DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 6

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS.—HAWORTH

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890, octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891, octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891, octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains a report upon the location and survey of reservoir sites during the fiscal year ending June 30, 1891, by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell, quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892, quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893, octavo, 486 pp.

Consists of three papers: Water supply for irrigation, by F. H. Newell; American engineering and engineering results of the Irrigation Survey, by Herbert M. Wilson; Construction of topographic maps and selection and survey of reservoir sites, by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893, octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

(Continued on third page of cover.)

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS

BY

ERASMUS HAWORTH

WASHINGTON
GOVERNMENT PRINTING OFFICE
1897

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 9, 1897.

SIR: I have the honor to transmit herewith a paper entitled Underground Waters of Southwestern Kansas, by Erasmus Haworth, geologist of the University Geological Survey of Kansas, and to recommend that it be published as the sixth number of the series of Water-Supply and Irrigation Papers.

The field work upon which this report is based was carried on by Professor Haworth during the summer of 1896 in connection with the investigations of the Division of Hydrography. Its object was to obtain detailed information concerning the amount and quality of the underground waters, in order to throw light upon the problems connected with the utilization of these in the development of agriculture upon the Great Plains. Although the investigations were of necessity confined to a somewhat limited area, the conclusions have a general value in showing the limitation to which similar areas of the public domain are subject.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

UNDERGROUND WATERS OF SOUTHWESTERN KANSAS.

By Erasmus Haworth.

INTRODUCTION.

SOURCE AND DISPOSITION OF WATER.

All terrestrial water comes primarily from the ocean, whence it is taken by evaporation. It may then be carried by the winds to the farthest portions of the dry-land areas and deposited on the surface of the ground, principally as rain, but partially as snow, mist, fog, or dew. No ground water available to man in any portion of our globe has had or can have any other ultimate source, whether we consider the water near the surface or that more deeply buried.

Water thus left upon the dry land deports itself in a variety of ways, dependent upon the different conditions under which it is placed. A large portion is evaporated directly from the surface before it has had an opportunity to run off or to be absorbed by the soil or to penetrate to greater depths. Of that which is absorbed, large portions are ultimately dissipated by evaporation from growing vegetation. A second portion runs from the plains and hillsides down into the streams and rapidly returns to the ocean whence it came, while a smaller portion more gradually works its way into the same streams by seeps and springs and reaches the same destination. Other portions soak into the soil and ground and serve as a permanent supply of moisture in the soils and surface coverings; while still other but lesser parts sink below the surface soils and below the roots of vegetation, where they remain a constant source of available water existing in sufficient quantities to more than saturate the ground, and hence become available when drill or spade penetrates it. Each of these several methods of deportment is important to the student of hydrology, and may therefore briefly be considered here.

SURFACE EVAPORATION.

A large but varying proportion of the total rainfall is evaporated from the surface before it has had an opportunity to run off or to be absorbed by the ground. The proportion thus evaporated varies greatly in different parts of the world and under different conditions of season and tillage of the soil. The dry, hot winds, the scorching rays of sunshine, and often the hot soil itself cause evaporation. Summer seasons and arid climates are most favorable for rapid evaporation. In countries where the rainfall is light, the climate warm, and the soil barren of vegetation the little rainfall that does occur is largely evaporated, but in the lowlands adjacent to large bodies of water in cool climates, where the precipitation is abundant, the evaporation is very light. The character of soil and soil covering also has a great influence upon the rate of evaporation. A mulch of any character whatever greatly retards the evaporating action. In cultivated fields a thin mulch of dust or of straw or other litter has this retarding influence, making the condition of tilth an important factor in determining the extent of evaporation.

RUN-OFF.

The water which flows from the plains and hillsides down into the streams has been called the "run-off." The percentage of total precipitation thus disposed of depends upon a number of conditions, such as aridity of climate, amount of moisture already in the soil, rapidity of precipitation, and the general character of the ground upon which the precipitation falls.

Other conditions being equal, the drier the soil the greater its absorptive powers. An ordinary rain falling upon a dry, cultivated field will be almost entirely absorbed; but if the ground is already charged with moisture nearly all the rain will run off the surface and be carried away through the ordinary drainage channels. The per cent of the total rainfall which joins the run-off in humid climates is therefore much greater than in arid climates unless other conditions modify the results. In general, therefore, the proportion of the total rainfall which may be counted on for filling reservoirs in arid and semiarid climates is much less than in humid climates.

The rapidity of precipitation is an important factor in the calculation of the relative percentages of rainfall and run-off. A mild rain continued through many hours will give but little run-off, while the same amount falling in a fourth or an eighth the time will give a greatly increased run-off. Unfortunately the climatic conditions are such in nearly all the arid portions of the world that what little rain does fall comes in the form of hard, driving storms. On the Great Plains of America it is by no means unusual for a 2-inch rain to fall in as many hours, while instances are of yearly occurrence in which 4 inches or more falls within one hour. Under such conditions almost all the water runs off, except in the most sandy places.

The most important of all the conditions named affecting the run-off is the character of the ground upon which the water falls. A loose, porous soil will absorb a large portion of a rainfall, as will also a sandy soil, while a close, compact soil sheds the greater part of it. Here the geologic conditions of a country become important. An area composed principally of a close-grained shale, and a soil resulting therefrom, which generally has a compact clay subsoil, has inferior absorptive properties, while one composed principally of sandstone and sand will let but little water run away.

The flood plains of rivers frequently have little power of absorption. In times of overflow a thin layer of a fine-grained sediment is deposited, which is partially cemented by an organic mucilage produced by the decomposition of organic matter of one kind or another. This material is almost entirely impervious to water, a thin layer of it being sufficient to prevent downward percolation, no matter how sandy the soil is below. Illustrations of such conditions may be found in many places along the valleys of the Arkansas River, the Rio Grande, and other streams, particularly those which rise at high elevations and have a strong velocity throughout their upper course and a low velocity farther downstream.

In times of freshet the muddy water drawn from the streams into irrigation ditches always deposits a film of sediment over the bottom of the ditch, provided its fall is not too great. This fills the little spaces between the grains of sand in the soil and renders the ditch water-tight. Likewise, when such a stream overflows its banks the muddy water deposits a corresponding film of fine mud over nearly the whole of the valley covered by the water, a filling-in process which, continued from century to century, forms an important part of the alluvial soils of the valley. Along the Arkansas Valley such an accumulation of silt has produced beds varying from 1 to 6 or more feet in thickness, a covering that will scarcely let water pass through it until it is loosened by cultivation. The common method of making reservoirs in the valley is based upon the impermeability of the soil to water, and such reservoirs require much less puddling to make them water-tight than those in localities where more sand is present in the soil.

Along the Rio Grande the well-known adobe soils are of the same general character. The adobe is a thin covering, generally from 1 to 3 feet thick, along the river flood plain, resting upon a mass of sand or sandy soil. A pool of water in such an adobe soil will remain in place until evaporated; but should a hole be made through the adobe covering into the sand below, the water will quickly sink.

Many of the upland areas in different parts of the world were at one time the flood plains of rivers, and were more or less covered with such fine sediments, and now constitute close-grained, compact soils, allowing but a small amount of water to penetrate them. Wind action, too, often helps to produce an impervious soil by blowing the finer particles of dust away from some localities and lodging them in others. Generally there is a compensating action here, for the coarser materials left behind form a covering with a high degree of absorptive power, and therefore decrease the amount of run-off.

SOIL MOISTURE.

A portion of the rainfall is consumed in keeping the soil moist. The ground can yield no water unless a portion of it is more than moist. It is not the amount of water a soil or stratum holds that is important, but the amount it will give up when penetrated. In recent years considerable work has been done in determining the capacity of different soils to hold moisture. This is an important investigation in connection with agriculture, and in calculating the percentage of run-off, but in connection with the problem of available underground water supply it is of less value, because it does not show the proportion of water that will be given up when the materials are punctured by the drill. In fact, the best character of ground for producing a good water supply is one which will not admit of a high percentage of soil moisture, but rather a soil that will readily yield almost all its moisture to the general water reservoir below. A sandy soil or a loose, open sandstone will gather large quantities of water from the rainfall and pass it down to the reservoirs below, where it is held available, while a soil with a greater capacity for holding moisture will yield less to the pump.

AVAILABLE GROUND WATER.

Throughout the humid regions of the world, with few exceptions, water can be found everywhere within a few feet of the surface, so that it is the common experience to obtain water for domestic uses by digging from 5 to 100 feet. This condition is so common that the masses of mankind throughout the humid areas of the world have come to look upon it as certain, and rarely give it any special consideration, and the industries and operations of civilized man are based upon a belief in the perpetual continuance of such condition.

The available ground water in all localities and under all circumstances is the residue of the rainfall after the portions mentioned above—the evaporation, the run-off, and the soil moisture—have been deducted. Each of them must be supplied, in whole or in part, before any available ground water can exist. In many places there is an underground movement, so that the available water under a given area may have fallen only in part as rain upon the surface at that place; yet somewhere and sometime it must have fallen as rain, some of which was evaporated, some carried off by the drainage, some held as soil moisture, and the remainder sunk below the surface, below the reach of growing plants, and held in an underground reservoir, inviting the spade or the drill to discover it and the pump to lift it to the surface. But even yet the wastes are not satisfied, for portions of this underground water are carried by underground drainage to the surfaces of ravines and bluffs, bursting forth as springs, and thus joining the general body of the run-off.

GEOLOGIC CONDITIONS GOVERNING GROUND WATER.

The stratified rocks of the earth are a heterogeneous mass of matter arranged in layers one above another. The strata are not coextensive with the surface of the earth, but some of them occur at one place and others at other places, each lapping under or over its neighbor, quite like shingles on a roof. Some of the strata are composed of loose, porous material, such as sandstone or badly fractured limestone, so that water can readily pass through them. Others are formed from the accumulation of finer sediments, such as clay and the finest of silt, while still other parts of the earth are composed of the crystalline rocks, such as granite, porphyry, and syenite. No substance known forming a constituent part of the earth is entirely impervious to water. The solid granite and the compact limestone and marble alike have moisture within them, commonly called "quarry sap," showing that water penetrates them. Compact, plastic clay is perhaps about as good a nonconductor of water as is known, while beds of sand and gravel are at the opposite extreme, allowing water to pass through them with relatively little resistance. The surface of the ground almost everywhere has a covering of residual soils, sands, and clays, varying from a few inches to many feet in thickness. This usually has high absorptive power for water, so that a large amount is received from the rains as they fall.

When the surface water comes in contact with the porous strata it is absorbed and immediately begins moving downward, or as nearly in that direction as possible. Sooner or later it comes in contact with an impervious stratum below, and thereafter can only move laterally down the incline of that surface. The rapidity of motion will now depend principally upon two conditions—the angle of inclination of the impervious surface and the degree of porosity of the material through which the water moves. Should this be a mass of gravel or sand or porous sandstone, the motion will be sufficient to be easily detected, and somewhere farther down the water will reappear as springs or seeps, supplying the streams with "living" water. It matters not whether this porous stratum is on the surface of the ground in the form of a soil covering or whether it is deeply buried by impervious layers, the water movement within it will be practically the same. When the latter condition prevails and a sufficient head is produced, a well drilled through the upper and impervious layers allows the water to rise through the drill hole, and an artesian well results. Where the porous layer is on the surface, as is often the case on the Great Plains, no pressure or head can be produced, for the water is simply running down an inclined surface with nothing above to prevent it from rising, so that it would be comparable to water flowing down a wide open trough.

A good illustration of this latter condition is found near the University of Kansas, at Lawrence. In 1893 the university authorities decided to own their own water supply. An investigation was therefore made to ascertain whether a sufficient supply could be had within a reasonable distance of the buildings. It was found that on the south side of the hill a large amount of débris produced by the decomposition of the limestone and shales of the hill had accumulated on the hillside, and that it was well charged with water. Fig. 1, drawn to scale, shows the conditions. The hill is composed principally of a fine-grained impervious shale, with a limestone mass (A) on top. At the boiler house, 300 feet south of the brow of the hill, the débris was found to be 40 feet deep. A well dug here (B) during the driest part of a dry year showed that the amount of water was not very considerable. At points farther down the hillside the water was more abundant. Finally, a large well was put down at the point C, 1,000 feet south of the brow of the hill, and galleries about 6 feet in height were run both east and west, just on top of the undecomposed shale, to intercept the

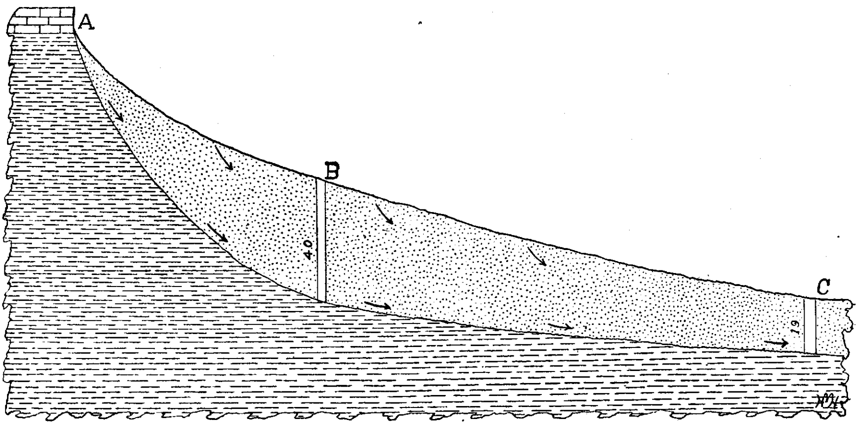


FIG. 1.—Diagrammatic section of hill at Lawrence, Kansas.

water as it moved down the slope and drain it into the well. It was reasoned that this greater distance from the summit of the hill was necessary because the gathering area above the boiler house was so limited that an insufficient amount of water would be obtained at that point, but that with the added distance to where the well was finally located a gathering area of sufficient extent was passed, considering that the average rainfall at Lawrence is a little more than 35 inches annually. Southward the thickness of the débris gradually decreases, so that a mile away it is only an ordinary soil above the undecomposed shale. Were the débris a mass of coarse sand, similar to that so often found in the western part of the State, without doubt the water would soon all run down the hillside and appear as springs in many places; but the débris from a mass of shale is principally a clay, which lets the water through it very slowly, and therefore its southward movement is so slow that little reaches the extreme southern limit of the débris.

Yet in the vicinity of the well a water supply is found sufficient to produce 5,000 gallons a day almost all the year, and 10,000 in wet weather, an amount which could be increased indefinitely by extending the east-west galleries.

Here we have a good illustration of the underground water plane having a very concave surface facing upward. Instead of the water lying in the form of an underground lake, with a level surface, it is a mass of water held in the clay in such a manner that its upper surface is nearly parallel with the highly inclined surface of the ground. We may speak of the clay within the body of water as being more than saturated, using the term saturated to mean holding a water content just equal to the largest amount the clay can hold without being compelled to give up a part of it whenever an opening is made into it. When the clay is in this condition and more water is added to it, this extra amount will run out into the opening made.

As the well at the point C was being dug it was noticed that the clay was moist almost from the surface, but that no water came into the well until it had reached to within about 6 feet of the undecomposed shale. Here the point of saturation was reached, and any greater depth passed clay which was more than saturated, that is, had more water within it than it could hold back from running into the well. This extra amount in excess of saturation is the available water in all cases. It is that which has an underground movement, and which is available in so many parts of the world as supply for man.

In the area under consideration, in the western part of Kansas, we find conditions remarkably similar to those just described for Lawrence. We have a broad expanse of country on which rain falls, and has been falling since the close of Tertiary time, and possibly longer. The surface of the ground is usually well adapted for the absorption of large amounts of this rainfall. After absorption the water obeys the laws of gravity and moves downward, except such portions as are used by the growing vegetation and for moistening the soil. The remainder continues downward until it meets with a stratum which is so nearly impervious that it is almost entirely arrested, after which it moves slowly along the upper surface of the impervious floor in a manner similar to the water in the clays at Lawrence. This floor lies at varying depths in different parts of the Great Plains area, sometimes so deep that the upper surface of saturation can not be reached within 200 feet, while at other places it comes entirely to the surface of the ground.

LOCATING GROUND WATER.

The ability to locate ground water is a qualification desired by many and possessed by few who do not understand the principles governing ground-water movement. The "open sesame" of mythical times gave way to the wand of the wizard, an instrument still employed in many parts of the civilized world, usually in the form of a forked twig from the bough of a tree, but occasionally a branch, forked or otherwise, from the bough of some particular tree or shrub. In a majority of cases, predictions in humid climates made by the use of the wand prove to be correct unless impervious material is met with in digging, for the whole ground is more or less saturated with water.

As above stated, the water which falls as rain or snow is partially absorbed by the surface materials and starts on its downward course under the influence of gravity. The laws governing its movements are identical with those which govern the movement of surface water. When impervious material is reached the water is arrested in its movements unless it can pass down an inclined plane, the surface of the impervious mass. If limestone or granite or other solid rock is reached, the water will follow the fissures in the rock, and will often ultimately be brought to the surface as springs along ravines and hillsides.

The proper way of considering the matter is to look upon the whole of the subsurface part of the ground as containing available water except where impervious materials exist. If a heavy bed of shale is found which is close-grained and compact, it is useless to look for water within it. Many examples are met with in mining operations which illustrate this, a few of which may be cited. In mining for rock salt at Lyons, Kansas, a mass of loose surface material was found to extend downward for nearly 300 feet. This was so thoroughly charged with water, particularly near the bottom, that it interfered seriously with the mining. Below this a bed of fine-grained Permian shale was reached, in which the salt is found. This shale is particularly impervious to water, as is shown by the fact that no water has come into the shaft since the surface water was shut out, although the shaft is 1,000 feet deep. Similar conditions are found in drilling for oil and gas in Kansas and elsewhere. Often a heavy bed of shale or a solid body of limestone is met which has no water whatever within it. The gas fields of Indiana likewise have similar conditions. Here, after passing through a few hundred feet of water-bearing materials, a 300-foot bed of fine-grained solid shale is found lying immediately over the Trenton gas-bearing limestone. This shale is impervious to water, and lets none of the surface water pass downward through it, and none of the deeper-seated water pass upward. It is so dry that water has to be added while drilling in it.

The existence of such shale beds, or beds of other impervious materials, can generally be recognized by the geologist by surface conditions if he is familiar with a sufficiently wide range of country; otherwise the drill is the only means of discovering it. Wherever large masses of such materials, or of granite or other solid and impervious crystalline rock, cover a wide extent of country, the only hope of finding ground water is along the ravines and hillsides, where a sufficient amount of surface débris has accumulated to hold the local rainfall, as already explained for Lawrence, Kansas.

Where limestone is the prevailing rock it usually has so many fissures that water finds its way into them and works downward and out through openings along the creeks and bluffs, so that much of it finally joins the run-off. Under such conditions well digging is hazardous, often resulting in failure. It is here that the term "vein" of water is applicable, a term which is generally used indiscriminately, whether the water occurs in veins or in broad beds of water-bearing materials. Here the "water witch" is in most demand.

In such countries careful observation of surface conditions will usually yield good results. The water slowly but surely dissolves the limestone, so that a falling in of the materials above to an appreciable degree is frequently noticed, often resulting ultimately in the production of a ravine of considerable size. The number of fissures along the bluffs will give some idea of the abundance of fissures generally, and therefore of the probability of one being found where a well is desired. But best of all and surest of all in such localities is it to search for places where the surface covering is heavy enough to hold the surface water. Few places in humid climates can be found where this is not sufficient for all ordinary purposes. By far the greater proportion of all the well water and spring water of the world comes from this source. On the great plains of western Kansas the surface covering is generally abundant and heavy, and holds surprisingly large quantities of water. To give a detailed description of the water supply of a limited portion of the plains of Kansas is the object of this paper.

GEOGRAPHY OF THE AREA.

The area discussed in this report is located in southwestern Kansas, and covers 1 degree each of latitude and longitude. It is bounded on the east by the one hundredth meridian west from Greenwich, on the west by the one hundred and first meridian, on the south by the thirty-seventh parallel, and on the north by the thirty-eighth. It includes all of Meade County, nearly all of Seward, Haskell, and Gray counties, about one-third of Ford County, and one-fourth of Finney County. Its eastern limit is approximately the line between ranges 24 and 25 west of the sixth principal meridian, and that on the west side near the middle of range 34. Its south line is about the middle of township 35, and the north line is the line between townships 23 and 24. It is, therefore, approximately 56 by 69 miles square, equal to about 3,864 square miles, or about two and a half million acres. It corresponds to four of the United States Geological Survey quadrangles, known as the Meade, Dodge, and Garden, and the one south of the Garden, not yet surveyed.

The Arkansas River enters this area at the northwest and flows across it in a southeasterly direction, passing out 16 miles south of the northeast corner. The Cimarron River passes across the southwest corner of the area, leaving the State near the middle of the southern boundary, but flows near the south line throughout the remaining distance to the one hundredth meridian. There is but one other stream of any considerable consequence in the area, Crooked Creek, a stream which rises near the central part and, after meandering in a manner indicated by its name, enters the Cimarron just south of the State line, near the southeast corner of the Meade quadrangle. Aside from these streams, a few lesser ones occur in the northeastern part of the Dodge quadrangle, which drain northeast into the Pawnee—such as Duck Creek, the Sawlog, and the Buckner.

A fair idea of the elevations of the area under consideration may be gained from the following data: The Arkansas River on the east border is 2,460 feet above sea level, and at Sherlock, in the extreme northwestern corner, its level is 2,860 feet, the river making an aggregate fall of 400 feet while crossing the area. The bluffs immediately north of the river at Dodge are 2,600 feet high, while in the extreme northeastern part the elevation is only 2,460 feet, or the same as that of the river at Dodge. The southeastern corner of the Meade quadrangle, near Englewood, has an elevation of 1,960 feet, and the southwest corner of the area, about 4 miles west of Liberal, has an elevation of approximately 2,900 feet. It is therefore a plain, or table-land, with the western edge nearly horizontal, sloping to the east with an average rate of about 7.1 feet per mile along the north end and nearly 17 feet per mile along the south.

The eastern border, therefore, slopes toward the south, making the southeast corner much the lowest part of the whole area. The elevations immediately adjacent to the Arkansas River are greater than can be found either north or south, except those in the southwest corner of the area, where we have higher land than exists along the river.

PHYSIOGRAPHY OF THE AREA.

GENERAL CONDITIONS.

The general physiographic features are those of a broad peneplain sloping gently to the east, into which, at different places, channels have been worn by recent processes of erosion. All the streams with their tributaries, except Arkansas River, appear to be mere channels cut down into the general plain. The Arkansas, on the contrary, throughout the most of its course within this area, seems to be a channel cut into a ridge extending from west to east, as though at one time the river had built its banks higher than the land on either side and had subsequently deepened its channel and produced a flood plain averaging more than 2 miles in width. Both east and west of here the conditions become more nearly normal, as is shown by tributaries entering the river from both sides.

North of the river, where the surface slopes to the northeast, the northeastern drainage often approaches to within a mile and a half of the Arkansas River. The almost complete absence of any tributaries entering the river from the north is remarkable. On the south the conditions in this respect are not quite so extraordinary. A strip of country varying in width from 4 to 18 miles is covered with masses of sand, which have been blown by the winds in recent times into exceedingly irregularly shaped hills and hillocks. Throughout a part of this area tributaries of the river rise from 6 to 10 miles south and work their way through the sand hills to the river. In most instances, even on the south, the drainage toward the southeast approaches surprisingly close to the bluffs on the south side of the Arkansas River.

In the northeast portion of the Dodge quadrangle the drainage is all to the northeast, the waters of which ultimately enter Arkansas River, near Larned, through the Pawnee. As the surface is inclined fully 10 feet to the mile, these little tributaries have cut their channels from 100 to 150 feet deep, and present sometimes almost precipitous bluffs, which bound the narrow flood plains of the different streams.

Over all the southern two-thirds of the area under consideration the drainage is entirely to the southeast. The inclination of the surface in this direction is quite rapid, averaging along the line from Santa Fe through Meade to Englewood more than 16 feet to the mile. The general appearance of the whole country is that of a broad, level plain, with almost no variations of any kind, except here and there where a tributary of the Cimarron or of Crooked Creek has worn its channel downward into the plain. These channels are usually quite narrow, with very rugged bluff lines, produced by the channels being cut to depths of 100 to 150 feet, and in extreme cases to greater depths. When one is standing on the plain the whole country appears to be level, but to one in a valley of a stream the bluff lines are so rugged and so varied that almost a mountainous aspect is presented. This is particularly the case along the Cimarron in the vicinity of Arkalon and along Crooked Creek and its tributaries almost anywhere below Meade.

CIMARRON RIVER VALLEY.

The valley of the Cimarron rarely exceeds 2 miles in width throughout its course across the Meade quadrangle, but it has scarcely passed beyond these limits when it suddenly widens to an unusual extent. Beginning a few miles above Englewood, it has a valley more than 5 miles wide. North of Englewood is a valley, or an area which seems to be a valley of erosion, 10 or 12 miles wide, now covered to varying depths with sand which has a very little silt and soil intermingled. Such a wide valley appearing so suddenly along the course of a stream is very interesting, as its origin is hard to determine. The bluff lines forming the western and northern boundaries correspond remarkably with those on the south side of the Cimarron. The general appearance of the valley, only a small portion of which is west of the one-hundredth meridian, is that of a valley of erosion, with the sandhills representing the residual sands left behind after the surface drainage had carried away the finer silt and clay.

The Cimarron seems to have reached base-level and to have begun meandering across its flood plain. Beautiful oxbow curves are frequent, and a sluggish nature is everywhere manifest during times of low water. The lesser tributaries usually have deep, narrow valleys, except near where they break through the bluff lines into the Cimarron. Here they often widen into surprising forms, and generally have their flood plains strewn with residual sands retained from the Tertiary beds of sand and clay.

CROOKED CREEK VALLEY AND FAULT.

Crooked Creek, the third largest stream in this area, has some anomalous features which make it interesting. It rises in the eastern part of Haskell County and flows almost due east to near the little village of Wilburn. Here it suddenly turns to the southwest, making an angle of about 60° with itself, to about 20 miles south of Meade, where it bears southeastward to its junction with the Cimarron River. The sharp angle in its course at Wilburn and its southwestern course between Wilburn and Meade, across a country with a maximum inclination to the southeast, are anomalous for a stream in southwestern Kansas. The area in the southeastern part of Meade County is gashed here and there with lesser drainage channels, all of which drain to the southeast in lines approximately parallel with the lower part of Crooked Creek. Some of these lesser channels rise almost on the eastern bank of Crooked Creek, leaving an unaltered table-land along the eastern bank of the creek, often little more than a mile in width, as is well shown on the Meade topographic sheet.

These peculiar physiographic conditions in the vicinity of Crooked Creek, in connection with geological data gathered from wells, led the writer to conclude that local deformation had produced them, and a preliminary notice of the same was published,[1] from which the following extracts may be taken:

The bluff lines along Crooked Creek are quite interesting in character, particularly below Meade. Throughout the portion of its course where it flows east the bluffs on either side of the creek are not especially different from the ordinary. Tributaries from the north are most numerous, but quite a number are found entering the creek from the south in the northwestern part of Meade County. Farther east, opposite the artesian area, no tributaries of any consequence are found on the south, while arroyos of greater or less size are found every mile or two on the north. For 20 miles below the sharp angle at Wilburn scarcely a tributary as much as 2 miles in length enters from the east, while below Meade the drainage streams flowing southeast to the Cimarron rise almost on the verge of the eastern bluffs of Crooked Creek. Throughout this distance many tributaries

[1] Am. Jour. Sci., 4th series, Vol. II, 1896, p. 368.

enter from the west, the most important being Spring Creek, about 12 miles long, and Stump Arroyo, nearly as long.

The general character of the uplands is that of a broad plain inclined to the southeast about 10 feet to the mile. The various drainage channels are cut down into this plain, generally producing abrupt bluffs on each side. From Wilburn to Meade, however, the bluffs of Crooked Creek are far apart, with the whole of the artesian area between. Below Meade the bluffs on the east side of the creek are high and abrupt, often being almost precipitous in character. They have a decidedly new appearance, as though the erosion which produced them was very modern. Almost none of the rounded forms of old age are to be found, but the angular points and steep walls of recent formation are everywhere present. On the western side there is a gently sloping plain stretching from the creek to from 1 to 5 miles away, producing an appearance scarcely duplicated within the State. The general upland plain from 8 to 12 miles to the west of Crooked Creek both physiographically and geologically corresponds with the plain on the east of the creek, which approaches to within less than a quarter of a mile of the creek valley. The general appearance from Meade southward is that of a fault, with the western wall dropped and Crooked Creek occupying a position over the fault line. Northward the whole artesian valley seems to have been dropped downward, leaving an abrupt wall on the west and a more gentle wall on the east. Standing anywhere in the valley, one can see the wall all around. On the west it is considerably over 100 feet in height, while to the east it is somewhat less, but still very perceptible. We have here a valley occupying about 60 square miles which is so different from anything else known in this part of the country that it is exceedingly difficult to explain its origin by attributing it to erosion. The peculiar position of the creek is likewise hard to explain by ordinary erosion. The sharp angle at Wilburn and the southwestern direction for nearly 20 miles across a plain sloping to the southeast are certainly very remarkable, and probably have a cause different from that which ordinarily determines the location and direction of streams. But if in post-Tertiary times a triangular area equaling in size and position the present artesian area could have dropped 100 feet or more, with a single fault line extending southward to beyond the limits of Kansas, thereby changing the direction of Crooked Creek into the present channel below Wilburn, the general physiographic conditions could easily be accounted for.

It should be added that there is a chain of wet-weather lakes reaching eastward from Wilburn to the north of Minneola which may represent the former channel of the eastward extension of Crooked Creek. An examination of the country lends more color to this view than can be gained from the United States topographic sheets, for 20-foot contour lines often fail to represent physiographic conditions of great importance in such studies as these.

Along the upper part of Crooked Creek, from a few miles above Wilburn, the general conditions are those of a stream that has not yet reached base-level. In the artesian area and at all points below, the creek has a valley of considerable width and the general appearance of a stream which has long ago reached its base-level. The numerous ox-bow curves, due to the migration of the channel, are everywhere present. In addition to this, it is generally found that it has built up its banks until they are higher than the adjacent valleys. This is true to a perceptible degree almost entirely through the artesian valley, and is also true, but to a less extent, in the valley below Meade.

The general uplands of the area under consideration have the appearance of a broad peneplain which has been so elevated that a new set of flood plains is now being produced along the various channels. In the western part the inclination of the surface is uniform and gentle, and but few channels of any description are found. The rapid inclination of the surface to the southeast throughout nearly all Meade County and the southern part of Seward County gives so great a fall to the streams that their erosive action is more pronounced, and consequently the surface has been changed to greater depth and a corresponding rugged topography produced. The rainfall is so meager that few of the streams have water in them as much as a quarter of the year. Those which have worn their channels deep enough to come into contact with the general underflow water have springs and seeps in great abundance along them, and pools of living water throughout the entire year. This wearing down probably has occurred, however, since the main part of the erosion was done, and consequently has exerted but a limited influence on the general physiographic features.

SAND DUNES.

One of the interesting topographic features frequently observed is that produced by the sand hills or sand dunes. On the south side of the Arkansas, throughout its entire length in this area, a strip of country varying from 4 to as much as 15 or 18 miles in width is covered by loose sand which has been blown by the winds into the hills and hummocks so common in sandy countries. The area is exceedingly irregular in its southern boundary. In some places it is not more than 3 or 4 miles across, while in others the distance is much greater. Near the western side of the Garden quadrangle the sand hills reach southward from the river almost uninterruptedly to within Haskell County, a distance of from 18 to 20 miles. Immediately south of Garden the sand hills extend only about 7 or 8 miles, where a strip of country is reached on which there is but little sand. But farther east, through the eastern tier of townships in Haskell County and Finney County, another southern projection of the sand hills area reaches from 12 to 15 miles south of the river. Still farther east, in Gray County, south of Ingalls and Cimarron, the sands likewise extend from 12 to 18 miles south of the river, or to within 5 or 6 miles of Montezuma. East of this area again, throughout the remainder of the Dodge quadrangle, the sand hills area gradually contracts in width, so that immediately south of Dodge it is only 4 or 5 miles in width. The extent and location of the sand hills are well represented on the topographic sheets of the United States Geological Survey.

In most places, both north and south of the river, outside of the area of river sand hills, relatively little sand is found on the uplands. In the vicinity of Wilburn and Fowler, however, east of Crooked Creek, an area of sand hills exists, covering 50 square miles or more, which has a general appearance similar to that of the river sand hills area. The character of the sand is practically the same, and in most respects the conditions south of the Arkansas River are duplicated.

Again, in the southeast part of Meade County, in the broad Cimarron Valley to the north of Englewood, an area of from 12 to 18 miles in width is covered with sand dunes which are practically the same as those on the south side of the Arkansas. The whole face of the country here for many miles up and down the Cimarron River, except some irregularly shaped areas, is covered with the sand. The exceptions referred to are peculiar and interesting. The greater part of the valley occupied by Colonel Perry's ranch has but few sand hills. Here we have an area 4 or 5 miles across, lying between the sand hills proper and the Cimarron River, the general character of whose soil is that of the alluvial soil common to the flood plains of rivers. Farther down the river to the east the sand hills approach almost to the river bank.

To the north of Englewood, where the sand hills are best developed, a portion of which territory lies within the Meade quadrangle, the sand practically covers the whole face of the country. It is blown into hills and valleys, irregular in outline and position, with no apparent indication of the directions from which the principal winds came. Here and there the sand is still blowing, producing barefaced hills with no vegetable covering, showing that the movement is still in progress. The greater part of the surface, however, is well covered with vegetation, which implies a cessation of the sand movement. The principal sand dunes seem to be residual in character—masses of sand left behind after the finer parts have been carried away by wind and water. For a fuller treatment of this subject the reader is referred to a discussion of the Physical Properties of the Tertiary, by the writer, in Volume II, University Geological Survey of Kansas.

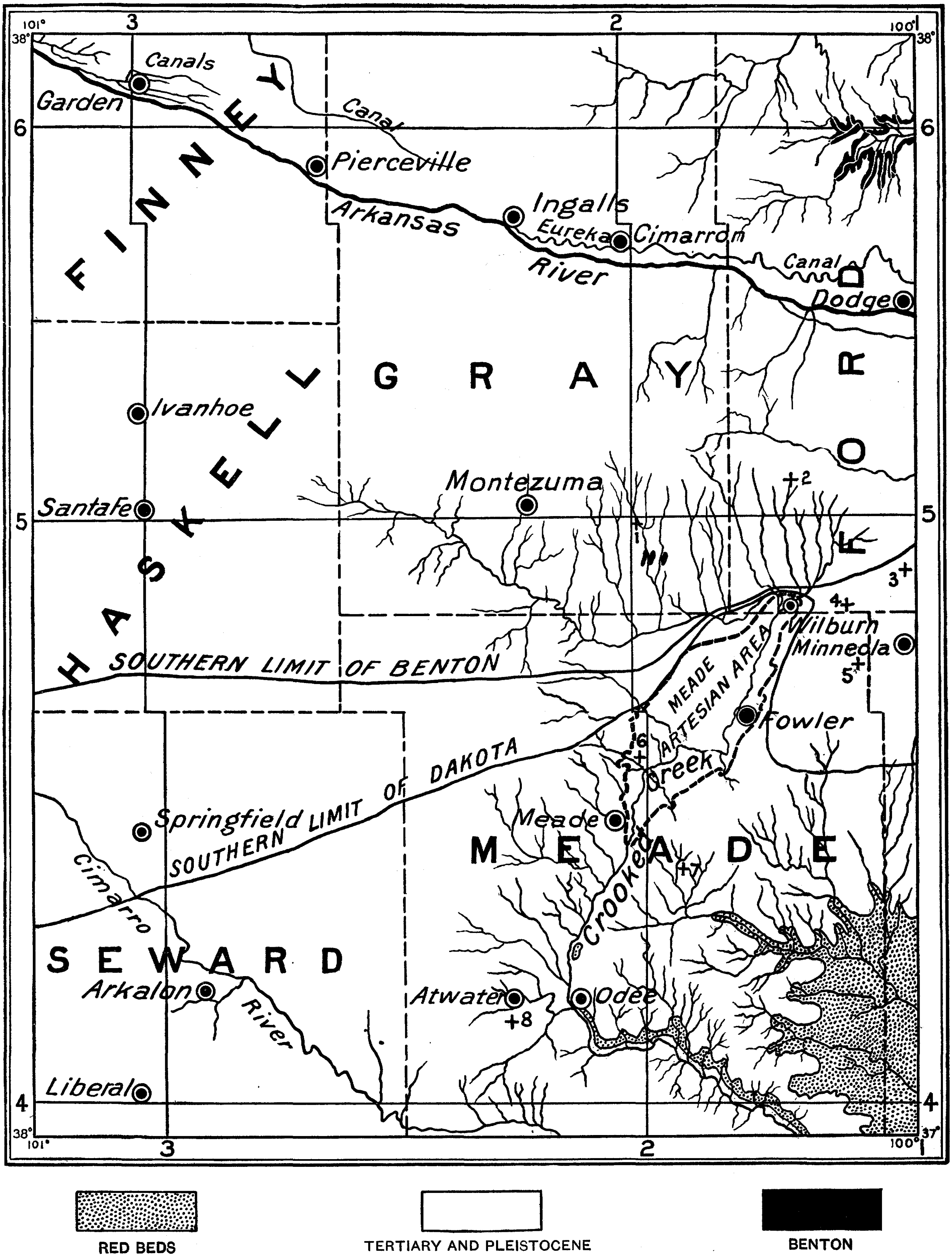
PECULIAR ARROYO EROSION.

A peculiar form of valley erosion is noticed throughout western Kansas, a form thus far unobserved elsewhere by the writer, and one upon which no literature seems to exist. The lesser tributaries to the principal drainage channels in their uppermost course frequently are quite void of water almost the entire year. As a result of this, buffalo grass or blue stem entirely covers the bottom of the arroyos. Such arroyos usually are from 50 to 200 feet in width, even to their very sources. The peculiar and characteristic feature of such arroyos is the shape of the bank at the margins. In almost all instances over the whole western part of Kansas such arroyos have a vertical wall at the outside part of the bank, varying in height from 2 to 3 feet to a minimum of only a few inches. The whole bottom of the arroyo is, as a rule, covered with grass, and seems to have no corrasion marks along it. But on the outer borders the arroyo is separated from the main upland plain by the vertical wall. This feature is sometimes noted to a limited extent along the little sink holes which are so abundant in this part of the country. Some of these depressions, measuring no more than 10 or 15 feet across, have the buffalo grass growing all over them, and have their walls assuming this vertical character, in every respect similar to the walls of the arroyos.

These interesting features of the physiography of the Tertiary plains seem to have been caused by the underground creeping of the looser sands and clay which are not held together by the grass roots of the sod. As water is so rare in the arroyos, the conditions are as favorable for the growth of vegetation in the bottom of the arroyos themselves as on the uplands. When the rains come, the ground is softened probably more in the arroyos than elsewhere, and is thereby made more easily movable. The existence of the water is of so short a duration that the mechanical action of its flow is not sufficient to corrade the surface. But as the inclination is generally quite steep, and as the water softens the clays and sands, gravity will cause a slow, but constant creeping downstream of the material which is not held in place by the grass roots. In this way the effect is similar to that which would be produced were a blanket spread from bank to bank of the arroyo, a blanket which was not removed or carried away by the drainage, but which would allow the grounds beneath to become softened and creep downstream by the influence of gravity. The blanket in question would move vertically downward as the material beneath it was carried away, and the vertical walls at the outside of the blanket would be maintained, constantly growing higher as the materials from beneath were removed by the downward creeping.

GEOLOGY OF THE AREA.

The general geology of this part of the State is now fairly well known. Excepting a few small portions in the southeast, the whole area is covered with Tertiary sands, gravels, and clays. The lowermost formation is the Red Beds, which are exposed along a few of the bluff lines and in some of the lowest valleys in the extreme southeastern part of the Meade quadrangle. Farther to the east, in Clark County and beyond, the Comanche overlies the Red Beds. This formation thins westward, however, so that only a few feet of the black Comanche shales is found anywhere within the Meade quadrangle, and that in the extreme eastern part. It seems entirely to disappear westward, as no traces of it have been found. Above the Comanche lies the Dakota, a formation consisting largely of sandstone. It is not exposed at the surface anywhere within this area, but has been reached frequently by wells, and is known to exist both to the east and to the west, so we are sure it is spread over the whole of the northern and central parts. The Dakota is followed by the Benton, which is largely a limestone formation consisting of beds of limestone alternating with black shale. It is found exposed at the surface in a few of the arroyos of Crooked Creek and along the Saw-



GEOLOGIC MAP OF AREA COVERED BY THIS REPORT.

log in the northeastern part of the Dodge quadrangle, and it probably underlies the northern part of the Meade quadrangle. Covering the whole of these is the thin mantle of the Tertiary sands and gravels.

RED BEDS.

The Red Beds cover wide areas in south-central Kansas. They occupy the surface over the greater part of Clark, Comanche, and other counties to the east as far as Sumner County. They extend westward into Meade County, and are found at or near the surface over five or six townships in the extreme southeast corner of the Meade quadrangle. The broad valley around Englewood, which reaches northwest almost to Cash City, has the Red Beds for its floor. The Tertiary sands and gravels are irregularly scattered over this valley, in some places as much as 50 or 100 feet thick, while elsewhere the Red Beds are exposed on the surface. They constitute the main mass of the hills and bluffs to the west and northwest of Englewood, but on account of the Tertiary capping of the hills and the Tertiary sands and gravels in the valley below, when represented on the map they appear as narrow strips winding back and forth through the course of the various lesser tributaries, unless, indeed, the thin covering of the Tertiary in the valley should be neglected, and the whole represented as the Red Beds. They are exposed in the bluffs on both sides of the Cimarron at Englewood and on both sides of Crooked Creek as far up as Odee post-office, the farthest northwest exposure known covering a small area on the east bank of Crooked Creek about 3 miles above Odee.

The character of the upper surface of the Red Beds is interesting on account of the great irregularities which it presents. An examination of section 1 of Pl. IV will show that the surface of the country drops rapidly southward from near Minneola, and that the surface of the Red Beds likewise drops, inasmuch as it is about parallel to the general surface of the country. Aside from this rapid inclination southward there are other local irregularities. In the Cimarron Valley, where the whole surface is covered by a layer of the soil and silt from 10 to 15 feet deep on an average, occasional places have been found in well drilling where great depressions exist. At one farmhouse, on the land of Colonel Perry, a well was sunk to the unusual depth of 175 feet without reaching the Red Beds, while less than a half mile away they are exposed almost at the surface. Such irregularities are probably due to surface erosion in pre-Tertiary time.

Another irregularity is present which is probably of a different kind. As just stated, the Red Beds constitute the main part of the bluffs on the eastern bank of Crooked Creek from Odee to its junction with the Cimarron, and on the left bank of the Cimarron a few miles below. On the west bank of Crooked Creek the Red Beds are not found. Neither are they found on the south side of the Cimarron until a point is reached near the mouth of Crooked Creek, or almost in line with the trend of the lower part of Crooked Creek, when suddenly they appear on the south side of the Cimarron in forms as massive and prominent as those on the north. This remarkable condition of the location of the Red Beds along Crooked Creek has already been referred to in these pages, and has been explained by assuming a fault line to exist along Crooked Creek, with the strata on the western side dropped to an unknown distance, at least 100 or 150 feet.

In constitution the Red Beds differ from anything else known in Kansas in a few important respects. Their bright color is their most striking characteristic. Wherever they are found they are readily recognized by this feature. No samples of them have yet been analyzed to determine their chemical composition, but it is evident that their brilliant color is due to the presence of large quantities of red oxide of iron intimately intermixed through the whole mass. They vary considerably from place to place, but seem to be composed entirely of clay and sand, very imperfectly bedded, but always colored with red iron oxide. In places far to the east we find beds of sandstone sufficiently cemented to form a low-grade building stone. Elsewhere the sands are entirely wanting. Many samples of the red clay have been examined which apparently contained not even traces of the fine sand.

Gypsum is another constituent, which assumes great prominence in the vicinity of Medicine Lodge and farther to the west. It seems to be well stratified in the vicinity of Medicine Lodge, forming heavy layers from 5 to 10 feet in thickness. These strata have a lateral extent of many miles, and have been important agents in the production of the peculiar and varied physiography for which portions of Barber and Comanche counties are noted. Gypsum has also been formed in many fissures, large or small, which cut the Red Beds in various places. These forms of gypsum are secondary in origin, and seem to have been deposited by infiltrating water probably long after the Red Beds themselves were lifted into dry land.

Salt is likewise scattered irregularly through the Red Beds. It is leached out by the water and is deposited along the salt marshes so common in the Cimarron River Valley to the south of the State line. Probably the salt is irregularly disseminated throughout the material; possibly heavy deposits of rock salt may yet be found beneath the surface, although no positive indication of such has yet been observed. It is certain, however, that in some way, while the Red Beds were forming, conditions were favorable for the accumulation of salt to so great an extent that in the aggregate the amount deposited is very considerable.

Thus far no fossils of any kind have been found anywhere in the Red Beds within this State. Those of Texas have yielded fossils of Permian character, and it is probable that they are of the same age as those of Kansas, although they have not yet been positively shown

VIEW OF RED BEDS BLUFFS, CAPPED WITH TERTIARY, ON JOHNSON'S CREEK, NEAR CASH, MEADE COUNTY, KANSAS.

to be connected. Little true stratification can be noted in the Red Beds in places where their principal component is clay, but when sand becomes more abundant, so as to form a sandstone, the bedding planes are more strongly marked. In the southeastern part of the Meade quadrangle, immediately at the summit of the Red Beds, is a tolerably well defined sandstone from 3 to 6 feet in thickness, called the Basin sandstone, on account of its being so prominent in the walls around the great basin in Clark County. At the southwesternmost exposure of the Red Beds at Odee this sandstone seems to be wanting, while the clay composing them is so entirely free from sand that no grit can be detected by the teeth.

This absence of local stratification is almost lost sight of when we contemplate the Red Beds as covering wide areas. They form a marked horizon between the Comanche or Dakota above and the black shales and buff limestone of the Permian below. Through all western Kansas they incline to the east or northeast or southeast, as is well shown by noting on the map their elevations at different places where found. Where exposed at Odee they have an elevation of nearly 2,400 feet, while in the bluffs near Englewood, in places where we know the measurements are made on the uneroded upper surface, their elevation is but little more than 2,100 feet, making a dip of the upper surface to the east of fully 250 feet in a distance of 15 miles, or an average of near 17 feet to the mile. The same Red Beds were reached in a deep well at Santa Fe years ago at an elevation considerably greater than where they are exposed at Odee, showing that as they extend westward their upper surface rises.

The origin of the Red Beds is pretty well indicated by their character. The large amount of iron oxide, of gypsum, and of salt which they contain, and the total absence of fossils, imply that they are the result of the accumulation of sediment in a concentrated ocean water. Many characteristics of the formations in central Kansas in the Upper Permian point to the existence of an inland ocean which was evaporating more rapidly than it was filling from surface drainage, thus producing a stronger and stronger brine. The large deposits of rock salt in what has heretofore been called the Upper Permian—the salt beds supplying the mines at Hutchinson, Lyons, and other places in the south-central part of Kansas—have probably been formed by the desiccation of an inland ocean. The dark-colored shale which is embedded with the salt in these places likewise implies that sufficient organic matter, either from sea or land, was accumulated with the earthy masses which constitute the shale to give them their black color. As time passed the accumulation of organic matter from all sources was finally prevented. As a result, the surface oxidation of the iron compounds leached from the adjacent land was carried on to an extent sufficient to produce the red color in the sands and clays of the Red Beds.

An important lesson may be gathered from these considerations by one studying the water problem in western Kansas. Should a well penetrate the Red Beds, their fine-grained, compact, argillaceous character makes it extremely doubtful whether water in any considerable quantity can be obtained from them; and still worse, should water be obtained it is almost certain to be so mineralized with salt and gypsum and other soluble products that it will be entirely unsuited for either domestic purposes or for irrigation. Therefore, should anyone when using the drill in the search for water anywhere in the southwestern part of the State penetrate the Red Beds, he should immediately discontinue boring, lest he spoil the character of the water he may have already obtained.

DAKOTA.

The Dakota formation underlies about three-fourths of the area covered by this report. Its position is well shown in the accompanying geologic sections (Pl. IV, p. 42). From these it will be seen that it gradually thickens to the north and thins southward until it entirely disappears. The southeastern limits of the Dakota can not be outlined in detail on account of the heavy mantle of Tertiary which conceals it from view in most places.

In character the Dakota is largely a sandstone formation, so much so, indeed, that it is frequently spoken of as the Dakota sandstone. Every deep well which has penetrated it in southwestern Kansas shows that shales are embedded with the sandstone. The extent of these shale deposits is not known, for nowhere can we find any exposure of the Dakota at the surface. Farther east, in other parts of Kansas where they come to the surface, it is seen that a considerable proportion of the thickness—probably more than half—is shale of some kind. In most places where exposed at the surface in Kansas the sandstone is colored brownish red by iron oxide, and in some places in this area the drill has brought up the same brownish-colored sand. Farther west in Kansas and Colorado the brown color is not so prominent.

The Dakota formation has an unusually great extension. It reaches from the Dakotas southward into Texas, and probably beyond; from central Kansas westward to the "Hogback," near the eastern foothills of the Rocky Mountains, and northwestward into Montana and Wyoming. As a sandstone it is characterized by great uniformity of texture and a small amount of cementing material to bind the grains together. The latter property makes it an open and porous rock, so that it can serve as a great underground reservoir capable of holding a high percentage of water or of allowing a relatively free transmission of water from one place to another within it. Westward from Kansas it is found sometimes at the surface, where it can absorb the rainfall, sometimes in contact with the Tertiary, so that the underground water of that formation mingles with its own, and sometimes buried beneath the Benton and higher Cretaceous formations. It seems to have an unbroken continuity from its exposure in Kansas westward almost to the mountains, throughout which distance it has an average dip to the east of from 5 to 8 feet to the mile. It is, therefore, a most important formation to anyone studying the water problem in Kansas, and will be recalled for a further discussion later in this report.

BENTON.

Above the Dakota lies the Benton, a formation composed of alternating beds of limestone and black or dark-colored shale. The proportion of shale to limestone is probably about as 1 to 4 or 5. The limestone is generally a light buff in color, sometimes inclined to a bluish hue on unweathered surfaces. It is usually much softer than ordinary limestone, but fragments exposed at the surface show perceptible hardening. It always contains large quantities of fossil shells.

The Benton formation is exposed at the surface in the northeastern part of the Dodge quadrangle along Sawlog Creek and some of its deeper tributaries. It is again exposed over small areas in places along the northern tributaries of Crooked Creek in the southern part of Gray County. Aside from these two limited areas it is entirely concealed from view by the overlying Tertiary sands and clays. However, we know from the records of different wells and from its occurrence elsewhere that it underlies the Tertiary formations over the whole of the northern part of this area, reaching southward to the banks of Crooked Creek, and probably farther on the western side.

Many wells reached it at different places in township 29, in the southern part of Gray and Ford counties, some of which penetrated it 150 feet and more without passing through it, while others, farther east and south, proved that its thickness there was much less. The city well at Santa Fe is reported to have found but 13 feet of the Benton limestone. It would seem, therefore, that there is a considerable thickening east from Santa Fe, as shown in the geologic section.

Farther west, in the vicinity of Hartland, Kendall, Syracuse, and Coolidge, the Benton is exposed in the bluffs along the north bank of the Arkansas River, furnishing a limestone which is quarried at different places. There is little room to doubt, therefore, that the Benton underlies the whole of the area north from the southern limits along Crooked Creek to Santa Fe, as already described.

Neither the Benton limestones nor shales are water bearing. Not a single well has yet been drilled in the shales which found water in them. The limestone is a fine-grained mass, capable of holding or transmitting but little water, while the shales are so close and compact that they are entirely incapable of permitting any considerable quantity of water to pass through them. The Benton, therefore, furnishes a floor impervious to the water of the overlying Tertiary sands, a floor preventing the Tertiary ground water from passing downward and the water of the Dakota sandstone from passing upward.

TERTIARY.

The Tertiary formations in Kansas are composed principally of gravel, sand, black sand, clay, and silt, with a small amount of material usually called "volcanic ash." These materials are mixed together in an irregular manner, so that the same relation does not exist between them in different localities. The gravel consists of pebbles varying in size from 4 or 5 inches in diameter to the finest, grading into sand. They are composed principally of the ordinary rock-forming minerals, and seem to be fragments of granite, syenite, porphyry, andesite, rhyolite, basalt, and not infrequently of pure quartz. Their character leaves little room for doubt that they were carried here from the mountains to the west.

The relative position of the gravel beds is variable. In some places they seem to be near the bottom of the Tertiary; elsewhere they are on the summit of the highest hills. A good example of the latter is found along Spring Creek, in Meade County, about 4 to 8 miles southwest of Meade Center. Here the so-called mortar beds—a mass of gravel and sand cemented with calcium carbonate—cap the top of the highest hills in the country. Some of them have the butte form so common where hills of erosion have a hard covering rock on top of a larger mass of soft material.

The sand is composed of sand grains ranging in size from the ordinary coarse sand which grades into gravel down to the finest of sand. The grains are principally of ordinary quartz, but are usually intimately associated with feldspar particles, confirming the teachings of the gravel regarding their origin. The sand is about as well stratified as the gravels already mentioned. In places beds of sand are found well stratified, while elsewhere it is so intimately mixed with clay or gravel that the formation can hardly be called sand beds.

Almost everywhere in the Tertiary are found small accumulations of black sand, which have been slightly segregated by rain water carrying away the finer materials and leaving these little grains behind. Originally they are intimately mixed with the clay and finer quartz sand. The little rivulets of water on the hillside carry away the lighter particles of clay and silt and let the black sand grains accumulate along the wagon tracks of the country roads and the eddies of the small ravines. These black grains are found to be composed entirely of black oxide of iron, principally magnetite, but partially dark hematite. Doubtless they were original constituents of the crystalline rocks of the mountains to the west. When the rocks were disintegrated by weathering and the débris was transported eastward by water, the iron oxide grains were carried along with the

TERTIARY BLUFF AND SPRING-FED POOL, DUCK CREEK, 5 MILES NORTH OF DODGE, KANSAS.

other material and lodged here and there wherever the current velocities permitted.

The clays and silts vary in character from place to place and at different depths. Occasionally almost pure masses of clay are found, beds almost entirely free from admixtures of sand, clay with a high degree of plasticity and in every respect resembling the purest known, except that it contains sufficient impurities to modify its color. Frequently such masses of clay seem to be colored with decaying organic matter, as though during its accumulation such matter in one form or another was present, at least in limited quantities. Elsewhere the color of the clay seems to indicate the absence of organic matter of any kind.

The stratigraphic property of the clay is interesting. In places it exists in broad layers, apparently extending for miles in unbroken beds. Elsewhere it forms lenticular masses, oblong in horizontal dimensions and irregular in peripheral outlines. Sometimes it is interbedded with the heavy gravel and sand beds, and elsewhere seems to be relatively distinct from them.

Along the Arkansas River Valley, near the bluffs north of Garden City, a heavy bed of clay nearly 100 feet thick extends up and down the valley for 4 or 5 miles. Its north-south diameter is usually about half a mile. South of the river 12 or 15 miles from Garden City is another locality in which occur irregularly shaped clay beds or clay bowlders, as they are locally called. During August, 1896, a well was drilled about three-fourths of a mile south of Atwater, in Meade County. It went to the surprising depth of 288 feet, passing through nothing but a light-blue plastic clay almost the entire depth. Other wells on every side of this one, from 1 to 2 miles away, found the usual amount of water-bearing sand at from 20 to 40 feet. Such illustrations could be multiplied until the whole of the Tertiary of Kansas was covered. Everywhere such irregularities exist. Few wells have been made which did not pass through both sand and clay. Even in the sand hills south of the Arkansas River the few wells dug or bored invariably found clay. The State well in the sand hills just south of Cimarron may be taken as an example. At a depth of 23½ feet a bed of remarkably compact plastic clay was reached, about 5 feet in thickness.

In many places in western Kansas and elsewhere on the plains a small amount of a fine-grained matter is found, which is generally called volcanic ash. A few deposits of the same material have been found in this territory. The best exposure known is along a tributary to Crooked Creek, about three-fourths of a mile west of Meade Center, although other lesser deposits are known in Meade County and elsewhere.

Over a large portion of the whole Tertiary area of the plains the surface is covered with a fine-grained soil which has so high a percentage of clay within it that it has a relative high plasticity and other properties that have given it the name "Plains marl." It covers more than half of the surface, but by no means all of it. Neither is it confined to the surface, for often the same kind of material is found interbedded between layers of other materials. It is probably composed of the finest silt and clay particles which migrated eastward during Tertiary time and were lodged here and there wherever the conditions of water velocity dictated. In recent times, also, the winds have exerted a sorting action on the surface materials, which has helped to make the Plains marl more characteristic. The strong winds pick up the finest dust and carry it for miles and deposit it wherever a suitable lodging can be secured. This not only concentrates the finest materials together by movement, but also leaves the coarser soils and sands behind, so that the same process produces sand dunes and sandy soils which are often mere residual products after the finer silt has been blown away.

The structural relations of the different Tertiary materials are far from regular. It is doubtful if there can be any definite stratigraphic relations established covering a considerable scope of country. The gravel and sand are frequently cemented into a moderately firm rock by the presence of a variable amount of a calcium carbonate cement. This cement is sometimes found in the clay as well, but it is most abundant in the sand and gravel, producing a sort of sandstone or conglomerate to which the name "mortar beds" or "grit" is generally applied. Some of the varieties of this are the so-called "natural mortar," which is extensively used throughout the West for making a mortar to plaster with and to roof houses. These mortar-bed horizons are prominent features in many places and constitute the only hard and resisting strata in the Tertiary. The idea so frequently expressed, that they are located near the base of the Tertiary, is correct for some localities, but incorrect for others.

Along the Buckner, in the southwestern part of Hodgeman County, the sand and gravel are as firmly cemented as at any place known to the writer. Here they form a tolerably solid rock which lies at the top of the bluffs on the south side of the Buckner. They are in beds from 10 to 20 feet thick, varying much more than ordinary sandstone beds do. Below them in this locality the bluffs are composed of a looser and finer material. At other places along the Sawlog, near by, the mortar beds are found near the bottom of the Tertiary, and not infrequently resting immediately upon the Benton limestone.

The north bluff line of the Arkansas River from some distance below Dodge westward almost to Garden is protected by a well-developed mass of mortar beds. Throughout the most of this distance three distinct layers of mortar beds can be traced, while in other places four or more may be found. They are composed of cemented sand and coarse gravel, and are separated from each other by beds of clay and fine sand. The weathering processes wear away the soft clay beds more rapidly than the mortar beds, producing a series of narrow terraces along the bluffs similar to those generally observed in places where the limestones and shales alternate with each other, as so frequently occurs in the eastern part of the State.

South of the Arkansas River but little of the mortar-bed material is to be seen until the vicinity of Crooked Creek and the Cimarron is reached. Here we have the same lack of regularity so noticeable elsewhere. The most pronounced form of the mortar beds is often found at the very summit of the bluffs, but by no means always so. In other places they occur midway up the bluff, and not infrequently near the base. The bluffs of Crooked Creek below Meade are good examples of this. On the eastern side of the creek they are very rugged, with frequent instances of mortar beds being well developed, but by no means do they form a constant stratum continuously along the bluff. On the western side the bluff line is not so abrupt, and consequently there is not so good an opportunity for observing the mortar-bed masses. To the southwest of Meade, along the upper portion of Spring Creek, however, some of the hilltops are very distinct, and the erosive forms are significant of hills with a protecting cap of hard material covering softer materials. These can well be studied from the Meade topographic sheet. A few of these hills are particularly noteworthy. On the north bluff of Spring Creek, about 4 miles above Crooked Creek Valley, the mortar beds are found lying at the summit of the hill. The sandy clay underneath is worn away, so that quite frequently the mortar-bed rock projects several feet, forming an overhanging cliff. South of Spring Creek a similar condition obtains. Hill point after hill point stands out in the landscape as a prominent feature, on the top of which a horizontal mass of mortar-bed rock serves as a protection to the soft and easily eroded sandy clays beneath.

Along the Cimarron River from some distance above Arkalon to where the river encounters the Red Beds near Englewood its valley is cut downward into the broad plain to a depth of nearly 200 feet. As one stands on a prominent point on either side of the valley and looks up and down the stream, it is easy to see the line of light-colored mortar beds lying almost at the summit of the bluffs, with the darker colored shales and sands beneath. A more careful examination shows that for many miles along the stream relatively firm rock covers the topmost part of the bluffs, and it is largely to this that the precipitous character so pronounced on either side of the river around Arkalon is due. Beneath the mortar beds are found masses of sandy clay, which constitutes the main mass of the bluffs. At other places, particularly along some of the tributaries of Spring Creek near Meade Center, the mortar beds in a well-developed form are found on low ground more than 100 feet below those capping the hills a mile or so away, with no connection between them.

During the last two years the Kansas State Board of Irrigation has sunk twenty wells in western Kansas, the greater portion of which are confined to the Tertiary. One of the provisions in the contract for the drilling of each well was that a carefully selected and accurately labeled suite of samples should be preserved and delivered to the board, such samples to be taken with sufficient frequency to accurately represent the character of the material passed through. These samples from the different wells were turned over to the writer by the Board of Irrigation and have been carefully examined. This is the first time it has been possible to examine the Tertiary materials at any considerable depth below the surface, except where they are found along the bluff lines of the various drainage streams. They are therefore of more than ordinary importance, and are worthy of notice in this connection.

It was found that little relation existed between the distance from the surface and the size of the gravel. Gravel beds of a considerable degree of coarseness were frequently found near the surface, and the finest sand and clay and silt were not infrequently found near the base of the Tertiary. There was such an irregularity of position shown with reference to any one material, and such a lack of definite relation between the different kinds of material, that it seemed as though but little if any dependence could be placed in any older classification.

In studying the physical properties of the Tertiary it is necessary to emphasize the statement that the so-called mortar beds are simply the sand and gravel and clay materials cemented usually with calcareous cement. The real stratigraphic conditions probably do not depend upon the presence or absence of cementing material, but rather upon the continuity of beds of like material. A stratum of gravel which is not cemented should be considered as important as though it had chanced to have its individual constituents held together by a cementing material of some kind. Yet in our study of the subject we are usually inclined to erroneously regard the beds which are cemented into a firm rock as more important than softer materials. It has been suggested by the writer that the formation of the cementing material has occurred since the deposition of the beds, and that it represents a process of weathering and desiccation still in progress. The ordinary weathering agents produce calcium carbonate near the surface, which is changed to the acid carbonate by rain water containing carbon dioxide washed from the atmosphere. It is then dissolved and carried downward until the dryness of the ground absorbs the moisture, precipitating thereby the neutral carbonate in whatever position it chances to be. As the beds of gravel and coarse sand more freely permit the passage of water through them than do other materials, naturally there would be a greater deposition of calcium carbonate in such beds.

It is doubtful if there can be any regularity discovered between the beds of the different kinds of Tertiary material in western Kansas. The mortar beds occur at all positions from the base to the summit, as do also the sands and the clays. It has been found impossible to trace a bed of any one material very far in any direction. The records of the State wells add to this difficulty rather than lessen it. Neither does the assistance of paleontology lessen the difficulty, but rather increases it. In Phillips County the mortar beds contain skeletons of the rhinoceros and other animals, indicating that they should be correlated with the Loup Fork beds of Nebraska, and that they are about the oldest Tertiary beds in Kansas. To the southwest, in Meade County, a mass of conglomerate, which is as typical a mortar bed as can be found, is rich in fossil horses, llamas, elephants, etc., which paleontologists class as Pleistocene fossils. We therefore have the mortar beds with Loup Fork fossils at one place and with Pleistocene fossils in another, not only showing a lack of stratigraphic continuity, but showing that, after all, the so-called Tertiary of the State may be part Tertiary and part Pleistocene.

WATER SUPPLY OF THE AREA.

In the discussion of waters on the Great Plains it is well to bear in mind the different conditions under which water exists and the different classes into which the ground waters may be divided with reference to the geologic character of the materials in which they are found. Geologically we have two great classes of ground waters. One exists in the Dakota sandstones. It probably has a slow movement eastward, has principally been gathered from the rains falling in the eastern part of Colorado and farther to the north over areas where the sandstone is exposed at the surface, and in its eastward movement passes underneath the Benton, Niobrara, and other superior Cretaceous formations, so that in most places it exists under a pressure sufficient to cause it to rise an appreciable distance above the level at which it is found by the drill, giving artesian wells, or wells decidedly artesian in character.

The other water is that which is commonly known as ground water, sheet water, or underflow, as these expressions are understood by the people of western Kansas. It is confined to the Tertiary sands and gravels. It lies immediately above the impervious Cretaceous or Red Bed floor, and is sufficient in quantity to more than saturate the materials in which it exists for a distance above the floor varying from 5 to more than 100 feet. Throughout the greater part of the plains area, therefore, these two classes of water are separated from each other by all of the Benton and higher Cretaceous deposits. In rare cases, however, the Tertiary rests immediately on the Dakota sands, permitting the Tertiary water and the Dakota water to commingle. Could we exhaust the supply of either one to an appreciable degree, the other would doubtless be drawn upon and a movement would be set up from one into the other. Still, for convenience of discussion and clear presentation of the water conditions, it is desirable that the two classes should be discussed separately.

DAKOTA SANDSTONE WATER.

The Dakota formation consists largely of beds of sandstone the grains of which are generally but poorly cemented together, leaving spaces between them which may well serve as receptacles for water. This sandstone, as before stated, underlies the greater part of the plains area from the British possessions on the north to Texas on the south. Throughout this entire distance it extends westward to the mountainous area, lapping upon the foothills along the eastern slope of the Rocky Mountains or capping the ridge generally known as the "Hogback," lying just east of the mountains in Colorado, as has been so well shown by Gilbert in his recent article on water conditions in eastern Colorado.[1] In this vast area are many localities where the Dakota is exposed to the surface, so that it can gather water from the rains and melting snows and occasionally from rivers which pass over it. The water which is absorbed passes eastward or southeastward or northeastward, the direction depending upon the inclination of its strata in different localities.

This great geologic formation is a continuous underground sheet for thousands of miles in extent, and has been imbibing water from the rains and snows perhaps for thousands of centuries. It has thus become a great reservoir filled with water, the leaks from which are known in the form of springs and seeps along its eastern borders in many places where it is brought to the surface, and also along the banks of streams which have cut their channels downward until the Dakota has been reached.

In a general way it may safely be said that all that is necessary to obtain water on the Great Plains is to penetrate to the Dakota sandstone. This proposition, although true in a general way, may not be verified in every instance. It is reasonable to suppose that a rock mass covering so wide an area is not perfectly uniform throughout. Here and there may be areas where the cementing material is more abundant than ordinary, or where the grains of sand are finer, or where the sand beds in their original form had silt and clay intermingled to a sufficient extent to produce a relatively impervious mass. We know, in part, that such conditions obtain at irregular intervals, and that consequently a drill hole made in such a place will yield but little if any water; not because the great Dakota beds were not reached, but because they were reached at a place where the open spaces between the sand grains had been filled with clay or mud or cementing material so that water could scarcely flow through.

Experience in drilling for water in the Dakotas, in Nebraska, in Colorado, and in Kansas abundantly verifies the statement just made, that in a general way one may confidently expect to obtain water in large supplies wherever the drill penetrates the Dakota sandstone.

[1] The underground water of the Arkansas Valley in eastern Colorado, by Grove Karl Gilbert: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 582.

CHARACTER AND OCCURRENCE OF DAKOTA WATER.

The character of the water obtained from the Dakota sandstone is variable. Underground water is pure or is mineralized, according to its opportunities for dissolving soluble mineral salts. Could water be confined continuously in a perfectly pure mass of sand or sandstone which had no soluble materials within it, and into which no soluble salts could be taken by infiltrating waters, its character would always remain pure. But nature rarely accumulates a mass of sand without having at least traces of soluble materials along with it. Few terranes are known anywhere in the world which can permit waters to percolate through them for hundreds of miles without giving up mineral matter to the water somewhere throughout the course. It is so with the Dakota sandstone, yet not universally so. For some reason which has not been determined, water which is lifted from the Dakota at one place may have a greater or less amount of dissolved mineral salts than water obtained from the same sandstone 50 or 100 miles away.

The natural processes by which the impurities are gathered from the rocks by the water are such that it is exceedingly difficult for one to give an approximate statement regarding the character of the water that may be found at any locality, unless one can be guided by the water which has already been found near by. This, likewise, is substantiated by our limited experience in drawing water from the Dakota sandstone. The wells at Rocky Ford, La Junta, and other places in Colorado are all mineralized to a similar extent. The springs which burst forth from the banks of the creeks and rivers near by are likewise mineralized.

In Kansas the few wells which have been drilled in the Dakota sandstone have produced different degrees of mineralized water, differing materially in composition from one another and from many of the wells of Colorado and Dakota. The artesian water at Coolidge, which is a Dakota sandstone water, is relatively fresh, carrying little more than 24 grains of solution to the gallon. It has but little odor of hydrogen sulphide, and is in every way a desirable water for all domestic purposes. Farther north, in the vicinity of Oakley, a well reached the same horizon and likewise obtained water, but this was so heavily charged with common salt and other soluble minerals that it was practically worthless. An artesian well east of Oakley, in Saline County, drawing large quantities of water from the same Dakota sandstone, produces a water which is somewhat different from either of those, but which is so salty that it is of but little value for domestic purposes or for irrigation.

In the vicinity of Ness City, Larned, and other points near the Arkansas Valley, the few wells which have reached the Dakota have uniformly obtained water of a high degree of purity, well suited for domestic purposes. These examples are sufficient to show the varied character of the water obtained from the Dakota sandstone; in some places the water is of good character, while in others it is highly mineralized.

Thus far but few wells in the special area discussed in this report have penetrated the Dakota sandstone. Not one is known to the writer to have done so north of the middle of the area, and but few to the south. In northeastern Meade County and the southern part of Ford County, four or five different wells are known to have passed through the Benton and reached the Dakota. In every instance the water obtained seems to be very abundant, rises to a height of from

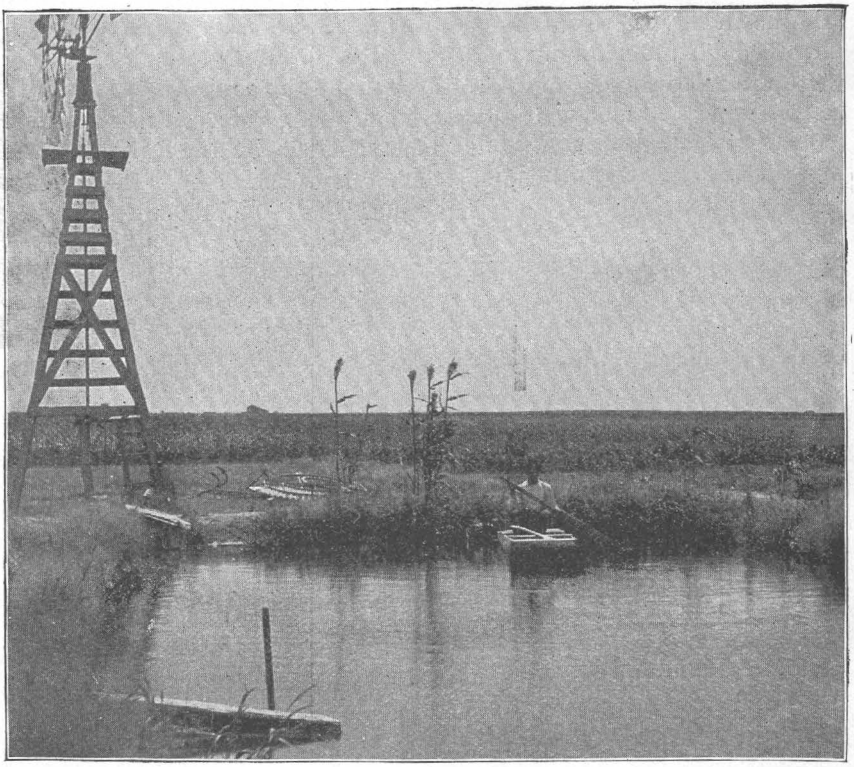


FIG. 2.—Reservoir and windmill pumping water from Dakota sandstone, about 18 miles south of Dodge, Kansas.

50 to 150 feet above where it was first reached, and is of so high a degree of purity that no mineral properties whatever are noticeable to the taste. At Santa Fe, likewise, the city well passed through the Benton into the Dakota and obtained a good supply of water of as high a degree of purity as anyone could desire for domestic purposes. These Dakota waters have not been analyzed, largely because their purity is so apparent that analysis has seemed unnecessary.

By referring to the accompanying map (Pl. I) it will be noticed that the southern limit of the Dakota formation passes from a line near Minneola, on the east, to a point a few miles south of Santa Fe, on the west. It may confidently be stated that the Dakota sandstone extends northward from this boundary under the whole of the area, and that it is water bearing throughout its whole extent. Therefore, a well put down to a depth sufficient to reach the Dakota sandstone will be supplied with abundance of water.

These predictions are based upon the well-known extension of the Dakota sandstone and its property as a water-bearing formation. The depth to which wells at different places will have to be carried to reach the waters of the Dakota sandstone can only be given approximately. By referring to the different geologic sections on Pl. IV it will be seen that the Dakota deposits to the north lie at a similar angle. Our knowledge of this subject is only fragmentary. A deep well at Garden is reported to have reached the Dakota at a depth of 461 feet. This information is all that was available from that part of the area, and section 3 was based upon it.

North of Dodge the Benton is exposed on the surface. Its thickness at this place is not known, but different wells have passed into it from 100 to 200 feet. Farther south, in southwestern Ford County, the Benton is known to be at least 150 feet thick, while farther to the northeast, where it is exposed at the surface, it is estimated to have a thickness of about 400 feet. From these data it was estimated that its thickness at the northeast corner of the Dodge quadrangle is about 400 feet, and section 1 was drawn accordingly.

The areas lying between sections 1 and 2 and 2 and 3 will have the Dakota at about the same distance from the surface. If, therefore, anyone should desire to estimate the depth he would have to go at any particular place to reach the Dakota sandstone, he could obtain an approximate idea by referring to these sections.

The representations here made should be regarded as only approximations, but the best that can be made with our present knowledge. Should a few wells be drilled north of the Arkansas deep enough to reach the Dakota sandstone, corrections could then be made which would make it possible to estimate the distance below the surface at which the Dakota would be reached over the whole area.

ARTESIAN PROPERTIES OF THE DAKOTA WATER.

The Dakota water in all places has artesian properties to a greater or less degree; that is, the water rises through a varying number of feet from the level at which it is found. At Coolidge different wells, when properly cased, gave a constant flow of from 40 to 50 gallons per minute from a 3-inch well. Farther east, at Syracuse, like wells have reached the Dakota and have produced water, but not one has yet been properly cased to determine whether or not the water would rise to the surface.

Northward, in the vicinity of Ness, where the surface elevation is slightly less than the uplands in the vicinity of Dodge, the waters from the Dakota sandstone rise to within from 35 to 75 feet of the surface. It is probable that wells of this character could be sunk in the area under discussion in which the water would rise nearly to the surface, and possibly in some instances an artesian flow might be obtained. Yet one should not depend too much upon obtaining an actual flow, for it is doubtful if such would be obtained anywhere except in the lowest ground. There can be no good reason, however, for doubting that the water would rise to a point rarely more than 100 feet below the surface, and in many instances much higher than this.

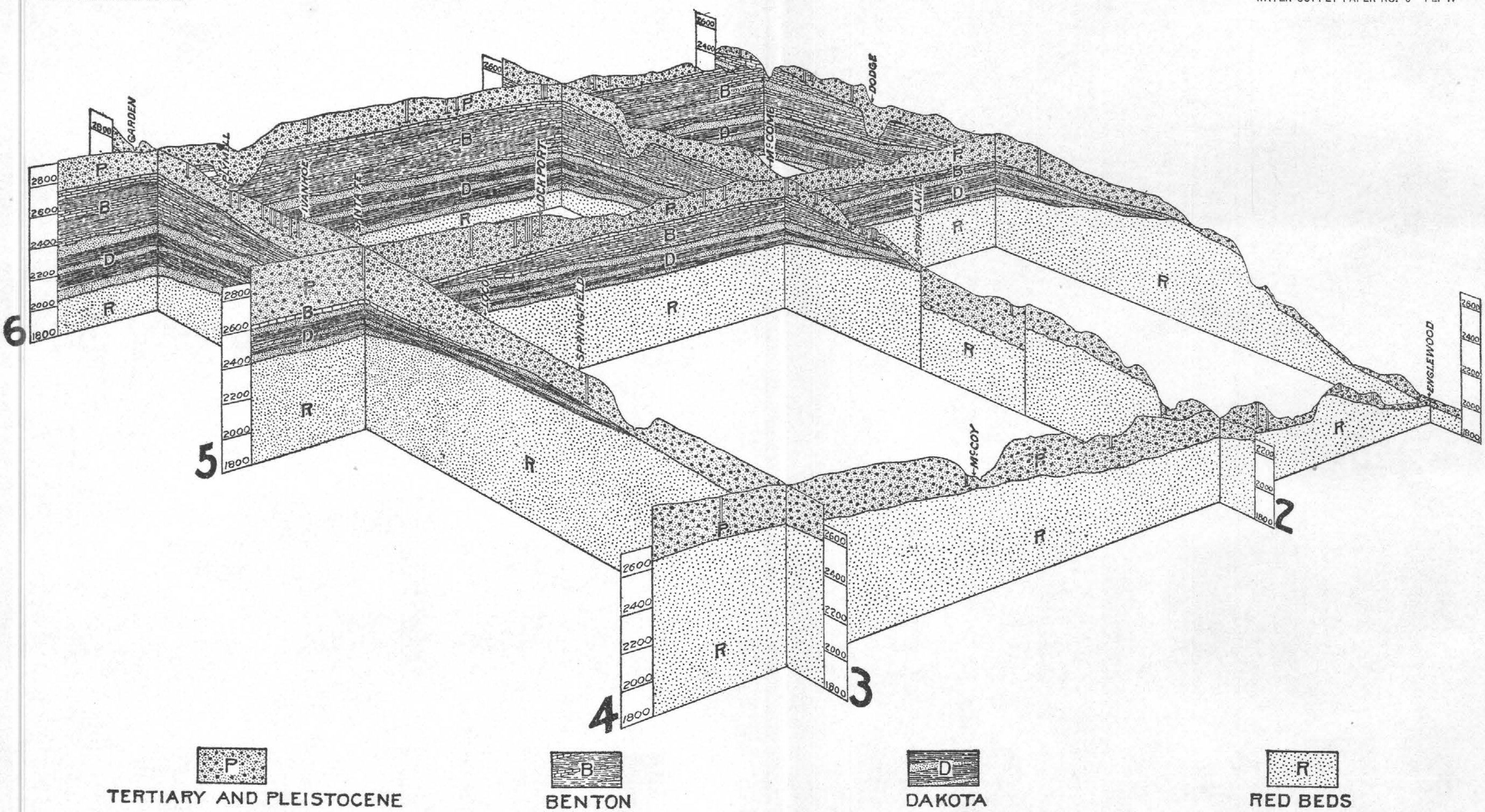
The constant drainage along the eastern borders of the Dakota decreases the water pressure to so great an extent that the height to which it will rise is materially reduced in the Dakotas[1] and Minnesota. The decrease in pressure is frequently as great as 4 feet to the mile near the eastern border of Dakota, a decrease which is attributed largely to leakage. No observation has been made in Kansas to determine the rate of decrease in pressure. Such, in fact, could not be done to any satisfactory degree without a larger number of wells upon which observations could be made.

HOW TO FIND THE DAKOTA SANDSTONE.

Many inquiries have been made by citizens in various parts of Kansas regarding the means by which they could determine how to find the Dakota by boring. As already stated, the whole of the area covered by this report north of the south limit of the Dakota is underlain by the Dakota sandstone. When one drills a well expecting to reach this formation, the Tertiary sands, gravels, and clays will probably first be passed through, and whether or not the Tertiary water is found will depend upon a number of conditions which obtain in the vicinity of the well. Below the Tertiary, limestone and black or dark shale alternating will probably be found. The shale is the material commonly called "soapstone" by the most of the well drillers. In all such cases, as long as the drill is in the shale or limestone the driller should keep on going deeper. Finally the drill will pass through the Benton shales and limestones and enter the Dakota sandstones and clays.

If for any cause or combination of circumstances the desired supply of water is not obtained, he should go deeper, for the Dakota sandstone exists in two or more different layers, separated from each other by clay or shale of varied characters. The only condition which should cause him to stop drilling before the desired amount of water is obtained is that the drill has reached the Red Beds exposed on the surface in the southeast part of Meade County. We do not know how far north these Red Beds extend, but probably they reach far beyond the limits of the territory to which this report pertains. They can be

[1] Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, 1896, p. 666.



GEOLOGIC SECTIONS OF THE AREA DISCUSSED IN THIS REPORT.

recognized when reached by the drill in a number of ways. They are generally free from sand, but not always; they are usually slightly salty or in some other way mineralized, so that they may be recognized by the taste; and they have mixed through them small masses of gypsum, a property rarely observed in the Dakota clays or shales lying between the Dakota sandstones. As soon as the driller becomes satisfied that his drill has entered the Red Beds, operations should be stopped immediately. There is no evidence favoring a hope that the Red Beds will produce water in large quantities, while there are many reasons for believing that the small amount which may be obtained from them will be so highly mineralized as to be entirely unfit for use of any kind.

TERTIARY GROUND WATER.

Under this heading are placed the waters drawn from the Tertiary formations. They include all water that may be found in Tertiary sands, gravels, and clays; that is, all available water lying above the uppermost Cretaceous formation. It is the water which is generally known in the West by the terms "underflow" or "sheet water," names which reflect the popular idea regarding the extent and character of the ground water of the plains. The water is found in greatest abundance just above the Red Beds or the Cretaceous floor. The lower portion of the Tertiary sand and gravel is more than saturated, and available water results. The thickness of the water-bearing beds is variable, sometimes being more than 100 feet, and elsewhere being less than 5, but always the water-bearing horizon rests on the impervious Cretaceous or Red Bed floor, or on a like impervious floor of clay.

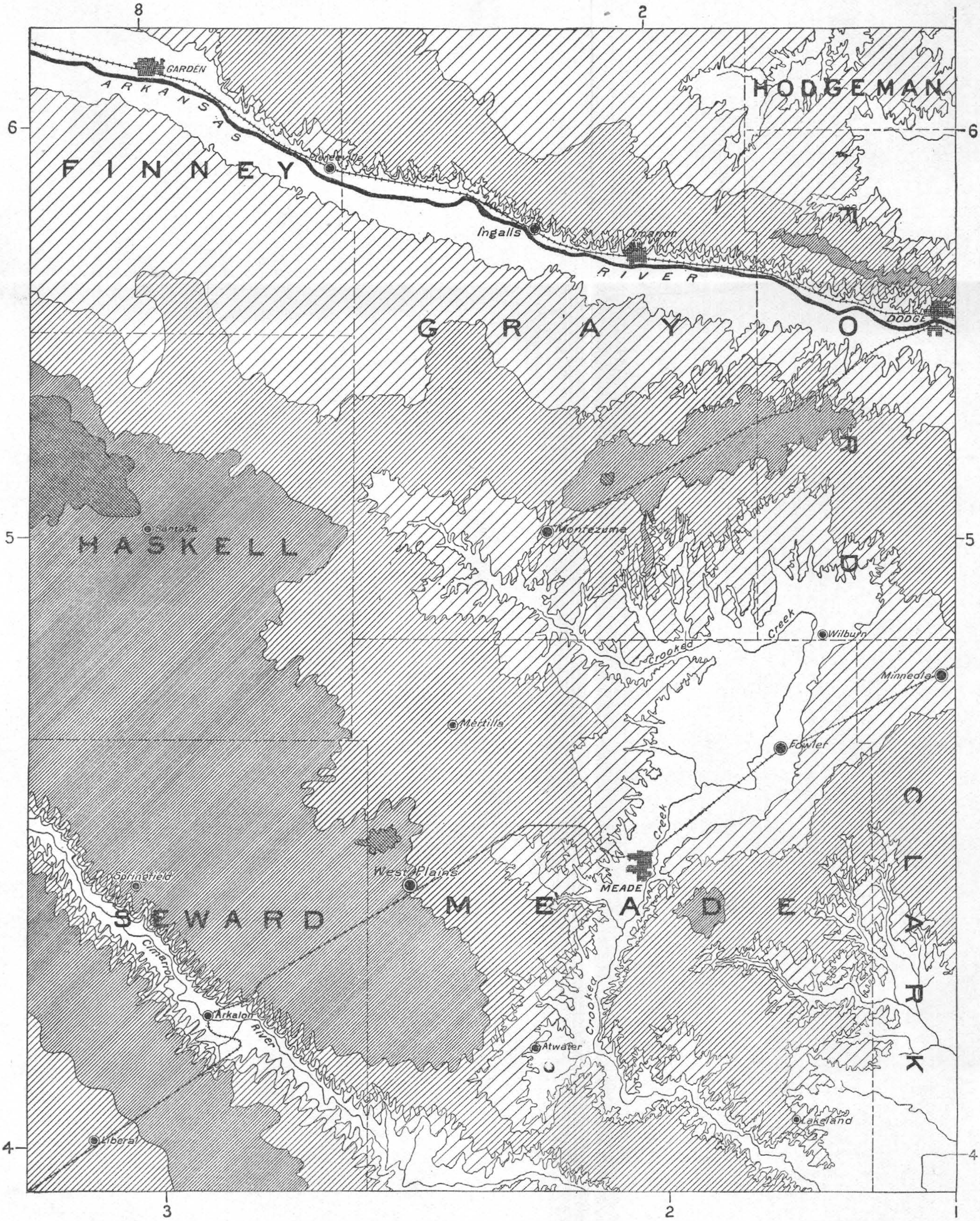
Almost all the area comprised in this report is underlain by large quantities of water. In the Arkansas Valley and the low grounds along other streams the water is usually found at depths varying from 5 to 12 feet. On the higher uplands its distance below the surface is greater, in some places even reaching 200 feet, and possibly more. The water is everywhere present except in a few small areas, such as the area in the northeast corner of the Dodge quadrangle, where the Benton limestone is exposed at the surface, and similar areas in the southeast part of the Meade quadrangle, where the Red Beds come close to the surface. Elsewhere, speaking in a general way, a well put down at random on any quarter section will produce water if carried to a sufficient depth.

DEPTH OF TERTIARY GROUND WATER.

An attempt has been made to represent graphically the distance below the surface at which water may be found for the whole area. Extensive examinations were made during the past summer, which included an investigation of almost every well outside the Arkansas Valley. Mapping the location of the wells and noting the depth from which water had to be pumped, it was possible to draw a series of lines on the surface of the map which may be called the water contours. These lines divide the area into a number of little groups, so that those similarly marked have water at about the same depth, somewhat as the contour lines on an ordinary topographic map represent areas of equal altitude. The results obtained by this method of representation are shown on the accompanying map (Pl. V), on which the different areas represented by the same pattern have the water lying at about the same depth from the surface. It may be said that too much confidence should not be placed in this map. When the long distances between wells on the uplands are considered, and the relatively large proportion of the uplands over which wells have not been drilled, it will be seen that it is necessarily impossible to construct a map of this kind which will be entirely accurate. Yet it is believed that the one here presented has a fair degree of accuracy, and that confidence may be placed in it to a moderate extent.

By an examination of the map it will be seen that along the principal river valleys the water may be found at a depth of 50 feet or less. Over the whole Arkansas Valley, aggregating 200 square miles or more, the depth varies from 5 to 12 feet. Likewise in the Meade artesian valley, along Crooked Creek, the surface water rarely exceeds 12 or 15 feet in depth. The valley of the Cimarron to the southwest is another place, where water can generally be obtained at a depth of less than 20 feet. An area to the north and northwest of Dodge, along the Sawlog and Buckner, covering many square miles, likewise has the water less than 50 feet in depth, while still another area in the southeast corner of Meade County, an area equal to 75 square miles or more, has water, when found at all, generally at a depth of less than 50 feet. This area, however, is one of the most uncertain ones in the county. The Red Beds are near the surface, with an irregular covering of sand and gravel. Sometimes the well will pass into the Red Beds without obtaining water in any considerable quantity, while perhaps less than a mile away water is found in apparently inexhaustible supplies. This variation of conditions seems to be due to the irregularity of the surface of the Red Beds, a condition which can not be foretold and which can be determined only by the extended use of spade or drill.

The areas over which water may be found at depths varying from 50 to 100 feet are greater in the aggregate than those just given. Nearly the whole of the country lying to the north of the Arkansas River comes under this division, although the high bluff lines along the Arkansas are not included. South of the river a strip reaches from west of Garden eastward entirely to the east side of the Dodge quadrangle. There is another area of like depth through the high divide between the Arkansas and Crooked Creek, covering the main portions of the south part of Ford and Gray counties and reaching far into Meade County on each side of the artesian valley and along Crooked



MAP GIVING DEPTH OF GROUND WATER.

Creek, with irregular areas in the east-central part of Meade County and lesser outlying areas elsewhere.

The next contour, with a depth varying from 100 to 150 feet, covers a like area and includes a portion of the high divide from Dodge westward almost to Garden, a portion of the divide between the Arkansas River and Crooked Creek, and a large portion of the high uplands in Meade County and a considerable part of Haskell and Finney counties. The area covered by the next contour interval, that of from 150 to 200 feet, covers nearly all the remaining territory. North of the Arkansas River it is represented by a small, irregular strip near Dodge. Southward it covers the remainder of the high divide between the Arkansas River and Crooked Creek and a small portion of Meade County to the southeast of Meade. It likewise occupies a large territory north of the Cimarron River, in the vicinity of West Plains and Springfield, reaching northward to beyond Santa Fe, thus occupying nearly all the broad, apparently level plain from Santa Fe to Springfield. The contour interval greater than 200 feet is represented in but few places in this area so far as we know. A few miles to the north of West Plains wells were found which were more than 200 feet deep, likewise in the southwestern part of Seward County and in an area northwest of Santa Fe. Could a larger number of wells be drilled over the high plains of Seward and Haskell counties, it is quite possible that this contour interval would be extended.

LEVEL OF TERTIARY GROUND WATER.

The water contours cross and recross the elevation contours in an irregular manner. In one respect they are independent of the elevation contours, and yet over small areas they bear a close relation to them. Thus on a given farm a well in the valley will have to be sunk a much less depth than on the uplands near by, and the difference in depth can usually be closely estimated by obtaining the difference in the surface elevation. For example, water in the Arkansas Valley at Cimarron can be had at a depth of from 6 to 12 feet, while 2 miles to the north, on the uplands, 140 feet higher, a well would probably have to be sunk 150 feet before water could be reached. We may cover much wider areas and still find the same condition obtaining in a general way. If a closer scrutiny of the conditions over wide areas be made, it is found that the upper surface of the available water is by no means on a level, but that it has marked variations of elevation which in a general way agree or correspond with the upper surface of the Cretaceous formations which lie buried beneath the Tertiary sands.

These conditions are well illustrated by the six different geologic sections crossing the area to be described. By reference to them (Pl. IV) it will be seen that the water level in the various wells is almost independent of the distance below the surface of the ground, but that it is largely dependent upon the distance above the impervious floor. In directions along which the floor lies in a horizontal position the water level is likewise approximately horizontal. In directions along which the floor varies greatly in elevation the water level likewise varies. Thus in section 1, passing north and south along the one hundredth meridian through Dodge, the same as in sections 2 and 3 having a north-south direction, the water level is approximately horizontal wherever the Cretaceous floor is horizontal. Along the southern portion of section 1, where the upper surface of the Red Beds dips so rapidly to the south, the water level correspondingly falls at the same rate.

In the Cimarron Valley, in the vicinity of Englewood, the water is found at less than 2,000 feet above the sea level, while 25 miles to the north it is found at nearly the same depth below the surface, which makes it fully 2,400 feet above sea level, or 400 feet higher. We therefore have an average inclination of the water level southward along the one hundredth meridian, from Minneola toward Englewood, of more than 25 feet to the mile. In east and west directions we likewise find perceptible inclinations of the water level. Section 5, drawn east and west through Santa Fe, shows a fall of fully 200 feet in 56 miles, while section 6, passing east and west near Garden, shows a decline of the water surface of fully 300 feet in the same distance, or a fall of over 5 feet to the mile.

The same conditions are found to obtain over areas much wider even than that covered by this report. The water in the Arkansas River Valley at Coolidge is no farther from the surface than at Dodge, although the latter is about 860 feet lower, or at Great Bend or Hutchinson or Wichita or Arkansas City, although all the latter points are much lower than Coolidge. Similarly, the water of the high uplands anywhere in western Kansas, in general, is found at about the same depth, whether near the western side of the State or near the eastern limit of the Tertiary, although the difference in elevation may be a thousand feet or more. It is, therefore, correct, in a general way, to speak of the upper surface of the ground water as being approximately level when limited distances are considered, or when a distance extending in a direction which chances to cover a level surface of the underground Cretaceous floor is considered. The elevation contours are consequently of great value in determining the depth to which a well would have to be carried to obtain water if located near a well of known depth. But if the prospective well is to be drilled 5, 10, or 20 miles from any known well the elevation contours would be of but little if any value.

The existence of such vast quantities of water in an arid and semiarid portion of the Great Plains appears very remarkable. Could the thousands of pioneers who traversed these regions prior to the operation of the transcontinental railway lines have known that the purest and sweetest water existed in such unlimited quantities at so short a distance beneath the surface, how many of them in a few hours' time with spade and shovel would have supplied water to slake the thirst and maintain the life of man and beast throughout the course of those perilous journeys! But the idea of such quantities of water existing within easy reach rarely entered their minds. It took years of occupancy of the Great Plains by thousands of citizens for such an idea to become well established. Even now, after almost ten years of active agitation of the subject, few people outside the immediate localities where such water exists realize the extent to which water may be found.

As already explained, the whole country is underlain by a mass of impervious material, the Cretaceous formations, or the Red Beds. This impervious floor prevents the downward movement of water which may be above it. The Tertiary sands, gravels, and clays furnish a thin and moderately even covering on the top of this floor, a loose, porous covering, well adapted for absorbing all precipitation that may fall upon it and well suited for the transportation through it of water from one part of the country to another. It is not necessary, therefore, that the water under any particular area should have fallen as rain or snow immediately upon that area, but it may have been precipitated tens or hundreds of miles away and traveled by the slow movement now known to exist. Nor is it necessary to assume that all this water must have been precipitated within recent times. There is no reason for believing that climatic conditions on the Great Plains have sensibly varied for thousands of years. The rains throughout this long period have been falling as at present, and such portions of them as were not carried away by the run-off or by surface evaporation or held as soil moisture have sunk to the floor and there await the drill and the pump. As the water accumulates above the impervious floor it first moistens the sand to the degree of saturation, and any excess is held under such conditions that it can be drawn off by proper methods.

As the downward percolation continues, the level at which available water exists gradually rises, so that in the true sense of the term we may speak of the ground being saturated upward, meaning thereby that in the natural order of the events of accumulation the level at which the ground water first became sufficiently abundant to yield a supply was immediately above the impervious floor, and that, with the increase of water from above and from the sides, this level of available water gradually rose in a manner similar to the way the upper surface of water in a vessel rises when water is added. The upward saturation of the sands and gravels, therefore, is dependent upon the accumulation of a larger supply of water from precipitation or from underground movements.

We may think of this body of underground water as existing in the form of a lake or pool; not a lake with a perfectly level surface, nor one filled entirely with water, but an underground lake the upper surface of which is inclined in any particular direction, dependent upon the relative conditions of supply and exhaustion and the rapidity with which water may move through the sands. Let us again refer to fig. 1, explained in the introduction, the figure representing the underground conditions at Lawrence, in the vicinity of the State University. Here we have a lake in one sense of the term, an area holding an excessive amount of water, so that the smallest opening made in it is instantly filled by the water flowing into it from all sides, just as an opening in a body of water will be filled by the movement of the adjacent water from all directions. But the upper surface of this lake is not level, because the water movement is so retarded that in the lower portions of the ground it can move neither upward nor laterally as rapidly as the supply is brought from above; consequently there is a piling up of the water similar to the way grain may be piled up in a bin.

This represents the conditions in the western part of Kansas, the only essential difference being that the Tertiary sands and gravels permit a more rapid movement than can be obtained in the clays at Lawrence. This great underground lake or sheet of water is consequently uneven of surface and variable in depth. A depression in the floor will be filled or partially filled, so that the water-bearing sands in the valley of the depression will be thicker than on the sides. And yet we may have a floor inclined 10 or 20 feet to the mile, with the water-bearing sands uniformly distributed over it, so that the water will lie at about an equal distance above the surface of the floor over the whole plane.

MEADE COUNTY WELLS.

The Meade artesian area is located in the valley of Crooked Creek, to the northeast of Meade Center, extending from Meade Center to Wilburn. This gives it a length of about 20 miles, with a width in places of nearly 6 miles. The area over which artesian water has been found to a greater or less extent covers from 60 to 80 square miles. It is a broad, flat valley, apparently almost level, with scarcely any irregularities of surface within it, except here and there small drainage channels which are cut downward from 5 to 8 feet, almost like an artificial ditch. On all sides and in every direction from the valley the ground is higher, so that there appears to be a natural wall all around it. On the east and southeast the wall is from 50 to 100 feet high, with gently sloping sides, and the surface is largely covered with sand hills. On the north is a gentle rise toward Crooked Creek, producing a maximum elevation of about 75 feet between the main part of the valley and Crooked Creek itself. But at the northeast, toward Wilburn, the wall is much more abrupt, rising rapidly to a height of 100 to 140 feet. A few drainage channels originate in the high ground to the west and pass across the artesian valley to Crooked Creek. Such channels present the appearance of mere ditches throughout their whole length within the valley, usually having their banks lifted higher than the ground some distance back, showing the filling-in process to have been carried on by them, as is so commonly done by rivers after reaching their base-level. Crooked Creek is, throughout the valley, scarcely distinguishable from some of its tributaries just described. It is almost insignificant in appearance, generally but a few feet wide, and can rarely be observed in the landscape until one is within a hundred feet of it, so closely does it resemble an artificial ditch in its general characters. It has also lifted its banks higher than the adjacent land to so great an extent that in some instances the surface a quarter of a mile away is lower than the top of the bank immediately at the creek.

The uplands to the west of the artesian valley increase in height rapidly, so that the plains to the north and northwest of Jasper, as shown by the Meade topographic sheet, are more than 2,700 feet high not more than 10 miles away, while the general elevation of the artesian valley is between 2,400 and 2,500 feet. The Tertiary ground water of the high plains to the west is found at a depth of from 125 to 150 feet; consequently the level of the water 10 miles to the west of the artesian valley is from 100 to 120 feet above the surface of the valley itself.

The artesian valley throughout is covered with Tertiary or Pleistocene deposits. The thickness of these formations is not known; the different artesian wells vary from 50 to 250 feet in depth, and no one of them has yet passed through the formations. To the north, beyond Crooked Creek, the Benton is shown at the surface in a few places and has been reached in many of the wells. To the northeast, a few miles beyond Wilburn, the Dakota was found by different wells. South of the valley the Red Beds appear at the surface, as the Benton and Dakota gradually grow thinner at the south until they disappear. It is further believed that the strata were here faulted so that the Meade Valley was sunk to an unknown distance, at least 100 to 150 feet, and that it has since been filled in to a considerable extent, probably in Pleistocene time. The character of the materials, as shown in the borings from different wells here and there over the valley, can not be distinguished from the Tertiary materials adjacent on all sides. It is composed of silt, clay, sand, and fine gravel, quite irregularly mixed, so that there is no greater continuity of the bedding planes than may be found in the Tertiary deposits elsewhere.

The mortar beds produced by the cementing of the coarse sand seem to be almost wanting, but here and there the finer sand and clay are frequently partially cemented by calcium carbonate, producing a certain degree of hardening similar to that observed in the mortar beds elsewhere. In character the cement so frequently assumes a concretionary aspect that it seems probable it was deposited in the sands and clays by infiltrating water after they were placed where they are now found. The artesian water is drawn from the Tertiary or from Pleistocene beds composed of materials in every respect similar to the Tertiary materials surrounding the valley upon all sides. It seems sharply distinguishable from the Dakota artesian water known to exist to the north and northwest.

The whole of the artesian valley is supplied with the ordinary underground water, which may be found at from 5 to 15 feet below the surface. Its abundance is not known, as no one cares to use it. It would seem that it is sharply distinguished from the deeper-lying artesian water, as it has no apparent artesian properties. But at the same time it must be admitted that we are in relative ignorance regarding the reasons why the two are not connected.

The artesian wells at present in successful operation number considerably more than 300, an exact enumeration of them not having yet been made. In depth the wells vary greatly, some of them being but little more than 50 feet deep, while others are as much as 250 feet. There is a strong similarity between the materials passed through by all the wells if considered in a general way, but a lack of similarity if considered in great detail. Each one passes through the surface soil, below which it encounters alternations of clay, sand, and soil. The sand is frequently partly cemented, so that the well drillers speak of it as rock, but the layers thus cemented are rarely more than 12 inches thick, and frequently not more than 6 inches. Two wells within 40 rods of each other found a great variation in the number and relative position of the beds of clay, sand, and rock, but all of them passed through the same materials. So far as could be learned, there is no particular stratum which must be reached before artesian water is obtained. A mass of bluish clay, the color showing that considerable unoxidized organic matter is contained within it, frequently rests on the top of a bed of uncemented sand, stained yellow with iron rust. Such sand always contains water, generally the artesian water, and indicates by the degree to which the iron oxide is produced that the artesian water is a surface water which has not yet been robbed of its supply of oxygen gathered from the atmosphere.

But few wells have been studied carefully while being drilled. In August, 1896, the writer had a well put down especially for making an examination. It was located on the land of Mr. W. F. Foster, near the center of section 6, township 31 south, range 27 west. The drill used was one rented from Mr. Cooper, a well driller living in the valley. In addition to the bit on the end, a pump was attached so that water was forced down through the drill pipe, causing a constant flow upward outside of the pipe, the current bringing up the cuttings of the drill. In this way it was impossible to tell within a few inches, or possibly a foot or two, of the depth at which a change of material was made unless there was a change in the degree of hardness of the

VIEW OF MARR'S ARTESIAN WELL, MEADE, KANSAS.

material, so that the one turning the drill could detect the difference. The well was carried to a depth of 167 feet and obtained a moderate flow of water from a loose, yellow sand.

Well of Mr. W. F. Foster, on section 6, township 31 south, range 27 west.

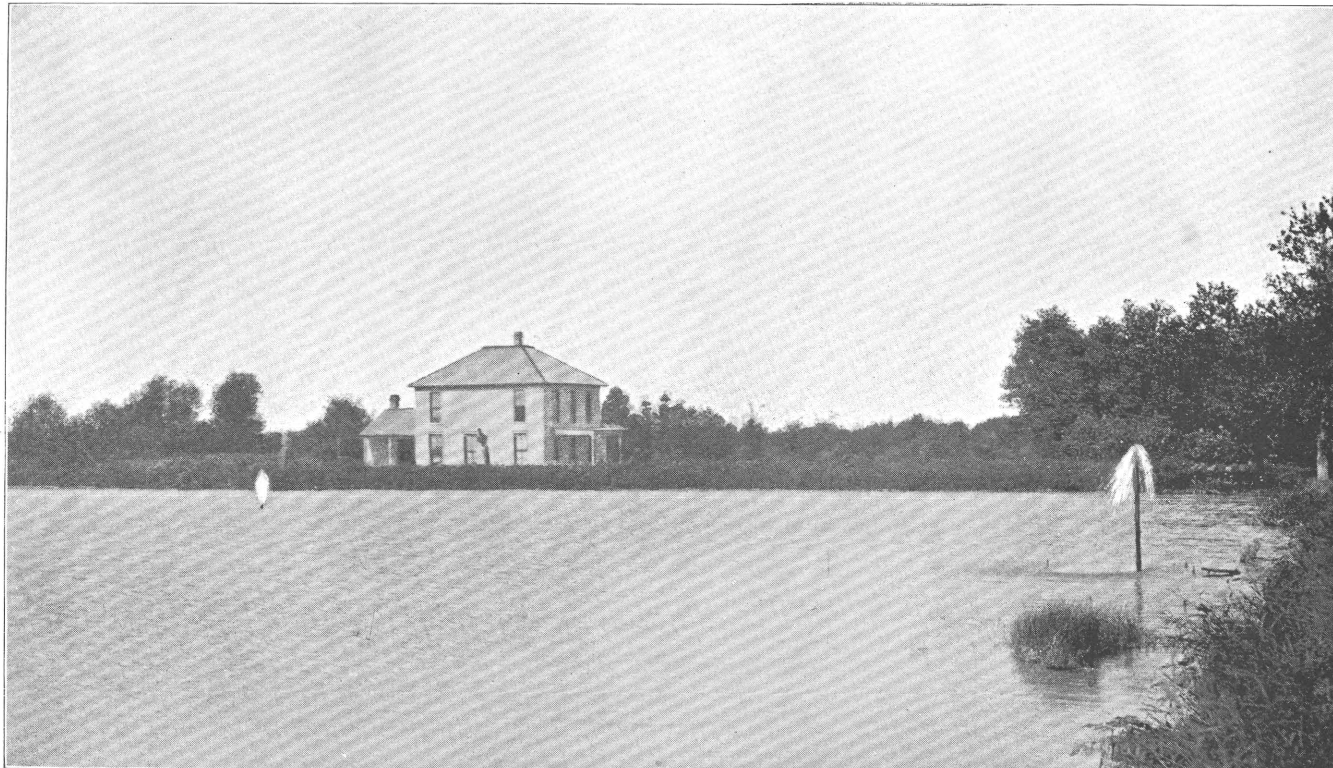
No. of stratum.	Thickness of stratum, feet.	Description of stratum.	Total depth to bottom of stratum, feet.
1	7	Soil and subsoil	7
2	13	Mortar beds, almost entirely free from sand or gravel, small concretionary mass of calcium carbonate intermingled with the clay	20
3	11	Light-colored clay, grading into gray and grayish-blue in color	31
4	5	Blue clay which grades into No. 5	36
5	4	Light-colored clay which grades into No. 6	40
6	10	Blue clay	50
7	2	Mortar beds similar to No. 2	52
8	14	Blue clay	66
9	19	At depth of 66 feet began striking thin layers of hard substance, which seemed to be layers of sand sufficiently cemented with calcium carbonate to produce considerable resistance to the drill. Three or four of these were passed during 19 feet. They were separated from each other by beds of blue clay	85
10	3	A fine white sand at the top, grading into bluish sand at the bottom, and which was sufficiently cemented with calcium carbonate to produce a relatively solid rock	88
11	3	Blue clay, at the bottom of which was a hard sandrock similar to those above	91
12	11	Clay, with sand intermingled	102
13	3	Light-colored sand	105
14	1	Soft clay, grading into No. 15	106
15	6	Alternating layers of clay and sand sufficiently cemented to be noticeable	112
16	18	At 113 feet struck unusually (for this well) hard sandrock less than 1 foot thick, below which there was a frequent alternation of clay and sand partially cemented, the layers being from 2 inches to 6 inches thick	130
17	20	At about 130 feet a fine sand with clay was struck, a light bluish-yellow in color, which was 20 feet thick	150
18	10	At 150 feet the color changed to more of a reddish-brown	160
19	7	At 160 feet the sand became coarser and the clay redder in color. The drill gradually sank of its own weight, occupying less than two minutes in sinking 3 feet, while the pump was kept running. At the bottom of this formation the clay seemed to disappear almost entirely, and the artesian flow came from the coarse, yellowish sand	167

It was learned from Mr. Foster and the parties who did the drilling that a well previously drilled, located not over 40 rods to the west, struck almost none of the harder material. The house well of Mr. Marrs, a quarter of a mile to the east, one of the best wells in the valley, likewise struck none of the harder materials. Each of these two wells was drilled in about four hours' time, which further shows the soft character of the materials passed through. It was reported that a few wells not more than 50 feet deep have produced considerable amounts of artesian water. From this they increase in depth to a maximum of 250 feet, the depth of a well drilled on Mr. Cooper's place, about 2½ miles to the southwest of the Foster well.

With but one exception, no well has yet been drilled in this valley large enough to admit more than a 3-inch pipe. The drills that have been available for use have been owned locally, and have been handled by men who have had but little experience in well drilling outside the valley. Usually a gas pipe from 12 to 18 feet long is put down to shut off the first water, after which no piping is used. In a few instances wells have been piped almost their entire depth. The best now flowing gave but little water when first drilled. They had a mild flow bringing up sand, the flow increasing as more sand was brought out. In some cases two or three wagonloads of sand have thus been thrown out by the water, after which time the flow reached a maximum amount and the movement of sand almost ceased. Little experimenting has been done to determine whether or not an increase of water could be produced by properly piping the wells, or by pumping them vigorously until all the loose sand was removed. It is quite possible that flows could be greatly increased by these methods.

An artesian flow may be found almost anywhere over the valley. Yet there are many instances in which wells have been drilled that did not yield a sufficient quantity of water to be of value. It is difficult to decide, with the data at hand, why some of the wells are successes and some are failures. In a few places the surface elevation seems to be a little too high. A well in the bottom of a ravine will yield a pretty good flow, while in one drilled on the banks near by, the water will rise almost to the surface, but not high enough to flow. In other instances two or more wells may be close together with the surface elevation the same, some of which will be good flowing wells and others not. It seems probable that this difference is due to two or more causes. The great diversity in the character of the material passed through in drilling the different wells makes it certain that the clay beds are irregular in formation and distribution. One can well understand how the disposition of these beds may cause a variation in the results obtained. A mass of clay may carry the water so deep that the drill can not reach it. Or it is possible for a mass of sand to be entirely surrounded by an impervious clay, so that a drill penetrating the sand will receive no flow because there is no pressure on the water the sand contains. The heterogeneous character of the clay beds, therefore, may be one of the main causes for such differences in wells so close together. The experience with wells which are of little value for weeks, or even months, after which time they become strong flowing wells, shows that in some way they become choked with sand, permitting only a mild flow until the sand is removed by pumping or otherwise.

It seems that the northern and western sides of the valley are the more productive. At present the best wells are in the northwestern portion of the valley, but flowing wells have been obtained all the way from Wilburn, on the northeast, to Meade, or possibly a mile or two south of Meade, to the southwest. The flow of the wells varies from a pailful in five minutes to 45 gallons per minute. Approxi-



VIEW OF VICK'S ARTESIAN WELL AND RESERVOIR, NORTH OF MEADE, KANSAS.

mate measurements have been made of twenty or more of the strongest wells. A large bucket was accurately measured and filled by the flow a number of times, one person handling the bucket, the other holding a watch to determine the number of seconds required for filling the bucket. The test was repeated a number of times to eliminate errors of observation as far as possible. In this way it is believed the probable error of measurement is not greater than 1 or 2 per cent. Five or six different wells were found to yield 45 gallons per minute. Twenty or thirty exist which yield 30 gallons per minute or more, from which the wells grade downward to the minimum flow.

The water obtained from the wells is largely used for irrigation purposes. Many of the wells were simply left flowing, and the water allowed to waste, without any attempt to use it. The number of acres irrigated is far less than the estimated possibility.

From data already given regarding elevations in the artesian valley and the uplands to the west, it will be seen that the water level from 5 to 15 miles to the west of the valley is considerably higher than the surface of the ground within the valley. The wells along the arroyos to the west of the artesian valley have artesian properties which gradually decrease westward. The depth of the water on the uplands to the west is nearly as great a mile away as it is 5 miles away, excepting where the well is located in an arroyo of considerable depth. It will not do, therefore, to consider the water on the uplands as moving eastward under favorable conditions for creating a pressure throughout the whole distance, but rather it should be considered that the impervious Cretaceous or Red Bed floor slopes to the east at nearly the same rate as the surface, and that the water is gradually moving down this gentle incline toward the east. Here and there, however, it passes under local clay beds, which carry the water to lower levels than it otherwise would occupy, and a corresponding pressure is set up. In some way, as the large artesian area is approached, the water descends, and in the descent passes underneath the clay beds of the valley, so that a limited pressure is established.

A few experiments were made to test the height to which water would rise in an open tube at the well. All such experiments show that the rise is only a few feet, perhaps always less than 20. The pressure which causes the flow from the wells, therefore, can not be due to the extra height the water has 10 miles to the west, otherwise the head would be much greater and the flow correspondingly stronger. It would seem rather that the pressure is due to the head generated by the gentle dipping downward of the water level as it passes under the clay beds near the west border of the artesian area, perhaps rarely extending farther away than from 2 to 4 miles. The water in the artesian wells seems to be continuous with the general upland water to the west. It is like it in character, and the two areas are connected by various wells.

Springs throughout the artesian valley are by no means unknown.

A few are located in arroyos along the western border. The most noted area for springs is in the vicinity of Mr. Simms's ranch, a mile and a half north of Fowler. On the eastern side of Crooked Creek, a fourth of a mile or more away, a large area is so abundantly supplied with springs and seeps that hundreds of acres of land are rendered worthless. The springs are principally located just along the border line between the valley proper and the higher lands to the east. The rank growth of vegetation produced by the moisture has provided a tough and heavy sod which protects the softer ground beneath, so that the range animals can pass over it with safety, except in the immediate vicinity of the strongest pools. Here the upward movement of the water is so rapid and the sand which is frequently brought up with the water accumulates to such an extent that vegetation does not grow for a few feet around the springs. Such areas are death traps to range animals. Mr. Simms stated that numerous instances have come under his observation of animals becoming ingulfed in the mud and sinking out of sight, or, if not out of sight entirely, sinking the full length of the body. In many of the springs, by using a long pole, one can feel bones at a distance of from 8 to 15 feet below the surface, presumably those of buffalo and other wild animals which lost their life in the springs. It seems probable that these springs and the artesian wells receive their supplies from the same source. The character of the water is the same; the location in general is the same; for artesian wells can be obtained in the immediate vicinity of the springs, and the whole character of the surroundings implies that there is no essential difference between the sources of the two classes of water. The location of the largest springs is near the southeast valley line, along the eastern side of the valley. If the valley has been dropped by faulting, the water-bearing sands in the valley are doubtless on a level with the Red Beds, or the underlying Dakota on the east. This condition would cause springs to be more abundant along the east line than elsewhere.

Farther south, along the western tributaries to Crooked Creek and in the valley of Crooked Creek itself, springs and seeps abound. The largest amount of spring water flows through Spring Creek, a stream about 3 miles south of Meade. Springs are abundant throughout almost the entire length of this stream, but are particularly so about 3 miles south of Meade, in section 21. Here most beautiful springs exist. At one place with an area of not more than 10 square rods, the cold, clear water comes bursting forth from under the mortar-beds bluff, forming a stream like a mill race. An approximate measurement from this one area gave fully 3 second-feet, which is equivalent to more than 2,000 acre-feet, or enough to irrigate more than 2,000 acres with 12 inches of water each year. This is one of the most remarkable groups of springs anywhere in the West. It would seem that there is an abundance of water, however, in this one little stream to irrigate more than 3,000 acres 12 inches each year, provided

HEAD OF IRRIGATION DITCH SUPPLYING THE "CROOKED L" RANCH, MEADE COUNTY, KANSAS.

Ditch to left; Spring Creek to right.

it were all used for irrigation purposes and proper care taken to guard against waste. About a mile below this group of springs a ditch draws water from Spring Creek to irrigate the alfalfa fields on Crooked L ranch. The remainder of the water passes on down the creek, and is principally used for stock water, although here and there small amounts are taken for irrigation. South from Spring Creek the next most important tributary from the west is Stump Arroyo, a stream along which frequent springs occur, but which does not yield nearly so much water. One principal ditch draws water from this creek to farms below. All these springs are in the true sense connected with the artesian area to the north, and the discussion of them is relevant here, because they throw light on the origin of the water in the artesian valley.

Reviewing the whole matter regarding the origin of the water in the artesian wells and artesian springs, it must be admitted that it seems the water is continuous with the ordinary underground water to the west, and that it is therefore a part of the same. It is certainly distinct from the Dakota water, and is so deep that we can not think it lies above the eastern extension of the water plane on the west.

It is of great practical importance to arrive at some conclusion regarding the amount of available water in the artesian valley, and to decide whether or not the continued use year after year is liable to destroy the supply. It will hardly do to assume that wells could be put down every few rods over the entire valley, each one of which would flow independently of the others. Artesian water in almost all places thus far observed in any part of the world has been found in wells which acted sympathetically with one another. When a strong-flowing well is closed, ordinarily adjacent wells have their flow accelerated. Few experiments have been thus far made in the Meade artesian valley to determine the influence of one well upon another. Many inquiries were made of citizens here and there in the valley, and conflicting statements were given on these subjects. Some individuals were positive that the rapid flow of one well sensibly diminished the flow in weaker ones near by, while other farmers as emphatically stated that on their farm the flow of one had no influence on the flow of another. It is probable that the former class of reports are correct; in fact, it would be quite remarkable were they not.

This condition need not necessarily argue against the large supply of water in the valley. In all cases where wells are close together they mutually influence one another, provided the rate of flow through the water-bearing strata—sand, gravel, or whatever it may be—is not sufficiently great to maintain the flow as long as the supply lasts. But most beds of sand and gravel are so close grained that there is an appreciable check in the rate of movement of the water in the sand, which in most instances will result in the sympathetic action of adjacent wells.

It appears to the writer, therefore, that the question of supply of water for artesian wells depends more on the source of the water than it does on the mere rapidity of the flow from any well or from a group of wells. The facts already given certainly imply, as has been seen, that the source is the ordinary ground water to the west and northwest. If this is correct, the question of supply is essentially the same as the question of the supply in the upland areas. So long as water exists on the uplands from 5 to 20 or 40 miles away, it is probable that it will likewise exist in the artesian wells. Could a sufficient number of wells be drilled, and could the flow be continued from all of them a sufficient length of time, it seems reasonable to suppose that a diminution of the supply of water on the uplands would first be observed, and later of that in the valley. It is probable that the small area, less than 100 square miles, in the artesian valley and the valley of Crooked Creek below Meade, could drain the whole of the uplands to the west, and that their supply of water would not become exhausted so long as there was any available water anywhere in the broad plains to the west or northwest. We are therefore brought to the consideration of the amount of this ground water, a subject discussed later in this report. It is sufficient to say here that, in the judgment of the writer, water enough could be obtained, were it properly husbanded, to irrigate such parts of the Meade artesian valley as anyone is likely to want to irrigate during the next half century.

QUANTITY OF TERTIARY GROUND WATER.

DIFFICULTY OF ESTIMATION.

No one can give more than a mere approximation of the amount of Tertiary ground water in western Kansas. The wells which thus far have been drawing their supply from it, with but few exceptions, have shown no indications of failing. A few wells which were located on the outer margin of the water area have been known to become exhausted by rapid pumping. Others which have only penetrated the water-producing sands a few inches, or a foot at most, have likewise been known to fail. But no instances have yet been found of a well failing, or seeming to be in failing condition, provided it was unquestionably within the water-producing area and had a depth of 5 feet or more in the water-bearing sand. Of course this does not necessarily mean that the supply is inexhaustible, in the true sense of the term. But it may well be taken to mean that with any moderate amount of pumping—even an amount several times greater than has yet been pumped—the supply will not be found wanting.

It is supposed, and perhaps correctly, that water is more abundant in the Arkansas River Valley than on the uplands either north or south. More decisive pumping tests have been made here than at any place on the uplands. The city well at Garden represents the severest

WINDMILL AND RESERVOIR AT GARDEN, KANSAS.

test made within this area, a supply sufficient for a town of 2,000 inhabitants being furnished. The largest pumping plant within the State is located in the Arkansas Valley, at Hutchinson. Here the Hutchinson Packing Company have three pumps which have been running constantly for several months, pumping at the rate of about 1,300 gallons per minute, the equivalent of 5,616,000 gallons per day, without appreciably affecting the water supply. This is almost 3 second-feet, an amount approaching the flow from the big springs already described along Spring Creek. There is no reason for believing that the amount of water here is any greater than anywhere else in the valley from Coolidge to Arkansas City. A like amount, probably, could be pumped from every quarter section of land within the whole valley. Should such pumping be done all at once, it doubtless would decrease the supply, but no fear need be entertained that the water will not be sufficient for all demands that will be made upon it for a long time in the future.

Could the water level in the valley be appreciably lowered, it is quite evident that water would be drawn into the valley from the upland areas to the south, and to some extent from those to the north. The rapidity with which the movement toward the river would be made would depend upon a number of conditions, such as the degree of exhaustion and the character of the material through which the movement takes place. Should the draft be sufficient to lower the water in the valley 20 feet, there would result a high angle of inclination on the upper surface of the water at either side, tending to set up a rapid movement from both sides into the valley. Still, a gradient of 20 feet to the mile is less than now exists under normal conditions in the area to the north and west of Englewood, and yet the water is not drawn away so rapidly but that it is almost everywhere present. Should any other area be appreciably exhausted by the excessive pumping from a well, or a group of wells, so that the upper surface of the water would be materially lowered, water would flow in from all directions to supply the deficiency, and in this way the one well would drain a considerable area.

Is is therefore exceedingly difficult to draw decisive conclusions regarding the sum total of the water in the Great Plains of the West, judging from the amount that any given well or series of wells may produce, so long as the pump does not entirely exhaust the area. All that can be said with certainty at the present time is that, with the large amount of pumping which has already been done, no indications of exhaustion have yet been observed.

SOURCES OF TERTIARY GROUND WATER.

It is of great importance to consider the sources of the supply and the rapidity with which the supply can be transmitted to different localities. Should we look upon the ground water as constituting a great reservoir, it is evident that the amount would become entirely exhausted unless there were a corresponding continuance of the supply. Should pumping be begun from Lake Michigan, it would sooner or later entirely exhaust that vast body of water were it not for the large additions to its volume every year by the surface drainage of adjacent territory. It is possible to determine the amount of pumping that could be done without appreciably lowering the water in the lake, by an estimation of the amount of water added by the surface drainage year by year. Likewise the question of the supply of water for western Kansas is largely one of the rate of the renewal of the ground water. Any estimation on the subject which neglects this factor will in practice prove to be faulty, should the time ever come when the sum total of exhaustion is more rapid than the rate of supply. Enough is known on the subject to demonstrate that pumping from the underground reservoir must be many times greater than that which has yet been done before the exhaustion will nearly equal the rate of supply. In many places throughout the country springs of great strength abound, and lesser seeps supply water to pools and living streams. Should the exhaustion by pumping be appreciable, it would first be noticed in the rate of flow of the springs and seeps. Nothing of the kind has yet been observed.

The original source of all the Tertiary waters is precipitation. The areas over which this precipitation falls are large and varied. In Meade County the average rainfall is about 18 inches per annum, a rainfall which varies from year to year and from month to month. Sometimes heavy falls are known, reaching from 3 to 4 inches or more at a single storm. With such storms an undue proportion of the water runs off through the drainage channels, leaving perhaps less than half to be absorbed by the ground. At other times the rain is so light that it will wet the ground for only a few inches, and entirely evaporate within a few days or weeks, so that perhaps no appreciable part of the lighter rain joins the general ground water.

The character of the soil has a great influence on the run-off. In the sand hill area to the south of Arkansas River and to the east of Crooked Creek, and in the southeastern corner of Meade County, it requires an unusually heavy rain for any of the water to join the run-off, the whole of it being absorbed and held by the porous sands. On the uplands, where the Plains marl is abundant, as well as in the river valleys, where a similar soil exists, the character of the soil is such that only a small amount of the rainfall is absorbed, while a correspondingly large proportion joins the run-off. The conditions of the rainfall and the character of the surface soil over the whole of the Tertiary of western Kansas and eastern Colorado are about the same on the average as in the area covered by this report. Probably more than half of the total precipitation falls in severe storms, or in light rains. We have, therefore, unfavorable conditions for the absorption by the ground of a high per cent of rainfall. No one has made any accurate observations on this subject with a view to determining the per cent of the total rainfall which is absorbed by the ground; but, as seen in the Introduction, it is only a small part of the total amount absorbed that ever becomes available as water supply.

The Tertiary formations extend west, in some places reaching almost to the Rocky Mountains, but in other places they are separated from the foothills by the high ridge known as the "Hogback," and by the high divide farther north. Toward the mountainous area generally the rainfall increases, so that the average annual precipitation is greater than in the west of Kansas.

A great deal has been said and written regarding the probability that precipitation in the mountainous region will reach western Kansas. It may be added that little, if anything, is positively known on the subject. We have the Arkansas River carrying its waters all the way from the mountains through the Great Plains. The eastward inclination of the surface is such that the water in the bed of the stream at one place is higher than the uplands only a few miles below. Here and there throughout its course the Benton or Dakota bluffs hem the water in, so that it is confined to the channel of the stream. At other places such impervious bluffs do not exist, and the loose, porous Tertiary sands and gravel spread from the uplands directly down into the river valley. There are many places where, so far as the elevation of the underground floor itself is concerned, underground water may be drawn from the Arkansas River and spread over all the vast plains lying below. Whether this actually occurs or not can be determined only by a careful and detailed study of the water levels north and south of the river. At present we have so few wells in the great sand-hill area south of the river in Kansas and Colorado that no conclusion of value can be reached in this discussion. The level lines have shown that the water in the wells 6 or 8 miles south of the river at Garden is at a little lower level than the water in the river itself. The same in a general way is true at Dodge.[1] Later investigations have added but little information on this subject for the areas covered by the sand hills, the difficulty being that so few wells here exist.

From the meager data at hand, we are forced to conclude that at different places throughout its course, so far as the water gradients are concerned, ground water might be deflected from the river valley southward in its eastward movement and ultimately become a part of the great body of ground water on the plains only a few miles farther east. If such deflection ever occurs, we have a mass of water gathered from the rains and melting snows in the mountainous area being carried across the divide by the Arkansas River and ultimately spreading over the high uplands to the south of the river. This is only one of the conditions which are possible, so far as the information now at

[1] Report on Irrigation, 1893. Artesian and Underflow Investigation. Fifty-second Congress, first session, Senate Ex. Doc. 41, part 2, pp. 26-27, pls. 10 and 11.

hand indicates. It is entirely improbable, however, that any considerable proportion of the water in the plains south of the river comes from the river itself. It is probable that if a detailed examination were made it would be found that the water in the sand-hill region is a little higher than in the river. This statement is made because it is customary for rivers to serve as drainage channels rather than as supply channels. The usual condition is for underground drainage to be from the uplands into the rivers, the same as the surface drainage.

Should a considerable proportion of the water be deflected from the Arkansas River Valley to the plains at the south, we should find a much larger amount of water south of the river than exists to the north, unless there is a similar deflection in places to the north. There are some reasons for thinking that this may be true. Farther east, in Clark, Comanche, Kiowa, Pratt, and Stafford counties, and the level lands to the east toward Wichita, there is a larger proportion of springs and streams with living water in them than we find in general to the north of the Arkansas. But it must be confessed that with so few absolute data as are now available regarding the actual amount of ground water, arguments pro and con on this question are of little worth. A careful study of the subject would be of value.

At different places along the Arkansas, where the bluff lines of the valley are composed of Tertiary material, both in Colorado and Kansas, soundings should be made at frequent intervals to determine accurately the level of the ground-water surface both north and south of the river. If it should be found that there is a uniform rise of the level outward from the river, this would show that the underground drainage is uniformly toward the river rather than away from it. If, on the contrary, at any time during the year in periods of high water it should be found that the ground water at or near the river is higher than at localities farther back to the south or north, this would seem to show the possibility, and even the probability, of water being deflected from the river toward the general uplands. The direction of the movement need not be at right angles with the river, nor nearly so, but probably would be in directions somewhat similar to those usually followed by drainage channels which draw water from the river. If such lateral deflections of ground water are made to appear probable, there can be no doubt that at least a portion of the precipitation over the mountainous areas drained by the Arkansas and the Platte rivers may become spread out over the great upland plains and furnish an essential part of the plains ground water. If, on the other hand, such deflections of ground water in the river valleys are shown to be impossible, it may well be doubted if any of the mountainous precipitation joins the ground water of the plains.

It must be remembered that the underground movement is governed largely by the character of the surface of the underground

ST. JACOB'S WELL, CLARK COUNTY, KANSAS.

Cretaceous floor which has already been described. There are strong geologic reasons for believing that this Cretaceous floor in most places east of the foothills has a greater elevation than the underground water level in the great trough-like area trending north and south to the west of the "Hogback" and the high divide, so that the eastward motion of the water would be impossible, except here and there where there might be a channel or depression in the Cretaceous floor similar to those along the Arkansas and Platte rivers.

Whatever conclusion may ultimately be reached regarding the possibility of an eastward underground movement from the mountains themselves, the rate of the movement of the water through the sand is, after all, of the most importance. When water is being pumped from a well, it is not so important to know the amount of water 10, 50, or 100 miles away, as it is to know the rate of movement through the sand of the water immediately adjacent the well. The maximum supply that the well can furnish will be dependent upon the rate of the inflow to the well, and only remotely upon the sum total of the water over the whole area. The rate of movement is likewise of great importance in considering the total amount of available water on the plains as a whole.

Should the precipitation and the proportion of the precipitation which joins the ground water be greatly increased, unless the possible rate of underground movement were correspondingly increased, available masses of water would tend to pile up where the precipitation occurs, without sensibly affecting the supply in other parts of the country. Those who believe in a mountainous source for a part or the whole of the plains water must therefore be able to show that the rate of eastward movement is sufficiently rapid sensibly to increase the available water at different places on the plains. Otherwise the increased precipitation in the mountainous areas would be of no avail.

It is doubtful if laboratory tests are of much value in this discussion, because the conditions governing them are not applicable. The inclination of the surface, the porosity of the strata, the ease with which water may pass from one stratum into another as the strata become discontinued, are some of the questions which must be considered. In any experiment neglect of any one of these conditions, and probably others not yet fully understood, will cause the results obtained to be of little if any value in this consideration. We may have a mass of sand or gravel largely composed of coarse grains or pebbles, so that at first thought it would seem that water would flow freely through it. If, however, there is a small amount of silt or clay disseminated through the mass, this will have a most important influence. The coarse masses of gravel in such cases not only do no good, but do harm; for each grain, being impervious, renders just that much space impervious. It is probable that the rate of flow through a heterogeneous bed of this character is governed by the finest materials in the bed. Investigations of the subject, therefore, must consider the detailed geologic conditions of the area studied.

SUMMARY.

In summarizing the foregoing discussions regarding the amount of water, it may be concluded that there is a surprisingly large amount of water in the Arkansas Valley, and a similarly surprisingly large amount on the uplands, although perhaps smaller than in the valley. The springs along Spring Creek are the best single evidence we have of the large amount on the uplands, and the pumping tests in the valley, particularly at Hutchinson, are the best tests we have of the amount in the valley. These, combined with the almost universal presence of water, and the meteorologic and geologic conditions already explained, furnish good reasons for believing that the amount of ground water under the area here described is sufficient to meet any demands that will likely be made upon it, even should industries spring up in the West which will use many times as much water as now seems probable. The greatest needs for western Kansas now, and for the whole plains area, are better methods of raising water from beneath the surface, and better methods in using it.

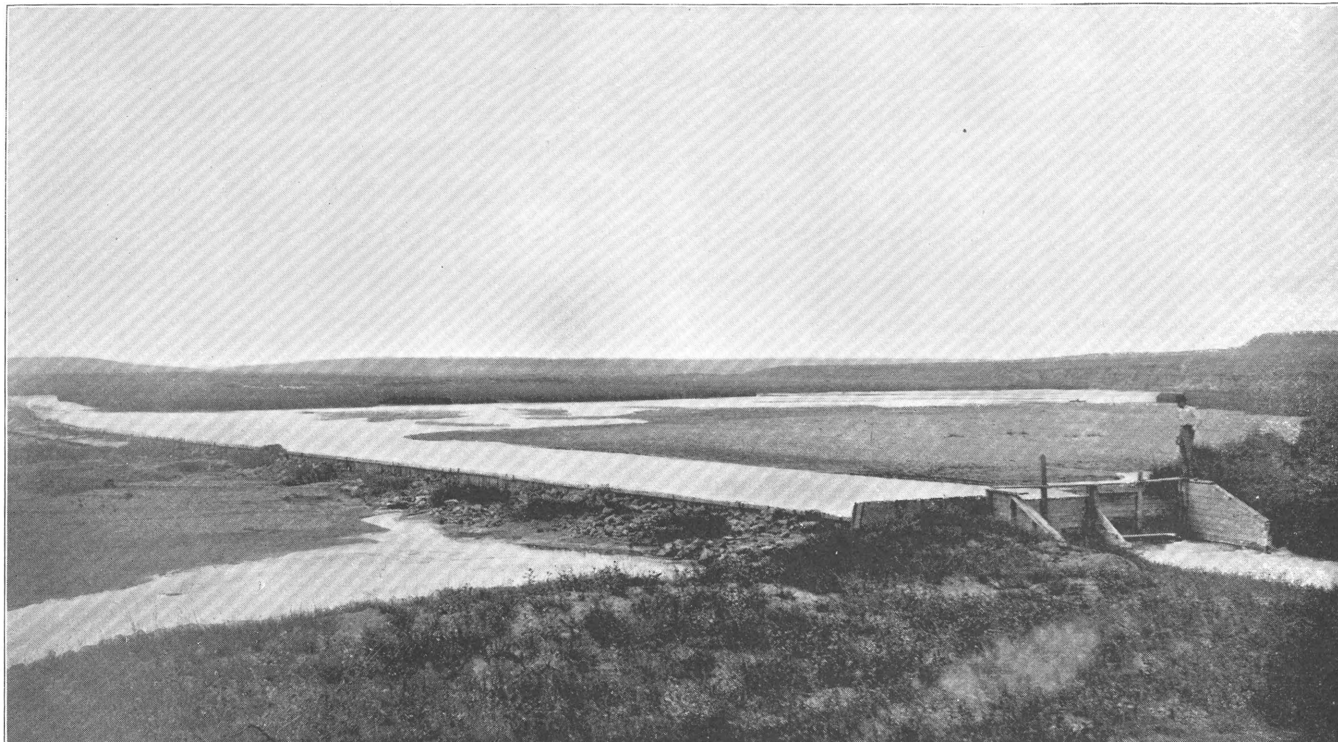
IRRIGATION DEVELOPMENT.

Irrigation is now practiced to a considerable extent in the Arkansas Valley and along the Cimarron River and Crooked Creek. Numerous small reservoirs and irrigation pumps are also established on the uplands, some of which have proved to be surprisingly successful. In the valleys the principal crops raised by irrigation are alfalfa and fruit, but on the uplands little is irrigated besides gardens and fruit.

The water in the Arkansas River is so low during the greater part of the year that the canals are dry, but in times of freshets they are used to a considerable extent, and the thousands of acres of alfalfa and orchards and other crops are quite thoroughly irrigated once a year at least, and upon the average two or three times. This is sufficient to produce a moderate crop of alfalfa during a dry year, while in an ordinary season it will give from three to four cuttings of hay.

The acreage varies from year to year, depending upon many matters which affect the prosperity of the farmers in that part of the State.

Several hundred acres are also irrigated in the valley from pumps. In most places the water is raised less than 12 feet, so that windmills are very efficient, a 14-foot wheel furnishing ample power to run an 8-inch pump that will throw from 5 to 8 gallons at a stroke. Irrigation from mills is on the increase, as it frequently happens that dry weather in the spring and early summer is disastrous before water from the river is available.

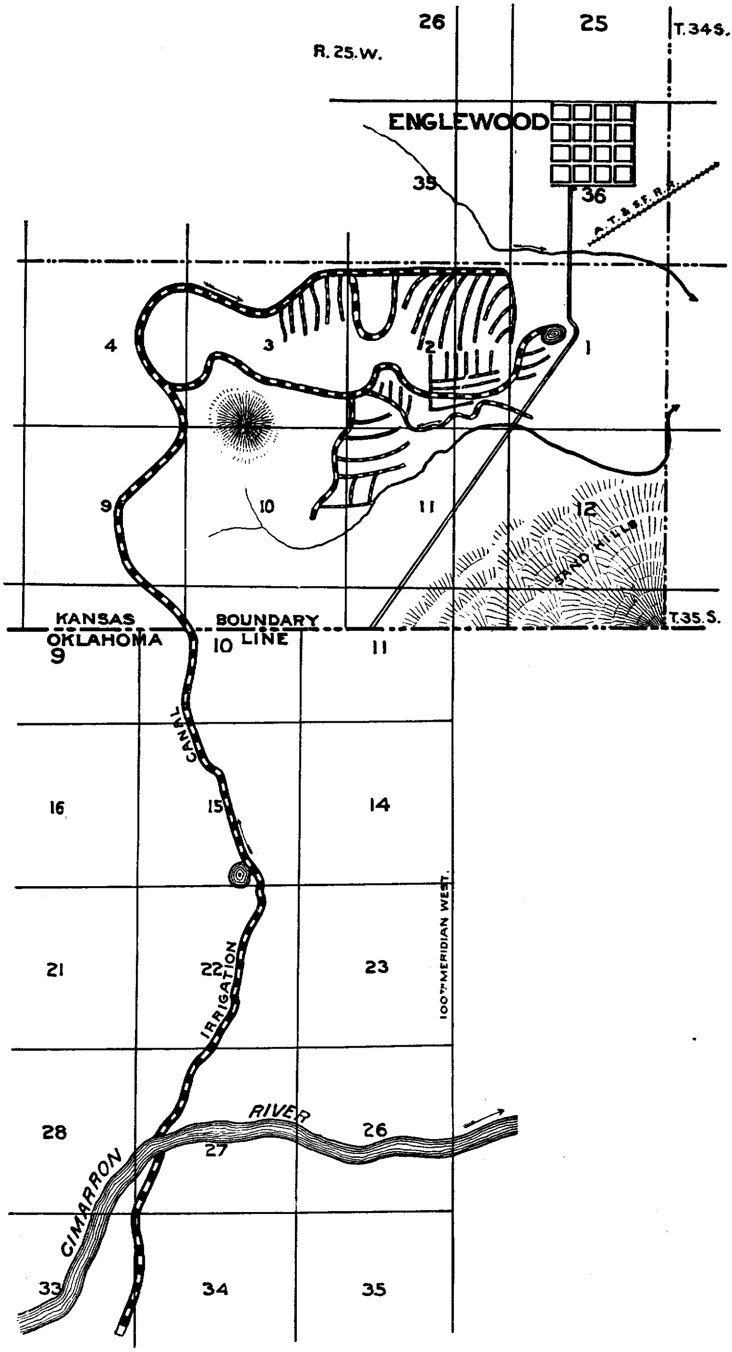


HEAD OF PERRY IRRIGATION CANAL, CIMARRON RIVER, NEAR ENGLEWOOD, KANSAS.

Cimarron River carries a large amount of water during a part of the year and is rarely dry in this part of the State, as it is fed by springs from the ground water. Irrigation is practiced to a considerable extent in different places along the valley. The largest tract under water from the river at present is the Clearmont ranch of Col. C. D. Perry, at Englewood. This ranch at present has about 1,100 acres under ditch, but Colonel Perry's plans are to reduce this amount to 800 acres, as he thinks the same amount of labor expended on a smaller acreage will give better returns than when spread over a larger piece of land. Formerly general farming was conducted at this ranch, but it has been found that with the markets as they have recently been it is more profitable to raise feed for stock and to market the animals. During the summer of 1896, therefore, no field crops of consequence were raised except alfalfa, sorghum, and kaffir corn, each of which grows with great luxuriance. Pl. XII is a map of Clearmont ranch, showing how the water is drawn from the Cimarron and the principal laterals employed in distributing it over the ranch.

At certain times in the year the water in the Cimarron is slightly salty, particularly in dry weather. This apparently produces no bad soil effects, principally because the most irrigation is done at times when the river is flush and consequently the water least salty.

The large amount of water furnished by the springs of Spring Creek is partially used on the Crooked L ranch, which lies in the valley at the junction of Spring Creek and Crooked Creek. Here about 500 acres are under irrigation, devoted principally to alfalfa, the water for which is drawn from Spring Creek. Pl. VIII is reproduced from a photograph, showing the head of the supply ditch. Below the mouth of Spring Creek a few small fields are irrigated from the creek, but none so large as the Crooked L ranch.



MAP OF CLEARMONT RANCH, NEAR ENGLEWOOD, KANSAS, SHOWING HOW WATER IS DRAWN FROM THE CIMARRON AND THE PRINCIPAL LATERALS.

INDEX.

1894.

Report on agriculture by irrigation in the western part of the United States at the eleventh census, 1890, by F. H. Newell, 1894, quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical condition and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, in two parts, Part II, Accompanying papers, 1894, octavo, 597 pp.

Contains papers on potable waters of the eastern United States, by W J McGee; natural mineral waters of the United States, by A. C. Peale; results of stream measurements, by F. H. Newell. Illustrated by maps and diagrams.

1895.

Sixteenth Annual Report of the United States Geological Survey, 1894-95, Part II, Papers of an economic character, 1895, octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894, octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Big Horn Range and Big Horn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar year 1893-94, by F. H. Newell, 1895, octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895-96, Part II, Economic geology and hydrography, 1896, octavo, 864 pp.

Contains papers by G. K. Gilbert on the underground water of the Arkansas Valley in eastern Colorado; by Frank Leverett on the water resources of Illinois; and by N. H. Darton on a reconnaissance of the artesian areas of a portion of the Dakotas.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896, octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896, octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

Survey bulletins can be obtained only by prepayment of cost as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier.
8. Windmills for irrigation, by E. C. Murphy.
9. Irrigation near Greeley, Colorado, by David Boyd.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker.

In addition to the above, there are in various stages of preparation about twenty other papers relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

Application for these papers should be made either to members of Congress or to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.