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The ground-water system in southeastern Laramie County, Wyoming

by

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Abstract

Increased development of irrigation wells in southeastern Laramie County, Wyo., has caused concern about the quantity of water available. Ground water from approximately 230 large-capacity wells is used to irrigate most of the 18,165 acres under irrigation.

The purpose of this study is to provide more knowledge about the character of the aquifers, quantity of water in storage, rate of withdrawal, and the effect of withdrawals on streamflow. The area studied consists of about 400 square miles in southeastern Laramie County in the extreme southeast corner of Wyoming.

The White River Formation of Oligocene age and alluvium of Quaternary age are the principal aquifers. The White River Formation is made up primarily of clay, silt, and fine sand. Secondary permeability in the White River Formation accounts for it being an important aquifer. The alluvium, which includes terrace and flood-plain deposits, consists of sand and gravel that contain some lenses of silt and clay.

Existence of secondary permeability in the White River Formation has been accepted for some time although the nature of the secondary permeability has been disputed. Examination of downhole conditions with a television camera during this study revealed openings in the formation that appeared to be similar to tubes or caverns. The openings were of various sizes and shapes but only a few appeared to be associated with fracturing. Solution activity in the formation probably is an important factor in the development of secondary permeability.

The study area was divided into the Pine Bluffs-Egbert area and the Carpenter area. Ground-water movement in the Pine Bluffs-Egbert area is generally eastward into Nebraska; in the Carpenter area, movement is generally southward into Colorado.

Pumpage from large-capacity wells in the Pine Bluffs-Egbert area was estimated to be about 21,790 acre-feet in 1971. Water levels exhibited a declining trend annually in some areas during the period of record. Data indicate that pumpage in the Pine Bluffs-Egbert area probably is the cause of decreased base flow in Lodgepole Creek since approximately 1961. Increased pumpage, above that in 1971, will result in further reduction of discharge of Lodgepole Creek into Nebraska.

In the Carpenter area, it was estimated that the terrace deposit contained about 1 million acre-feet of saturated sediments in March 1971. The amount of ground water in storage in the White River Formation in this area is unknown.

Pumpage from large-capacity wells in the Carpenter area was estimated to be about 7,090 acre-feet in 1971. Recharge to the area was not estimated but there was no indication of a net decline in water levels between September 1970 and September 1971.

Introduction

The increasing number of irrigation wells in the vicinity of Pine Bluffs, Egbert, and Carpenter has caused concern about the quantity of water available to meet the demand. Pumping many irrigation wells in the summer months lowers the water table below the bottom of some of the older shallow stock, domestic, and irrigation wells. This has necessitated deepening those wells or drilling new ones. Some residents of the area have expressed concern that addition of more irrigation wells might lower the water table permanently.

As of January 1971 about 18,165 acres were under irrigation in the area of this report (Hunter and others, 1971). Ground water is pumped for most of the irrigation and for all the municipal and industrial needs. In 1971 there were 222 irrigation, 6 municipal, and 2 industrial wells known to be in use in the area.

On March 1, 1971, a critical area was designated in southeastern Laramie County by a written order of the Wyoming State Board of Control. The definition of "critical area," as given in Wyoming Statutes 1957, as amended, Section 41-129, is as follows:

> Critical areas - Designation; duty of the State Engineer; hearings generally. - Any underground water district or subdistrict in which either (a) the use of underground water is approaching a use equal to the current recharge rate, (b) ground-water levels are declining or have declined excessively, (c) conflicts between users are occurring or foreseeable, (d) the waste of water is occurring or may occur, (e) or other conditions require regulation in the public interest, is hereby designated as a "critical area."

Because the critical area boundary does not coincide with hydrologic boundaries, no attempt was made in this investigation to define or separate hydrologic conditions within the critical area from those outside the critical area.

This investigation is a part of the program of the U.S. Geological Survey in cooperation with the Wyoming State Engineer. Fieldwork was started in August 1970 and completed in December 1971.

Purpose of the investigation

The purpose of this study is to provide more knowledge about the character of the aquifers, quantity of water in storage, rate of withdrawal, and effect of withdrawals on streamflow in southeastern Laramie County. This information can be used to guide future exploration and development of the water resources in the area.

Location and extent of the area

The area studied in this report consists of about 400 square miles in the southeast corner of Wyoming (fig. 1). The western and northern boundaries were chosen to include the area in southeastern Laramie County where the most ground water is pumped for irrigation.

Previous investigations

Several reports have been prepared that describe the geology and water resources in part, or all, of the area of the present investigation. Darton (1905) made a reconnaissance of the geology of the central Great Plains. The U.S. Geological Survey has published water-supply papers by Meinzer (1917); Rapp, Warner, and Morgan (1953); Babcock and Bjorklund (1956); Bjorklund (1959); and Lowry and Crist (1967). Other reports on ground-water conditions in southeastern Laramie County include reports by the Wyoming Geological Survey (Knight and Morgan, unpub. data, 1936, 1937) and by the U.S. Department of Agriculture (Burleigh and others, 1938). Denson and Banks (written commun., 1971) mapped the Tertiary formations throughout parts of Wyoming, Colorado, and Nebraska.

Method of investigation

The inventory of large-capacity wells used for irrigation, municipal, and industrial purposes, which was updated to 1971, totaled about 230 wells. All the known large-capacity wells are listed in table 1 at the end of this report.

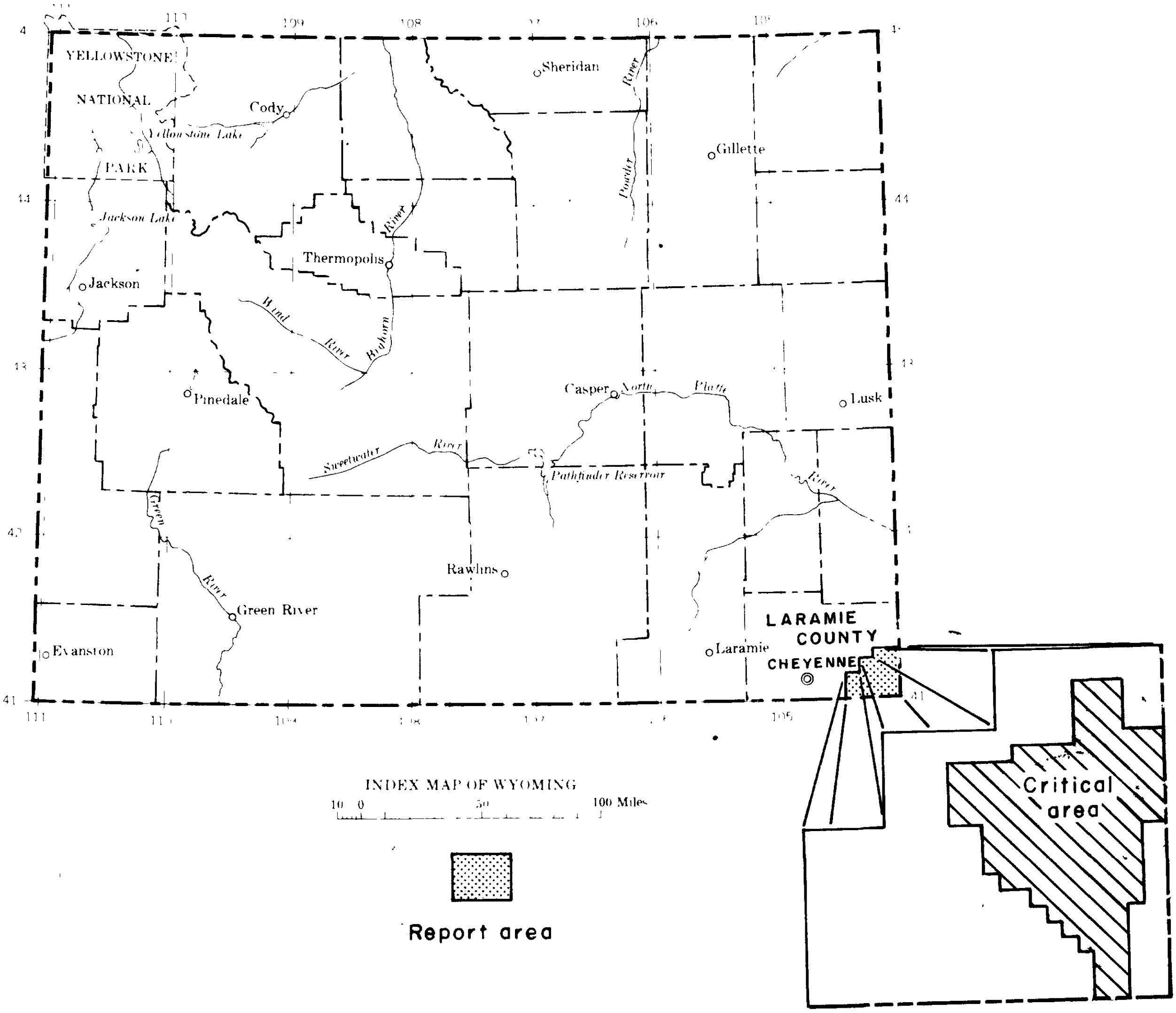

Figure 1.--Location of the area studied in this report. Enlargement shows the relative position of the critical area.

Drillers' logs from wells, test holes, and seismograph holes were used to construct a contour map of the surface of the White River Formation of Oligocene age. Twenty-nine test holes, totaling about 1,615 feet, were augered by the U.S. Geological Survey during the investigation to obtain additional information about the geology and hydrology of the area. Five of the test holes were cased with 1½-inch-diameter plastic casing and were used as observation wells for water level changes.

Water levels were measured in many wells in March and September 1971 to provide data for construction of water-level contour maps. During the irrigation season, water levels were measured monthly in 34 observation wells and recorded continuously in four wells.

Pumpage was estimated by using electric-power records and data from well-efficiency tests. Power records were obtained from the city of Pine Bluffs and the Rural Electric Association, and efficiency tests were run on 58 irrigation wells in the study area during the 1971 irrigation season. The yields and pumping water levels measured for all wells tested are given in table 1. Efficiencies of wells measured early in the season are probably higher than average for the year, and those measured late in the season are probably lower than average because of the seasonal decline of the water table. The efficiency was not measured at any well that was surging (that is, the pumping rate was fluctuating because pump capacity was greater than amount of water entering the well).

Pumpage from the 58 wells was estimated by dividing the efficiency (in terms of kilowatt hours per acre-foot of water) into the kilowatt hours used. The mean efficiency (in terms of kilowatt hours per acre-foot of water per foot of lift) of the 58 wells was used to estimate pumpage from wells where efficiency tests were not made. Pumpage from wells not pumped with electric power was assumed to be the same per well as the average pumpage per well calculated for those pumped with electric power. In 1971 electricity was used for power at about 91 percent of the large-capacity wells.

Well-numbering system

Water wells and test holes cited in this report are numbered according to the Federal system of land subdivision in Wyoming (fig. 2). The first number indicates the township, the second the range, the third the section in which the well or test hole is located. Lowercase letters following the section number indicate the position of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are lettered a, b, c, and d in counterclockwise direction, starting in the northeast quarter. If more than one well is listed in a 10-acre tract, consecutive numbers starting with 1 follow the last lowercase letter of the well number. If a section does not measure 1 mile square, it is treated as a full section with the nearest section corner serving as the reference point for the subdivisions of the section.

Acknowledgments

The authors appreciate the cooperation of the many residents in the area who contributed information about their wells and gave permission to use their irrigation wells for efficiency tests and periodic measuring of water levels. Jay Brown, Elmer Glantz, William Gross, Jr., Leroy and Richard Gardner, and Walter Peters gave permission to operate a downhole television camera in their wells. Marlin E. Lowry and James E. Eddy of the U.S. Geological Survey were principals in the use of the downhole television camera; Lowry suggested the use of the camera and did much of the interpretation of the video film obtained; Eddy provided the technical assistance necessary for operation of the camera. The work done by Waite Ostercamp of the U.S. Geological Survey in the preparation of the geologic map for this report is greatly appreciated.

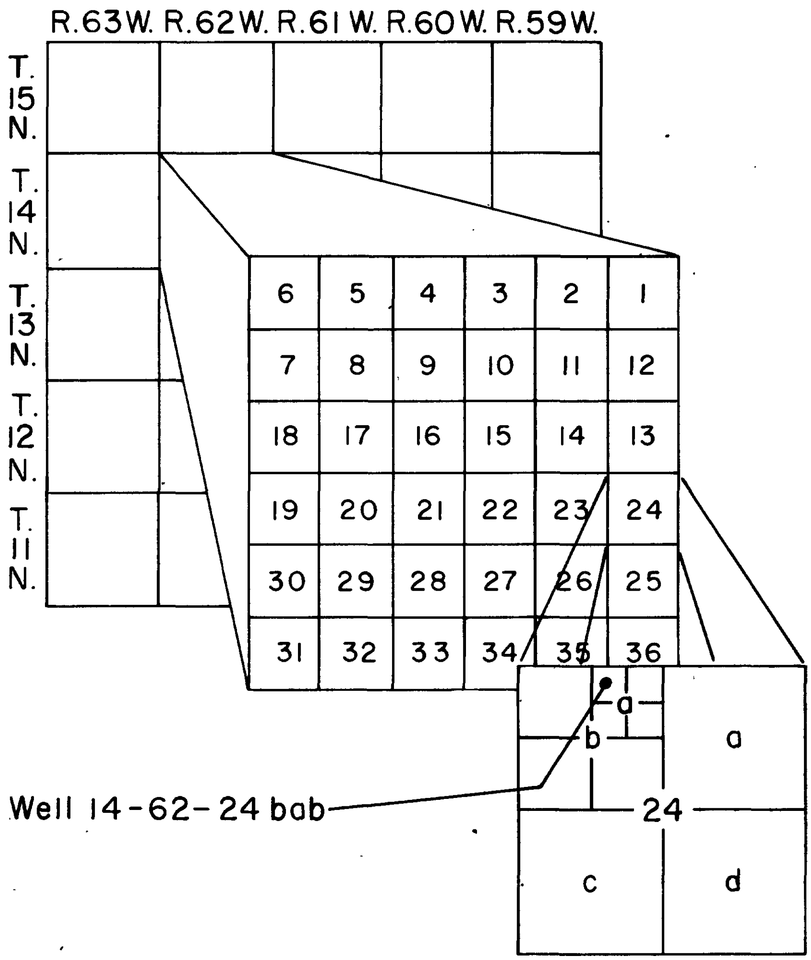

Figure 2.--System of numbering water wells and test holes.

Landforms and drainage

The topography and drainage have been described by Rapp, Warner, and Morgan (1953), and the following is a summary of their description. The study area lies in the Great Plains physiographic province. Altitudes range from about 5,000 feet to about 5,680 feet above mean sea level. The eastern, northern, and western margins of the area are relatively flat uplands. The north-central part is gently undulating lowland that comprises the valley of Lodgepole Creek and lower parts of the valleys of Muddy Creek, Spring Creek, and Chevington Draw. A broad flat terrace extends eastward from Carpenter. West of Carpenter is a low undulating embayment that extends westward to a steep escarpment.

Lodgepole Creek and Crow Creek head in the Laramie Mountains, about 50 miles west of the study area, and are the principal drainages through the study area. Lodgepole Creek has three principal tributaries--Muddy Creek, Spring Creek, and Chivington Draw. Perennial flow in Lodgepole Creek starts near the junction with Muddy Creek. Perennial flow in Muddy Creek extends from about sec. 30, T. 14 N., R. 62 W., to about sec. 18, T. 14 N., R. 60 W. Muddy Creek is dry from the end of perennial flow to near the junction with Lodgepole Creek. The channel of Muddy Creek is not distinguishable through much of the dry reach because the land is farmed. Chivington Draw drains a large area but flows only after heavy rains. The channel of Chivington Draw is also farmed and is not distinguishable below sec. 30, T. 15 N., R. 60 W. Spring Creek is perennial downstream from sec. 9, T. 14 N., R. 60 W. Crow Creek is perennial as far downstream as sec. 25, T. 13 N., R. 63 W. It is dry through the rest of its course in the Carpenter area except after heavy rains and in early spring.

Geohydrology

Geologic formations exposed in the area have been described by Lowry and Crist (1967) and by Rapp, Warner, and Morgan (1953). Rocks in the area are divided into the following formations (fig. 3): White River Formation of Oligocene age, Arikaree Formation of early Miocene age, and Ogallala Formation of late Miocene and Pliocene age. Terrace and flood-plain deposits are of Quaternary age. Each of these units is capable of yielding sufficient quantities of water for irrigation, industrial, and municipal wells within the study area. Most of the large-capacity wells tap either the White River Formation or the terrace deposit; therefore, emphasis is placed on describing the geohydrologic conditions in these aquifers.

Aquifer characteristics

White River Formation

Denson and Bergendahl (1961, p. C170) described the White River Formation in southeastern Wyoming as consisting of "65 to 85 percent silt and 5 to 25 percent very fine grained sand imbedded in a matrix of clay-size particles." Such a formation without secondary permeability [1] would not yield enough water for irrigation wells.

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[1] Permeability is the property of a porous material that permits it to transmit a fluid under pressure through interconnected openings in the material. Pressure or chemical action upon the material after deposition can alter the original permeability; such action usually enlarges or makes additional openings. The new permeability is referred to as secondary permeability.

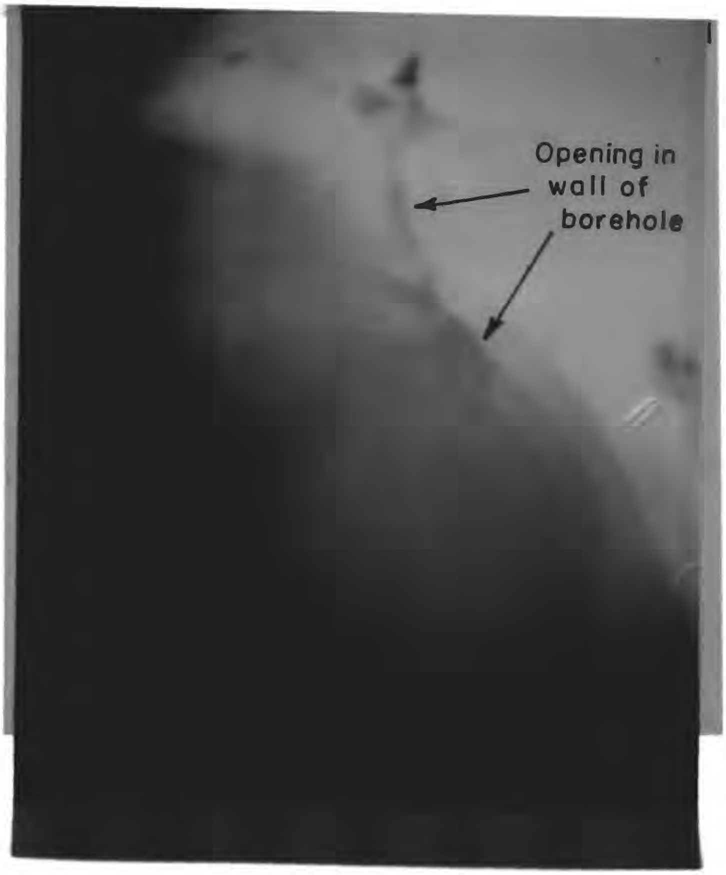
Figure 3.--Geologic map of southeastern Laramie County, Wyoming. (In pocket)

Early investigators attributed secondary permeability in the White River Formation (referred to as Brule Formation in some earlier reports) to joints, fissures, and fractures formed after deposition. Because Lowry (1966) could not find open vertical fissures in the White River Formation or evidence that large-yield wells are related to structural features such as faults, he discounted the theory that various kinds of fractures could account for all the secondary permeability. On the basis of work by other authors and his own investigation, Lowry stated that most of the large-yield wells that are reported to yield water from the White River Formation probably yield water from alluvium made up of reworked White River. Because considerably different yields have been obtained from two closely spaced wells reported to tap the White River Formation and drilled to equal depth, Lowry concluded that the openings that transmit water are neither uniformly distributed nor of uniform size. He suggested that the openings are more likely to be tubes formed by piping [1] before the formation was buried by alluvium. Lowry inferred that piping would not occur below the depth of maximum relief, which is about 100 feet near Pine Bluffs.

[1] Piping is the process by which subterranean channels form as a consequence of the movement of water in relatively insoluble and incoherent clastic rocks such as the White River Formation (Lowry, 1966, p. D220).

The White River Formation was examined in wells during the present investigation. In August 1970 a television camera was lowered into 10 wells in the vicinity of Pine Bluffs and Carpenter. Most of the wells completed in the White River Formation are cased only deep enough to keep out surficial material; therefore, the formation could be examined in the wellbore. All wells examined were found to be drilled in the White River Formation and not the alluvium. The camera revealed openings in the formation that resemble tubes or caverns. A feature interpreted to be secondary permeability was found as deep as 239 feet below the surface of the White River Formation in a hole a few feet from well 14-60-5bbd (244 feet was the maximum depth examined). In many cases, large openings that appear on one side of the hole cannot be seen on the opposite side as is the case of the openings shown in figure 4. The openings were of various sizes and shapes and were found at various depths but only a few appeared to be associated with fracturing of the formation. Some of the openings such as those shown in figure 4 may have enlarged, caused by pumping, since the well was drilled. Drillers in the area, however, have reported finding cavern-like openings in the White River Formation when drilling new wells.

Secondary permeability was not apparent in two of the 10 wells investigated with the television camera. Yields from these two wells were reported to be insufficient for irrigation.



Photograph at left is a "downhole" view of an opening in the wall at about 72 feet below land surface. The opening is about 1 foot long from top to bottom. Water level is about 61 feet below land surface.

Photograph at right is a closeup view of an opening at about 91 feet. Note the flat bottom of the opening. Well is about 93 feet deep.

Figure 4.--Secondary permeability in the White River Formation in well 13-60-8ccb These are photographs of a television screen monitoring the video tape that was obtained with a downhole television camera.

Early drillers found that the permeability could be drastically different within short distances. For many years, a practice of increasing the yield of a well in the White River Formation was to drill another hole, or several holes, a few feet from the original well and connect the holes under the water table. Another method currently used (1971) to increase the yield of a well is to make vertical saw cuts in the side of the well bore below the water table in wells that are completed as open holes. These cuts radiate from the well in several directions and penetrate about 7 feet into the formation. Success of these methods depends on the interception of additional secondary permeability.

Solution activity is probably an important factor in the development of secondary permeability in the White River Formation. A sample of the formation (fig. 5), obtained while drilling a well with a reverse circulation drilling rig, indicates that some secondary permeability results from solution activity. The most soluble minerals in the formation are the carbonate and bicarbonate compounds. Nineteen samples of White River Formation collected from test holes were analyzed for carbonate content. The analytical procedure given by Pierce, Haenisch, and Sawyer (1958, p. 254-255) was used except that a weighed sample in distilled water was titrated to pH 3 with standard HCl solution then back-titrated to pH 4.5 with standard NaOH solution. The results listed in the following table are reported as carbonate content even though they probably include soluble oxides, bicarbonates, and trace amounts of sulfates.

Figure 5.--Secondary permeability in a sample of White River Formation. Voids in the siltstone show as dark shapes and specks. The sample was obtained from a well being drilled in the NE 1/4 sec. 14, T. 12 N., R. 63 W.

Test hole location	Depth of sample (feet below land surface)	Altitude of sample (feet above mean sea level)	Carbonate content (percent CO_3 equivalents by weight)
12-63- 4dda 1/	85	5,320	5.30
14a 1/	2/ 65	5,313	6.57
15aaa 1/	37	5,347	7.67
13-60-17ccc 1/	20	5,120	5.59
	50	5,090	5.77
13-62-12bbb 3/	75	5,292	1.90
14-60-21abb 1/	32	5,035	2.76
14-61-24bbc 3/	42	5,140	13.70
	62	5,120	6.32
	92	5,090	8.37
25ccb 1/	27	5,140	1.80
	47	5,120	6.59
	77	5,090	2.86
30ccc 3/	37	5,326	3.55
35dda 3/	16	5,241	7.47
	47	5,210	5.62
	77	5,180	7.91
14-62-36dda 1/	21	5,255	2.70
	41	5,235	3.25

1/ In vicinity of several irrigation wells tapping the White River Formation.

2/ Approximate depth.

3/ Not near any irrigation wells known to tap the White River Formation.

Several of the samples analyzed were collected at the same altitude in areas of successful and unsuccessful irrigation wells. The carbonate content given in the table is probably the approximate percent of carbonate in the sample. As the samples from areas of successful irrigation wells averaged slightly less carbonate content than samples from areas where few irrigation wells have been developed, leaching of soluble compounds from the formation probably accounts for part of the success in developing irrigation wells.

The results interpreted from pumping tests of aquifers having secondary permeability are usually less reliable than those from pumping tests of aquifers that are more homogeneous and isotropic. A homogeneous and isotropic aquifer is made up of like material and the material has the same properties in all directions. In general, the White River Formation would not be considered to have such qualities because of the secondary permeability; however, if a large enough volume of the aquifer is examined, the local effects of secondary permeability are lessened so that nonhomogeneity does not distort the results in any particular direction from the pumped well.

Data from a pumping test of the White River Formation were analyzed by the Theis nonequilibrium formula and the Theis recovery formula (Theis, 1935). The results are listed in the following table:

Location of pumped well	Distance of observation well from pumped well (ft)	Transmissivity 1/ (ft² per day)	Storage coefficient 2/	Length of test (hrs)	Date of test
14-60-5bcb2	-----------	12,800	-----------	24	Oct. 28, 1970
	850 (south)	32,600	3.18×10^{-3}		
	1,320 (east)	21,800	1.68×10^{-3}		
	1,600 (west)	28,900	1.57×10^{-3}		

1/ Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. The units are given in ft^2 per day (square feet per day; before cancellation of units, this is cubic feet per day per foot width of aquifer). In order to convert to gallons per day, multiply by 7.48

2/ Storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

The values of transmissivity and storage coefficient from the pumping test agree fairly well, but they should be regarded as representative of the White River Formation only in the vicinity of the test site. Pumping tests were made at two other sites (Lodgepole Creek and Muddy Creek valleys), but the data could not be interpreted because the White River is so nonhomogeneous at those locations.

Arikaree Formation

The Arikaree Formation is exposed only in the northwest part of the area. The formation is fairly homogeneous and consists mostly of massive very fine grained to fine-grained sandstone. Much of the sandstone is so friable that it can be crushed between the fingers. The remainder is hard owing to cementation of the sand by calcium carbonate. The formation also contains some layers of siltstone.

Lowry and Crist (1967, p. 28) reported that wells yielding more than 350 gpm probably can be developed in the Arikaree wherever the zone of saturation is at least 200 feet thick. Larger yields could be obtained where secondary permeability has developed in the sandstone. A downhole television camera survey in a well near Lusk in Niobrara County, Wyo., about 100 miles north of Pine Bluffs, revealed secondary permeability in the Arikaree sandstone that appeared similar to the voids in the siltstone shown in figure 5.

Transmissivities determined from four pumping tests of the Arikaree in Niobrara County (Whitcomb, 1965, p. 48) ranged from 1,070 to 10,300 ft^2 per day (8,000 to 77,000 gpd per ft). The larger transmissivity may be the result of secondary permeability. Weeks (1964, p. 44) reported transmissivities ranging from about 350 to about 1,300 ft^2 per day (2,600 to 10,000 gpd per ft) for the Arikaree Formation near Wheatland in Platte County, Wyo. The Arikaree Formation in Laramie County is considered to have hydrologic characteristics similar to those of the Arikaree in Platte and Niobrara Counties. In the area of this report, the Arikaree probably serves more as a source of recharge to the underlying White River Formation than as an aquifer for irrigation wells.

Ogallala Formation

The Ogallala Formation is an important aquifer throughout most of Laramie County but, in the area of this report, only one large-capacity well is known to be developed in this aquifer. At most locations in the report area, the Ogallala does not contain a zone of saturation thick enough for a large capacity well. Much of the water that is recharged to the underlying Arikaree and White River Formations in the report area falls as precipitation on the Ogallala. The terrace deposit in the southern part of the report area probably receives some recharge by lateral percolation from the Ogallala.

Alluvium

Alluvium consisting of terrace and flood-plain deposits extends throughout a large part of the study area. These deposits consist mostly of sand and gravel with lenses of silt and clay.

The principal terrace extends from about 2 miles west to about 11 miles east of Carpenter and from about 4 miles south of the Wyoming-Colorado State line to about 2 miles north of Lodgepole Creek. In Wyoming this terrace is a nearly continuous surface cut only by Crow Creek, Muddy Creek and its tributaries, and Lodgepole Creek. The thickness of the terrace deposit ranges from a few feet at the edge to about 150 feet in and around sec. 18, T. 12 N., R. 61 W. The thickness of this deposit can be estimated by subtracting the altitude of the top of the White River Formation from the altitude of the land surface (fig. 3).

The greatest saturated thickness in the terrace deposit is in a large trough carved into the White River Formation (fig. 6). Contours drawn on the top of the White River (fig. 3) show this trough heading in the vicinity of Carpenter and extending southeast to the State line. The saturated thickness map was constructed by superimposing the contour maps of the top of the White River Formation and the water-level surface. The control points on figure 6 have been omitted for clarity.

Figure 6.--Saturated thickness map of formations overlying the White River Formation in southeastern Laramie County, Wyoming. (In pocket)

The zone of saturation in the terrace deposit is about 45 feet thick at well 12-62-10aba2 where a discharge of 95 gpm was measured. The reason for the low yield is probably low permeability because other wells in the vicinity of this well have yields ranging up to several hundred gallons per minute. Optimum drilling sites for wells in the terrace deposit would be in the areas of greatest saturated thickness.

Lowry and Crist (1967, p. 39) reported that transmissivity for the terrace deposit ranged from 2,810 to 19,420 ft^2 per day (44,800 to 146,000 gpd per ft). The storage coefficient ranged from 4.65×10^{-3} to 5.43×10^{-2} corresponding to the respective transmissivity. Yields of irrigation wells developed in the terrace deposit range from less than 100 gpm to about 1,000 gpm.

Most of the streams and dry washes in the study area are underlain by flood-plain deposits, but only those deposits along major drainages are shown on the geologic map. In Lodgepole Creek valley near Pine Bluffs, these deposits are as much as 85 feet thick. Elsewhere, the flood-plain deposits generally are thin and, in some cases, are completely above the water table. The flood-plain deposits are hydraulically interconnected with the underlying formations in areas where the flood-plain deposits contain saturation. Only a few wells are believed to pump water from only the flood-plain deposits.

The water table

Hydraulic interconnection between the geologic formations is assumed to be sufficient to permit contouring one continuous water-level surface (water table) throughout the study area. The degree of hydraulic interconnection may change from place to place and, undoubtedly, causes some anomalies in the water-level surface. Regionally, water-table conditions rather than artesian conditions prevail in the aquifers; that is, the water generally does not rise above the level it was encountered in drilling the well.

Ground-water movement is downgradient in the direction of the maximum slope of the water-level surface. The general direction of movement can be determined by drawing a line perpendicular to the water-level contour. Divides on the water-level surface, referred to as ground-water divides, are analogous to divides between two drainage basins on the land surface. Ground water does not move across ground-water divides. Divides, however, are not stable and may shift in response to changes in recharge and discharge.

A ground-water divide shown in figure 7 separates northward ground-water movement toward Lodgepole Creek from southward ground-water movement into Colorado. North of the ground-water divide, the general ground-water movement is eastward into Nebraska.

The rate of ground-water movement depends on the slope (hydraulic gradient) of the water-level surface and the permeability of the aquifer. If the amount of water moving through a cross section of an aquifer is constant, a steepening of the hydraulic gradient (closer spacing of water-level contours) indicates a lesser permeability; a flattening of the hydraulic gradient (wider spacing of water-level contour lines) indicates a greater permeability.

Figure 7.--Hydrologic map of southeastern Laramie County, Wyoming. (In pocket)

Configuration

The configuration of the water table is influenced by surface drainage systems. This is particularly noticeable along Crow Creek, Porter Creek, and the lower reach of Lodgepole Creek. The water-level contours (fig. 7) along Crow Creek and Porter Creek show that the streams lose water to the aquifer because the direction of ground-water movement is away from the streams. In the lower reach of Lodgepole Creek, the contours show that the stream gains water because the direction of ground-water movement is toward the stream.

A water-level surface contour map of the study area was prepared for March and September 1971, using data obtained by measuring the depth to water in wells. The contour map for September and areas of greatest water-level decline since March are shown on the hydrologic map (fig. 7). The decline in the vicinity of Crow Creek west of Carpenter is due to natural flattening of the ground-water mound that had been built up by recharge from Crow Creek during the spring months. The other areas of decline are caused by pumping during the season and do not represent a permanent drop in water levels. It might be noted that pumping for irrigation in the area about 3 miles east of Carpenter has caused a bend, or shift, in the water-level contour lines. This indicates the seasonal lowering of the water level in the area.

The areas of decline were defined by superimposing the contour maps for March and September 1971. A number of irrigation wells were pumping in September when the water levels were measured; therefore, some of the decline could reflect local influence from pumping.

Fluctuation

A network of 38 observation wells was used to monitor water-level changes during the irrigation season. Water levels were measured monthly in 34 wells and were measured continuously by graphic water-stage recorders in four wells. The long-term trend of water levels in most of the wells measured monthly could not be established because the record was too short. Water levels measured by recorders are more meaningful because a more detailed interpretation can be made of the water-level fluctuations. Figure 8 consists of hydrographs for the four wells equipped with graphic water-stage recorders. Water levels on the first and fifteenth of each month were used in plotting the hydrographs.

The water level in well 14-61-20bcc is representative of the ground-water fluctuations in the upper reach of Lodgepole Creek valley. There was a sudden rise of the water level in late spring 1971 after which the water level declined during the irrigation season then started to recover in September. The record is too short to define a water-level trend other than the seasonal fluctuation.

The hydrograph for well 14-60-5bcb represents the trend of water levels in the Chivington Draw area. From 1962 to 1969, the highest water level reached in the spring varied little from year to year. The drought in 1964 caused the recovery in the spring of 1965 to be less than in most years. The peak in 1967 was caused by flooding in Chivington Draw. Since 1969, the water level has been lower each year at corresponding times. The increased drawdown during the irrigation season since 1969 is caused by pumping a nearby well.

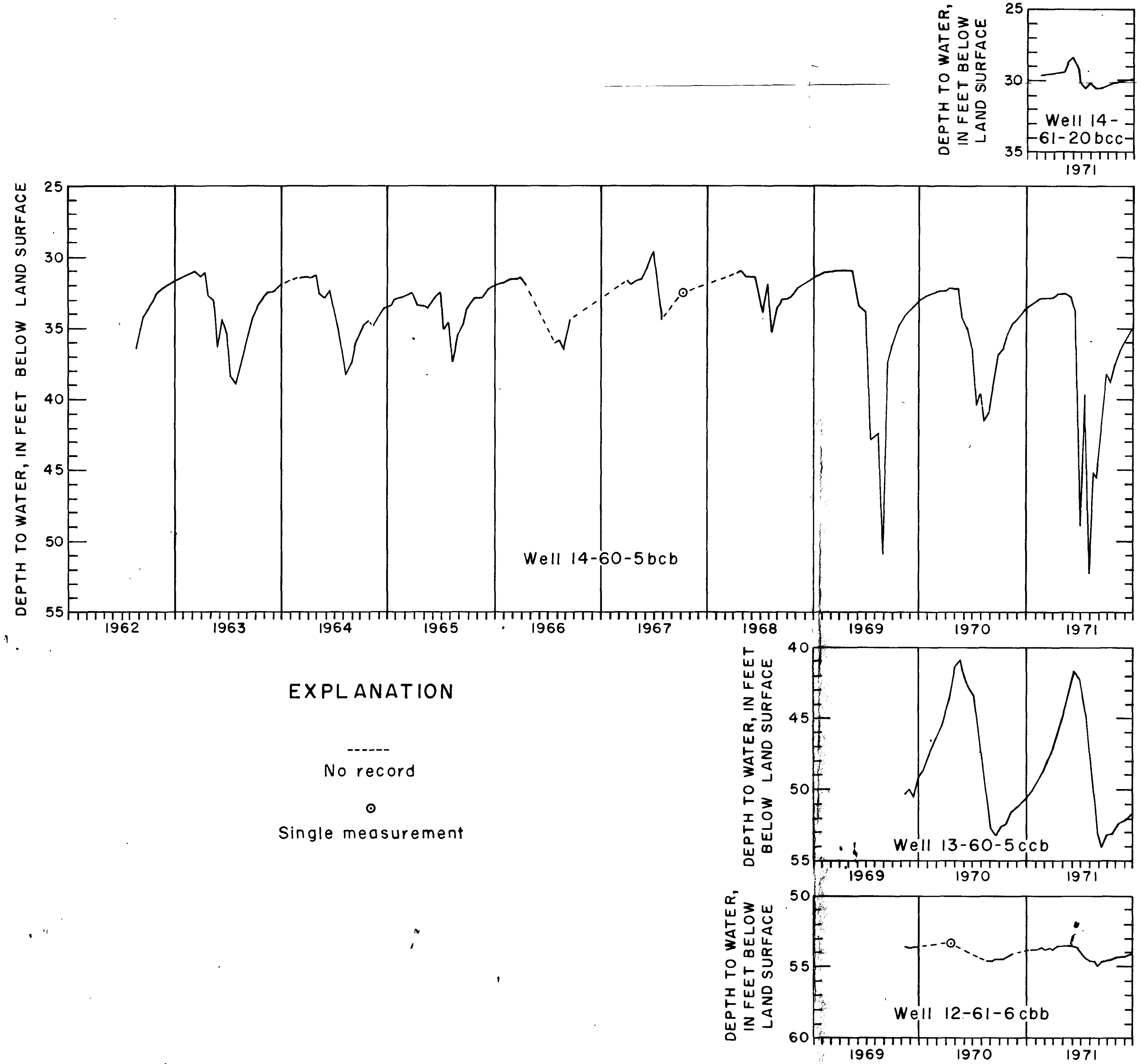


Figure 8.--Highest water levels on the first and fifteenth day of the month as recorded by graphic water-stage recorders.

The water-level fluctuations in wells 13-60-5ccb and 12-61-6cbb are representative of water-level changes in Muddy Creek valley and the terrace deposit east of Carpenter, respectively. Water levels fluctuate about 12 feet each year in Muddy Creek valley and a declining trend is noticeable during the period of record. The largest drawdown occurs during the irrigation season when pumping is maximum. The large fluctuation is the result of pumping from an aquifer that has low storage. Water levels in the terrace deposit fluctuate only slightly during the irrigation season but the record is too short to indicate a significant change from year to year.

Water-level measurements at six wells in the study area (12-62-8dca, 12-63-12dca, 13-60-8ccb, 13-60-31aaa, 14-60-11bcc, and 14-60-28bbb) over the past 30 years do not indicate any significant difference between water levels measured in the early 1940's and in 1971. For the most part, measurements were made semiannually--in fall and spring--and significant annual changes in water levels over the 30-year period are not obvious. The water levels vary from year to year in response to changes in the relationship of recharge and discharge.

Pine Bluffs-Egbert area

The Pine Bluffs-Egbert area is the name given the area north of the ground-water divide shown in figure 7. Any ground water not consumed or stored in the area is assumed to be discharged into Nebraska through Lodgepole Creek valley.

Ground-water discharge maintains perennial flow in Lodgepole Creek from near Pine Bluffs downstream to a gaging station near Bushnell, Nebr. This station is about 9 miles east of the Wyoming State line and has been in operation since October 1931. Examination of data from this station for water years 1968-72 (U.S. Geol. Survey, 1968-72) shows that stream discharge was relatively constant during the period October through December of each year. Streamflow during these months is principally derived from ground-water discharge (base flow) and therefore should be representative of the amount of ground water being discharged from the Pine Bluffs-Egbert area.

A plot of the cumulative discharge versus time (fig. 9) at the gaging station near Bushnell for the months October, November, and December (base-flow period) from 1931-71 indicates a decrease in base flow since approximately 1961. A similar plot of the cumulative annual precipitation (at Pine Bluffs) versus time (fig. 10) from 1931-71 indicates an increase in the precipitation since approximately 1954. These data show that changes in precipitation can be eliminated as the cause for decreased base flow. Pumping of wells in the Pine Bluffs-Egbert area is probably the cause for decreased base flow at the gaging station.

Estimated monthly pumpage from large capacity wells in the Pine Bluffs-Egbert area for the period April through October 1971 is listed in the following table:

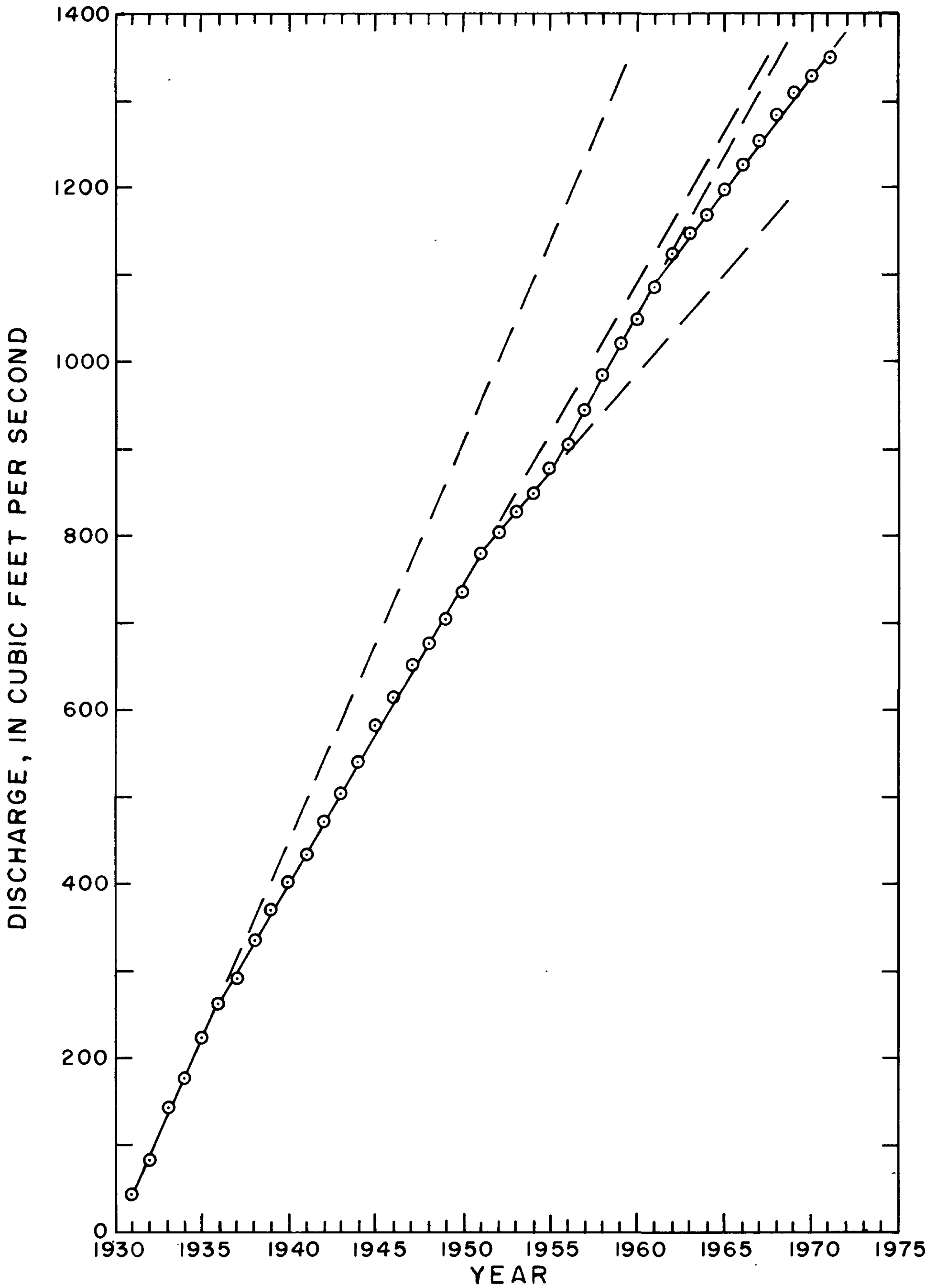


Figure 9.--Cumulative mean discharge of Lodgepole Creek at Bushnell, Nebr., for base flow period (October, November, and December) 1931 to 1971.

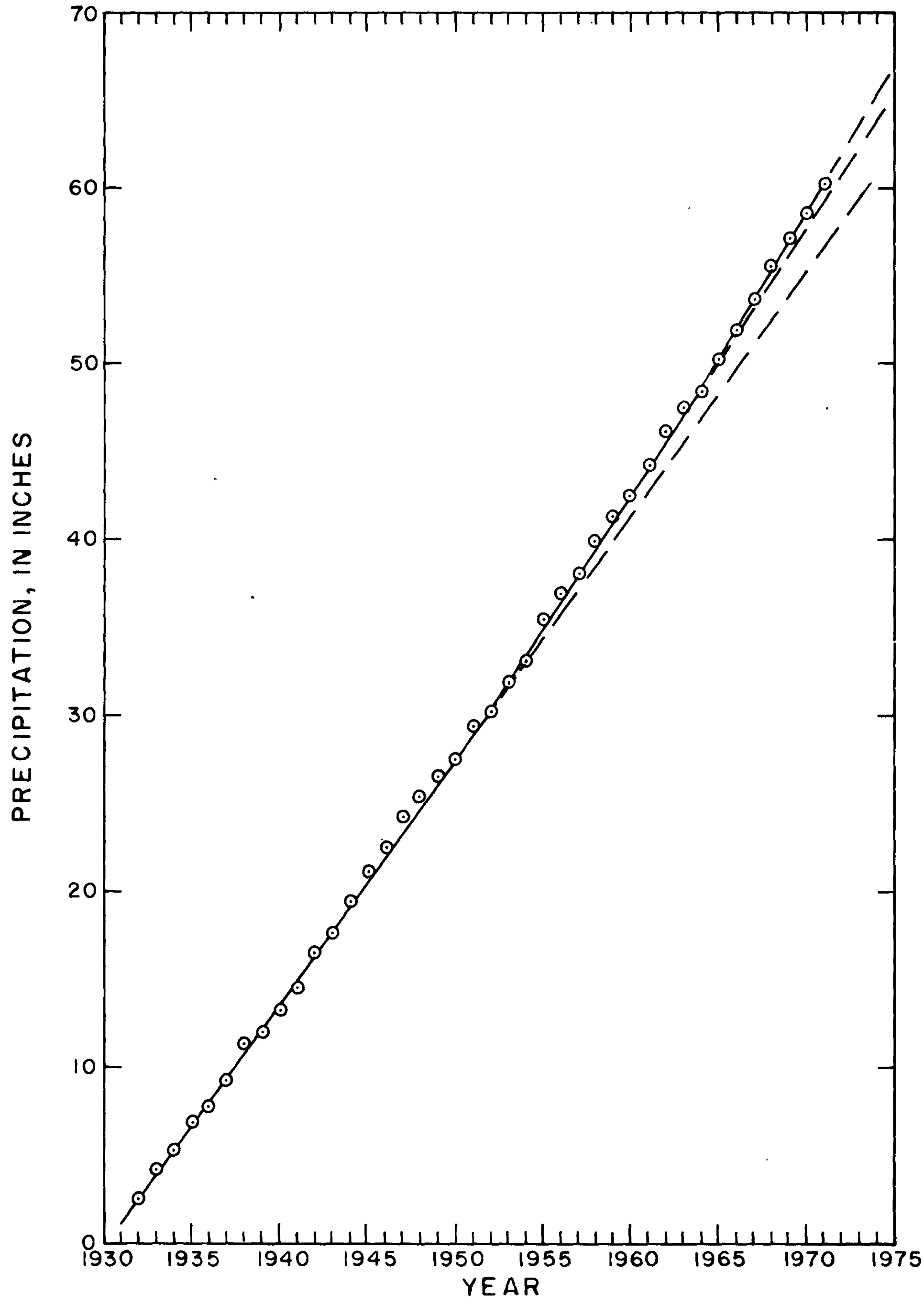


Figure 10.--Cumulative annual precipitation at Pine Bluffs, Wyo., 1931 to 1971.

	Irrigation supplies (acre-feet)	Municipal and industrial supplies (acre-feet)	Total (acre-feet)
April	140	20	160
May	600	30	630
June	3,250	60	3,310
July	7,500	70	7,570
August	6,740	60	6,800
September	2,150	30	2,180
October	1,110	30	1,140
Totals	21,490	300	21,790

Increasing annual pumpage from the Pine Bluffs area above the 1971 pumpage will result in further reduction of base flow in Lodgepole Creek at the Bushnell gaging station. It is possible that continued pumping at the 1971 rate may cause further reduction in base flow if the full effect of current pumping has not yet reached the gaging station.

Interference between wells in the Pine Bluffs-Egbert area is a matter of concern. Most of the irrigation wells are concentrated along the major drainages. When a well is pumped, the water table is drawn down around the well in the shape of a cone. This is referred to as the "cone of depression." If two wells are close enough to each other that they are within the cone of depression of the other when pumping, the drawdown in each well will be greater than if only one well is pumped, assuming constant yield from the wells. This problem is compounded if several wells interfere and the cones of depression overlap. The result would be greater lowering of the water level throughout the area of overlap, reduction of the saturated thickness of the aquifer at each well, and a decrease in the yield of each well.

The effects of interference can be illustrated as follows: The average saturated thickness of White River Formation is about 70 feet in irrigation wells in the Pine Bluffs-Egbert area. Theoretical optimum operation of a well occurs when the drawdown (in a uniform aquifer) is about 2/3 (67 percent) of the maximum drawdown (Johnson, 1966, p. 108), or about 47 feet (70 x 67 percent) in this example. If interference from other wells lowers the water level in a well 10 feet, this would leave 60 feet of saturation in the well. After the interference, optimum operation of the well is with a drawdown of about 40 feet. If the specific capacity (yield per foot of drawdown) were 30 gpm per ft (gallons per minute per foot) at this well, the yield would be reduced 210 gpm [(47-40)x30] if optimum operation is to be continued.

Optimum spacing of wells in the Pine Bluffs-Egbert area cannot be estimated because of the erratic nature of permeability in the White River Formation. The foregoing example, however, illustrates the consequence of spacing wells close together.

Carpenter area

The Carpenter area refers to that part of the study area south of the ground-water divide (fig. 7). The Carpenter area has two aquifers that are hydraulically interconnected, the terrace deposit and the White River Formation.

East of Crow Creek, the terrace deposit is the principal aquifer. It was estimated that this deposit contained about 1 million acre-feet of saturated sediments in March 1971. This volume multiplied by the specific yield of the terrace deposit would be the volume of water in storage. Specific yield is the ratio of the volume of water a rock will yield, after being saturated, to its own volume. In an unconfined aquifer, the specific yield is virtually equal to the storage coefficient.

West of Crow Creek the White River Formation is the principal aquifer, even though there is some saturation in the terrace deposit. Some of the water in the terrace deposit moves downward and recharges the underlying White River Formation. The amount of ground water in storage in the White River Formation in this part of the Carpenter area is unknown.

Estimated monthly pumpage from 42 irrigation wells in the Carpenter area, for 1971, is given in the following list:

Month	Acre-feet
April	160
May	230
June	1,390
July	2,530
August	2,350
September	300
October	130
Total	7,090

These estimates were calculated from the electric-power records for 35 wells. The average pumpage per well for each month was calculated for these wells, and this average pumpage was used to estimate pumpage from seven other wells not powered by electricity.

The quantity of ground water moving into Colorado from the Carpenter area is not known; however, on the basis of the transmissivities determined from pumping tests (p. 30) and an average gradient of approximately 20 feet per mile (fig. 7), ground-water movement into Colorado in the terrace deposit could range from about 40 to about 270 acre-feet per month per mile width of aquifer.

Rapp, Warner, and Morgan (1953, p. 19) estimated that recharge from Crow Creek to the gravel (terrace deposit) in the Carpenter area averages 5 cfs (cubic feet per second). Crow Creek discharge was measured on June 16, 1971. In the NW$\frac{1}{4}$ sec. 25, T. 13 N., R. 63 W. discharge was about 18 cfs and in the SE$\frac{1}{4}$ sec. 12, T. 12 N., R. 63 W. discharge was about 13 cfs. By August 3, 1971, discharge at the upper station was 0.8 cfs and the streambed was dry at the lower station. The streambed at the lower station remained dry at least through November 1971. It is doubtful that recharge from Crow Creek averaged 5 cfs (3,620 acre-ft per year) during 1971. Subsurface inflow from the west and recharge from precipitation is also contributed to the Carpenter area. Comparison of water-level measurements made in September 1970 and September 1971 indicates that the average water level was slightly higher in 1971. This is the result of any or all of several variables such as amount of pumpage, time of maximum pumpage, and change in precipitation in the area.

Additional irrigation wells that tap the White River Formation southwest of Carpenter were drilled in 1971 and 1972 but they are not included in the pumpage inventory because they were not used in 1971. Because of the increased number of wells, it is anticipated that pumpage in this area will increase in 1972.

Summary

The White River Formation is the source of most of the ground water pumped in southeastern Laramie County. Yields of as much as 1,680 gpm have been measured for an irrigation well in the White River. Such high yields are possible because of secondary permeability in the formation. The secondary permeability is in the form of tubes or cavern-like openings, which may or may not be associated with fractures in the siltstone. There is no consistency in either size of openings or depth of occurrence. Areal extent of the secondary permeability has not been determined but most of the successful large-capacity wells in the White River Formation have been developed along present drainages. The permeability in the formation may differ drastically within short distances. Success of irrigation wells in the White River Formation depends upon whether or not the wells penetrate zones of secondary permeability.

Pumpage in the Pine Bluffs-Egbert area was estimated to be about 21,790 acre-feet for the period April through October 1971. Records indicate that water levels are declining annually in some areas. Interference between wells is a matter of concern but optimum well spacing cannot be estimated because of the erratic nature of permeability in the White River Formation.

Data indicate that pumping of wells in the Pine Bluffs-Egbert area probably has caused a decrease in the base flow in Lodgepole Creek at the Bushnell gaging station since approximately 1961. Increased pumpage above that for 1971 will result in further reduction of the discharge of Lodgepole Creek into Nebraska.

Pumpage in the Carpenter area was estimated to be about 7,090 acre-feet for the period April through October 1971. The terrace deposit was estimated to contain about 1 million acre-feet of saturated sediments in March 1971. No estimate could be made for the amount of ground water in storage in the White River Formation.

Additional irrigation wells that tap the White River Formation southwest of Carpenter were drilled in 1971 and 1972. These wells were not pumped in 1971 but an increase in pumpage is anticipated in this area in 1972.

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