gravel-	42	7-?-50	T, 1,004 (m)-	Irr	Crow No. 3; L, W.
						94	10	--do--					
						204	2	--do--					
						250	5	Gravel--------					
10K1	-----do-----	V, 3,936.3--	1,000	14	100	60	5	--do--	55	1953	T, 574 (m)---	Irr	Crow No. 9; Ca, L, W.
						80	5	Gravel--------					
						170	45	Volcanic rock--					
						950	35	"Sand and gravel"--					
11P1	-----do-----	V, 3,922.6--	200	12	128	54	4	Sand and gravel-	42	8-?-50	T, 852 (m)---	Irr	Crow No. 4; Ca, L, W.
						98	8	--do--					
						140	50	Volcanic rock--					

TABLE 1.—*Records of representative wells in Cow Valley, Oreg.*—Continued

[Well number: See p. M4 for description of well-numbering system. Topography and altitude: Vs, valley slope; V, valley. Altitude of land-surface datum at well, in feet above mean sea level, determined by barometric surveys and spirit leveling. Type of well: All wells listed are drilled. Water level: Depths given in feet and decimal fractions were measured; those in whole feet were reported by well owners or drillers. All water levels are related to land-surface datum at well. Type of pump: J, jet; N, none; T, turbine. Yield: Letter in parenthesis indicates source of data; (e), estimated sustained discharge of pump; (m), measured during discharge test by Geological Survey; (r), reported by driller or owner. Additional reported yield data are presented with drillers' logs in table 2. Use of water: D, domestic; Irr, irrigation; Nu, not used; S, stock. Remarks: Ca, chemical analysis in table 3; H, hydrograph included in this report; L, log in table 2; W, water-level record in table 4]

Well	Owner or occupant	Topography and altitude (feet)	Depth of well (feet)	Diameter of well (inches)	Depth of casing (feet)	Water-bearing zone(s) Depth to top (feet)	Thickness (feet)	Character of material	Water level Feet below datum	Date	Type of pump and yield (gallons per minute)	Use	Remarks
						T. 15 S., R. 40 E.—Continued							
12M1	Gus Davis Estate	V, 3,893.2	280	14	66			Gravel	18.6	4-29-55	N, 1,200 (r)	Nu	Davis No. 3; L, W.
12Q1	---do---	V, 3,911.6	100	14		44	2	Gravel	37.8	11-6-54	N	Nu	Davis No. 4; L, W.
13D1	---do---	V, 3,910.3	300	14	162	80	5	---do---	38.9	4-29-55	T, 950 (e)	Irr	Davis No. 1; Ca, L, W.
						287	13	Volcanic rock					
								Cinders					
13G1	---do---	V, 3,933.0	173	14	156	120	53	Volcanic rocks	57.7	5-18-55	T, 950 (e)	Irr	Davis No. 2; L, W.
14L1	Rankin Crow	V, 3,951.6	285	12	160	170	15	Sand and gravel	68	11-?-50	T, 1,617 (m)	Irr	Crow No. 5; Ca, L, W.
						245	40	Volcanic rock					
14Q1	---do---	V, 3,969.4	248	14	157½	223	25	Volcanic cinders	90	9-?-51	T, 1,157 (m)	Irr	Crow No. 8; Ca, L, W.
15K1	Gus Davis Estate	V, 3,952	274	14	160	56	100	Sand, gravel and clay	64.3	1-11-56		Nu	L.
						T. 15 S., R. 41 E.							
7J1	Rankin Crow	V, 3,917	338	12	150	95	45	Sand and gravel	46	1951	T, 1,546 (m)	Irr	Crow No. 7; Ca, L, W.
						314	24	Volcanic rock					
8A1	---do---	V, 3,890	128	6	128			Sand	19.1	5-18-55	J	D,S	W.
8K1	---do---	V, 3,900		6								D	
8N1	---do---	V, 3,920	360	12	100	160	5	Gravel	52	1951	T, 1,880 (m)	Irr	Crow No. 6; Ca, L, W.
						320	40	---do---					
11M1	Esther Davis	Vs, 3,908		8				Volcanic rock	43.8	11-5-54	J	S	W.

TABLE 2.—*Materials penetrated by wells*

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40-1C1		

[Mrs. W. E. Anderson. Locey No. 1. Drilled by Max O. Holloway, 1953. Casing: 14 in. to 300 ft; perforated from 180 to 245 ft and from 275 to 290 ft. Pumped 1,400 gpm (gallons per minute) for short period, dd (drawdown), 70 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	30	30
Sand and gravel	90	120
Sand and gravel, water-bearing	55	175
Boulders, 6-in. diameter	5	180
Sand and gravel, water-bearing	35	215
Sand, fine	30	245
Sand and gravel, water-bearing	55	300
Sand rock	12	312
Volcanic rocks:		
Boulder, lava, large; water	18	330

15/40-2J1		

[Max Holloway. Holloway No. 1. Drilled by owner, 1949. Casing: 12 in. to 55 ft. Pumped 1,000 gpm for 8 hrs, dd 31 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	10	10
Hardpan	3	13
Clay, yellow	4	17
Gravel, water-bearing	6	23
Clay, hard, yellow	74	97
Gravel, water-bearing	3	100
Clay, brown; mixed with gravel	80	180
Clay, gray, hard	57	240
Clay, hard, red	80	320
Volcanic rocks:		
Cinders, red, water-bearing	3	183
Lava boulders, water-bearing	6	326
Clay, hard, dark-brown	89	415
Boulders, large, water-bearing	6	421

15/40-2M1		

[Max Holloway. Holloway No. 2. Drilled by owner, 1952(?). Casing: 12 in. to 250 ft; perforated from 40 to 100 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	65	65
Gravel, water-bearing	3	68
Clay	15	83
Sand, coarse, and gravel	17	100
Sand, fine, quick	140	240
Clay, hard	81	321
Volcanic rocks:		
Basalt, hard, black	72	393
Lava, porous	137	530
Lava, broken	5	535

TABLE 2.—*Materials penetrated by wells*—Continued

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40-2N1		

[Rankin Crow.   Crow No. 2.   Drilled by Max Holloway, 1949-50.   Casing: 10 in. to 170 ft; perforated from 80 to 170 ft.   Filled with sand to 128 ft in August 1950.   Static water level when well was drilled was 37½ ft below land surface.   Pumped 650 gpm for a short time, dd 50 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	4	4
Hardpan	4	8
Clay, yellow	40	48
Sand and gravel, fine	2	50
Clay	10	60
Sand, fine, and mud, mixed	18	78
Sand rock, hard	2	80
Clay, yellow	60	140
Sand and gravel	25	165
Sand rock	20	185
Clay, yellow	60	245
Sand rock, red	40	285
Sand and gravel, fine, mixed	20	305
Gravel, coarse	5	310

Materials	Thickness (feet)	Depth (feet)
15/40-2Q1		

[Rankin Crow.   Crow No. 1.   Drilled by Max Holloway, 1949.   Casing: 10 in. to 121 ft; perforated from the top fo 121 ft.   Pumped 1,000 gpm for a short period, dd 18 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	17	17
Gravel	4	21
Clay and sand, mixed	93	114
Gravel	4	118
Clay and sand, mixed	187	305
Sand, cindery	3	308
Clay, hard, sticky	54	362

Materials	Thickness (feet)	Depth (feet)
15/40-10B1		

[Rankin Crow.   Crow No. 3.   Drilled by Max Holloway, 1950.   Casing: 12 in. to 130 ft; perforated from 6 to 130 ft.   Pumped 840 gpm for a short time, dd 38 ft]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Soil	4	4
Hardpan	4	8
Clay, yellow	42	50
Sand and gravel	4	54
Clay, yellow, hard	40	94
Sand and gravel	10	104
Clay, yellow, hard	100	204
Gravel	2	206
Clay, yellow, hard	44	250
Gravel, coarse	5	255

TABLE 2.—*Materials penetrated by wells*—Continued

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40–10K1		
[Rankin Crow. Crow No. 9. Drilled by Max Holloway, 1953. Casing: 14 in. to 100 ft; perforated from 60 ft to bottom. Pumped 580 gpm for 1 hr, dd 121 ft]		
Alluvium:		
Soil	20	20
Clay	40	60
Gravel, water-bearing	5	65
Clay	15	80
Gravel, water-bearing	5	85
Clay	85	170
Volcanic rocks:		
Rock, small amount of water	45	215
Older rocks:		
Clay (soil and weathering zone?)	75	290
Shale, blue	280	570
Rock, with a little water	50	620
Sandstone, black	70	690
Sandstone rock, black, some water	30	720
Shale, blue	80	800
Sandstone, blue and gray	70	870
Shale, blue, with soapstone	15	885
Shale, blue, hard, and "hot"	15	900
Sandstone and gravel	50	950
"Sand and gravel," with warm water	35	985
Shale, blue, sticky	15	1, 000
15/40–11P1		
[Rankin Crow. Crow No. 4. Drilled by Max Holloway, 1950. Casing: 12 in. to 128 ft; perforated from 40 to 128 ft. Pumped 800 gpm for 2½ hr, dd 120 ft]		
Alluvium:		
Soil	2	2
Hardpan	4	6
Loam	8	14
Clay, yellow	40	54
Sand and gravel, mixed	4	58
Clay, yellow	40	98
Sand and gravel, mixed	8	106
Clay, yellow, hard	34	140
Volcanic rocks:		
Lava rock, porous, creviced	50	190
Basalt, black, hard	10	200

TABLE 2.—*Materials penetrated by wells*—Continued

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40–12M1		
[Gus Davis Estate. Davis No. 3. Drilled by Max Holloway, 1954. Casing: 14 in., set to 66 ft. Pumped 1,200 gpm with lift from 80 ft]		
Alluvium:		
Soil	19	19
Sand and gravel	3	22
Clay	34	56
Sand and gravel	8	64
Clay, hard	56	120
Gravel	3	123
Gravel in clay	37	160
Gravel and sand	5	165
Clay, hard	20	185
Gravel	5	190
Clay, burnt, red	30	220
Gravel	5	225
Volcanic rocks(?):		
Clay, burnt	50	275
Gravel, lava	5	280
15/40–12Q1		
[Gus Davis Estate. Davis No. 4. Drilled by Max Holloway, 1954]		
Alluvium:		
Soil	15	15
Clay	29	44
Gravel, water-bearing	2	46
Clay, sandy	14	60
Clay, hard	20	80
Gravel	5	85
Volcanic rocks(?):		
Clay, burnt	15	100
15/40–13D1		
[Gus Davis Estate. Davis No. 1. Drilled by Max Holloway, 1954. Casing: 14 in. to 162 ft. Pumped 900 gpm with lift from 110 ft]		
Alluvium:		
Soil	15	15
Chalk	5	20
Clay	29	49
Sand and gravel	11	60
Not reported	11	71
Clay	23	94
Gravel and sand	10	104
Volcanic rocks(?):		
Clay, burnt, red	26	130
Gravel	3	133
Clay, red	7	140
Gravel, bedded in clay	40	180
Clay, burnt, hard	100	280
Gravel	7	287
Cinders, red	13	300

TABLE 2.—*Materials penetrated by wells*—Continued

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40–13G1		
[Gus Davis Estate. Davis No. 2. Drilled by Max Holloway, 1954. Casing: 14 in. to 156 ft. Pumped 900 gpm with lift from 110 ft]		
Alluvium:		
Soil	15	15
Clay	50	65
Gravel, water-bearing	10	75
Gravel in clay	45	120
Volcanic rocks:		
Cinders, red	32	152
Rock, hard	18	170
Lava, broken, porous	3	173
15/40–14L1		
[Rankin Crow. Crow No. 5. Drilled by Max Holloway, 1950. Casing: 12 in. to 160 ft; no perforations. Pumped for 2 hrs at progressively greater rates to 1,300 gpm. Pumped 1,300 for ½ hr, dd 24 ft]		
Alluvium:		
Soil	4	4
Gravel, cemented	16	20
Clay, red	50	70
Sand and gravel	4	74
Clay, yellow	35	109
Sand, fine, with mud intermixed	40	149
Sand rock	21	170
Sand and gravel, fine, mixed	15	185
Clay, yellow, hard	60	245
Volcanic rocks:		
Lava, porous	35	280
Lava rock, loose, caving	5	285
15/40–14Q1		
[Rankin Crow. Crow No. 8. Drilled by Max Holloway, 1951. Casing: 14 in. to 157½ ft; no record of perforations. Pumped at progressively greater rates for 1¼ hours; maximum rate 2,500 gpm for ½ hr. dd 45 ft]		
Alluvium:		
Soil with rocks	41½	41½
Gravel, cemented	28	69½
Clay, brown, with gravel	3	72½
Gravel, cemented, water at 94 ft	22½	95
Sandstone	2	97
Clay, brown, with little gravel	125	222
Sand and gravel	1	223
Volcanic rocks:		
Cinders	25	248

TABLE 2.—*Materials penetrated by wells*—Continued

[Tentative stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
15/40–15K1		
[Gus Davis Estate. Drilled by Forrest Skinner, 1951. Casing: 14 in. to 160 ft; no perforations]		
Alluvium:		
Top soil _____	4	4
Volcanic rocks (?):		
Gravel, cemented_____	26	30
Clay_____	26	56
Sand, gravel and clay, water-bearing_____	100	156
Clay, tan_____	66	222
Shale, gray_____	10	232
Sand and gravel_____	15	247
Older rocks:		
Shale, green_____	25	272
Clay, white, sticky_____	2	274
15/41–7J1		
[Rankin Crow. Crow No. 7. Drilled by Max Holloway, 1951. Casing: 12 in. to 150 ft; no record of perforations. Pumped 2,000 gpm; no record of duration or drawdown.]		
Alluvium:		
Soil_____	75	75
Gravel, water-bearing_____	5	80
Clay_____	15	95
Sand and gravel, water-bearing_____	45	140
Clay, hard_____	174	314
Volcanic rocks:		
Rock, hard_____	20	334
Rock, loose, water-bearing_____	4	338
15/41–8N1		
[Rankin Crow. Crow No. 6. Drilled by Max Holloway, 1951. Casing: 12 in. to 100 ft; no record of perforations. Pumped 1,880 gpm; no record of duration or drawdown]		
Alluvium:		
Soil_____	15	15
Gravel and boulders_____	25	40
Clay_____	10	50
Sand and clay_____	25	75
Quicksand_____	15	90
Clay, hard_____	70	160
Gravel, water-bearing_____	5	165
Clay and sand_____	35	200
Clay, hard_____	50	250
Clay and small gravel_____	50	300
Gravel and clay, warm_____	20	320
Talus material(?):		
Gravel, large, and boulders, water-bearing_____	40	360

TABLE 3.—*Analyses of water from wells in Cow Valley*

[Analyses by U.S. Geological Survey. Parts per million except for last four items which are in the evaluation units commonly used]

Well No	15/40–2J1[1]	15/40–2N1[2]	15/40–2Q1[2]	15/40–10K1[3]	15/40–11P1[1]	15/40–13D1[4]	15/40–14L1[1]	15/40–14Q1[1]	15/41–7J1[1]	15/41–8N1[1]
Date of collection	7–21–55	5–24–55	5–23–55	5–24–55	5–26–55	7–22–55	5–25–55	5–26–55	5–21–55	5–25–55
Temperature (°F)		54	54	76	57		54	59½	65	67
Silica (SiO_2)	46	55	53	87	54	49	48	48	63	52
Calcium (Ca)		26	46	13	37		39	29	25	25
Magnesium (Mg)		10	23	8.9	14		15	9.3	6.2	5.5
Sodium (Na)	25	19	25	54	42	19	19	21	22	21
Potassium (K)		3.3	4.1	12	5		2.9	3.6	4.1	4.1
Bicarbonate (HCO_3)	153	143	165	195	284	175	228	181	138	139
Carbonate (CO_3)	9	8	15	18	0	11	0	0	9	6
Chloride (Cl)	9	8	40	7	7	6	8	4	4	4
Nitrate (NO_3)		1.4	2.5	.3	.6		1.4	1.9	2.3	2.1
Hardness (as $CaCO_3$)										
(Calcium, magnesium)	108	106	210	69	150	138	159	111	88	85
(Noncarbonate)	0	0	50	0	0	0	0	0	0	0
Specific conductance (Micromhos at 25°C)	318	293	533	382	465	328	399	304	288	264
Sodium-adsorption ratio (SAR)		.8	.8	2.8	1.5		.66	.87	1.0	1.0
Percent sodium		27	20	58	37		20	28	34	34
pH	8.6	8.7	8.6	8.8	8.2	8.7	8.2	8.2	8.7	8.6

[1] Taps water in gravel and sand of the alluvium and volcanic rocks.
[2] Taps water in gravel and sand of the alluvium.
[3] Taps water in gravel of the alluvium, volcanic rocks, and older rocks.
[4] Taps water in the volcanic rocks.

TABLE 4.—*Records of water levels in wells*

[In feet below land-surface datum]

Date	Water level	Date	Water level	Date	Water level

15/40–1C1

[Mrs. W. E. Anderson. Measuring point is top of 1½-in. pipe on east side of pump, altitude 3,974.8 ft, 2.0 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
1953	90±	Apr. 11, 1956	100.32	May 7, 1958	102.29
Nov. 6, 1954	99.81	July 19, 1956	[2] 135.35	Dec. 10, 1958	104.15
May, 18, 1955	100.35	Aug. 14, 1956	106.07	May 19, 1959	103.54
May 22, 1955	101.08	Oct. 23, 1956	104.18	Dec. 9, 1959	105.90
May 23, 1955	100.93	Jan. 7, 1957	102.84	May 11, 1960	104.20
Jan. 12, 1956	101.60	May 7, 1957	101.59		

15/40–2L1

[Max Holloway. Holloway No. 3. Measuring point is top of casing on east side, altitude 3,912.4 ft, 1.7 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
May 18, 1955	35.64	June 17, 1955	42.48	July 19, 1956	42.18
May 19, 1955	35.61	July 21, 1955	42.91	Aug. 15, 1956	41.19
May 20, 1955	35.58	July 22, 1955	42.43	Oct. 23, 1956	38.65
May 21, 1955	35.57	Aug. 1, 1955	43.16	May 7, 1957	38.76
May 22, 1955	35.54	Sept. 14, 1955	42.17	Dec. 12, 1957	39.86
May 23, 1955	[3] 36.44	Oct. 10, 1955	36.96	May 5, 1958	38.67
May 24, 1955	[3] 37.62	Nov. 27, 1955	37.50	Dec. 10, 1958	38.62
May 25, 1955	[4] 35.84	Dec. 28, 1955	37.76	May 19, 1959	43.84
May 26, 1955	[4] 35.86	Jan. 13, 1956	37.63	Dec. 9, 1959	41.02
June 15, 1955	42.33	Apr. 11, 1956	35.40	May 11, 1960	41.11

See footnotes at end of table.

TABLE 4.—*Records of water levels in wells*—Continued

Date	Water level	Date	Water level	Date	Water level

15/40-2M1

[Max Holloway. Holloway No. 2. Measuring point is top of 2-in. inclined pipe, altitude 3,916.6 ft, 0.3 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
1952 (?)_____	[1] 40	Apr. 11, 1956_____	42.60	Dec. 12, 1957_____	47.72
Nov. 5, 1954_____	43.60	July 19, 1956_____	[2] 79.25	May 5, 1958_____	45.47
May 18, 1955_____	44.22	Aug. 15, 1956_____	51.75	Dec. 10, 1958_____	46.93
May 22, 1955_____	41.83	Oct. 23, 1956_____	47.11	Dec. 9, 1959_____	49.32
Jan. 13, 1956_____	44.66	May 7, 1957_____	45.18	May 11, 1960_____	48.97

15/40-2Q2

[Rankin Crow. Domestic well. Measuring point is top of casing, altitude 3,897.6 ft, 0.27 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
May 18, 1955_____	22.52	Jan. 12, 1956_____	24.71	Oct. 23, 1956_____	25.67
May 22, 1955_____	22.89	Apr. 11, 1956_____	22.48	May 7, 1957_____	25.59
June 15, 1955_____	[4] 39.51	July 19, 1956_____	[3] 43.45	Dec. 12, 1957_____	27.18
July 22, 1955_____	[3] 39.40	Aug. 15, 1956_____	43.31		

15/40-10B1

[Rankin Crow. Crow No. 3. Measuring point is bottom of slot on south side of casing, altitude 3,921.7 ft, 1.2 ft below land-surface datum]

Date	Water level	Date	Water level	Date	Water level
July 1950_____	[1] 42	Apr. 12, 1956_____	47.46	Dec. 12, 1957_____	51.69
Sept. 12, 1954_____	50.57	July 19, 1956_____	[2] 119.2	May 7, 1958_____	50.50
Nov. 5, 1954_____	48.50	Oct. 23, 1956_____	53.40	Dec. 10, 1958_____	53.39
May 18, 1955_____	46.36	Jan. 7, 1957_____	51.52	Dec. 9, 1959_____	55.70
May 22, 1955_____	46.29	May 7, 1957_____	50.15	May 11, 1960_____	52.47
Jan. 12, 1956_____	50.23				

15/40-10K1

[Rankin Crow. Crow No. 9. Measuring point is bottom of slot in north side of casing, altitude 3,935.3 ft, 1.0 ft below land-surface datum]

Date	Water level	Date	Water level	Date	Water level
1953_____	[1] 55	Apr. 12, 1956_____	61.01	Dec. 12, 1957_____	65.65
Sept. 12, 1954_____	62.30	July 19, 1956_____	[2] 201	May 7, 1958_____	62.76
May 18, 1955_____	58.10	Oct. 23, 1956_____	65.76	Dec. 10, 1958_____	65.72
May 24, 1955_____	58.03	Jan. 7, 1957_____	63.78	Dec. 9, 1959_____	68.94
Jan. 12, 1956_____	62.52	May 7, 1957_____	62.13	May 11, 1960_____	64.48

15/40-11P1

[Rankin Crow. Crow No. 4. Measuring point is top of 1½-in. pipe, altitude 3,923.6 ft, 1.0 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Aug. 1950_____	[1] 42	Apr. 11, 1956_____	48.43	Dec. 12, 1957_____	53.89
Sept. 12, 1954_____	49.08	Oct. 23, 1956_____	53.27	May 7, 1958_____	50.31
May 18, 1955_____	47.14	Jan. 7, 1957_____	52.38	Dec. 10, 1958_____	52.76
May 26, 1955_____	47.27	May 7, 1957_____	50.03	May 11, 1960_____	52.43
Jan. 12, 1956_____	49.96				

15/40-12M1

[Gus Davis Estate. Davis No. 3. Measuring point is top of 1½-in. pipe, altitude 3,893.5 ft, 0.3 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Apr. 4, 1955_____	18.53	Apr. 11, 1956_____	19.94	Dec. 12, 1957_____	24.55
May 18, 1955_____	18.55	July 19, 1956_____	25.47	May 7, 1958_____	20.93
May 22, 1955_____	18.37	Aug. 15, 1956_____	26.28	May 7, 1958_____	23.93
May 24, 1955_____	18.36	Oct. 23, 1956_____	24.32	May 19, 1959_____	24.04
June 15, 1955_____	20.97	Nov. 14, 1956_____	23.50	Dec. 9, 1959_____	25.94
July 22, 1955_____	23.03	Jan. 7, 1957_____	23.05	May 11, 1960_____	24.02
Jan. 12, 1956_____	21.73	May 7, 1957_____	21.84		

See footnotes at end of table.

TABLE 4.—*Records of water levels in wells*—Continued

Date	Water level	Date	Water level	Date	Water level

15/40–12Q1

[Gus Davis Estate. Davis No. 4. Measuring point is bottom of perforation on west side of casing, altitude 3,911.6 ft, at land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Nov. 6, 1954_____	37. 83	Apr. 11, 1956_____	38. 76	Dec. 12, 1957_____	43. 52
Apr. 4, 1955_____	36. 56	July 19, 1956_____	43. 79	May 7, 1958_____	38. 63
May 18, 1955_____	36. 55	Aug. 15, 1956_____	44. 91	Dec. 10. 1958_____	42. 92
May 22, 1955_____	36. 52	Oct. 23, 1956_____	43. 27	May 19, 1959_____	41. 06
June 15, 1955_____	38. 65	Nov. 14, 1956_____	42. 85	Dec. 9, 1959_____	44. 90
July 22, 1955_____	42. 23	May 7, 1957_____	39. 97	May 11, 1960_____	40. 40
Jan. 11, 1956_____	40. 30				

15/40–13D1

[Gus Davis Estate. Davis No. 1. Measuring point is top of 1½-in. pipe through north side of casing, altitude 3,911.1 ft, 0.8 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Apr. 4, 1955_____	38. 86	July 19, 1956_____	[2] 84	Dec. 10, 1958_____	42. 05
May 18, 1955_____	34. 74	Oct. 23, 1956_____	42. 62	May 19, 1959_____	40. 98
June 15, 1955_____	37. 90	May 7, 1957_____	39. 31	Dec. 9, 1959_____	44. 01
Jan. 11, 1956_____	39. 46	Dec. 12, 1957_____	42. 58	May 11, 1960_____	41. 64
Apr. 11, 1956_____	37. 85	May 7, 1958_____	39. 57		

15/40–13G1

[Gus Davis Estate. Davis No. 2. Measuring point is top of 1½-in. pipe, altitude 3,934.0 ft, 1.0 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
May 18, 1955_____	57. 69	Oct. 23, 1956_____	65. 05	Dec. 10, 1958_____	64. 86
June 15, 1955_____	60. 43	May 7, 1957_____	61. 77	May 19, 1959_____	64. 29
July 22, 1955_____	[5] 64. 53	Dec. 12, 1957_____	65. 03	Dec. 9, 1959_____	66. 45
Jan. 11, 1956_____	61. 86	May 7, 1958_____	62. 27	May 11, 1960_____	64. 14
Apr. 11, 1956_____	60. 47				

15/40–14L1

[Rankin Crow. Crow No. 5. Measuring point is top of 1½-in. pipe, altitude 3,953.1 ft, 1.5 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Nov. 1950_____	[1] 68	May 25, 1955_____	74. 80	Apr. 11, 1956_____	76. 12
May 18, 1955_____	74. 86	Jan. 12, 1956_____	78. 68	Oct. 23, 1956_____	81. 86

15/40–14Q1

[Rankin Crow. Crow No. 8. Measuring point is top of 1½-in. pipe, altitude 3,969.9 ft, 0.5 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Sept. 1951_____	[1] 90	Apr. 11, 1956_____	96. 38	Dec. 12, 1957_____	100. 48
Sept. 12, 1954_____	96. 98	July 19, 1956_____	[2] 126. 5	May 5, 1958_____	97. 71
May 18, 1955_____	93. 78	Oct. 23, 1956_____	102. 52	Dec. 10, 1958_____	99. 88
May 25, 1955_____	93. 75	Jan. 7, 1957_____	98. 62	Dec. 9, 1959_____	101. 85
May 26, 1955_____	93. 83	May 7, 1957_____	97. 16	May 11, 1960_____	99. 58
Jan. 12, 1956_____	97. 68				

15/41–7J1

[Rankin Crow. Crow No. 7. Measuring point is top of 1½-in. pipe on east side of well, altitude about 3,917 ft, 1.15 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
1951_____	[1] 46	May 22, 1955_____	49. 23	Apr. 12, 1956_____	50. 88
Sept. 12, 1954_____	51. 35	May 25, 1955_____	[5] 49. 91	July 19, 1956_____	[2] 116
May 18, 1955_____	48. 55	Jan. 11, 1956_____	51. 25	Oct. 23, 1956_____	54. 98

See footnotes at end of table.

TABLE 4.—*Records of water levels in wells*—Continued

Date	Water level	Date	Water level	Date	Water level
		15/41–8A1			

[Rankin Crow. Stock and domestic well. Measuring point is top of 6-in. casing in concrete pit, altitude about 3,890 ft, 5.0 ft below land-surface datum]

Date	Water level	Date	Water level	Date	Water level
May 18, 1955	19.14	Oct. 24, 1956	21.10	Dec. 11, 1958	21.99
June 22, 1955	18.70	Jan. 7, 1957	20.52	May 19, 1959	21.03
Jan. 12, 1956	22.64	May 7, 1957	20.07	Dec. 9, 1959	[2] 27.70
Apr. 12, 1956	19.27	Dec. 12, 1957	20.43	May 11, 1960	20.96
July 19, 1956	19.44	May 7, 1958	19.48		

15/41–8N1

[Rankin Crow. Crow No. 6. Measuring point is top of 1½-in. pipe on east side of well, altitude about 3,920 ft, 0.7 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
1951	[1] 50	Jan. 11, 1956	48.95	Dec. 12, 1957	52.95
Aug. 4, 1953	52.20	Apr. 12, 1956	46.69	May 7, 1958	48.12
Sept. 12, 1954	52.50	July 19, 1956	[3] 75	Dec. 10, 1958	50.50
May 18, 1955	45.58	Oct. 23, 1956	51.05	Dec. 9, 1959	51.46
May 22, 1955	45.56	May 7, 1957	47.87	May 11, 1960	50.06
May 24, 1955	[5] 45.41				

15/41–11M1

[Esther Davis. Stock well. Measuring point is top of casing, altitude about 3,908 ft, 1.0 ft above land-surface datum]

Date	Water level	Date	Water level	Date	Water level
Nov. 5, 1954	43.80	Apr. 12, 1956	41.96	May 7, 1957	42.33
May 26, 1955	42.89	July 19, 1956	42.14	Dec. 11, 1958	43.05
Jan. 12, 1956	43.10	Oct. 24, 1956	42.90	May 19, 1959	43.32

[1] Depth to water reported by driller.
[2] Pumping when measured.
[3] Nearby well pumping.
[4] Nearby well pumped recently.
[5] Pumped recently.

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