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STATE GEOLOGICAL SURVEY OF KANSAS

BULLETIN 35

A PRELIMINARY REPORT ON THE WATER SUPPLY OF THE MEADE ARTESIAN BASIN, MEADE COUNTY, KANSAS

By JOHN C. FRYE

Prepared by the United States Geological Survey and the State Geological Survey of Kansas, with the coöperation of the Division of Sanitation of the Kansas State Board of Health, and the Division of Water Resources, Kansas State Board of Agriculture.

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STATE GEOLOGICAL SURVEY OF KANSAS

RAYMOND C. MOORE, Ph. D., Sc. D.,
State Geologist and Director

KENNETH K. LANDES, Ph. D.,
State Geologist and Assistant Director

Division of Ground Water

STANLEY W. LOHMAN
Geologist in Charge

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A PRELIMINARY REPORT ON THE WATER SUPPLY OF THE MEADE ARTESIAN BASIN, MEADE COUNTY, KANSAS

By John C. Frye

ABSTRACT

The Meade artesian basin is situated in Meade county, southwestern Kansas, at the eastern edge of the high plains. It is underlain by unconsolidated gravel, sand, silt, and clay, of Pliocene, Pleistocene, and Recent age, which lie unconformably on Cretaceous and Permian rocks. Most of the artesian water is obtained from the Pliocene deposits, but some of it comes from the Pleistocene beds at shallow depths. Development of the artesian water in this area was started in 1886, and in 1938 approximately 3,860 acre-feet of water was produced from wells by pumping and natural flow from the artesian aquifers of the area. In addition, about 3,240 acre-feet of water was discharged by large springs in 1938. The head of the artesian water in wells has declined only a few feet since the first well was drilled, and the increased discharge from flowing wells has been about equal to the decrease in spring discharge. The shallow nonartesian water is derived partly from upward leakage of artesian water. The water table has been depressed considerably during the last 50 years. The perennial yield obtainable from the artesian water-bearing beds without decreasing the head is about equal to the total annual discharge at the present time, that is, about 7,100 acre-feet annually, of which 3,860 acre-feet is derived from wells and 3,240 acre-feet from springs. A considerable quantity of artesian water is lost by leakage into the overlying body of shallow ground water. It is estimated that under conditions of general pumping over the basin sufficient to lower the head enough to stop all surface flow and underground leakage, an annual yield of about 10,000 acre-feet could be obtained from wells. Under such conditions, however, the main source of recharge to the shallow water reservoir would be destroyed and serious consequences to naturally subirrigated crops might result.

INTRODUCTION

In July, 1939, an investigation of the geology and ground-water resources of Meade county, Kansas, with special reference to the Meade artesian basin, was undertaken jointly by the United States Geological Survey and the State Geological Survey of Kansas, with coöperation from the Division of Sanitation, Kansas State Board of Health, and the Division of Water Resources, Kansas State Board of Agriculture. This work was done under the general administration of R. C. Moore and K. K. Landes, state geologists, and O. E. Meinzer, geologist in charge of the Division of Ground Water of the federal survey; and under the immediate supervision of S. W. Lohman, federal geologist in charge of ground-water investigations in Kansas. Approximately three months was spent by me in Meade county during the season of 1939, and an additional three months is to be spent during the season of 1940. The area studied is shown in figure 1.

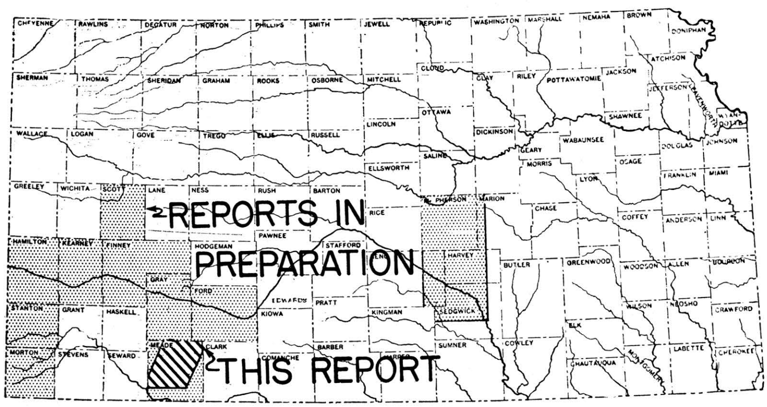


FIG. 1. Index map of Kansas showing area covered by this report and other areas for which coöperative ground-water reports are in preparation

During 1939 I visited 326 wells on which flow or water-level measurements, or both, were made. Three-fourths of these wells are situated in or adjacent to the artesian basin. In addition to this general well inventory, the water levels are being measured periodically in 29 observation wells, one of which has been equipped with an automatic water-stage recorder. Four test holes have been drilled in Meade County State Park by Ellis D. Gordon, Perry McNally, and Fred T. Holden, using a rotary drilling machine owned by the

State and Federal Geological Surveys, and additional test holes will be drilled in the county in 1940.

The field work in the county when completed is to include a detailed study of the geology, the completion of the inventory of wells more or less distant from the artesian basin, the determination of the elevation of many wells to facilitate the preparation of a water-table contour map, and the drilling of additional test holes.

Thanks and appreciation are expressed to the many residents of Meade county who supplied information and aided in the collection of field data. Special thanks are due to William Sourbeer, who drilled many of the early wells in the artesian basin and has supplied much of the historical data for this report, and to J. E. McColm, county agent, and R. S. Kirk, county engineer, for their helpful advice. George S. Knapp, chief engineer of the Division of Water Resources, Kansas State Board of Agriculture, supplied measurements of artesian pressure made under his supervision in this area in 1923. These data have proved to be of much value. Thanks are also extended to Claude W. Hibbard and H. T. U. Smith, of the University of Kansas, for valuable suggestions and criticisms. Hibbard (1937) has been making an intensive study of the vertebrate fauna of the Tertiary and Quaternary beds of the area, and Smith has spent considerable time in the field studying the stratigraphy and structure of the basin (see Smith, 1940). The manuscript for this report has been critically reviewed by S. W. Lohman, O. E. Meinzer, George S. Knapp, R. C. Moore, K. K. Landes, and Ralph King. The illustrations were drawn by Donald E. Dowers.

HISTORY OF ARTESIAN-WATER DEVELOPMENT IN THE BASIN

The first flowing artesian well was drilled in the Meade basin in 1886 on the farm of B. F. Cox (NE¼ NE¼ sec. 5, T. 31 S., R. 27 W.). The second flowing well was drilled later in the same year on the Jasper farm (SE¼ SW¼ sec. 33, T. 30 S., R. 27 W.), and in 1887 the third well was drilled on the farm of Frank Sourbeer (SE¼ SE¼ sec. 31, T. 30 S., R. 27 W.). After the drilling of these three wells the development of the basin proceeded rapidly, reaching its peak about 1900. By that time several hundred flowing wells had been drilled. Drilling has since continued in the basin, although recently the number of new wells added each year has been very small. Plate 1 shows two typical flowing wells of small diameter. One is on the farm of W. W. Marr and was constructed at about the time of maximum drilling activity in the basin (pl. 1A); the

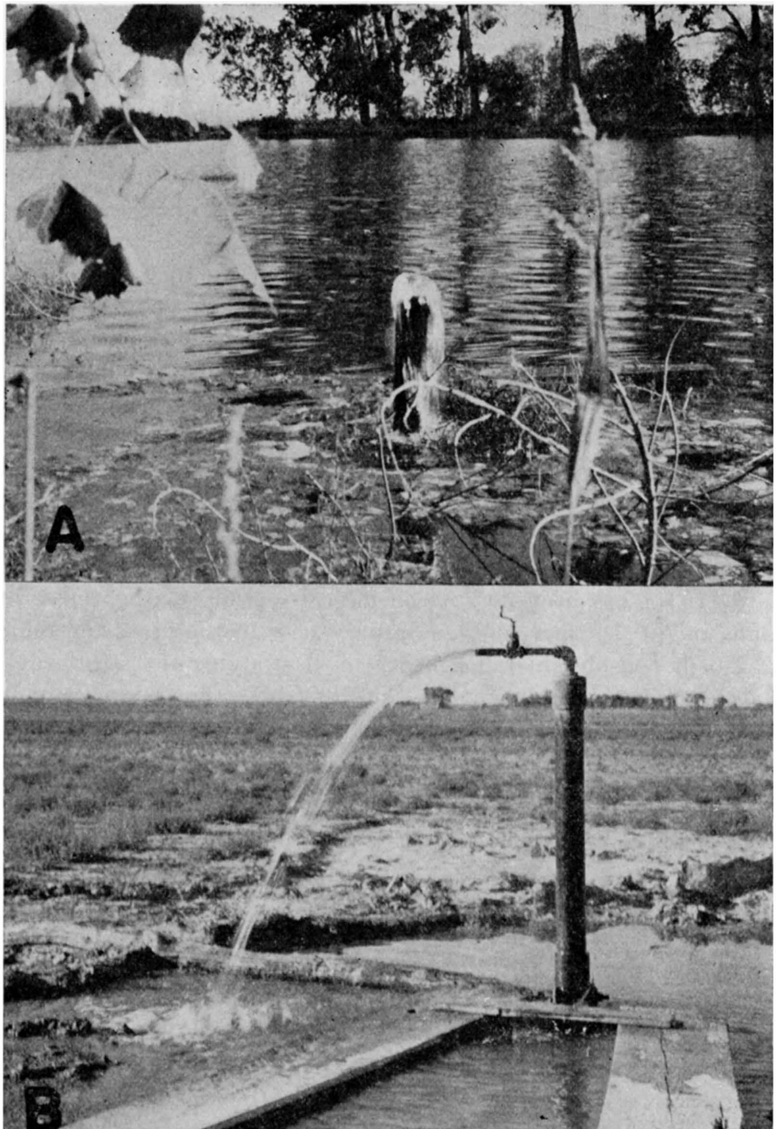


PLATE 1. Flowing wells of small diameter. A, Well on the farm of W. W. Marr; B, Well on the farm of C. F. Wells.

other was completed in 1939 on the farm of C. F. Wells, about a quarter of a mile west of the second artesian well drilled in the basin.

Most of the wells were drilled either by the jetting method or by the hydraulic rotary method. Horse power was quite generally utilized by the early drillers, and the drilling tools were light and incapable of penetrating hard rock. Most of the wells range in diameter from 1½ to 3 inches, although there are a few wells of larger diameter. Most of the early wells are uncased except for about 30 feet of pipe left in the upper part of the hole. In recent years most of the new wells have been cased to their full depth. The bottom part of the casing is generally perforated and serves as a screen. It is estimated that approximately 1,000 flowing wells have been drilled in the basin since 1886. Only a few hundred wells, however, are in usable condition at the present time.

Irrigation from pumped wells is a relatively recent development in the Meade basin. With the exception of a well on the Norman farm (NE¼ sec. 6, T. 31 S., R. 27 W.), which was pumped for irrigation purposes in 1909 only, and a well drilled a few years later on the Walker farm (SW¼ sec. 4, T. 30 S., R. 26 W.) but not used extensively until the last few years, the first large pumped irrigation well in the county was drilled in 1928 by L. L. Meng in the SE¼ sec. 18, T. 30 S., R. 26 W. Since that date ten irrigation wells have been drilled and put into operation in the artesian basin. These wells with one exception are in the parts of the basin in which the pressure-head of the ground water is not sufficient to produce flow at the surface. A typical irrigation well on the farm of Christopher Sobba, northwest of Fowler, is shown in plate 2A.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Permian rocks.—The oldest rocks exposed in the area are of Permian age.* These rocks are generally red in color and consist of shale, siltstone, and sandstone. Permian rocks are known to contain beds of salt and gypsum at a depth of only a few hundred feet below the surface.

Water can be obtained from these rocks only in meager quantity, and in most places it is highly mineralized. Locally these waters contain considerable chloride.

*These rocks have been referred by Norton (1939, pp. 1813, 1814) to the Big Basin formation, but are classed by the Kansas Geological Survey as belonging to the Taloga formation (Cragin, 1897, p. 362).

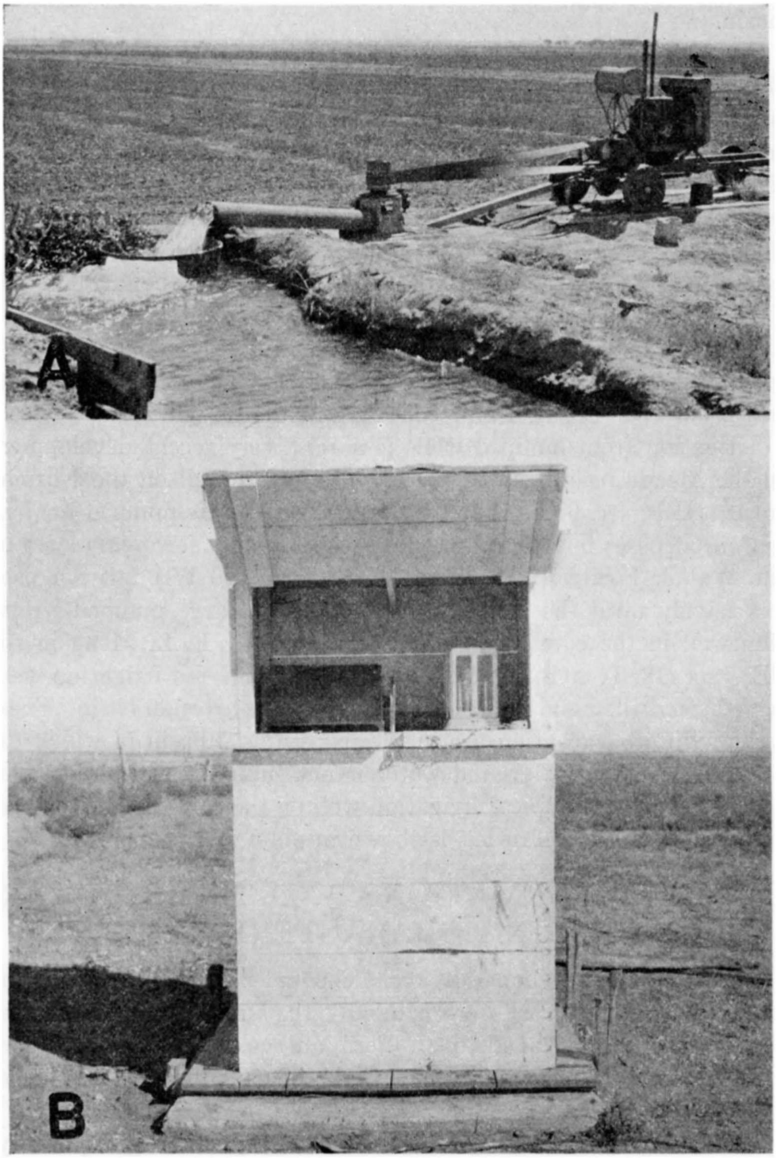


PLATE 2. Irrigation and observation wells on the Christopher Sobba farm, northwest of Fowler. A, Irrigation well in operation; B, Shelter enclosing automatic water-stage recorder and recording microbarograph in operation at observation well, 320 feet north of irrigation well.

Cretaceous rocks.—Cretaceous rocks are not known to crop out anywhere in the county. Well records in southwestern Ford county show Cretaceous rocks overlying the Permian, however, and drillers' logs of wells in northeastern Meade county indicate that the Dakota sandstone directly underlies the Tertiary.

No specific data are available at the present time as to the quantity or quality of water obtainable from the Dakota sandstone in Meade county.

Tertiary rocks.—Rocks of Tertiary (Pliocene) age underlie the entire basin and include the most important water bearers. The character and occurrence of these and younger rocks of southwestern Kansas are described by Smith (1940).

Rocks of middle Pliocene age (Ogallala formation* underlie the greater part of the county, and consist of gravel, sand, silt, and clay, in many places indurated by calcium carbonate to form "Mortar beds". Coarse unconsolidated gravel occurs locally at the base, and beds and lentils of pervious sand are encountered throughout the entire thickness of the deposits. The maximum thickness of these deposits in Meade county will be revealed only by future test drilling. The thickness is now known to range from a few feet to more than 150 feet.

In the Meade basin the middle Pliocene deposits are overlain by upper Pliocene deposits of clay, silt, and sand, and locally peaty beds. From these deposits Hibbard (1937) has described the Rexroad fauna of upper Pliocene age, and Smith (1940) has named the deposits the Rexroad formation. The sands are mostly lenticular and in some places are cemented with calcium carbonate. These beds are marked by abundant vertebrate and invertebrate fossils and by the almost total absence of fossil grass seeds so common in the underlying Ogallala. The upper Pliocene deposits of Meade county locally attain a thickness of more than 200 feet.

The Tertiary deposits of the Meade artesian basin yield abundant supplies of water of good quality and supply most of the flowing wells of the area.

Quaternary rocks.—At many places throughout the basin, and adjacent to it, the Tertiary rocks are overlain by sediments of Pleistocene age, referred to the Odee formation, the Kingsdown formation, the Jones Ranch beds, and the *Equus niobrarensis* beds by Smith (1940). These Pleistocene sediments consist of sand, gravel, silt,

* The Ogallala formation is classed as Pliocene by the United States Geological Survey. Smith (1940) restricts the Ogallala to the middle Pliocene, and includes the upper Pliocene beds of Meade county in the Rexroad formation.

and clay, and locally contain volcanic ash. The Recent deposits are alluvial sand and silt. Plate 3A shows Pleistocene beds cropping out along the valley of Sand creek, and Recent, water-bearing, sandy alluvium along the valley bottom.

The Pleistocene beds yield moderate quantities of water of good quality, and probably supply some of the shallower flowing wells in the Meade basin. Unconfined water also occurs in the Pleistocene and Recent deposits of the basin and the adjacent tributary valleys.

GEOLOGIC HISTORY

The detailed geologic field work in this area has not been completed, so that the discussion of the geologic history given here is generalized and brief and is subject to later revision.

TERTIARY PERIOD

The bedrock floor of the basin is composed mainly of Permian rocks but also probably in part of Cretaceous rocks. This bedrock was subjected to erosion during most of Tertiary time, and by the advent of the Pliocene epoch it was reduced to a relatively featureless surface. During middle Pliocene time, streams flowing from the Rocky Mountain region began depositing part of their transported load, and fluvial sediments were spread over the entire area. Considerable material derived from the Cretaceous and Permian rocks is intermixed with the igneous materials from the mountains.

Earlier workers in this area have disagreed as to the origin of the topography, and of the structure of the Tertiary and Quaternary beds. Haworth (1897, pp. 22, 23) believed faulting alone to be the controlling factor, whereas Johnson (1901, pp. 712-732) believed that solution of salt in the underlying Permian rocks, which caused collapse or subsidence of the overlying deposits, was the only process involved in the production of the basin. It seems probable, on the basis of present data, that the structure and topography of the area have been controlled by several factors, of which these two processes have played almost equally important roles.

The first recognizable faulting in the basin followed immediately the close of middle Pliocene sedimentation. The interpretation of the faults and stratigraphy is shown in a generalized section across the southern part of Crooked creek valley (fig. 2). A short period of erosion may have intervened between middle and upper Pliocene sedimentation. It is probable, also, that some solution of underlying Permian salt beds during this time may have played an important role in the upper Pliocene and Quaternary history of the basin. This solution presumably was localized and intensified by the Pliocene faulting, which allowed ground water to circulate much more freely than in unfaulted beds. Solution undoubtedly deepened the structural trough, or produced a series of basins along this zone of faulting. Seemingly, it was this topographic anomaly that allowed the accumulation of the thick sequence of upper Pliocene beds in this area, for in adjacent areas equivalent beds are thin or absent.

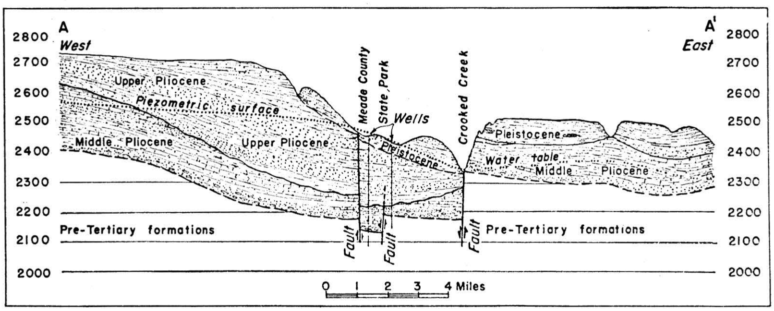


FIG. 2. Generalized east-west section across Crooked creek valley, through Meade County State Park. Two test holes in park indicated by thin vertical lines.

Faulting seems to have been recurrent in this area at least to the beginning of Recent time. The initial movement along the major fault, which in many places coincides with the course of Crooked creek, seems to have occurred in upper Pliocene time, and subsequent movement—south of Meade—probably took place during the Pleistocene epoch.

QUATERNARY PERIOD

PLEISTOCENE EPOCH

Pleistocene sediments accumulated above the upper Pliocene deposits, and there was only a slight hiatus between them. In this area the Pleistocene beds are not as widespread as those of late Pliocene age. Ponded water seems to have covered much of the area for a short time during the early Pleistocene, and in this slack-water environment clay, silt, and thin-bedded volcanic ash accumulated. Many fresh-water mollusks can now be found in these fine sediments. At some time during the Pleistocene epoch the topographic depression was completely filled and sediments were spread across the upland east of Crooked creek. This Pleistocene depositional plain comprises the upland surface east of Crooked creek south of Meade. Channel cutting probably occurred also sometime during the Pleistocene. These channels may have been controlled in whole or in part by sinkhole development, but it is impossible to determine with certainty the controlling process on the basis of present data. During the late Pleistocene time these channels—or connecting sinkholes—were filled with sediments derived from the adjacent Tertiary and Pleistocene beds.

About the close of Pleistocene time additional faulting occurred, accompanied by renewed movement along the Crooked Creek fault. This faulting probably induced the solutional subsidence that produced the present form of the Meade basin north of Meade. A late Pleistocene fault seems to supply the openings for the escape of artesian water at the springs in Meade County State Park and Big Springs ranch.

Recent Epoch

The Recent history of this area is not completely known; the general aspects seem to be fairly well established, however.

Meade Lake.—After the close of Pleistocene time and the completion of the major solutional subsidence in the area northeast of Meade and west of Fowler, this area may have been occupied by a lake, at least temporarily. This is indicated by (1) the nature of the bluffs along the western side of the basin, which may have been cut to their present shape by wave action; (2) the location of the sand-dune area north of Fowler, which has the aspect of a beach dune area; (3) the sharp constriction of the basin at Meade—south of which point Crooked creek has a much steeper gradient; and (4) certain parts of the basin floor have the appearance of wave-cut benches. A detailed discussion of the evidence indicating the presence of a lake in this area will be presented later. The outlet of the lake may always have been Crooked creek. Lowering of the outlet caused extinction of the lake, or else drainage of the lake resulted from the headward erosion of Crooked creek. It is evident that the outlet of the lake was never Sand creek, for that stream now—at a comparable distance from the old strand line—is at a lower elevation than Crooked creek, and so could not have been captured by it.

Stream deposits.—A large part of the floor of the Meade basin (north of Meade) is underlain by Recent stream deposits. Deposition by Crooked creek and its tributaries seems to have occurred

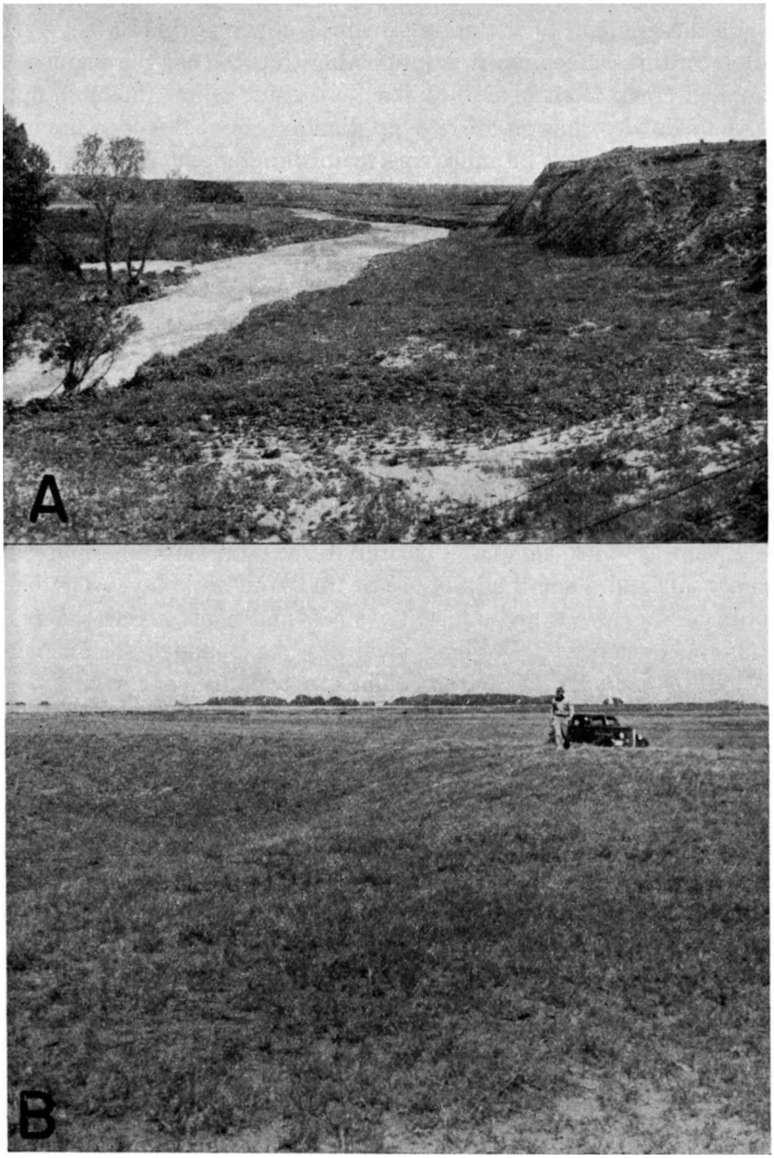


PLATE 3. Stream valleys in Meade county. A, Sand creek valley northeast of Jones ranch. Pleistocene beds are exposed along the valley walls, and water-bearing alluvium occurs in the valley bottom; B, Natural levee built by a tributary of Crooked creek, about half way between Meade and Fowler. Note grass covering of sides and channel bottom. Photograph by H. T. U. Smith.

only in the area between Meade and Fowler and to the northwest, where the gradient of the main stream is now less than 3 feet to the mile. In this connection it is interesting to note that the segment of Crooked creek from Meade to the Ford county line (about 7 miles north of Fowler) has an average gradient of only 3.3 feet to the mile, whereas for the next 20 miles upstream the gradient is 5 feet to the mile, and for 15 miles south of Meade it is 8 feet to the mile. Several undrained depressions that exist on the floor of the basin are receiving deposits at the present time.

Natural levees.—Natural levees have been built by Crooked creek and several of its tributaries (pl. 3B). The levees are formed as the streams build up their channel bottoms several feet above the adjacent land surface. Locally the streams have broken through the levees and the channels have shifted several times, producing a complicated system of abandoned levees and channels. This type of deposition has given rise to a "corrugated" topography that is well shown by photographs. Several artificial cuts through the levees show that they are composed entirely of structureless fine material, mainly silt and a small admixture of fine sand and clay. The back slopes of the levees are unusually steep and short. For the most part, the levees, and in some localities the channel bottoms, are covered by a thick mat of grass. The exact manner of forming these levees is not known, but it is my opinion that they were built slowly by successive overflows, a thin layer of fine material being trapped by the grass covering each time the silt-laden water spilled over the stream banks. Excessive floods may have killed some of the grass, but probably it grew back before the next overflow. The streams probably broke through old levees when successive overflows occurred before the sod cover had become reëstablished. This type of deposition seems to account both for the steep back slopes of the levees and for the absence of bedding in the deposits.

Recent erosion.—Except for thin floodplain deposits along the present stream valleys, no sediments of Recent age were found south of Meade. The Recent history of this part of the area has been dominantly erosional. Headward spring sapping has played a minor role in valley development in the vicinity of Meade County State Park (sec. 15, T. 33 S., R. 39 W.) and Big Springs ranch (sec. 17, T. 32 S., R. 28 W.). Here, small boxhead valleys cut by spring migration, probably along the plane of the controlling fault, are tributary to the major stream-cut valleys.

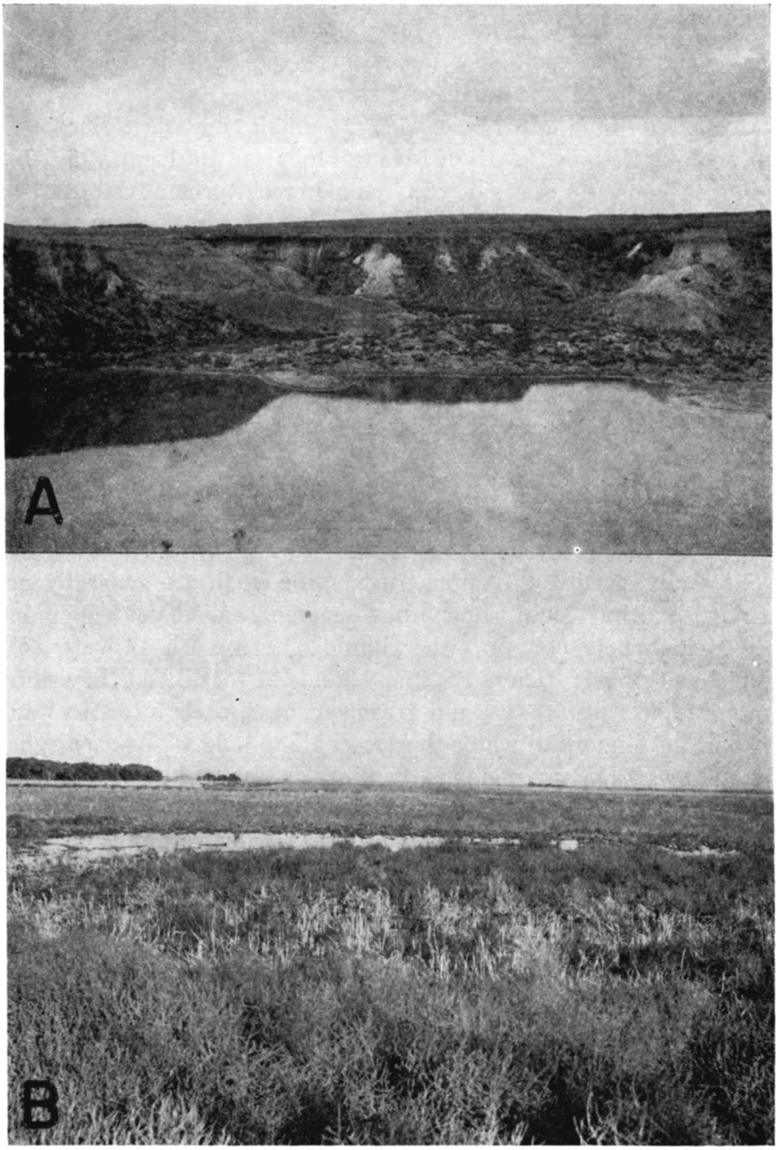


PLATE 4. A, Meade "salt well" 1.5 miles south of Meade. View looking north; B, Bog produced by unused flowing well. The casing has been broken off at the land surface and the well has not been plugged.

In the southwestern part of the area a small sinkhole has been formed by solution and collapse. It is filled with Pleistocene and Recent deposits, which are being dissected by the headwaters of Sand creek. The sink does not seem to be related to the major structure of the Meade basin.

Meade salt sink.—In March, 1879, a small sinkhole formed suddenly about 1.5 miles south of Meade (Johnson, 1901, pp. 706, 707). This sink is on the east side of Crooked creek, probably formed on or just east of the major fault. It has been referred to as the salt sink or the "salt well" because salt water rose in the sinkhole to a level within 14 feet of the surface. The water in the sink is nearly fresh at the present time. Although this sinkhole is of small extent, it indicates that solution of the underlying salt beds has not ceased entirely. A view of the Meade "salt well" as it appeared in 1939 is shown in plate 4A.

ARTESIAN WATER

OCCURRENCE

The rocks forming the outer crust of the earth are generally not entirely solid but contain numerous openings, called voids or interstices, which may contain either liquid or gas, such as water, oil, natural gas, or air. There are many kinds of rocks, and they differ in the number, size, shape, and arrangement of their interstices and hence in the amount of water they are able to hold. The occurrence of ground water in any region is therefore determined by the geology. A detailed treatment of the occurrence of ground water is given by Meinzer (1923) and a shorter treatment referring especially to Kansas has been published by Moore (1940).

The amount of water that can be stored in any rock depends on the porosity of the rock, commonly expressed as the percentage of the total volume of the rock that is occupied by interstices. A rock is said to be saturated when all its interstices are filled with water. Porosity, however, determines only how much water a given rock can hold, not how much it may yield to wells. The permeability of a rock may be defined as its capacity for transmitting water or other fluid under pressure and is measured by the rate at which it will transmit water through a given cross section under a given difference of pressure per unit of distance. A bed of silt or clay may have as high a porosity as a bed of coarse sand, but because of the small size of its interstices it may require the application of great pressure to transmit water; hence, under ordinary hydraulic gradients it may be entirely impermeable. Not all the water in a saturated rock is available to wells, because part of the water is held against the force of gravity by molecular attraction. In a fine-grained rock the molecular attraction is very great and only a small part of the water can be drained out by the force of gravity, whereas in a coarse sand or gravel having the same porosity only a small part of the water is retained by molecular attraction and the rest becomes available to wells.

Gravel and sand are among the most productive water-bearing materials. It is from material of this type that all the water of the Meade artesian basin is obtained. As stated, these deposits were laid down by streams. As the streams built up the surface over which they flowed, they probably migrated from side to side, so that at any one locality well-sorted sand or gravel may alternate with finer, less permeable materials. Thus the unconsolidated deposits in the area consist principally of layers of fine particles of low permeability that enclose "pipes" and discontinuous sheets of permeable gravel or sand, which serve as arteries of ground water. In the Meade basin most wells drilled to a depth of 200 feet or more encounter at least two, and probably more, such water-bearing beds. As shown in figure 2, these alternating beds of permeable and nonpermeable material dip downward beneath the floor of the Meade artesian basin. Water entering these strata northwest of the area at an elevation higher than the floor of the basin moves down the dip between the confining layers of impervious material. Under these conditions wells drilled in the topographically low basin encounter water that is under artesian pressure—that is, water that rises in wells to a level above the local water table. The many wells in which the water rises high enough to flow at the surface are termed flowing artesian wells.

AREA OF ARTESIAN FLOW

The areas in Meade county in which artesian flows can be obtained at the present time are shown in plate 5. It is evident from the map that the location and shape of the areas of flow are controlled principally by the topography, and that the extent of such areas will vary from time to time with the fluctuations of the pressure-head of the artesian water. Little accurate historical information is available as to the former extent of the flowing well area; it is probable, however, that the area has decreased only slightly since the earliest development. There may have been some decrease in the area of flow west of Fowler.

In Meade county there are six distinct areas in which flowing wells can be obtained. These areas are shown in plate 5, and each is discussed briefly below.

Meade district.—The Meade district is by far the largest and most important of the flowing-well areas. It includes approximately 33 square miles, in which are located more than 200 flowing wells in usable condition at the present time. This area extends along the valley of Crooked creek in a narrow strip for about 12 miles

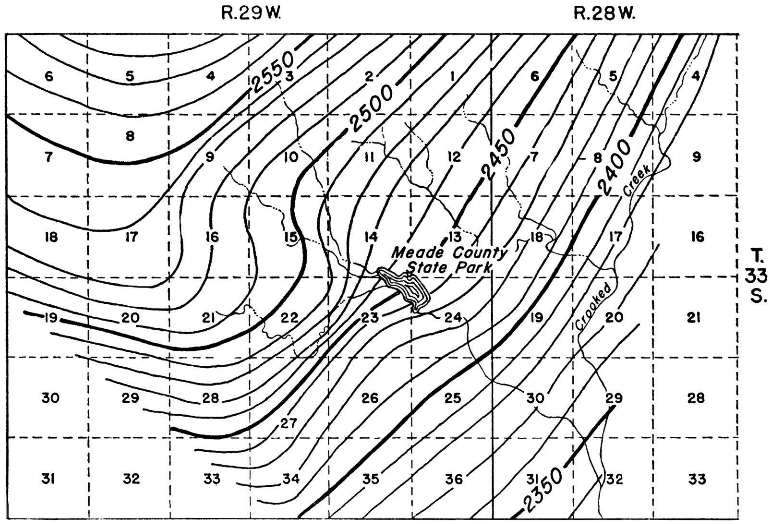


Fig. 3. Contour map of the piezometric surface in the vicinity of Meade County State Park.

south of Meade. North of Meade it broadens into the Meade basin proper, extending within 1 mile of Fowler on the east, and within 3.5 miles of the Ford county line on the north.

State Park district.—The State Park district, comprising less than 1 square mile, is located about 10 miles southwest of Meade. Although no permanent artesian wells exist in this district, several large artesian springs supply water for the hatchery ponds at the State Park. During the fall of 1939, four test holes were drilled by the State and Federal Geological Surveys on the grounds of the park. Two of these wells were flushed out and cased to a shallow depth so that measurements of the artesian head could be made. In one well the water rose to a point 17.4 feet above the land surface. All test holes were plugged after these measurements were made.

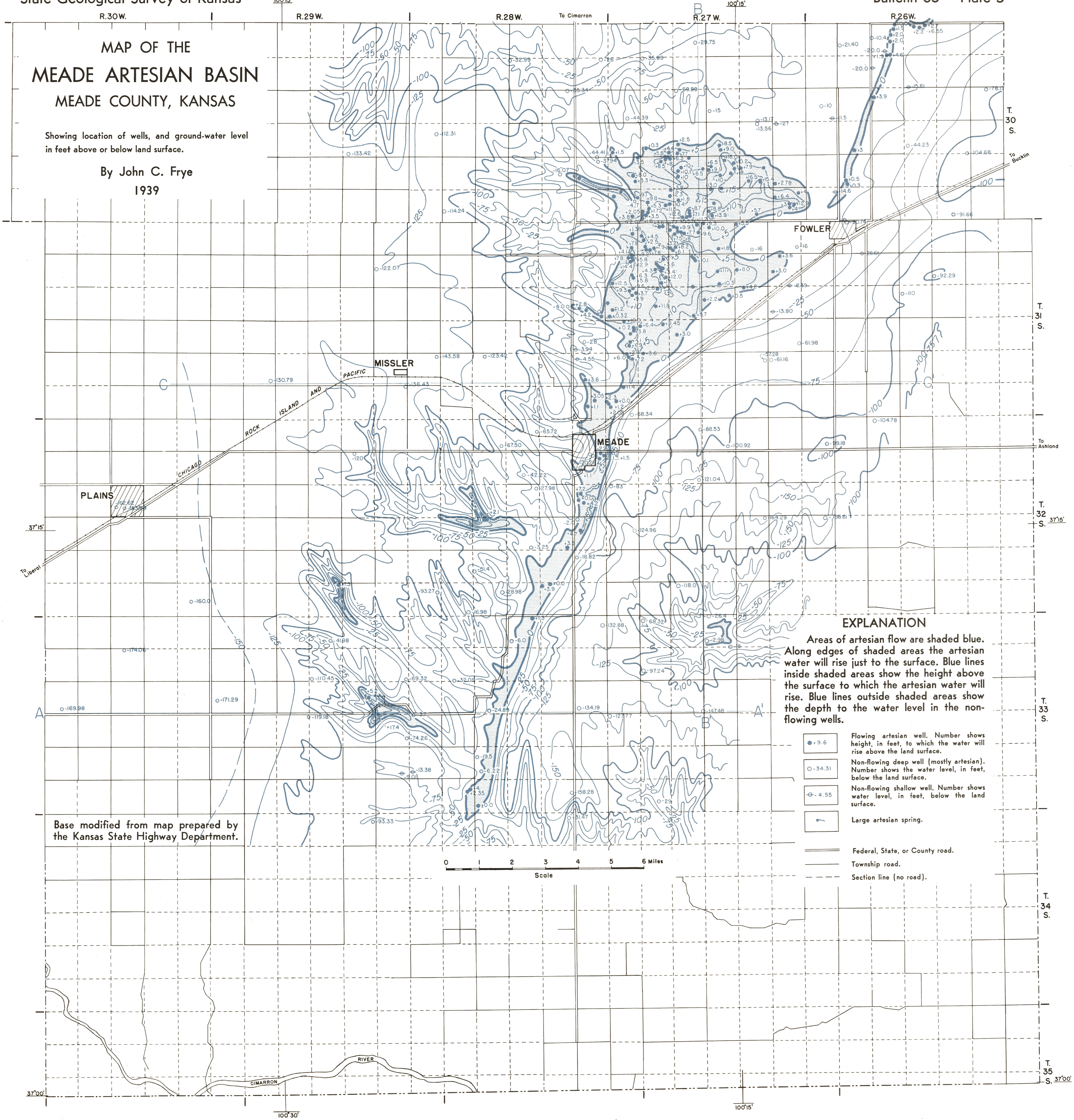
A. B. Hungerford, of the National Park Service, ran levels to these test wells and to several adjacent wells in which the depth to water level had been measured. On the basis of these data a map was made of the piezometric surface (representing the altitude to which the artesian water will rise) as is shown in figure 3.

Berghaus district.—The Berghaus flowing-well district embraces about 0.25 square mile in sec. 33, T. 32 S., R. 29 W., most of which is on the Berghaus property along a tributary to Crooked creek about 3 miles north-northwest of Meade County State Park. As the valley bottom is narrow, and the bluffs steep, the strip enclosed within the zero line, plate 5, is narrow. In this district there is one small flowing well, which is located at the site of a former spring.

Big Springs Ranch district.—A flowing-well area of slightly less than 1 square mile occurs along Spring creek on the Big Springs ranch (secs. 17, 20, and 21, T. 32 S., R. 28 W.,) 3 miles southwest of Meade. There are several large springs along the valley flat, and three small flowing wells near the Big Springs ranch house. This district is less than 1 mile from the southern part of the Meade district.

Fowler district.—Flowing wells occur along the valley of Crooked creek north of Fowler to the Ford county line, and along the valley of its tributary, Spring creek (secs. 3, 4, 9, 16, 20, and 29, T. 30 S., R. 26 W.). This area is separated from the eastern extension of the Meade district by an area of nonflowing wells in which the water rises to levels within a few feet of the surface. The district includes an area in Meade county of somewhat more than 1 square mile, and at the present time it contains 13 flowing wells.

Eastern district.—The eastern district, comprising an isolated filled sinkhole, is about 7 miles southeast of Meade. This small area, described on page 18, contains water under artesian pressure, and at least one flowing well has been drilled in it. The area of flow is restricted to the valley bottoms of Sand creek and its tributaries, and seems to include less than 0.25 square mile, confined entirely to sec. 4, T. 33 S., R. 27 W. The area of flow seemingly has decreased somewhat as a result of pumping from a well that formerly flowed.


MAP OF THE
MEADE ARTESIAN BASIN
MEADE COUNTY, KANSAS
Showing location of wells, and ground-water level in feet above or below land surface.
By John C. Frye
1939
R.30W.
R.29W.
R.28W.
R.27W.
R.26W.
T. 30 S.
T. 31 S.
T. 32 S.
T. 33 S.
T. 34 S.
T. 35 S.
100°15'
100°30'
37°15'
37°00'
To Cimarron
To Bucklin
To Ashland
To Liberal
FOWLER
MEADE
MISSLER
PLAINS
CHICAGO ROCK ISLAND AND PACIFIC
CIMARRON RIVER
EXPLANATION
Areas of artesian flow are shaded blue. Along edges of shaded areas the artesian water will rise just to the surface. Blue lines inside shaded areas show the height above the surface to which the artesian water will rise. Blue lines outside shaded areas show the depth to the water level in the non-flowing wells.
Flowing artesian well. Number shows height, in feet, to which the water will rise above the land surface.
Non-flowing deep well (mostly artesian). Number shows the water level, in feet, below the land surface.
Non-flowing shallow well. Number shows water level, in feet, below the land surface.
Large artesian spring.
Federal, State, or County road.
Township road.
Section line (no road).
0 1 2 3 4 5 6 Miles
Scale
Base modified from map prepared by the Kansas State Highway Department.

HEAD OF ARTESIAN WATER

The hydrostatic level, or static water level, of the artesian water at any point is the level to which the water will rise in a tightly cased well drilled to the artesian reservoir. If the static water level stands above the land surface, the well will overflow at the surface; if a flowing well is tightly cased and capped, the artesian water will exert a pressure that can be measured. The term head, as used in this report, refers to the height, in feet, that the water will rise above the land surface in a tightly cased flowing artesian well. The heads of flowing wells given in plate 5 and elsewhere in this report were measured in the following manner. The discharge pipe was closed by inserting a plumber's soil-pipe test plug of the proper size. The seal between the test plug and the well casing is effected by a soft rubber collar that is expanded outwardly by turning a large wing nut. A length of garden hose was then attached to the test plug and the open end of the hose elevated until the flow just ceased. The hose was kept in this elevated position so as to prevent flow until all the discernible recovery had taken place. The height of the top of the hose above a fixed point was then determined with a steel tape. Some head measurements may be somewhat inaccurate owing to slight leaks in the equipment or in the casings of the wells. In such wells the heads determined by this method should, therefore, be regarded as minimum heads.

The piezometric surface, or pressure-indicating surface, of an artesian aquifer is an imaginary surface that everywhere coincides with the static level, or head, of the water in the aquifer.

Original head.—The original head of the artesian water in the Meade basin is not definitely known. The earliest known measurements of head in this area were made by W. D. Johnson (1901, p. 718), who in 1898 or 1899 visited 209 flowing wells in use in the basin. How many of these wells were actually measured is not known, but he states that the strongest measured head in the basin at that time was 22 feet above the land surface. Conversations that I have had with old residents of the county indicate that in the early days of artesian development, a well from which water would rise above the second floor of a house was regarded as an exceptionally strong flowing well, and that water from many wells would rise only a few feet above the land surface. Also, Haworth in 1897 (p. 53) states that the heads at that time were ". . . perhaps always less than 20 feet." This seems to imply that Johnson's figure of 22 feet may safely be regarded as the approximate maximum head obtainable in the basin during the earliest period of record.

Head in 1923.—Measurements of the pressure head of many artesian wells were made in November and December, 1923, by V. W. Stanbaugh, of the Division of Water Resources, Kansas State Board of Agriculture, and were made available by George S. Knapp, chief engineer of the Division. These measurements were made with a calibrated gas proving gauge reading in pounds to the square inch and having a full circle deflection of 15 pounds. The gauge was read to the nearest quarter pound and the gauge was held at the outlet of the well casing. For the purpose of discussion and comparison in this report, these values have been converted to feet of water. The heads of 24 wells measured in this way are given in column 4 of table 1. Owing to the facts that these meaurements were recorded only to the nearest quarter pound, and that there are several inherent mechanical inaccuracies in this method of measurement, the 1923 heads given in the table should be regarded as accurate only within about 0.5 foot. The strongest head recorded in 1923 was 15.4 feet; no measurement was then made on the wells that showed the strongest heads in 1939, however. From the foregoing, it is estimated that the maximum head in the Meade basin in 1923 was between 18 and 20 feet above the land surface.

Head in 1939.—In July, August, and September, 1939, head measurements were made by me on 145 flowing wells in Meade county. The location of these wells, and 40 other flowing wells on which flow measurements only were obtained, are shown in plate 5. This map also shows the generalized heads in the several artesian basins. The strongest head measured in 1939 was 17.4 feet above the land surface, and was obtained in a test well in Meade County State Park. Inasmuch as all the earlier measurements were made in the Meade and Fowler districts, this well cannot be compared with them. The pressure in the strongest two flowing wells measured in the Meade basin proper was sufficient to force water to heights of 17.0 feet and 16.5 feet. A generalized representation of the piezometric surface, and its relation to the land surface and the shallow water table are shown along two cross profiles in figure 4.

Decline in head.—On the basis of present data the decline in head in the Meade basin during the last 50 years does not seem to have been great. In order to show the extent of this decline, some of the data presented earlier will be reviewed and compared.

As pointed out, the maximum head obtainable in the basin when development was initiated probably was not greater than 22 feet above the land surface, and the maximum head measured in 1939 was 17 feet above the land surface. Thus it seems that the maximum head measured in 1898 was 5 feet higher than the maximum head measured in 1939. It is my opinion that this figure is not accurate, and is probably larger than the actual decline in maximum head during this period. This opinion is based on the following facts: (1) Johnson did not give the location of the strongest well that he measured and thus it is impossible to know whether this well was among those measured by me, if indeed it is still in existence; (2) the earliest measurements were made on relatively

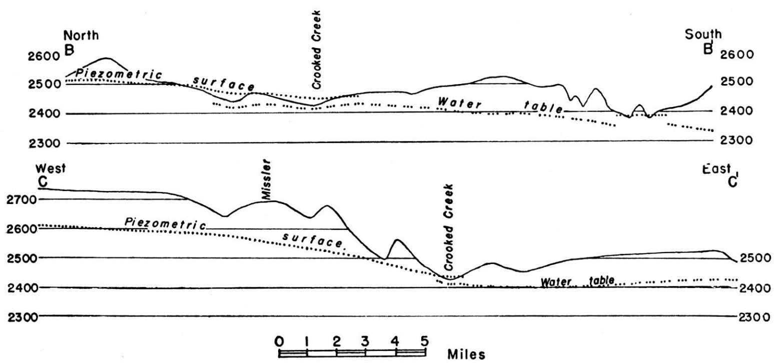


FIG. 4. Profiles across the Meade artesian basin. See plate 5 for locations. A, North-south profile, 4 miles east of Meade. B, East-west profile, 2 miles north of Meade.

new wells, whereas most of the 1939 measurements were made on old wells, some of which are known to be "sanded up", or to have underground leaks in the rusted casing; and (3) the strongest wells at the present time are situated in areas where the concentration of wells seems to be greater than any that existed in the basin 40 years ago, and as it was impracticable to close in many of the wells while measurements were being made, the well being measured was undoubtedly influenced more or less by the cones of depression, or areas of pressure relief, of the near-by wells. When these facts are considered and given proper weight, it seems safe to conclude that the total decline in maximum head, by 1939, has been less than 5 feet but more than 3 feet.

Head measurements made in 1923 are given in table 1. Owing to the fact that the strongest heads were not necessarily included in the measurements, no comparison of maximum heads can be made on the basis of these data. Of the wells measured in 1923, however, 24 were remeasured in 1939. As indicated in table 1, the average decline in the head of the 24 wells during the 15½-year period is 1.7 feet. It should be noted, however, that the change in head of individual wells ranged from a slight increase for some wells to a decline of 6.8 feet in one well. It should also be noted that the 1923 measurements were made in the winter, whereas the 1939 measurements were made in the summer and fall. The period

TABLE 1.—*Head measurements of 24 flowing artesian wells in 1923 and 1939, and decline or rise during that period*

LOCATION.	Reported depth of well (feet).	Diameter of well (inches)	Head above measuring point (in feet).		Decline (—) or rise (+).
			1923 *a*.	1939 *b*.	Difference between columns 4 and 5.
1	2	3	4	5	6
NW ¼ sec. 3, T. 30 S., R. 26 W. .	190	2	Weak *c*	2.7	. . . .
NE ¼ sec. 4, T. 30 S., R. 26 W. .	120	2	Weak	2.0	. . . .
SW ¼ sec. 21, T. 30 S., R. 27 W. .	170	2	5.8	6.5	+.7
NE ¼ sec. 27, T. 30 S., R. 27 W. .	175	3	10.4	7.7	—2.7
NW ¼ sec. 27, T. 30 S., R. 27 W. .	180	2	4.6	3.5+	—1.1
NE ¼ sec. 29, T. 30 S., R. 27 W. .	200	. . . .	8.1	5.8	—2.3
SW ¼ sec. 32, T. 30 S., R. 27 W. .	175	2	3.5	2.0	—1.5
SE ¼ sec. 24, T. 30 S., R. 28 W. .	180	2	Weak	1.5	. . . .
NW ¼ sec. 4, T. 31 S., R. 27 W. .	350	2	6.4	7.8	+1.4
NW ¼ sec. 5, T. 31 S., R. 27 W. .	. . . .	2	5.1	5.5	+.4
NE ¼ sec. 6, T. 31 S., R. 27 W. .	200	3	3.5	3.6	+.1
SW ¼ sec. 5, T. 31 S., R. 27 W. .	. . . .	3	5.6	7.0	+1.4
SW ¼ sec. 5, T. 31 S., R. 27 W. .	. . . .	3	4.6	4.8	+.2
SW ¼ sec. 6, T. 31 S., R. 27 W. .	260	2	10.4	9.2	—1.2
SW ¼ sec. 6, T. 31 S., R. 27 W. .	190	2	6.3	2.5	—3.8
SE ¼ sec. 6, T. 31 S., R. 27 W. .	260	2	5.1	4.5	—.6
NE ¼ sec. 8, T. 31 S., R. 27 W. .	180	2	10.3	7.6	—2.7
NW ¼ sec. 18, T. 31 S., R. 27 W. .	175	. . . .	12.7	5.9	—6.8
NE ¼ sec. 12, T. 31 S., R. 27 W. .	150	4	6.9	5.7	—1.2
SE ¼ sec. 12, T. 31 S., R. 28 W. .	140?	3	4.6	4.9	+.3
NE ¼ sec. 13, T. 31 S., R. 28 W. .	300	3	15.4	9.6	—5.8
NW ¼ sec. 12, T. 32 S., R. 28 W. .	180	2	3.5	.2	—3.3
SW ¼ sec. 22, T. 32 S., R. 28 W. .	150	2	3.5	2.0	—1.5
NE ¼ sec. 4, T. 33 S., R. 28 W. .	180	2	7.4	1.0	—6.4
Average.	195	. . . .	6.6	4.9	—1.7

a. Heads measured in November and December, 1923, by V. W. Stanbaugh, Division of Water Resources, Kansas State Board of Agriculture. Measurements were made in pounds to the square inch and have been converted to feet. Believed to be accurate within 0.5 foot.

b. Heads measured by me in July-September, 1939, by the method described in text. Accurate to approximately 0.2 foot.

c. Head too weak to register a readable amount on the gage, probably less than 2.5 feet.

of record of the observation wells in the area is not yet sufficiently long to determine at what times during the year the water in the artesian wells stands at the highest and lowest levels. It is evident, however, that the decline in artesian pressure has been small.

Fluctuations in head.—At the time of writing, less than one year's record of water-level fluctuations is available in Meade county. For this reason it is not practicable to draw any conclusions as to the annual fluctuations of water level or pressure head of the artesian water in the basin. Considerable data have been obtained as to shorter range fluctuations, however.

An automatic water-stage recorder has been maintained on a well owned by Christopher Sobba, and the record shows a pronounced barometric effect. The effect of atmospheric pressure on the water level has been summarized by Meinzer (1932, pp. 140-142) as follows:

> If a shallow well ends in a formation that lies at the surface and is freely permeable throughout, only slight barometric effects or none at all are to be expected, because any change in the atmospheric pressure is transmitted almost as freely to the water table through the permeable material as to the water level in the well. . . . If a well ends in an artesian formation and this formation or the overlying confining beds have sufficient strength to resist deformation by slight changes in pressure at the surface, the well will act as a barometer. The fluctuations of its water level will have virtually the same range of fluctuations as would be shown by a water barometer, or 13.5 times the range of a mercury barometer. . . . If a well ends in an artesian formation that has volume elasticity, such as incoherent sand, and is confined beneath beds of soft shale that is impermeable but yields to even slight pressures, its water level will have smaller fluctuations resulting from atmospheric changes than that of a water barometer, and the ratio of the movements in the well to the corresponding movements in the barometer should give a measure of the resistance of the water-bearing and confining beds.

A hydrograph obtained from the automatic water-stage recorder and the inverted barograph obtained from a recording microbarograph located in the same shelter are shown in figure 5. It can be seen from these graphs that the fluctuation of the water surface is only about twice as great as the comparable fluctuations in a column of mercury, hence this well may be said to have a barometric efficiency of only about 15 percent. It may be concluded either that the resistance to deformation of the artesian aquifer and the confining beds is probably not very great or that the seal effected by the confining beds is not complete.

Fluctuations of water level due to pumping are of particular interest. Data bearing on this problem in the Meade basin are available from several sources. The observation well mentioned above is located 320 feet from a pumped irrigation well, and a hydrograph from the observation well is shown in figure 6, together with the pumping record of the irrigation well. This hydrograph illustrates

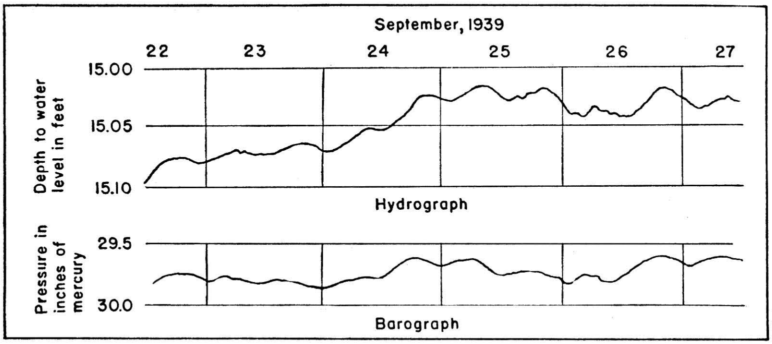


FIG. 5. Hydrograph and inverted barograph obtained at the observation well on the farm of Christopher Sobba, northwest of Fowler.

the speed with which draw-down, or release of pressure, is transmitted through the artesian aquifer, and the extent of the draw-down in the water level at a distance of 320 feet from the pumped well. The irrigation well was pumped at a rate of approximately

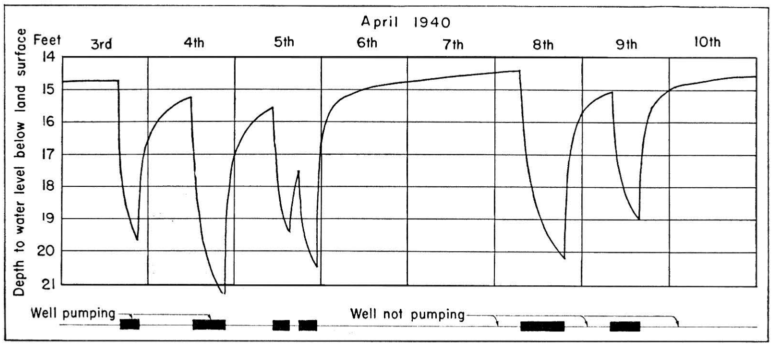


FIG. 6. Hydrograph of observation well and pumpage record of irrigation well 320 feet distant. Located on the farm of Christopher Sobba, northwest of Fowler.

850 gallons a minute, and the first period of pumping indicated on the graph represents the first pumping of the irrigation well after a winter of rest. Comparable recovery curves are shown in figure 7 of two of the municipal wells at Meade. The sharp draw-downs and

rapid recoveries as shown by these curves, are typical of artesian conditions.

A pumping experiment on a large scale, carried out in the flowing-well area in 1909, was reported to me by several residents of Meade county, and is of considerable interest in a study of fluctuations caused by pumping. A 5⅝-inch artesian well was drilled to a depth of 190 feet in the SE¼ NE¼ sec. 6, T. 31 S., R. 27 W. This well was equipped with a centrifugal pump, and pumped for irrigation at a rate of 700 gallons a minute. After this well had been pumped for ten consecutive days, a well 0.75 mile away ceased flowing. On August 28, 1939, the well located 0.75 mile from the pumped

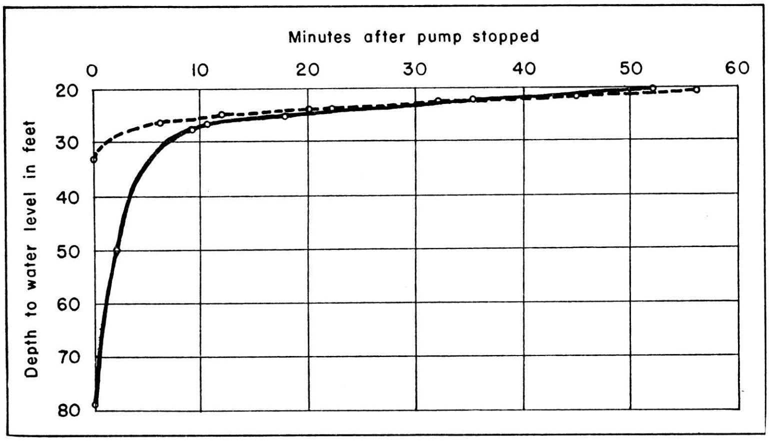


Fig. 7. Recovery curves of two of the municipal wells at Meade. The solid line represents the pumped well and the dashed line an unpumped well 120 feet distant. Pump was stopped after about 4 hours of pumping. Wells located at east edge of city.

well was located and was found to have a head of 4.8 feet above the top of the discharge pipe. It is reported that the discharge pipe in 1909 was lower than it is at the present time, and the well at that time (prior to the near-by pumping) probably had a somewhat higher head than it does now. From the foregoing data it may safely be concluded that the pumping of the irrigation well during 10 days lowered the piezometric surface by more than 4.8 feet over an area of more than 1.75 square miles.

MOVEMENT OF ARTESIAN WATER

During the field season of 1940 levels are to be run to most of the wells in which water-level measurements have been made, and a detailed contour map of the piezometric surface will be prepared. At the present time it is possible to state only that the general direction of movement of the artesian water in the basin is toward the southeast, but there are many local departures from this general direction. Details of the shape of the piezometric surface are shown in figure 3 for a small area at the southern end of the basin. The average slope of the piezometric surface in this area is about 36 feet to the mile. More detailed information concerning the direction and rate of ground-water movement is to be presented in a later report.

DISCHARGE

The discharge of water from the artesian water-bearing beds seems to take place in the following three ways: (1) Natural discharge at the surface from springs and seeps and by transpiration and evaporation; (2) discharge from wells by natural flow and by pumping; and (3) underground leakage.

Natural Discharge at the Surface

Springs.—Flow from artesian springs constitutes one of the most important means of discharge of artesian water in the area. The largest springs at the present time are those south of Meade, along valleys tributary to Crooked creek from the west. The largest spring in the county, known as Big Spring, is situated on the Big Springs ranch, about 3 miles southwest of Meade. From measurements of the cross-sectional area of the discharge channel and the surface velocity of the water the flow from this spring was determined to be about 840 gallons a minute on August 4, 1939. There are several smaller springs along this same valley. The other locality of important spring discharge is in Meade County State Park; here three springs, located within a few hundred yards of each other, were estimated to have an aggregate discharge of about 680 gallons a minute. Several small springs occur along the western side of the Meade district, both north and south of Meade. The total annual discharge of springs in the area at the present time is estimated to be about 2,010 gallons a minute, or about 3,240 acre-feet annually. (One acre-foot is the quantity of water required to cover one acre to a depth of one foot, or 325,851 gallons.)

Although the earlier investigators made few, if any, measurements of spring flows in this area, it is evident that since the early development there has been a marked decrease in the total discharge from artesian springs. Haworth (1897, pp. 54, 55) states that, "The most noted area of springs is in the vicinity of Mr. Simms' ranch, a mile and a half north of Fowler." He describes these springs as being of such extent that cattle became bogged down in them, and sank entirely out of sight. Only small springs exist there now. Haworth also notes that the springs along Spring creek, on the Big Springs and Crooked L ranches, had an approximate annual flow of 3,000 acre-feet. The total annual discharge from these springs in 1939 is estimated to be only about 1,300 acre-feet. Because of insufficient data it is impossible to determine whether or not there had been a decrease of flow from the springs in Meade County State Park; owing to the isolated position of these springs, however, it is possible that their discharge has remained about the same during the last 40 years. In addition to the decreased flow from the important springs it is reported that the flow from numerous small springs has decreased considerably or ceased entirely.

It is estimated that the total spring discharge in the Meade artesian basin has decreased more than 50 percent during the last 45 years, or from more than 7,000 acre-feet a year to about 3,240 acre-feet a year at the present time.

Seepage into streams.—Several of the former springs may now constitute seepages into streams, but the quantity of artesian water discharged in this way seems to be insignificant. The most important seepages are from the body of shallow ground water and are probably supplied in part indirectly from the artesian reservoir. The quantity of artesian water discharged in this way is included in the estimate for underground leakage given below.

Transpiration and evaporation.—There seems to be little or no direct loss of artesian water by transpiration or evaporation. Both of these processes play an important part in the discharge of shallow ground water in the basin, and therefore have an indirect bearing on the artesian reservoir. The quantity of water lost by this means is included in the estimate of underground leakage given below.

Discharge from Wells

Flowing wells.—Flow measurements were made on 180 artesian wells in 1939. These measurements were made by catching the discharged water in a container of known volume—in most cases a one-gallon can—and determining with a stop watch the length of time required to fill the container. Some of the larger flows were measured in five-gallon cans and a few were measured in large drums that had been calibrated by filling from a one-gallon can. The flows were found to range from a few drops a minute to about 100 gallons a minute, and the average discharge is about 7 gallons a minute. The total annual discharge from flowing wells is about 3,230 acre-feet. In 1898 or 1899, Johnson (1901, p. 726) estimated an aggregate flow of 4 second-feet, which would amount to 2,896 acre-feet annually. These figures indicate only a small increase in the total annual discharge from flowing wells in the area during the last 40 years.

Nonflowing wells.—Of the total discharge of artesian water in 1938, approximately 206,100,000 gallons, or about 630 acre-feet, was brought to the surface by pumping. Most of this water was pumped for municipal, industrial, and irrigation supplies. Owing to the facts that the use of pumped irrigation wells is a relatively new development in the basin, and that the quantity pumped for municipal use has increased, it seems safe to conclude that the quantity of water pumped in this area probably has increased by more than 50 percent during the last 15 years.

Relation of spring flow to well discharge.—It is estimated (p. 30) that the total discharge from artesian springs has decreased by more than 50 percent, or by about 3,760 acre-feet annually. The total annual discharge from artesian wells in the area is now about 3,860 acre-feet annually (3,230 acre-feet from flowing wells plus 630 acre-feet from pumped wells). This indicates that the total present discharge of artesian water in the basin is only slightly more than the total discharge prior to the widespread development of artesian wells. This fact is particularly important in considering the relatively insignificant decline in head that seems to have occurred during this same period.

Underground Leakage

An undetermined quantity of water is discharged from the artesian water-bearing beds by upward leakage through the confining beds into the shallow-water reservoir. The fact that the upper seal in this area may not be complete was first recognized by Johnson (1901, p. 727). These confining beds are composed of silt and clay, and a small amount of water under artesian pressure probably migrates upward through them. Leakage also occurs by way of abandoned and improperly constructed wells and along minor faults and fractures produced by the irregular settling of these unconsolidated sediments in response to solution of underlying salt beds. It is probable that recent geophysical exploration for oil has added to the leaks in the upper confining beds. Holes of small diameter were drilled into the surficial deposits and charges of explosive were set off at various depths below the surface, and it is probable that in the subsequent plugging of some of these holes the confining bed was not completely sealed. Some of the natural openings through confining beds are sufficiently large to allow water to issue at the surface as springs. In such places the quantity of water discharged is measurable at the surface and is not included with the underground leakage.

Summary of Discharge

It is believed that if consideration is given to the water discharged from the artesian water-bearing beds by upward leakage through the confining beds, along faults, and through defective and abandoned wells, the total annual discharge of artesian water may be estimated at about 10,000 acre-feet. The available discharge data are summarized in table 2.

Table 2.—*Summary of discharge of artesian water at the surface*

Source	Quantity in acre-feet
Springs	3,240±
Flowing wells	3,230
Nonflowing wells	630
Total measurable discharge	7,100±

RECHARGE

The area of recharge of the artesian-water bearers is inferred to lie to the north and west of the Meade basin. This is indicated principally by three observations: (1) The piezometric surface slopes from northwest to southeast; (2) as shown in figure 2, the water-bearing rocks dip the same direction; and (3) recharge from the east is prevented by a fault along the east side of the basin, and the water table east of the fault is lower at many places than the adjacent piezometric surface to the west. The stratigraphy and structure beneath the high plains to the northwest are not yet completely known, but it is evident that the plains surface in the Meade basin is not underlain by more or less typical Ogallala strata, as has been assumed. The exact location and extent of the recharge area can be determined only by future geologic studies.

The quantity of water entering the artesian aquifers as recharge may be regarded as approximately equal to the total annual discharge from these beds. The estimated total discharge from the artesian water-bearing beds is 10,000 acre-feet annually, and it is reasonable to conclude that about an equal quantity of water enters these same beds each year as recharge.

SHALLOW GROUND WATER

OCCURRENCE

In 1911, Parker (1911, p. 43) wrote that, "The whole artesian valley is supplied with the ordinary ground water, which is found at 5 to 15 feet below the surface. Its abundance is not known, for no one cares to use it."

The shallow ground water in the Meade basin is nonartesian, or unconfined. In most wells this water does not rise above the point at which it is first encountered, and so the static water level coincides with the upper surface of the zone of saturation, or the water table.

Shallow water is obtainable over most of the area of the Meade basin (in the Meade, State Park, and Big Springs ranch districts); however, there are some localities in which the surficial deposits, down to the shallowest artesian aquifer, are so fine grained that only a very small quantity of water is obtainable from wells.

THE WATER TABLE

Detailed information as to the position of the shallow water table was not obtainable. Since the early development of artesian water in the area very few shallow wells have been constructed, and many of those formerly in use have been abandoned and filled. Consequently, it was possible to measure the depth to water level in only five shallow wells in the Meade district, and one in the State Park district. Although little can be determined concerning the shape of the water table from these meager data, a few facts are known. In the northeastern part of the Meade district the water table lies 8 to 30 feet beneath the land surface, and the piezometric surface in most places is 10 to 15 feet above the water table. In the western and southern parts of the basin the difference in elevation of the two surfaces seems to increase. The relationship of the water table to the piezometric surface is shown in figure 4.

In the State Park district at the one well in which a shallow-water measurement was obtained, the depth to water level was 2.8 feet below the land surface, and the artesian head at the same point was 5.2 feet above the land surface.

In contrast to the piezometric surface, the shallow water table seems to have been depressed considerably since the early settlement of the area. Residents of the area report that many shallow wells in the basin went dry before they were abandoned. Depression of the shallow water table is also indicated by the progressive decrease of the area on which alfalfa can be grown successfully by natural subirrigation. Alfalfa was the most important crop in the Meade basin 50 years ago. The steady decline in this crop is probably attributable to the somewhat rapid lowering of the water table. The shallow water reservoir rock has a low permeability and, as the rate of recharge is slow, the water table has seemingly not risen far, if at all, in recent years in spite of the extensive reduction in the acreage of alfalfa.

RECHARGE

Precipitation.—Rainfall on the surface of the basin itself and on the upper drainage basin of Crooked creek plays an important role in recharging the shallow water of the basin. After a heavy rain, water collects in numerous shallow depressions that are scattered over the floor of the basin, and Crooked creek and its tributaries overflow into them. Although the surficial material in most places is relatively impervious and the rate of evaporation from the shallow ponds is rapid, a small part of the precipitation percolates downward, reaching the water table.

Flowing and irrigation wells.—Downward recharge by percolation of water from the surface is augmented by water discharged upon the surface by flowing wells, many of which are allowed to flow continuously throughout the year. In the irrigated areas water from deep pumped wells is spread over the surface during certain periods of the year, and although a large part of this water is lost in the atmosphere by evaporation and transpiration, a small part of it probably reaches the water table.

Leakage through confining beds.—Upward leakage through the confining beds from the artesian aquifers seems to have been the most important source of water for replenishing the shallow water in the past. It occurs as upward migration of artesian water through the sediments themselves and through fractures, minor faults, and openings produced by drilling. Such recharge has not been sufficient to maintain the water table at the surface of the ground, owing to the high friction of flow through such restricted passageways, and the large natural discharge from the shallow water reservoir.

DISCHARGE

Transpiration and evaporation.—At least since the settlement of the area, transpiration by plants and direct evaporation probably have accounted for a large part of the discharge from the shallow water reservoir. Most ordinary grasses and field crops obtain water for their growth from the upper few feet of soil (Meinzer, 1923a, p. 26). Corn, wheat, and barley probably do not use water from depths of more than 7 feet. Alfalfa, on the other hand, develops roots that may penetrate 30 feet or locally even much greater depths in order to reach the water table. It is reported that in the early years of settlement alfalfa was raised over the Meade basin generally, but during the last 40 or 50 years production has declined sharply.

Wells.—Withdrawal of water by wells from the shallow water-bearing beds is quantitatively insignificant now and probably it has never been very great. A few stock and domestic wells account for the total withdrawal of water by this means.

Seepage into streams.—The part of the total shallow water discharge not accounted for by transpiration, evaporation, and pumpage from wells, passes as seepage into the surface streams of the area. The total quantity of water thus contributed to the surface streams is not known, but it was formerly larger than it is now. The small amount of present seepage into surface streams is indicated by the fact that parts of Crooked creek in the Meade basin are dry during part of the year. North of Fowler several fields along the valley flat of Crooked creek have been equipped with tile drainage pipes, the discharge of collected water systems emptying into the creek. The quantity of this induced seepage ranges within wide limits seasonally, but it rarely stops entirely.

QUALITY OF WATER

During the field season of 1939 I collected 24 samples of ground water from Meade county, most of them taken from flowing wells in the artesian basin. The samples were analyzed by Robert H. Hess, chemist in the Water and Sewage Laboratory of the Kansas State Board of Health. Approximately 40 additional samples of water will be collected during the field season of 1940, and all analyses will be published in a later report. Only a brief summary of the quality of the waters in the basin is given here.

The artesian waters of the Meade area are only moderately hard, and the hardness is chiefly carbonate hardness. In most places the chloride content is less than 10 parts per million, and the fluoride content less than 2 parts per million. A marked change in the quality of the water occurs just east of the Crooked creek fault, south of Meade. Here the ground waters contain considerably more chloride than those to the west, the maximum determined amount being 315 parts per million. Except for the increased quantities of sodium chloride, the waters east of the fault are similar to those in the Meade basin. The chloride content decreases gradually eastward from the fault, and, except for the wells that draw water from the underlying Permian rocks, the hardness remains about constant.

UTILIZATION OF WATER

The total discharge of artesian water from springs and wells, as stated above, is estimated to be about 2,300,000,000 gallons, or about 7,100 acre-feet, annually. About 9 percent (630 acre-feet) of this amount is pumped and the remainder (6,470 acre-feet) flows out on the surface from flowing wells and springs. Of the water brought to the surface by pumping, somewhat more than half, or about 5 percent of the total (355 acre-feet), is utilized for public and industrial supplies, and includes the small part pumped in this area for domestic and stock supplies. The remainder of the amount pumped, constituting 4 percent (285 acre-feet) of the total, is used for irrigation.

The remaining 91 percent of the total consists about equally of discharge from flowing wells and from springs. Several large springs in Meade County State Park supply water for fish-hatchery ponds and for the irrigation of young trees and shrubs, the excess water being used to maintain the level of the lake. The springs also supply the water used by the CCC camp located in the park. Thus the entire discharge of the artesian springs in the State Park is utilized, and amounts to about 16 percent (1,140 acre-feet) of the total water discharged to the surface in the entire area. Water from some of the other large springs is used to a small extent for stock water and irrigation.

Only part of the water supplied by the flowing wells is put to any specific use. Although no attempt has been made to segregate the various uses of this water, an amount representing about 25 percent (1,770 acre-feet) of the total annual discharge in the area from wells and springs is used for domestic, stock, and irrigation purposes. The remainder, amounting to about 50 percent of the total annual discharge, or about 3,550 acre-feet, flows out at the surface and is more or less wasted. This unused water leaves the area as run-off, or by transpiration and evaporation, or it enters the ground to recharge the body of shallow ground water. Plate 4B shows an abandoned well in which the casing has been broken off below the land surface. A bog has been produced in the field, part of the water evaporating and part sinking into the ground.

A summary of the several uses of artesian water in this area for 1938 is given in table 3.

TABLE 3.—*Summary of estimated uses of water from wells and springs in Meade county*

Use	Percent of total	Acre-feet per year
Pumped water—		
Municipal and industrial	5	355
Irrigation	4	285
Total pumped	9	630
Flowing water (from springs and flowing wells)—		
Meade County State Park	16	1,140
Domestic, stock, and irrigation	25	1,770
Wasted	50	3,550
Total flow	91	6,470
Total	100	7,100

FUTURE DEVELOPMENT OF THE ARTESIAN BASIN

During the last 12 years irrigation from pumped wells has been started in the nonflowing part of the basin, and many of the residents of the Meade flowing-well district have become interested in the possibilities of irrigation from large pumped wells. For this reason it is desirable to discuss briefly the probable future groundwater supply of the area. As was pointed out above, during the last 40 years the decline in head seems to have been small and the total discharge of artesian water on the surface seems to have remained nearly constant. It is evident that the maximum quantity of water obtainable in the basin, from wells and springs, without depressing the head sufficiently to restrict the area of artesian flow appreciably, is only about equal to the present total discharge, or about 7,100 acre-feet annually. It has been demonstrated (p. 28) that large-scale pumping in the flowing-well area depresses the piezometric surface for a considerable distance around a pumped well. If a large number of pumped wells were installed, it seems altogether possible that the head of the artesian water would be depressed sufficiently to cause all flows in the basin to cease.

The question now arises as to the probable quantity of water available under such conditions of heavy pumping. As pointed out above, the total recharge of the artesian aquifers is equivalent to the total discharge at the surface, plus the underground leakage into the body of shallow ground water. This leakage is subsequently lost by transpiration, evaporation, seepage into streams, and to a very small extent by pumping. Thus the maximum quantity of water that could be recovered perennially by pumping from the artesian aquifers is represented by the total surface discharge from wells and springs at the present time plus the quantity lost by underground leakage. This quantity of water seems to be of the order of magnitude of 10,000 acre-feet a year. During the initial stage of such a pumping program, withdrawal of water from storage would make a somewhat larger quantity available, but added supply probably could be obtained for a few years only.

In considering future irrigation development it should be pointed out that about 3,550 acre-feet of water a year is now discharged upon the surface by springs and wells and is not used. If this water were all conserved and utilized for irrigation at the same rate as in the extensive irrigation projects in Ford county (average 1.69 acre-feet per acre in 1938 according to personal communication from H. A. Waite), an additional 2,000 acres could be irrigated. On the other hand, it is estimated that if the maximum yield of the area were attained by increased pumping from wells, an additional 4,000 acres could be irrigated—or 2,000 acres more than by use of all existing natural flows. In order to recover this additional quantity of water, however, the piezometric surface would of necessity be lowered enough not only to stop all the flowing wells, but also to stop upward leakage into the shallow water reservoir. As has been pointed out, this upward leakage is probably the most important source of recharge to the shallow water reservoir, and therefore this procedure would lower the shallow water table considerably. Before any such development is undertaken in the basin the possible effect of the lowering of the shallow water table on crops grown by natural subirrigation should be studied.

The figures for the maximum number of acres that could be irrigated by the water now wasted and by additional water that could be made available by a large-scale pumping plan are based on the assumption of complete conservation of the water. I am well aware of the fact that complete utilization of the water in this area is hardly possible, and therefore these estimates of acreages should be regarded as maxima that probably could not be attained in practice.

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